THERMODYNAMICS OF COUPLED CHANNEL SYSTEM

POK MAN LO (盧博文)

University of Wroclaw

29-31 JULY 2020,
CRITICALITY IN QCD AND
THE HADRON RESONANCE GAS

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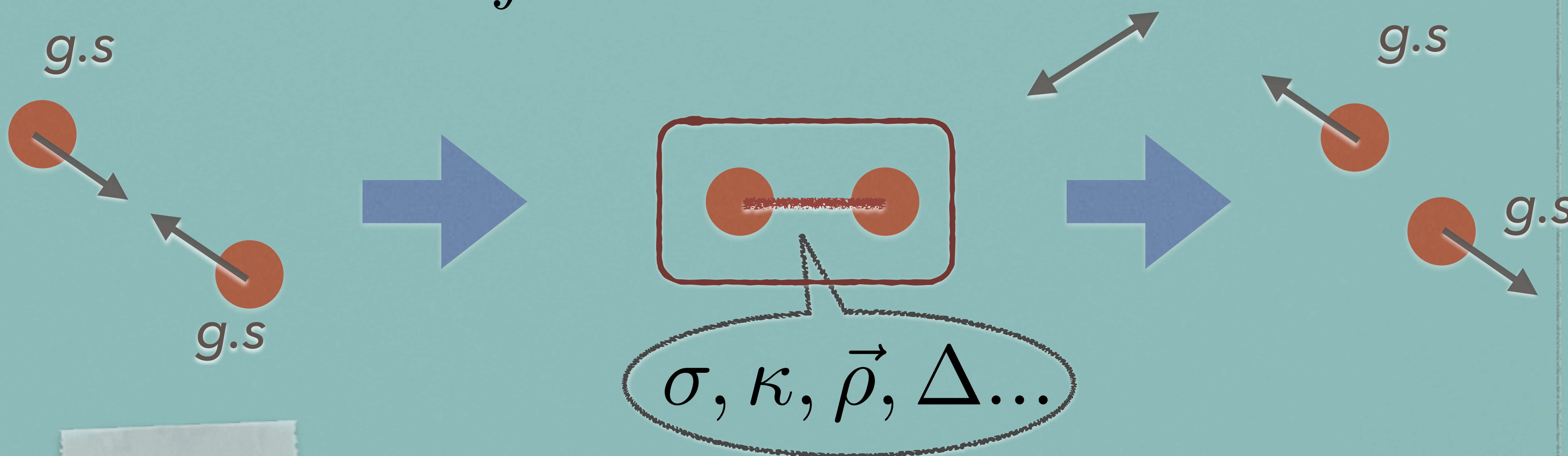
S-MATRIX FORMULATION OF STATISTICAL MECHANICS

S-MATRIX FORMULATION OF STATISTICAL MECHANICS

$$\Delta \ln Z = \int dE \, e^{-\beta E} \times \frac{1}{\pi} \frac{\partial}{\partial E} \mathrm{tr} \, (\delta_E) \, .$$

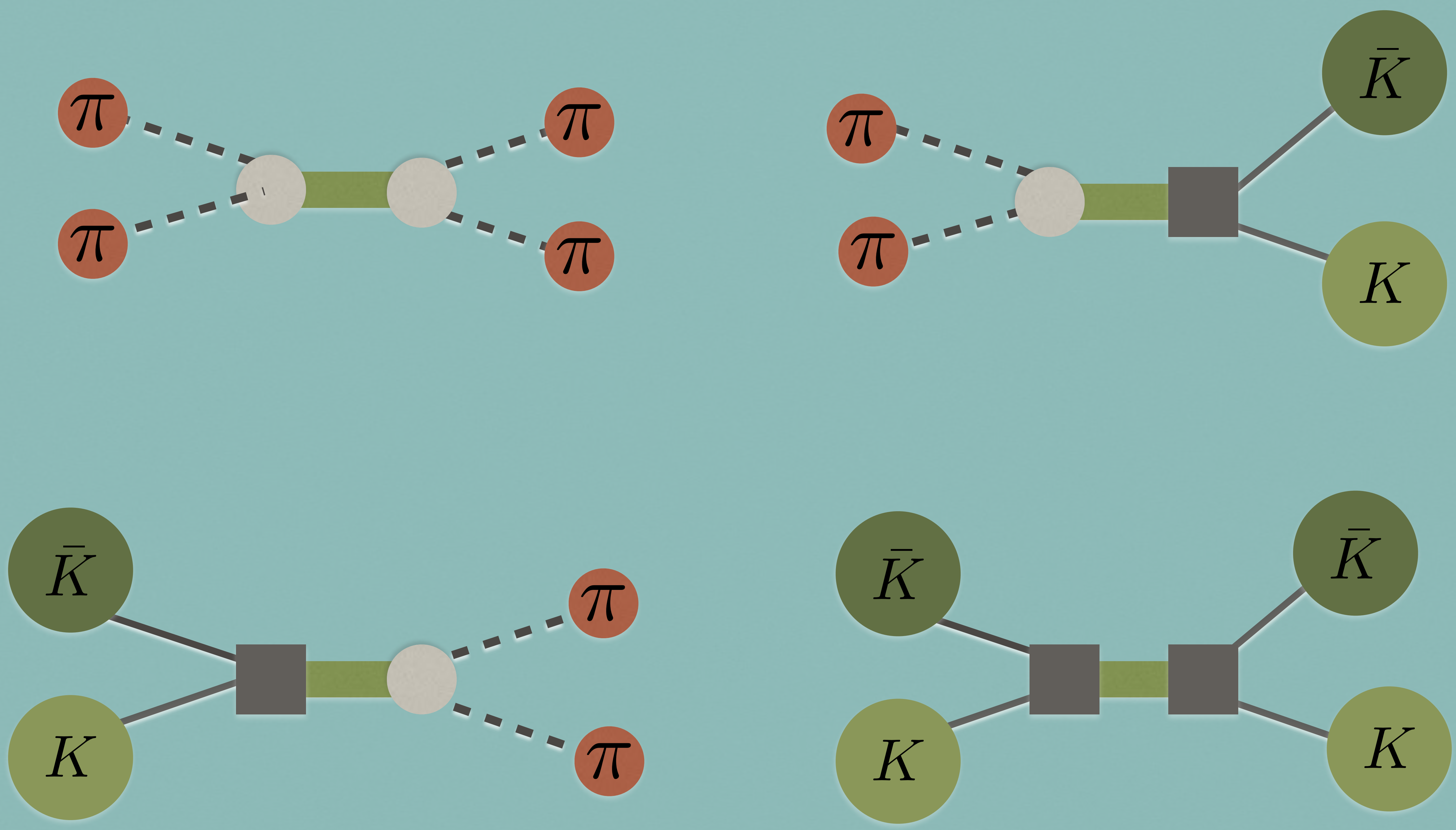


+ repulsions

PWA
X
S-matrix thermo.

$$\delta \longrightarrow \mathcal{Q}(M) \equiv \frac{1}{2} \, \mathrm{Im} \, (\mathrm{tr} \ln \mathrm{S})$$

1 RES. 2 CHANNELS PROBLEM



COUPLED-CHANNEL PROBLEM

$$\{\gamma_1, \gamma_2, m_{\rm res}\} \longleftrightarrow \{\delta_1, \delta_2, \eta\}$$

$$S = \begin{pmatrix} \eta\, e^{2\,i\,\delta_I} & i\sqrt{1-\eta^2}\, e^{i\,(\delta_I+\delta_{II})} \\ i\sqrt{1-\eta^2}\, e^{i\,(\delta_I+\delta_{II})} & \eta\, e^{2\,i\,\delta_{II}} \end{pmatrix}$$

branching ratio

f0(980) system

$$\pi\pi \rightarrow \begin{pmatrix} \pi\pi \\ K\bar{K} \end{pmatrix} \rightarrow \pi\pi$$

$$K\bar{K} \rightarrow \begin{pmatrix} \pi\pi \\ K\bar{K} \end{pmatrix} \rightarrow K\bar{K}$$

COUPLED-CHANNEL PROBLEM

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$$\begin{aligned} \mathcal{Q}(M) &\equiv \frac{1}{2}\,\mathrm{Im}\,(\mathrm{tr}\ln\,\mathrm{S}) \\ &= \frac{1}{2}\,\mathrm{Im}\,(\ln\,\det\,[\mathrm{S}]) \\ &= \delta_I + \delta_{II}. \end{aligned}$$

f0(980) system

$$\pi\pi \to \begin{pmatrix} \pi\pi \\ K\bar{K} \end{pmatrix} \to \pi\pi$$

$$K\bar{K} \to \begin{pmatrix} \pi\pi \\ K\bar{K} \end{pmatrix} \to K\bar{K}$$

HOW TO COUNT?
S-MATRIX POINT OF VIEW

indecently optimistic…

VOLUME 34, NUMBER 3 JULY, 1962

S-Matrix Theory of Strong Interactions without Elementary Particles*†

GEOFFREY F. CHEW
Department of Physics and Lawrence Radiation Laboratory, University of California, Berkeley, California

1. INTRODUCTION

IN this paper I present an indecently optimistic view of strong interaction theory. My belief is that a major breakthrough has occurred and that within a relatively short period we are going to achieve a depth of understanding of strong interactions that a few years ago I, at least, did not expect to see within my lifetime. I know that few of you will be convinced by the arguments given here, but I would be masking my feelings if I were to employ a conventionally cautious attitude in this talk. I am bursting with excitement, as are a number of other theorists in this game.

tell me that this is a fetish, that field theory is an equally suitable language, but to me the basic strong-interaction concepts, simple and beautiful in a pure *S*-matrix approach, are weird, if not impossible, for field theory. It must be said, nevertheless, that my own awareness of these concepts was largely achieved through close collaboration with three great experts in field theory, M. L. Goldberger, Francis Low, and Stanley Mandelstam. Each of them has played a major role in the development of the strong interaction theory that I describe,[1] even though the language of my description may be repugnant to them. Murray Gell-Mann, also, although he has not actu-

PARTICLES AS S–MATRIX POLES; HADRON DEMOCRACY *

satisfy unitarity. There is no "reason" for any others. Similarly, as Feynman and Heisenberg have both emphasized, there is no reason why some particles should be on a different footing from others. The elementary particle concept is unnecessary, at least for baryons and mesons.

The second assumption may turn out to be closely

but some are more equal than the others?

Geoffrey F. Chew

Chew at his California home on July 2014

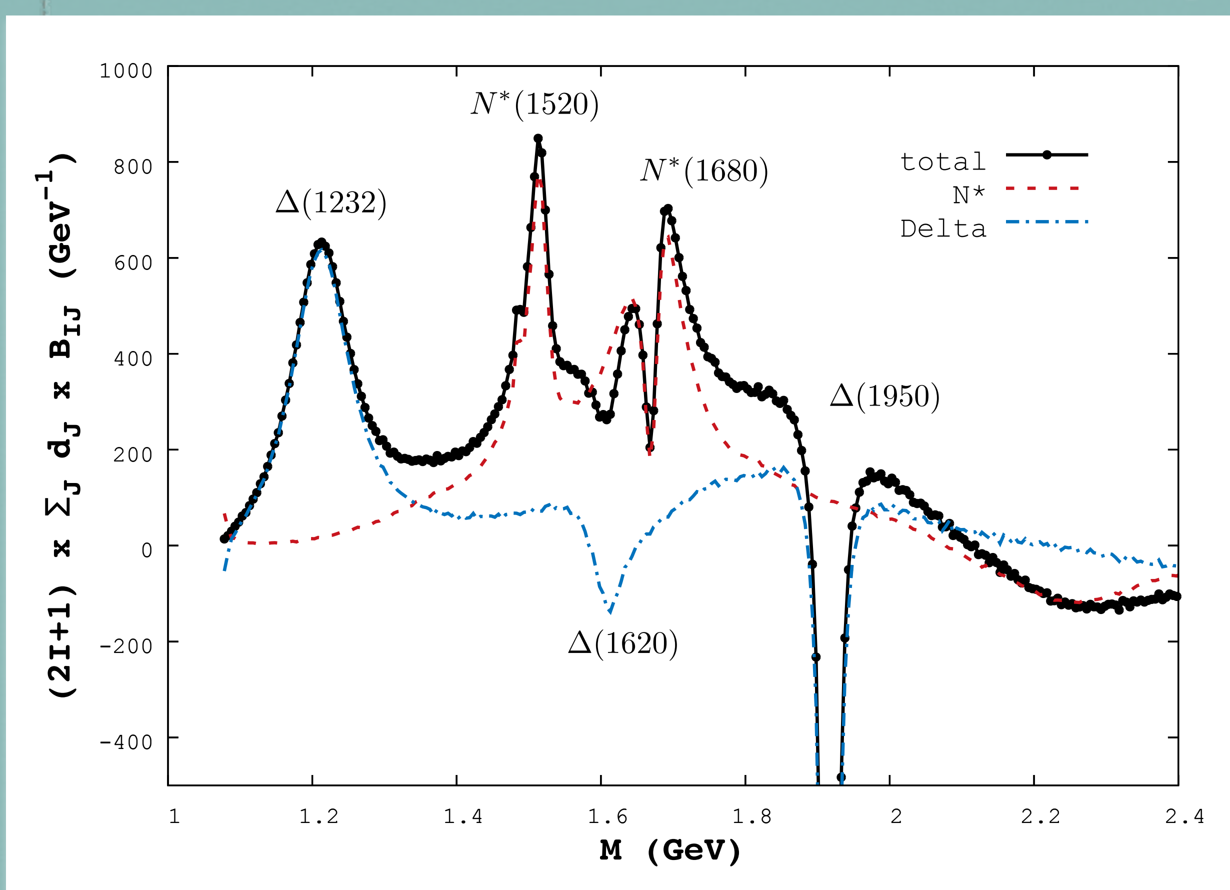
Born	June 5, 1924 Washington, D.C., United States
Died	April 12, 2019 (aged 94) Berkeley, California, United States
Nationality	American
Alma mater	University of Chicago
Known for	S-matrix theory, bootstrap theory, strong interactions, Chew–Frautschi plot
Awards	Hughes Prize (1962) Lawrence Prize (1969) Majorana Prize (2008)
Scientific career	
Fields	Theoretical physics
Institutions	University of Illinois UC Berkeley
Doctoral advisor	Enrico Fermi
Doctoral students	David Gross John H. Schwarz John R. Taylor

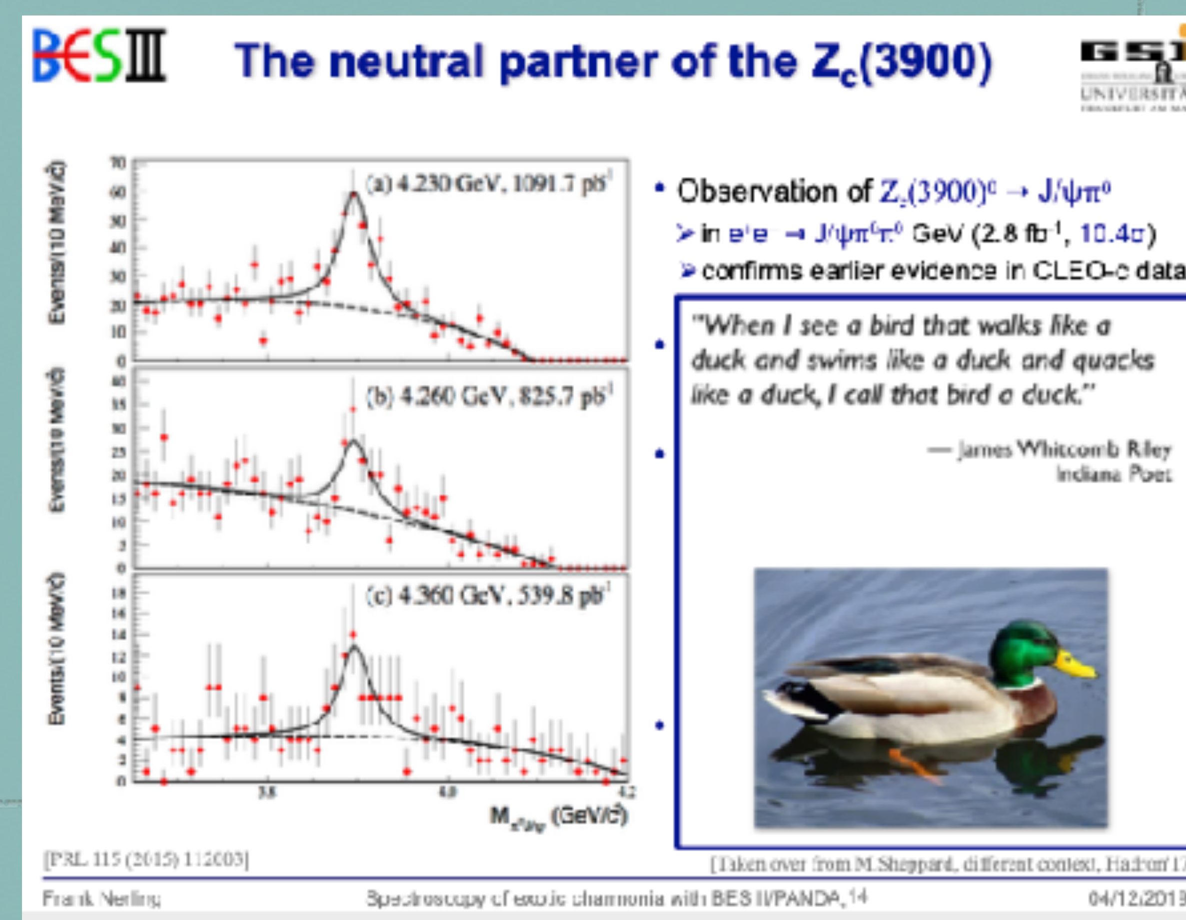
RESONANCES / EXCITATIONS VIA SCATTERING STATES

- broad /overlapping resonances
- molecular states
- threshold effects /cusps

non-resonant interactions: +/-

$$\pi N \to \Delta \to \pi N$$

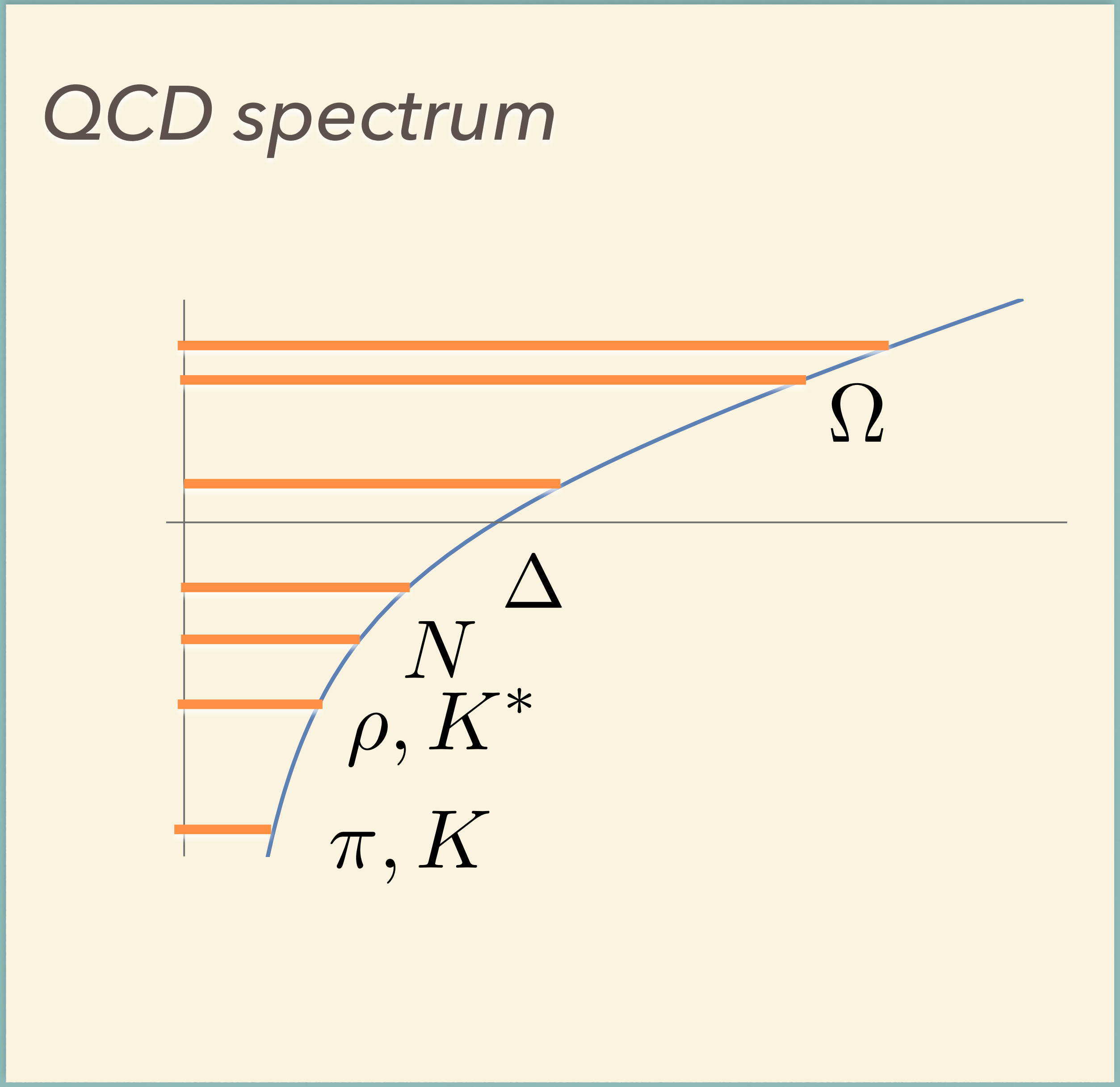




DENSITY OF STATES

QUENCHED QCD & CONSTITUENT QUARK MODELS

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



COUPLING TO CONTINUUM

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

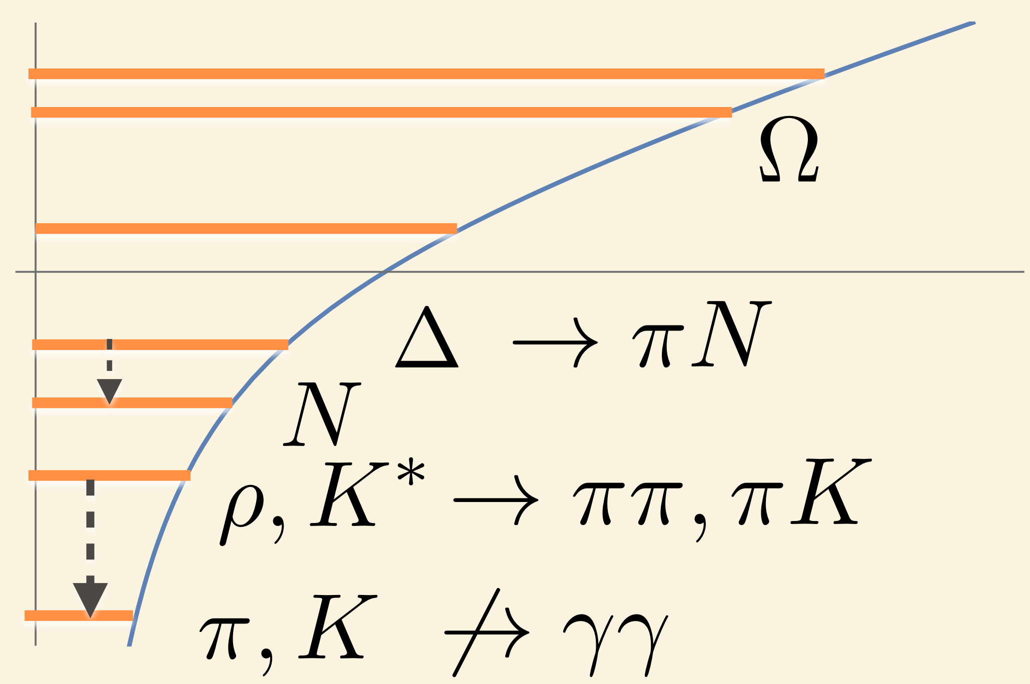
meson loops effects:

shift in hadron masses

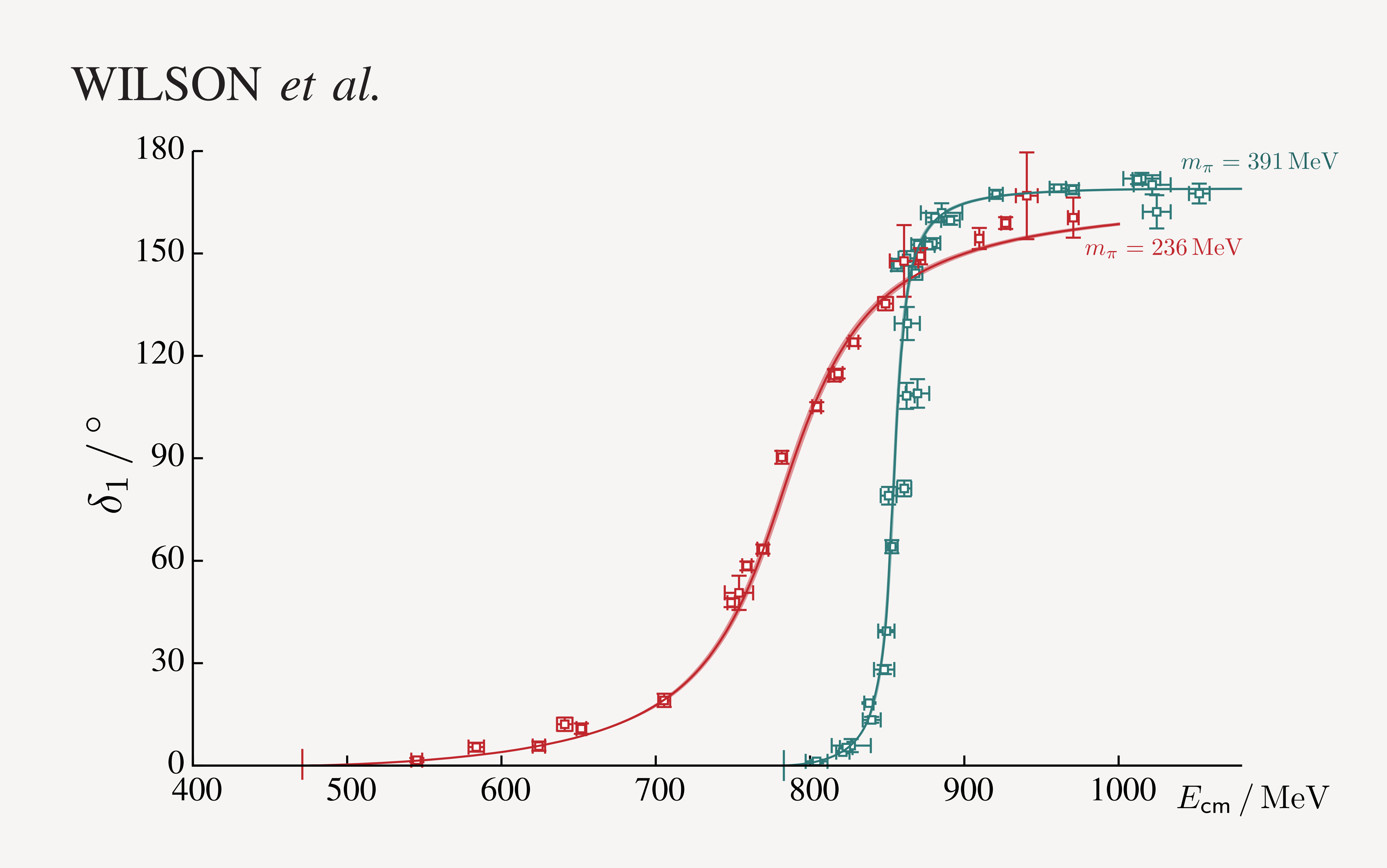
S-matrix issues:

how resonances are expressed by the scattering states?

QCD spectrum

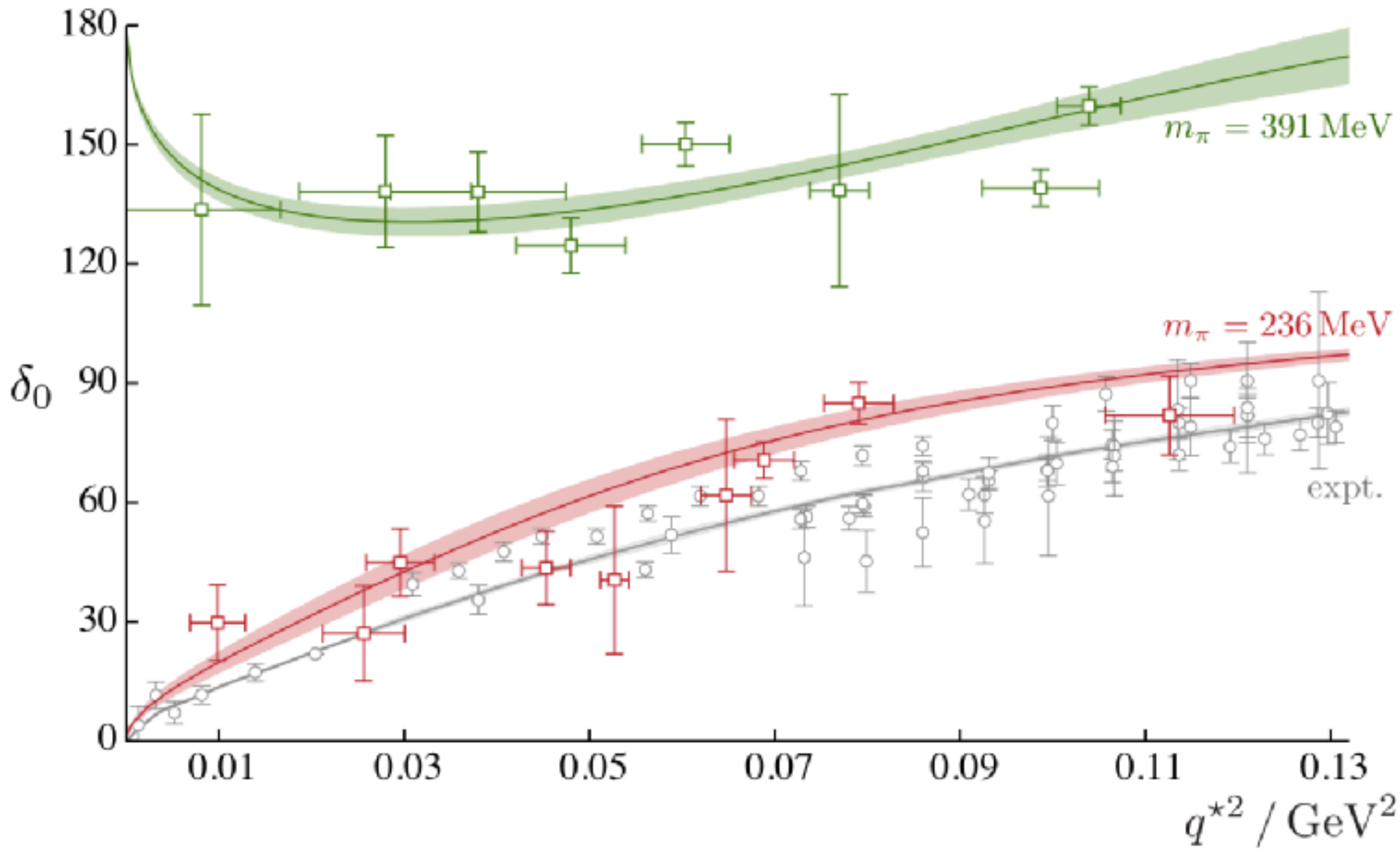


LATTICE COMPUTATIONS ON PHASE SHIFT



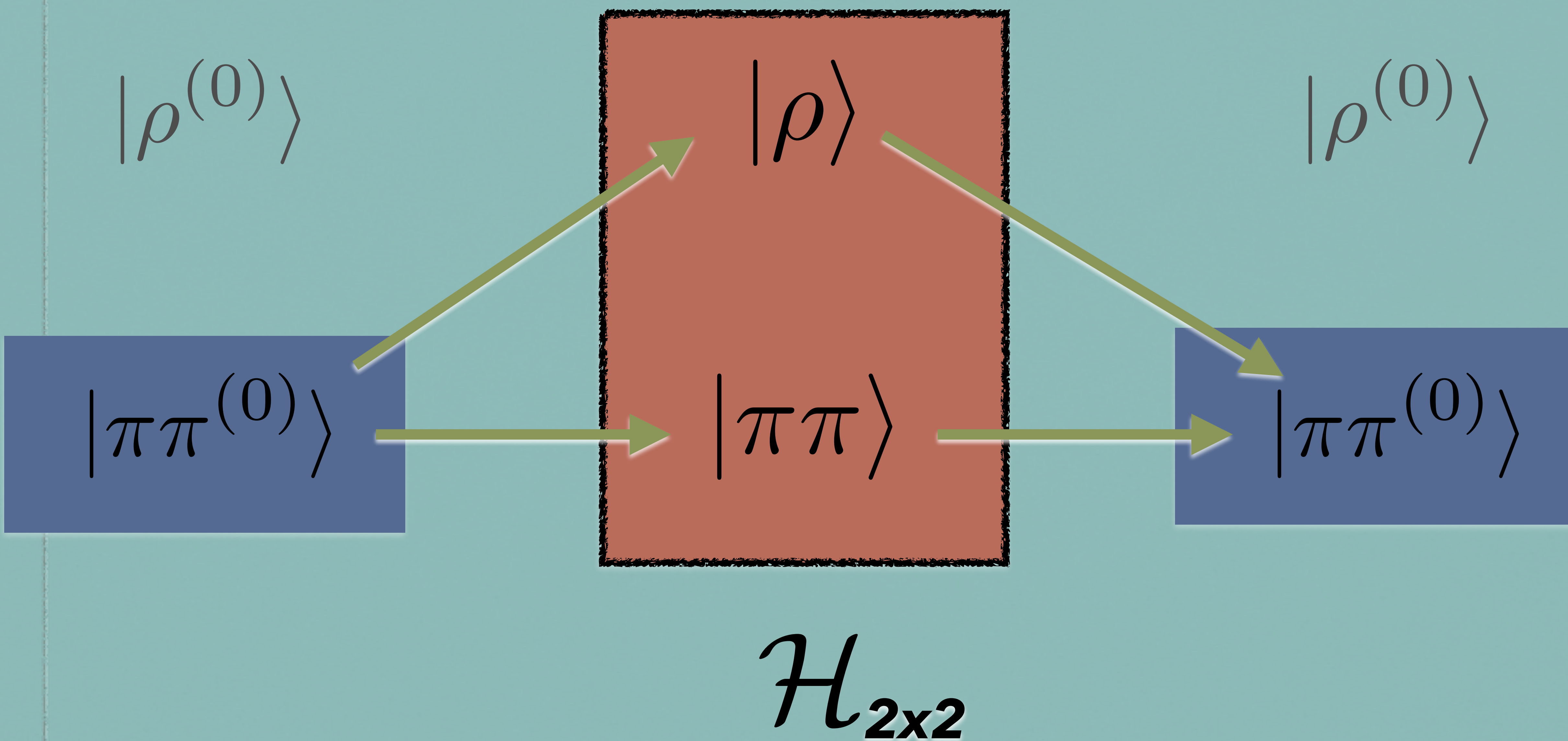
LATTICE COMPUTATIONS ON PHASE SHIFT

deuteron physics?

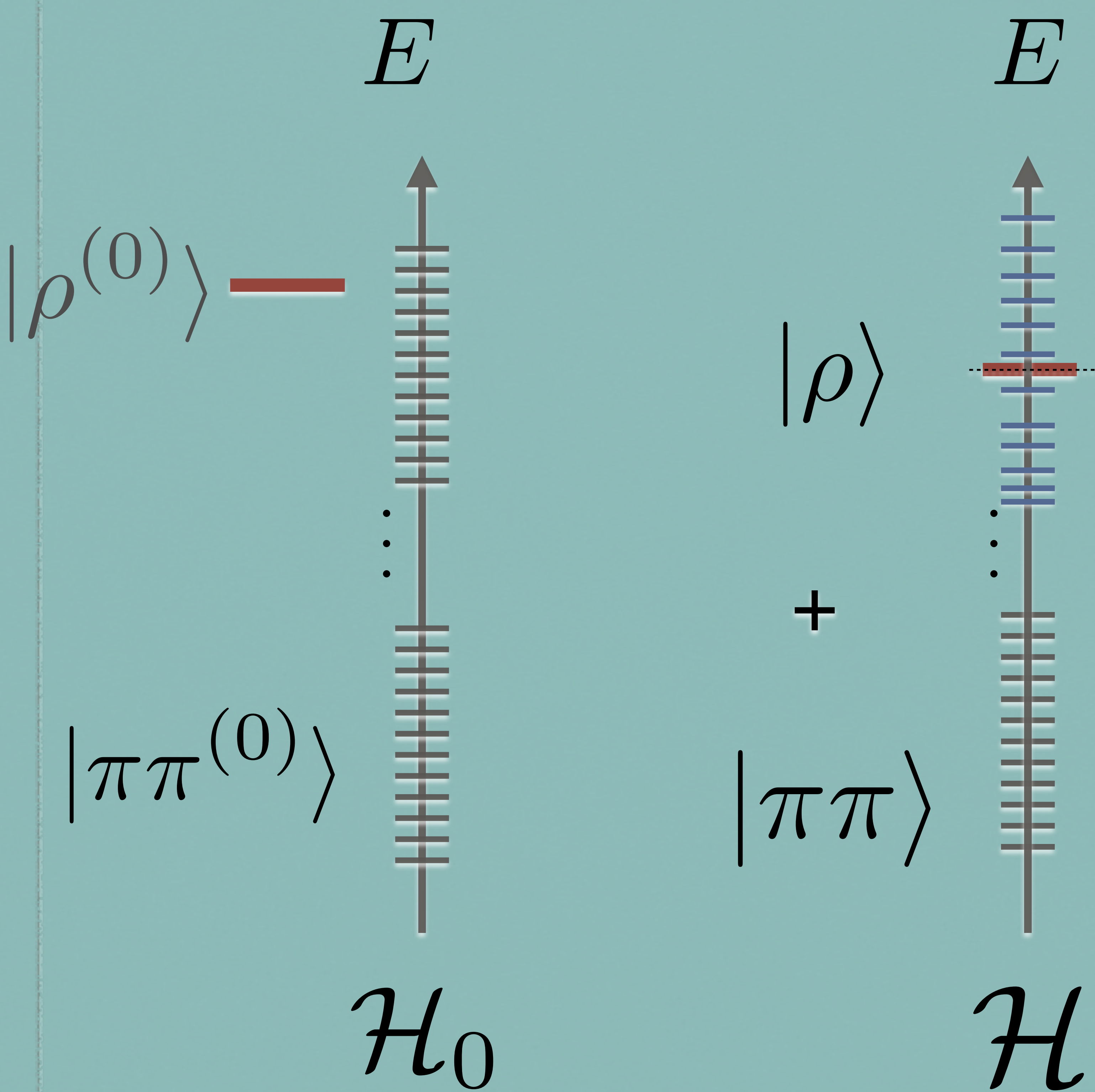


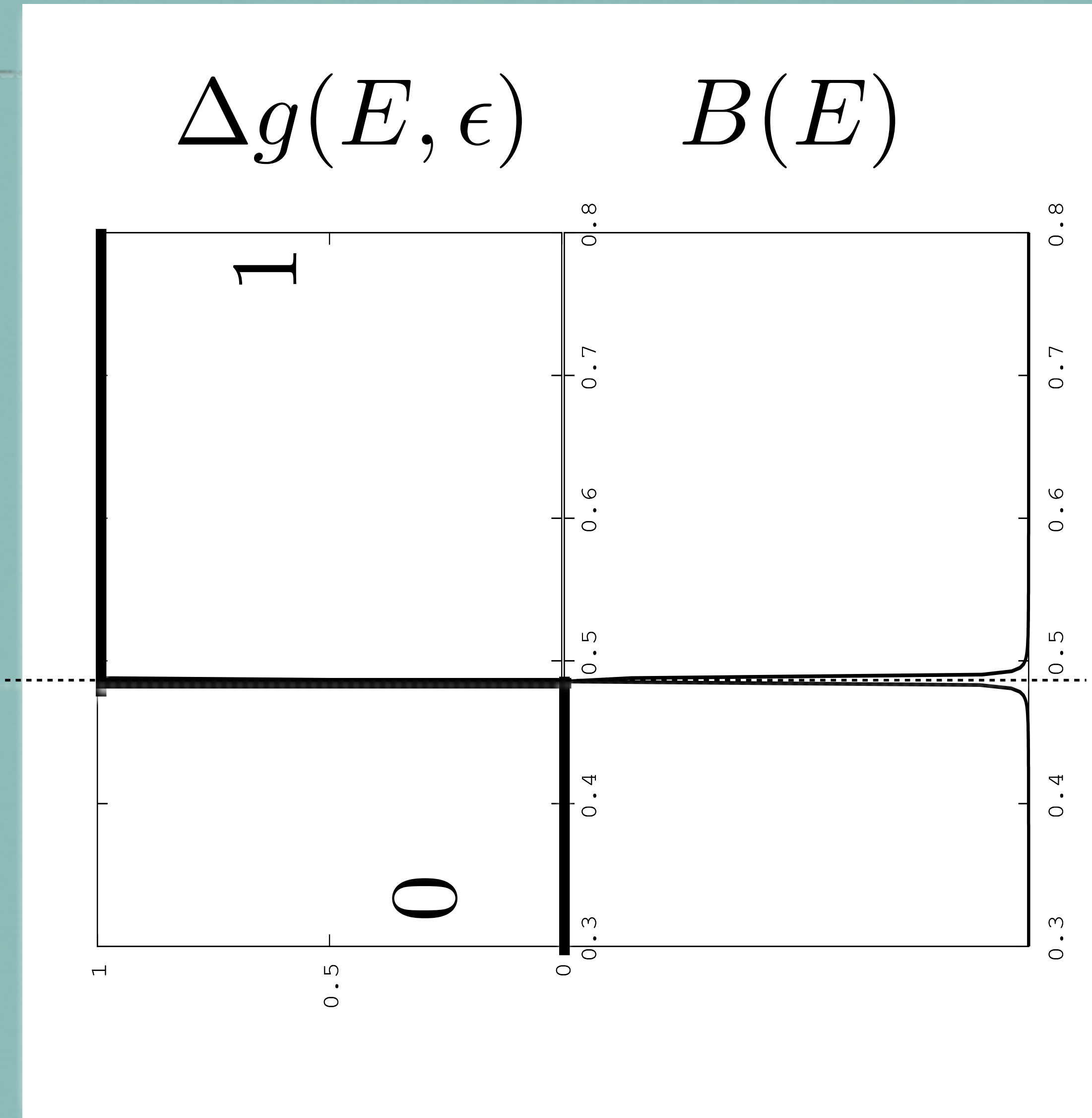
R. A. Briceno, J. J. Dudek and R. D. Young, arXiv:1706.06223 [hep-lat].

SCATTERING THEORY VS HAMILTONIAN (LEE MODEL)



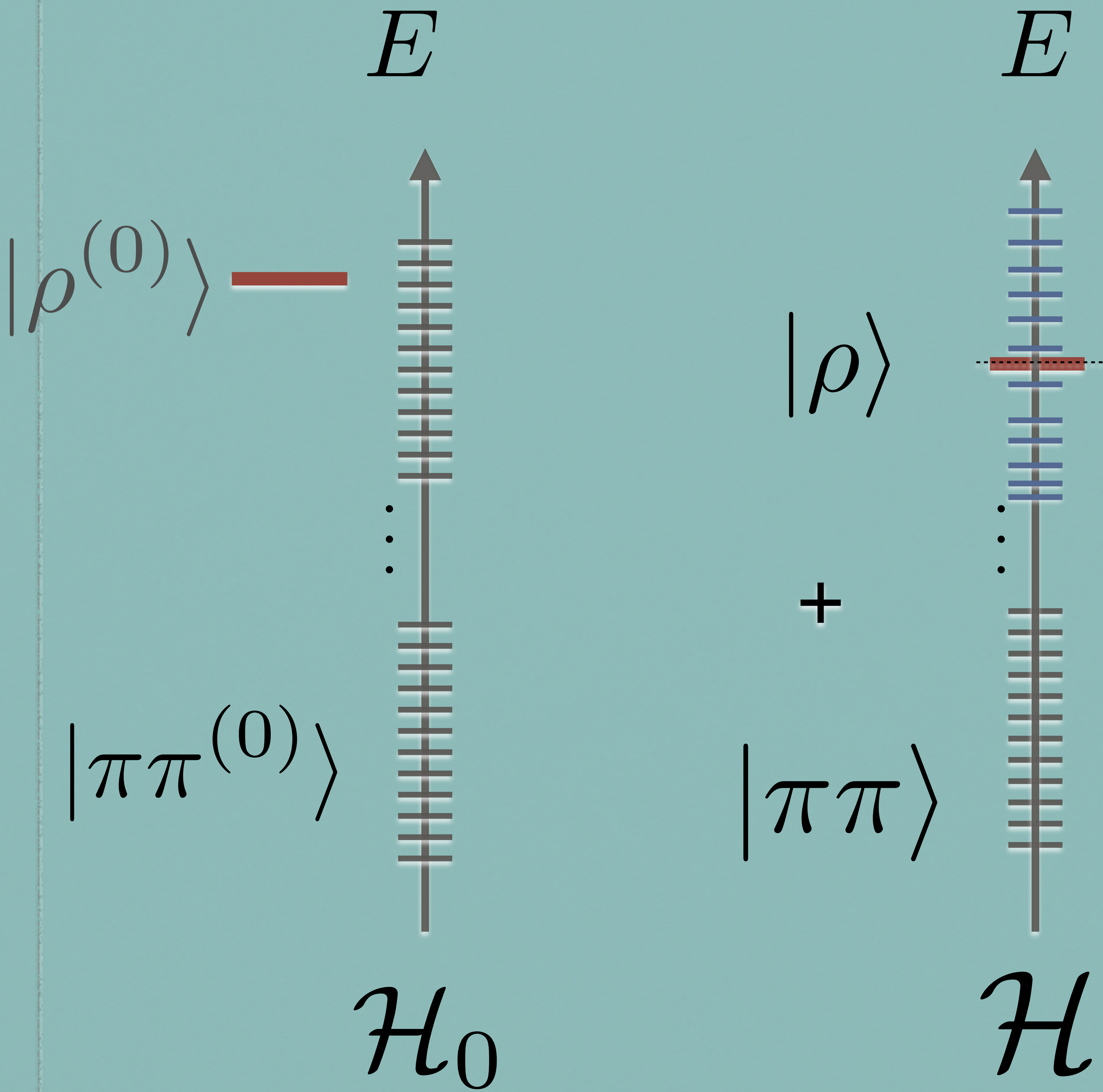
PML, Francesco Giocosa EPJC **79** (2019)

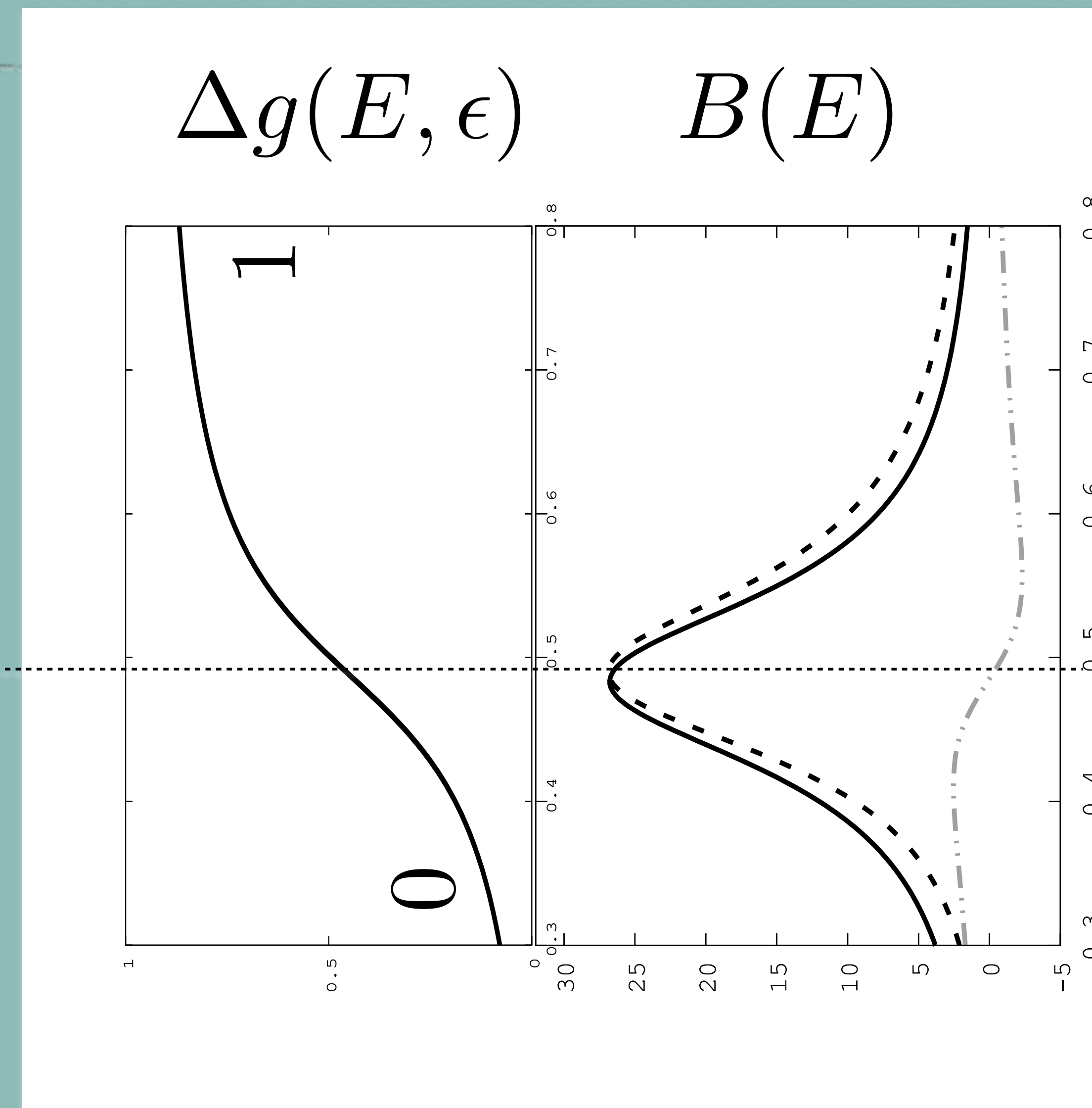




$$g(E,\epsilon) = \sum_n \theta_\epsilon(E - E_n)$$

$$B(E) = 2\pi \frac{d}{dE} \Delta g(E,\epsilon)$$





$$g(E,\epsilon) = \sum_n \theta_\epsilon(E - E_n)$$

$$B(E) = 2\pi \frac{d}{dE} \Delta g(E,\epsilon)$$

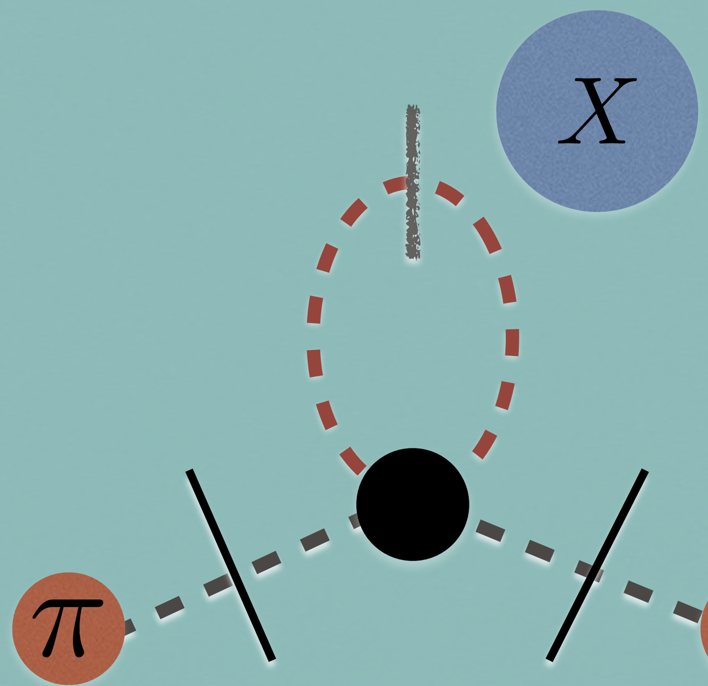
$$= A_\rho + \Delta A_{\pi\pi}$$

medium effects

$\mathrm{Tr}\, e^{-\beta \mathcal{H}_0}$ *vs* $\mathrm{Tr}\, e^{-\beta \mathcal{H}}$

IN-MEDIUM EFFECTS FROM S-MATRIX

$$\Sigma_\pi =$$



$$\propto \int \frac{d^3q}{\omega_q} n_X \, T_{\pi X}(s)$$

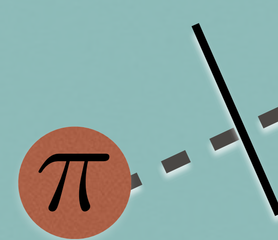
forward amplitude

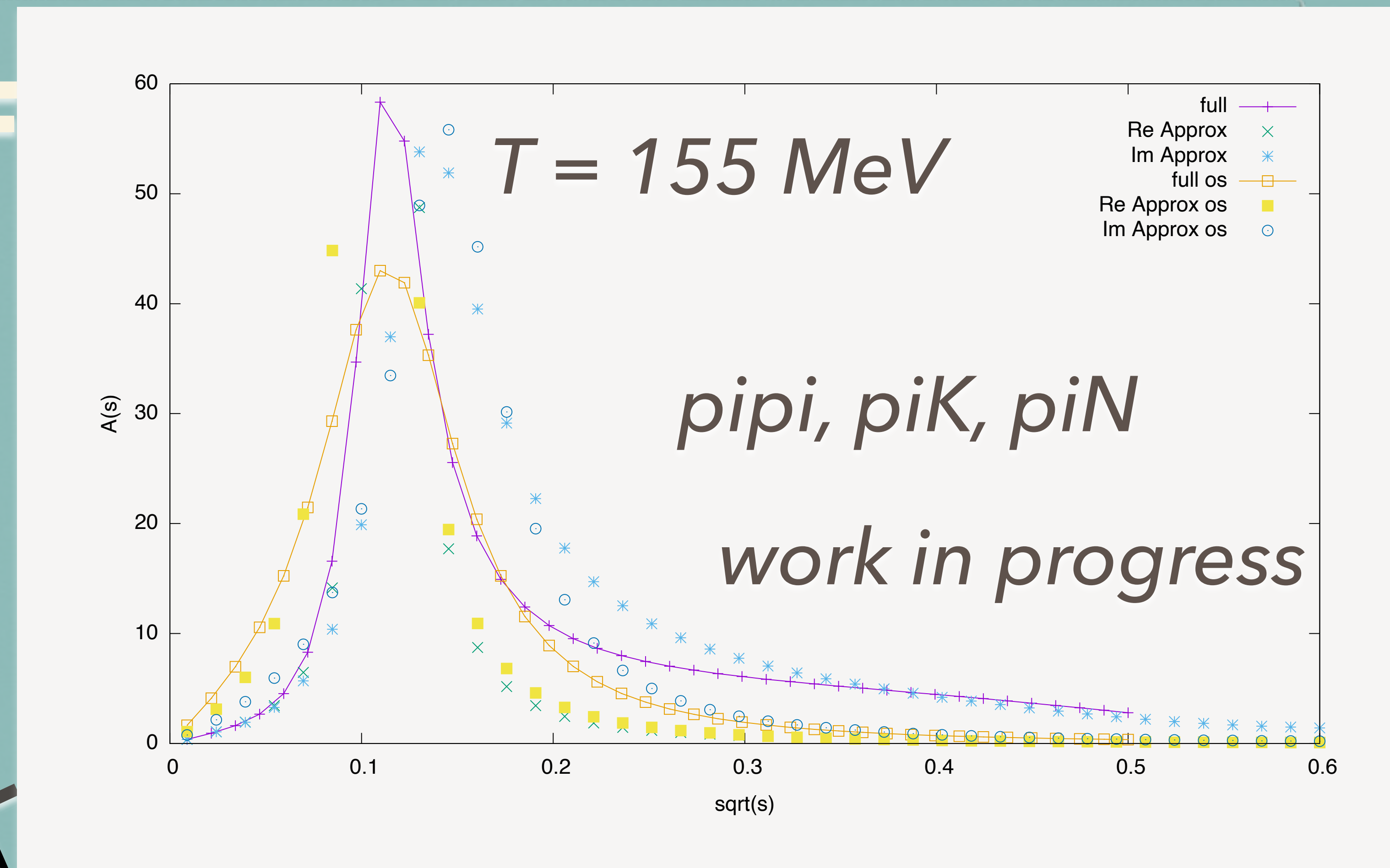
A. Schenk NPB 363(1991)

S. Jeon and P. J. Ellis PRD 58 045013 (1998)

IN-MEDIUM EF
S-MATRIX

$$\Sigma_\pi =$$





$$\propto \int \frac{d^3q}{\omega_q} n_X T_{\pi X}(s)$$

forward amplitude

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VACUUM PHYSICS?

Quantum statistical mechanics of gases in terms of dynamical filling fractions and scattering amplitudes

André LeClair

Newman Laboratory, Cornell University, Ithaca, NY, USA

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Online at stacks.iop.org/JPhysA/40/9655

It helps to realize that at least in principle it is possible to decouple the zero temperature dynamics and the quantum statistical sums. The argument is simple: the computation of the partition function $Z = \mathrm{Tr}(\mathrm{e}^{-\beta \mathrm{H}})$ is in principle possible from the complete knowledge of the zero temperature eigenstates of the Hamiltonian H. In practice this is rather difficult and one resorts to perturbative methods such as the Matsubara method, which unfortunately entangles the zero temperature dynamics from the quantum statistical mechanics. However,

S-MATRIX FORMULATION OF THERMODYNAMICS

thermo-statistical ***dynamical***

$$\Delta \ln Z = \int dE \, e^{-\beta E} \frac{1}{4\pi i} \mathrm{tr} \left\{ S_E^{-1} \overleftrightarrow{\frac{\partial}{\partial E}} S_E \right\}_c$$

R. Dashen, S. K. Ma and H. J. Bernstein, Phys. Rev. 187 (1969) 345.

A SIMPLE TRICK

$$S_E = e^{2i\delta_E}$$

$$\frac{1}{4\pi i}\,\mathrm{tr}\left\{S_E^{-1}\frac{\overleftrightarrow{\partial}}{\partial E}S_E\right\}_c$$

$$= \frac{1}{2\pi}\times 2\,\frac{\partial}{\partial E}\,\frac{1}{2}\,\mathrm{Im}\,\mathrm{tr}\,\{\ln S_E\}$$

$$\Delta \ln Z = \int dE\, e^{-\beta E}\times\frac{1}{\pi}\frac{\partial}{\partial E}\mathrm{tr}\,(\delta_E)\,.$$

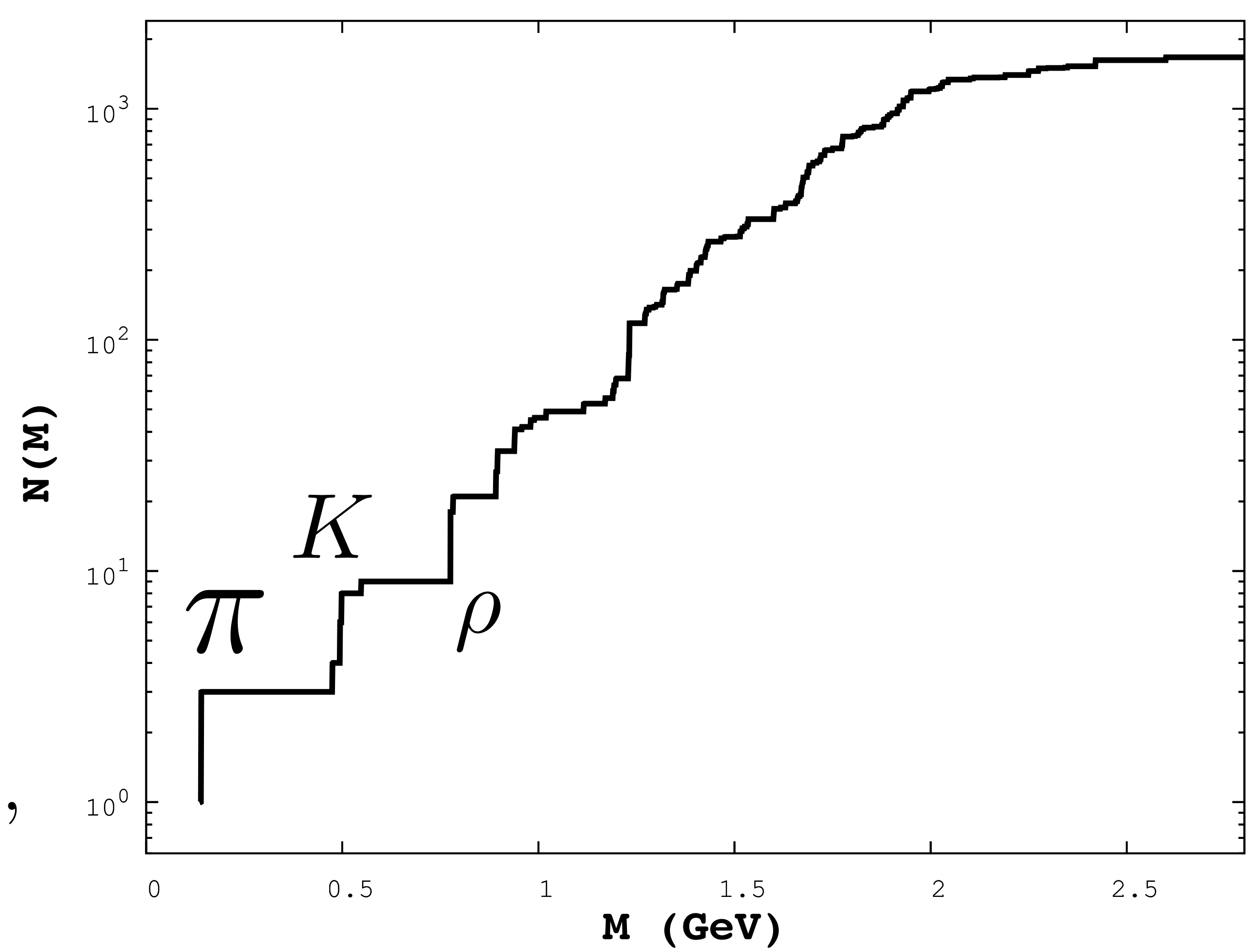
E. Beth and G. Uhlenbeck,
Physica (Amsterdam) 4, 915 (1937).

HRG AS AN S-MATRIX SCHEME

$$\det S(E) = \prod_{\{\text{res}\}} \frac{z^{\star}_{\text{res}} - E}{z_{\text{res}} - E}, \qquad z_{\text{res}} \approx m_{\text{res}} - i\,0^{+}.$$

$$\mathcal{Q}(M) \equiv \frac{1}{2}\,\text{Im}\,(\text{tr}\ln\,\text{S})$$

$$\mathcal{Q}_{\text{HRG}}(E) = \sum_{\text{res}} d_{IJ} \times \pi\,\theta(E - m_{\text{res}}),$$



HRG AS AN S-MATRIX SCHEME

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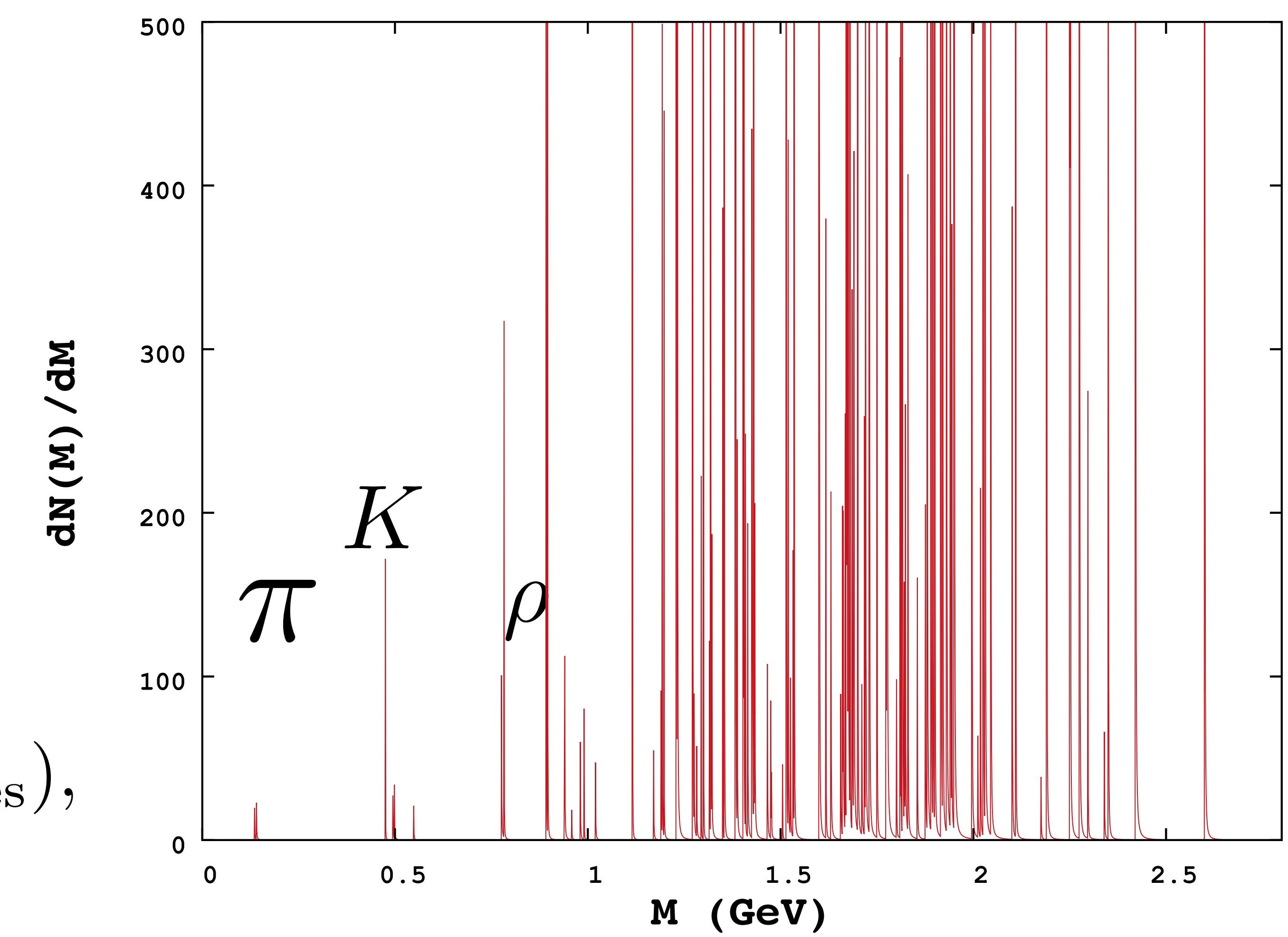
$$\mathcal{Q}(M) \equiv \frac{1}{2}\,\text{Im}\,(\text{tr}\ln\,S)$$

$$\frac{\partial}{\partial E}$$

$$\mathcal{Q}_{\text{HRG}}(E) = \sum_{\text{res}} d_{IJ} \times \pi\,\theta(E - m_{\text{res}}),$$

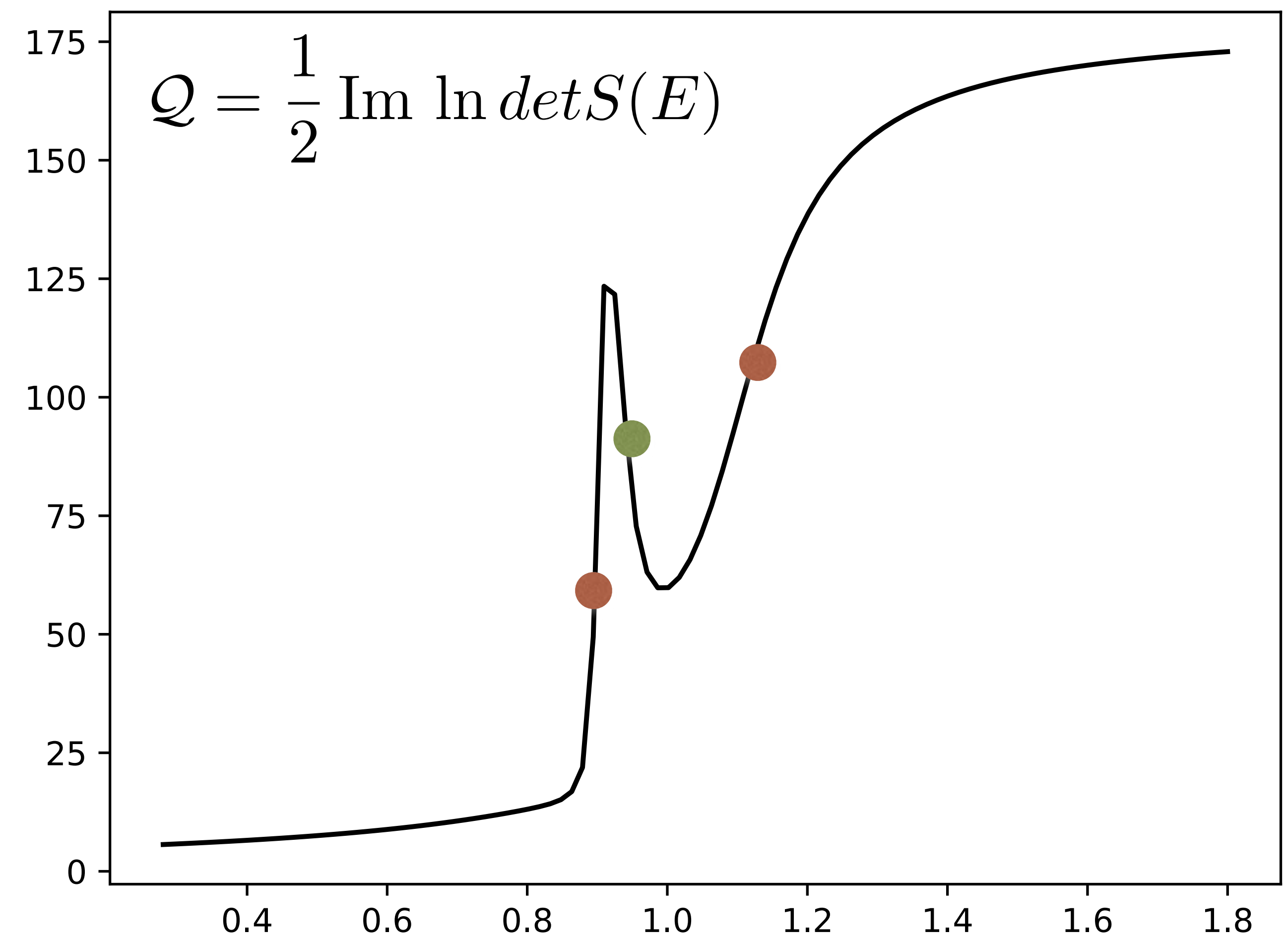


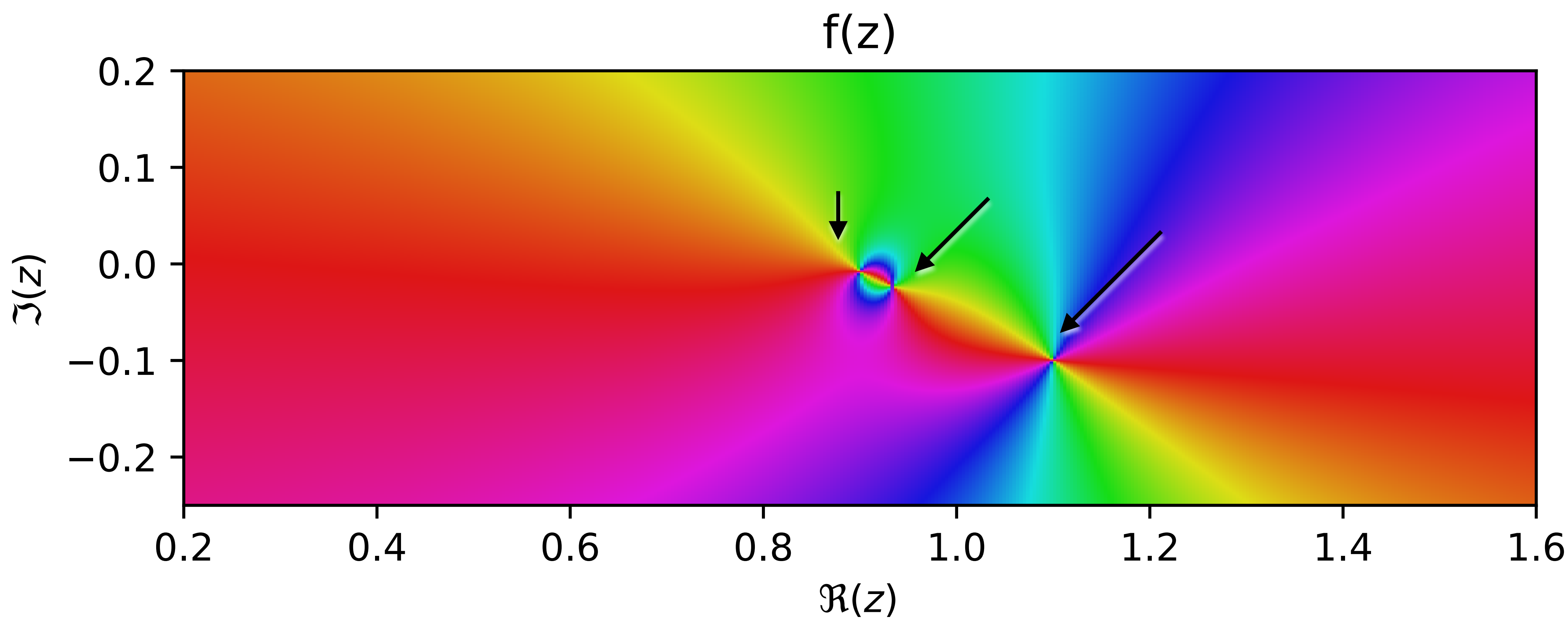
ROOTS IN S-M

2 pole + 1 root

$$detS \propto \frac{g_1}{E-p_1} + \frac{g_2}{E-p_2}$$

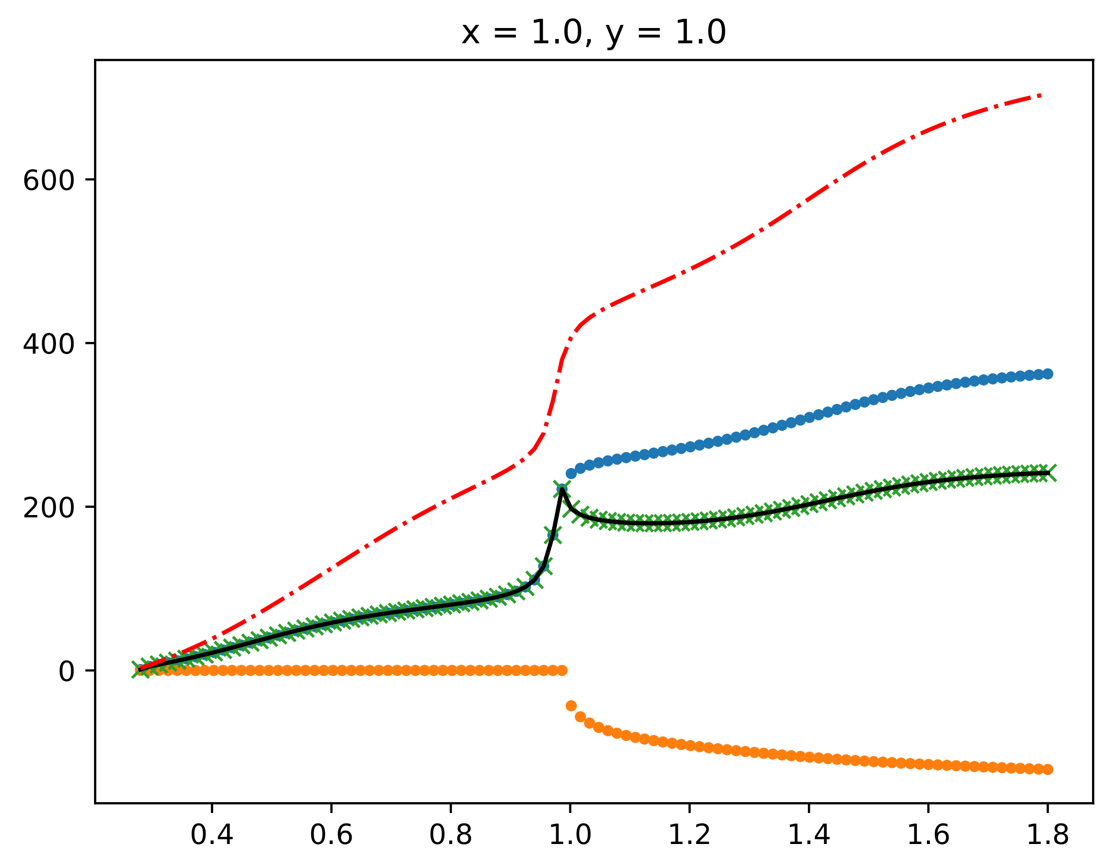
$$detS \propto \frac{g_1}{E-p_1} \times \frac{g_2}{E-p_2}$$

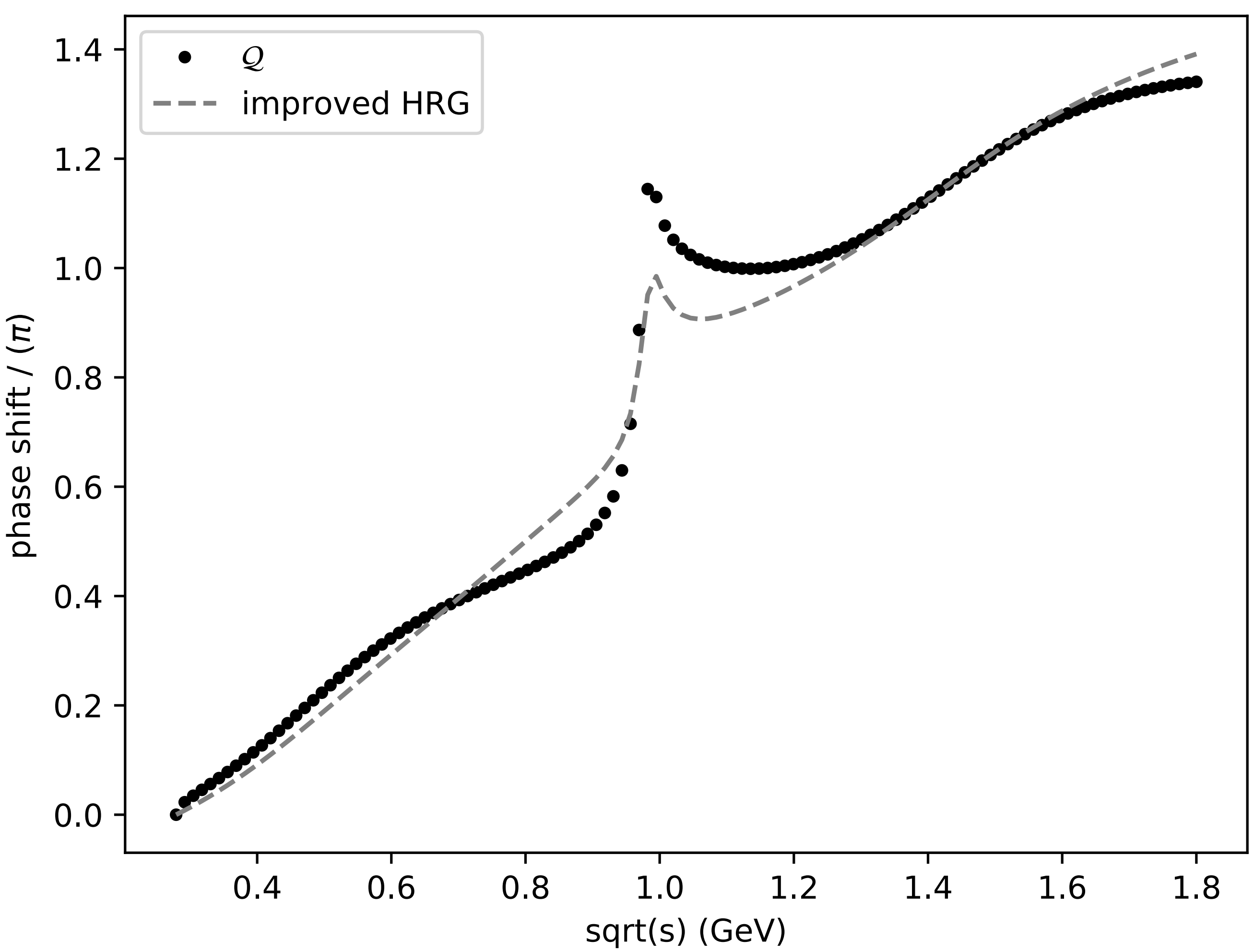




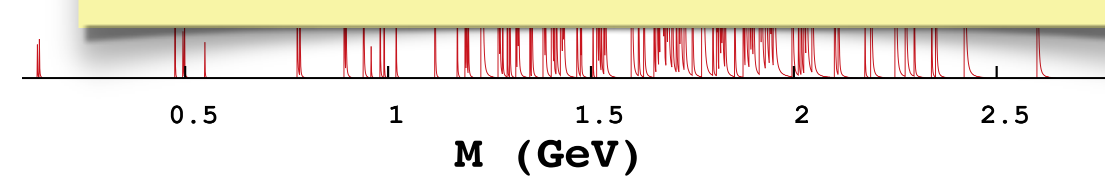
f. [54, 55]

	Re $\sqrt{s}$	Im $\sqrt{s}$	sheet
p1	0.4637	-0.2357	II
p2	0.975	-0.0164	II
p3	1.401	-0.249	II
p4	0.6654	-0.2263	III
p5	1.4176	-0.2640	III
r1	0.787	+0.259	I
r2	1.410	+0.691	I
r3	0.981	-0.032	II
r4	1.393	-0.669	II
r5	0.918	+0.248	IV





repulsive corrections in HRG-like scheme: via roots



DYNAMICAL GENERATION OF BS / RESONANCES

- dynamical generation of bound states / resonances:
  f(980) close to K Kbar threshold
  f(500) dynamically generated
- coupling of open channels: pipi, kkbar with a $|q\bar{q}\rangle$ state

Locher, Markushin, Zheng, EPJC 4 (1998)
Kaminski, Lesniak, Loiseau, EPJC 9 (1999)

what you give $\neq$ *what you get* *1 in 5 out!*

$$\frac{1}{E - \mathcal{H}_0} = \begin{array}{c} |\pi\pi\rangle \\ |K\bar{K}\rangle \\ |R^0\rangle \;\; (|q\bar{q}\rangle) \end{array} \begin{bmatrix} \Pi_{\pi\pi}(E) & & \\ & \Pi_{K\bar{K}}(E) & \\ & & \dfrac{1}{E - m^0_{res}} \end{bmatrix}$$

$$V_{int} = \begin{bmatrix} g_{\pi\pi} & g_{\pi K} & g_{\pi R} \\ g_{\pi K} & g_{KK} & g_{KR} \\ g_{\pi R} & g_{KR} & \end{bmatrix}$$

$$G = G_0 + G_0 V_{int} G$$

From Hamiltonian to Scattering Matrix

$$\frac{1}{E - \mathcal{H}_0 \pm i\delta}$$

$$\begin{aligned}
\tilde{S} &= (I - G^0_- V)(I + G^0_+ T) \\
&= I - G^0_- V + G^0_+ T - G^0_- V G^0_+ T \\
&= I - G^0_- V + G^0_+ V + G^0_+ V G^0_+ T - G^0_- V G^0_+ T \\
&= I + (G^0_+ - G^0_-) V + (G^0_+ - G^0_-) V G^0_+ T \\
&= I + (G^0_+ - G^0_-) T \\
&\to I + 2\, i \, \mathrm{Im}\, (G^0_+) \times T.
\end{aligned}$$

on-shell limit

TESTING THE ROBUSTNESS

$$Q(E) = \frac{1}{2}\mathrm{Im}\mathrm{Tr}\{\ln S_E\}$$

Getting Effective DOS on REAL Energy

effective DOS

$$B = 2\frac{d}{dE}Q$$

what is being counted?

can it handle dynamically generated states?

TESTING THE ROBUSTNESS

$$Q(E) = \frac{1}{2}\mathrm{Im}\mathrm{Tr}\{\ln S_E\}$$

Getting
Effective DOS
on
REAL Energy

effective DOS

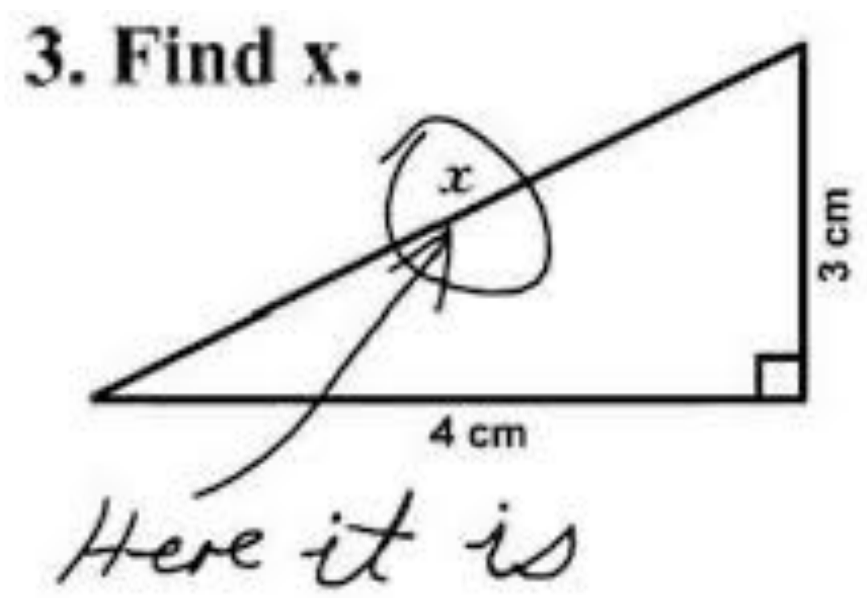
$$B = 2\frac{d}{dE}Q$$

Need to find all the poles...

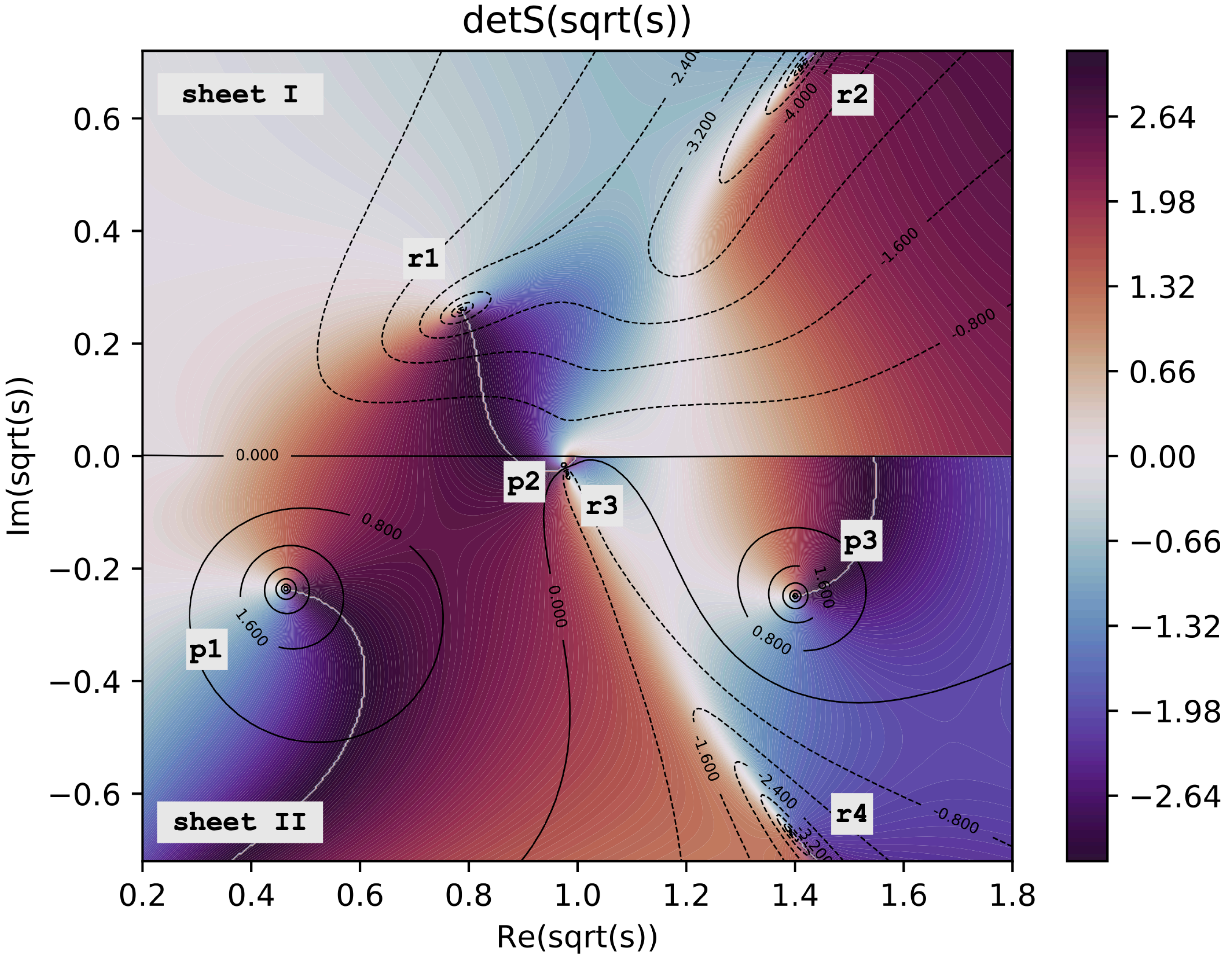
l?

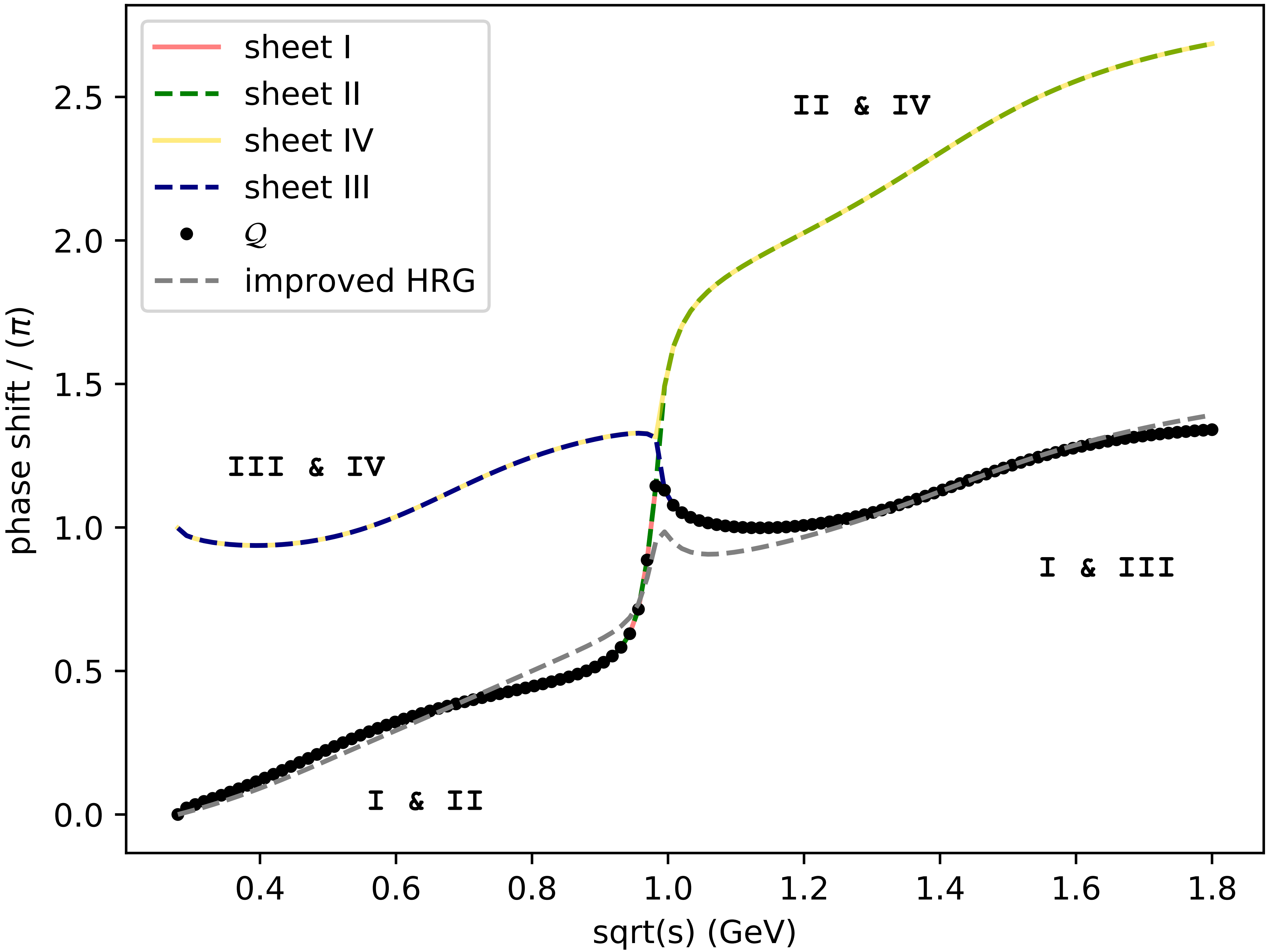
ally generated st

How to find poles (and roots, and sheets, and many other?)

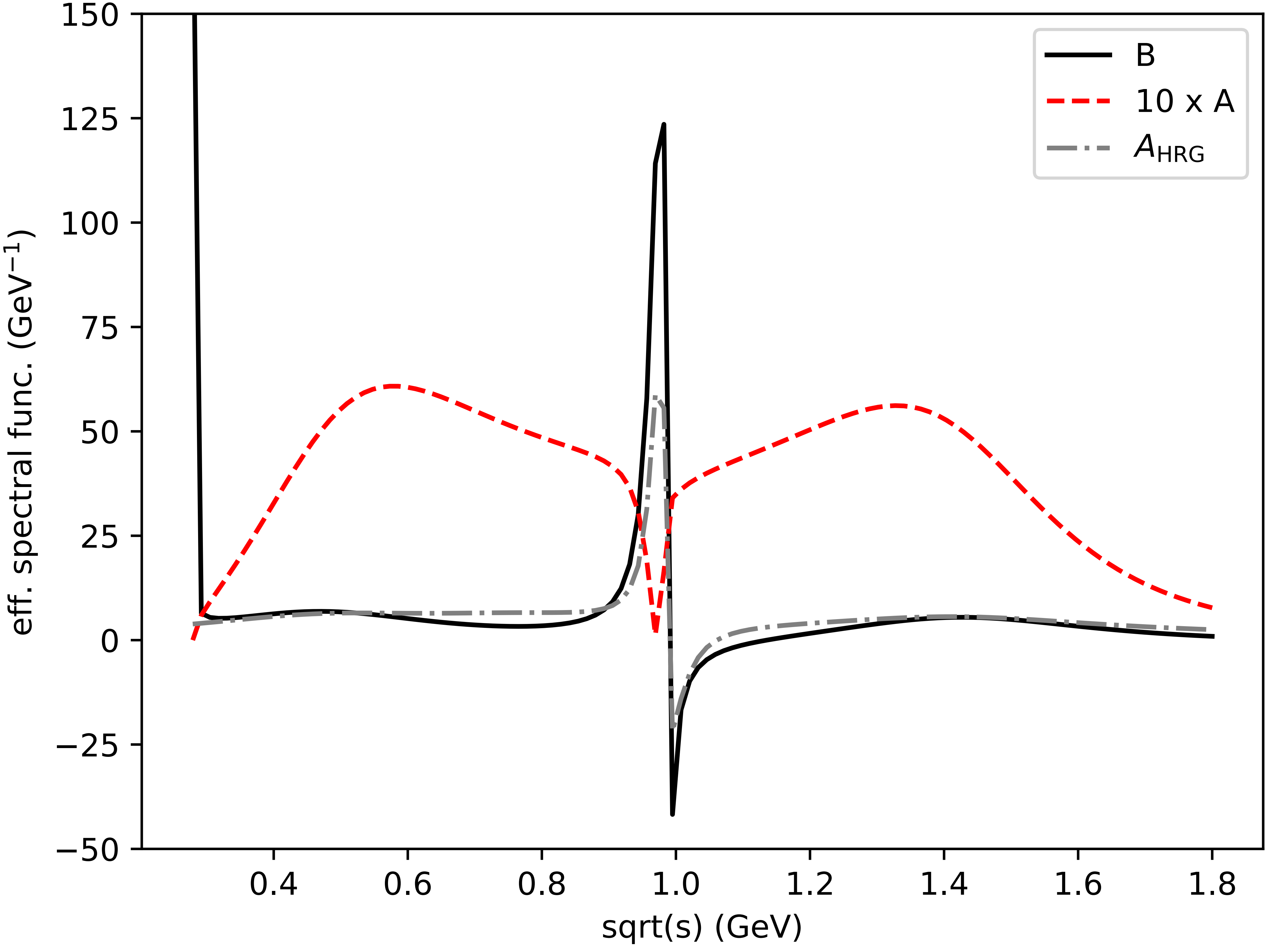


The power of graphical solution


detS(sqrt(s))
sheet I
sheet II
r1
r2
r3
r4
p1
p2
p3
-2.400
-3.200
-4.000
-1.600
-0.800
0.000
0.800
1.600
-2.400
-3.200
2.64
1.98
1.32
0.66
0.00
−0.66
−1.32
−1.98
−2.64
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Im(sqrt(s))
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Re(sqrt(s))



sheet I
sheet II
sheet IV
sheet III
$\mathcal{Q}$
improved HRG
II & IV
III & IV
I & III
I & II
phase shift / (π)
sqrt(s) (GeV)
0.0
0.5
1.0
1.5
2.0
2.5
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8



150
125
100
75
50
25
0
−25
−50
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
eff. spectral func. (GeV^{-1})
sqrt(s) (GeV)
B
10 x A
A_{HRG}

PROTON PUZZLE

BQ CORRELATION

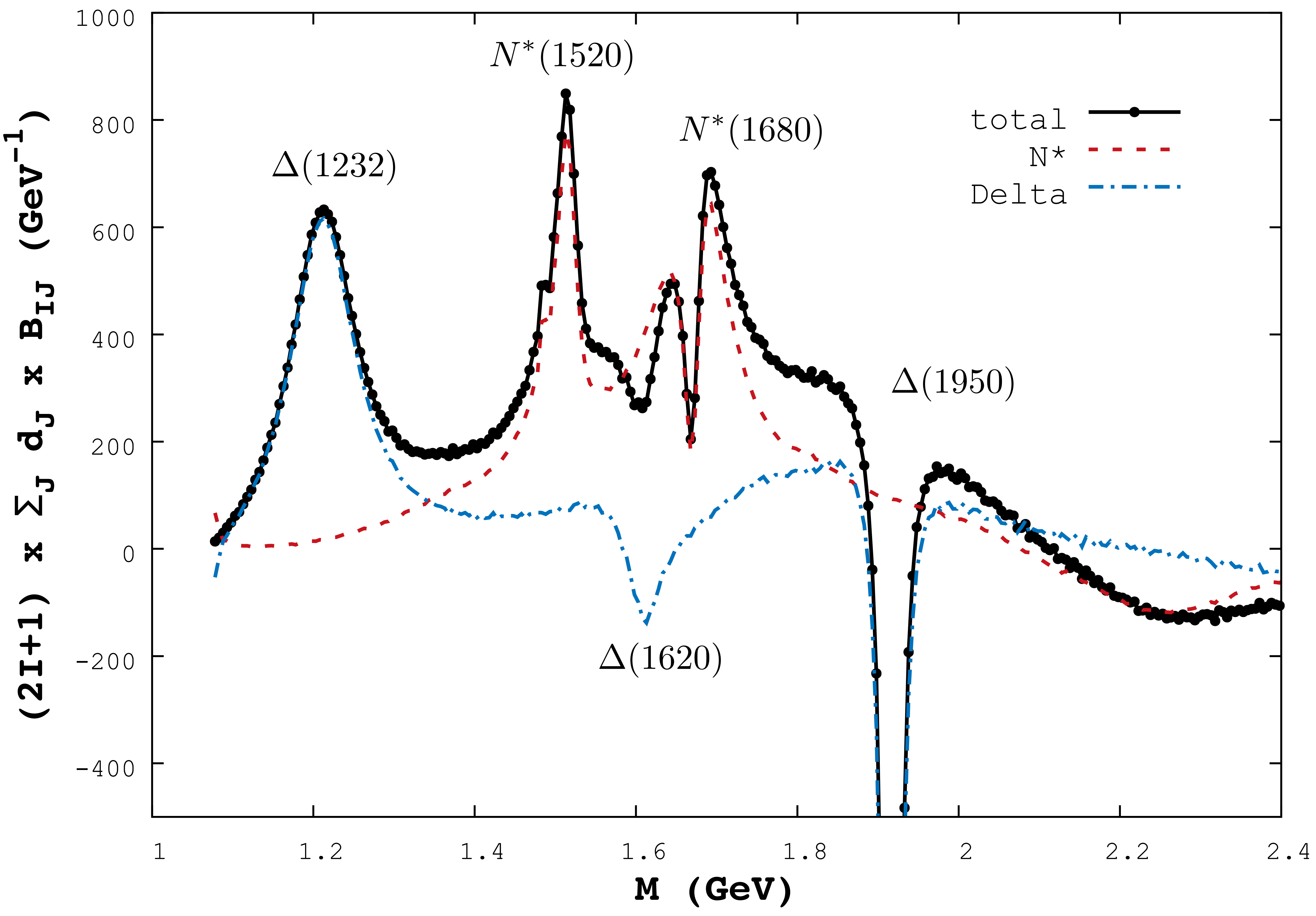
$$\chi_{BQ}/T^2 = \sum_{I_z;B} d_J \underline{B\,Q} \times \int_{m_{\rm th}}^{\infty} \frac{d\sqrt{s}}{2\pi} B_{I,J}(s)$$

$$\times \frac{1}{T^3} \int \frac{d^3p}{(2\pi)^3} \frac{e^{\beta\sqrt{p^2+s})}}{(e^{\beta\sqrt{p^2+s}}+1)^2}$$

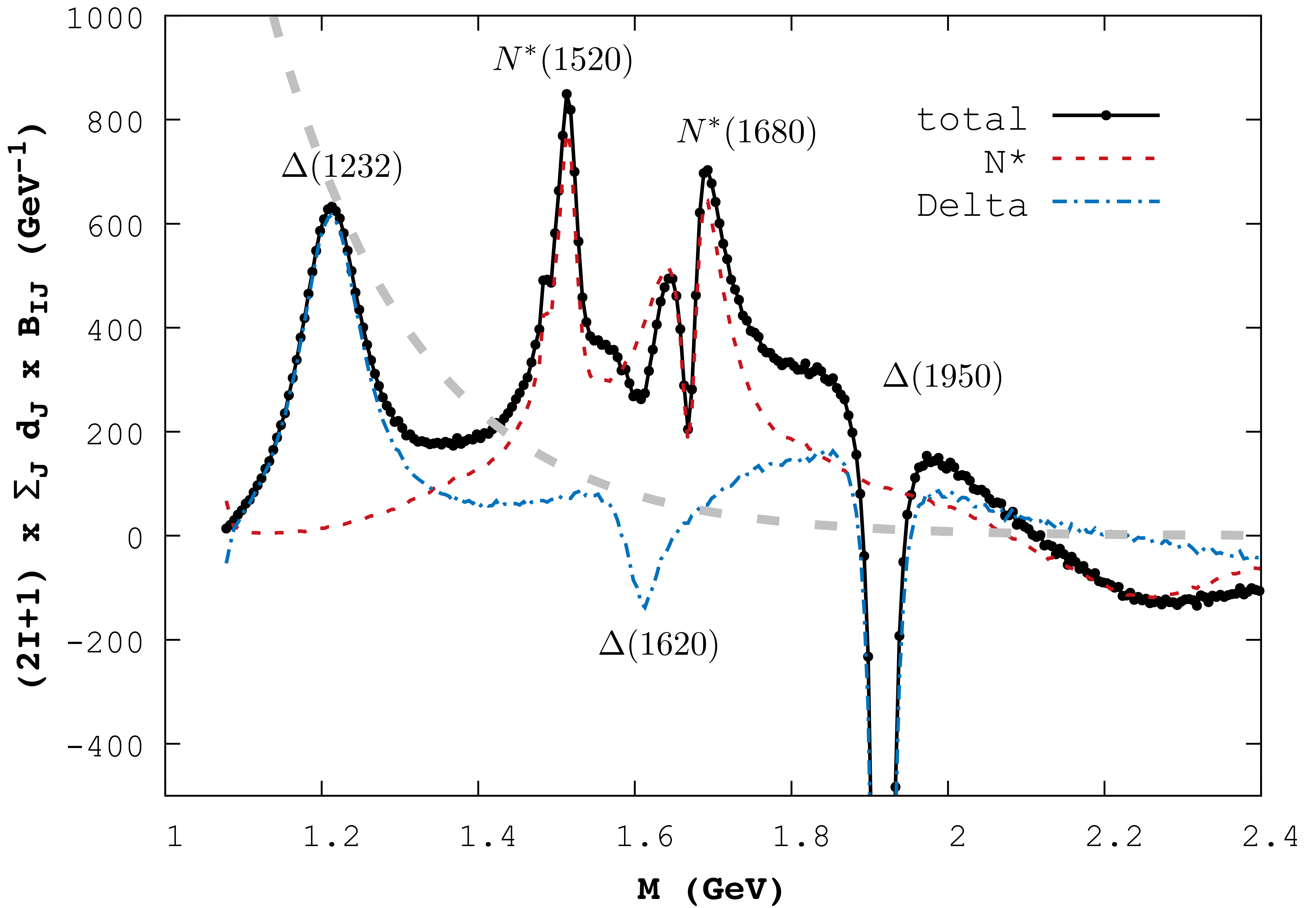
- (in)famous resonances:
  N*: 1535 (S11), 1440 (P11), 1520 (D13) ...
  Δ : 1232 (P33), 1620 (S31) ...

- S = -1 hyperons are excluded:

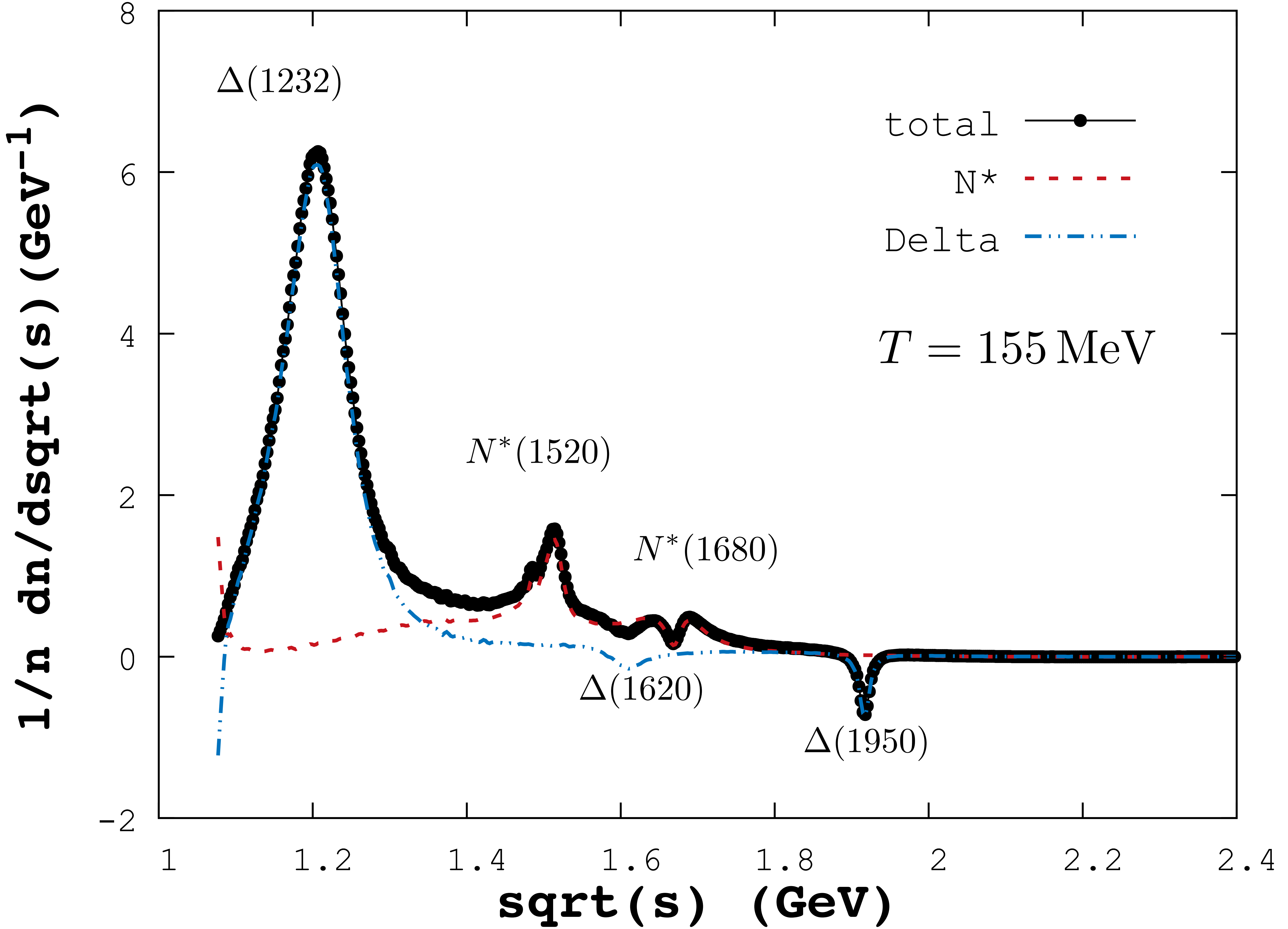
$$Q = I_z + \frac{1}{2}(B+S)$$



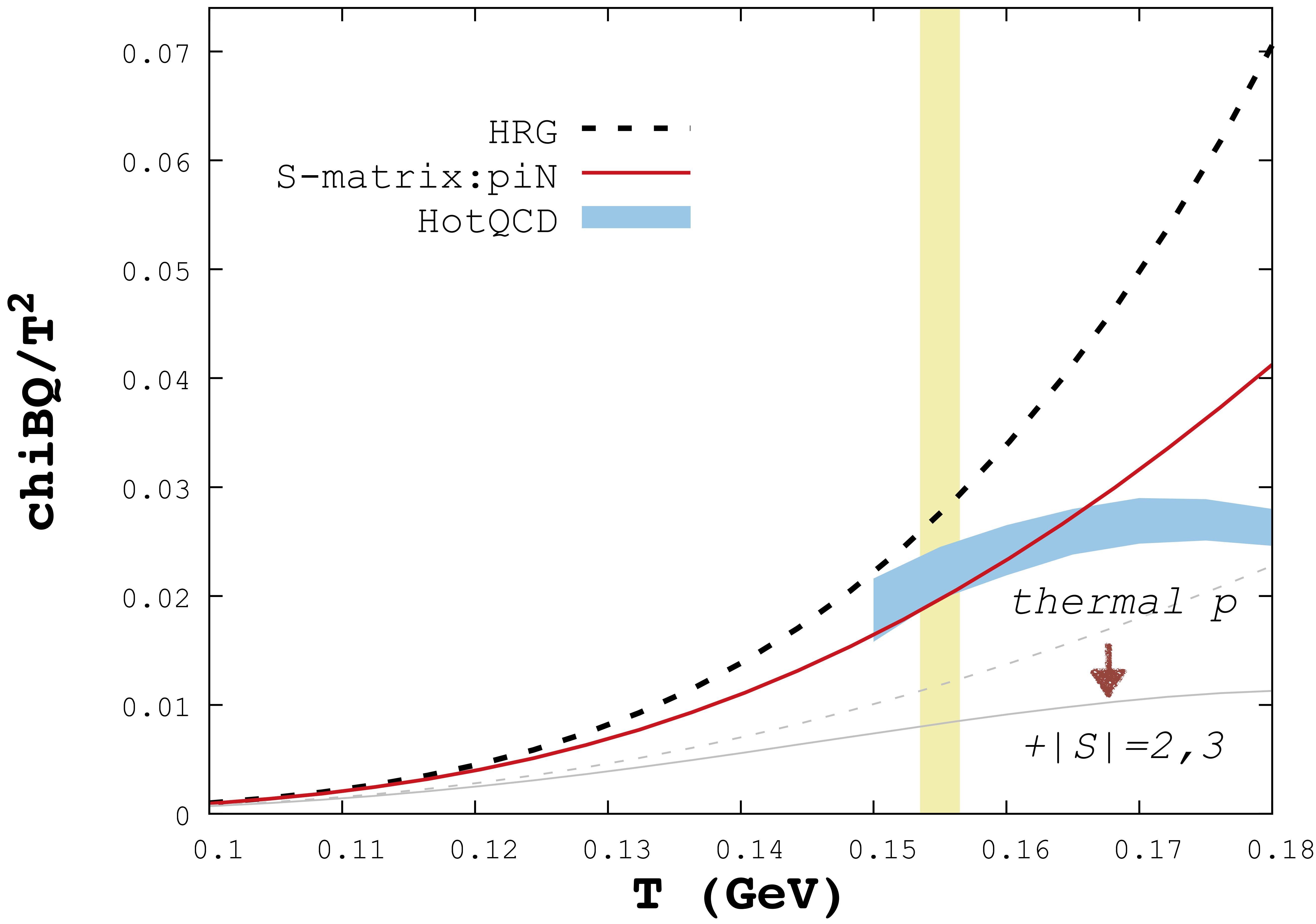
$N^*(1520)$
$N^*(1680)$
$\Delta(1232)$
$\Delta(1950)$
$\Delta(1620)$
total
N*
Delta
1000
800
600
400
200
0
-200
-400
1
1.2
1.4
1.6
1.8
2
2.2
2.4
M (GeV)
(2I+1) x Σ_J d_J x B_{IJ} (GeV^{-1})



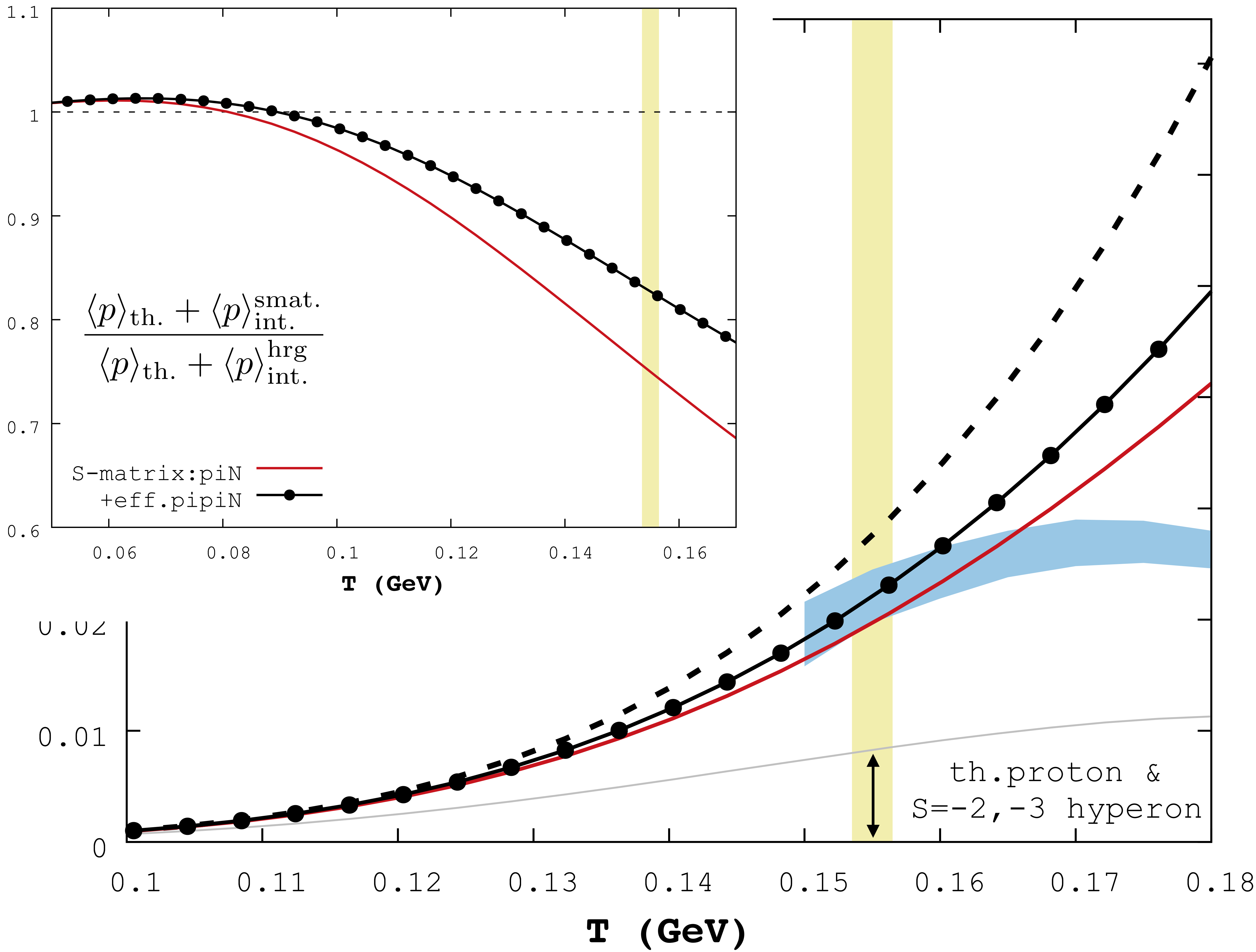
1000
800
600
400
200
0
-200
-400
1
1.2
1.4
1.6
1.8
2
2.2
2.4
M (GeV)
(2I+1) x Σ_J d_J x B_{IJ} (GeV^{-1})
$N^*(1520)$
$N^*(1680)$
$\Delta(1232)$
$\Delta(1950)$
$\Delta(1620)$
total
N*
Delta



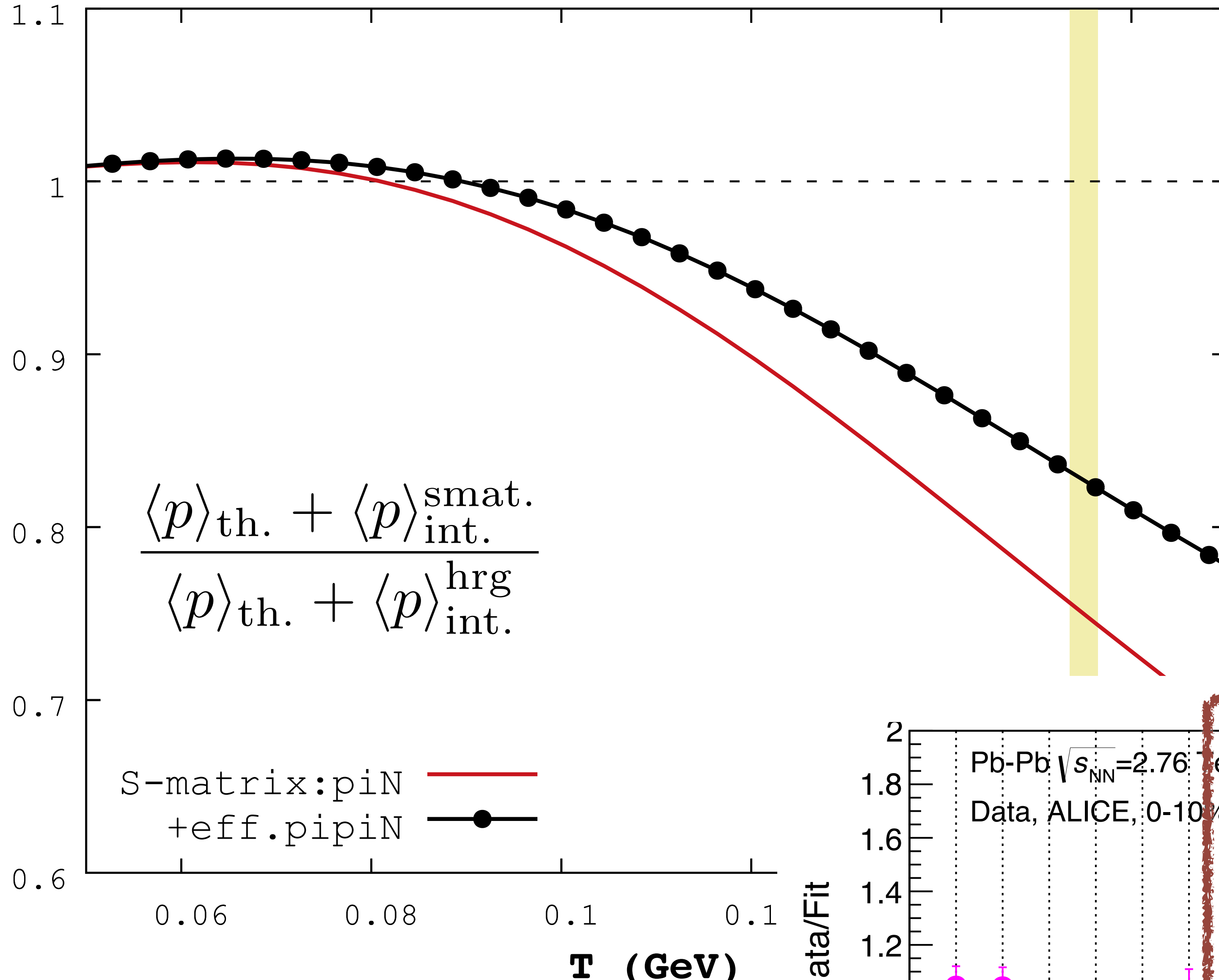
1/n dn/dsqrt(s) (GeV^{-1})
sqrt(s) (GeV)
8
6
4
2
0
-2
1
1.2
1.4
1.6
1.8
2
2.2
2.4
total
N*
Delta
$T = 155\,\mathrm{MeV}$
$\Delta(1232)$
$N^*(1520)$
$N^*(1680)$
$\Delta(1620)$
$\Delta(1950)$



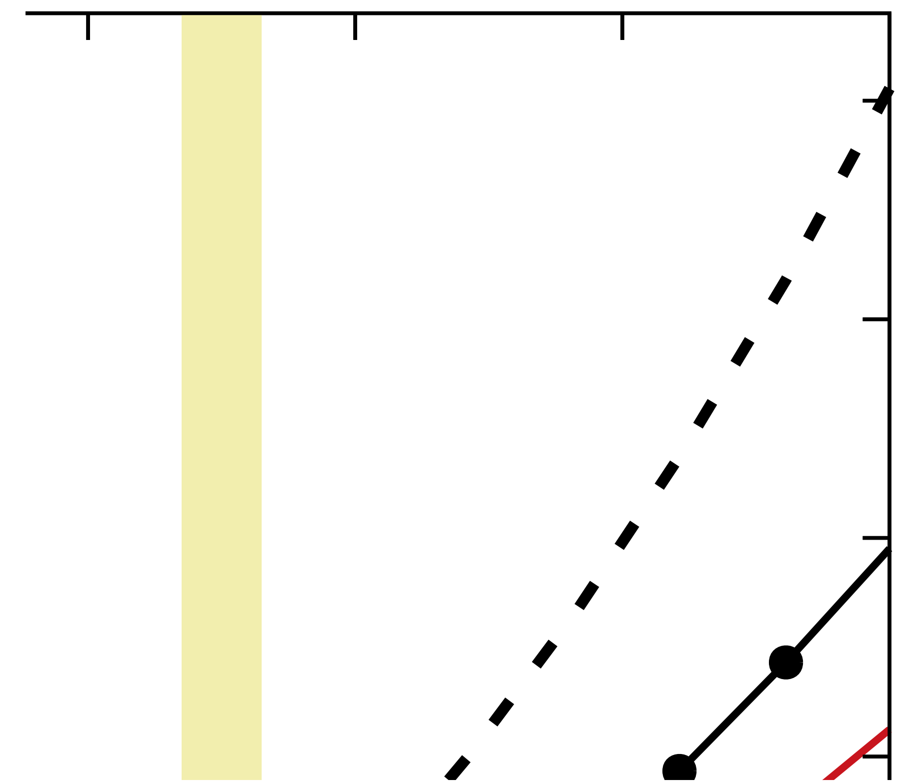
HRG
S-matrix:piN
HotQCD
thermal p
+|S|=2,3
chiBQ/T^2
T (GeV)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18

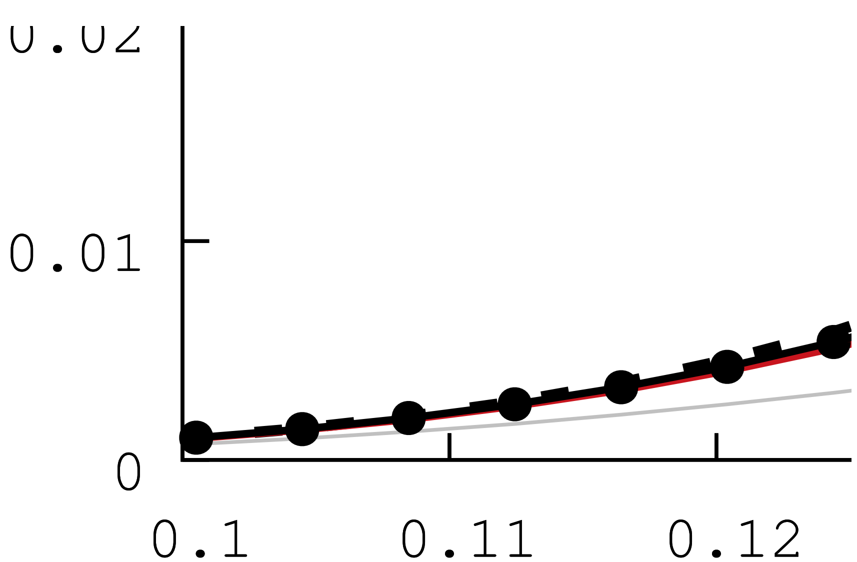


$\frac{\langle p\rangle_{\rm th.} + \langle p\rangle^{\rm smat.}_{\rm int.}}{\langle p\rangle_{\rm th.} + \langle p\rangle^{\rm hrg}_{\rm int.}}$
S-matrix:piN
+eff.pipiN
T (GeV)
th.proton &
S=-2,-3 hyperon
T (GeV)

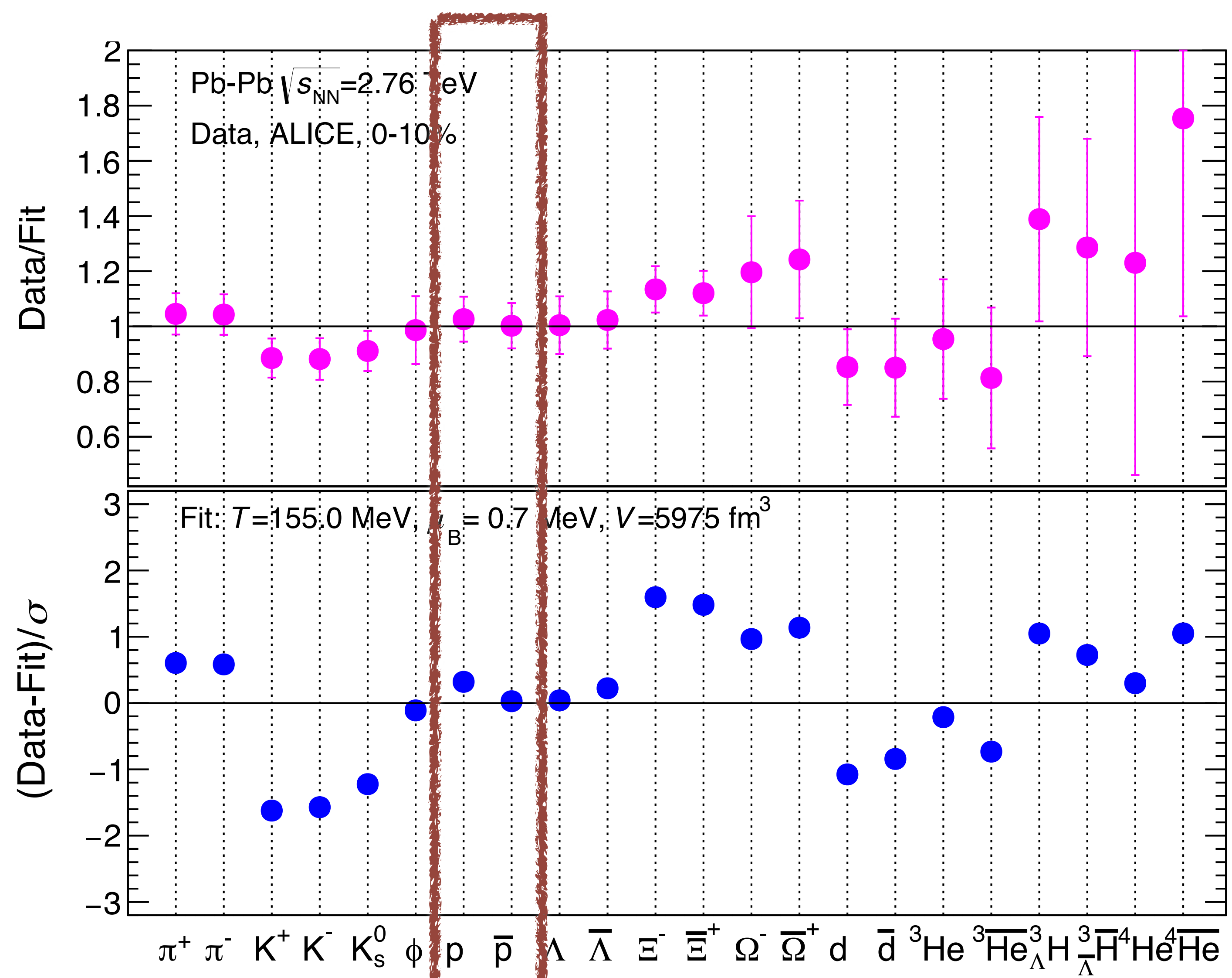


1.1
1
0.9
0.8
0.7
0.6
0.06
0.08
0.1
0.1
T (GeV)
$\frac{\langle p \rangle_{\rm th.} + \langle p \rangle_{\rm int.}^{\rm smat.}}{\langle p \rangle_{\rm th.} + \langle p \rangle_{\rm int.}^{\rm hrg}}$
S-matrix:piN
+eff.pipiN

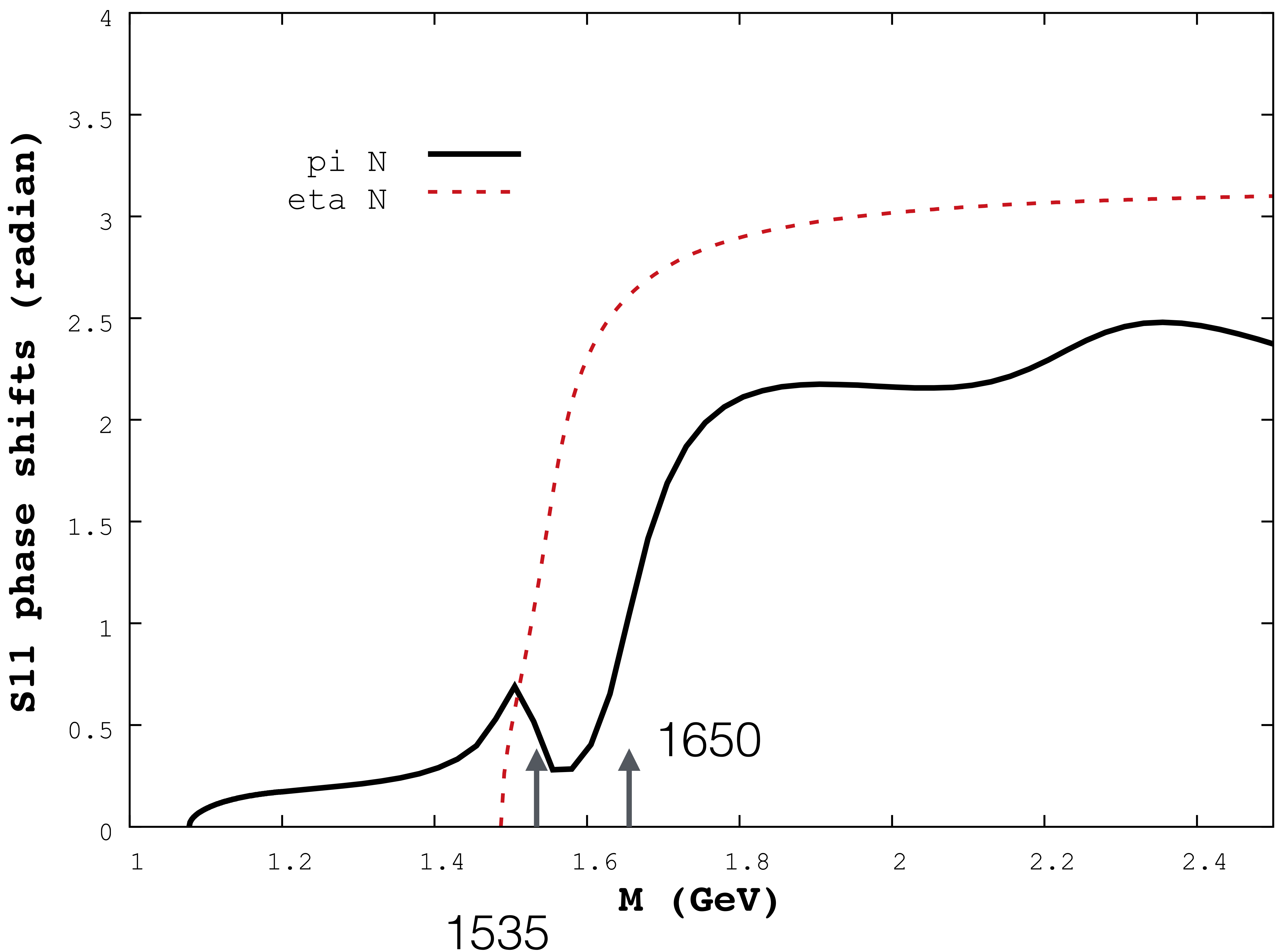




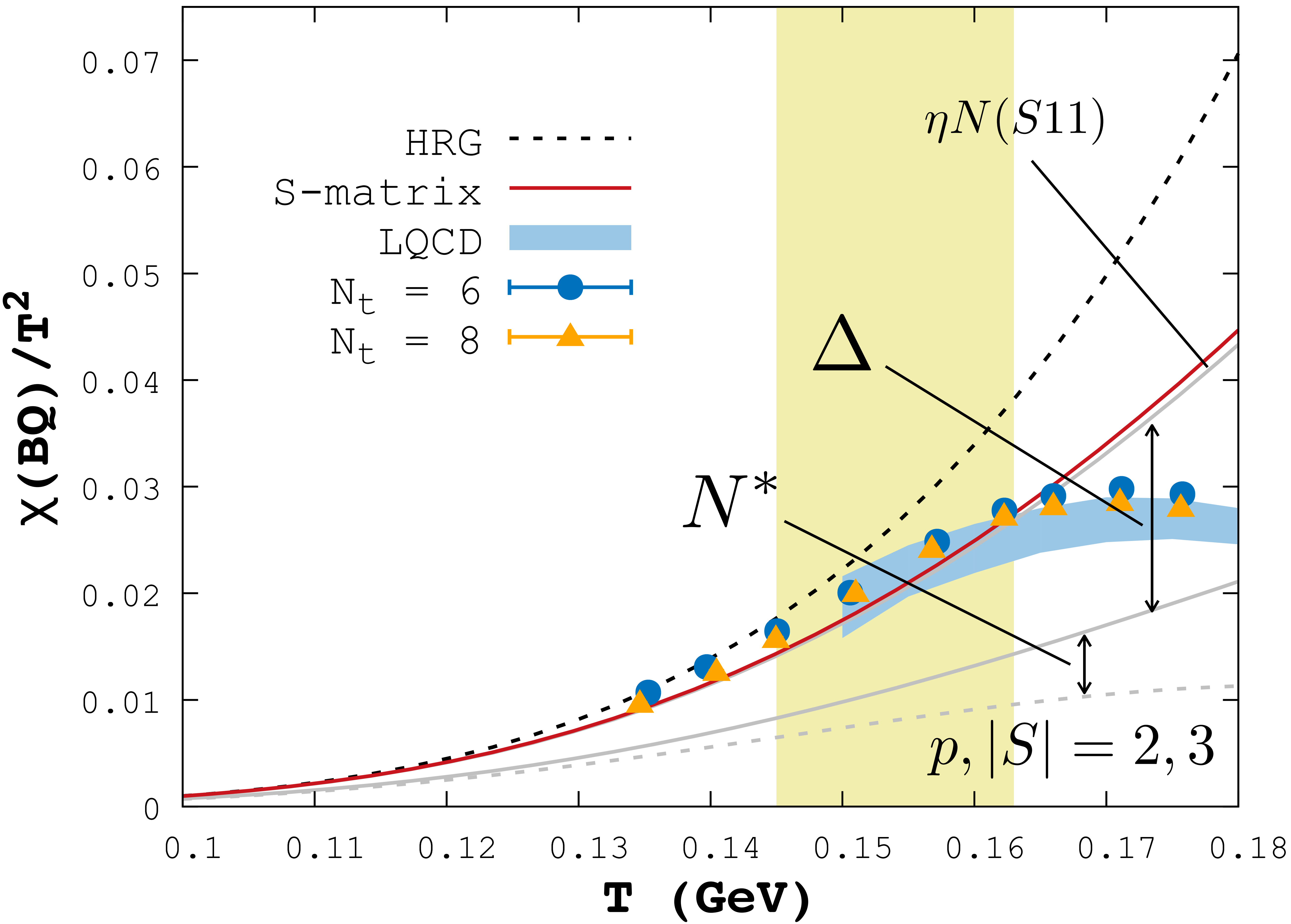
0.01
0
0.1
0.11
0.12



Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV
Data, ALICE, 0-10%
Data/Fit
Fit: T=155.0 MeV, μ_B = 0.7 MeV, V=5975 fm^3
(Data-Fit)/σ
π^+ π^- K^+ K^- K^0_s ϕ p $\bar{p}$ Λ $\bar{\Lambda}$ Ξ^- $\bar{\Xi}^+$ Ω^- $\bar{\Omega}^+$ d $\bar{d}$ ^{3}He $^3\overline{\rm He}$ $^3_\Lambda$H $^3_{\bar\Lambda}\overline{\rm H}$ ^{4}He $^4\overline{\rm He}$



S11 phase shifts (radian)
pi N
eta N
1650
1535
M (GeV)
0
0.5
1
1.5
2
2.5
3
3.5
4
1
1.2
1.4
1.6
1.8
2
2.2
2.4


HRG
S-matrix
LQCD
$N_t = 6$
$N_t = 8$
$\eta N(S11)$
Δ
N^*
$p, |S| = 2, 3$
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
$\chi(BQ)/T^2$
T (GeV)

S = -1 HYPERONS
COUPLED CHANNEL SYSTEM

C. Fernandez-Ramirez, PML, and P. Petreczky,
PRC **98**, 044910 (2018)

PHASE SHIFT FROM PWA

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--------------------------------------------------------------------------------

Coupled Channels partial wave calculator for KN scattering

by the Joint Physics Analysis Center (JPAC)

Version: September 1, 2015

--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Authors:

Cesar Fernandez-Ramirez (Jefferson Lab)
Igor V. Danilkin (Jefferson Lab)
Vincent Mathieu (Indiana University)
Adam P. Szczepaniak (Indiana University and Jefferson Lab)

Citation: Fernandez-Ramirez et al., arxiv:1510.07065 [hep-ph]

First version: Cesar Fernandez-Ramirez (Jefferson Lab)
This version: Cesar Fernandez-Ramirez (Jefferson Lab)

Contact: cefera@gmail.com (Cesar Fernandez-Ramirez)

Disclaimers:

1 - This code follows the 'garbage in, garbage out' philosphy. If your
parameters do not make sense, the output will not make sense either.
2 - You can use, share and modify this code under your own responsability.
3 - This code is distributed in the hope that it will be useful,
but WITHOUT ANY WARRANTY; without even the implied warranty of
MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
4 - No PhD students or postdocs were severely damaged during the development
of this project.

------------------------------------------------------------------
```

STRANGENESS CONTENT IN A HADRON GAS

- K-N system require

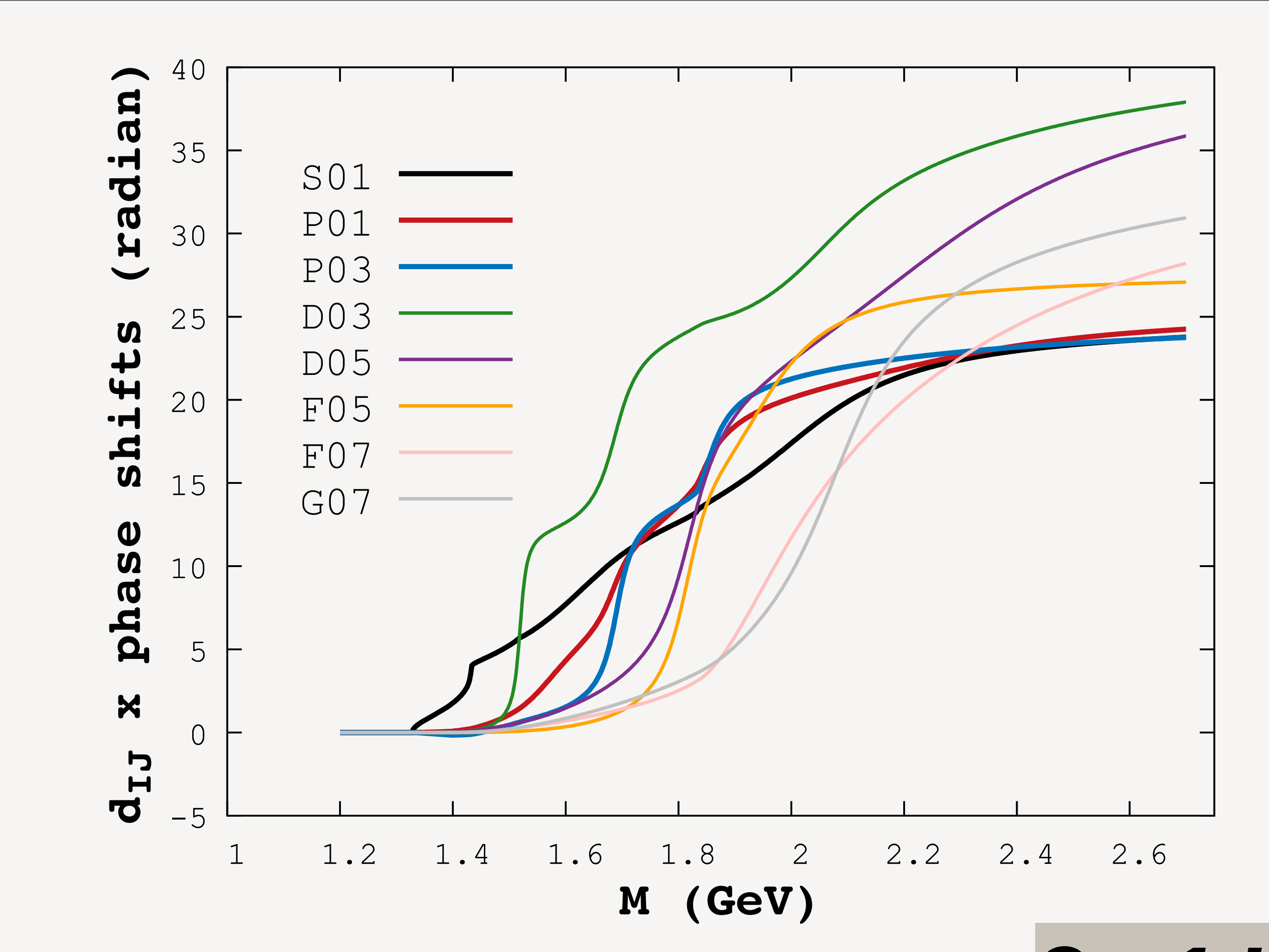
$|\bar{K}N\rangle, |\pi\Sigma\rangle, |\pi\Lambda\rangle, |\eta$

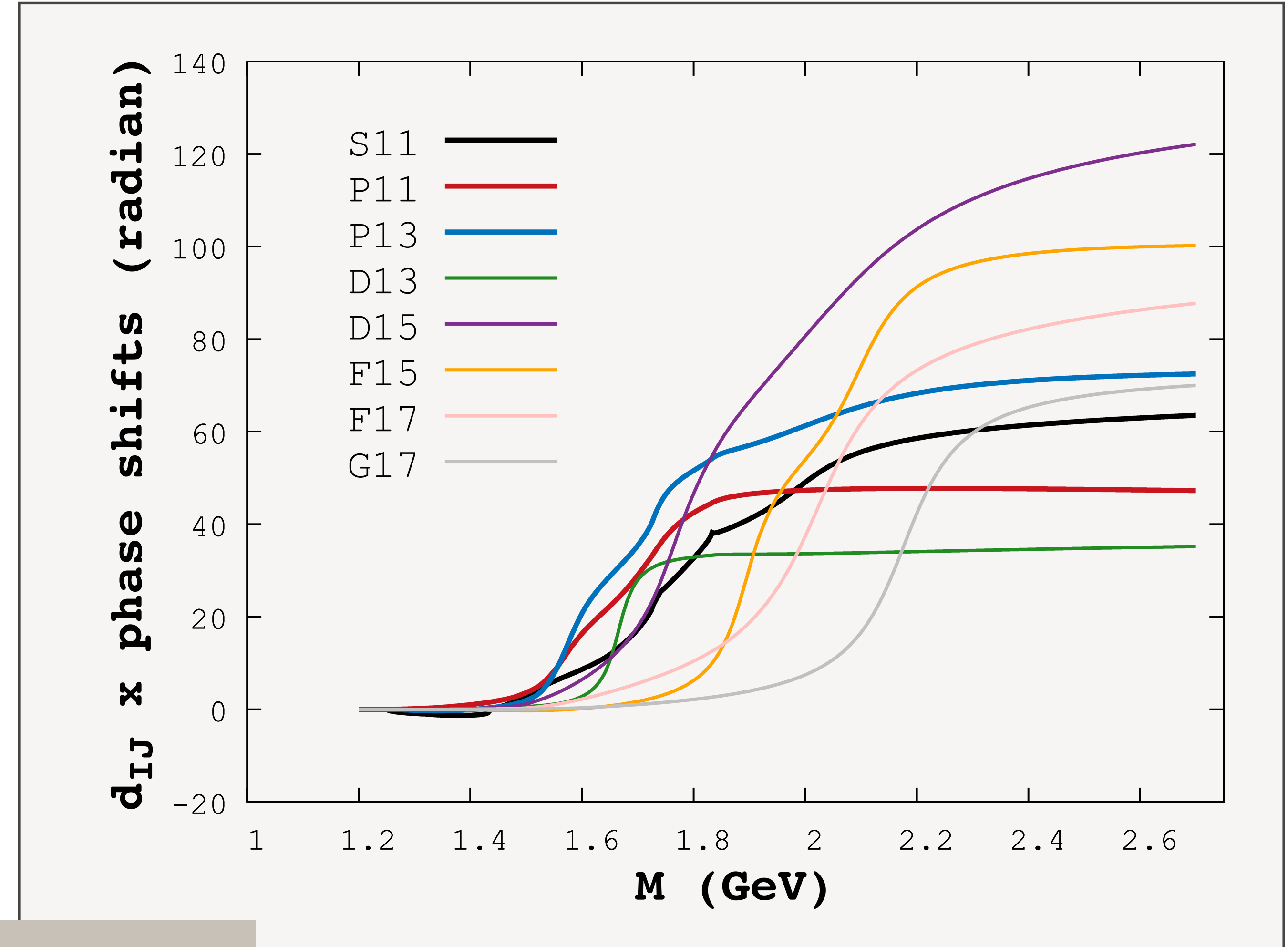
$$\mathcal{Q}(M) \equiv \frac{1}{2}\,\mathrm{Im}\,(\mathrm{tr}$$

$$= \frac{1}{2}\,\mathrm{Im}\,(\ln$$

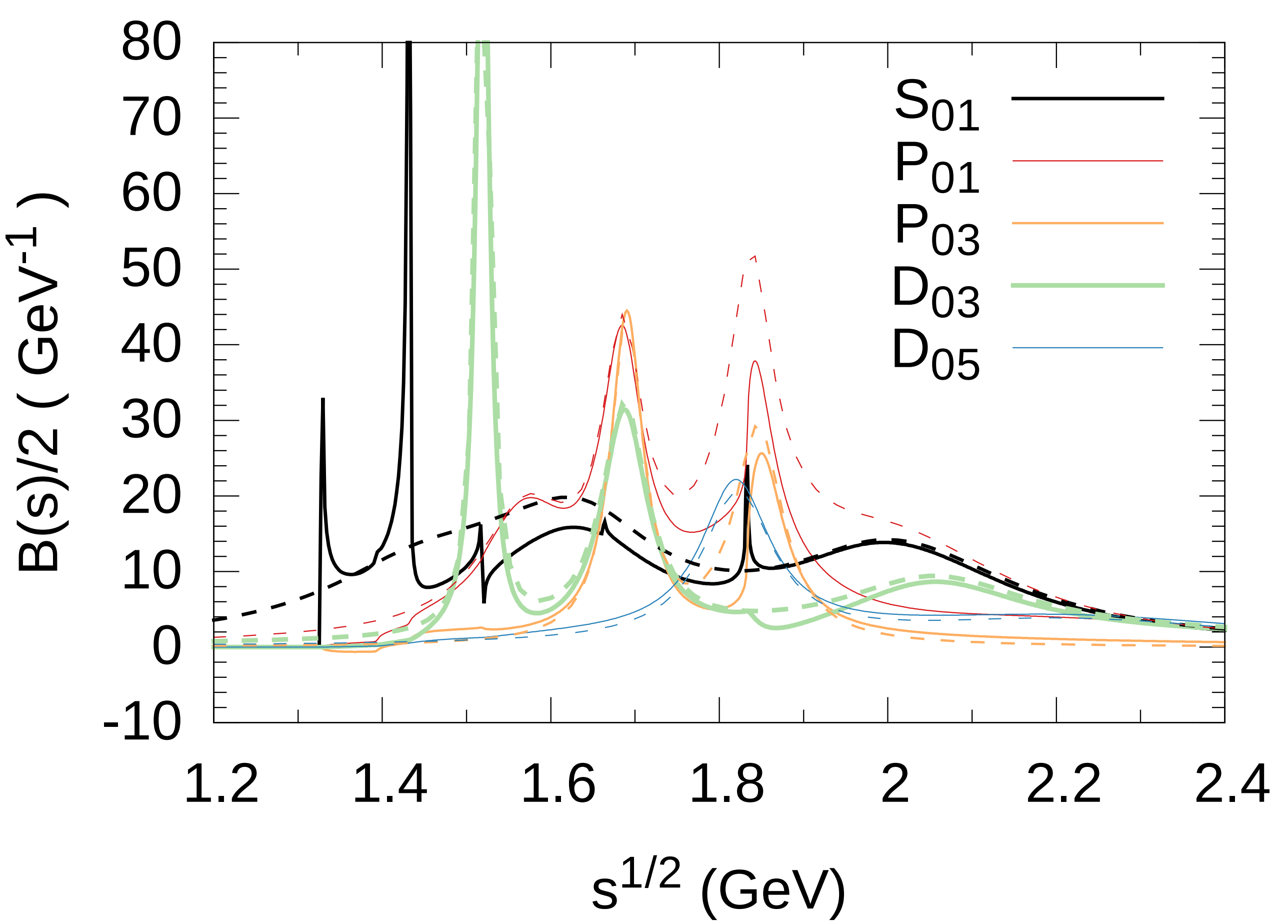
$$= \delta_{\bar{K}N} + \delta$$

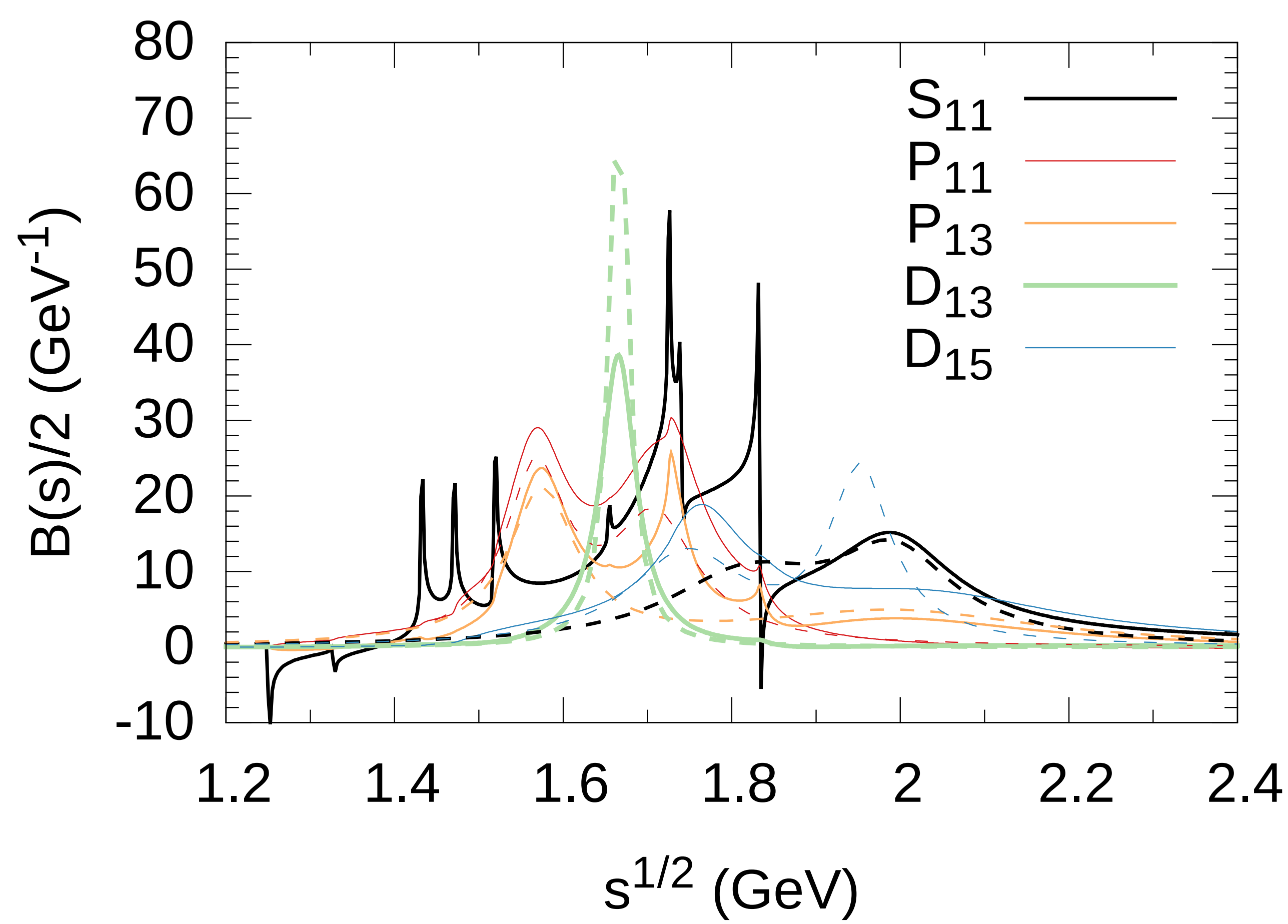
- 1 → $\bar{K}N$,
- 2 → $\pi\Sigma$,
- 3 → $\pi\Lambda$,
- 4 → $\eta\Lambda$,
- 5 → $\eta\Sigma$,
- 6 → $\bar{K}_1N$,
- 7 → $\left[\bar{K}_3N\right]_-$,
- 8 → $\left[\bar{K}_3N\right]_+$,
- 9 → $[\pi\Sigma^*]_-$,
- 10 → $[\pi\Sigma^*]_+$,
- 11 → $\left[\bar{K}\Delta\right]_-$,
- 12 → $\left[\bar{K}\Delta\right]_+$,
- 13 → $[\pi\Lambda(1520)]_-$,
- 14 → $[\pi\Lambda(1520)]_+$,
- 15 → $\pi\pi\Lambda$,
- 16 → $\pi\pi\Sigma$.

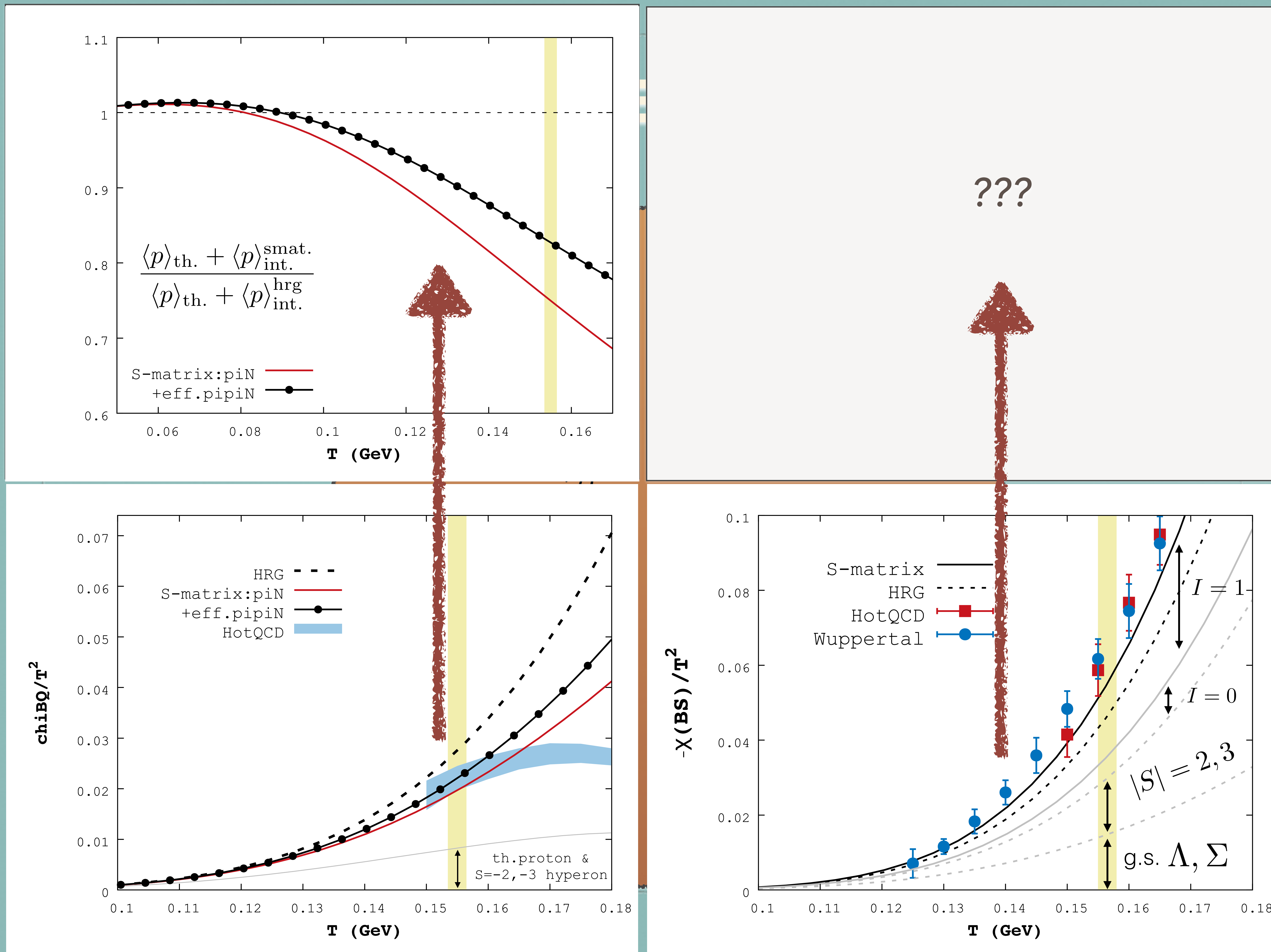

dIJ x phase shifts (radian)
M (GeV)
S01
P01
P03
D03
D05
F05
F07
G07
40
35
30
25
20
15
10
5
0
-5
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6


dIJ x phase shifts (radian)
M (GeV)
S11
P11
P13
D13
D15
F15
F17
G17
140
120
100
80
60
40
20
0
-20
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6

S=-1 Hyperon


B(s)/2 (GeV-1)
s1/2 (GeV)
S01
P01
P03
D03
D05
80
70
60
50
40
30
20
10
0
-10
1.2
1.4
1.6
1.8
2
2.2
2.4


B(s)/2 (GeV-1)
s1/2 (GeV)
S11
P11
P13
D13
D15
80
70
60
50
40
30
20
10
0
-10
1.2
1.4
1.6
1.8
2
2.2
2.4


$\frac{\langle p \rangle_{th.} + \langle p \rangle_{int.}^{smat.}}{\langle p \rangle_{th.} + \langle p \rangle_{int.}^{hrg}}$
S-matrix:piN
+eff.pipiN
T (GeV)
???
chiBQ/T^2
HRG
S-matrix:piN
+eff.pipiN
HotQCD
th.proton &
S=-2,-3 hyperon
T (GeV)
-χ(BS)/T^2
S-matrix
HRG
HotQCD
Wuppertal
$I = 1$
$I = 0$
$|S| = 2, 3$
g.s. Λ, Σ
T (GeV)

UNQUENCHING THE QUARK MODEL

NO SERIOUS MESON SPECTROSCOPY WITHOUT SCATTERING*

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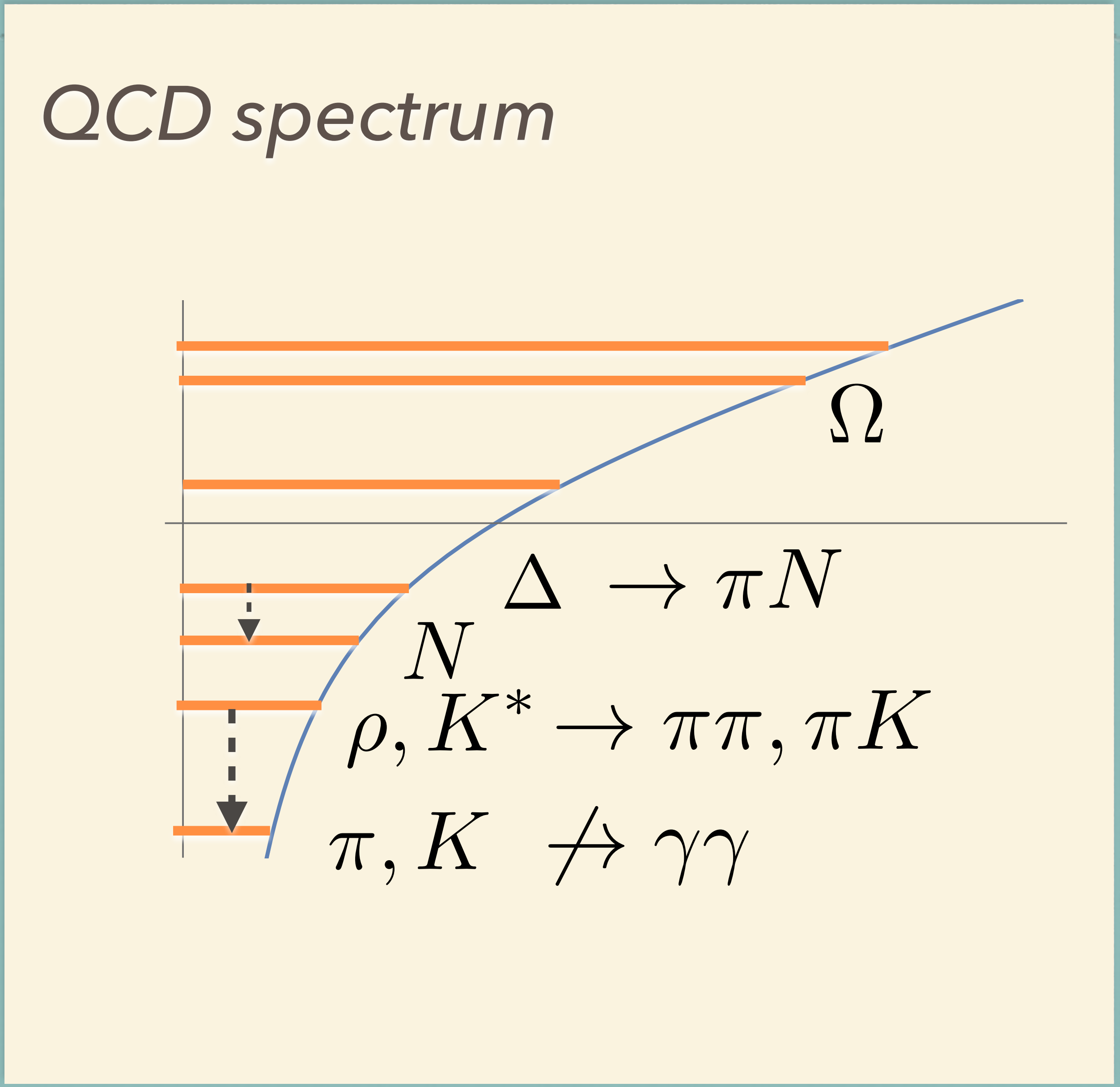
Institute of Modern Physics, CAS, Lanzhou 730000, China

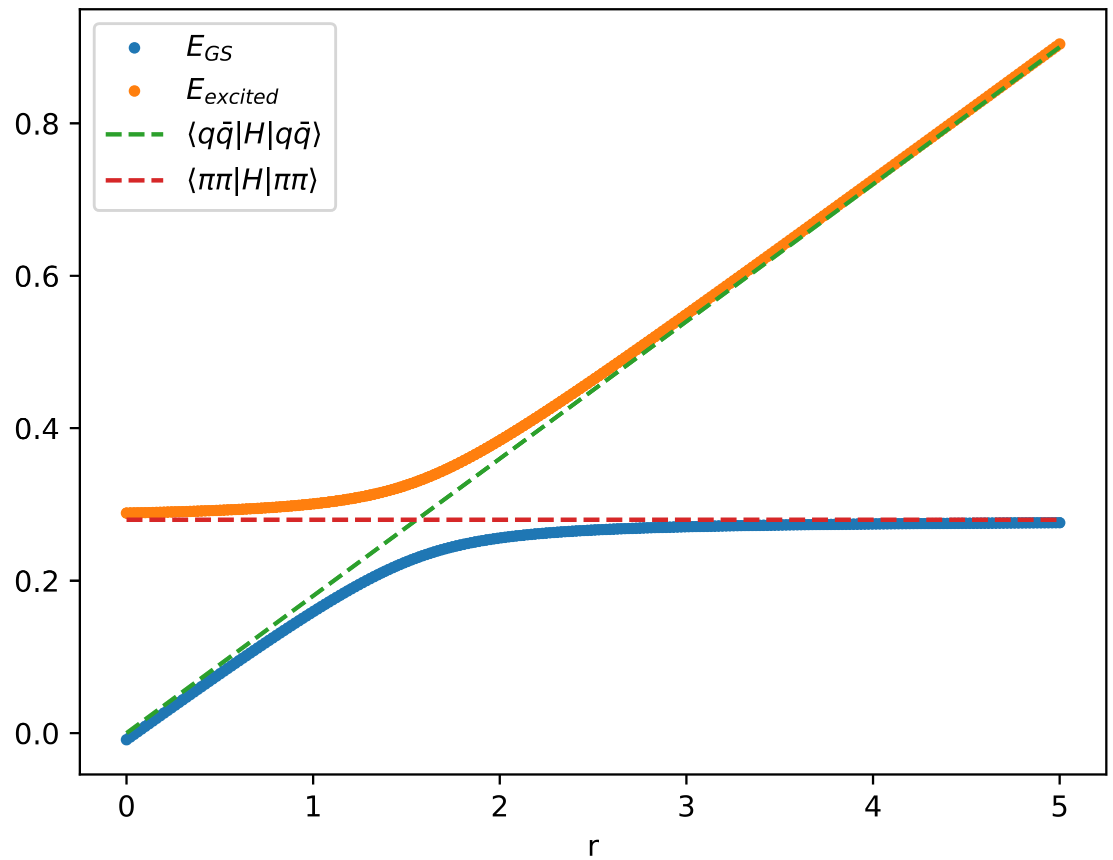
(Received January 26, 2015)

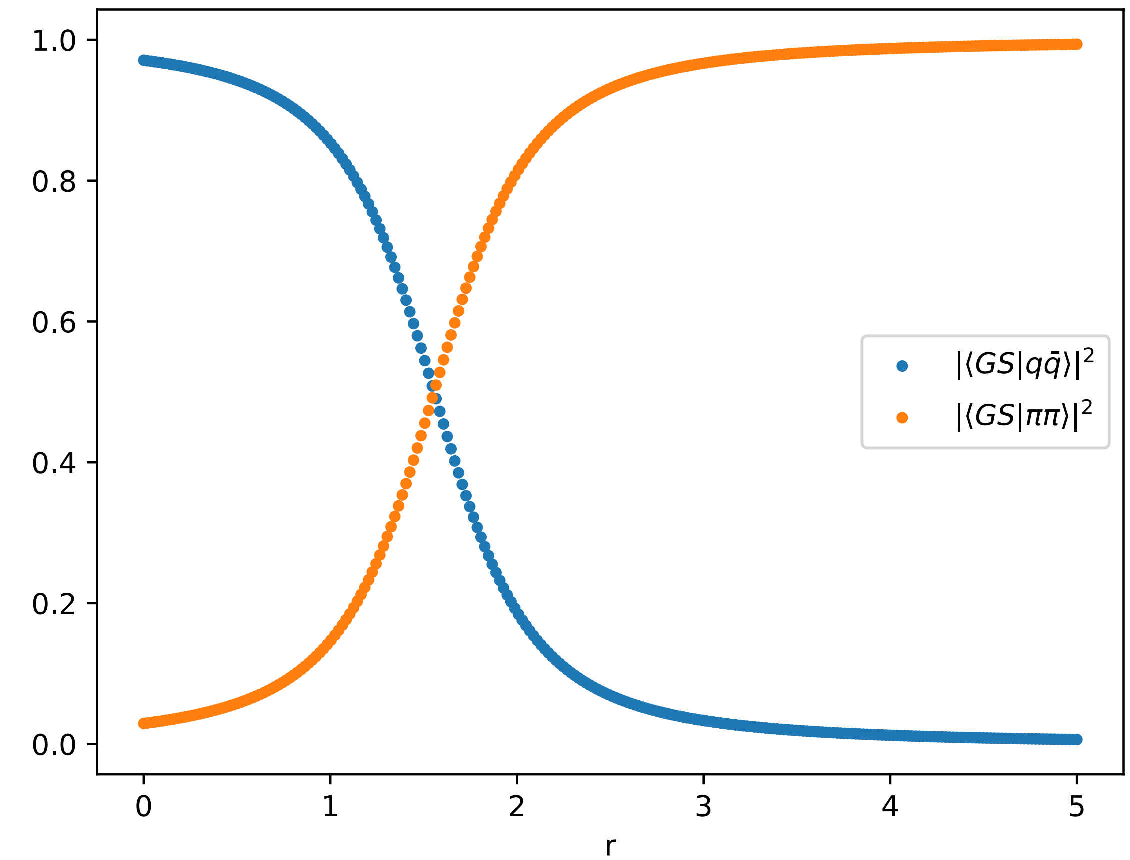
HADRON RESON
MODEL

- Confinement

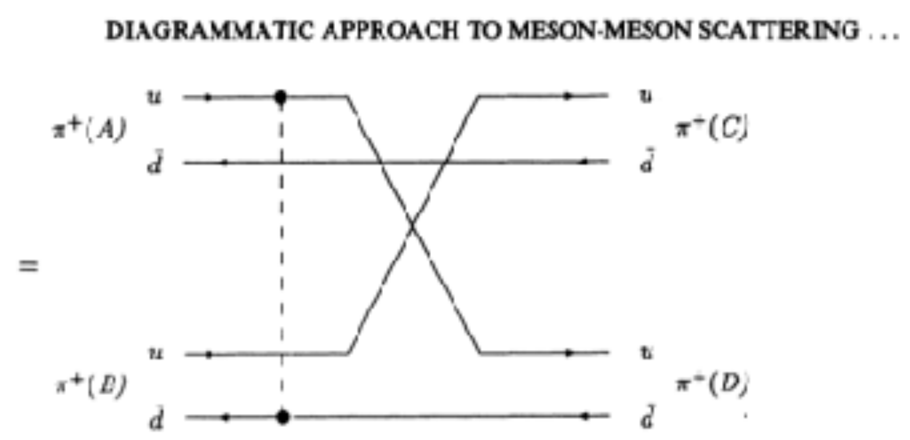


$$Z = \sum_{\alpha=B,M} \langle\alpha|e^{-\beta H}|\alpha\rangle$$





need to study the adiabatic surfaces…



NOW WE KNOW HOW TO COUNT…

- impact of pipiN on thermodynamics
- lifetimes of unstable states / exotics
  in a thermal system
- thermal aspects in unquenching the quark model
- S-matrix interpretation of in-medium effect
- N-body forces

THANK YOU