

Is there a low p_T “anomaly” in the pion momentum spectra from relativistic nuclear collisions?

Pasi Huovinen
Uniwersytet Wrocławski

ULtra-RelativistiCH HEavy IoNZ 2016

July 19, 2016, CERN

in collaboration with

Pok Man Lo

and M. Marzenko, K. Redlich, C. Sasaki

Is there a low- p_T “anomaly” in the pion momentum spectra from relativistic nuclear collisions?*

J. Sollfrank, P. Koch, U. Heinz

Institut für Theoretische Physik, Universität Regensburg, Postfach 397, W-8400 Regensburg, Federal Republic of Germany

Received 20 May 1991

Abstract. The influence of resonance production in relativistic hadron–hadron and nucleus–nucleus collisions, and their role in explaining the so-called “anomalous” behaviour of the hadronic transverse momentum spectra at low p_T , is studied qualitatively and quantitatively in the framework of a simple thermodynamical model. In the discussion effects from the different kinematics in 2- and 3-body decays and from the finite width of the resonances are included. We compare our results with data from the NA35 collaboration for pion, kaon, proton and Λ p_T -spectra from 200 A GeV S + S collisions and with pp data at similar energies. The model can successfully describe both S + S and pp data, with $T = 200$ MeV, $\mu_b = 200$ MeV and $T = 180$ MeV, $\mu_b = 250$ MeV, respectively. We discuss the consistency of these parameters by comparing with measured particle ratios and checking the freeze-out conditions. We conclude that the low- p_T

scaling with a common temperature of about 200 MeV. Only the low- p_T region of the pion-spectra violates this empirical rule. This so-called low- p_T enhancement has attracted a lot of interest, and several mechanisms with far-reaching consequences for the state of matter produced in these collisions have been suggested to explain this behaviour (for an overview see e.g. [2, 3]).

Staying more conventional we have shown recently [4] that an important contribution to the low- p_T enhancement of pions is due to resonance decays. This effect was already noted more than a decade ago in pp and πp collision experiments [5–8]. Several experiments extracted the yield of pions coming from resonance decays, and found contributions in pp -collisions at $\sqrt{s} = 53$ GeV of more than 60% in [5], about 55% in [6] and at $\sqrt{s} = 27.5$ GeV of about 45% in [7]. In $\pi^+ p$ interactions at 16 GeV/c incident momentum only about 10 to 30% of the pions result from direct production [8]. Therefore

* Part of the Ph.D. thesis of P. Koch, Universität Regensburg, 1991.

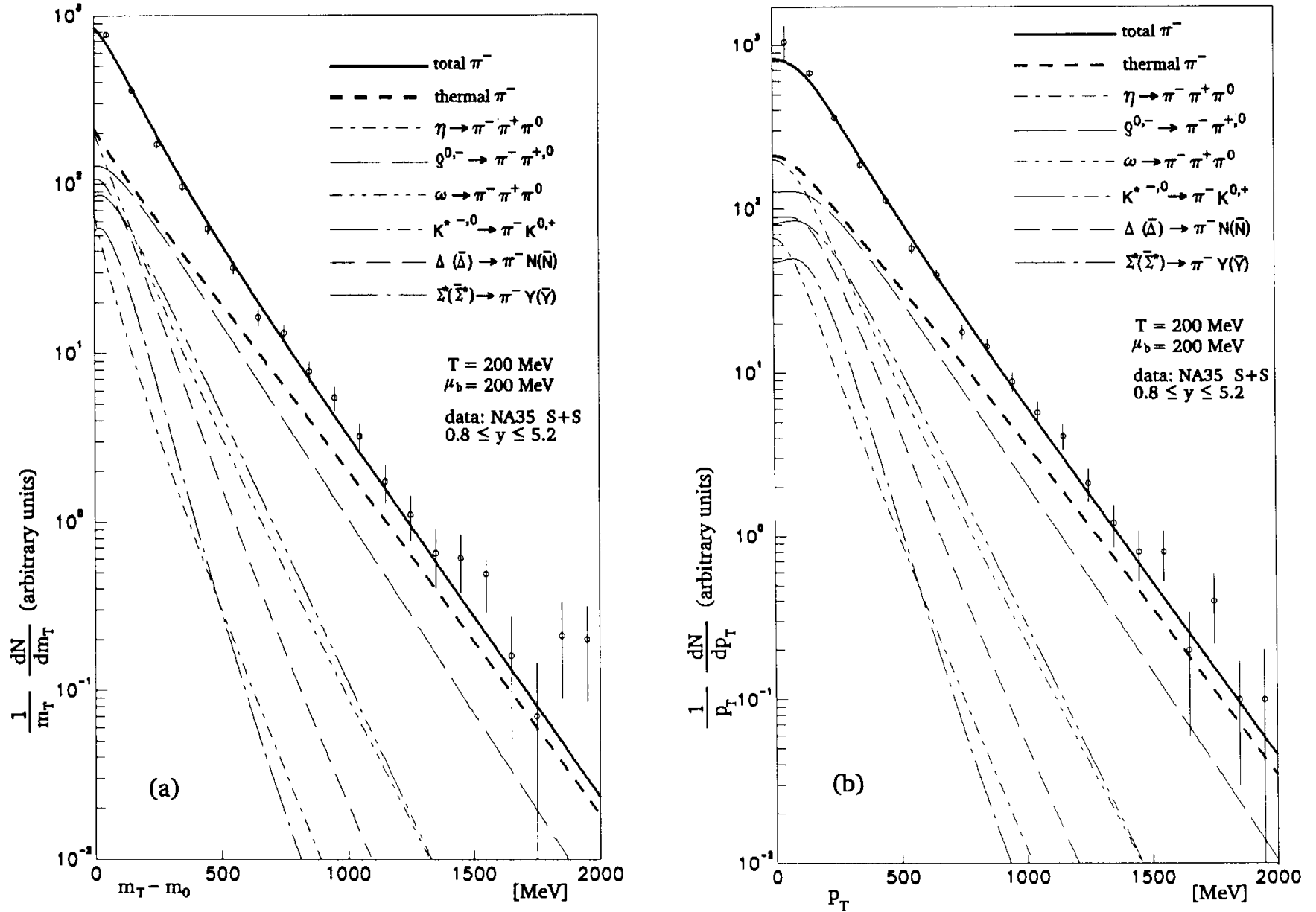
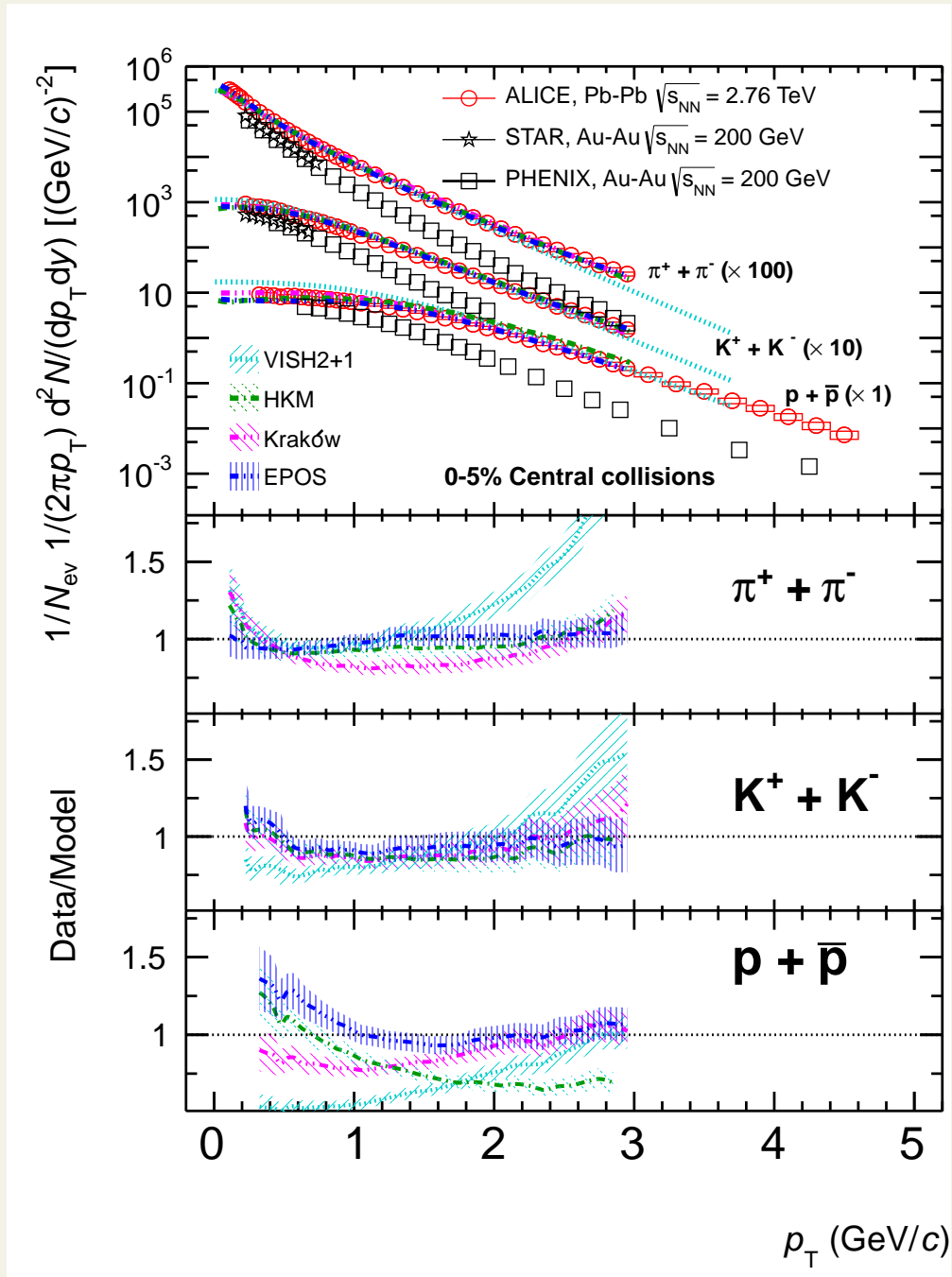
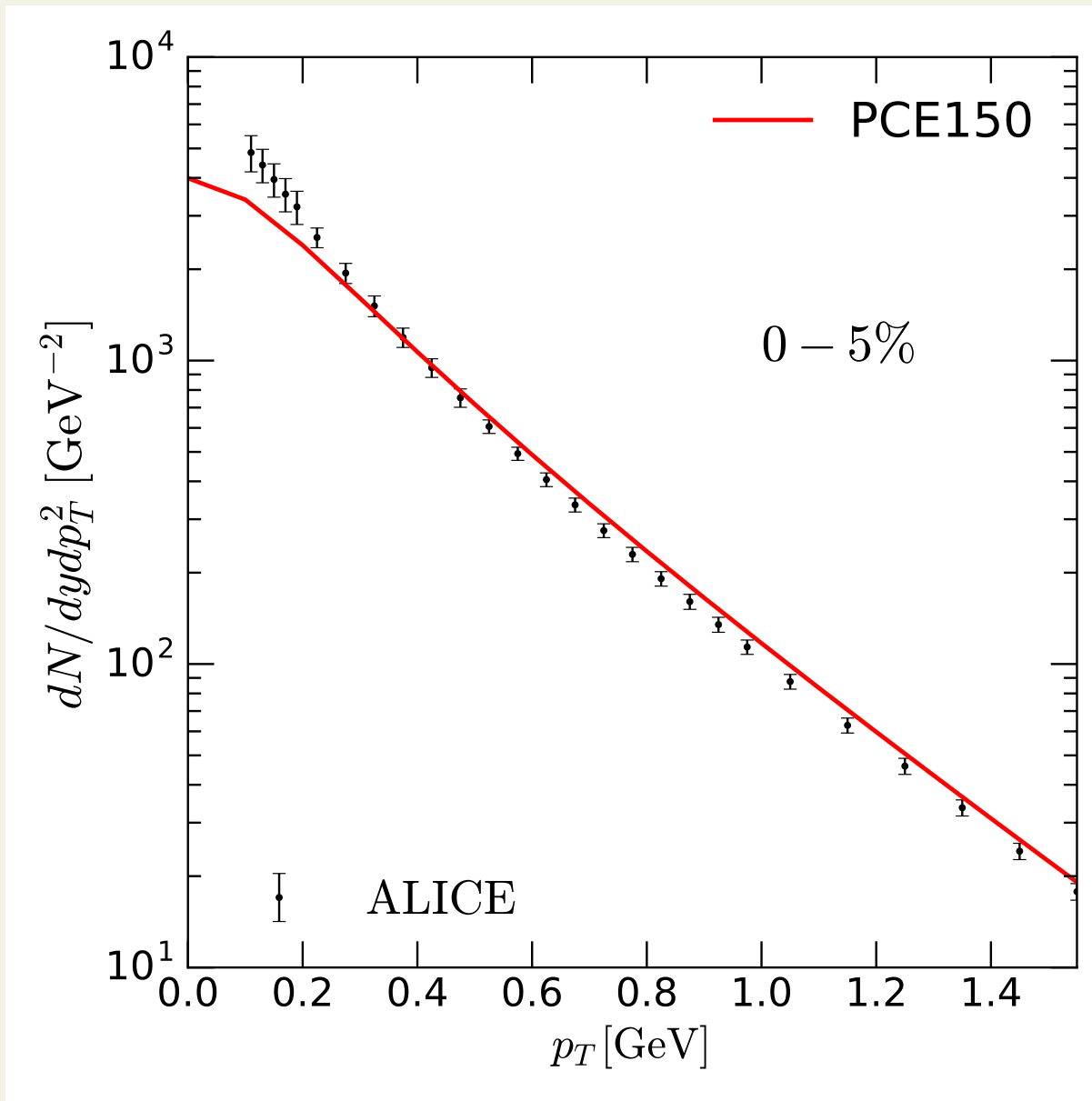


Fig. 6. **a** m_T -distribution of π^- from a resonance gas at $T = 200$ MeV and $\mu_b = 200$ MeV, including direct thermal π^- radiation as well as π^- from various decay channels. The resulting total m_T -distribution is compared with NA35 data [20] (S + S at 200 Å GeV) for the full rapidity region covered by the experiment, $0.8 \leq y \leq 5.2$. **b** Same as **a** but plotted against p_T and compared with the NA35 data [20] binned in p_T

Identified particle p_T spectra at LHC



Pion p_T spectrum at LHC

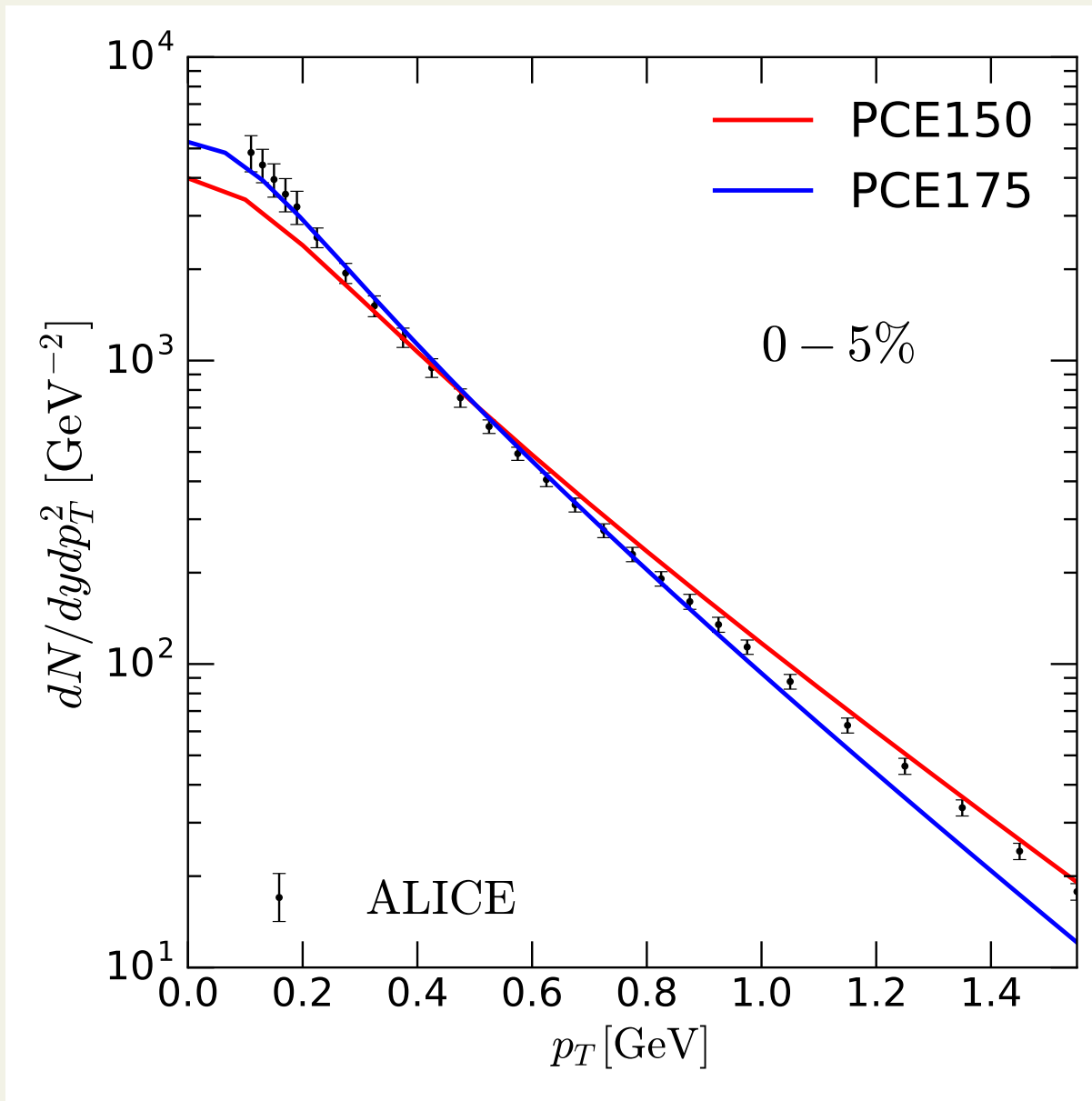


- viscous hydro
- initial state:
pQCD+saturation
- $\tau_0 \approx 0.2\text{fm}/c$

PCE150:
fit to π , K , p yields
no fit to spectrum

©H. Niemi

Pion p_T spectrum at LHC



- viscous hydro
- initial state:
pQCD+saturation
- $\tau_0 \approx 0.2\text{fm}/c$

PCE150:
fit to π , K , p yields
no fit to spectrum

PCE175:
no fit to yields
fits the spectrum

©H. Niemi

- **need more resonances**
- **yield proportional to Boltzmann factor**

$$N \propto \exp\left(-\frac{m}{T}\right)$$

- need more resonances
- yield proportional to Boltzmann factor

$$N \propto \exp\left(-\frac{m}{T}\right)$$

- resonance mass?

- **need more resonances**
- **yield proportional to Boltzmann factor**

$$N \propto \exp\left(-\frac{m}{T}\right)$$

- **resonance mass?**
- **usually no width, i.e. resonances have their pole mass**

Dashen-Ma-Bernstein:

If interactions mediated by *narrow* resonances, properties of interacting hadron gas are those of noninteracting hadron-resonance gas

⇒ **Hadron resonance gas model**

Dashen-Ma-Bernstein:

If interactions mediated by *narrow* resonances, properties of interacting hadron gas are those of noninteracting hadron-resonance gas

⇒ **Hadron resonance gas model**

Dashen-Ma-Berstein: S-matrix formulation of statistical mechanics:

⇒ **Second virial coefficient can be evaluated in terms of scattering phase shift (as far as interaction is manifested in elastic scattering)**

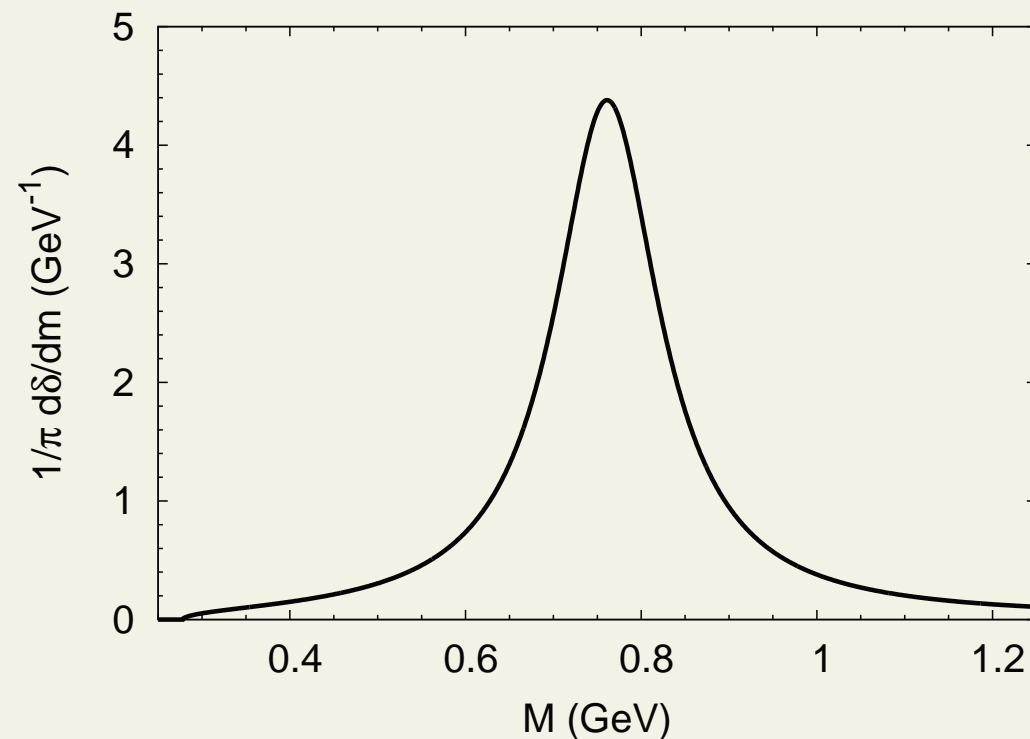
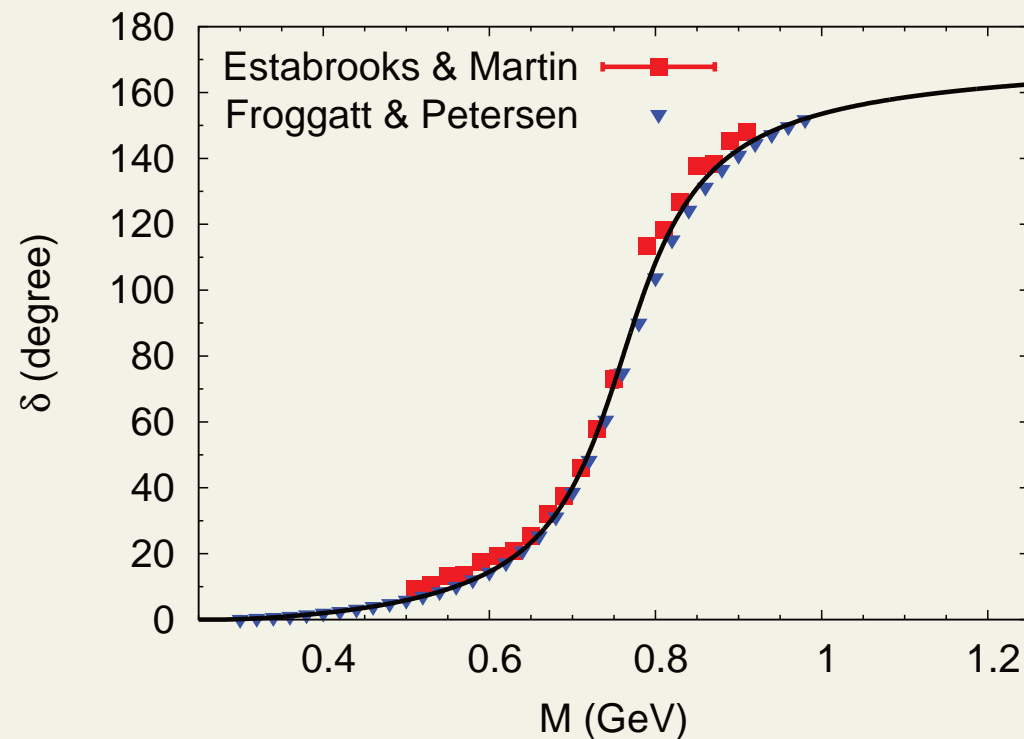
⇒ **relativistic Beth-Uhlenbeck form**

Beth-Uhlenbeck

- effects of interactions expressed in terms of scattering phase shifts

$$n = \int d^3\mathbf{p} \int dm \frac{d\rho}{dm} f(p, m) \quad \text{with} \quad \frac{d\rho}{dm} = \frac{1}{\pi} \frac{d\delta}{dm}$$

- $\pi\pi$ scattering, P-wave, i.e. ρ resonance

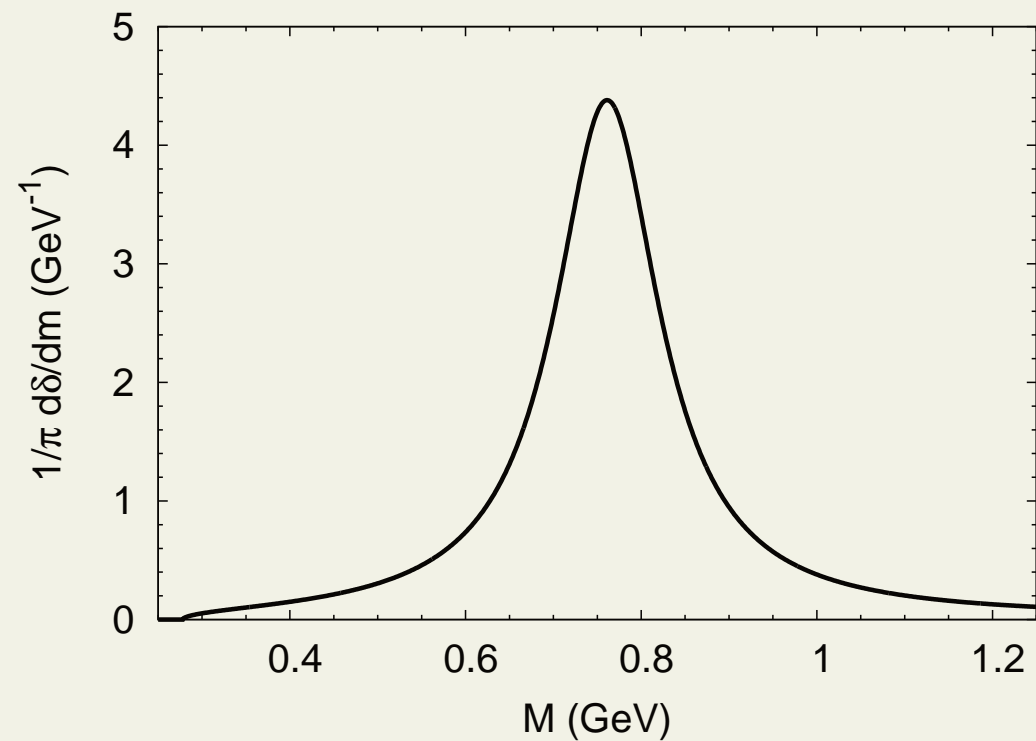
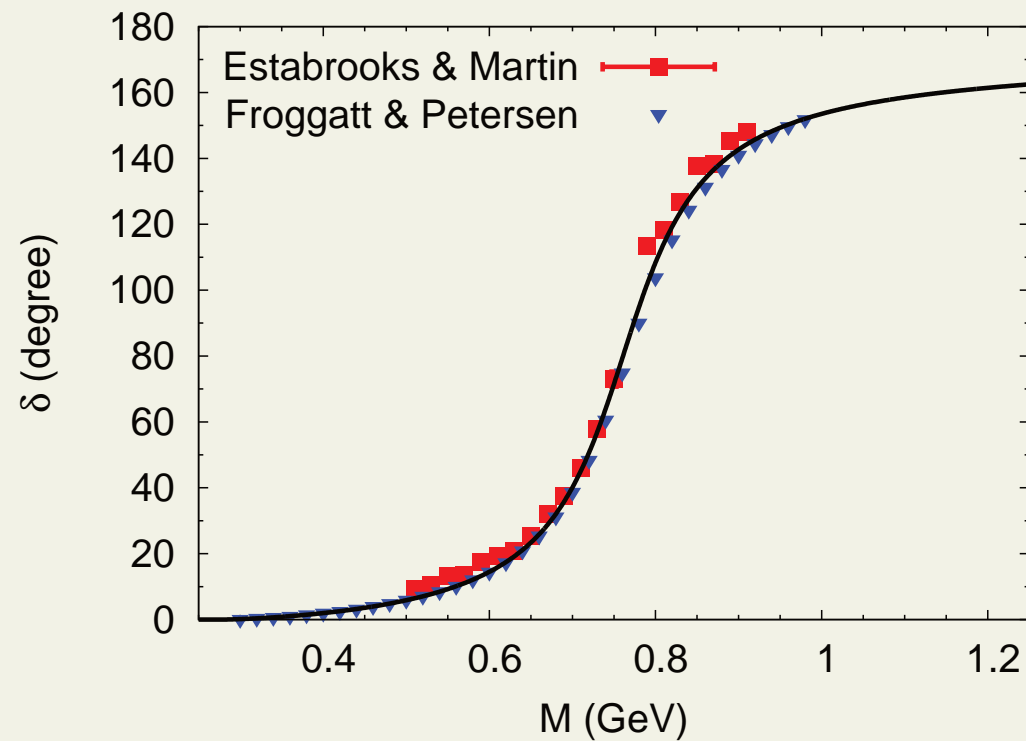


Beth-Uhlenbeck

- effects of interactions expressed in terms of scattering phase shifts

$$n = \int d^3\mathbf{p} \int dm \frac{d\rho}{dm} f(p, m) \quad \text{with} \quad \frac{d\rho}{dm} = \frac{1}{\pi} \frac{d\delta}{dm}$$

- $\pi\pi$ scattering, P-wave, i.e. ρ resonance

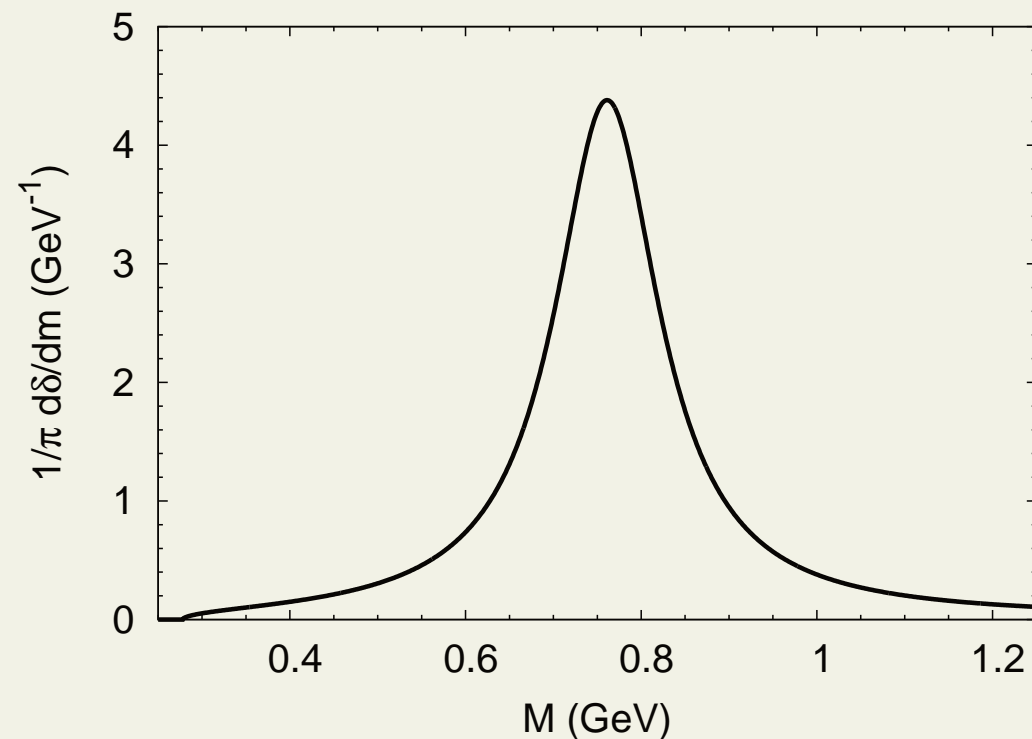
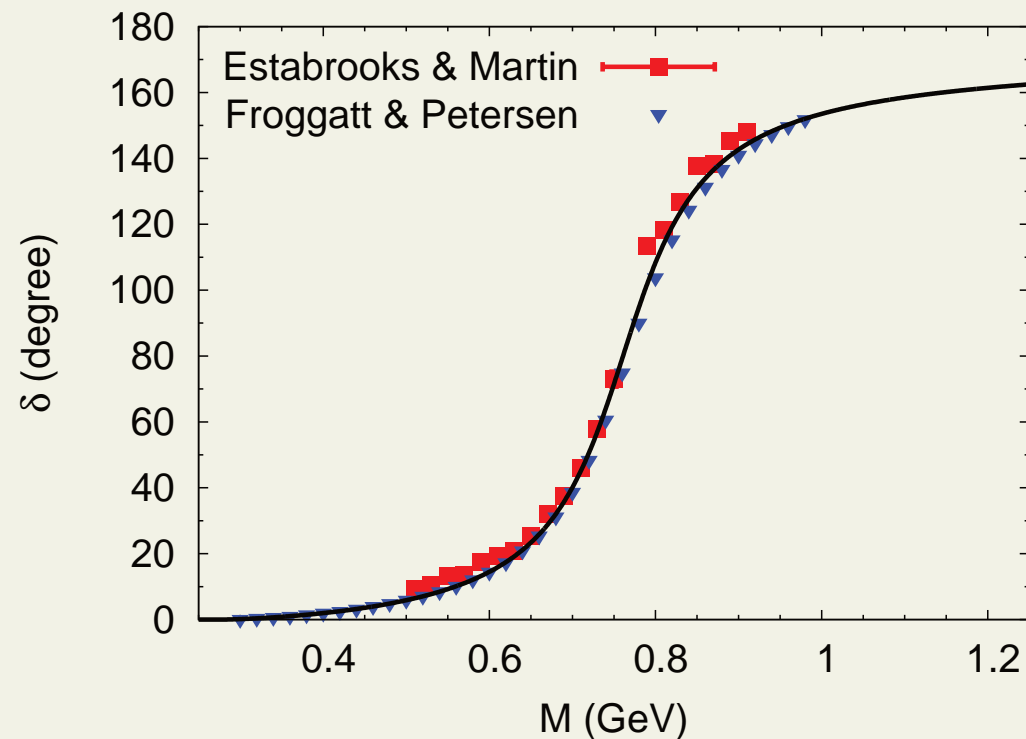


Beth-Uhlenbeck

- effects of interactions expressed in terms of scattering phase shifts

$$n = \int d^3\mathbf{p} \int dm \frac{d\rho}{dm} f(p, m) \quad \text{with} \quad \frac{d\rho}{dm} = \frac{1}{\pi} \frac{d\delta}{dm}$$

- $\pi\pi$ scattering, P-wave, i.e. ρ resonance

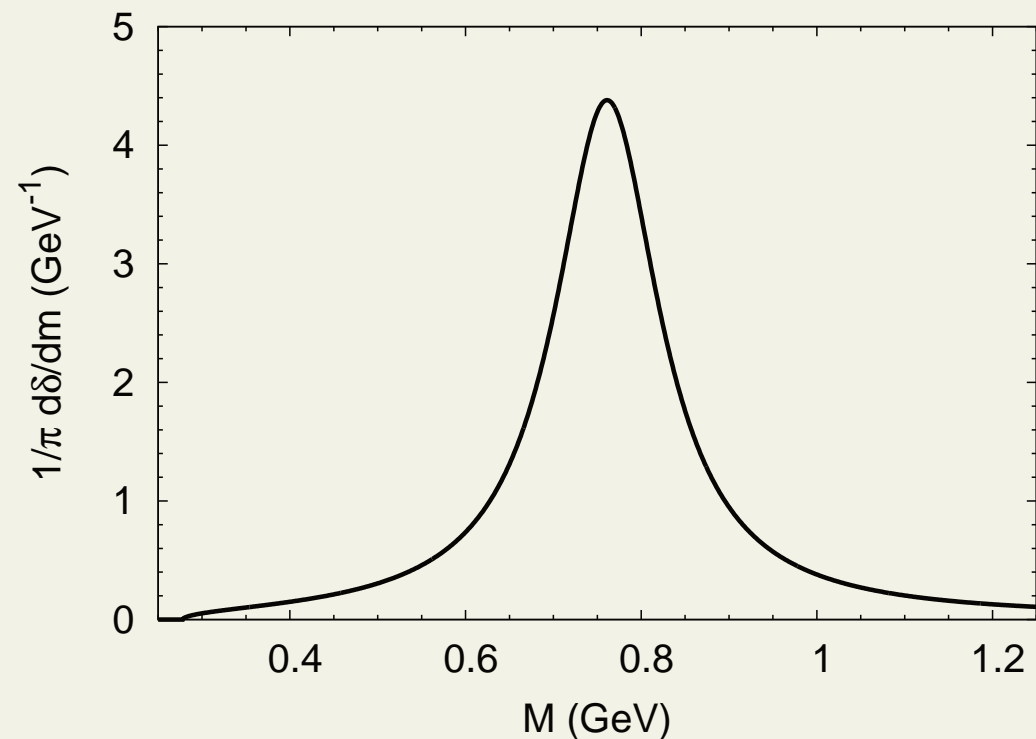
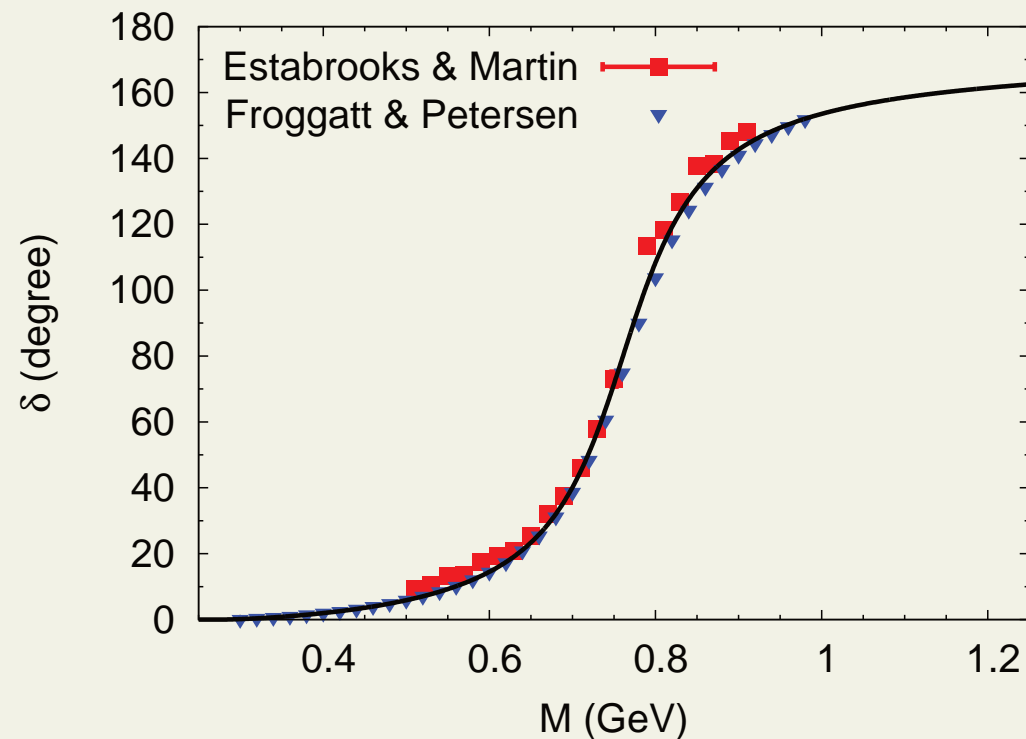


Beth-Uhlenbeck

- effects of interactions expressed in terms of scattering phase shifts

$$n = \int d^3\mathbf{p} \int dm \frac{d\rho}{dm} f(p, m) \quad \text{with} \quad \frac{d\rho}{dm} = \frac{1}{\pi} \frac{d\delta}{dm}$$

- $\pi\pi$ scattering, P-wave, i.e. ρ resonance

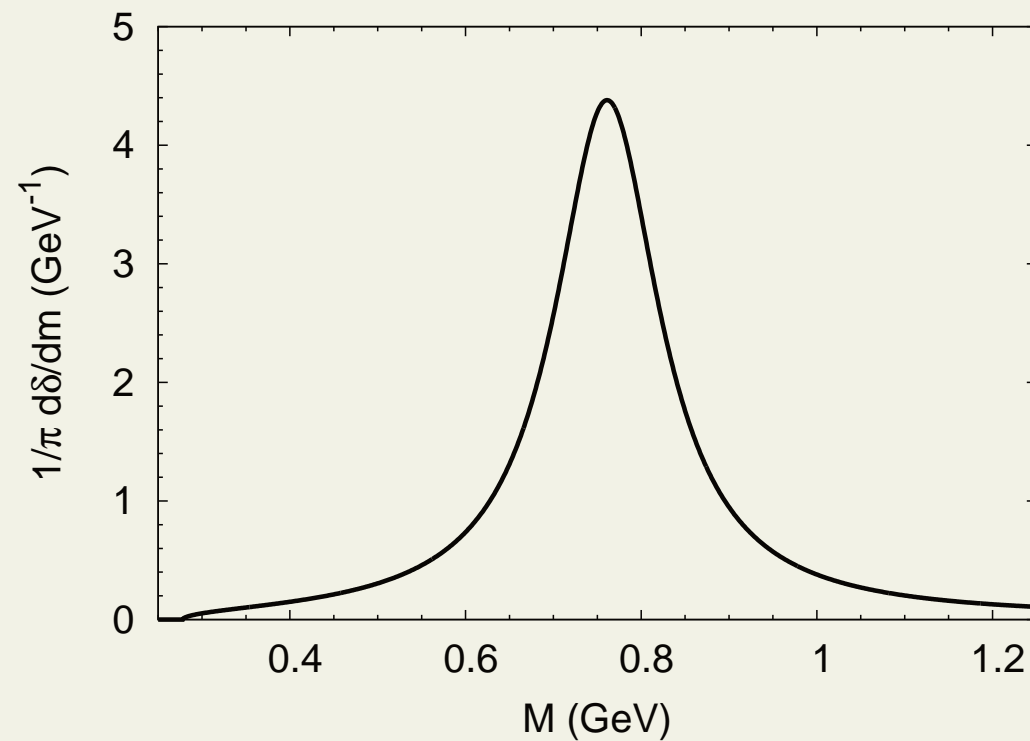
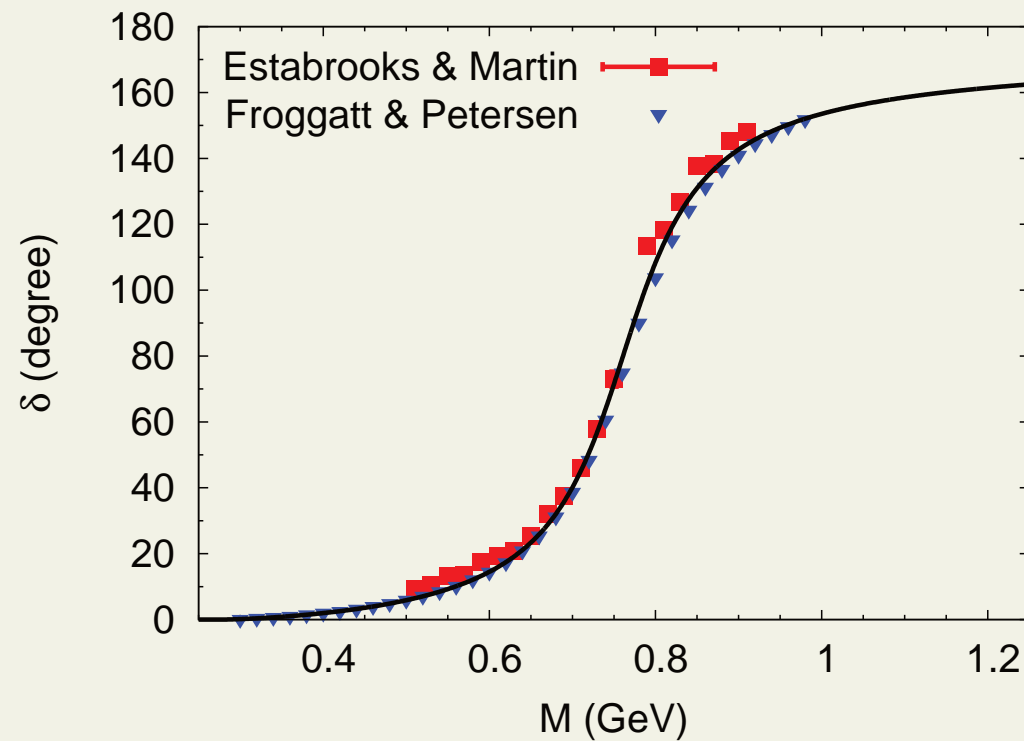


Beth-Uhlenbeck

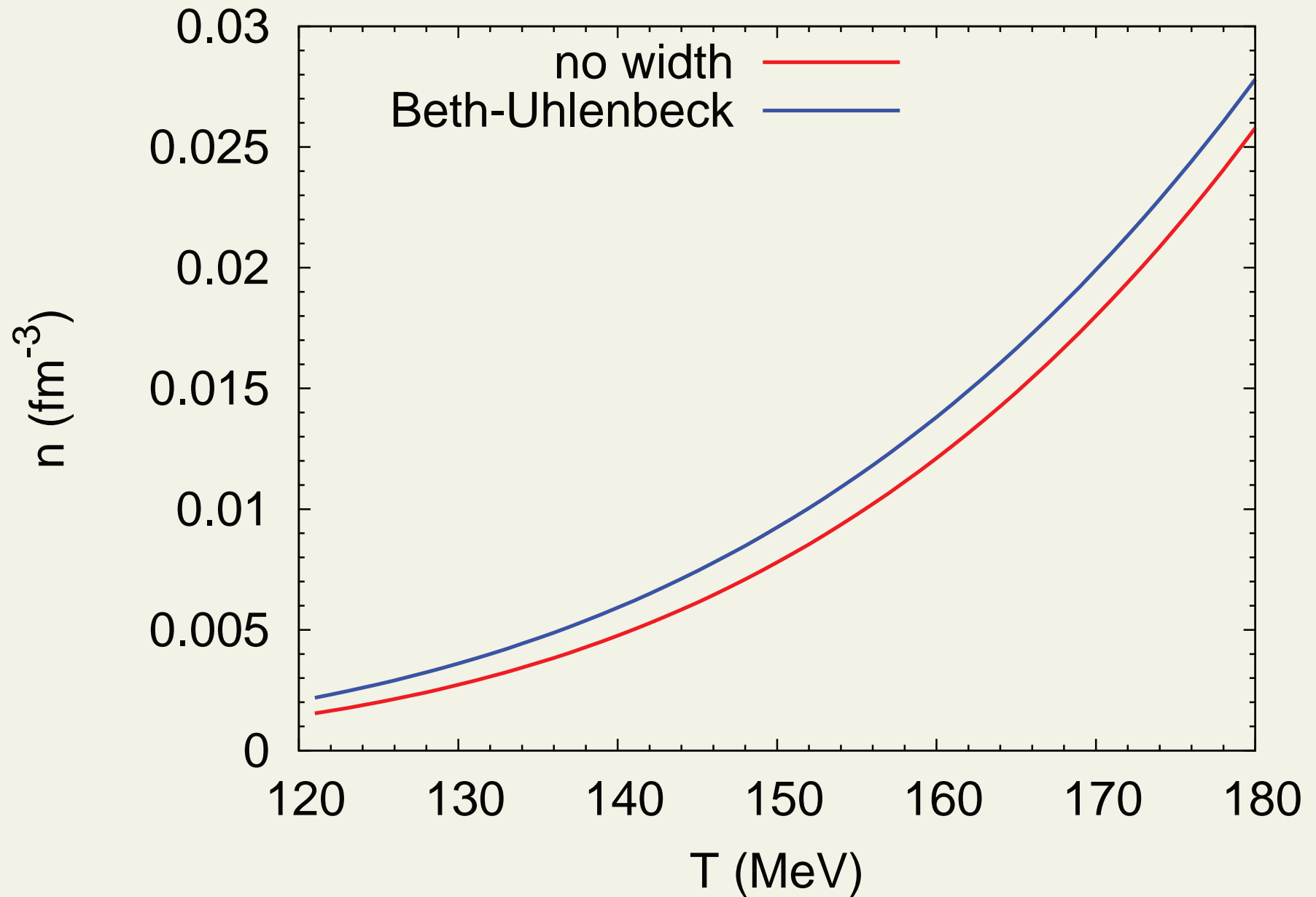
- effects of interactions expressed in terms of scattering phase shifts

$$n = \int d^3\mathbf{p} \int dm \frac{d\rho}{dm} f(p, m) \quad \text{with} \quad \frac{d\rho}{dm} = \frac{1}{\pi} \frac{d\delta}{dm}$$

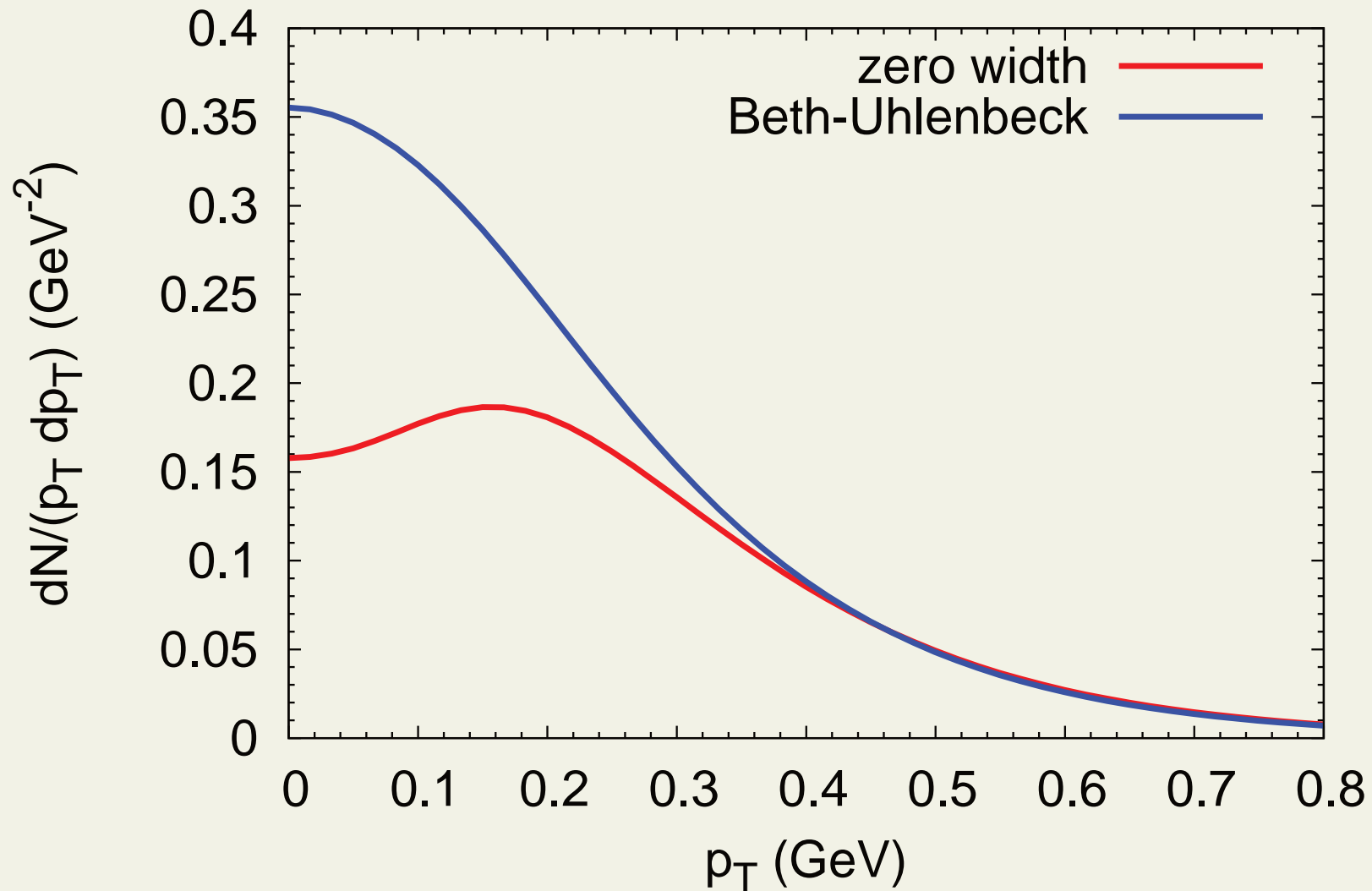
- $\pi\pi$ scattering, P-wave, i.e. ρ resonance



ρ -density

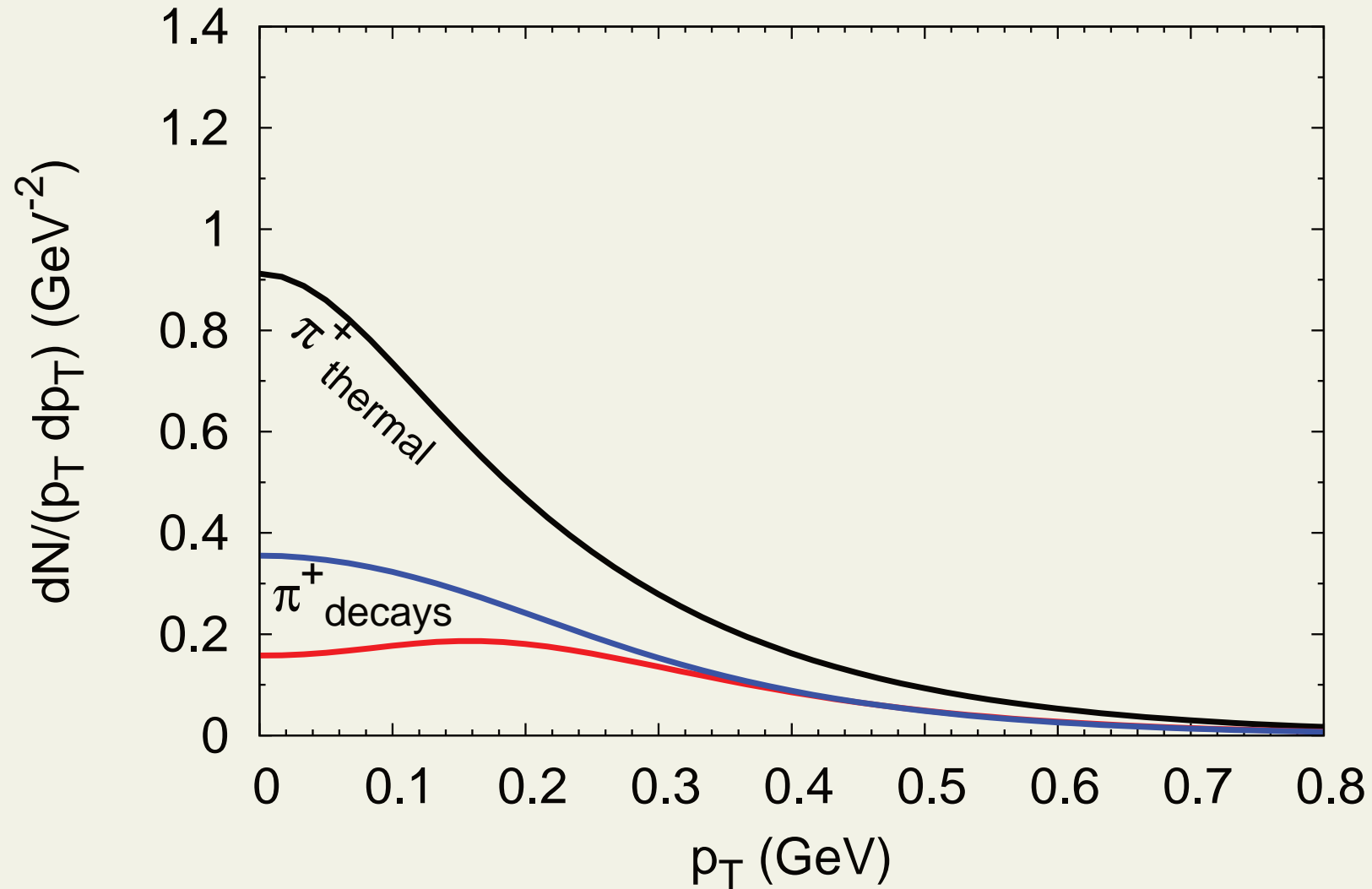


Pions from ρ decays



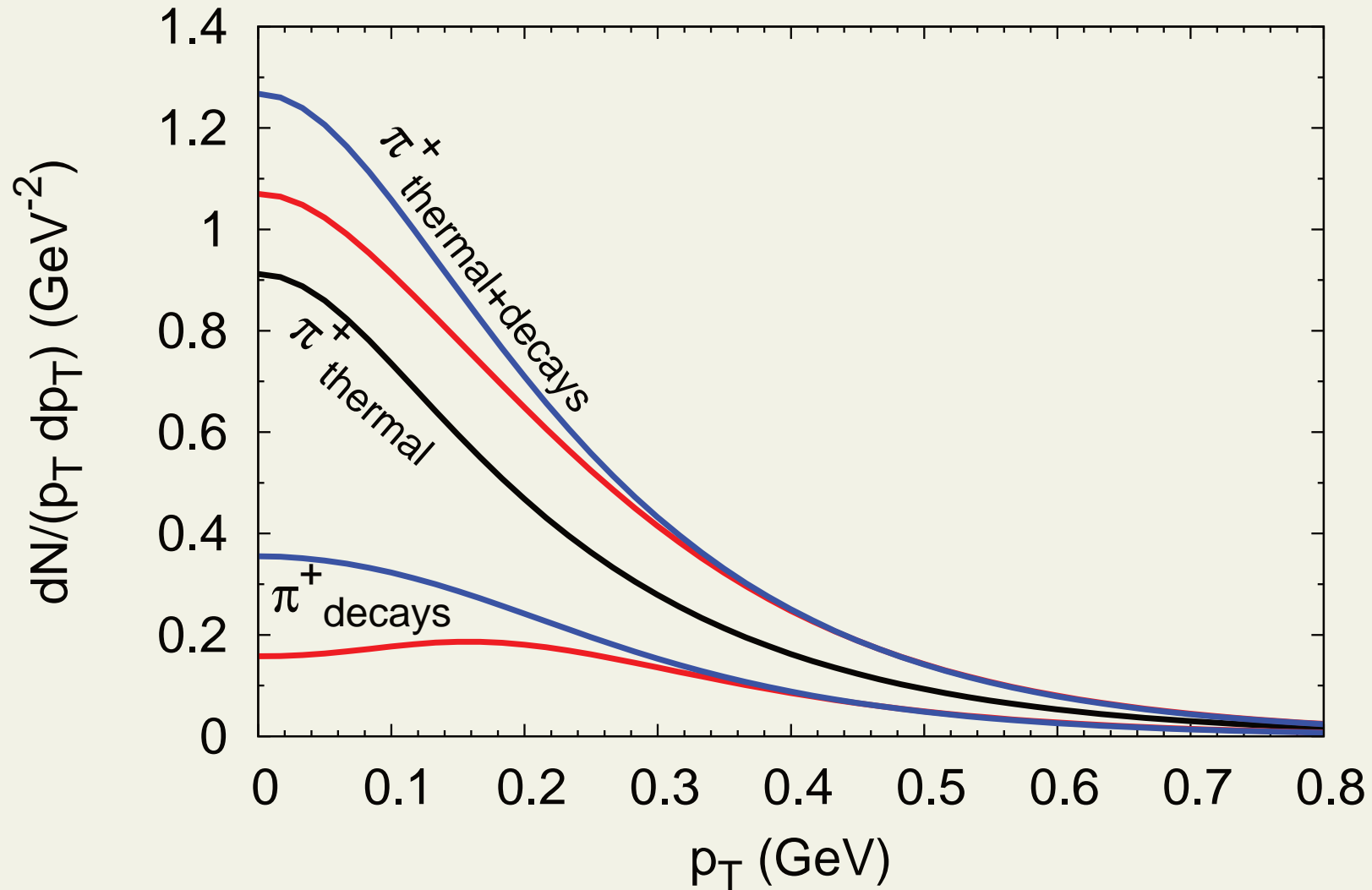
- **static source**, $T = 155$ MeV

Thermal pions + pions from ρ decays



- static source, $T = 155 \text{ MeV}$

Thermal pions + pions from ρ decays



- **static source, $T = 155 \text{ MeV}$**

blast-wave parametrisation

PHYSICAL REVIEW C

VOLUME 48, NUMBER 5

NOVEMBER 1993

Thermal phenomenology of hadrons from 200A GeV S+S collisions

Ekkard Schnedermann,^{1,2} Josef Sollfrank,¹ and Ulrich Heinz¹

¹*Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany*

²*Department of Physics, Brookhaven National Laboratory, Upton, New York 11973*

(Received 14 July 1993)

We develop a complete and consistent description for the hadron spectra from heavy ion collisions in terms of a few collective variables, in particular temperature, longitudinal, and transverse flow. To achieve a meaningful comparison with presently available data, we also include the resonance decays into our picture. To disentangle the influences of transverse flow and resonance decays in the m_T spectra, we analyze in detail the shape of the m_T spectra.

PACS number(s): 25.75.+r

I. INTRODUCTION

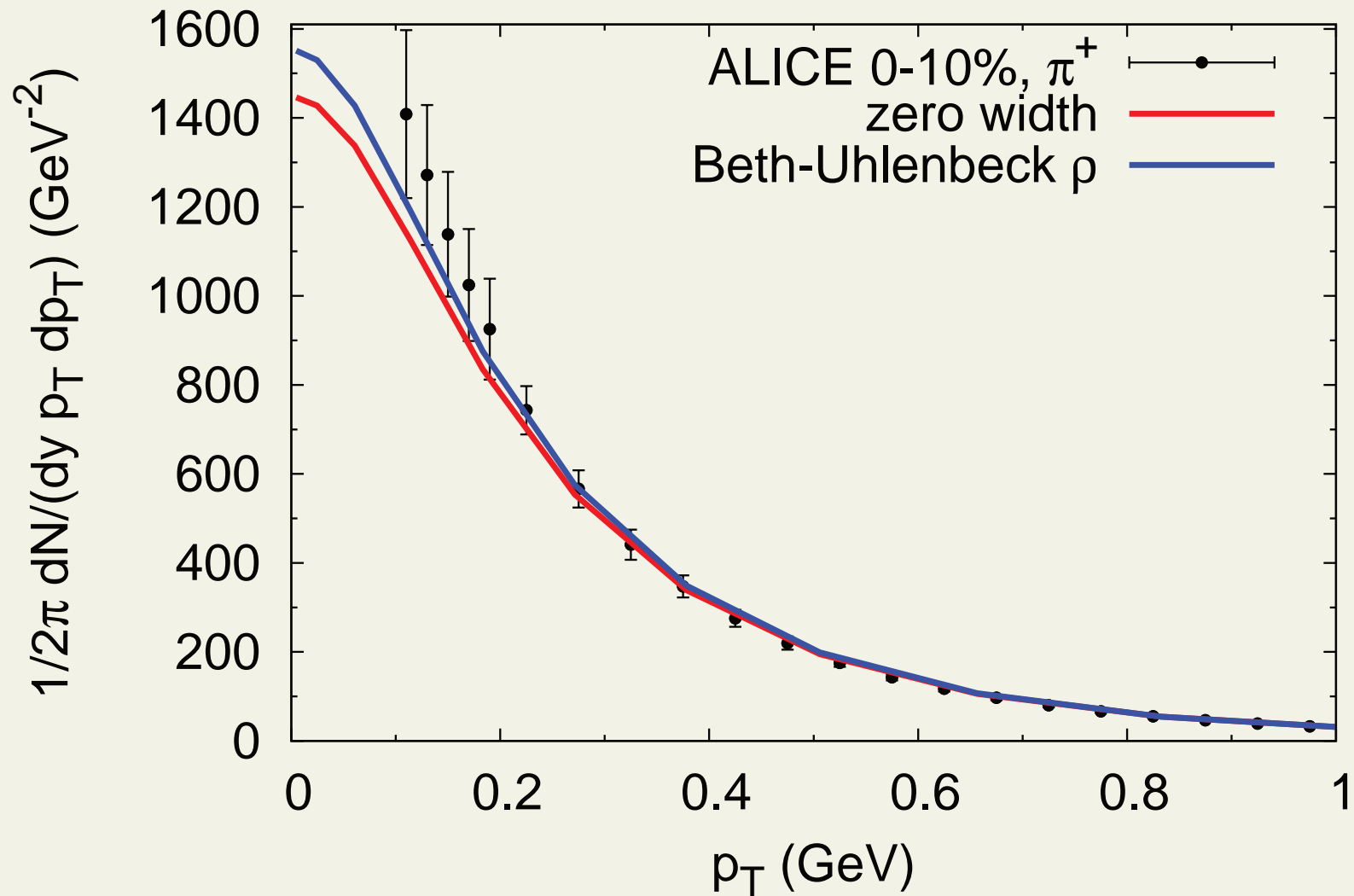
Our current understanding of QCD results basically from high-energy experiments with small collision systems suffering hard interactions which are relatively easy to analyze. In a first attempt to test QCD predictions for larger systems, especially the predicted phase transition from hadronic matter to the hypothetical quark gluon plasma, existing accelerators were modified to experiment with nuclei instead of only protons. The first round of experiments with nuclear beams took place during the years 1986–1990 at the AGS (Alternating Gradient Synchrotron) of the Brookhaven National Laboratory (BNL) and at the SPS (Super Proton Synchrotron) at CERN.

us to the introduction of longitudinal flow. On the other hand, as shown in Sec. IV B, the existence of transverse flow cannot be established from the data. However this can be clarified by a closer theoretical investigation of the reaction prior to freeze out, which was briefly reported in [2] and will be presented in detail in [3]. Finally in Sec. V we critically assess the relevance of our model in the light of pp data and give a conclusion of our work.

II. CHOICE OF DATA

From the large amount of data from many experimental groups at BNL and CERN, which have been measured

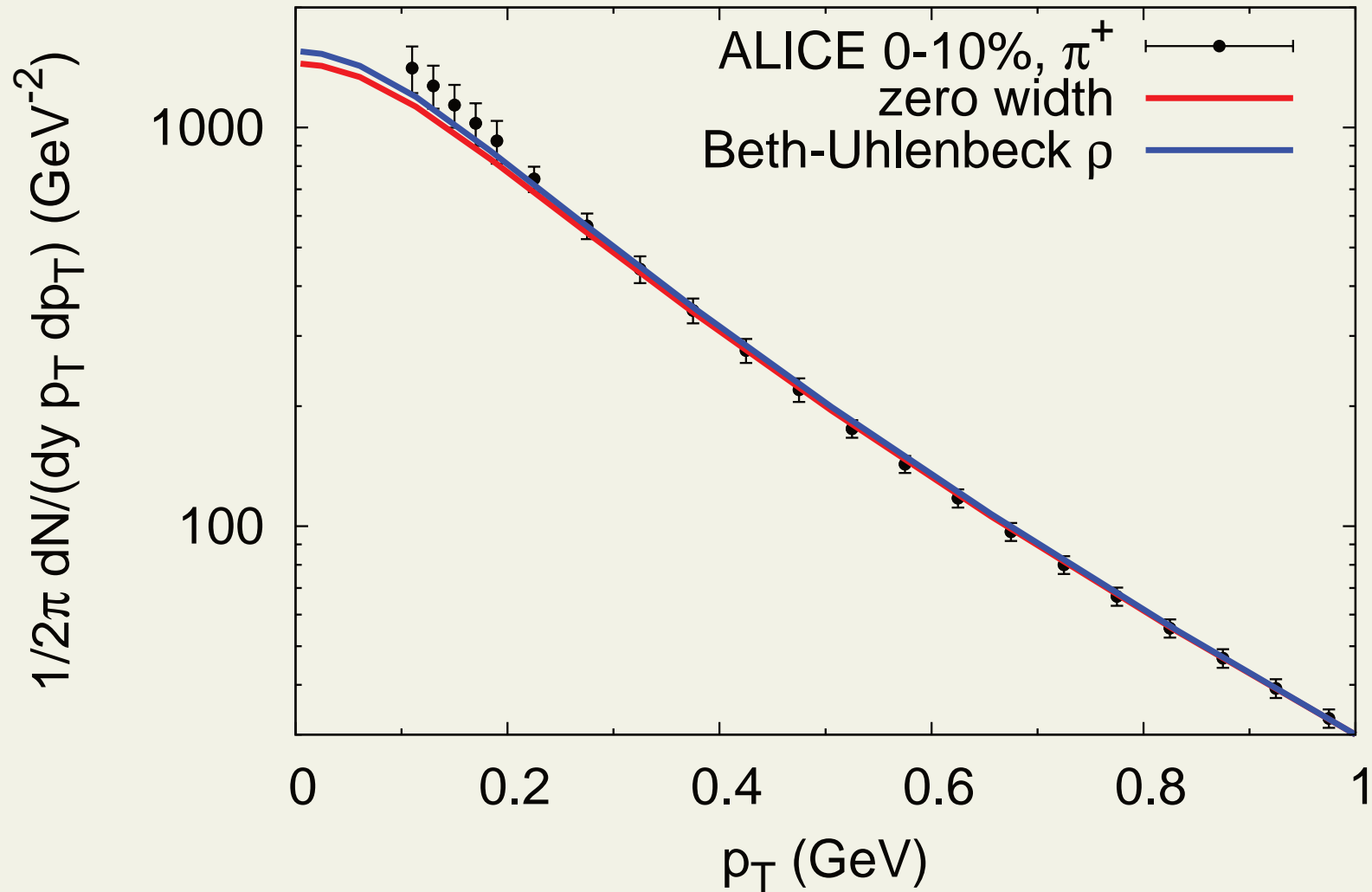
Pions from blast wave



- $\tau = 13.7 \text{ fm}$
- $R = 10 \text{ fm}$
- $v_{max} = 0.78$

- all resonances up to 2 GeV
- Beth-Uhlenbeck for rhos
- zero width for everything else

Pions from blast wave



- $\tau = 13.7 \text{ fm}$
- $R = 10 \text{ fm}$
- $v_{max} = 0.78$

- all resonances up to 2 GeV
- Beth-Uhlenbeck for rhos
- zero width for everything else

caveats

- so far only rho mesons

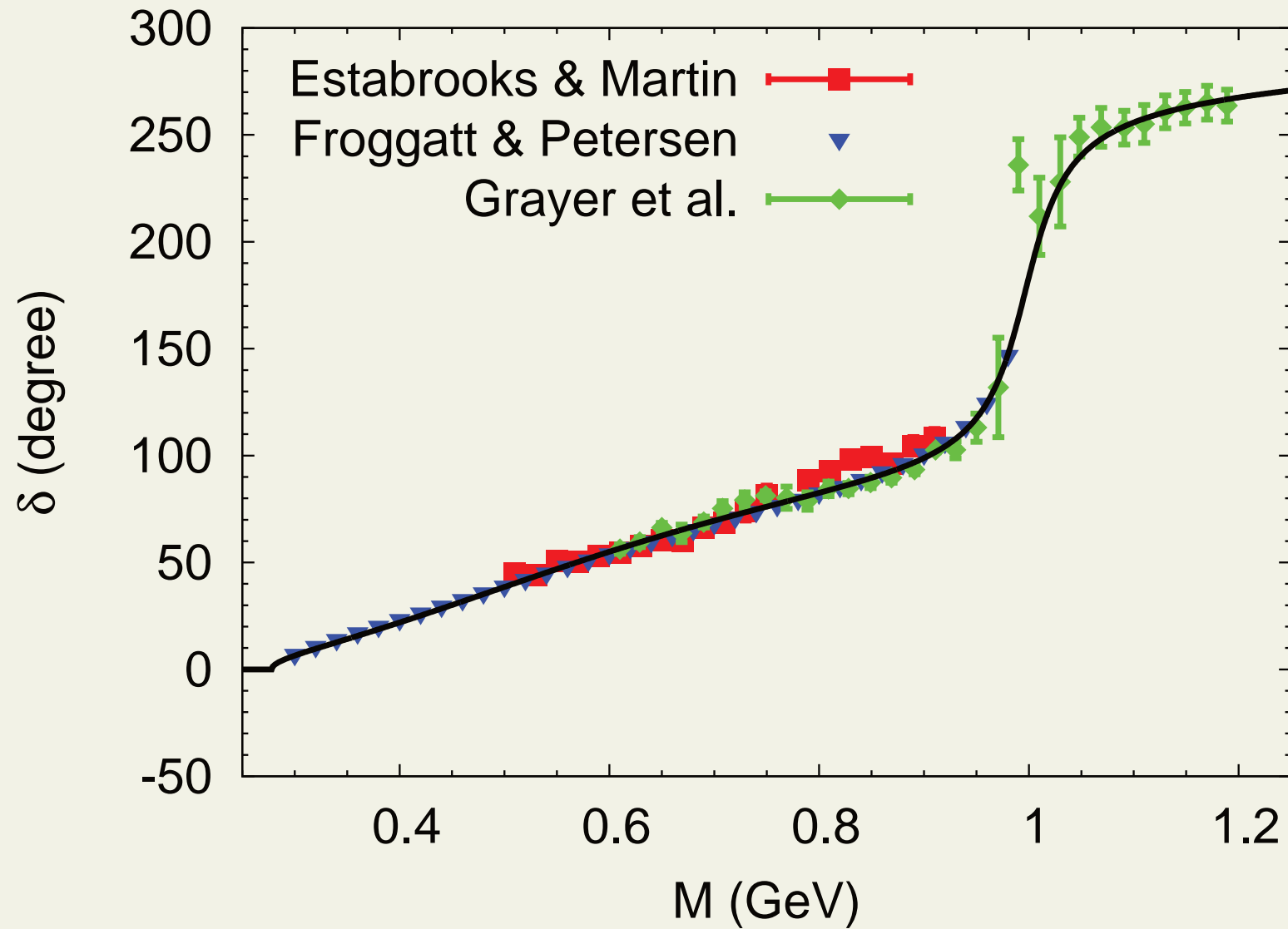
caveats

- so far only rho mesons
- Beth-Uhlenbeck applicable to **elastic scatterings only!**

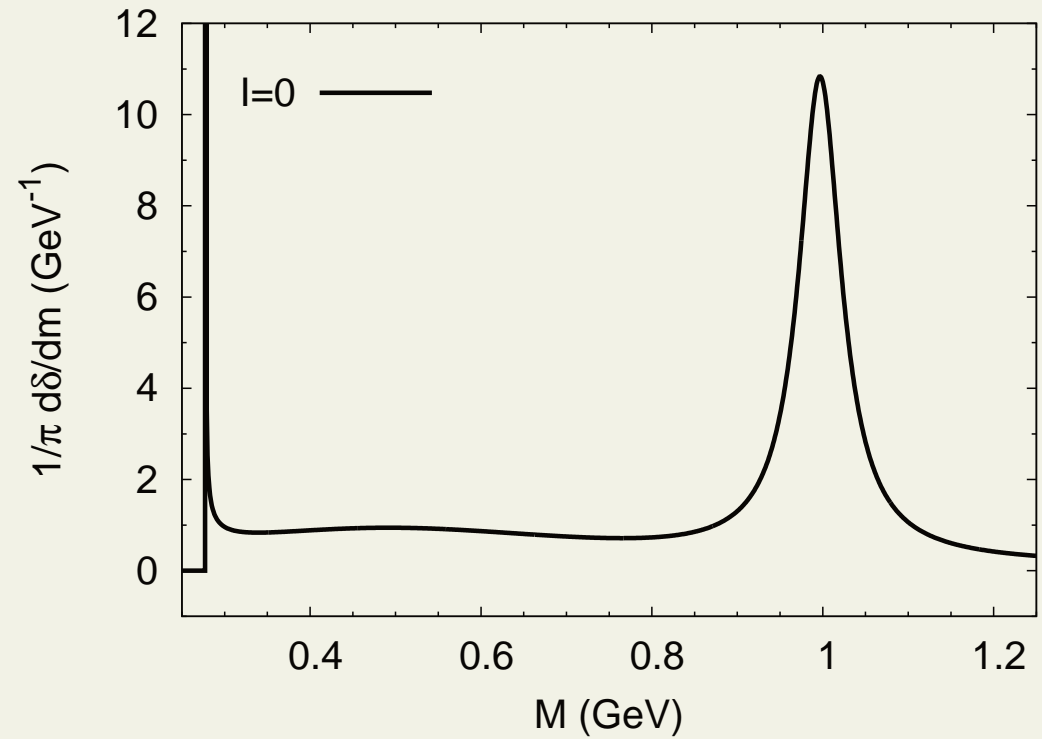
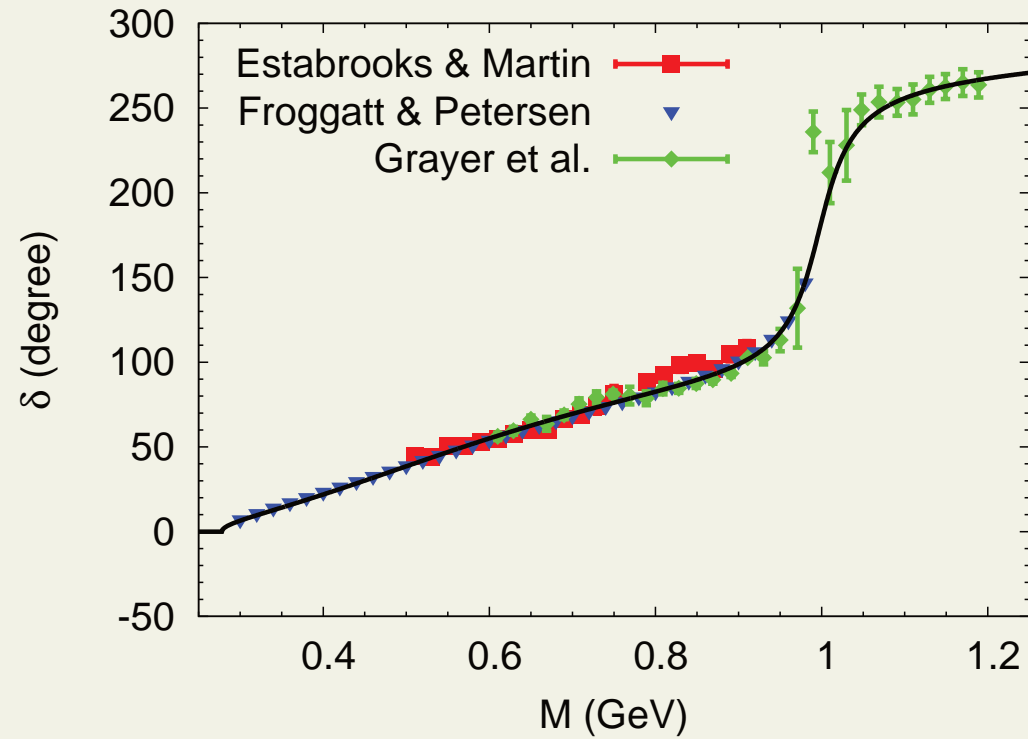
caveats

- so far only rho mesons
- Beth-Uhlenbeck applicable to **elastic scatterings only!**
- how about σ a.k.a. $f_0(500)$?

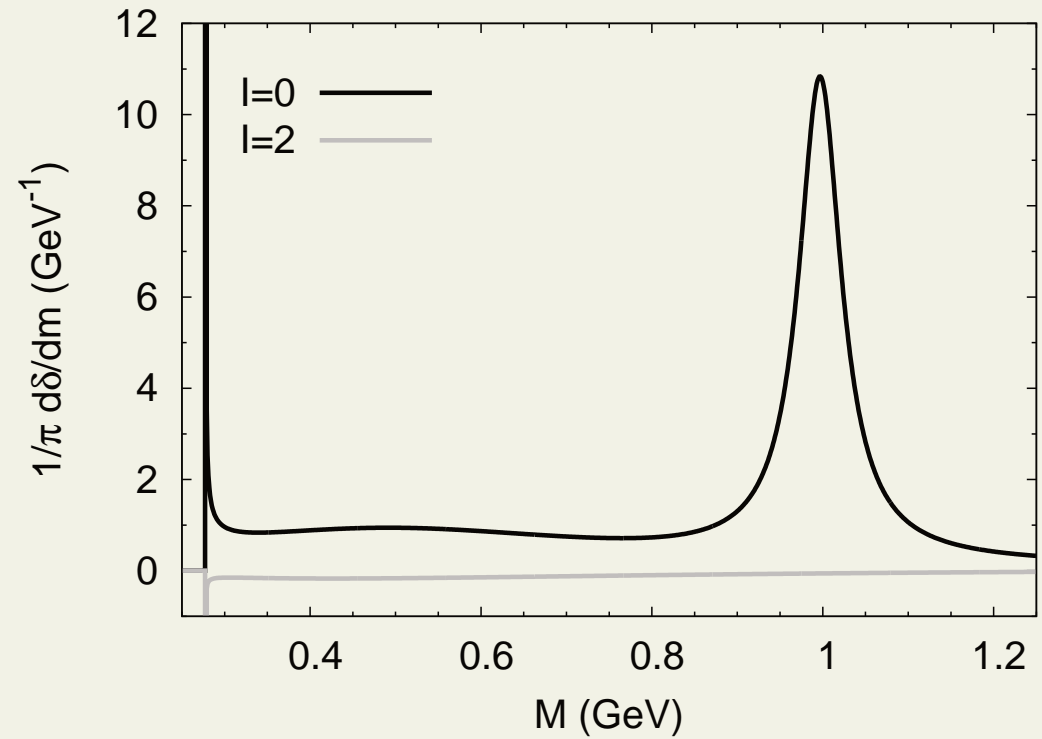
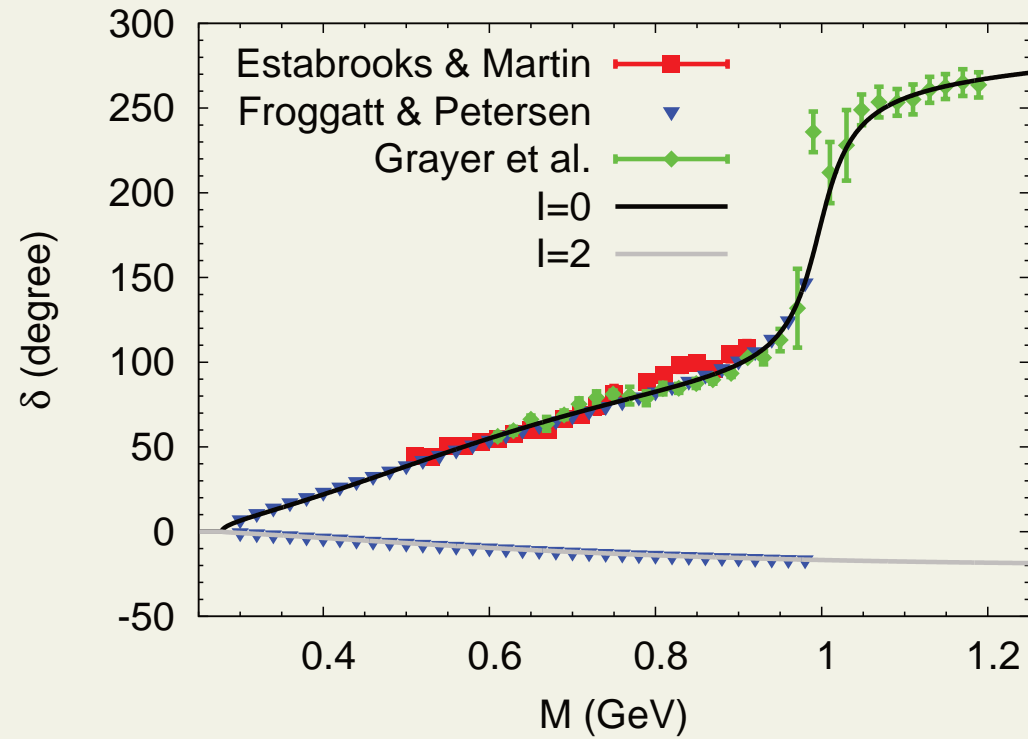
S-wave $\pi\pi$ scattering



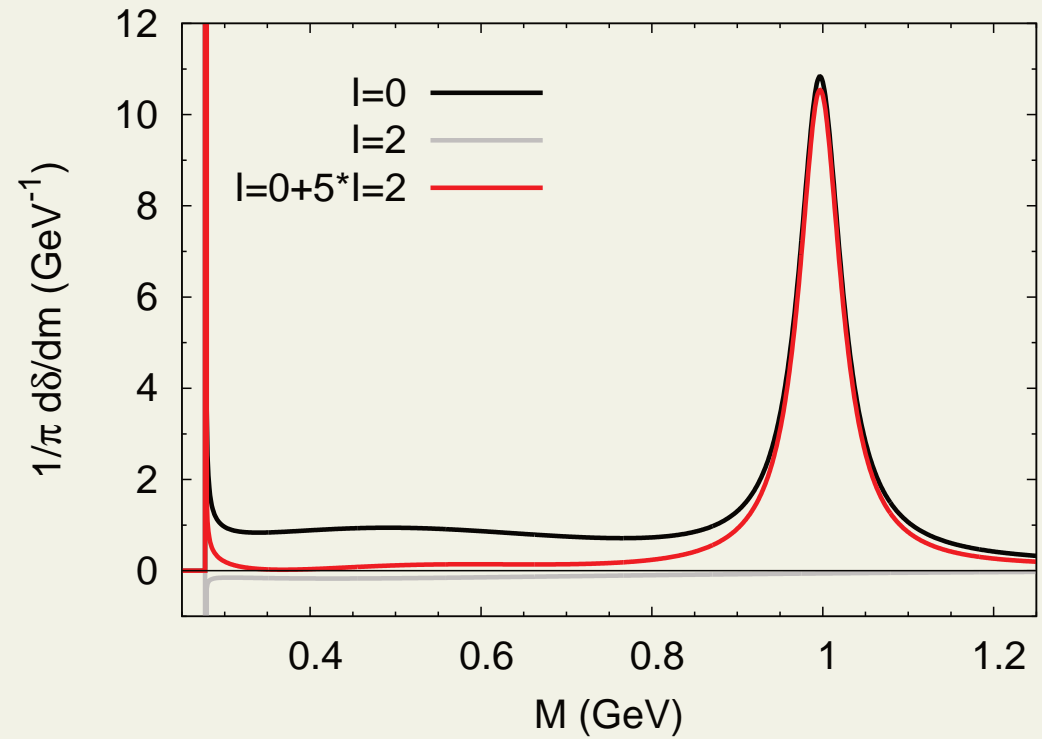
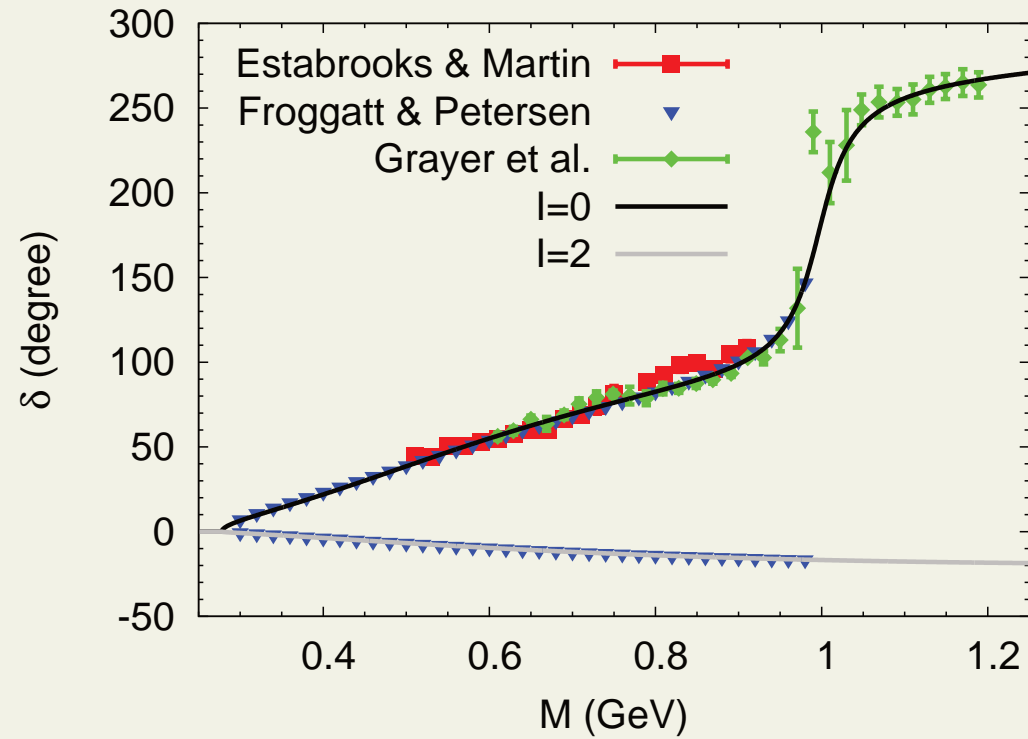
S-wave $\pi\pi$ scattering



S-wave $\pi\pi$ scattering



S-wave $\pi\pi$ scattering



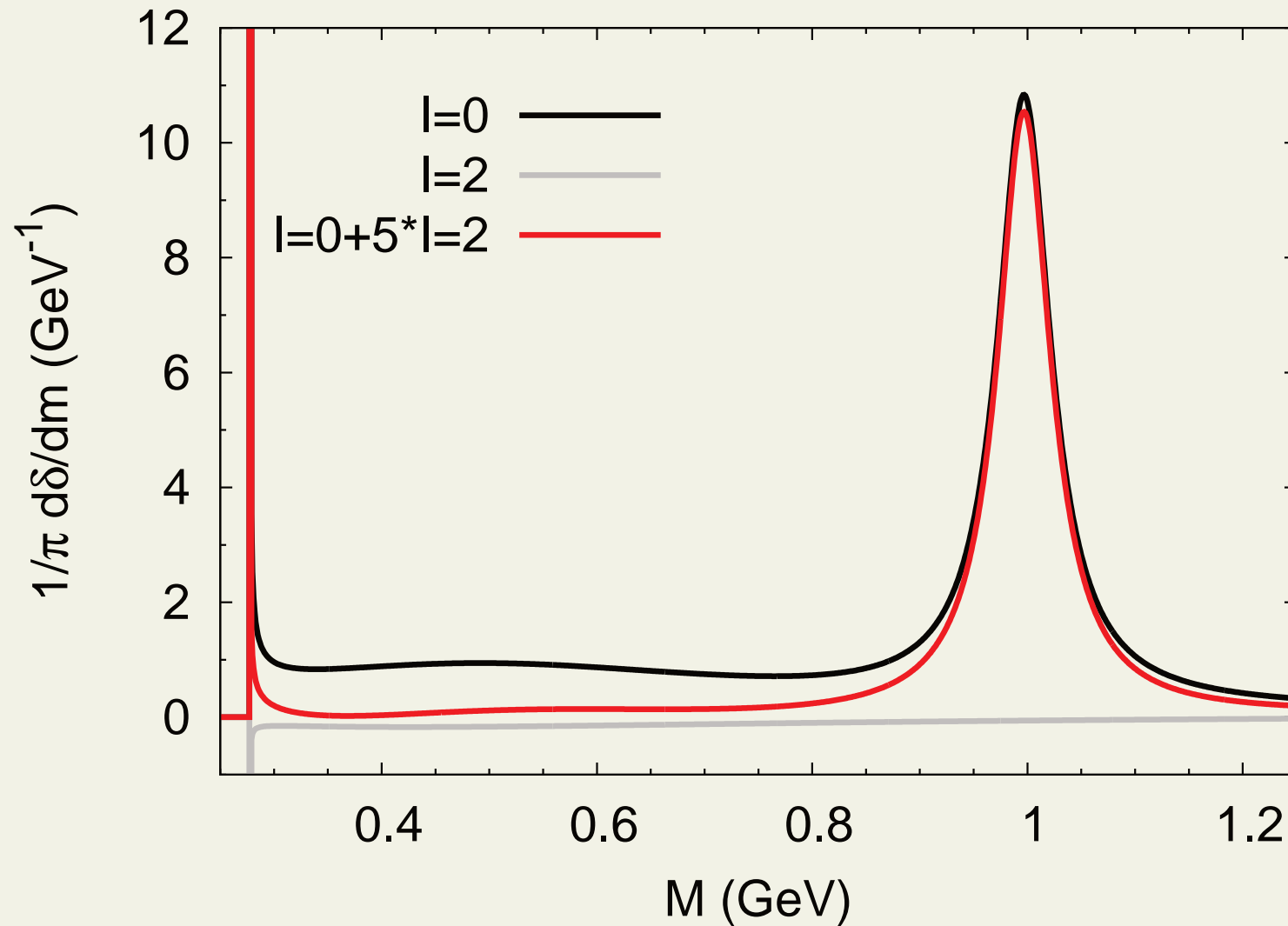




as advocated by

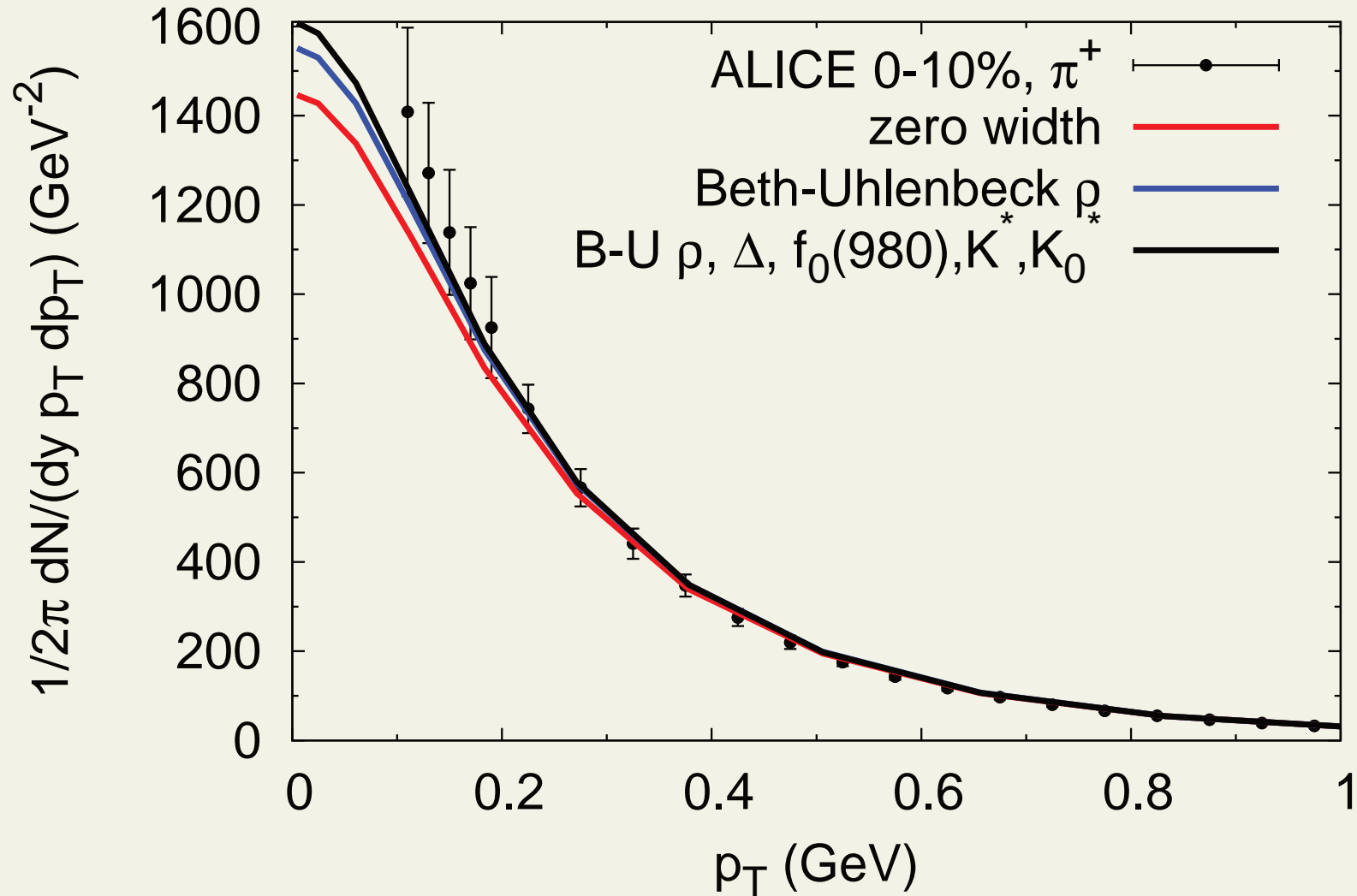
- Broniowski, Giacosa & Begun, PRC92, 034905 (2015)
- Prakash & Venugopalan, NPA546, 718 (1992)

S-wave $\pi\pi$ scattering



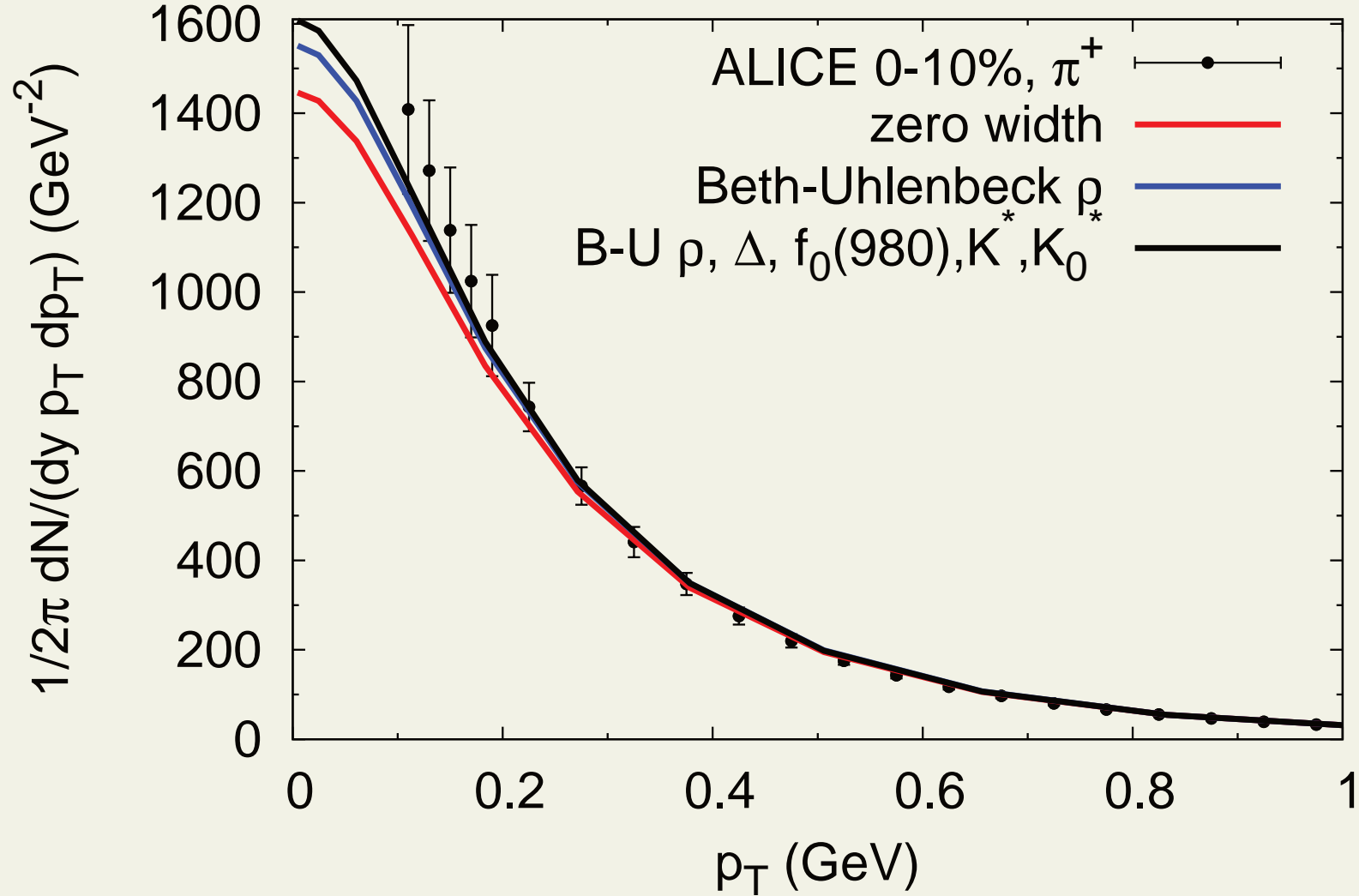
- $f_0(980)$ nicely described
- data also for $\Delta(1232)$, $K^*(892)$, $K_0^*(1430)$

Pions from blast wave



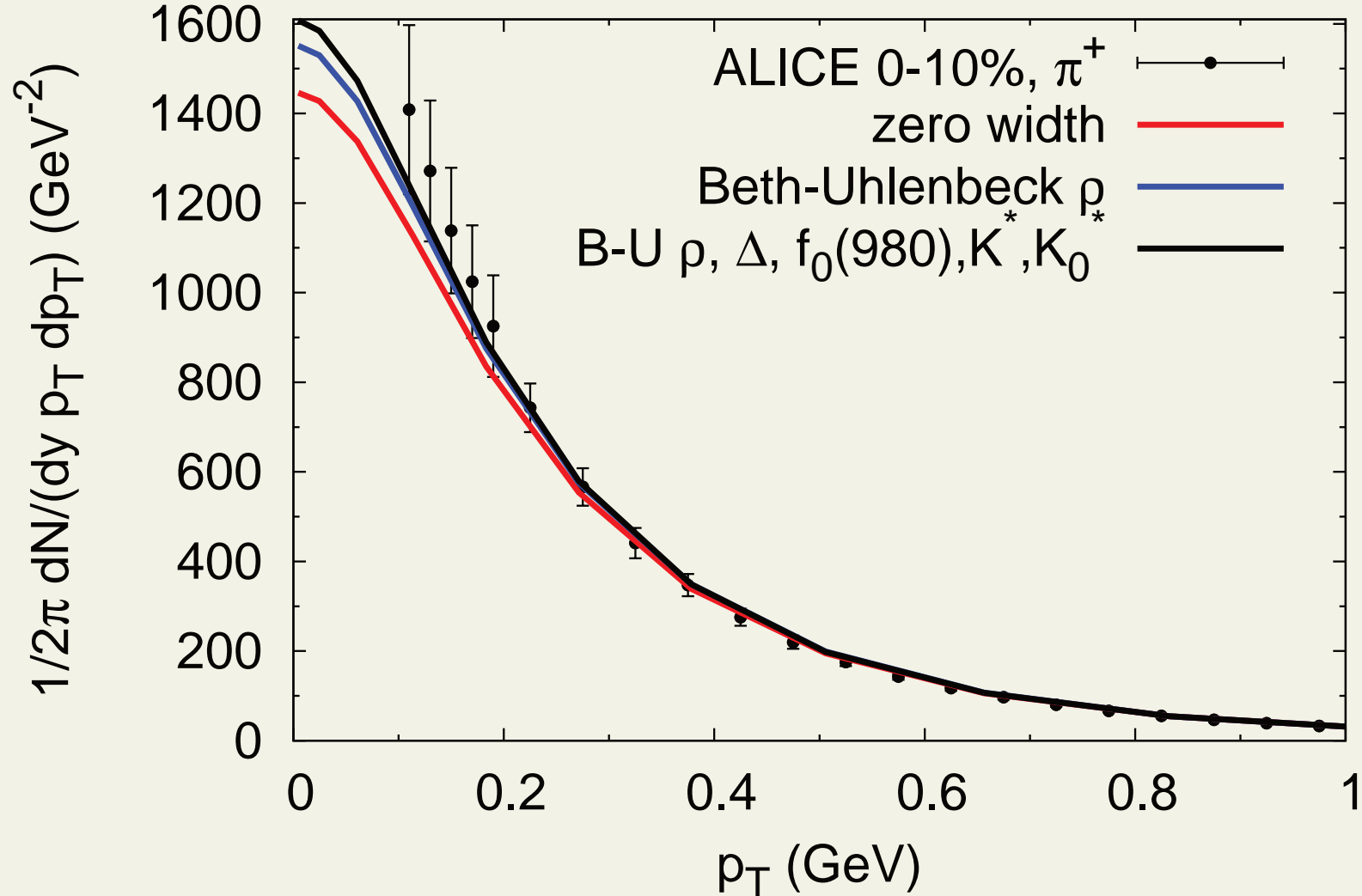
- $\tau = 13.7 \text{ fm}$
- $R = 10 \text{ fm}$
- $v_{max} = 0.78$
- **all resonances up to 2 GeV**
- **Beth-Uhlenbeck for $\rho, \Delta, f_0(980), K^*(892), K_0^*(1430)$**
- **zero width for everything else**

Pions from blast wave



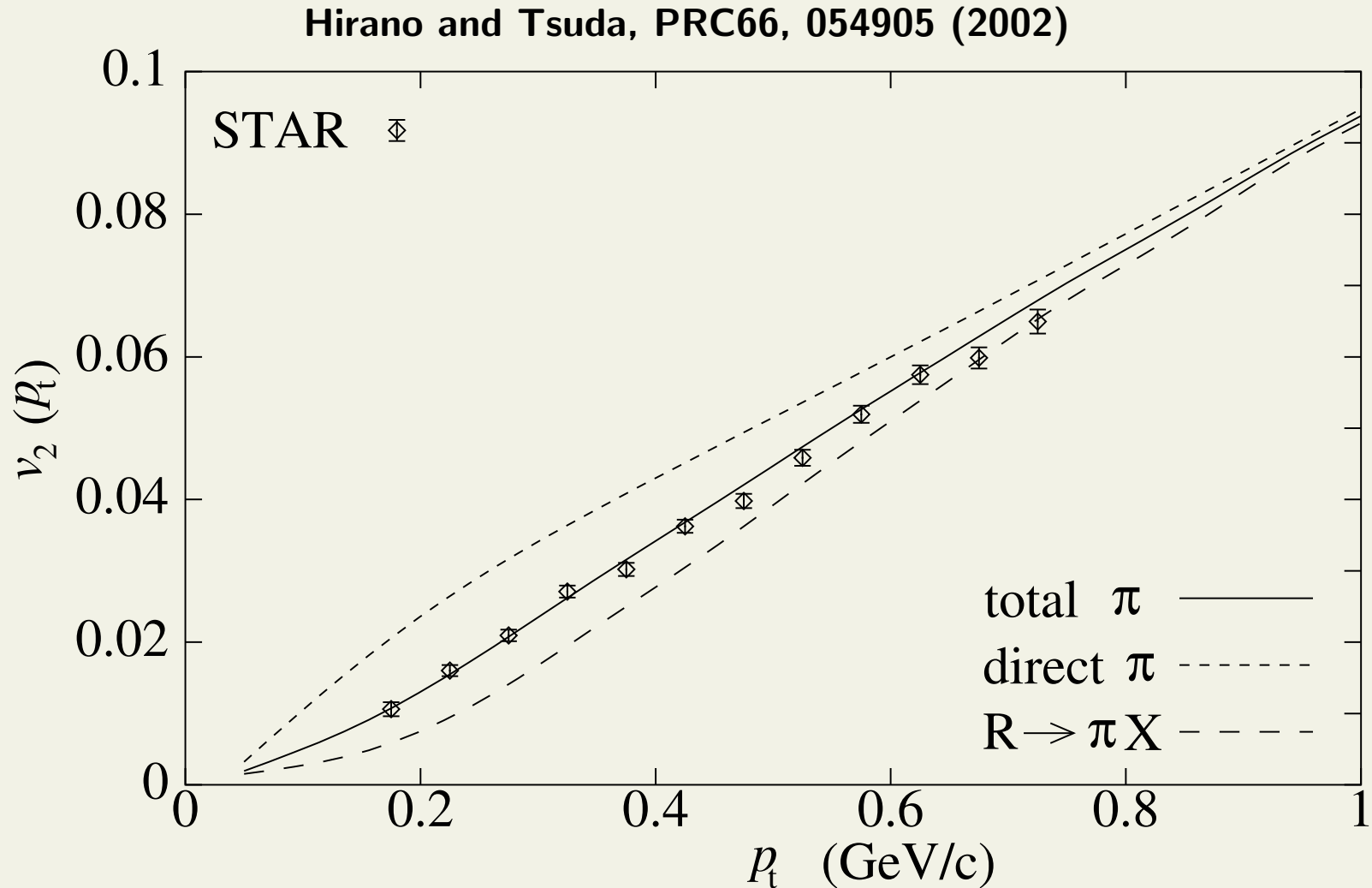
- So is there anomaly. . . ?
 - **Probably not**

Pions from blast wave



- How to treat all the other resonances?
 - **K-matrix approach?**

Effect of resonance decays on $v_2(p_T)$



- yield changed at very low p_T
- relative contributions change at moderate p_T . . .

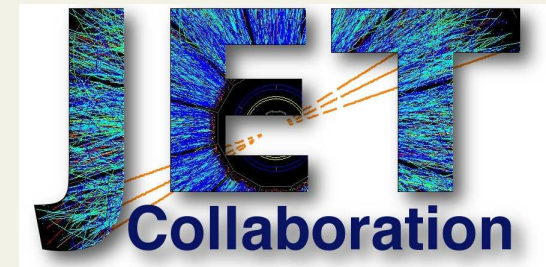
The QGP shear viscosity – elusive goal or just around the corner?*



DEPARTMENT OF
PHYSICS

Chun Shen & Ulrich Heinz

Department of Physics
The Ohio State University
191 West Woodruff Avenue
Columbus, OH 43210



presented at

QUARK MATTER 2011, Annecy, May 22-28, 2011

In collaboration with

S.A. Bass, T. Hirano, P. Huovinen, Zhi Qiu, and H. Song

See also posters #4 (C. Shen) and #52 (H. Song) (Tuesday)

*Supported by the U.S. Department of Energy (DOE)



The QGP shear viscosity – elusive goal just around the corner

**Congratulations
Ulrich!**