Is there a low p_T anomaly in the pion momentum spectrum at LHC?

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Transport meeting

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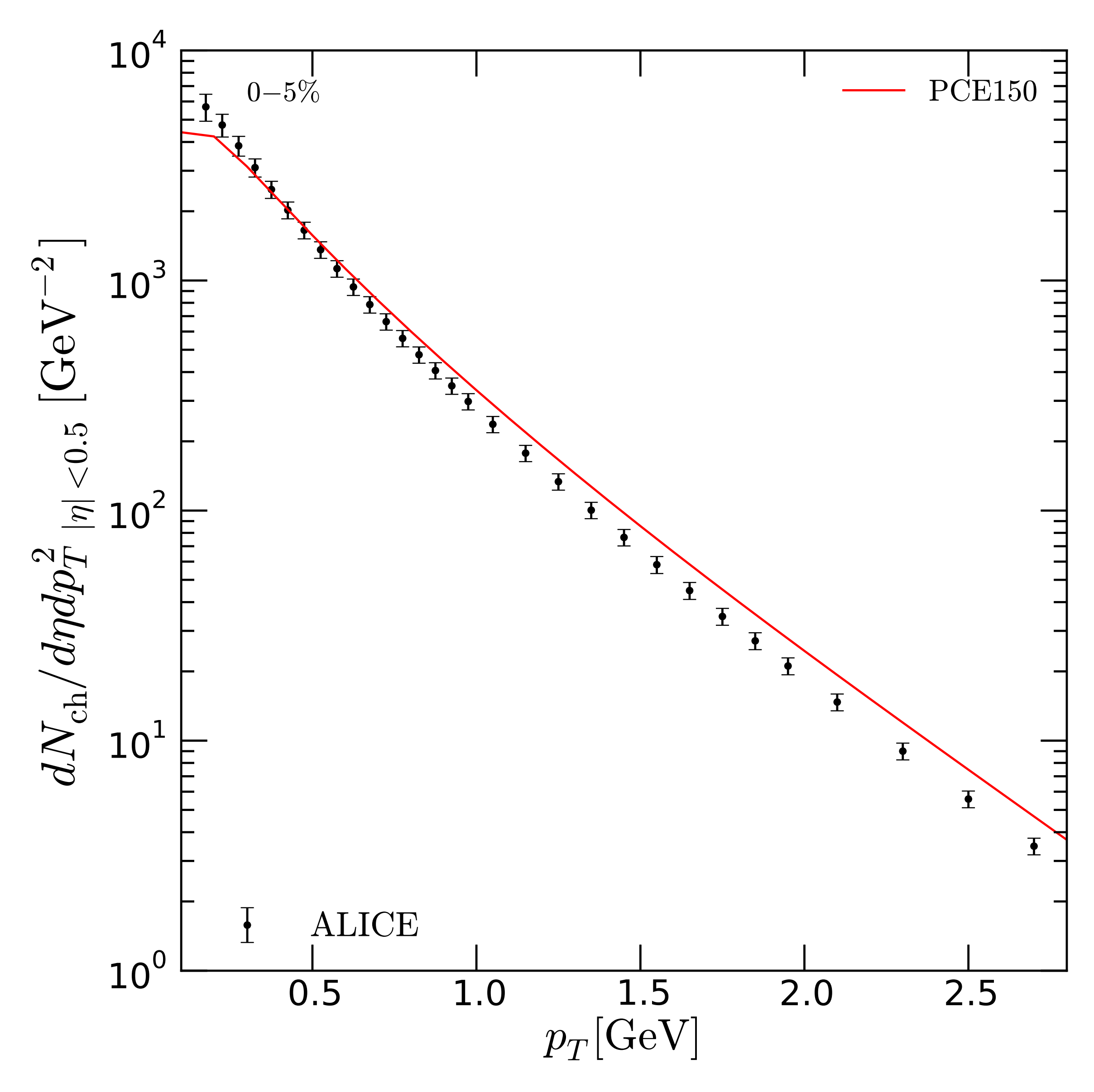
in collaboration with
P. M. Lo, M. Marczenko, K. Redlich, and C. Sasaki

Charged hadron p_T spectrum at LHC



- **viscous hydro**
- **initial state:**

pQCD+saturation

- $\tau_0 \approx 0.2\mathrm{fm}/c$

PCE150:

fit to π, K, p yields

no fit to spectrum

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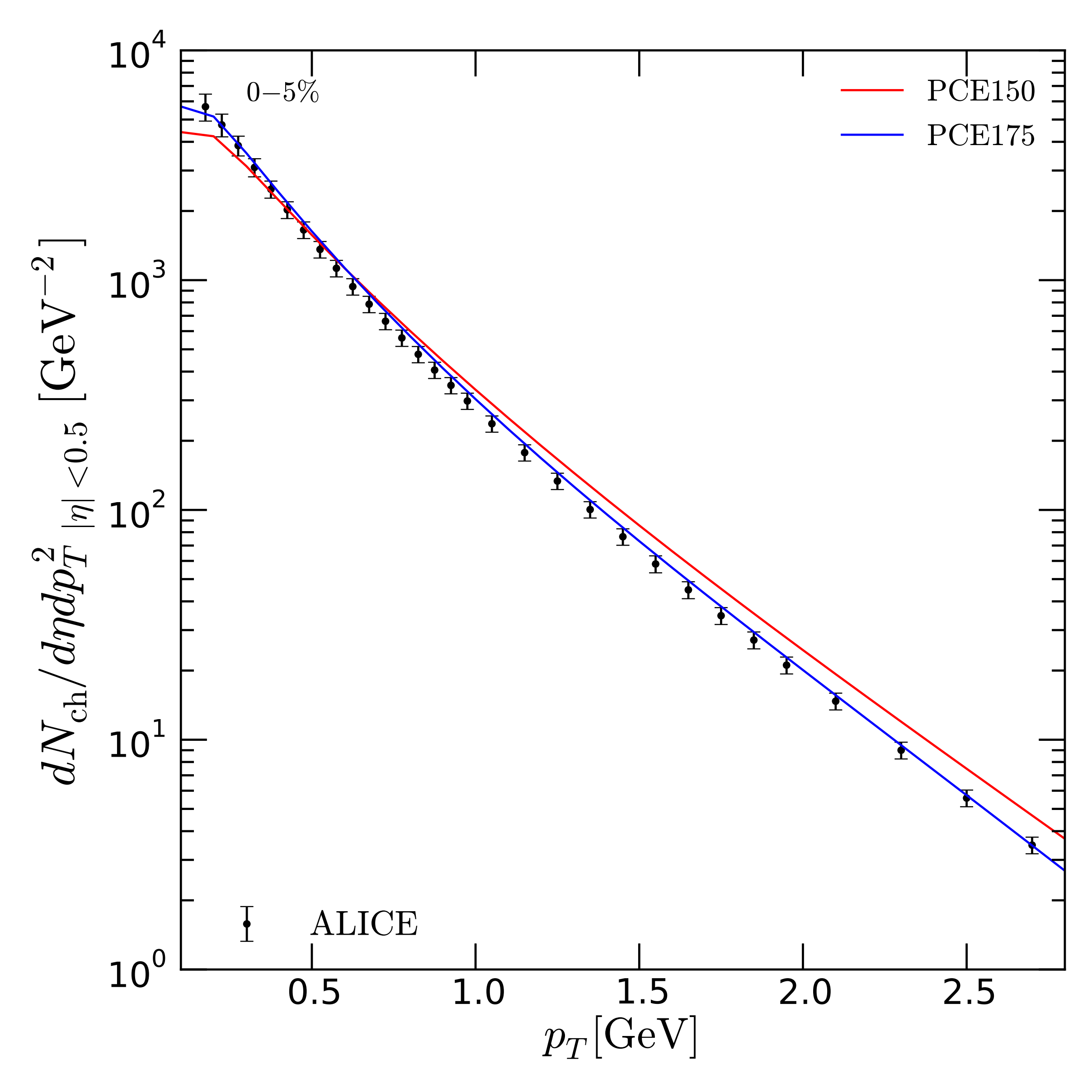
Charged hadron p_T spectrum at LHC



- viscous hydro
- initial state:

pQCD+saturation

- $\tau_0 \approx 0.2\mathrm{fm}/c$

PCE150:

fit to π, K, p yields

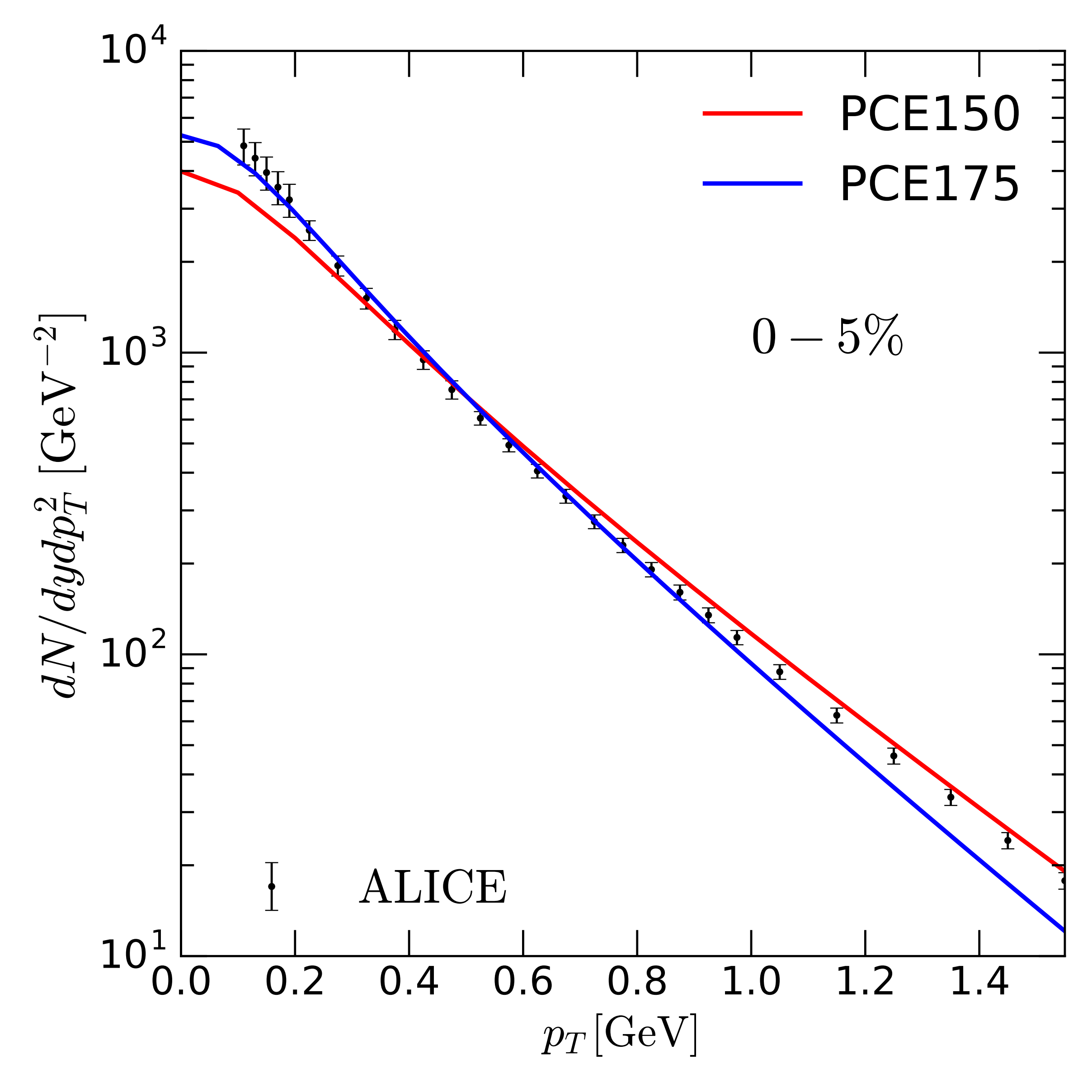
no fit to spectrum

PCE175:

no fit to yields

fits the spectrum

Pion p_T spectrum at LHC



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- **need more resonances**

- **yield proportional to Boltzmann factor**

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

- **need more resonances**

- **yield proportional to Boltzmann factor**

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- **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

effect of Breit-Wigner width on number density:

$$n = \int \mathrm{d}^3\mathbf{p}\, f(p)$$

$$\Rightarrow n = \int \mathrm{d}^3\mathbf{p} \int \mathrm{d}m^2 \frac{\mathrm{d}\rho}{\mathrm{d}m^2}\, f(p,m)$$

where

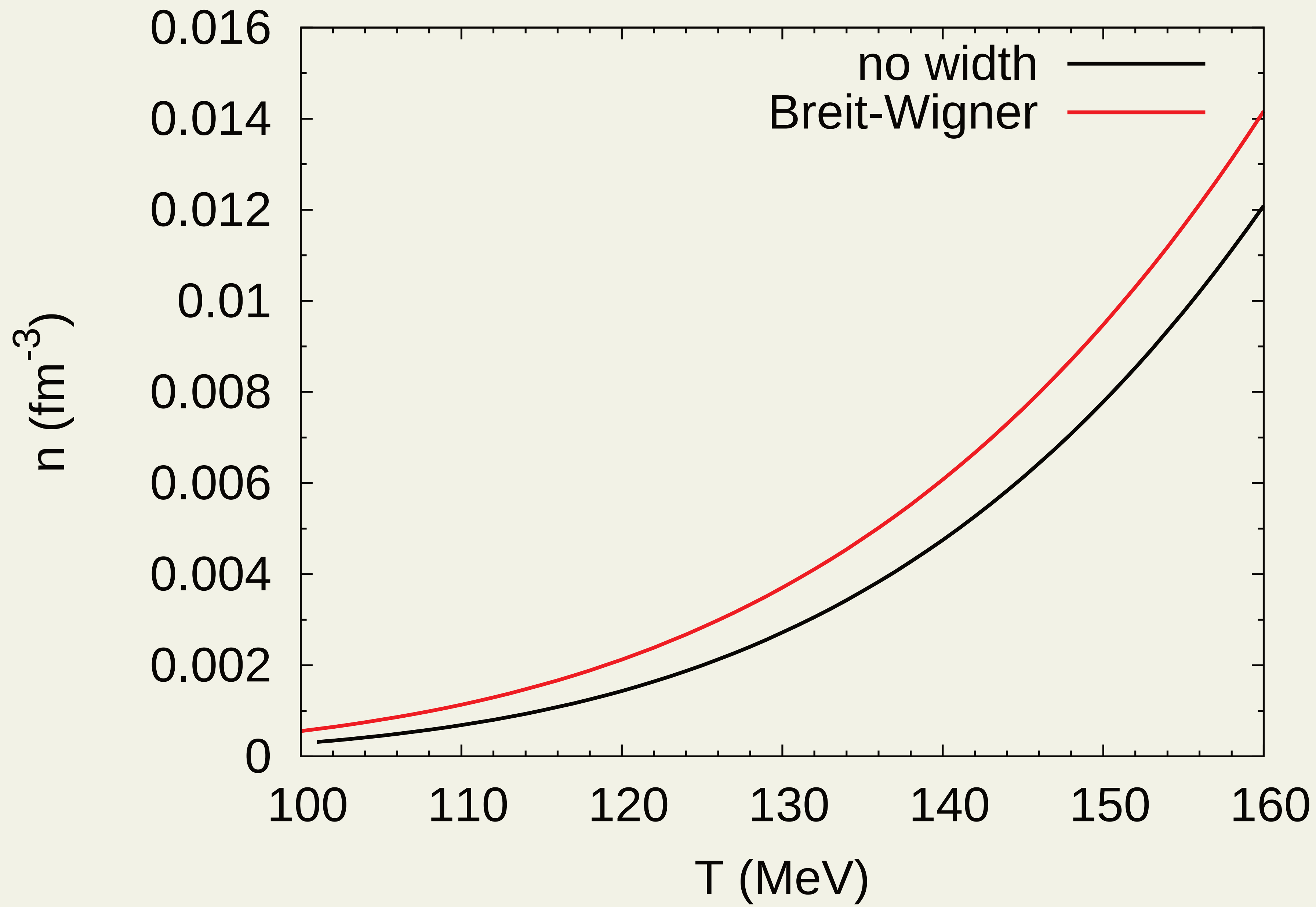
$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m_R\,\Gamma}{(m^2 - m_R^2)^2 + m_R^2\Gamma^2},$$

with normalisation

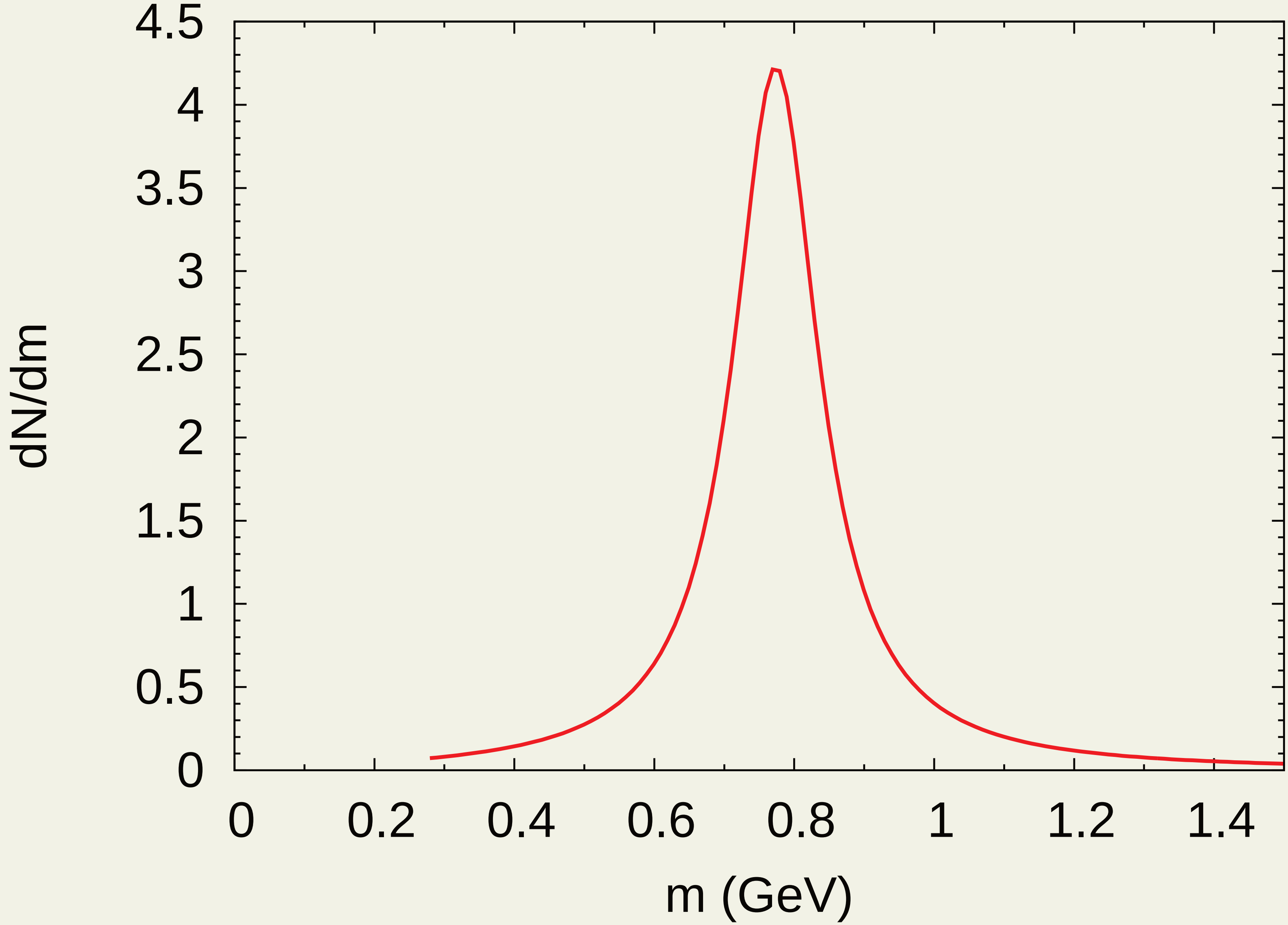
$$N = \int_{m_0}^{\infty} \mathrm{d}m^2 \frac{m_R\,\Gamma}{(m^2 - m_R^2)^2 + m_R^2\Gamma^2},$$

For ρ^0 $m_R = 775.26\,\mathbf{MeV}$ **and** $\Gamma = 147.8\,\mathbf{MeV}$

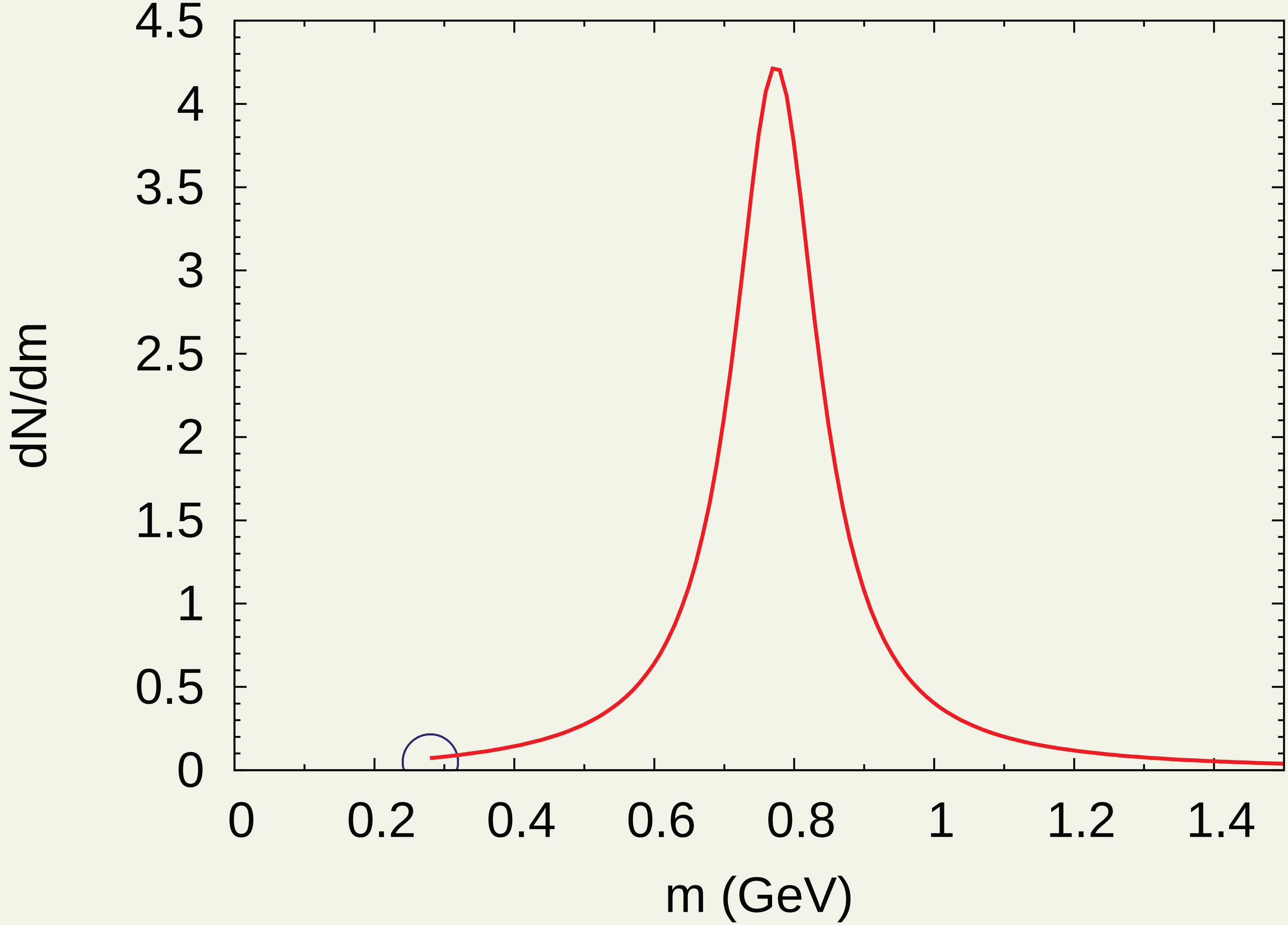
ρ-density


0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
n (fm^{-3})
100
110
120
130
140
150
160
T (MeV)
no width
Breit-Wigner

Breit-Wigner



Breit-Wigner



Mass dependent width

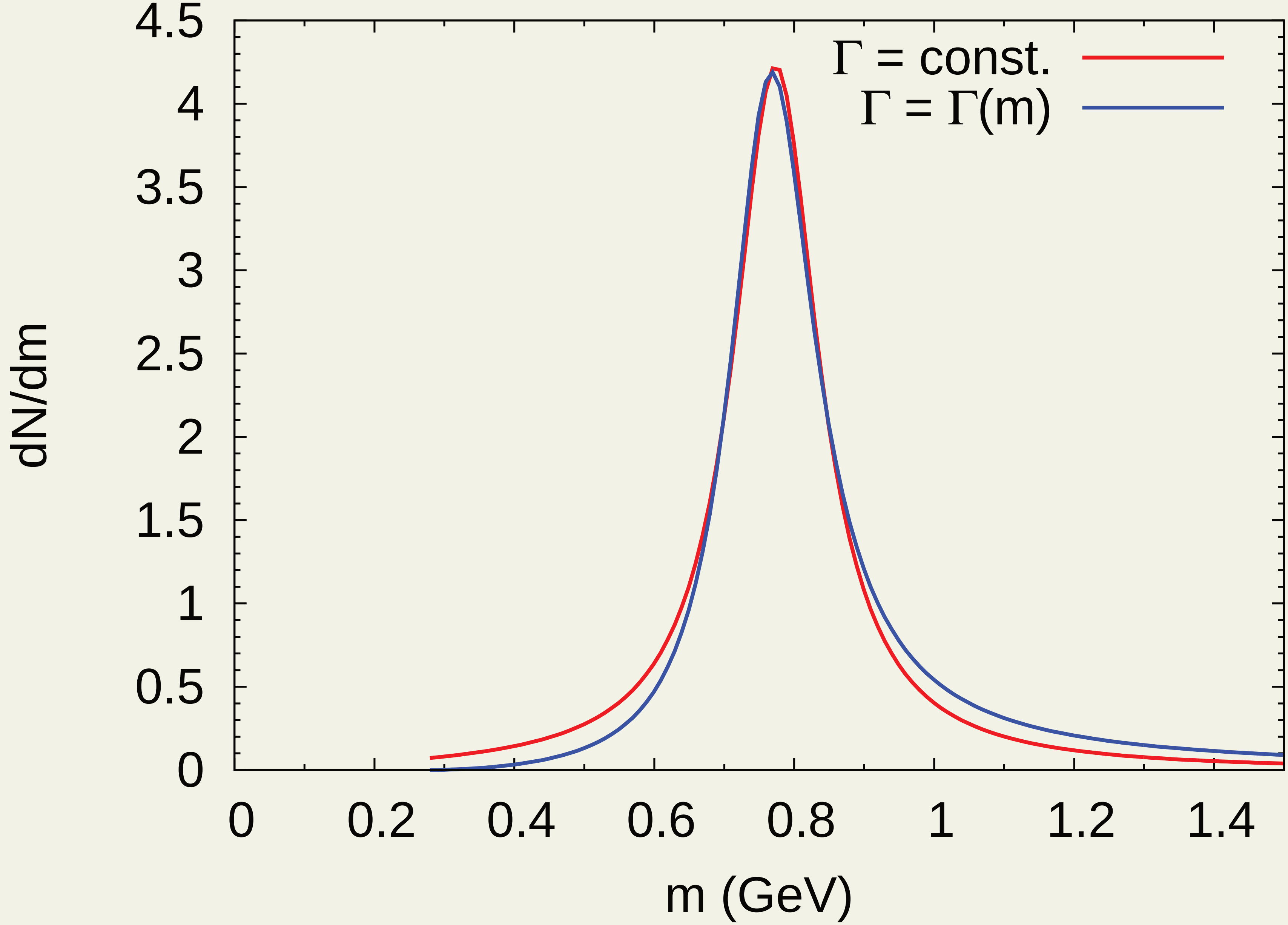
$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m_R\,\Gamma(m)}{(m^2-m_R^2)^2+m_R^2\Gamma(m)^2},$$

with width

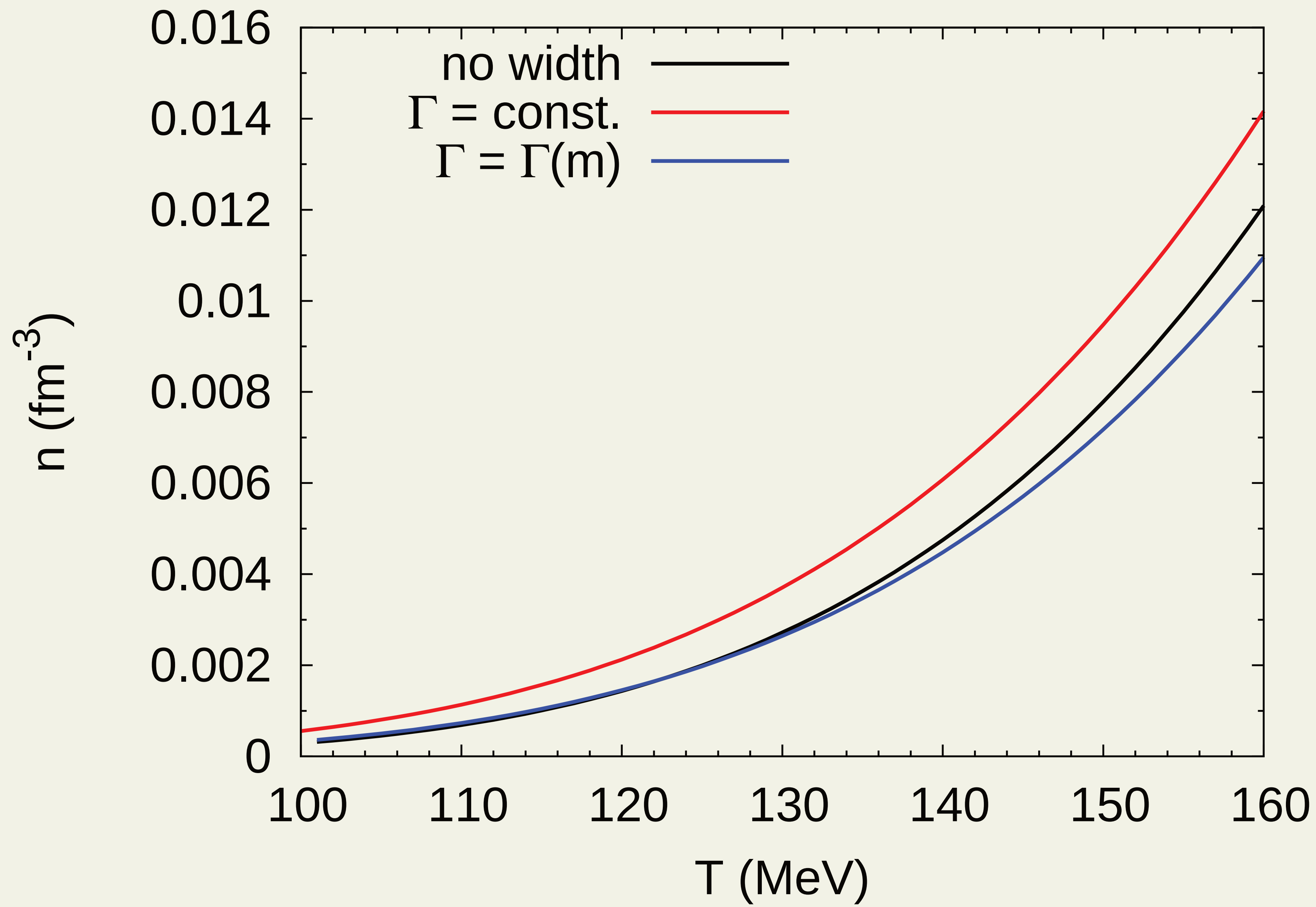
$$\Gamma(m) = \frac{1}{2}\,\frac{p_{\mathrm{CMS}}^3 r_0^2}{1+p_{\mathrm{CMS}}^2 r_0^2}$$

where $r_0 = 6.3$ **GeV**$^{-1}$

Breit-Wigner



ρ-density


no width
Γ = const.
Γ = Γ(m)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
n (fm-3)
100
110
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140
150
160
T (MeV)

relativistic Breit-Wigner

$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m_R\,\Gamma(m)}{(m^2-m_R^2)^2+m_R^2\Gamma(m)^2}$$

or:

$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m\,\Gamma(m)}{(m^2-m_R^2)^2+m^2\Gamma(m)^2}$$

relativistic Breit-Wigner

$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m_R\,\Gamma(m)}{(m^2-m_R^2)^2+m_R^2\Gamma(m)^2}$$

or:

$$\frac{\mathrm{d}\rho}{\mathrm{d}m^2} = \frac{1}{N}\frac{m\,\Gamma(m)}{(m^2-m_R^2)^2+m^2\Gamma(m)^2}$$

But if $\Gamma(m) \propto m$ at large m,

$$N = \int_{m_0}^{\infty} \mathrm{d}m^2 \frac{m\,\Gamma(m)}{(m^2-m_R^2)^2+m^2\Gamma(m)^2} = \infty$$

Particle Data Group about ρ:

`...the line shape does not correspond to`
`a relativistic Breit-Wigner function...but`
`requires some additional shape parameter`

Garbage in, garbage out

Dashen-Ma-Berstein theorem: If interactions mediated by *narrow* resonances, properties of interacting hadron gas are those of noninteracting hadron-resonance gas $\Rightarrow$ **Hadron resonance gas model**

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

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

$\Rightarrow$ relativistic Beth-Uhlenbeck form

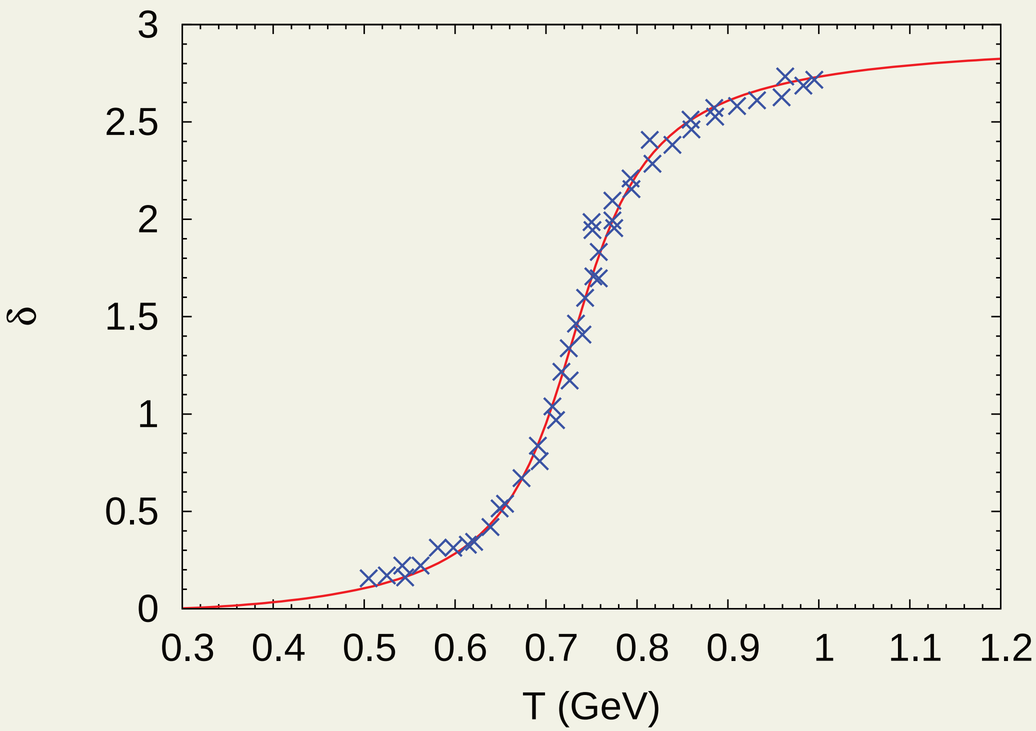
Beth-Uhlenbeck

- **effects of interactions expressed in terms of scattering phase shifts**

$$n = \int \mathrm{d}^3\mathbf{p} \int \mathrm{d}m \frac{\mathrm{d}\rho}{\mathrm{d}m} f(p,m)$$

with

$$\frac{\mathrm{d}\rho}{\mathrm{d}m} = \frac{1}{\pi}\frac{\mathrm{d}\delta}{\mathrm{d}m}$$

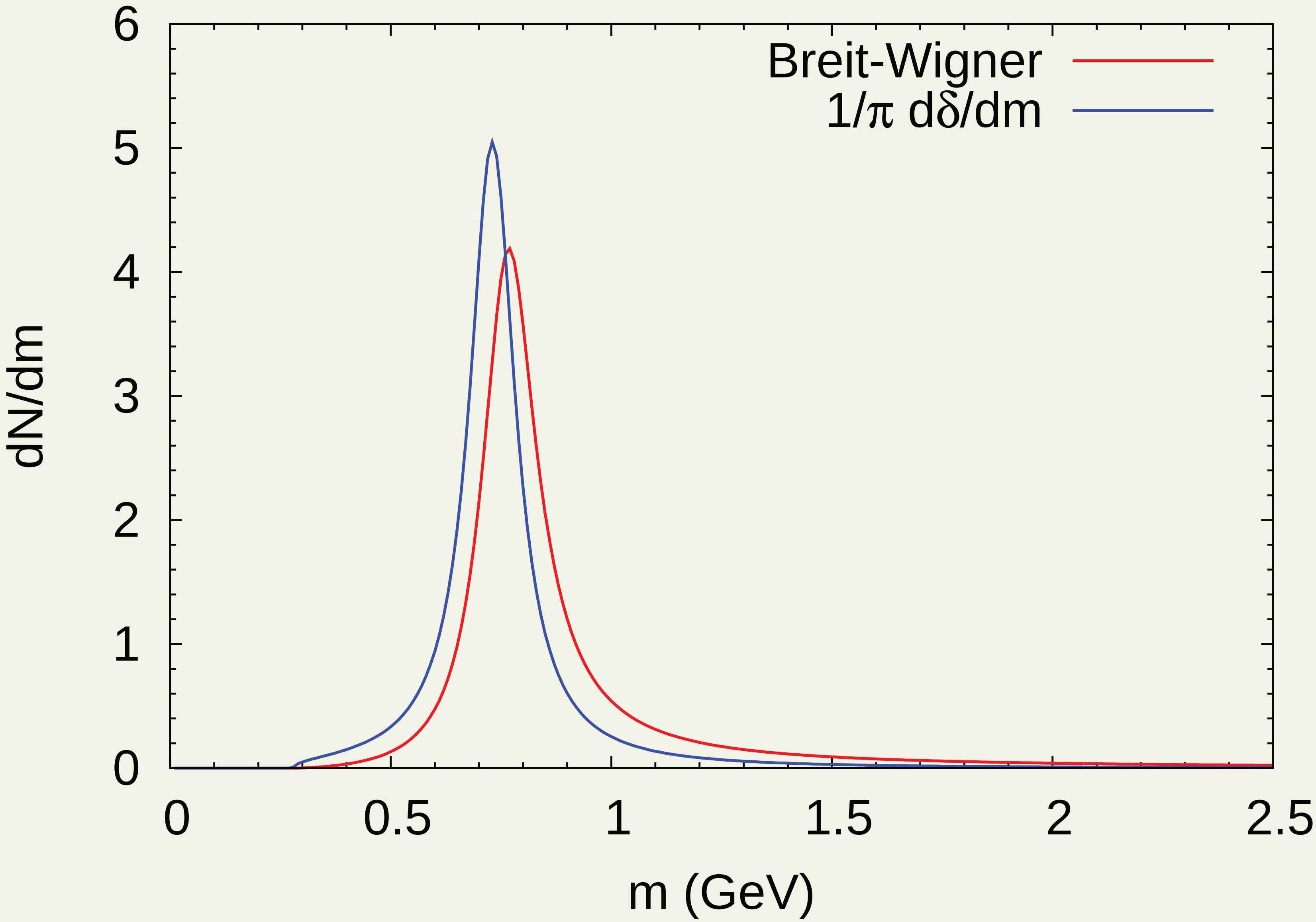


$$\delta(m) = \arctan \frac{-2\alpha}{3} \frac{p^3_{\mathrm{CMS}}}{m(m^2 - \hat{m}_r^2)}$$

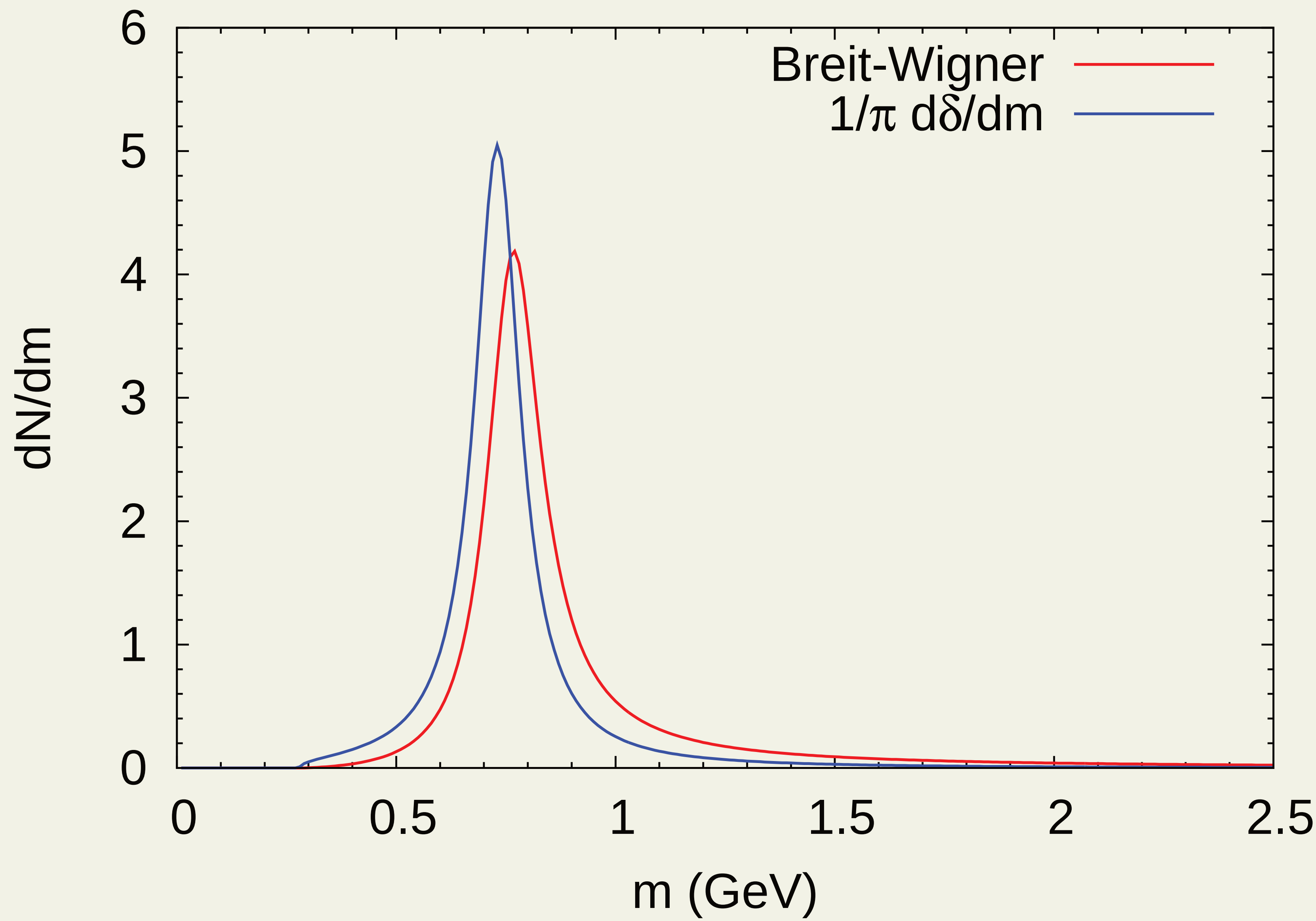
where

$\alpha = 2.64526$

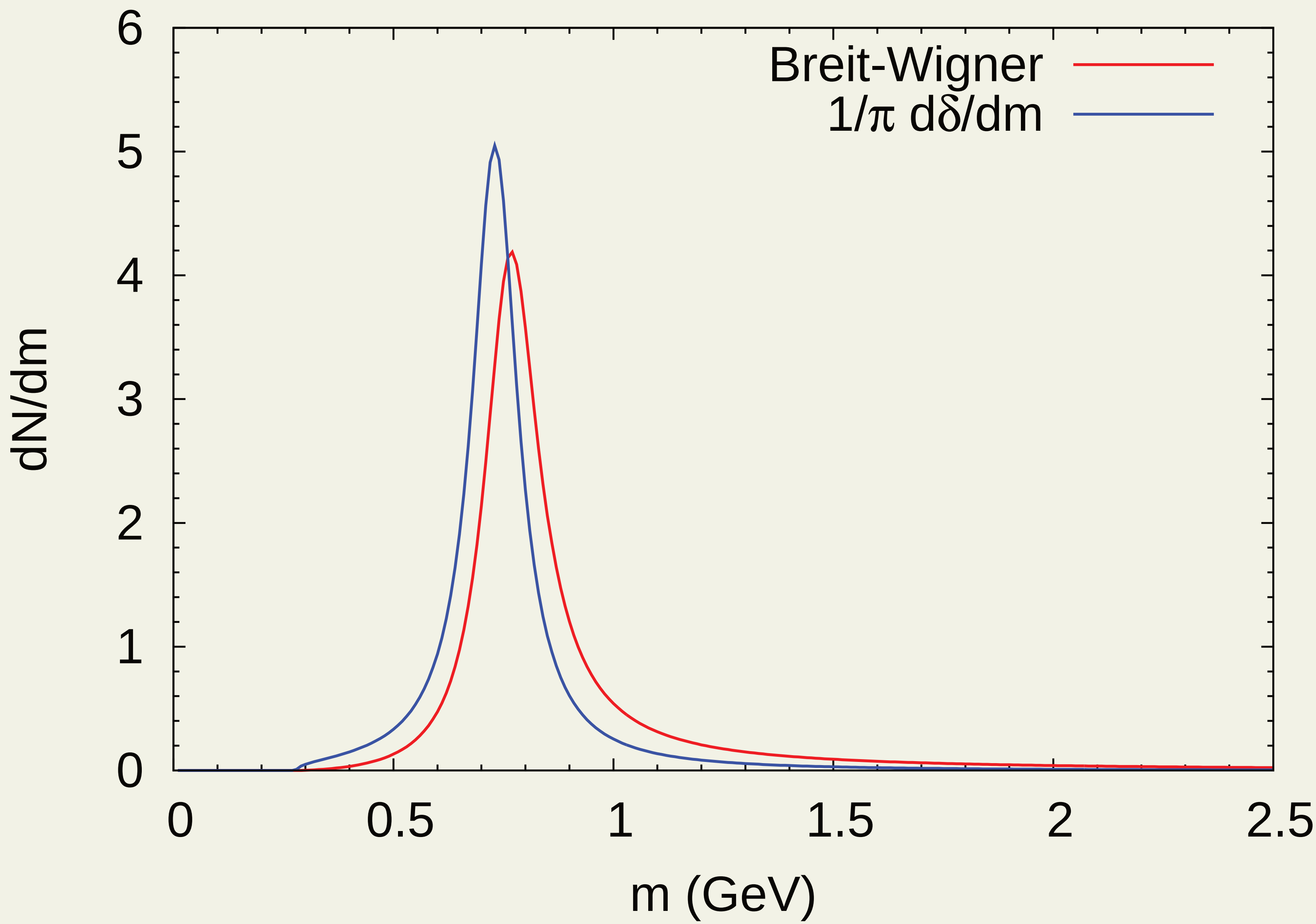
$\hat{m}_r = 0.741395$



Note: $$\frac{\mathrm{d}n}{\mathrm{d}m} = \frac{1}{\pi}\frac{\mathrm{d}\delta}{\mathrm{d}m} = \frac{2\hat{m}_r^2\,\Gamma_\delta(m)}{(m^2-\hat{m}_r^2)^2 + m^2\Gamma_\delta(m)^2} + \ldots$$

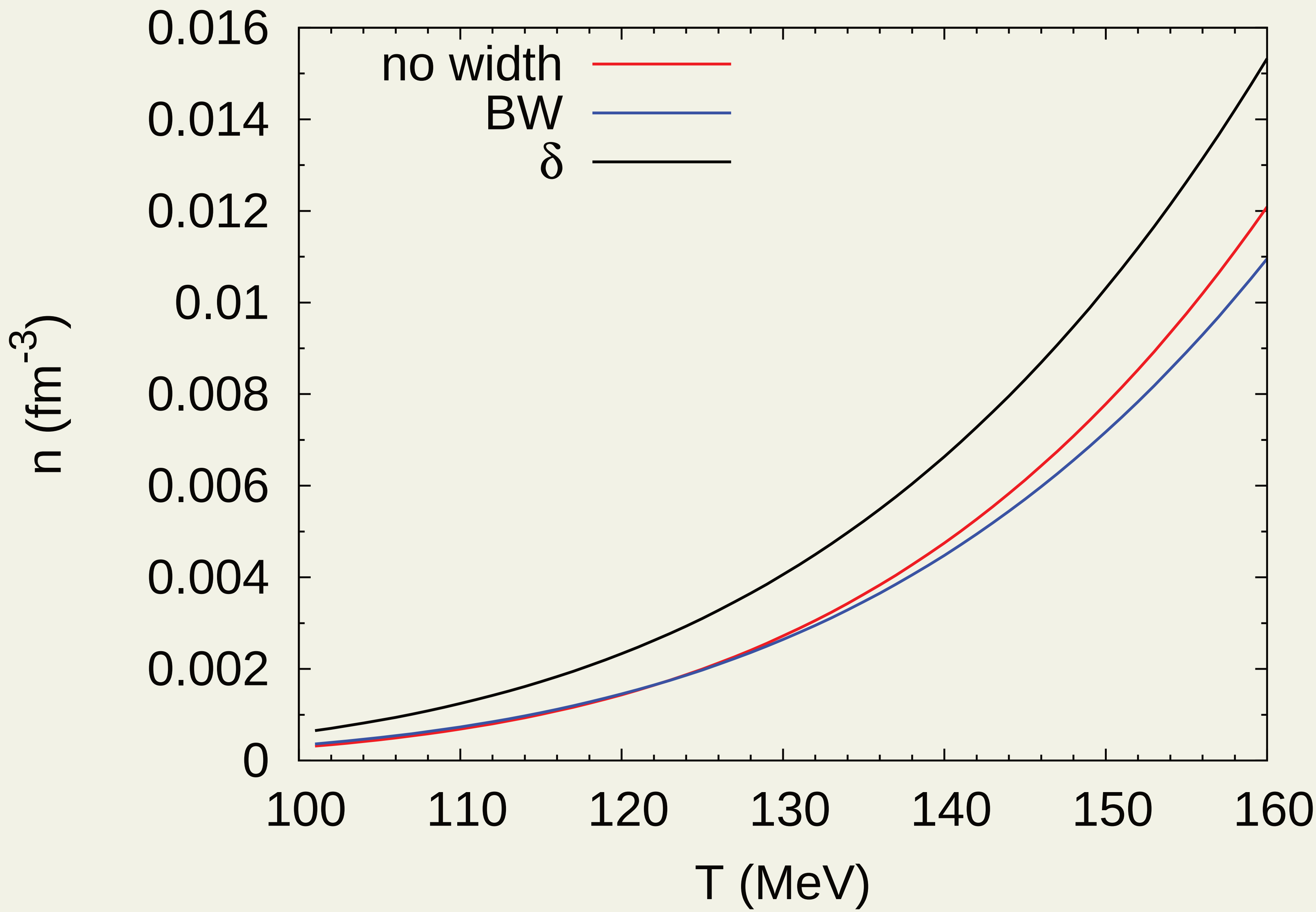


Note: $$\frac{\mathrm{d}n}{\mathrm{d}m} = \frac{1}{\pi}\frac{\mathrm{d}\delta}{\mathrm{d}m} = \frac{2\hat{m}_r^2\,\Gamma_\delta(m)}{(m^2-\hat{m}_r^2)^2 + m^2\Gamma_\delta(m)^2} + \frac{\Gamma_\delta(m)}{p_{\mathrm{CMS}}^2}\frac{3m_\pi^2(\hat{m}_r^2 - m^2)}{(m^2-\hat{m}_r^2)^2 + m^2\Gamma_\delta(m)^2}$$



Note: $m_\rho = 775.26\,\mathbf{MeV}$ **vs.** $\hat{m}_r = 741.395\,\mathbf{MeV}$

ρ-density



0.016
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n (fm^{-3})
no width
BW
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100
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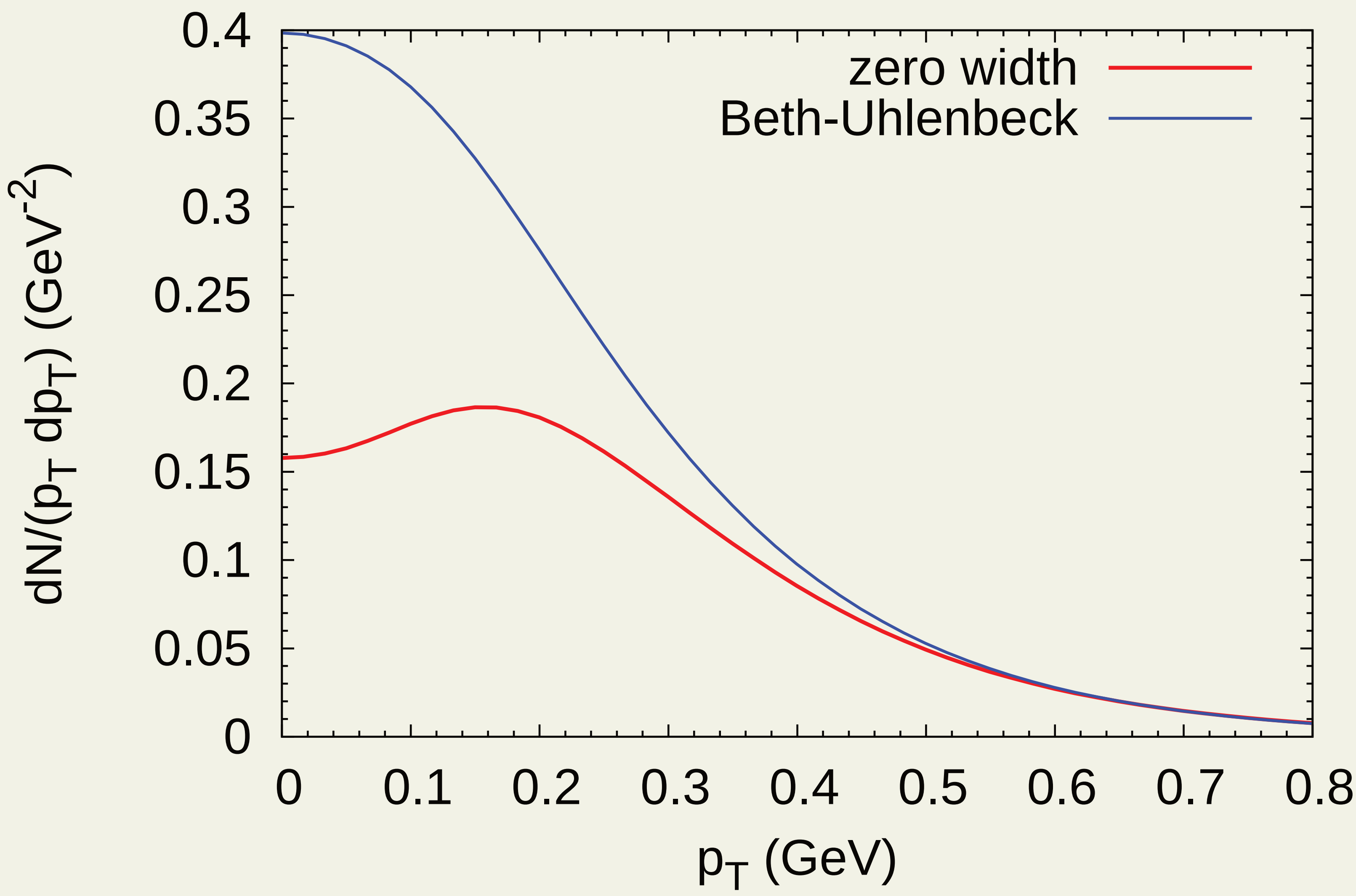
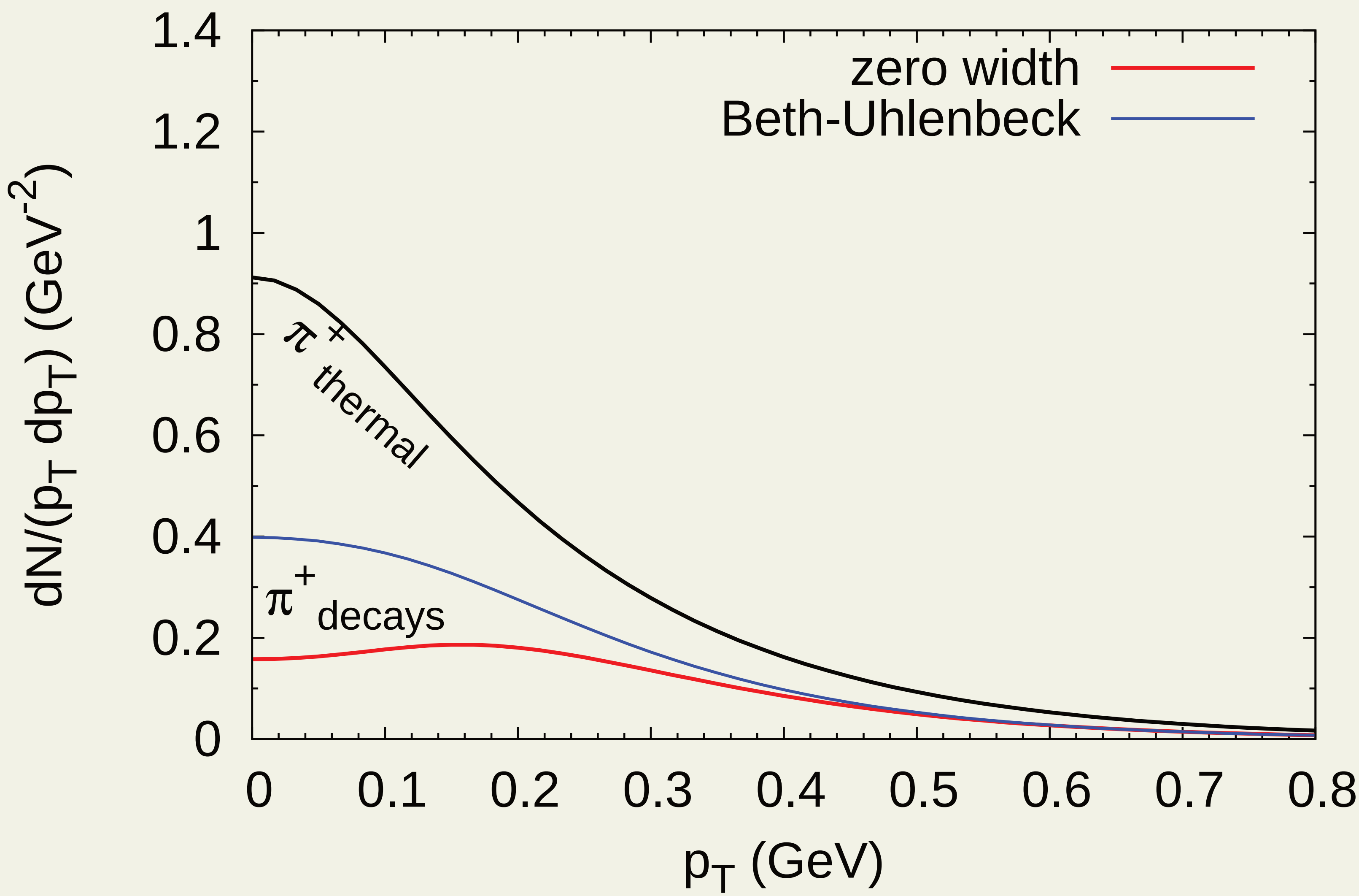
T (MeV)

Pions from ρ decays



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

Thermal pions + pions from ρ decays



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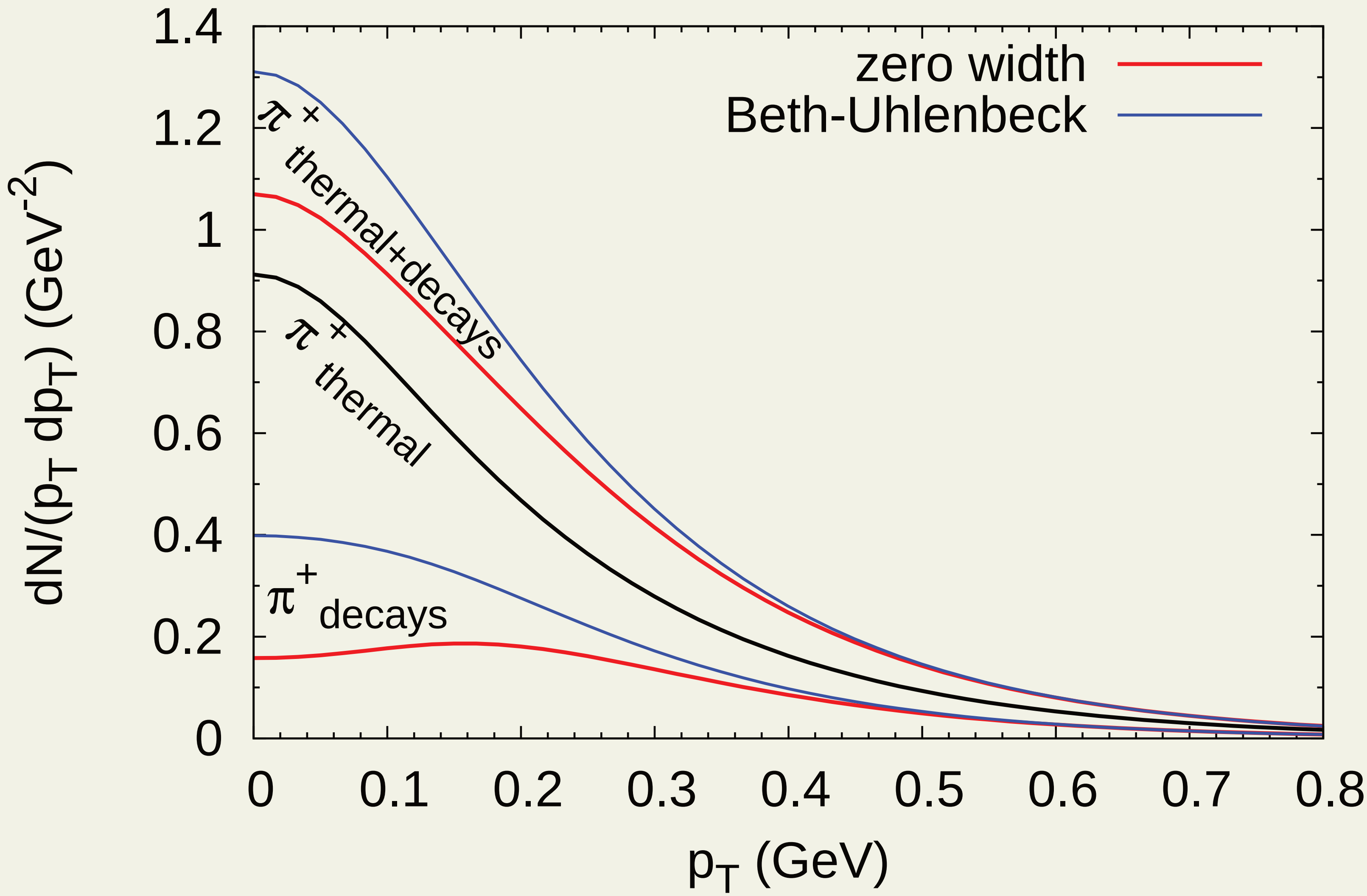

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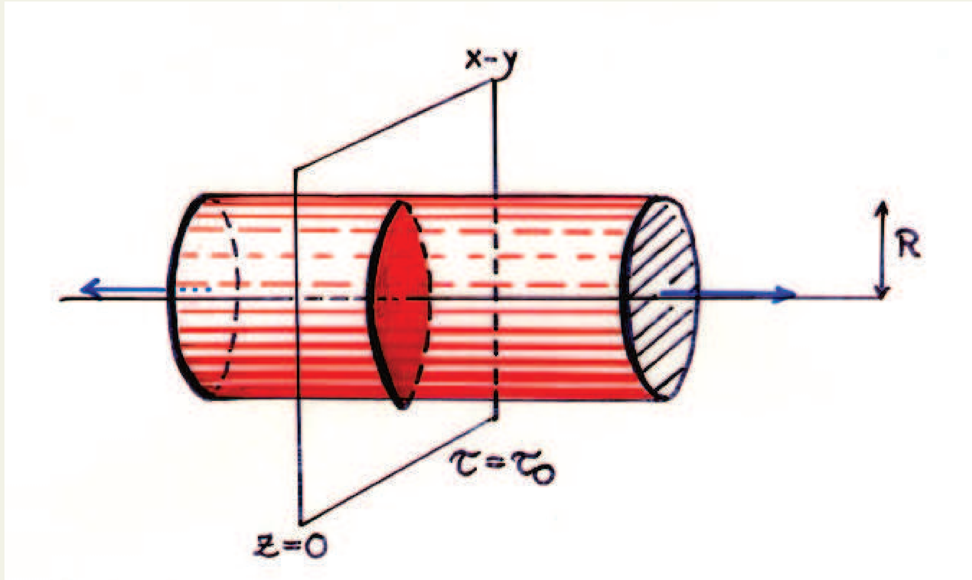
blast-wave parametrisation

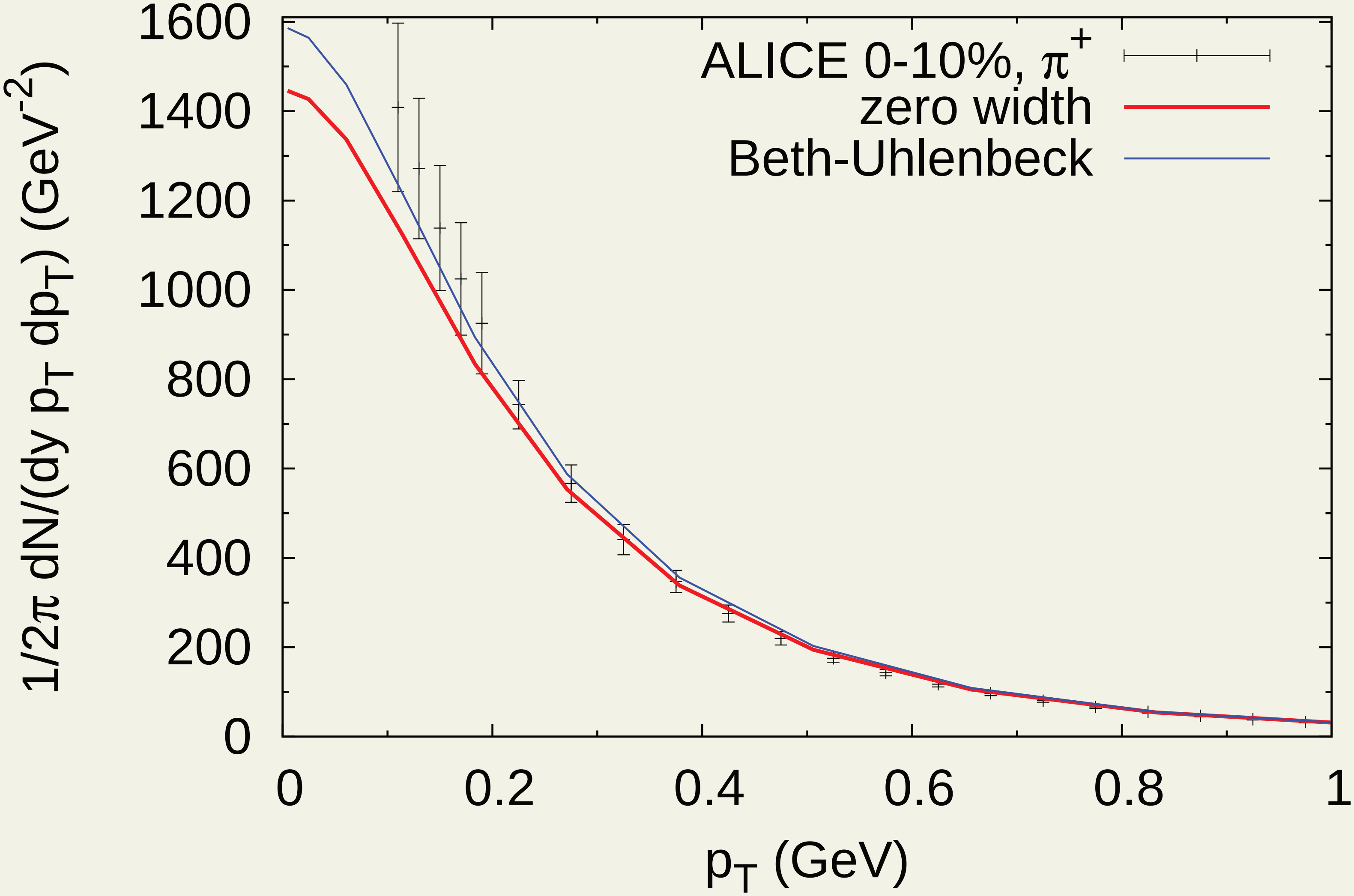


- boost invariant & cylidricly symmetric
- decoupling at constant τ, i.e. volume emission
- transverse velocity $v = v(r)$

$$E\frac{\mathrm{d}N}{\mathrm{d}p^3} = \frac{g\tau m_T}{2\pi^2}\int_0^R r\,\mathrm{d}r\int_{m_{\mathrm{th}}}^{\infty}\mathrm{d}m\frac{\mathrm{d}\rho}{\mathrm{d}m}\sum_{n=1}^{\infty}(\mp 1)^{n+1}I_0\left(n\frac{p_T\gamma_r(r)v_r(r)}{T}\right)K_1\left(n\frac{m_T\gamma_r(r)}{T}\right)$$

$\tau = 13.7\,\mathrm{fm}$, $R = 10\,\mathrm{fm}$, $v_{max} = 0.78$

Pions from blast wave



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

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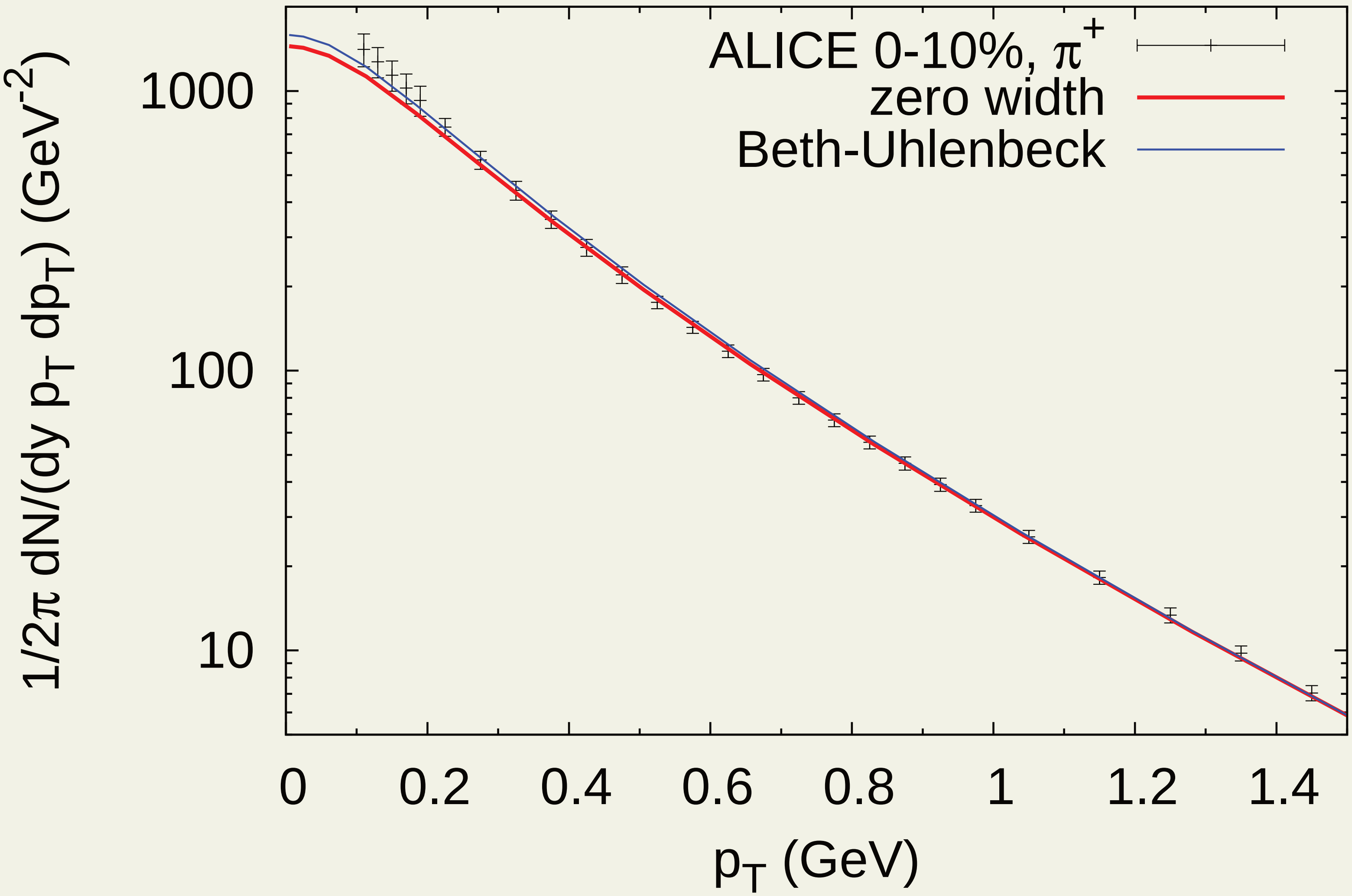

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  - **data exists**

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- $\Lambda(1405)$, $\Xi(1530)$ applicable
  - no data
- and everything else?

Summary

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  - **Probably not**

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Summary

- So is there anomaly. . . ?
  - Probably not
- Resonance widths affect yields and distributions
- Better treatment of resonances needed