Thermal sources in PLUTO

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The implementation of thermal sources is realized via class *PFireball*, with utility functions set in classes *PThermal* and *PData*.

In case of **long-lived particles** the mass is sharp, i.e. fixed at a pole mass and only the total energy E is sampled as a relativistic Boltzmann distribution in the NN cm frame:

$$dN/dE \ \propto \ p\,E\,e^{-\frac{E}{T}} \tag{1}$$

This distribution is not explicitly normalized to 1; this is done (numerically) by the ROOT TF1 object used to implement it.

A 2-temperature source, as observed e.g. in pion production, is realized by:

$$dN/dE \ \propto \ p\,E\,[f\,e^{-\frac{E}{T_1}} + (1-f)\,e^{-\frac{E}{T_2}}] \tag{2}$$

where f and $1-f$ are the respective fractions of the two components.

Optionally, radial flow is implemented using the Siemsen-Rasmussen formulation (see. PRL 42 (1979) 880):

$$dN/dE \ \propto \ p\,E\,e^{-\gamma_r\frac{E}{T}}\left[\left(\gamma_r + \frac{T}{E}\right)\frac{\sinh\alpha}{\alpha} - \frac{T}{E}\cosh\alpha\right] \tag{3}$$

with:
- β_r = blast velocity, (note that in the limit $\beta_r \rightarrow 0$, Eq. 1 is recovered)
- $\gamma_r = 1/\sqrt{1-\beta_r^2}$
- $\alpha = \beta_r\gamma_r p/T$
- $p = \sqrt{E^2 - M^2}$

In case of two temperatures, T_1 and T_2, Eq. 3 is extended as:

$$\begin{aligned} dN/dE \ \propto \ p\,E\Bigg\{ & f\,e^{-\gamma_r\frac{E}{T_1}}\left[\left(\gamma_r + \frac{T_1}{E}\right)\frac{\sinh\alpha_1}{\alpha_1} - \frac{T_1}{E}\cosh\alpha_1\right] \\ & + (1-f)\,e^{-\gamma_r\frac{E}{T_2}}\left[\left(\gamma_r + \frac{T_2}{E}\right)\frac{\sinh\alpha_2}{\alpha_2} - \frac{T_2}{E}\cosh\alpha_2\right]\Bigg\} \end{aligned} \tag{4}$$

These distributions are sampled spatially isotropic or, optionally, with:

$$dN/d\Omega \ \propto \ 1 + A_2\cos^2\theta_{cm} + A_4\cos^4\theta_{cm} \tag{5}$$

Note that most transport codes and some data too show an angle dependence of temperature itself, i.e. $T = T(\theta_{cm})$. Such an effect can be optionally and roughly modeled in PLUTO as well.

For **broad particles** (short-lived resonances), the energy and mass are sampled concurrently as:

$$d^2N/dEdM \ \propto \ Boltzmann(E)\cdot Beit-Wigner(M) \qquad E \geq M \tag{6}$$

The mass sampling is done following S. Teis et al. (see Z. Phys. A356 (1997) 421) using a relativistic Breit-Wigner distribution:

$$dN/dM \;\propto\; \frac{M^2\,\Gamma_0\,\Gamma(M)}{(M^2\,-\,M_0^2)^2 + M^2\,\Gamma^2(M)} \tag{7}$$

with M_0 the pole mass of the resonance and $\Gamma_0 = \Gamma(M_0)$. Again, this distribution, corresponding to the vacuum spectral function, is not normalized to 1.

The mass-dependent width $\Gamma(M)$ is calculated differently for hadronic and for leptonic decays.

For sampling **hadronic** decays, e.g. $\rho^0 \to \pi^+\pi^-$, we use:

$$\Gamma(M) \;=\; \Gamma_0 \underbrace{\frac{M_0}{M}\left(\frac{q}{q_0}\right)^{2l+1}}_{phase\ space} \underbrace{\left(\frac{q_0^2+\delta^2}{q^2+\delta^2}\right)}_{cut\ off} \tag{8}$$

with:
- $q = \pi$ momentum in the ρ rest frame
- $q_0 = q(M_0)$
- $\delta = 0.3$ GeV/c (cut-off parameter)
- $l =$ orbital angular momentum of decay ($l = 1$ for $\rho^0 \to \pi^+\pi^-$)

For sampling **leptonic** decays, e.g. $\rho^0 \to e^+e^-$, we use:

$$\Gamma(M) \;=\; \Gamma_0 \underbrace{\left(\frac{M_0}{M}\right)^3}_{VDM} \underbrace{\sqrt{1-4\,\frac{m_e^2}{M^2}}\left(1+2\,\frac{m_e^2}{M^2}\right)}_{phase\ space} \tag{9}$$

Finally, in PLUTO, the 2-dimensional $d^2N/dEdM$ is sampled via a TF2 object implementing (in the most simple case):

$$d^2N/dEdM \;\propto\; p\,E\,e^{-\frac{E}{T}} \cdot \frac{M^2\,\Gamma_0\,\Gamma(M)}{(M^2\,-\,M_0^2)^2 + M^2\,\Gamma^2(M)} \qquad E \geq M \tag{10}$$

This distribution depends of course strongly on the temperature. Examples are shown in the following graphs for $T = 0.1$ GeV and 0.05 GeV:

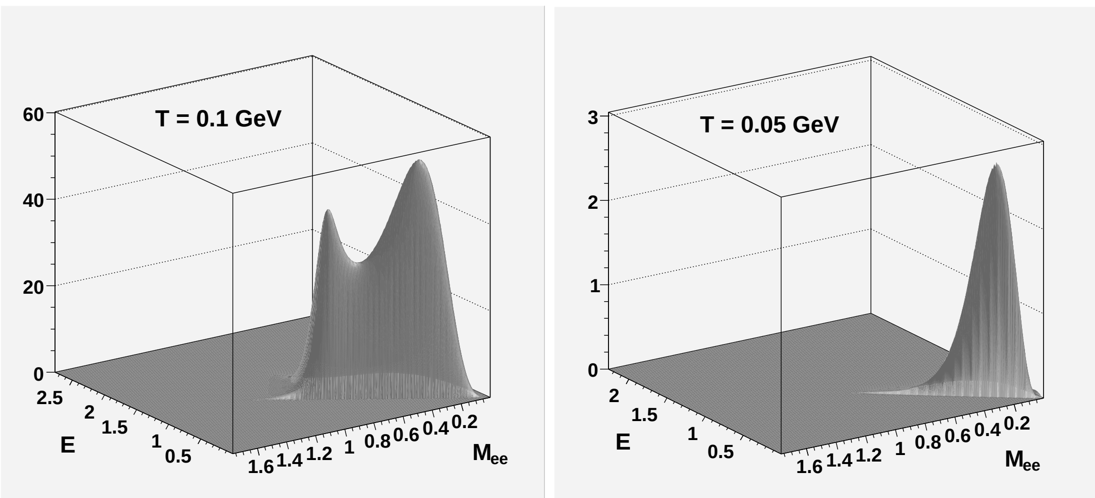

Figure 1: PLUTO generated $d^2N/dEdM$ distributions for leptonic ρ^0 at $T = 0.1$ GeV (left) and at $T = 0.05$ GeV (right). Axis units are GeV.