Supplement: Electron Heating in Perpendicular Low-Beta Shocks

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SUPPLEMENTAL MATERIAL - ERROR REGIONS IN FIGURE 4

Several quantities in Figure 4 are summed with a coarse timestep $\Delta t_{\mathrm{out}} = 400\Delta t = 9\ {\omega_{\mathrm{pe}}}^{-1}$, namely: $W_{\perp,\mathrm{ad}}$, $W_{\perp} - W_{\perp,\mathrm{ad}}$, $W_{\perp,\mathrm{HF}}$, $W_{\parallel,\mathrm{HF}}$, $W_{\mathrm{DC},x} + W_{\mathrm{DC},z}$, and $W_{\mathrm{DC},y}$. To check convergence, we downsample each quantity's summand by 4 and compute an error δf at discrete time t_n as:

$$\delta f(t_n) = \max \left\{ \left| f(t_m) - f_{1/4}(t_m) \right| \mid 0 \leq m \leq n \right\} \tag{1}$$

where $f_{1/4}$ is the 4× downsampled version of f. Thus δf is strictly non-decreasing with t_n. The coarse timestep integrated quantities are generally well behaved, but $W_{\mathrm{DC},x} + W_{\mathrm{DC},z}$ is a difference of two large quantities and so accrues more noise. The error regions defined by Eq. 1 are plotted in Fig. 4. We also plot curves with $2, 4, 8\times$ downsampling in Supplemental Figure 3.

SUPPLEMENTAL MOVIES

Supplemental Movie 1.— Time evolution of Figure 1.

Supplemental Movie 2.— Time evolution of our electron sample, described in the text, traversing the shock front. The electron particles are plotted over ion density n_{i}, parallel electric field $E_{\parallel}$, and the electric field component E_x. The ion density n_{i} is scaled to upstream density n_0, and the electric field components are scaled to upstream motional electric field magnitude $u_0 B_0/c$. The $E_{\parallel}$ colormap spans $[-1, +1]$ and saturates on small-scale waves, despite being a wider range than in Figure 3 of the main text.

Supplemental Movie 3.— Time evolution of Figure 3 with additional views of electron sample's phase space. The momentum component $\gamma\beta_{\perp,1}$ is the projection along $(\hat{b} \times -\hat{x}) \times \hat{b}$, and the component $\gamma\beta_{\perp,2}$ is the projection along $\hat{b} \times -\hat{x}$. Because the local magnetic field unit vector $\hat{b}$ mostly orients along $\hat{y}$, the components $\perp, 1$ and $\perp, 2$ roughly correspond to $-\hat{x}$ and $+\hat{z}$ so that $(\perp, 1; \perp, 2; \parallel)$ form a right-handed coordinate system. The $E_{\parallel}$ colormap is the same as in Supplemental Movie 2.

SUPPLEMENTAL FIGURES

Supplemental Figure 1.— Fiducial 2-D simulations are converged with respect to transverse width. Black curves are fiducial 2-D $m_{\mathrm{i}}/m_{\mathrm{e}} = 625$ simulations from Figure 2(a). Colored curves are same shock parameters with varying input `my`, as defined in Supplemental Table 1. Panel titles have $\mathcal{M}_{\mathrm{s}}$ computed differently from the rest of the text: we assume $\Gamma = 2$ for $\mathcal{M}_{\mathrm{s}} \leq 5$ and $\Gamma = 5/3$ for $\mathcal{M}_{\mathrm{s}} \geq 7$. Most of the varying transverse width simulations are *not* listed in Supplemental Table 1.

Supplemental Figure 2.— Like Figure 4(a-c), but now showing electron samples traversing the shock at different times. At $t' = 0\ {\omega_{\mathrm{pi}}}^{-1}$, we selected all electrons in the regions $x \in [5.60, 5.62] c/\omega_{\mathrm{pi}}$, $x \in [6.00, 6.02] c/\omega_{\mathrm{pi}}$, and so on with even spacing $0.4 c/\omega_{\mathrm{pi}}$ to get seventeen electron particle samples of similar volume and number. Curves are as in Figure 4.

Supplemental Figure 3.— Like Supplemental Figure 2, but now shows the numerical convergence of all quantities integrated with the coarse timestep Δt_{out}, namely: $W_{\perp,\mathrm{ad}}$, $W_{\perp} - W_{\perp,\mathrm{ad}}$, $W_{\perp,\mathrm{HF}}$, $W_{\parallel,\mathrm{HF}}$, $W_{\mathrm{DC},x} + W_{\mathrm{DC},z}$, and $W_{\mathrm{DC},y}$. For each quantity, we increase the sample spacing Δt_{out} by 2×, 4×, and 8× and plot the down-sampled integration with progressively decreasing opacity.

SUPPLEMENTAL TABLES

Supplemental Table 1.— This is a comma-separated value (CSV) ASCII file with input parameters, derived shock parameters, run duration, and downstream temperature measurements for all simulation runs shown in our manuscript. The first row is the high-resolution run used in Figures 3–4 of the main text, and the remaining rows are presented in Figure 2. Below, we define all table columns. We also display the table in human-readable format.

SUPPLEMENTAL TABLE 1: COLUMN DEFINITIONS

- `mi_me` is the ion-electron mass ratio $m_\mathrm{i}/m_\mathrm{e}$.

- `theta` and `phi` specify the upstream magnetic field orientation, measured in the simulation frame. θ is the angle between $\vec{B}$ and the x-coordinate axis. φ is the angle between the y-z plane projection of $\vec{B}$ and the z-coordinate axis. To visualize these angles, see Fig. 1 of Guo *et al.* [1], but note that their $\varphi_\mathrm{B} = \pi/2 - \varphi$ is the complement of our φ. For all our simulations, θ corresponds to the angle between $\vec{B}$ and shock normal. The 2-D simulations with in-plane $\vec{B}$ have $\theta = 90^\circ$ and $\varphi = 90^\circ$. The 2-D simulations with out-of-plane $\vec{B}$ (i.e., $\vec{B}$ along $\hat{z}$) have $\theta = 90^\circ$ and $\varphi = 0^\circ$. The 1-D simulations with oblique $\vec{B}$ have have $\theta < 90^\circ$.

- `my` and `mz` are the numbers of grid cells along $\hat{y}$ and $\hat{z}$. Our 2-D simulations have `mz` $= 1$, and 1-D simulations have `my` $=$ `mz` $= 1$.

- `betap`, `Ms`, `Ma`, and `Mms` are the shock plasma beta β_p, sonic Mach number $\mathcal{M}_\mathrm{s}$, Alfvén Mach number $\mathcal{M}_\mathrm{A}$, and fast magnetosonic Mach number $\mathcal{M}_\mathrm{ms}$. These numbers are *derived* from TRISTAN-MP input parameters `sigma`, `delgam`, and `u0` (defined just below). First, the plasma beta is:

$$\beta_\mathrm{p} = \frac{4\gamma_0 \Delta\gamma_\mathrm{i}}{\sigma\left(\gamma_0 - 1\right)\left(1 + m_\mathrm{e}/m_\mathrm{i}\right)}$$

  where $\gamma_0 = 1/\sqrt{1-(u_0/c)^2}$ is the Lorentz factor of the upstream flow in the simulation frame. The sonic Mach number depends on the upstream plasma speed in the shock's rest frame:

$$\mathcal{M}_\mathrm{s} = \frac{u_\mathrm{sh}}{c_\mathrm{s}} = \frac{u_0}{\left(1 - 1/r\left(\mathcal{M}_\mathrm{s}\right)\right) c_\mathrm{s}}$$

  and we solve this implicit expression for $\mathcal{M}_\mathrm{s}$ (and thus also u_s) using an input u_0 and assumed fluid adiabatic index $\Gamma = 2$ (note that Γ enters into both the Rankine-Hugoniot expression for MHD shock compression ratio r and the sound speed c_s). Once $\mathcal{M}_\mathrm{s}$ and u_sh are known, $\mathcal{M}_\mathrm{A}$ and $\mathcal{M}_\mathrm{ms}$ are known as well. This procedure for estimating shock parameters is taken directly from Guo *et al.* [2].

- `sigma` is the magnetization, a ratio of upstream magnetic and kinetic enthalpy densities:

$$\texttt{sigma} = \sigma \equiv \frac{{B_0}^2}{4\pi\left(\gamma_0 - 1\right)\left(m_\mathrm{i} + m_\mathrm{e}\right) n_0 c^2}.$$

- `delgam` is the upstream plasma temperature, scaled by ion rest energy:

$$\texttt{delgam} = \Delta\gamma_\mathrm{i} \equiv \frac{k_\mathrm{B} T_0}{m_\mathrm{i} c^2}.$$

- `u0` is the upstream plasma velocity, scaled by speed of light:

$$\texttt{u0} \equiv u_0/c$$

  Note that `sigma`, `delgam`, and `u0` are defined using velocity, density, and magnetic field measured in the simulation frame. The ion temperature is measured in the upstream plasma's co-moving frame, as usual.

- `ppc0` is number of particles (both electrons and ions) per cell in the upstream plasma.

- `c_omp` is the number of grid cells per electron skin depth c/ω_{pe}.
- `ntimes` is the number of current filter passes.
- `dur` is the simulation duration in units of upstream ion cyclotron time ${\Omega_{\mathrm{i}}}^{-1}$.
- `Te_Ti` is our measurement of downstream temperature ratio $T_{\mathrm{e}}/T_{\mathrm{i}}$. As described in the main text, we manually choose a downstream region that is minimally affected by the left-side reflecting wall and the right-side shock front relaxation. Our measurement of $T_{\mathrm{e}}/T_{\mathrm{i}}$ uses downsampled grid output of the particle temperature tensor; however, the temperature tensor itself is calculated for each grid cell using the full particle distribution in a 5^N cell region, where $N \in \{1, 2, 3\}$ is the domain dimensionality.
- `Te_Ti_std` is the standard deviation of $T_{\mathrm{e}}/T_{\mathrm{i}}$ within the downstream region that we consider. Like `Te_Ti`, downsampled grid output is used for this estimate.
- `Te` and `Ti` are the downstream electron and ion temperatures scaled to their respective rest masses; i.e., $k_{\mathrm{B}}T_{\mathrm{e}}/(m_{\mathrm{e}}c^2)$ and $k_{\mathrm{B}}T_{\mathrm{i}}/(m_{\mathrm{i}}c^2)$. We measure all of `Te`, `Ti`, and `Te_Ti` in the same manually-chosen downstream region.

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[1] X. Guo, L. Sironi, and R. Narayan, Non-thermal Electron Acceleration in Low Mach Number Collisionless Shocks. I. Particle Energy Spectra and Acceleration Mechanism, Astrophys. J. **794**, 153 (2014).

[2] X. Guo, L. Sironi, and R. Narayan, Electron Heating in Low-Mach-number Perpendicular Shocks. I. Heating Mechanism, Astrophys. J. **851**, 134 (2017).

mi_me	theta	phi	my	mz	betap	Ms	Ma	Mms	sigma	delgam	u0	ppc0	c_omp	ntimes	dur	Te_Ti	Te_Ti_std	Te	Ti
625	90	90	2400	1	0.250	6.86	3.43	3.07	4.7854E−1	8.0944E−6	2.3245E−2	128	20	64	6.7	NaN	NaN	NaN	NaN
625	90	90	720	1	0.251	3.00	1.50	1.34	1.0117E+1	1.6189E−5	7.1502E−3	32	10	32	20.1	8.525E−1	1.380E−1	1.295E−2	2.430E−5
625	90	90	1440	1	0.250	4.00	2.00	1.79	2.3774E+0	1.6189E−5	1.4749E−2	32	10	32	15.0	5.595E−1	2.330E−1	1.735E−2	4.962E−5
625	90	90	960	1	0.250	5.00	2.50	2.24	1.1237E+0	1.1332E−5	1.7949E−2	32	10	32	20.1	4.524E−1	1.694E−1	1.957E−2	6.923E−5
625	90	90	1200	1	0.250	6.86	3.43	3.07	4.7854E−1	8.0944E−6	2.3245E−2	32	10	32	14.2	3.653E−1	1.279E−1	2.830E−2	1.239E−4
625	90	90	1440	1	0.250	9.99	4.99	4.47	1.9968E−1	4.8566E−6	2.7873E−2	32	10	32	12.1	3.183E−1	1.224E−1	3.649E−2	1.835E−4
625	90	90	1440	1	0.250	15.19	7.60	6.79	8.1402E−2	1.6189E−6	2.5205E−2	32	10	32	10.0	2.968E−1	1.215E−1	2.801E−2	1.510E−4
625	90	90	1440	1	0.250	20.37	10.18	9.11	4.4398E−2	8.0944E−7	2.4133E−2	32	10	32	9.8	1.985E−1	5.987E−2	1.826E−2	1.472E−4
625	90	0	1440	1	0.251	3.00	1.50	1.34	1.0117E+1	1.6189E−5	7.1502E−3	32	10	32	19.0	8.620E−1	1.202E−1	1.304E−2	2.420E−5
625	90	0	1440	1	0.250	4.00	2.00	1.79	2.3774E+0	1.6189E−5	1.4749E−2	32	10	32	19.9	4.712E−1	1.776E−1	1.595E−2	5.417E−5
625	90	0	1440	1	0.250	5.00	2.50	2.24	1.1237E+0	1.1332E−5	1.7949E−2	32	10	32	15.0	2.494E−1	1.284E−1	1.235E−2	7.926E−5
625	90	0	1440	1	0.250	7.00	3.50	3.13	4.5493E−1	8.0944E−6	2.3840E−2	32	10	32	15.2	1.065E−1	5.445E−2	1.024E−2	1.539E−4
625	90	0	1440	1	0.250	10.00	5.00	4.47	1.9912E−1	4.8566E−6	2.7912E−2	32	10	32	9.8	4.482E−2	2.295E−2	6.824E−3	2.436E−4
625	90	0	1440	1	0.250	15.00	7.50	6.71	8.3580E−2	1.6189E−6	2.4874E−2	32	10	32	8.5	2.544E−2	2.433E−2	3.112E−3	1.958E−4
625	90	90	1	1	0.251	3.00	1.50	1.34	1.0117E+1	1.6189E−5	7.1502E−3	512	10	32	40.0	8.519E−1	1.047E−1	1.316E−2	2.473E−5
625	90	90	1	1	0.250	4.00	2.00	1.79	2.3774E+0	1.6189E−5	1.4749E−2	512	10	32	40.0	4.279E−1	1.858E−1	1.582E−2	5.916E−5
625	90	90	1	1	0.250	5.00	2.50	2.24	1.1237E+0	1.1332E−5	1.7949E−2	512	10	32	25.2	2.360E−1	8.397E−2	1.240E−2	8.404E−5
625	90	90	1	1	0.250	7.00	3.50	3.13	4.5493E−1	8.0944E−6	2.3840E−2	512	10	32	25.0	1.011E−1	3.874E−2	1.018E−2	1.612E−4
625	90	90	1	1	0.250	10.00	5.00	4.47	1.9912E−1	4.8566E−6	2.7912E−2	512	10	32	15.2	5.025E−2	3.443E−2	7.030E−3	2.239E−4
625	90	90	1	1	0.250	15.00	7.50	6.71	8.3580E−2	1.6189E−6	2.4874E−2	1024	10	32	15.1	2.381E−2	1.568E−2	2.854E−3	1.918E−4
625	90	90	1	1	0.250	20.00	10.00	8.94	4.6080E−2	1.1332E−6	2.8027E−2	2048	10	32	10.1	1.353E−2	1.183E−2	2.054E−3	2.428E−4
625	85	90	1	1	0.251	3.00	1.50	1.34	1.0117E+1	1.6189E−5	7.1502E−3	2048	10	64	40.0	9.148E−1	7.963E−2	1.360E−2	2.379E−5
625	85	90	1	1	0.250	4.00	2.00	1.79	2.3774E+0	1.6189E−5	1.4749E−2	2048	10	64	40.0	4.908E−1	1.611E−1	1.699E−2	5.540E−5
625	85	90	1	1	0.250	5.00	2.50	2.23	1.1237E+0	1.1332E−5	1.7949E−2	2048	10	64	25.2	2.786E−1	1.566E−1	1.356E−2	7.787E−5
625	85	90	1	1	0.250	7.00	3.50	3.13	4.5493E−1	8.0944E−6	2.3840E−2	2048	10	64	20.0	1.352E−1	4.984E−2	1.348E−2	1.595E−4
625	85	90	1	1	0.250	10.00	5.00	4.47	1.9912E−1	4.8566E−6	2.7912E−2	2048	10	64	15.2	1.287E−1	3.693E−2	1.745E−2	2.169E−4
625	80	90	1	1	0.251	2.99	1.50	1.34	1.0117E+1	1.6189E−5	7.1502E−3	2048	10	64	30.1	8.732E−1	4.514E−2	1.267E−2	2.322E−5
625	80	90	1	1	0.250	3.99	2.00	1.79	2.3774E+0	1.6189E−5	1.4749E−2	2048	10	64	30.1	6.576E−1	1.091E−1	1.938E−2	4.716E−5
625	80	90	1	1	0.250	4.99	2.50	2.23	1.1237E+0	1.1332E−5	1.7949E−2	2048	10	64	25.2	5.283E−1	1.623E−1	2.129E−2	6.446E−5
625	80	90	1	1	0.250	6.99	3.49	3.13	4.5493E−1	8.0944E−6	2.3840E−2	2048	10	64	20.0	2.384E−1	1.269E−1	2.054E−2	1.378E−4
625	80	90	1	1	0.250	9.99	5.00	4.47	1.9912E−1	4.8566E−6	2.7912E−2	2048	10	64	15.2	1.894E−1	8.866E−2	2.265E−2	1.913E−4
625	75	90	1	1	0.251	2.98	1.49	1.34	1.0117E+1	1.6189E−5	7.1502E−3	2048	10	64	40.0	8.544E−1	2.439E−2	1.267E−2	2.373E−5
625	75	90	1	1	0.250	3.98	1.99	1.78	2.3774E+0	1.6189E−5	1.4749E−2	2048	10	64	30.1	6.454E−1	7.817E−2	1.938E−2	4.804E−5
625	75	90	1	1	0.250	4.98	2.49	2.23	1.1237E+0	1.1332E−5	1.7949E−2	2048	10	64	25.2	7.759E−1	1.815E−1	2.693E−2	5.554E−5
625	75	90	1	1	0.250	6.98	3.49	3.12	4.5493E−1	8.0944E−6	2.3840E−2	2048	10	64	20.0	1.111E+0	1.904E−1	5.518E−2	7.945E−5
625	75	90	1	1	0.250	9.98	4.99	4.46	1.9912E−1	4.8566E−6	2.7912E−2	2048	10	64	15.2	2.575E−1	1.274E−1	3.087E−2	1.918E−4

mi_me	theta	phi	my	mz	betap	Ms	Ma	Mms	sigma	delgam	u0	ppc0	c_omp	ntimes	dur	Te_Ti	Te_Ti_std	Te	Ti
20	90	90	720	1	0.250	3.00	1.50	1.34	9.8755E+0	5.0590E−4	3.9505E−2	32	10	32	39.2	8.622E−1	9.548E−2	1.286E−2	7.459E−4
20	90	90	720	1	0.250	4.00	2.00	1.79	2.2975E+0	5.0590E−4	8.1851E−2	32	10	32	39.2	4.433E−1	1.687E−1	1.583E−2	1.785E−3
20	90	90	720	1	0.250	5.00	2.50	2.24	1.0872E+0	3.5413E−4	9.9512E−2	32	10	32	29.5	2.832E−1	1.405E−1	1.381E−2	2.438E−3
20	90	90	720	1	0.250	6.84	3.42	3.06	4.6363E−1	2.5295E−4	1.2868E−1	32	10	32	24.5	2.130E−1	8.367E−2	1.735E−2	4.072E−3
20	90	90	720	1	0.250	9.93	4.97	4.44	1.9289E−1	1.5177E−4	1.5439E−1	32	10	32	19.6	1.848E−1	8.656E−2	2.338E−2	6.326E−3
20	90	90	720	1	0.250	15.12	7.56	6.76	7.9463E−2	5.0590E−5	1.3896E−1	32	10	32	14.7	1.702E−1	4.140E−2	1.823E−2	5.355E−3
20	90	90	960	1	0.250	20.27	10.14	9.07	4.3483E−2	2.5295E−5	1.3285E−1	32	10	32	14.7	1.639E−1	4.357E−2	1.687E−2	5.149E−3
49	90	90	1440	1	0.250	3.00	1.50	1.34	1.0020E+1	2.0649E−4	2.5420E−2	32	10	32	39.5	8.533E−1	1.092E−1	1.283E−2	3.069E−4
49	90	90	1440	1	0.250	4.00	2.00	1.79	2.3453E+0	2.0649E−4	5.2528E−2	32	10	32	39.5	4.783E−1	2.113E−1	1.588E−2	6.778E−4
49	90	90	1440	1	0.250	5.00	2.50	2.24	1.1090E+0	1.4454E−4	6.3899E−2	32	10	32	25.0	3.366E−1	1.706E−1	1.537E−2	9.322E−4
49	90	90	1440	1	0.250	6.85	3.42	3.06	4.7256E−1	1.0325E−4	8.2703E−2	32	10	32	25.6	3.262E−1	1.428E−1	2.349E−2	1.469E−3
49	90	90	1440	1	0.250	9.97	4.98	4.46	1.9696E−1	6.1947E−5	9.9192E−2	32	10	32	25.0	2.751E−1	6.969E−2	3.222E−2	2.390E−3
49	90	90	720	1	0.250	15.16	7.58	6.78	8.0625E−2	2.0649E−5	8.9530E−2	128	10	32	15.0	1.809E−1	4.457E−2	1.916E−2	2.162E−3
49	90	90	720	1	0.250	20.33	10.17	9.09	4.4032E−2	1.0325E−5	8.5672E−2	128	10	32	14.9	1.324E−1	3.758E−2	1.422E−2	2.192E−3
49	90	90	360	1	0.250	30.63	15.32	13.70	1.9157E−2	4.1298E−6	8.2153E−2	128	10	32	10.0	1.144E−1	3.668E−2	1.106E−2	1.973E−3
200	90	90	1440	1	0.250	3.00	1.50	1.34	1.0099E+1	5.0590E−5	1.2629E−2	32	10	32	33.1	8.543E−1	1.162E−1	1.280E−2	7.493E−5
200	90	90	1440	1	0.250	4.00	2.00	1.79	2.3715E+0	5.0590E−5	2.6060E−2	32	10	32	39.3	5.401E−1	2.040E−1	1.796E−2	1.663E−4
200	90	90	1440	1	0.250	5.00	2.50	2.24	1.1210E+0	3.5413E−5	3.1711E−2	32	10	32	29.0	4.751E−1	2.003E−1	2.033E−2	2.140E−4
200	90	90	1440	1	0.250	6.86	3.43	3.07	4.7744E−1	2.5295E−5	4.1064E−2	32	10	32	21.5	3.658E−1	1.520E−1	2.668E−2	3.647E−4
200	90	90	1440	1	0.250	9.98	4.99	4.46	1.9918E−1	1.5177E−5	4.9241E−2	32	10	32	20.0	3.732E−1	1.158E−1	3.908E−2	5.235E−4
200	90	90	1440	1	0.250	15.18	7.59	6.79	8.1259E−2	5.0590E−6	4.4512E−2	32	10	32	15.0	2.439E−1	7.439E−2	2.508E−2	5.141E−4
200	90	90	1440	1	0.250	20.36	10.18	9.11	4.4331E−2	2.5295E−6	4.2614E−2	64	10	32	10.2	1.515E−1	6.247E−2	1.553E−2	5.127E−4
49	90	90	192	192	0.250	4.00	2.00	1.79	2.3453E+0	2.0649E−4	5.2528E−2	32	10	32	24.1	4.652E−1	2.230E−1	1.572E−2	6.895E−4
49	90	90	192	192	0.250	5.00	2.50	2.24	1.1090E+0	1.4454E−4	6.3899E−2	32	10	32	35.3	3.369E−1	2.067E−1	1.574E−2	9.537E−4
49	90	90	192	384	0.250	6.85	3.42	3.06	4.7256E−1	1.0325E−4	8.2703E−2	32	10	32	17.4	2.738E−1	1.403E−1	2.124E−2	1.583E−3
49	90	90	192	192	0.250	9.97	4.98	4.46	1.9696E−1	6.1947E−5	9.9192E−2	32	10	32	15.0	2.370E−1	1.609E−1	2.844E−2	2.448E−3
49	90	90	192	192	0.250	15.16	7.58	6.78	8.0625E−2	2.0649E−5	8.9530E−2	32	10	32	8.9	1.497E−1	7.620E−2	1.582E−2	2.155E−3

mi_me	theta	phi	my	mz	betap	Ms	Ma	Mms	sigma	delgam	u0	ppc0	c_omp	ntimes	dur	Te_Ti	Te_Ti_std	Te	Ti
49	90	90	1440	1	0.125	4.00	1.41	1.33	1.1537E+1	2.0649E−4	3.3500E−2	32	10	32	24.8	7.712E−1	1.317E−1	1.276E−2	3.377E−4
49	90	90	1440	1	0.125	5.00	1.77	1.67	3.4565E+0	1.4454E−4	5.1197E−2	32	10	32	24.8	4.144E−1	1.981E−1	1.060E−2	5.219E−4
49	90	90	1440	1	0.125	6.68	2.36	2.23	1.2431E+0	1.0325E−4	7.2128E−2	32	10	32	25.0	2.416E−1	1.353E−1	1.144E−2	9.662E−4
49	90	90	1440	1	0.125	9.78	3.46	3.26	4.4927E−1	6.1947E−5	9.2894E−2	32	10	32	24.8	3.092E−1	1.340E−1	2.685E−2	1.772E−3
49	90	90	1440	1	0.125	14.99	5.30	5.00	1.7122E−1	2.0649E−5	8.6888E−2	32	10	32	20.1	2.652E−1	8.510E−2	2.324E−2	1.788E−3
49	90	90	1440	1	0.125	20.19	7.14	6.73	9.1148E−2	1.0325E−5	8.4213E−2	32	10	32	15.1	2.096E−1	6.007E−2	1.885E−2	1.835E−3
49	90	90	360	1	0.125	30.53	10.79	10.18	3.8916E−2	4.1298E−6	8.1516E−2	128	10	32	10.1	1.466E−1	8.278E−2	1.355E−2	1.887E−3
49	90	90	720	1	0.500	2.00	1.41	1.15	3.5805E+1	2.0649E−4	9.5092E−3	32	10	32	38.8	9.948E−1	6.623E−2	1.139E−2	2.337E−4
49	90	90	1440	1	0.500	3.00	2.12	1.73	2.2310E+0	2.0649E−4	3.8088E−2	32	10	32	38.8	6.171E−1	1.696E−1	1.540E−2	5.094E−4
49	90	90	1440	1	0.500	3.87	2.74	2.24	9.2639E−1	2.0649E−4	5.9093E−2	32	10	32	25.9	3.995E−1	1.414E−1	1.929E−2	9.855E−4
49	90	90	1440	1	0.500	4.90	3.47	2.83	4.8236E−1	1.4454E−4	6.8506E−2	32	10	32	26.0	3.995E−1	1.288E−1	2.299E−2	1.175E−3
49	90	90	1440	1	0.500	6.98	4.93	4.03	2.0639E−1	1.0325E−4	8.8477E−2	32	10	32	25.6	2.804E−1	5.219E−2	2.807E−2	2.043E−3
49	90	90	1440	1	0.500	10.08	7.13	5.82	9.2084E−2	6.1947E−5	1.0257E−1	32	10	32	25.5	2.046E−1	3.552E−2	2.943E−2	2.936E−3
49	90	90	1440	1	0.500	15.26	10.79	8.81	3.9095E−2	2.0649E−5	9.0910E−2	32	10	32	19.9	1.470E−1	1.985E−2	1.777E−2	2.468E−3
49	90	90	1440	1	1.000	2.00	2.00	1.41	4.4802E+0	2.0649E−4	1.9008E−2	32	10	32	25.0	9.191E−1	1.390E−1	1.338E−2	2.970E−4
49	90	90	1440	1	1.000	3.00	3.00	2.12	8.2034E−1	2.0649E−4	4.4412E−2	32	10	32	25.0	5.176E−1	1.546E−1	1.763E−2	6.951E−4
49	90	90	1440	1	1.000	4.00	4.00	2.83	3.6299E−1	2.0649E−4	6.6745E−2	32	10	32	25.0	3.642E−1	1.078E−1	2.374E−2	1.330E−3
49	90	90	1440	1	1.000	4.99	4.99	3.53	2.1083E−1	1.4454E−4	7.3265E−2	32	10	32	24.8	3.424E−1	8.279E−2	2.551E−2	1.520E−3
49	90	90	1440	1	1.000	7.06	7.06	4.99	9.6333E−2	1.0325E−4	9.1569E−2	32	10	32	24.8	2.183E−1	3.835E−2	2.536E−2	2.371E−3
49	90	90	1440	1	1.000	10.15	10.15	7.18	4.4490E−2	6.1947E−5	1.0434E−1	32	10	32	25.0	1.593E−1	2.530E−2	2.493E−2	3.193E−3
49	90	90	1440	1	1.000	15.31	15.31	10.82	1.9246E−2	2.0649E−5	9.1619E−2	32	10	32	24.8	1.319E−1	1.908E−2	1.638E−2	2.535E−3
49	90	90	1440	1	2.000	2.00	2.83	1.63	1.4344E+0	2.0649E−4	2.3754E−2	32	10	32	24.8	8.557E−1	1.855E−1	1.501E−2	3.581E−4
49	90	90	1440	1	2.000	3.00	4.24	2.45	3.5747E−1	2.0649E−4	4.7572E−2	32	10	32	24.8	5.236E−1	9.726E−2	2.035E−2	7.932E−4
49	90	90	1512	1	2.000	4.00	5.66	3.27	1.6927E−1	2.0649E−4	6.9110E−2	32	10	32	27.8	3.385E−1	4.341E−2	2.633E−2	1.587E−3
49	90	90	1512	1	2.000	5.00	7.07	4.08	1.0012E−1	2.0649E−4	8.9824E−2	32	10	32	24.6	2.577E−1	3.863E−2	3.214E−2	2.545E−3
49	90	90	1440	1	2.000	7.11	10.05	5.80	4.6506E−2	1.0325E−4	9.3186E−2	32	10	32	24.9	1.856E−1	2.316E−2	2.416E−2	2.657E−3
49	90	90	2016	1	2.000	10.19	14.41	8.32	2.1861E−2	6.1947E−5	1.0525E−1	32	10	32	18.8	1.334E−1	1.288E−2	2.264E−2	3.464E−3
49	90	90	1440	1	2.000	15.33	21.69	12.52	9.5477E−3	2.0649E−5	9.1978E−2	32	10	32	12.0	1.219E−1	2.357E−2	1.570E−2	2.627E−3
49	90	90	1440	1	4.000	2.00	4.00	1.79	5.9285E−1	2.0649E−4	2.6126E−2	32	10	32	25.1	8.345E−1	1.874E−1	1.618E−2	3.957E−4
49	90	90	1512	1	4.000	3.00	6.00	2.68	1.6743E−1	2.0649E−4	4.9151E−2	32	10	32	23.8	4.905E−1	6.764E−2	2.208E−2	9.188E−4
49	90	90	1512	1	4.000	4.00	8.00	3.58	8.1810E−2	2.0649E−4	7.0292E−2	32	10	32	34.3	3.453E−1	4.170E−2	2.787E−2	1.648E−3
49	90	90	1512	1	4.000	5.00	10.00	4.47	4.9023E−2	2.0649E−4	9.0767E−2	32	10	32	36.6	2.596E−1	2.301E−2	3.319E−2	2.609E−3
49	90	90	1440	1	4.000	7.13	14.27	6.38	2.2843E−2	1.0325E−4	9.4017E−2	32	10	32	25.1	1.695E−1	1.458E−2	2.314E−2	2.787E−3
49	90	90	2160	1	4.000	10.21	20.42	9.13	1.0835E−2	6.1947E−5	1.0571E−1	32	10	32	19.0	1.354E−1	1.222E−2	2.333E−2	3.516E−3