Chapter 29

Thomson Scattering Unit

Figure 29.1: The ThomsonScattering unit with ray tracing directory tree.

The ThomsonScattering unit records a Thomson scattering spectrum of certain sections of the domain at certain simulation times. There are currently two versions of the unit: 1) a more recent version, which takes into account deflection of both laser and detector rays as well as energy deposition by the laser rays and 2) an initial simple version in which no ray tracing is performed (i.e. all laser and detector rays move in straight lines). The first version is computationally more involved, as it is not known beforehand where the Thomson scattering region is located due to ray deflection. To preserve flexibility and for comparison tests, the first version allows for suppression of ray deflection and energy deposition as well as ray power depletion while crossing the domain. This way one can study different ray effects on the Thomson spectra.

Currently, for the first version, ray deflection is done using the cell average algorithm AVG 17.4.4.1 described in the EnergyDeposition unit. Placement of several detectors are possible, with more than one detector receiving rays from the same laser. However, no detector can record spectra coming from different lasers. The possibility of placing several detectors associated with the same laser allows a detailed study of how the Thomson spectra change with orientation of the detector.

29.1 Thomson Scattering including Ray Tracing and Deflection

The Thomson scattering unit including ray tracing and deflection is a detector driven unit, meaning that the outer loop is over all Thomson detectors specified. Since for each detector there is only one associated laser, the code checks whether the associated laser is currently active and if it is, this laser/detector pair is
being processed. The inclusion of ray deflection in a Thomson scattering code presents some computational challenges. The main difficulty that arises is that the Thomson scattering interaction region (IR) from where the spectra will be accumulated, is not known beforehand, but must be established in a first pass through the ray tracing procedure. For each laser/detector pair, the ray tracing Thomson scattering code consists of two main sections during each time step of the simulation: 1) determination of the interaction region and 2) assembling the Thomson spectra. Both sections require a complete laser/detector ray tracing procedure over the entire set of both laser and detector rays. In what follows we will describe each section separately.

### 29.1.1 Identifying the Interaction Region

Per definition, the interaction region (IR) consists of those cells of the domain that will have both: 1) incoming laser (I, from incident) rays and 2) emerging detector (S, from scattered) rays. Each of these so called IR cells contribute to the final spectrum. In order to find all the IR cells for a specific laser/detector pair, the complete set of rays for both the laser and the detector are launched towards the domain and the cells on which both sets intersect will be identified as IR cells. Both laser and detector rays are launched statistically from their corresponding lenses and towards their target areas. Ray creation, specification and storage follow much the same way as presented for the EnergyDeposition unit in chapter 17.4.7. Setup of laser/detector beams and pulses are also done as presented in chapters 17.4.6 and 17.4.5. If no Ray deflection is specified and both laser and detector beams are cylindrical in shape, the resulting set of IR cells are contained in a region resembling a Steiner solid, i.e. the space obtained from two intersecting cylinders. Ray deflection usually broadens up the IR region and there can be even cases in which the set of IR cells within the IR region is not connected, for example if the number of rays used for the laser and the detector is very low. The user must therefore make sure that the resulting IR region is dense by launching enough rays from the laser and the detector. On the other hand, as we will see below, assembling the Thomson spectrum from the set of each IR cell’s laser (I) and detector (S) rays is a multiplicative task in which each I-ray is allowed to scatter into all S-rays. There is hence a delicate balance as to how many rays are launched and the size of the intended IR region for computations to remain manageable.

The identification of each IR cell is done by introducing extra two counting cell variables ICNT (for laser) and SCNT (for detector) into the UNK array (see chapter 6.1). ICNT and SCNT are incremented by +1 whenever a laser or detector ray hits the cell. After the complete sets of laser and detector rays have been processed through the domain, the IR cells are those for which both ICNT and SCNT are > 0. Once an IR cell has been identified, its ICNT value is overwritten by its unique tag, which will serve both as a counting index as well as identifying this cell as an IR cell (for example, for visualization purposes) in the domain.

During identification of the IR cells, the laser rays will not be allowed to deposit energy in the domain, as this will change subsequent ray tracing for the same laser/detector pair as well as other still to be processed laser/detector pairs. Also power loss by both laser and detector rays is not done at this stage.

### 29.1.2 Assembling the Thomson Scattering Spectra

Using maximum sized array dimension information from the interaction region finding step, storage arrays are allocated that will hold detailed info about each I-ray and S-ray for each IR cell. The complete set of laser and detector rays for the current IR cell’s laser (I) and detector (S) ray is a multiplicative task in which each I-ray is allowed to scatter into all S-rays. There is hence a delicate balance as to how many rays are launched

On each node the local Thomson spectra are assembled by looping over all local IR cells. Each IR cell contains per definition a set $nI$ of incoming laser rays and a set $nS$ of scattered detector rays. Each laser/detector ray pair (total of $nI \times nS$) info is now used to determine its contribution to the local spectrum. Each such pair defines a local IR cell scattering angle as well as a scattering direction. Together with the info of the local IR cell, a spectrum contribution to all recording frequencies is calculated using the time-averaged
scattered power equation for a collection of charges in the low-velocity charge \((v/c \ll 1)\) limit:

\[
\frac{dP_s}{d\omega_s} = P_t v_e^2 L n_e d\Omega |\hat{s} \times (\hat{s} \times \hat{E}_i)|^2 S(k, \omega),
\]

(29.1)

where \(P_s\) is the time-averaged scattered power, \(\omega_s\) the scattered frequency, \(\omega = \omega_s - \omega_i\) the frequency shift between the laser and scattered frequency, \(P_t\) the incident laser power, \(v_e\) the classical electron radius, \(L\) the distance travelled by the ray inside the IR cell, \(n_e\) the electron number density in the IR cell, \(d\Omega\) the detector lens area in steradians, \(\hat{s}\) the scattering direction unit vector, \(\hat{E}_i\) the unit vector along the incident laser electric field, \(k = k_s - k_i\) the shift in wavenumber between the laser and scattering wave vectors and \(S(k, \omega)\) the spectral density function. For an unpolarized laser, the unitless scattering direction factor \(|\hat{s} \times (\hat{s} \times \hat{E}_i)|^2\) is averaged over all possible \(\hat{E}_i\) orientations:

\[
|\hat{s} \times (\hat{s} \times \hat{E}_i)|^2 = 1 - \frac{1}{2} \sin^2 \theta,
\]

(29.2)

where \(\theta\) is the angle between the laser direction and the scattering direction (zero in case of same direction). If a polarized laser is used, an additional angle \(\phi\) between the polarization plane and the scattering plane is needed, giving:

\[
|\hat{s} \times (\hat{s} \times \hat{E}_i)|^2 = 1 - \sin^2 \theta \cdot \cos^2 \phi.
\]

(29.3)

The spectral density function describes how the spectrum varies in terms of velocity distributions and correlations of the ions with the scattering electrons and thus contains all the plasma information of the IR cell. Currently only the spectral density function for an unmagnetized, collisionless, low-temperature plasma containing possibly several ions is implemented:

\[
S(k, \omega) = \frac{1}{k} \left| \frac{1 + \sum_i \chi_i}{1 + \chi_e + \sum_i \chi_i} \right|^2 f_e(\omega/k) + \frac{1}{k} \left| \frac{\chi_e}{1 + \chi_e + \sum_i \chi_i} \right|^2 \frac{\sum_i n_{ei} Z_i f_i(\omega/k)}{n_e},
\]

(29.4)

where \(\chi_e\) and \(\chi_i\) are the electron and individual ion susceptibilities and \(n_{ei}\) and \(n_e\) the number of electrons from the i-th ion and the total number of electrons, respectively. \(f_e(\omega/k)\) and \(f_i(\omega/k)\) are the electron and i-th ion one-dimensional Maxwellian velocity distributions for the phase velocity \(\omega/k\):

\[
f_q(\omega/k) = \sqrt{\frac{m_q}{2\pi k_B T_q}} \exp(-\frac{m_q(\omega/k)^2}{2 k_B T_q}),
\]

(29.5)

with \(k_B\) the Boltzmann constant and \(m_q\) and \(T_q\) the electron \((q = e)\) and ion \((q = i)\) mass and temperature. Note the two kind of electron-ion correlation parts in the above \(S(k, \omega)\) expression: 1) the first term represents the ion influence on the electron velocity distribution and 2) the second term is the electron influence on the ions velocity distribution. Derivation of the \(S(k, \omega)\) expression is involved and the reader is referred to the literature (Froula et al. 2011, chapters 3 and 5). Since the units of the lhs of Eq.\((29.1)\) are power per radial frequency (i.e. power per rad/s), we see that the units for \(S(k, \omega)\) must be s/rad, which is also seen from Eq.\((29.4)\), where the units of \(k\) are rad/cm and the units for the velocity distribution functions is s/cm and the other quantities are dimensionless. The electron and ion susceptibilities are calculated using derivatives


of the plasma dispersion function $W$:

\[
\chi_q(k, \omega) = -\frac{1}{2} \alpha_q^2 \frac{\partial W(\xi_q)}{\partial \xi_q} \tag{29.6}
\]

\[
\alpha_q = \frac{\omega p_q}{v_{Tq} k} \tag{29.7}
\]

\[
\omega p_q = \sqrt{\frac{4\pi Q_q^2 n_q}{m_q}} \tag{29.8}
\]

\[
v_{Tq} = \sqrt{\frac{k_B T_q}{m_q}} \tag{29.9}
\]

\[
\xi_q = \frac{\omega}{k} \tag{29.10}
\]

\[
W(\xi_q) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{+\infty} e^{-z^2} \frac{dz}{z-\xi_q} = -2 \int_0^{\xi_q} e^{x^2-\xi_q^2} dx + i \sqrt{\pi} e^{-\xi_q^2} \tag{29.11}
\]

\[
\frac{\partial W(\xi_q)}{\partial \xi_q} = -2 \left( [1 + \xi_q W(\xi_q)] \right), \tag{29.12}
\]

where again $q = e, i$ represent the electrons or ions, $\omega p_q$ is the charge plasma frequency with $Q_q$ the charge of the particle and $n_q$ the particle density number, $v_{Tq}$ is the RMS thermal velocity of the charge and $\xi_q$ is the mean thermal velocity (equal to $\sqrt{2}$ times the RMS velocity) normalized phase velocity of the charge.

Note that $\alpha_q$ is dimensionless. The real integral in the last expression for $W(\xi_q)$ in Eq.(29.11) is equal to the Dawson integral $F(\xi_q)$. Details about how to evaluate $\frac{\partial W(\xi_q)}{\partial \xi_q}$ efficiently can again be inferred from Froula et al. 2011.

For higher temperature plasmas, relativistic effects start to get important, but their inclusion into the scattering equation becomes much more involved. In specific cases it is possible to include relativistic effects up to first order in $v/c$. For example, if the incident Thomson laser is polarized such that its electrical field $\mathbf{E}_i$ is perpendicular to the scattering plane and if a polarizer is placed before the detector that only detects scattered fields with electrical field parallel to $\mathbf{E}_i$, then it can be shown that Eq.(29.1) needs only be augmented multiplicatively by the relativistic term:

\[
\text{rel.Term} = \left[ 1 + \frac{2\omega}{\omega_i} \right]. \tag{29.13}
\]

This option has been added to the Thomson scattering code, with a default of setting this term equal to 1 when no relativistic treatment is wanted. The user must however remember that this relativistic correction applies only under very specific Thomson scattering setups.

After all local spectra contributions have been evaluated, the global contribution to the spectrum for the current laser/detector pair is calculated and added to the overall Thomson spectrum for the detector. Writeout to the Thomson detector file is done after the laser for each detector is no longer active.

29.1.3 Usage

To include the use of the ThomsonScattering unit with ray tracing, the following should be included into the setup line command:

\[+\text{ThomsonScatteringWrt thsc\_maxPulses=<number> thsc\_maxPulseSections=<number> thsc\_maxLaserBeams=<number> thsc\_maxDetectors=<number>}\]

The +ThomsonScatteringWrt is a shortcut that handles all the logistics for properly including the Thomson scattering unit in its ray tracing version. The next four setup variables override default values and it is always recommended to give appropriate values corresponding to the intended application.

- thsc_maxPulses: The maximum number of different laser pulses for the simulation.
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- **thsc_maxPulseSections**: The maximum number of power/time pairs per pulse.
- **thsc_maxLaserBeams**: The maximum number of Thomson laser beams for the simulation.
- **thsc_maxDetectors**: The maximum number of Thomson detectors for the simulation.

The *ThomsonScattering* unit reads all the information it needs to construct the Thomson scattering environment from runtime parameters specified in the flash.par file. Below is the list of runtime parameters that is needed to properly set up the Thomson scattering unit. As the Thomson pulse, laser and detector setup resembles the *EnergyDeposition* unit pulse and laser setup, it is encouraged to consult Figures 17.5, 17.6 and 17.7. Both the Thomson laser and the Thomson detector rays are created statistically on their respective lens and target areas. Regular grids, as for the lasers of the *EnergyDeposition* unit, are not supported.

#### 29.1.3.1 Thomson Laser Pulses Runtime Parameters

- **thsc_numberOfPulses**: Controls the number of different Thomson laser pulses that are going to be used.
- **thsc_numberOfSections_n**: Gives the number of power/time pairs that are going to be used to set up the shape of the n-th Thomson laser pulse. There must be at least as many of these runtime parameters as there are number of Thomson laser pulses defined, i.e. \( n = 1, \ldots, \text{thsc_numberOfPulses} \).
- **thsc_power_n_i**: Sets the i-th power of the i-th power/time pair of the n-th Thomson laser pulse. The ranges of the indices must be at least: \( i = 1, \ldots, \text{thsc_numberOfSections_n} \) and \( n = 1, \ldots, \text{thsc_numberOfPulses} \).
- **thsc_time_n_i**: Sets the i-th time of the i-th power/time pair of the n-th Thomson laser pulse. The ranges of the indices must be at least: \( i = 1, \ldots, \text{thsc_numberOfSections_n} \) and \( n = 1, \ldots, \text{thsc_numberOfPulses} \).

#### 29.1.3.2 Thomson Laser Beams Runtime Parameters

- **thsc_numberOfLaserBeams**: The number of Thomson laser beams that are going to be used.
- **thsc_laserCrossSecFuncType_n**: Thomson laser beam cross section power function (flat or gaussian decay) type. For a flat profile use 'uniform', for gaussian decay use 'gaussian2D' (n-th Thomson laser beam).
- **thsc_laserGaussCenterMajor_n**: The Gaussian center location along the major elliptical semiaxis (n-th Thomson laser beam).
- **thsc_laserGaussCenterMinor_n**: The Gaussian center location along the minor elliptical semiaxis (n-th Thomson laser beam).
- **thsc_laserGaussExponent_n**: The Gaussian super exponent \( \gamma \) for the Thomson laser beam cross section power function as presented in equation 17.106 (n-th Thomson laser beam).
- **thsc_laserGaussRadiusMajor_n**: The Gaussian radius (e-folding length) \( R_x \) along the major elliptical semiaxis as shown in equation 17.106 (n-th Thomson laser beam).
- **thsc_laserGaussRadiusMinor_n**: The Gaussian radius (e-folding length) \( R_y \) along the minor elliptical semiaxis as shown in equation 17.106 (n-th Thomson laser beam).
- **thsc_laserInitialRaySpeed_n**: The initial speed of the Thomson laser rays when hitting the domain boundary, in units of the speed of light (n-th Thomson laser beam).
- **thsc_laserLensSAMajor_n**: The major (largest) semiaxis length \( \ell_1 \) for the laser elliptical lens area (n-th Thomson laser beam).
- \texttt{thsc\_laserLensX\_n}: The x-component of the laser global lens center position vector \textbf{L} (n-th Thomson laser beam).
- \texttt{thsc\_laserLensY\_n}: The y-component of the laser global lens center position vector \textbf{L} (n-th Thomson laser beam).
- \texttt{thsc\_laserLensZ\_n}: The z-component of the laser global lens center position vector \textbf{L} (n-th Thomson laser beam).
- \texttt{thsc\_laserNoEnergyDeposition\_n}: If set true, no energy deposition is done for the Thomson laser rays (n-th Thomson laser beam).
- \texttt{thsc\_laserNumberOfRays\_n}: Number of statistical Thomson laser rays to be created for the Thomson laser beam (n-th Thomson laser beam).
- \texttt{thsc\_laserPolarizationAngle\_n}: Polarization angle \(\phi\) (in degrees) of the incident Thomson laser electrical field with respect to the scattering plane (cf. Eq.(29.3)). If a negative value is given, the Thomson laser beam is considered to be unpolarized (n-th Thomson laser beam).
- \texttt{thsc\_laserPulseNumber\_n}: The pulse shape identification number for the laser (n-th Thomson laser beam).
- \texttt{thsc\_laserSAMajorTorsionAngle\_n}: The major elliptical semiaxis torsion angle \(\phi_1\) along the Thomson beam’s lens target center line (n-th Thomson laser beam).
- \texttt{thsc\_laserSAMajorTorsionAxis\_n}: The major elliptical semiaxis torsion axis (‘x’, ‘y’, or ‘z’) from which the torsion angle \(\phi_1\) is defined (n-th Thomson laser beam).
- \texttt{thsc\_laserTargetSAMajor\_n}: The major (largest) semiaxis length \(\ell_1\) for the laser elliptical target area (n-th Thomson laser beam).
- \texttt{thsc\_laserTargetSAMinor\_n}: The minor (smallest) semiaxis length \(\ell_2\) for the laser elliptical target area (n-th Thomson laser beam).
- \texttt{thsc\_laserTargetX\_n}: The x-component of the laser global target center position vector \textbf{T} (n-th Thomson laser beam).
- \texttt{thsc\_laserTargetY\_n}: The y-component of the laser global target center position vector \textbf{T} (n-th Thomson laser beam).
- \texttt{thsc\_laserTargetZ\_n}: The z-component of the laser global target center position vector \textbf{T} (n-th Thomson laser beam).
- \texttt{thsc\_laserWavelength\_n}: The wavelength (in nm) of the Thomson laser (n-th Thomson laser beam).

29.1.3.3 Thomson Detectors Runtime Parameters
- \texttt{thsc\_numberOfDetectors}: The number of Thomson detectors that are going to be used.
- \texttt{thsc\_detectorLaserBeamNumber\_n}: The laser beam identification number associated with the detector (n-th Thomson detector).
- \texttt{thsc\_detectorLensSAMajor\_n}: The major (largest) semiaxis length \(\ell_1\) for the detector elliptical lens area (n-th Thomson detector).
- \texttt{thsc\_detectorLensX\_n}: The x-component of the detector global lens center position vector \textbf{L} (n-th Thomson detector).
- \texttt{thsc\_detectorLensY\_n}: The y-component of the detector global lens center position vector \textbf{L} (n-th Thomson detector).
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- **thsc_detectorLensZ_n**: The z-component of the detector global lens center position vector \( \mathbf{L} \) (n-th Thomson detector).
- **thsc_detectorNoRayDeflection_n**: If set true, the complete set of laser and detector rays will not be deflected, i.e. all rays will be straight lines. As the ThomsonScattering unit is detector driven, the detectors decide over the entire ray paths and transmit this info to the associated laser (n-th Thomson detector).
- **thsc_detectorNoRayPowerLoss_n**: If set true, the complete set of laser and detector rays will not experience power loss as they traverse the domain. Useful for comparisons and to see the effect of the domain on the Thomson spectra (n-th Thomson detector).
- **thsc_detectorNumberOfRays_n**: Number of statistical Thomson detector rays to be created for the Thomson detector (n-th Thomson detector).
- **thsc_detectorNumberOfSpecPoints_n**: Number of spectral points to be recorded on the Thomson detector (n-th Thomson detector).
- **thsc_detectorSAMajorTorsionAngle_n**: The major elliptical semiaxis torsion angle \( \phi_1 \) along the Thomson detector’s lens target center line (n-th Thomson detector).
- **thsc_detectorSAMajorTorsionAxis_n**: The major elliptical semiaxis torsion axis (‘x’, ‘y’ or ‘z’) from which the torsion angle \( \phi_1 \) is defined (n-th Thomson detector).
- **thsc_detectorScreenSpectralFlux_n**: If set true, the output (y-axis) on the detector will be \( \frac{dP_s}{d\omega_s} \) as in Eq.\ ((29.1)). If false, the output is in power \( \Delta P_s \), which is \( \frac{dP_s}{d\omega_s} \) multiplied by the corresponding bin size \( \Delta \omega_s \). One has to be aware that \( \Delta P_s \) can sometimes be grossly overestimated, particularly for very narrow Thomson spectra with small widths. This happens if the recording wavelength window is to broadly set (n-th Thomson detector).
- **thsc_detectorScreenWavelengths_n**: If set true, the horizontal output (x-axis, range of wavelengths or frequencies) on the detector will be given in wavelengths. If false, the horizontal output is in frequencies. The wavelength output will have equally spaced tics, while the frequency output will not (n-th Thomson detector).
- **thsc_detectorSkipTimeResolve_n**: If set true, the additional time-resolved Thomson spectra files will not be produced. Only the total Thomson spectra (i.e. without simulation time label) will be on disk after the simulation. The option of only time-resolved Thomson spectra is not available, meaning that the total Thomson spectra will always be produced (n-th Thomson detector)
- **thsc_detectorTargetSAMajor_n**: The major (largest) semiaxis length \( \ell_1 \) for the detector elliptical target area (n-th Thomson detector).
- **thsc_detectorTargetSAMinor_n**: The minor (smallest) semiaxis length \( \ell_2 \) for the detector elliptical target area (n-th Thomson detector).
- **thsc_detectorTargetX_n**: The x-component of the detector global target center position vector \( \mathbf{T} \) (n-th Thomson detector).
- **thsc_detectorTargetY_n**: The y-component of the detector global target center position vector \( \mathbf{T} \) (n-th Thomson detector).
- **thsc_detectorTargetZ_n**: The z-component of the detector global target center position vector \( \mathbf{T} \) (n-th Thomson detector).
- **thsc_detectorUseRelativityTerm_n**: If set true, an additional relativistic term as stated in Eq.\ ((29.13)) will be multiplicatively added to the scattered power equation \((29.1)\). One must be aware, however, that this relativistic term was derived for very special scattering setups: incident laser electric field \( \mathbf{E}_i \) is polarized and perpendicular to the scattering plane and a polarizer is used at the detector to
select the scattered radiation electric field $E_s$ to be parallel to $E_i$. Unless the experimental setup to be simulated does correspond exactly to this situation, it is best to avoid this term (n-th Thomson detector).

- **thsc_detectorWavelengthMax.n**: The maximum recording wavelength (in nm) of the Thomson detector (n-th Thomson detector).
- **thsc_detectorWavelengthMin.n**: The minimum recording wavelength (in nm) of the Thomson detector (n-th Thomson detector).

### 29.1.3.4 Thomson Scattering General Runtime Parameters

- **thsc.cellTimeEnergyDeposition**: If set true, the energy deposition by the Thomson laser rays is calculated based only on the time spent in each cell by calculating cell center values of $\ln \Lambda$ and $\nu_{ib}$ using Eq.(17.46) and replacing the time integration term in Eq.(17.47) by $\nu_{ib}t$, i.e. treating $\nu_{ib}$ as constant in the cell. If false, the more expensive time integration formalism from Eq.(17.59) is used.

- **thsc.cellWallThicknessFactor**: Controls the (imaginary) thickness of the cell walls to ensure computational stability of the Thomson scattering ray tracing algorithm. The cell thickness is defined as this factor times the smallest cell dimension along all geometrical axes. The factor is currently set to a default of $10^{-6}$ and should only very rarely be changed.

- **thsc_detectorWriteFormatX**: Format string for writing out the x-axis data (wavelengths or frequencies) on the detector screens (default ‘es20.10’).

- **thsc_detectorWriteFormatY**: Format string for writing out the y-axis data ($dP_s/d\omega_s$ or $\Delta P_s$) on the detector screens (default ‘es20.10’).

- **thsc.enforcePositiveNele**: (AVG algorithm 17.4.4.1) If true, the x-, y- and z-components of the gradients $\langle \nabla n_e \rangle$ will be rescaled such that they always deliver a positive (greater or equal zero) value for the number of electrons in a cell.

- **thsc.enforcePositiveTele**: (AVG algorithm 17.4.4.1) If true, the x-, y- and z-components of the gradients $\langle \nabla T_e \rangle$ will be rescaled such that they always deliver a positive (greater or equal zero) value for the electron temperature in a cell.

- **thsc.maxRayCount**: The maximum number of laser/detector rays that can be created on one processor. For the Thomson scattering this number must be at least as large as the maximum over all individual laser and detector sets of rays, i.e. always the entire set of either the laser or the detector rays for each possible laser/detector pair must fit into memory.

- **thsc.printEnergyInfo**: If true, it prints info about the Thomson laser energy entering and leaving the domain (cumulative and at each time step) to a file with name `<basename>ThscEnergyProfile.dat`, where `<basename>` is the base name of the simulation.

- **thsc.printLaserBeams**: If true, it prints detailed information about the Thomson laser beams to a file with name `<basename>ThscLaserBeamsPrint.txt`, where `<basename>` is the base name of the simulation.

- **thsc.printDetectors**: If true, it prints detailed information about the Thomson detectors to a file with name `<basename>ThscDetectorsPrint.txt`, where `<basename>` is the base name of the simulation.

- **thsc.printMain**: If true, it prints general information regarding the Thomson scattering setup to a file with name `<basename>ThscMainPrint.txt`, where `<basename>` is the base name of the simulation.

- **thsc.printPulses**: If true, it prints detailed information about the Thomson laser pulses to a file with name `<basename>ThscLaserPulsesPrint.txt`, where `<basename>` is the base name of the simulation.
• **thsc_printRays:** If true, it prints detailed information about all rays initially generated on each processor to a file(s) with name(s) `<basename><fileLabel><PID>.txt`, where `<basename>` is the base name of the simulation, `<fileLabel>` is a file label name given by the user and PID is the processor rank number. This runtime parameter should only be used for debugging purposes (default = false) by developers of the code.

• **thsc_printSpecies:** If true, it prints detailed information about the species present in the simulation to a file with name `<basename>ThscSpecies.txt`, where `<basename>` is the base name of the simulation.

• **thsc_rayDeterminism:** If true, the Grid Unit will be forced to use the Sieve Algorithm to move the ray particle data. Forcing this algorithm will result in a slower movement of data, but will fix the order the processors pass data and eliminate round off differences in consecutive runs.

• **thsc_rayZeroPower:** Below this value (erg/s), the Thomson laser ray is considered to have zero power.

• **useThomsonScattering:** If false, the Thomson scattering is not activated, even if the code was compiled to do so. Bypasses the need to rebuild the code.

• **threadThscRayTrace:** If true, in the innermost ray loop, tracing of all rays through a block is threaded. This runtime parameter can only be set during setup of the code.