WIND/STICS Level 2 Data Release Notes, revision D
Data Version 3.0

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1 Overview

The Suprathermal Ion Composition Spectrometer (STICS) is a charge-resolving, time of flight – energy (TOF-E) ion mass spectrometer, capable of identifying mass and mass per charge for incident ions from 6-230 keV/e (Gloeckler et al., 1995). It uses an electrostatic analyzer to admit ions of a particular energy per charge (E/Q) into the TOF chamber. The E/Q voltage is stepped through 32 values, sitting at each value for approximately 6 sec., to measure ions over the full E/Q range of 6 - 230 keV/e. It completes one total E/Q scan every ~3 min (184 sec, 60 spacecraft spins). Ions then pass through a carbon foil and TOF chamber, before finally impacting on a solid-state detector (SSD) for total energy measurement. STICS combines these three measurements of E/Q, TOF and total energy, producing ion event words for each ion measured in "triple coincidence". (Ion event words are often referred to as pulse height analysis (PHA) words for historical reasons.) Triple coincidence measurements enable calculation of an individual ion's velocity, mass (M), and charge(Q), as described in Gloeckler et al (1992). These ion events are analyzed on the ground to assign them to individual ion species. This triple-coincidence technique greatly improves the signal to noise ratio in the data, significantly reducing background noise. If an ion's incident energy falls below the SSD low energy threshold (~35 keV), an ion's total energy cannot be recovered and therefore the ion's mass and charge state cannot be separately determined. These measurements of E/Q and TOF can still be used to determine ion mass per charge (m/q). These so-called "double-coincidence" measurements are characterized by improved counting statistics since they include both the triple coincidence ions, as well as additional double coincidence ions. Ion identification in double-coincidence measurements are completed in E/Q--TOF space where ions can be separated by M/Q and is limited to select ions that are well separated in E/Q – TOF (and M/Q) space.

The STICS instrument provides full 3D velocity distribution functions during each E/Q scan, by combining multiple telescopes and accumulating over multiple spacecraft spins. The instrument includes three separate TOF telescopes that view distinct elevation sectors in and out of the ecliptic plane. These telescopes have a native field of view (FOV) of 53 degrees, with shared boundaries, providing a 159° total FOV, as shown in Figure 1. As the Wind spacecraft spins, the 3 telescopes to trace out an approximately 3π steradian viewing area. The azimuthal (in ecliptic) scans (resulting from spacecraft spin) are divided into 16 sectors that are each 22.5 degrees wide (Figure 2). The solar direction is within sectors 8-10 while the earthward direction is in sectors 0-2.

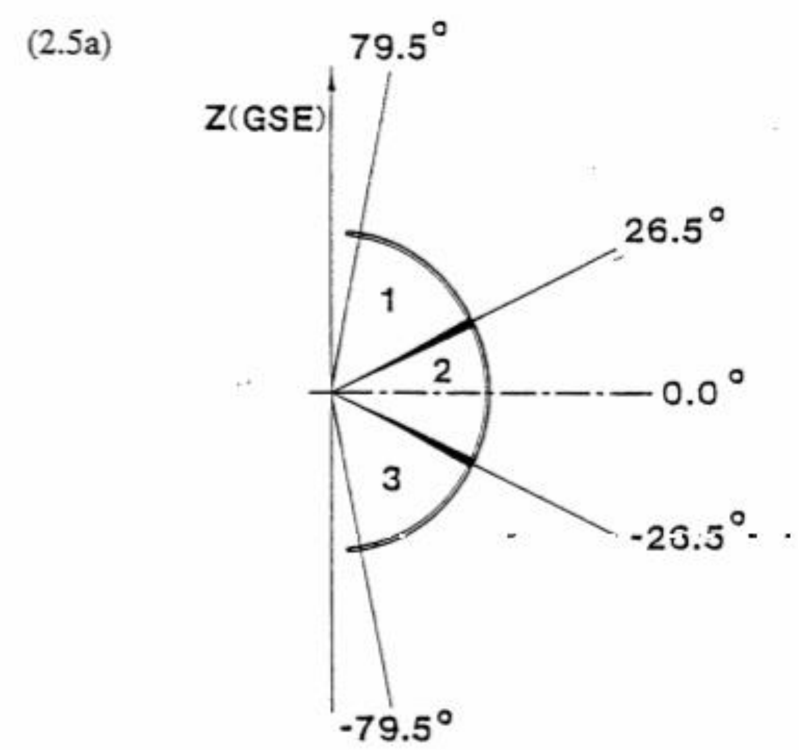


Figure 1. STICS is composed of 3 separate telescopes that view 3 different elevation ranges in and out of the ecliptic plane (Adapted from Chotoo et al. 1998).

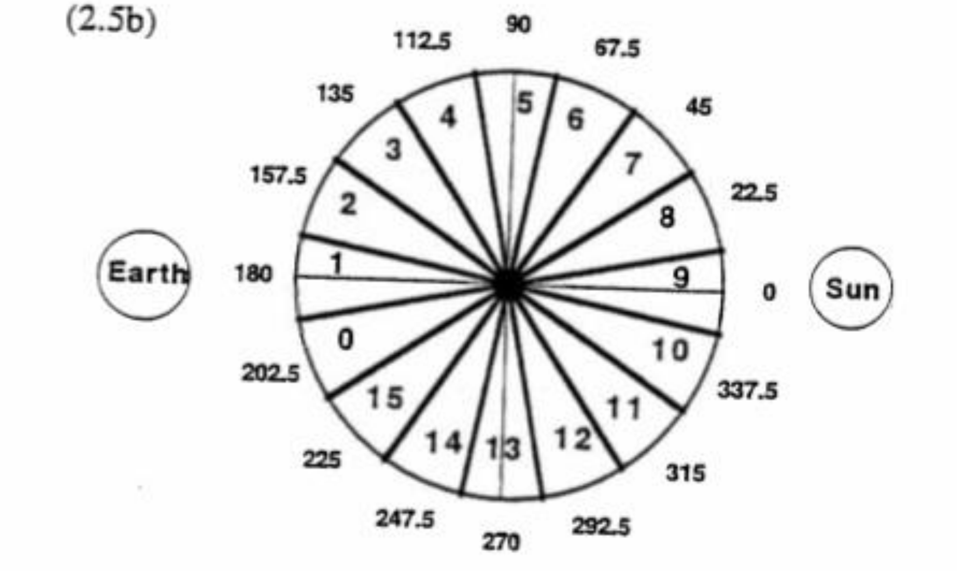


Figure 2. STICS spins through 360 degrees during one measurement cycle sweeping out 16 sectors in space in the ecliptic plane. Sectors 8-10 include the solar direction (Adapted from Chotoo et al. 1998).

2 Instrumental effects

STICS does not apply a post-acceleration voltage to boost ion energy (unlike Wind/SWICS see Gloeckler et al. 1992), so lower energy ions, regardless of charge, do not have enough kinetic energy at the lower E/Q steps to trigger the SSD (make sure it's defined above) and generate a full, triple-coincidence measurement. This results in a sharp cutoff in measured triple coincidence ions at E/Q values < 35 keV/e in the phase space density curve. The cutoff, being dependent on ion energy and number of nucleons, varies for each ion depending on the ions mass and velocity (total energy). The effect is less for highly-charged heavy ions — with more mass and therefore more energy, for a given E/Q and thus can be measured down to somewhat lower velocities (Gloeckler et al. 1995). This enables the VDF of heavy ions to extend down to lower ranges than their lighter counterparts. Ions that do not have sufficient energy to produce a triple-coincidence measurement often produce a double-coincidence measurement, allowing extension of STICS distributions to lower energy, at the expense of increased noise and difficulty of assignment to particular ions. Ions with the same mass per charge cannot be cleanly separated from each other in double-coincidence. The type of measurement, triple coincidence (TC) or double coincidence (DC) is indicated in the file name, described below.

As STICS is designed to measure ions in the suprathermal energy range, significantly above the normal solar wind energy range for low mass ions. The flux of particles in this range will vary considerably with solar wind density, velocity and thermal velocity, as well as due to many other solar phenomena (e.g. CMEs). Lower statistics of suprathermal populations frequently result in periods of time that have insufficient statistics for the calculation of distribution functions or parts of the distribution function. As a result, the distribution functions may not be continuous in velocity space and there may be gaps in time periods where there are insufficient counts from which to assemble quality distribution functions. It should be noted that the DC data has considerably higher statistics, at the expense of lower accuracy in species identification. The latter point means that in the DC data more noise counts may be attributed to ions and that more real ion events may be attributed to the wrong ions. The TC data has the opposite properties: species identification is more accurate, but statistics are lower. This is particularly true for observations made in the solar wind, where the flux of suprathermal particles is low enough under nominal solar wind conditions (e.g. ~440 km/s speeds) that there can very few TC counts for days on end, even some scans with zero counts. For observations made in the Earth's magnetosphere, especially the central plasma sheet, statistics, especially for protons and alphas, are usually quite good for both TC and DC data.

3 Method for assigning counts to ions

Since STICS does not measure mass and mass per charge directly, some interpretation of the measurements is required to assign individual event counts to particular ions. Full ion event words are accumulated for each E/q scan then assigned to individual ions via an inversion method, which preserves the statistical properties of the measurements (Gruesbeck, 2013). After assignment, these counts vs. E/Q arrays are transformed to distribution functions in units of phase space density (s^3/km^6) as a function of velocity.

This inversion/identification method is applied separately to the TC and DC data, since they have different parameters. Figure 3 (top) shows STICS TC measurements for a

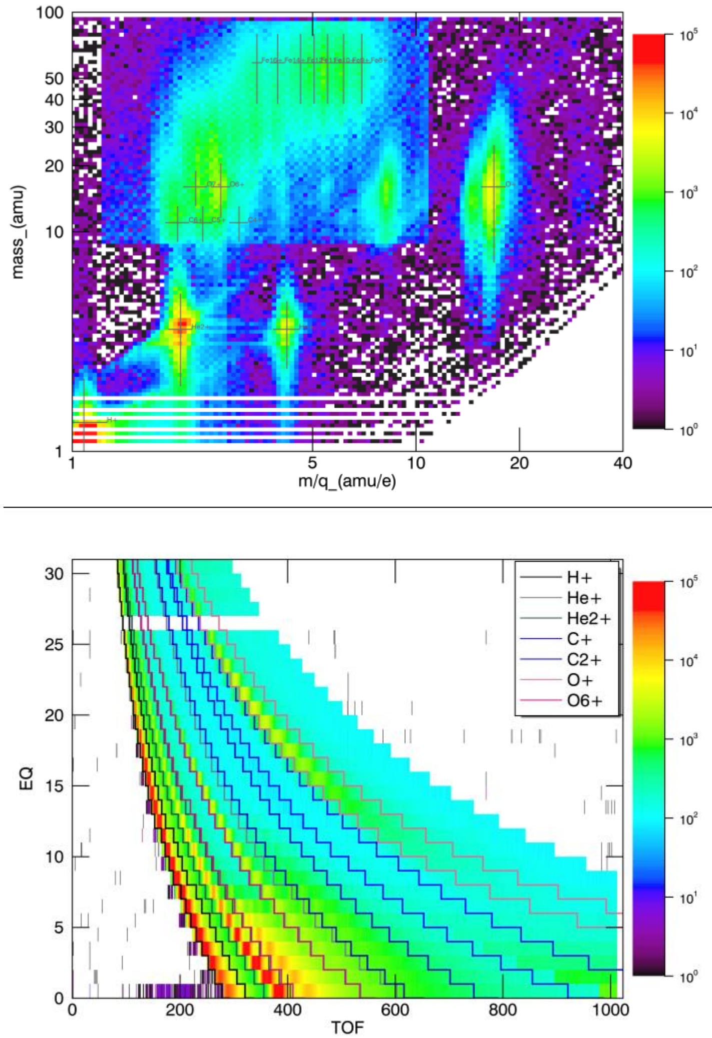


Figure 3. (top) STICS triple coincidence (TC) measurements for a single E/q step. Forward model positions for identified ions are indicated at black crosses. (bottom) STICS DC measurements with forward model tracks for indentified ions as colored curves.

single E/q step, with forward model positions for identified ions marked. This histogram of counts in energy – TOF space is known as an E-T slice. The TC inversion is applied independently for each E-T slice. Figure 3 (bottom) shows STICS DC measurements in E/q-TOF space. Different ion species group along curvesthat are then delineated into different species regions marked by the stair stepped lines, often called "tracks". The boundaries for each ion species are shown in the legend in Figure 3.

Though this analysis procedure is applicable to a wide range of ions, each requires independent validation to ensure usability for science. Users interested in ions shown in Figure 3 but not yet included in the public data release should contact the instrument team. More details can be found in Gruesbeck (2013).

4 Data Description

This dataset contains several different products for a range of ions. Work is ongoing to define, validate and release additional ion species. The current version includes the following ions:

TC: H+, He+, He2+, C5+, O+, O6+, and Fe10+.
DC: H+, He+, He2+, O+, O6+

The data is separated based on whether the measurements were accumulated in the magnetosphere (until 2004) or in the solar wind (full mission) using the Wind bow shock crossing list, https://wind.nasa.gov/mfi/bow_shock.html.

All data in this release is in the native STICS 3-minute time resolution. Users can build larger accumulations by simply accumulating over multiple time steps.

Values that cannot be properly calculated are filled with a value of -1.0 or left as 'nan' (not a number).

4.1 Velocity Distribution Functions (VDFs)

Velocity distribution functions (VDFs) provide the most information about a particular measured ion, separated by E/q, elevation angle and azimuthal angle bins at native resolution. Velocity space represents three of the six dimensions in phase space, the three velocity dimensions, as they are observed at one point in space. The three position coordinates can be retrieved from the Wind spacecraft orbit and attitude data from Space Physics Data Facility (SPDF).

The VDF files contain 3D velocity distribution functions in three units: phase space density, differential number flux and counts. There are 512 values for A(v) for each time step, corresponding to each directional sector (values 0-15 as shown above for a total of 16 look directions) and each Deflection Voltage Step (DVS) corresponding to a fixed E/q value (32 total voltage steps per sector). Subsequent time steps follow the same pattern.

Error values are based on counting/statistical error, $\sqrt{N}/N$, where N is the number of counts in a given step, propagated through the moment calculations.

The columns in these files are as follows:

Column	*Description*
Epoch	Time start of average interval (ms).
DF_dc_{ion}	(DC) 3D VDF in phase space density (s^3/km^6).
DF_error_dc_{ion}	(DC) Statistical VDF Error (s^3/km^6).
counts_dc_{ion}	(DC) 3D VDF in counts.
Counts_error_dc_{ion}	(DC) Statistical VDF Error, estimated assuming Poisson statistics.
dJ_dc_{ion}	(DC) 3D VDF in differential flux, dJ/dE (cm^2 s sr eV/eV)$^{-1}$.
dJ__error_dc_{ion}	(DC) Statistical VDF Error in differential flux (cm^2 s sr eV/eV)$^{-1}$.
DF_tc_{ion}	(TC) 3D VDF in in phase space density (s^3/km^6).
DF_error_tc_{ion}	(TC) Statistical VDF Error, in phase space density (s^3/km^6).
counts_tc_{ion}	(TC) 3D VDF in counts
counts_error_tc_{ion}	(TC) Statistical VDF Error, estimated assuming Poisson statistics.
dJ_tc_{ion}	(TC) 3D VDF in differential flux, dJ/dE (cm^2 s sr eV/eV)$^{-1}$.
dJ__error_tc_{ion}	(TC) Statistical VDF Error in differential flux (cm^2 s sr eV/eV)$^{-1}$.
eoq	Energy per charge (keV/e), 32 steps in total
SECTOR_labl	Sector labels provide the string 'Sector {index} {angle} deg' with quantities in brackets drawn from the sector variables described below. (See Figure 2)
SECTOR_index	Natural number referencing sectors (1-16).
SECTOR_angle	Center angle within each 22.5° wide sector (°).
SECTOR_number	List index referencing sectors (0-15).
Telescope_Labl	Telescope labels provide the string 'Telescope {index} ±{angle}deg' with quantities in brackets drawn from the telescope variables described below. (see Figure 2)
TELESCOPE_index	Natural number referencing the telescope (1-3).
TELESCOPE_angle	Center angle within the 53° wide telescope view {-53°, 0°, 53°}.
Telescope_number	List index referencing the telescope (1-3).
STEP_index	Step index used to identify the energy per charge step of each cycle (1-32).
delT	Accumulation time, 184 sec per scan.

Variables including '{ion}' are included for each individual ion delivered, e.g. counts_dc_he2 for He2+. To allow for future expansion without making extensive changes to the CDF format, placeholders for many additional ions are included. Ions not listed in this document (above) have not yet been delivered and will have only fill values.

4.2 Moments

Density and mean value of the energy distribution are provided to facilitate *browsing of the data*.
Due to the lower collecting power (geometric factor) of the instrument and the lower density of suprathermal tails (in both the solar wind and magnetosphere), STICS data values are often zero. Times with available data can be easily identified by their non-zero or non-fill density values. Searching through many days or years of data using the VDFs is complicated by the fact that the files are large in size (even when counts are low / zero), so that loading large ranges takes substantial computer memory and time. The moments, in contrast, are very small files so that years of data can easily be loaded and analyzed for periods of potential interest. Once identified, VDFs for these periods can can be studied in detail.

Density (0th moment) and the mean value of the energy distribution (1st moment) are the most appropriate moments for suprathermal ions as they do not assume any form of the distribution function, but simply provide a measure of its properties. They are formed by integrating the VDF over all three dimensions, E/q, elevation angle and azimuthal angle.

The columns in these files are as follows:

Column	*Description*
Epoch	Time start of average interval (ms)
n_dc_{ion}	Ion double coincidence number density (cm^{-3}).
n_err_dc_{ion}	Error in ion double coincidence number density assuming Poisson statistics (cm^{-3}).
E_ave_dc_{ion}	Ion mean double coincidence energy (keV)
E_ave_err_dc_{ion}	Error in ion mean double coincidence energy (keV).
n_tc_{ion}	Ion triple coincidence number density (cm^{-3}).
n_err_tc_{ion}	Error in ion triple coincidence number density assuming Poisson statistics (cm^{-3}).
E_ave_tc_{ion}	Ion mean triple coincidence energy (keV)
E_ave_err_tc_{ion}	Error in ion mean triple coincidence energy (keV).
V_dc_{ion}	Not used. Preserved for compatibility.
V_err_dc_{ion}	Not used. Preserved for compatibility.
V_tc_{ion}	Not used. Preserved for compatibility.
V_err_tc_{ion}	Not used. Preserved for compatibility.
DelT	Time difference since last time step (sec).

4.3 Angular Flux Maps (AFMs)

Angular Flux Maps (AFMs) give the flow direction of the measured plasma divided into 48 velocity vector components ranging over sixteen azimuthal sectors and three elevation bins . AFMs are formed by integrating the VDFs over E/q. Experience has shown that it is often easier to identify flow directions in this representation, since statistics are improved by integration over energy and since they are suited to 2D visualizations (such as Molleweide projections) which are intuitive to interpret. These are presented in the Geocentric Solar Ecliptic (GSE) coordinate system.

The columns in these files are as follows:

Column	***Description***
Epoch	Time start of average interval (ms).
AFM_dc_{ion}	(DC) Angular flux map of ion flux values for a given direction (cm^2 sr s)$^{-1}$.
AFM_tc_{ion]	(TC) Angular flux map of ion flux values for a given direction (cm^2 sr s)$^{-1}$.
SECTOR_index	Sectors are swept out by the spacecraft's spin motion within the ecliptic plane (see Figure 2). Sector numbers provide a natural number reference to the sector (1-16).
TELESCOPE_index	Three telescopes divide the 159° latitudinal coverage centered upon and ranging above and below the ecliptic plane (see Figure 2). Telescope index is the natural number referencing the telescope (1-3).
Telescope_Labl	Telescope labels provide the string 'Telescope {index} ±{angle}deg' with quantities in brackets drawn from the telescope variables described above and telescope angles {-53°, 0°, 53°}.

4.4 Energy-resolved pitch-angle distributions (ERPAs)

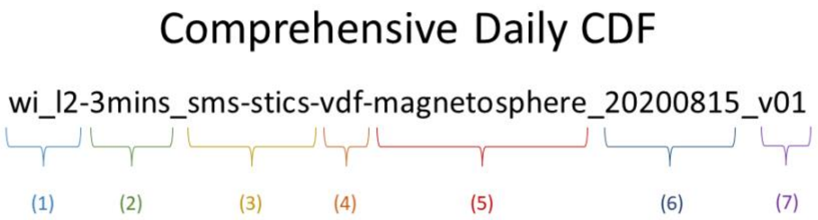
Energy-resolved pitch-angle distributions (ERPAs) organize the data by the angle relative to the magnetic field vector direction, in 7.5 degree bins. The energy separation is preserved at the native resolution of the E/q bins. Magnetic field data is from the Wind/MFI instrument. These are presented in the Geocentric Solar Ecliptic (GSE) coordinate system.

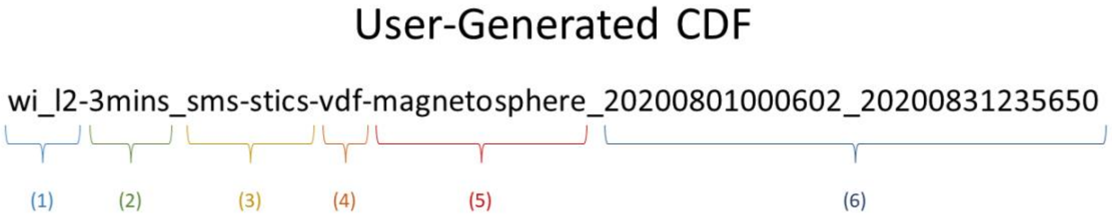
The columns in these files are as follows:

Column	***Description***
Epoch	Time start of average interval (ms).
ERPA_dc_{ion}	(DC) Energy-resolved pitch-angle distributions (s^3/km^6).
ERPA_tc_{ion}	(TC) Energy-resolved pitch-angle distributions (s^3/km^6).
SECTOR_angle	Sector angle.
SECTOR_index	Sector index.
PA 0-11	(TC) Phase space density in s^3/km^6 separated by pitch angle bin, 0-11, each 15 degrees wide. PA 0 is a 0-degree angle from the magnetic field.

5 File Naming Convention

There are two primary methods for downloading STICS data from the CDAWeb interface. The first method is to download the original daily comprehensive data files containing information on all available variables offered for a given data product. The second method for downloading data generates a single file covering a prescribed temporal range containing data limited to a list of variables chosen by the user. The files are named as follows:


Comprehensive Daily CDF


User-Generated CDF

1. Mission and data level: We use the string 'wi_l2' to signify the type of data.
2. Cadence: The time interval between data values is three minutes.
3. Instrumentation: This file contains data from SMS suite's STICS instrument.
4. Data product: These are 3D velocity distribution functions ('vdf').
5. Region: This data was taken in the solar wind.
6. Time range: The filenames include the date of the observations, in yyyymmdd format. For the original daily files this comprises the date observations were made whereas user-generated files describe the range of time for which the data is provided. For example, measurements in the above files were collected on 15 August 2020 (comprehensive daily) and between 01 August 2020 and 31 August 2020. The first date is the start date; the second one is the stop date.
7. The version of the original daily data.

The files following the new naming convention files replace older versions, named wtdcLV2_distfunc*.dat wtlv2_deliv_distfunc*.dat files. Improvements in our analysis techniques have led to the latest release.

6 Calibration Notes

STICS was calibrated with an ion beam prior to launch at both NASA GSFC and at the University of Bern in Switzerland (facility details can be found in Ghielmetti et al.,1983). Goddard tests included measuring the instrument response to H+, He+, C+, C2+, N+, N2+, O2+, and Ne2+. Beam measurements at Bern included H+, He+, C+, O+, Ne+, Ne3+, Ar4+, and Kr5+. Post-launch, STICS was cross calibrated with helium solar wind data from Wind/MASS and Wind/EPACT-STEP. The Time-of-Flight efficiencies were compared with those on Geotail/EPIC-STICS (heritage) and Ulysses/SWICS, which made similar measurements to Wind/STICS under 85 keV/e.

Further SMS calibration details can be found in Chotoo, 1998.

7 Contacts

For science questions relating to STICS, contact Sue Lepri (slepri@umich.edu), SMS Principal Investigator. For data and instrument operations questions, contact Jim Raines (jraines@umich.edu), SMS Instrument Scientist.

8 References

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Gruesbeck, J. R., Exploring the origin of coronal mass ejection plasma from in situ observations of ionic charge state composition, Ph.D. Thesis, 2013.

9 Revision History

Rev	Date	Author(s)	Description
	04Dec2007	JMR/STL	Initial writing.
A	18Dec2007	STL	Addition of calibration notes.
B	01Apr2010	STL/JMR	Release of double coincidence measurements.
C	10May2018	JMR/STL	Release of new data version and file format.
D	01Jun2019	JMR/STL	Release of additional data products (moments, AFM and ERPA) as well as heavy ions.
E	05Jul2022	TJE/JMR/STL	Updated to match new CDF files. Improved discussion of TC and DC data. Minor corrections made elsewhere.