PACS Spectrometer Beam Efficiencies:

The PACS beam efficiencies describe the relative coupling of a point source to each spaxel as a function of the source's position in the FOV. The efficiencies are the ratio of the beam profile convolved with each detectors response and with the radiation pattern of a source, and the total power received.

In order to characterise the PACS beam, Neptune raster maps at certain wavelengths (55, 62, 68, 73, 75, 84, 94, 110, 125, 136, 145, 150, 168, and 187 microns) were observed during the mission. Coarse 25x25 raster maps with raster step size 2.5" were obtained between ODs 174 and 751 in chopped mode covering all 25 spaxels. Also, fine Neptune 5x5 raster maps with raster step size 2” were executed on ODs 1311 and 1312. The combination of four such fine rasters, offset by 1", provide very high sampling for the central spaxel beam efficiency only. All raster maps were observed with only one chop -off position (aka, asymmetric chopNod). All these measurements were registered using least squares minimization in coordinates and gain, and a synthetic beam was constructed with the coarse raster outside the area covered by fine raster and from matched fine raster inside. Finally, this synthetic beam is interpolated into a 0.5" grid.
Data were processed using the telescope background normalisation scheme to obtain the telescope-normalised signal per spaxel. The WCS associated with the beam is in sky coordinates for position angle 0.
The final maps are a reconstruction of what each spaxel "sees" as the planet was rastered across each detector's aperture on the sky. Note the difference to a regular source map, where we reconstruct the spatial information as a function of position in the sky, even combining information coming from different spaxels.
Finally, the efficiencies were calculated normalising the raster maps in the following way:

- all the 25 beams were divided by the peak value of the central spaxel beam;
- then, they are multiplied to match the Point Source Correction calibration file (*pointSourceLoss* FM_4).

Note: The first two beam efficiency versions were normalised to the peak value of the beam on each spaxel, hence eliminating each individual spaxel's response in the final beam. The normalisation between v3-v5 (consisting of the first point in the above list) produced a beam which included the spaxels relative response.

Beam Efficiency version delivery history in PACS calibration twiki:

Beam Efficiency version	Date	Rasters	Grid step size	PSC
PCalSpectrometer_Beam_v1.tar.gz	14-07-2011	coarse	2.5"	no
PCalSpectrometer_Beam_v2.tar.gz	16-01-2012	coarse	2.5"	no
PCalSpectrometer_Beam_v3.tar.gz	05-03-2013	coarse+fine	0.5"	no
PCalSpectrometer_Beam_v4.tar.gz	22-05-2014	coarse+fine	0.5"	no
PCalSpectrometer_Beam_v5.tar.gz	28-05-2014	coarse+fine	0.5"	no
PCalSpectrometer_Beam_v6.tar.gz	20-08-2015	coarse+fine	0.5"	yes

Beam efficiencies v1 (14_07-2011): *PCalSpectrometer_Beam_v1.tar.gz*.

Beam efficiency of the central spaxel per observed wavelength (62, 68, 73, 75, 84, 94, 125, 136, 145, 150, 168, 187, and 204 microns). Grid step size 2.5". The beams are normalised to their peak value.

Beam efficiencies v2 (16-01-2012): *PCalSpectrometer_Beam_v2.tar.gz*.
Beam efficiency of all IFU spaxels. Grid step size 2.5". Each beam is normalised to its fitted peak value.

Beam efficiencies v3 (05-03-2013): *PCalSpectrometer_Beam_v3.tar.gz*.
Version 3 has the beam efficiencies for all IFU spaxels, and is a drastic improvement with respect to version 2 as the spacecraft pointing was reconstructed more accurately (pointing reconstruction with STR sub-pixel correction and GYR filter). This reconstruction resulted in a non-equidistant sampling of the beam efficiency in the sky, but the beam products offered are equidistantly-sampled on a grid of 0.5". Each beam is normalised to the fitted peak value of the central spaxel.
AKA Synthetic beams. The central part of the beam is the Gaussian fit to the measured beam efficiencies. This has been verified to be a very good description on the different raster observations we have of the central spaxels for wavelengths longer than 80 micron. Below 80 micron, the actual beam shows the square detector footprint, and the Gaussian approximation in the beam products v3 over-predicts the real beam efficiency by 1.5-2%. The outer part of the beams contains the interpolated values of the irregularly sampled measurements.

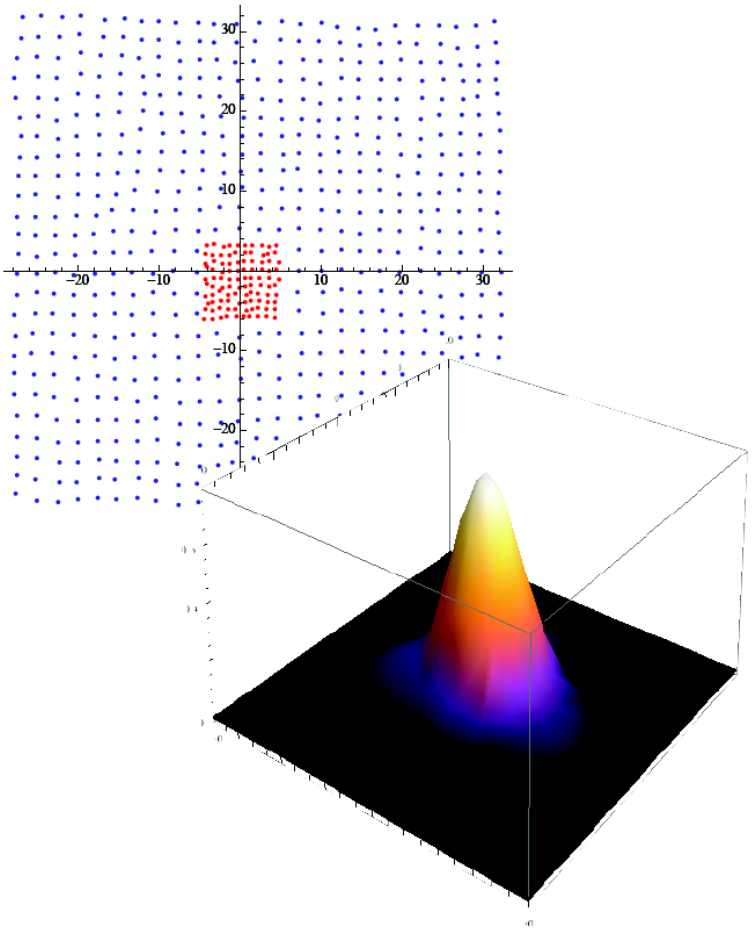

Fig. 1: Synthetic beam from coarse raster outside of area covered by fine raster and from matched fine raster inside.

Version 3 of the spectrometer beams are sharper than version 2, and shows the ghosts (ghosts are discussed in the Spectrometer Calibration Document) more clearly, as well as the three-lobe structure of the Herschel telescope PSF.

The raw data from which the PACS spectrometer beams (all versions) have been derived is also available as tables:

- SpecSpatial_BeamEfficiency_central_spaxel_tables_v1.tar.gz: This contains a FITS file for each wavelength measured for the central spaxel only. Raw data of the **coarse and fine rasters are combined**. The array dimension of the fits file is [3,npoints] where the first column gives the y raster position, the 2nd column the z raster position and the 3rd column the normalised flux measured at this raster position.
- SpecSpatial_BeamEfficiency_tables_v1.tar.gz: Raw measurements PACS beams - all spaxels, **coarse raster measurements only**: each FITS file corresponds to one wavelength. Each file contains the data for all spaxels of the coarse raster measurement only. Each FITS file holds an array of 3x25x25x25 where: (0,25,25,25)=y raster position, (1,25,25,25)=z raster position, (2,25,25,25)=flux normalised to the central spaxel. The second and third dimensions are the raster position indices (y and z) and the last dimension is the module number (=spaxel number).

Beam efficiencies v4 (22-05-2014): *PCalSpectrometer_Beam_v4.tar.gz*.
Intermediate version. Correction to the beam efficiencies v3 in data processing as they were created using *norm*, instead of *x* to obtain the telescope-normalised signal. Only the latter is a linear function.
Correction on cdelt2 sign in the FITS WCS keywords. The beams at wavelengths 68 and 75 microns in B2A and B2B, respectively are missing and 125 microns in R1 have different dimensions.

Beam efficiencies v5 (28-05-2014): *PCalSpectrometer_Beam_v5.tar.gz*.
Beam efficiency maps re-centred to have the central spaxel fall onto the centre of the grid. The centre was previously calculated as a centre of gravity of Gaussian fitted peak of all spaxels per wavelength/raster. The mean of all blue and the mean of all red coarse raster observations was used to determine a reference central spaxel position, and the offset between the centre-of-gravity and central spaxel per spectrometer channel was applied in the final interpolation.

Beam efficiencies v6 (20-08-2015): *PCalSpectrometer_Beam_v6.tar.gz*.
Beam efficiencies have been re-normalised with an additional step that multiplies the beams to match the Point Source Correction calibration file.

Beam Efficiencies in HIPE Calibration Tree:

The beam efficiency version system in the PACS calibration twiki page is different from the correspondent calibration file versions in HIPE. The mapping between both versioning system is the following:

PACS twiki version	Calibration file name	Calibration set version	Publication date
v3	BeamsPerSpaxelXXX_FM_v1	52	12-04-2013
v5*	BeamsPerSpaxelXXX_FM_v2	66,67	21-10-2014

v5	BeamsPerSpaxelXXX_FM_v3	69	12-12-2014
v6	BeamsPerSpaxelXXX_FM_v4	71	25-08-2015

*v5 was meant to be inserted in the calibration set version 66, but there were some problems that were only solved in version 69. This is explained in the release note for calibration set 68.

The calibration files BeamsXXX_FM_vX contain the beam efficiencies at the PACS frames level to be used by the Pointing Offset Correction ipipe scripts. These calibration files only feature the beam efficiencies up to v2, following the PACS Calibration twiki versioning system; i.e. coarse raster beam efficiencies.