Advancements in molecular medicine

Philips Ingenuity TF PET/MR calibration overview

Jerome Griesmer, Joe Futey, Navdeep Ojha, Michael Morich and Gordon Demester. Philips Healthcare – Nuclear Medicine, Cleveland, OH

Abstract

PET-MR imaging systems have been discussed and written about for many years. Philips has introduced the world's first CE marked whole body PET-MR imaging system, the Ingenuity TF PET/MR. The approach taken followed the realization that a sequential pair of scans, with both imaging scanners in the SAME ROOM could be achieved in far less time and cost than a simultaneous PET-MR and would achieve most of the potential benefits of the two modalities. We have designed, built and calibrated a PET/MR hybrid imaging system from two fully functional PET and MR imagers, obtaining exceptional combined images, and have developed a novel shielding design to address the difficult interaction issues that have previously prevented operation in the same room.

Discussion

The MR is the normal Achieva 3T X-series MR scanner and the PET is a modified version of our Ingenuity TF (Astonish TF) TOF scanner that meets all of our normal imaging performance measures.

Of course there is no way to operate the MR in the normal PET-CT environment due to lack of an RF shielded room, so we had to redesign the PET to operate inside the normal MR room. This primarily means that the PET scanner cannot emit any EMI that would interfere with the MR imaging and the PET PMTs needed to function normally in the fringe magnetic fields from the 3T magnet. Since those fields are in the range of 40 to 60 times the earth's typical magnetic field, PMTs are normally nonfunctional in such an environment.

The light emission from the 511keV gamma rays interaction with the PET scintillator crystal is not affected by the fringe magnetic field.

While a normal PET imager has EMI emissions that meet all normal regulatory requirements, the inside of an MRI room has to exclude even normal radio signals and the requirements are more stringent. This required modification to locate most of the electronics from the PET gantry to reside in the MR equipment room located outside the magnet/RF room. The PET gantry contains the normal crystal/PMT geometry and the first level of signal processing boards, along with the required PMT HV Supply and the electronics boards supply. All power and signal wires penetrating the MR walls need to pass through specially designed RF penetration panels to prevent EMI radiation from following the wires into the room.

The PET gantry was reworked to provide a level of magnetic shielding for the PMT sensors so that they are operating in 'normal' flux levels, near the level of the earth's magnetic field. Simulations indicated that the required bulk of the magnetic shell would not present a problem for the normal MR magnet calibration and shimming, and we could achieve the required low field at the PMTs without any additional magnetic material in the normal PET imaging path for the gamma rays. So there is no compromise on the performance of either the MR or the TOF PET imaging scanners due to the added magnetic shielding on the PET gantry.

PHILIPS

sense and simplicity

Before (no PET gantry) and after (PET gantry installed with magnetic shielding) MR Bo magnetic field shimming results:

The magnet of the MR scanner is designed to produce a highly uniform Bo magnetic field over a large imaging volume. It supports an imaging volume of X/Y/Z dimensions of 50 cm x 50 cm x 45 cm. Conventional passive (iron) shimming methods are used to make corrections to, i.e. homogenize, the static Bo field as needed during installation. A 24-plane, 24-angle NMR field plotting method is used to measure the field during, and at the completion of, shimming. During scanning procedures, active shimming (1st and 2nd/high-order) is used to further correct for small subject perturbations to the Bo field. For the 3T MR tested, resulting volume RMS homogeneity of the Bo field is provided below in Table 1, for several characterization volumes (note these volumes are spherical volumes; with indicated diameter in each direction being the same the sphere is not oblate or prolate).

Before PET installation		
Volume dimensions (X/Y/Z, each in cm)	Vrms (ppm) typical	Vrms (ppm) actual
40 x 40 x 40	0.5	0.37
30 x 30 x 30	0.12	0.07
20 x 20 x 20	0.03	0.014
10 x 10 x 10	0.004	0.002

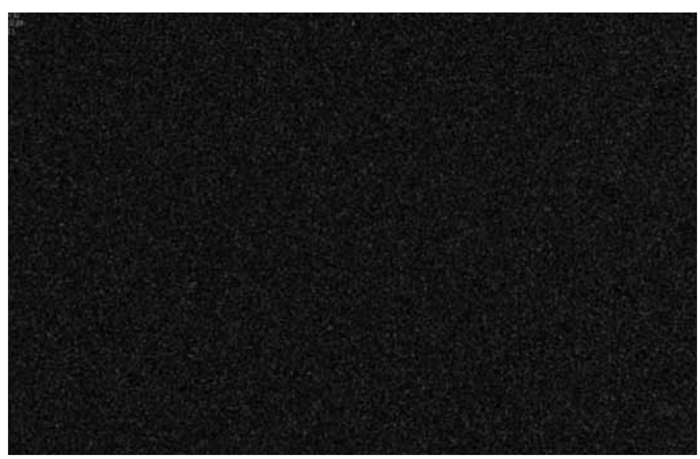
After PET installation with magnetic shielding of the PET		
Volume dimensions (X/Y/Z, each in cm)	Vrms (ppm) typical	Vrms (ppm) actual
40 x 40 x 40	0.5	0.32
30 x 30 x 30	0.12	0.08
20 x 20 x 20	0.03	0.017
10 x 10 x 10	0.004	0.002

Table 1 Bo Vrms homogeneity results following standard installation shimming before and after the PET gantry was installed in the 3T MR room. The Typical results column is what is typical for the 3T system. The actual results are below typical in both cases. Homogeneity is Vrms in units of parts per million (ppm), referenced to the 3T central field strength. Note: The field homogeneity is calculated on the characterization volumes based on spherical harmonic representation of the data as determined from 24-plane, 24-angle measurements on a larger volume.

RF noise characterization with PET OFF and PET ON

As mentioned, the PET system can produce EMI that manifests as increased image noise. Certain redesign, shielding and filtering of PET electronics and cabling was done to mitigate RF noise issues. Where discrete noise frequencies are present and are within the operating band of the MR scanner, the noise may manifest as 'noise lines' rather than as a general increase in background noise. MR image noise scans with the standard quadrature body coil are performed at various RF receive center frequencies and bandwidths to determine the presence or absence of such noise lines. These scans were conducted after PET scanner RF noise mitigations, with both the PET OFF and PET ON. To enhance the sensitivity of the noise pick-up method a 2m long copper wire was placed on the tabletop, extending from the edge of the quadrature body coil out the front of the MR scanner. Representative results are provided below showing no obvious evidence of noise lines.

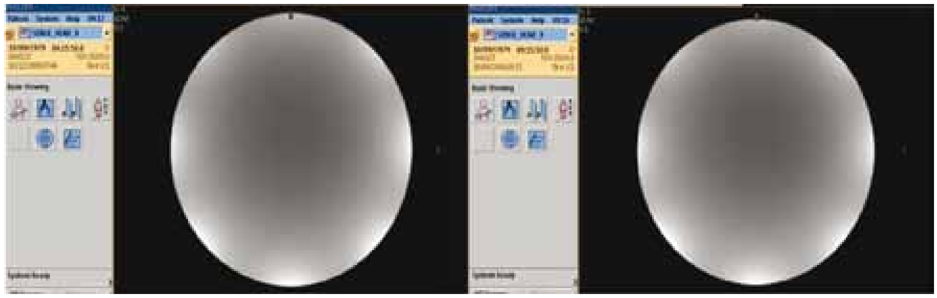
With the PET system powered off the fine spurious batch noise test with 2m wire in bore of magnet was run. Fine scan with wire at 128.02 MHz showing typical clean result.



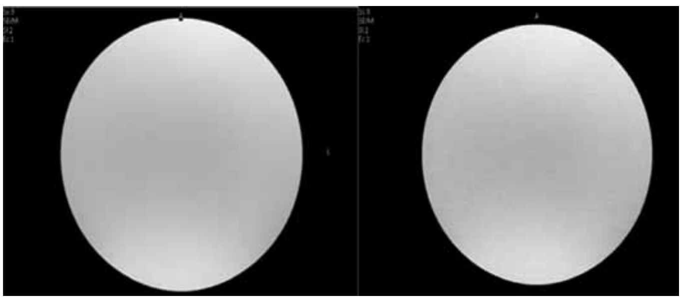
With the PET system powered the fine spurious batch noise test with 2m wire in bore of magnet was run. Fine scan with wire at 127.72 MHz showing typical clean result.

Examples of phantom-based MR image signal to noise ratio with PET OFF and PET ON:

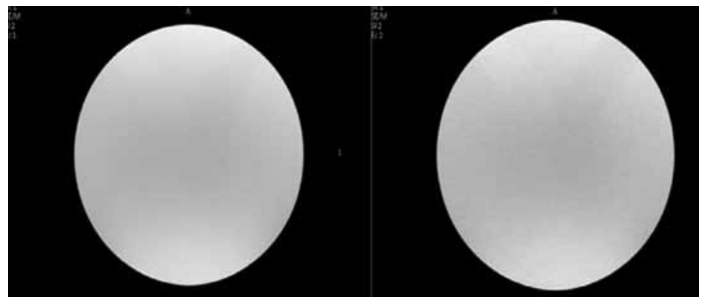
A number of MR sequences are used with phantoms to characterize image signal to noise ratio (SNR) and other parameters such as uniformity, resolution and slice thickness. An example set of images comparing SNR with PET OFF and PET ON are provided below. This utilized the standard quadrature body coil for both transmit and receive (T/R) and a multi-echo (dual, spin echo) technique with TE of 30 and 60 ms.



PET OFF (Left) and PET ON (Right): Spin Echo TE30 images with Body coil Transmit and 8 channel SENSE Head coil Receive. SNR with PET OFF measured at 129.5 and SNR with PET ON measured at 132.6.



PET OFF: Dual Echo (Spin Echo) images with TE30 ms (left), TE60 ms (right). SNR measured at 184.5 and 83.9, respectively. Body coil T/R.



PET ON: Dual Echo (Spin Echo) images with TE30 ms (left), TE60 (right) ms. SNR measured at 180.3 and 83.0, respectively. Body coil T/R.

Here are the test results on energy calibration:

Un-ramped energy summary

cent = 100.0 (**11.82%**)

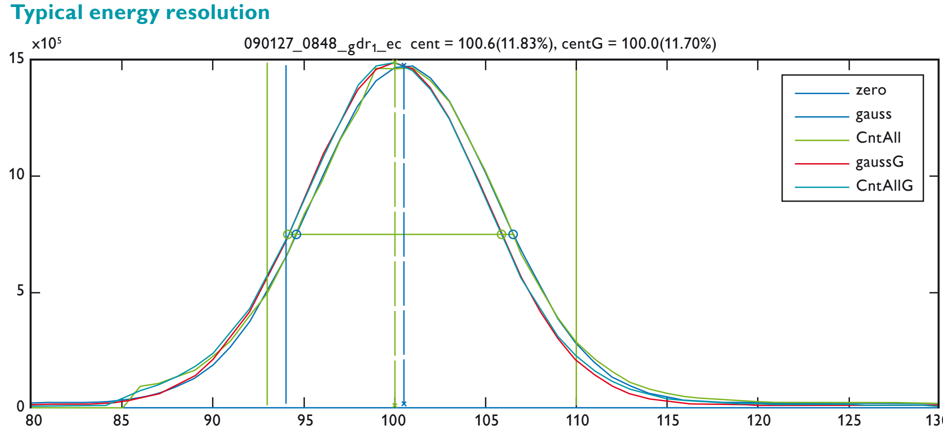
After bringing the MR field up to the normal 3T calibration level:

Ramped energy summary,

After re-cal

cent = 100.0 (**11.91%**)

Typical energy resolution



Here are the test results on timing calibration:

Un-ramped timing summary

cent = 128.0 (**572.9 ps**)

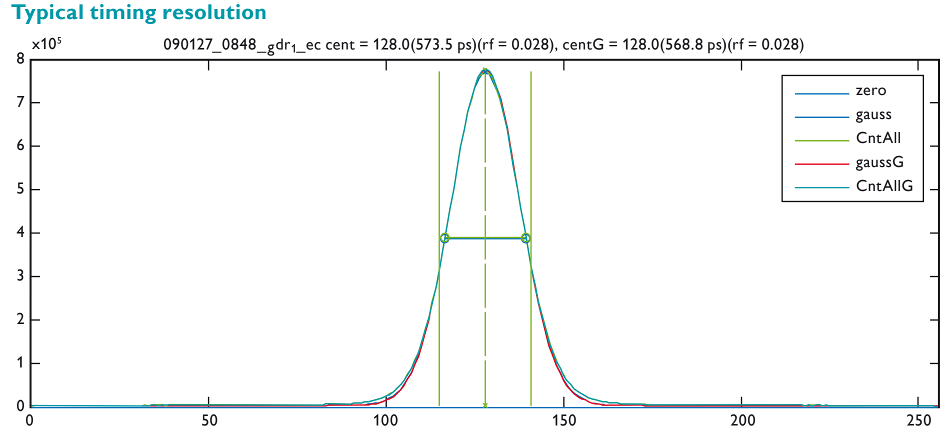
After bringing the MR field up to the normal 3T calibration level:

Ramped timing summary,

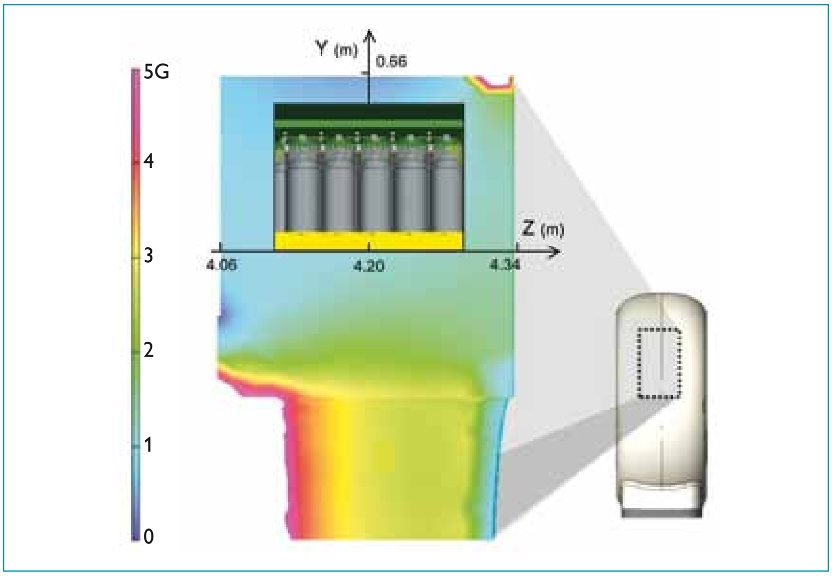
After re-cal

cent = 128.0 (**580.1 ps**)

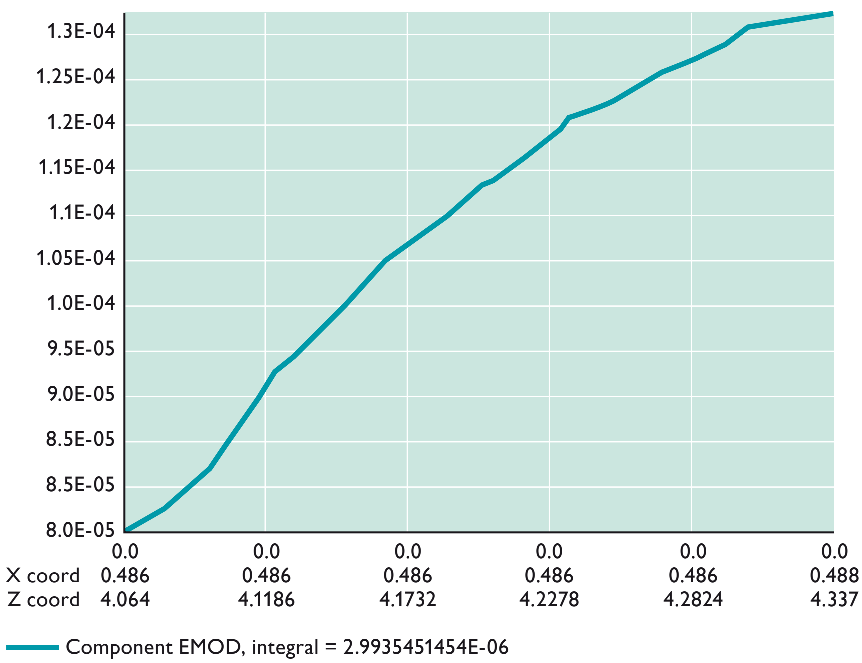
Typical timing resolution



Model 5 with gusset but no bore tube



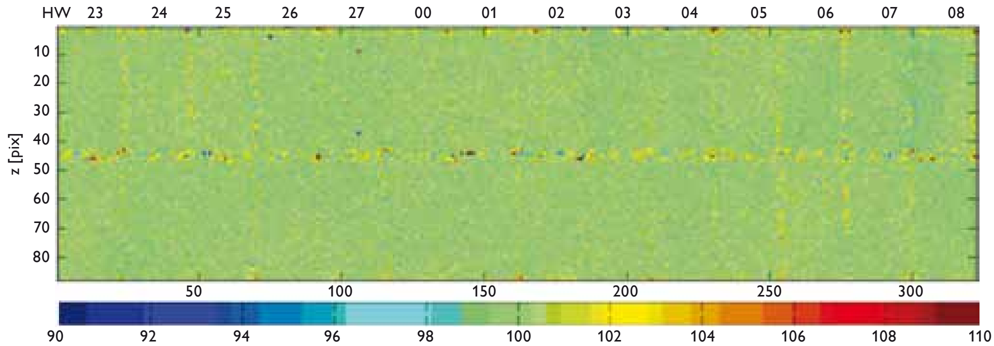
Magnetic flux density, B_{mod}, in the air inside the steel box. The box has a gusset but no bore tube.



Plot of $B_{mod}(z)$ axially inside of the shielded box at the rdius of the PM tube photocathode y = 0.486m. The model is shown above.

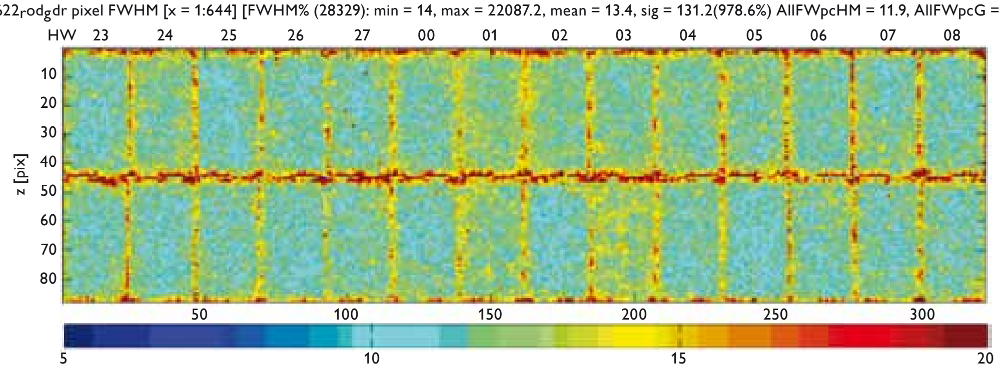
Energy Centroids (corrected)

090223$_{1}$622$_{r}$od$_{g}$dr pixel centroid [x = 1:644] [Cent (28329): min = 85.0, max = 149.4, mean = 100.0, sig = 0.8(0.8%)]



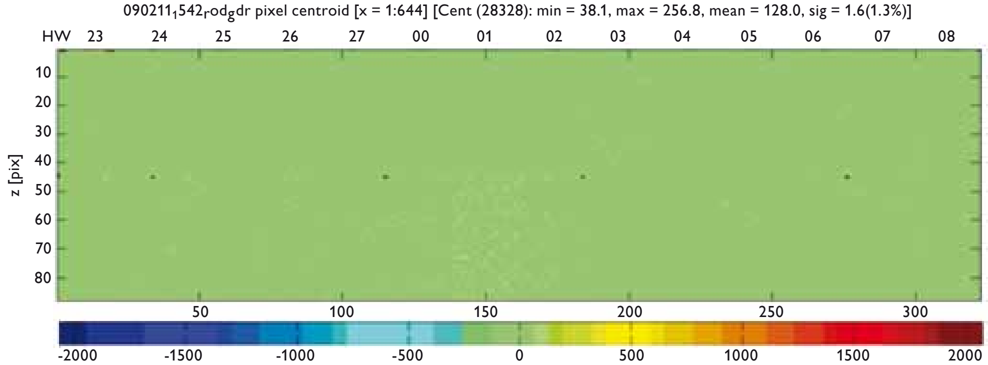
Energy FWHM

090223$_{1}$622$_{r}$od$_{g}$dr pixel FWHM [x = 1:644] [FWHM% (28329): min = 14, max = 22087.2, mean = 13.4, sig = 131.2(978.6%) AllFWpcHM = 11.9, AllFWpcG = 11.9] [CntMinFW = 30]



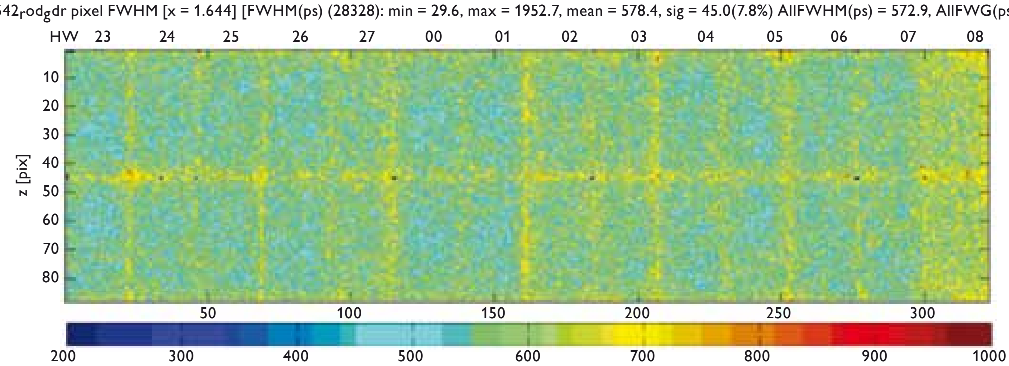
Timing Centroids (corrected)

090211$_{1}$542$_{r}$od$_{g}$dr pixel centroid [x = 1:644] [Cent (28328): min = 38.1, max = 256.8, mean = 128.0, sig = 1.6(1.3%)]



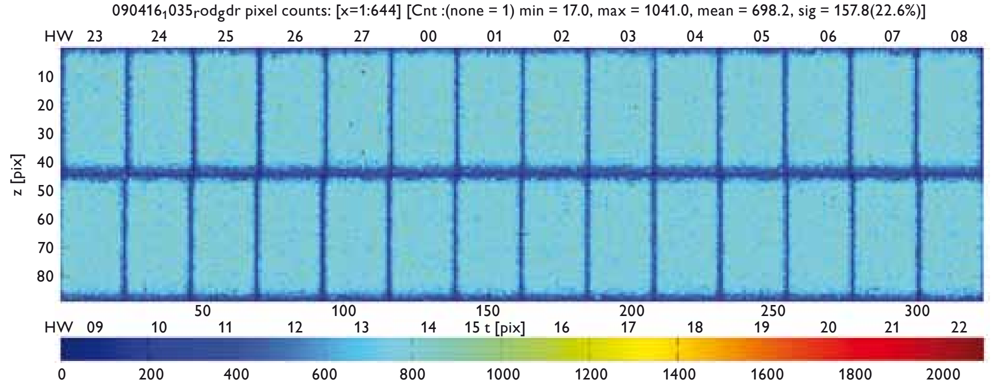
Timing FWHM

090211$_{1}$542$_{r}$od$_{g}$dr pixel FWHM [x = 1.644] [FWHM(ps) (28328): min = 29.6, max = 1952.7, mean = 578.4, sig = 45.0(7.8%) AllFWHM(ps) = 572.9, AllFWG(ps) = 567.7] [CntMinFW = 30]

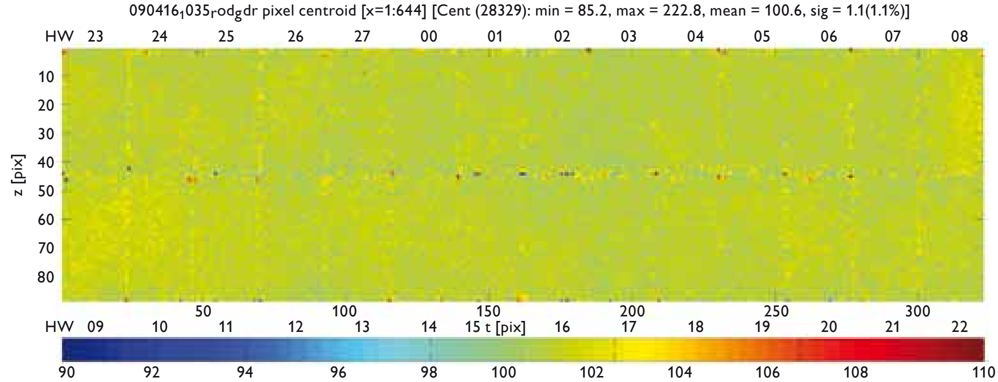


After new GDR

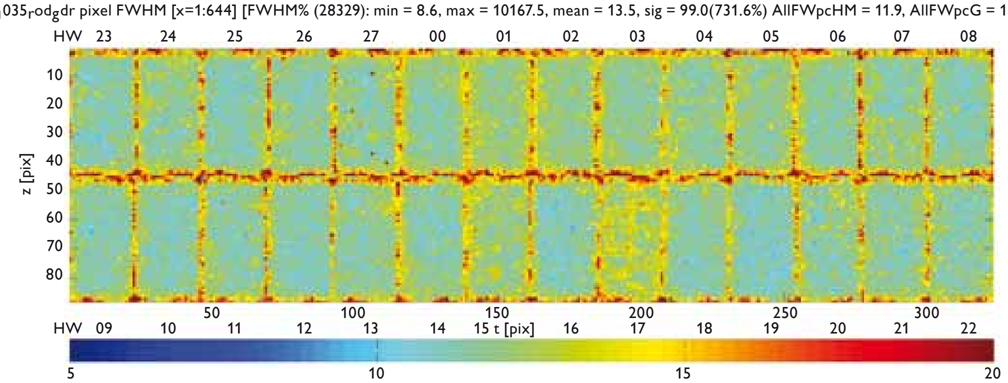
directory = 'C:\Projects\Maxwell\M001\090413Data\';mach = 'M001'; sys = 'Raptor'; filename = '20090416-1035_rod_gdr1_ec1_10MX.list'; noEng = 0; % 'ListModeReadPHASigC4GCT 6.m.080804.1033.m' %mdlDisp = -mdlDisp(1:xmx,1:45);'prot_Energy';comment_prot = 'std Energy'; % **************



090416$_1$035$_r$od$_g$dr pixel counts: [x=1:644] [Cnt :(none = 1) min = 17.0, max = 1041.0, mean = 698.2, sig = 157.8(22.6%)]



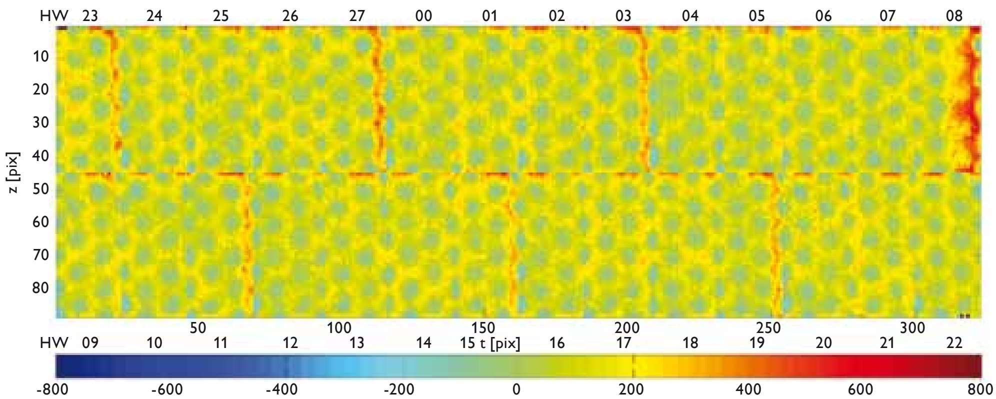
090416$_1$035$_r$od$_g$dr pixel centroid [x=1:644] [Cent (28329): min = 85.2, max = 222.8, mean = 100.6, sig = 1.1(1.1%)]



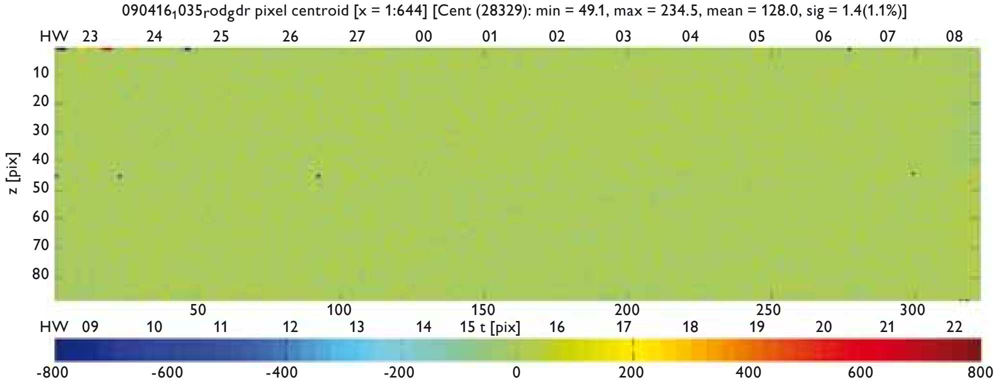
090416$_1$035$_r$od$_g$dr pixel FWHM [x=1:644] [FWHM% (28329): min = 8.6, max = 10167.5, mean = 13.5, sig = 99.0(731.6%) AllFWpcHM = 11.9, AllFWpcG = 11.9] [CntMinFW=30]

elpTime = 107592, rates: smin = 2950540, smax = 2972570,pmin = 139690, pmax = 144740, dmin = 0, dmax = 0 TOF (Xtal): cent = -31.1ps, FWHM = 642.9 ps [TOFratio=100.0%] {PSPB = 25.0} ,rf = 0.0277,rr = 2.5k cent = 100.6(11.89%), centG = 100.0(11.87%) cntsAll = 19784644, cntsAllG = 19296225 ‘prot_TOFtcorrdrift’;comment_prot = ‘std TOF , poscorr=0’; % ************

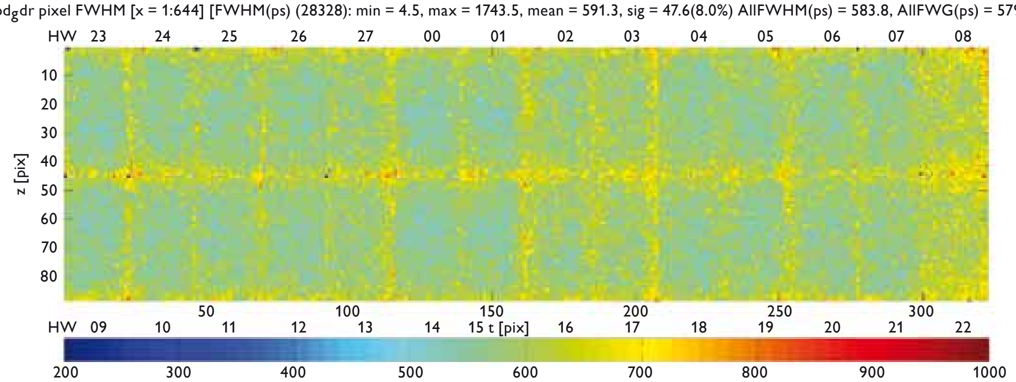
xtalTime-20090416.bin pixel tcorr [x = 1:644] [tcorr(28336): min = 1.00, max = 220.00, mean = 131.50, std = 4.12]



090416$_1$035$_r$od$_g$dr pixel centroid [x = 1:644] [Cent (28329): min = 49.1, max = 234.5, mean = 128.0, sig = 1.4(1.1%)]



090416$_1$035$_r$od$_g$dr pixel FWHM [x = 1:644] [FWHM(ps) (28328): min = 4.5, max = 1743.5, mean = 591.3, sig = 47.6(8.0%) AllFWHM(ps) = 583.8, AllFWG(ps) = 579.7] [CntMinFW = 30]



loading xtalTime-20090416.bin, tcorr(28336): min = 1.00,max = 220.00,mean = 131.50,std = 4.12 y center = -1.84 mm (x=9), w center = -0.80 mm (x = 170), z center = -0.97 mm (-1.13) Wp = wparse returns: PHA[28336x256],icntr = 107593,idata = 9892344,dlyCnt = 0,clipCnt = 0, toc = 1.23 elpTime = 107592,rates: smin = 2950540,smax = 2972570,pmin = 139690,pmax = 144740,dmin = 0, dmax = 0TOF (Xtal): cent = -23.6ps, FWHM = 584.3 ps [TOFratio = 100.0%] {PSPB = 25.0} ,rf = 0.0295,rr = 2.7k cent = 128.0(583.8 ps)(rf = 0.029), centG = 128.0(579.7 ps) (rf = 0.029) cntsAll = 19784644,cntsAllG = 19784139

Philips Healthcare is part of
Royal Philips Electronics

How to reach us
www.philips.com/healthcare
healthcare@philips.com

Asia
+49 7031 463 2254

Europe, Middle East, Africa
+49 7031 463 2254

Latin America
+55 11 2125 0744

North America
+1 425 487 7000
800 285 5585 (toll free, US only)

Please visit www.philips.com/IngenuityTFPETMR

Printed in The Netherlands.
4522 962 81641 * APR 2012