DAQ design and on-line performance from ASIC to image analysis

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Overview

- INSIDE hardware completion
  - Relay boards
  - RSW (Relay-Serial-Watchdog) board
  - Slow controls
  - Monitor functionality
- Coincidence finding software
  - Development history
  - Methods
  - Working principle
- DAQ performance in coincidences finding
- New GUI features
- Analysis program and framework

Completion of INSIDE PET system hardware

Work at Torino following on from previous presentation at INSIDE meeting 20/1/2016

Added relay boards for remote commutation of Tx board PSU's in case of radiation-induced misbehaviour

Added another FPGA evaluation board (RSW) and developed the firmware and software for remote control of Tx board PSU relays plus control and monitoring of chiller status

Updated slow controls program to incorporate RSW board functionality

Added online monitoring functionality for various FE performance-related counters to both Tx and Master board firmware and updated associated control software

All work completed in time for February 7th test at Pavia

Tx PSU relay boards

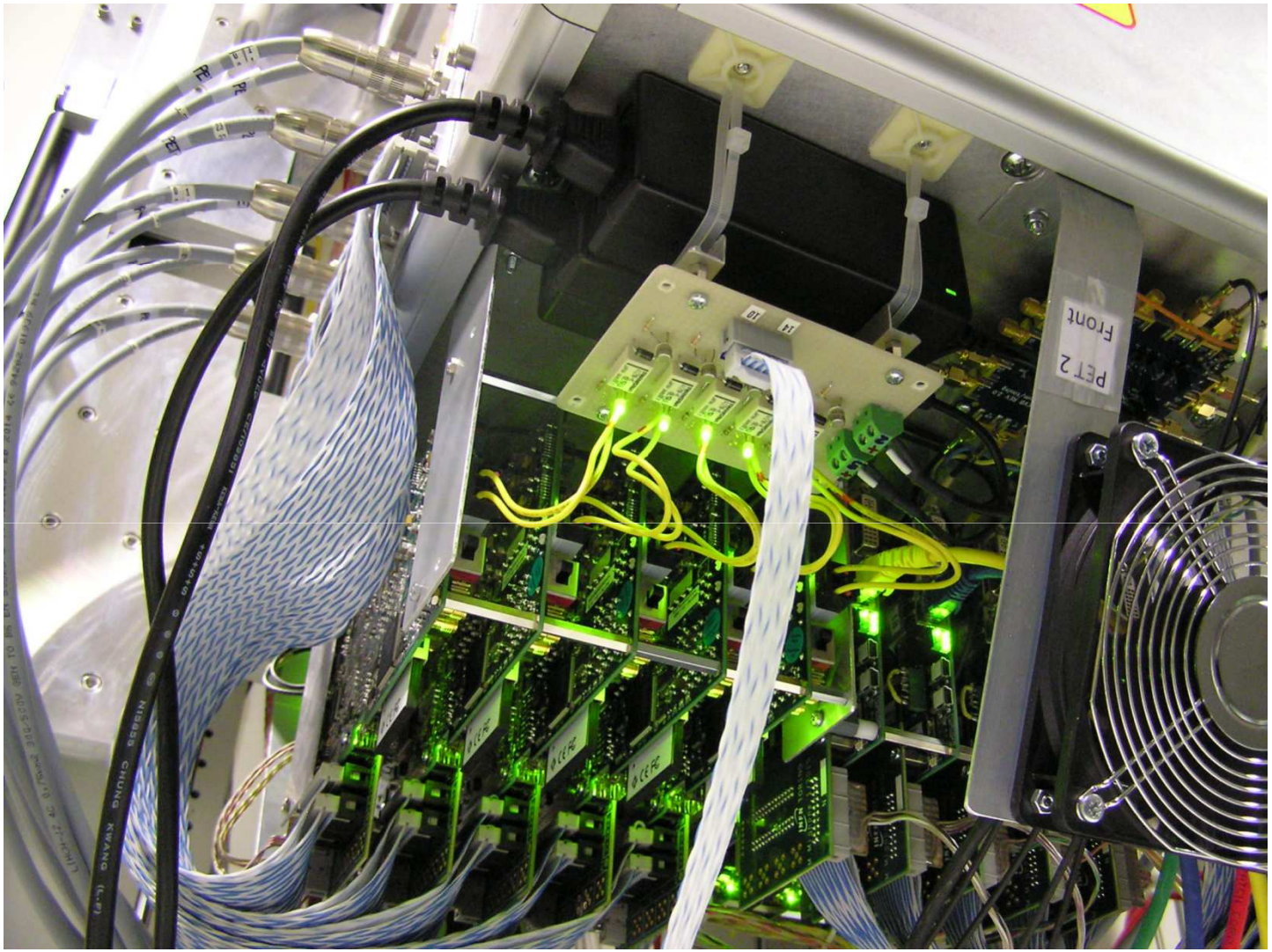
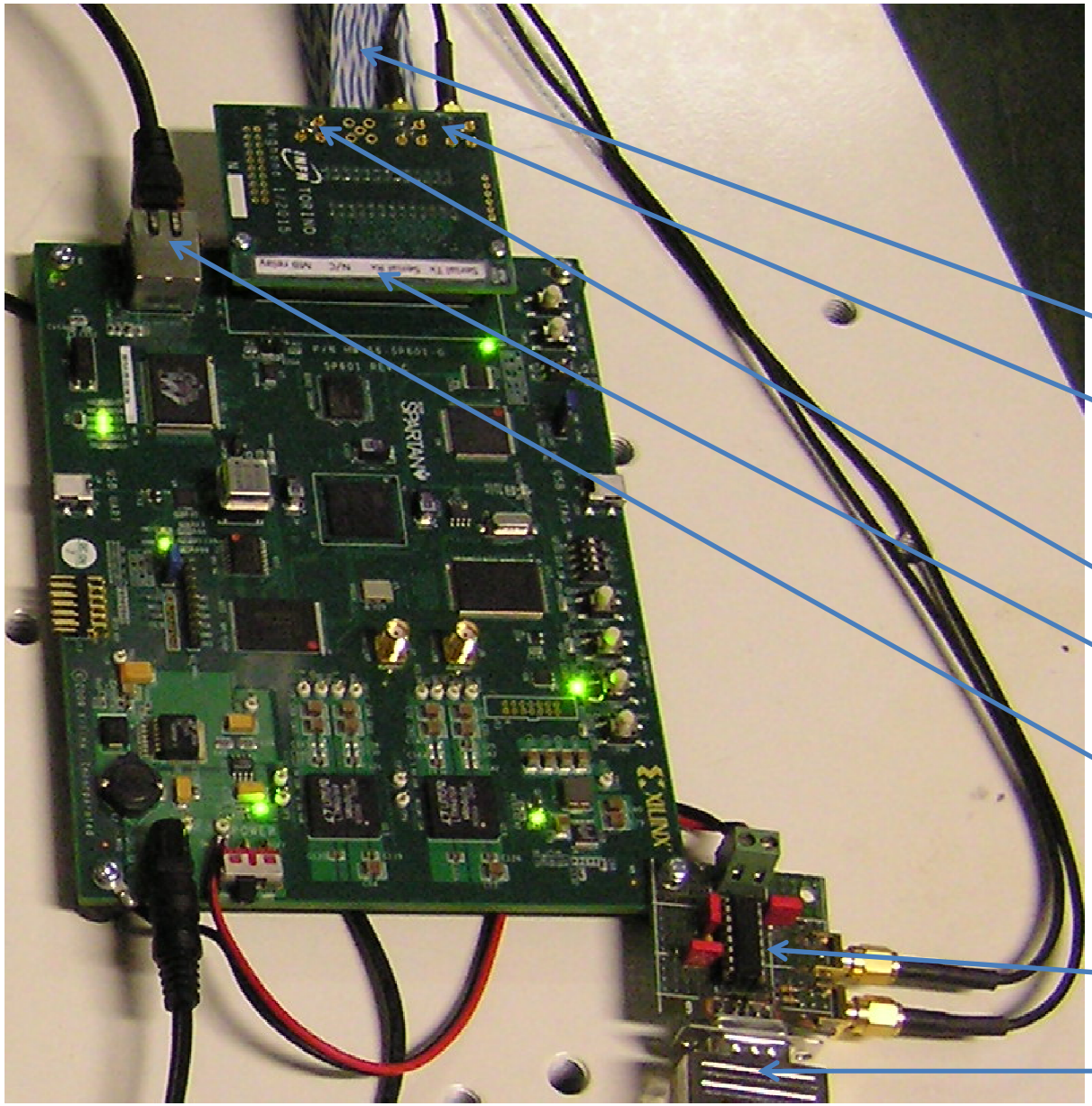


Photo is of first version, turns out that switch-on current peaks at 8A and was causing contacts to stick, had to substitute the 2A compact relays with 15A old-school models

Three out of four boards assembled (twice) by Giovanni Pirrone (Pisa)

RSW board



ML601 Spartan 6 evaluation board

Relays
Serial port
Watchdog (not implemented)

Tx board relays control

Serial I/O
(custom MODBUS in firmware)

Master board relay control

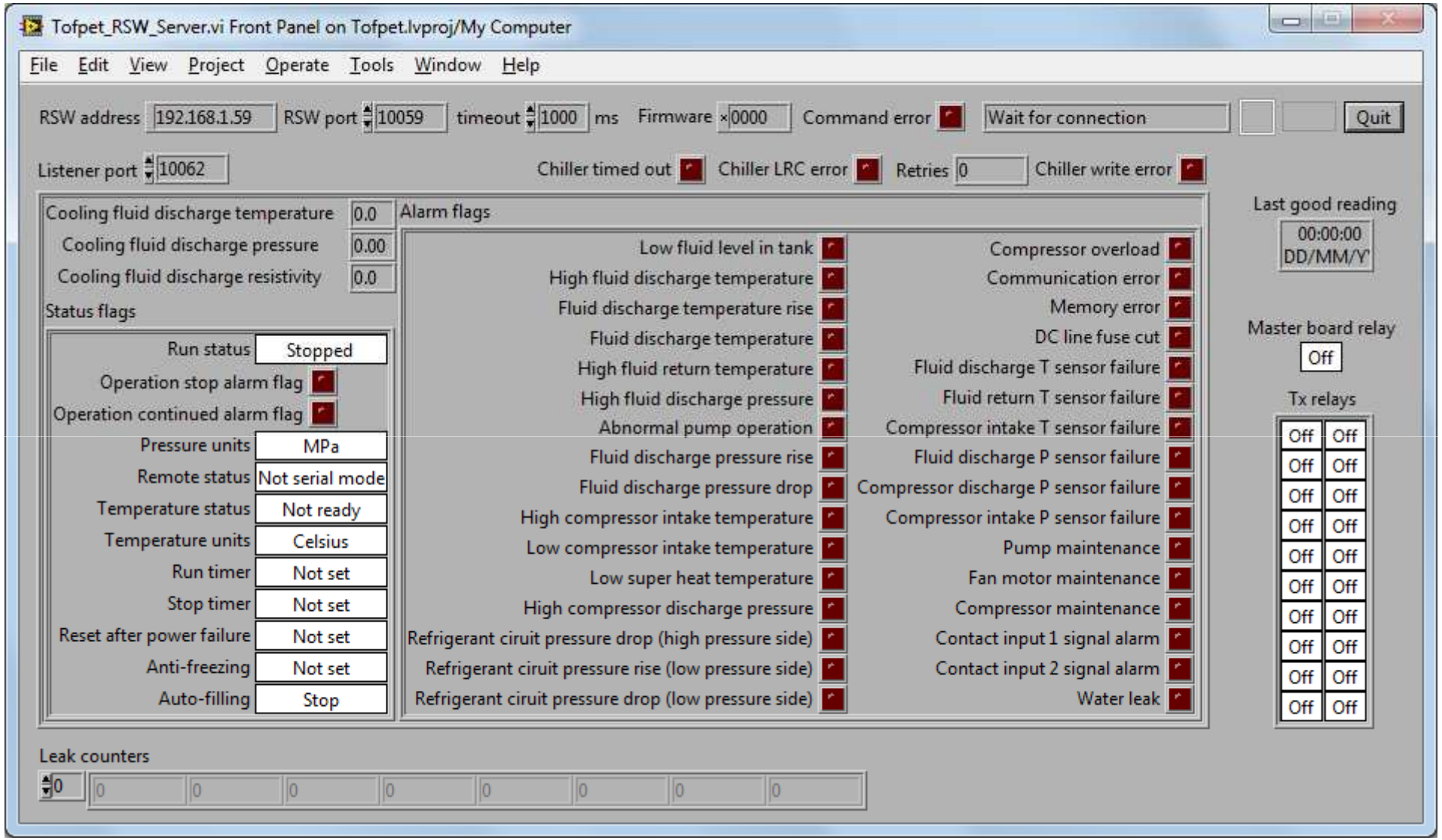
FMC LPC adapter

Gigabit Ethernet

RS232 level shifter board

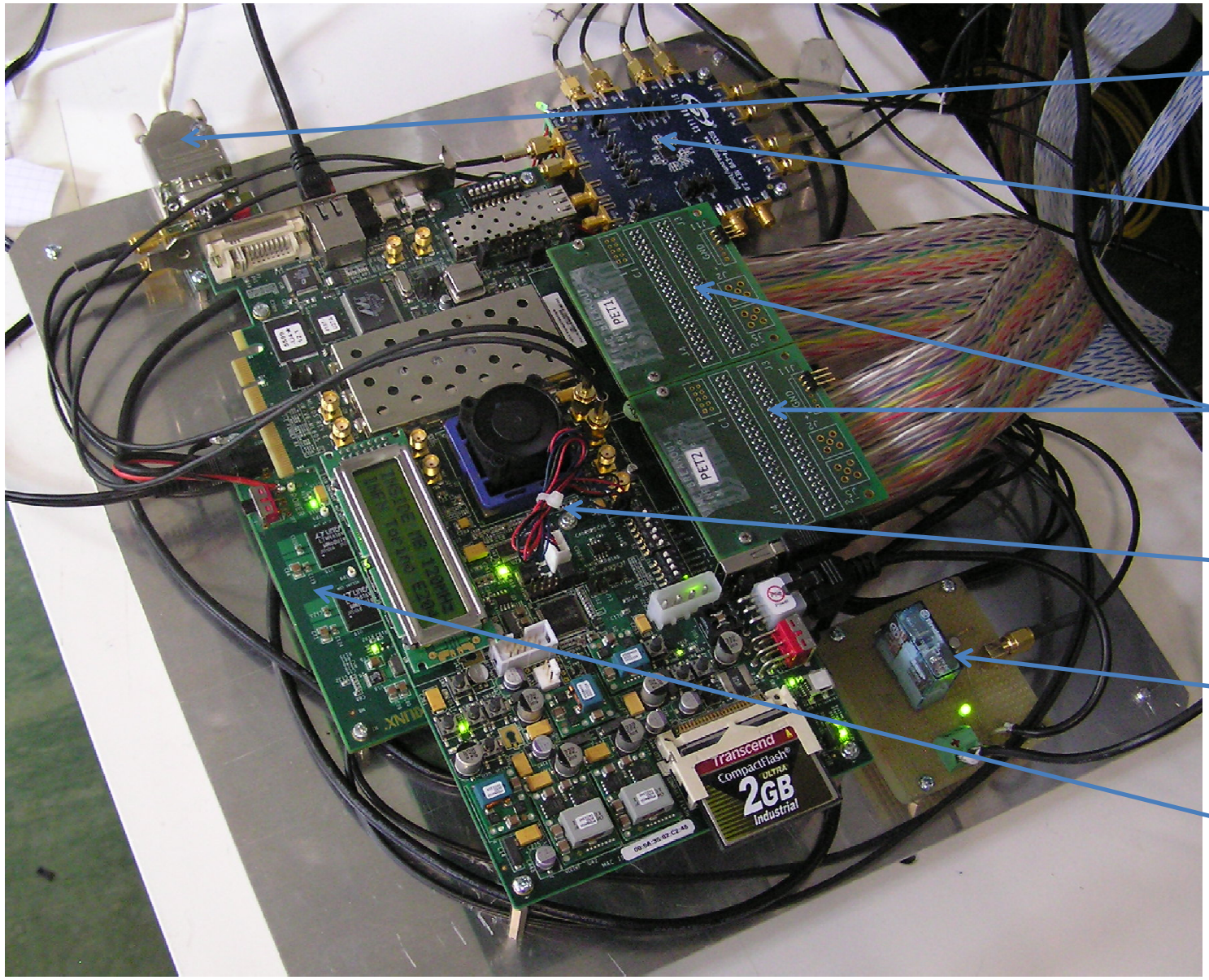
Serial connection to chiller

RSW control server



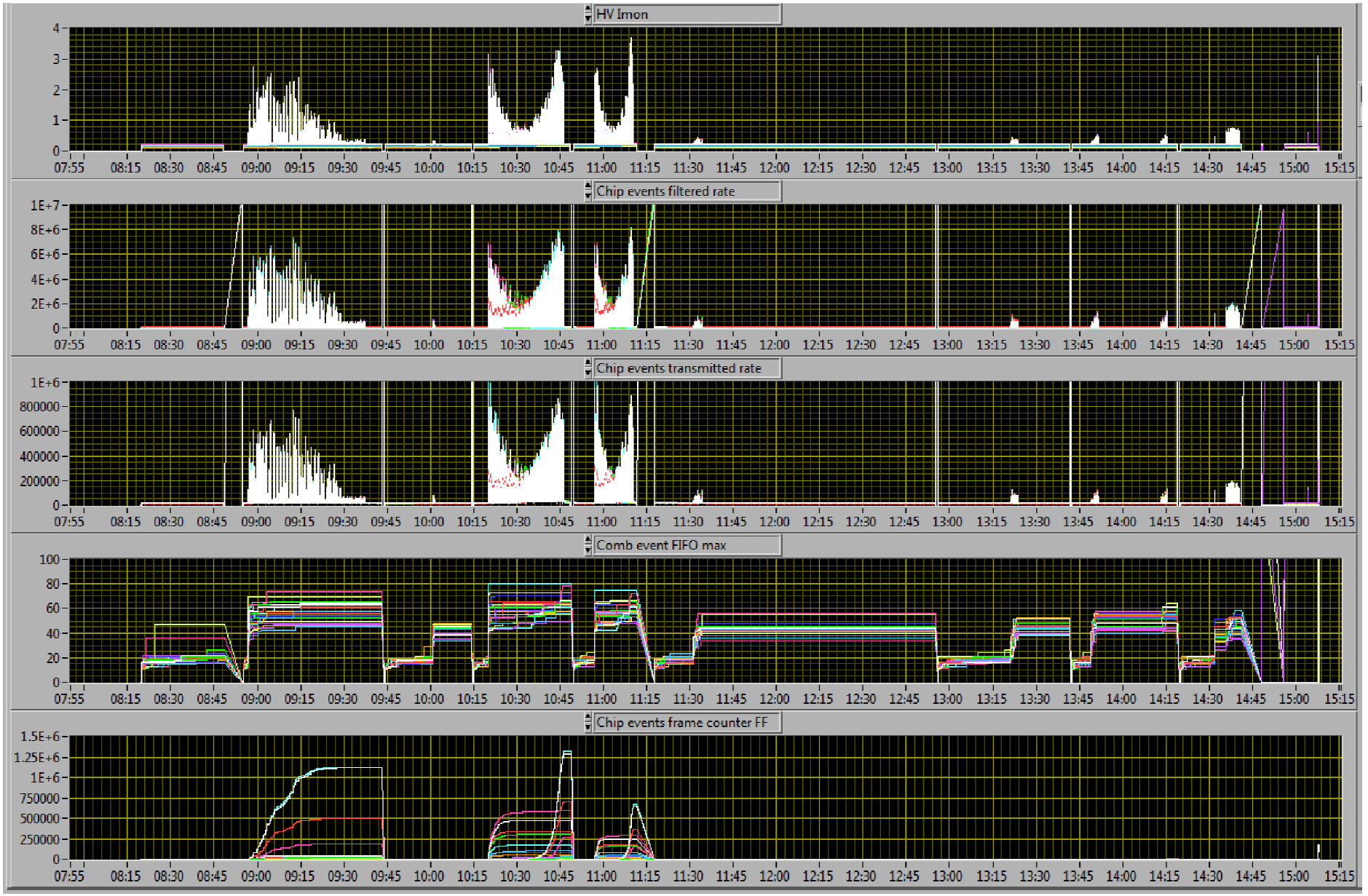
Slow controls program communicates via TCP/IP with independent RSW control server program

Master board, RSW board, Clock distribution board assembly



Assembly intended to be positioned directly beneath lower PET head to minimise exposure to radiation

Module bias current and Tx board online data



Data from 3rd April 2016 beam test

Coincidences finding software: history

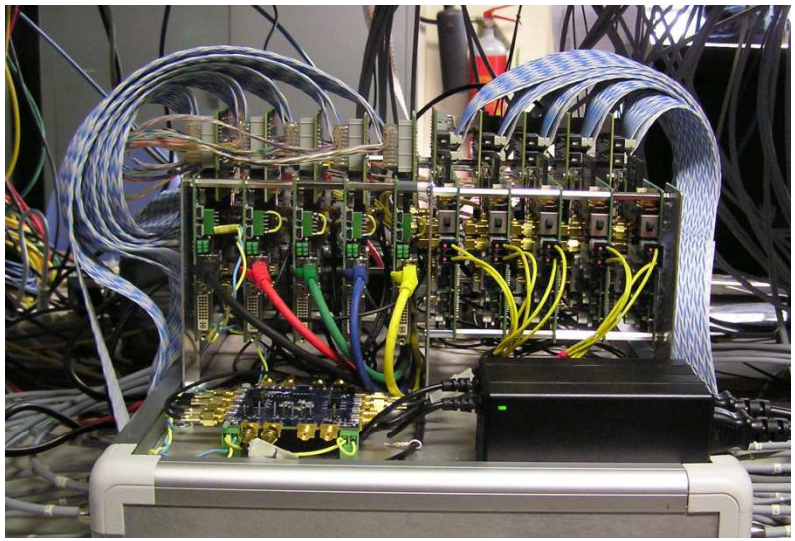
- Late June 2015: development started *from scratch*:
  - Input: LabView-simulated readout, 2 boards data
  - Preliminary data format:
    - Lot of overhead
    - Easy checks (e.g. boards transmit also empty frames)
- October 2015: begin development of second algorithm version
  - New data format:
    - Less overhead
    - *Lot* of checks needed
- November 23, 2015: installation on server:
  - First true multi-core test
- December 14, 2015: INSIDE mounted
  - First version tested with 20 boards background data
- February 4-7, 2016: INSIDE in-beam PET@CNAO, first beam test
  - Program overall OK
  - Must pay attention to TOT window
- March 20-22, 2016: technical beam test:
  - Fixed (last?) annoying bug at high-rate
  - Final CF software
- April 1-7 and June 6-8, 2016 beam test: software successfully used

In-house test time about 1.5 months

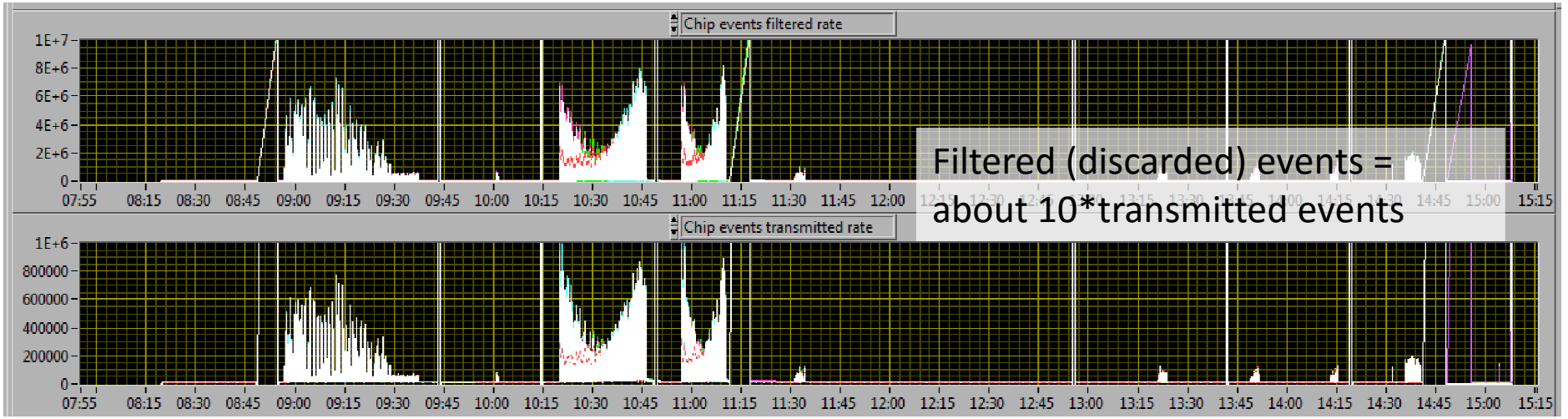
Coincidences finding software: methods

Requirements and issues to face	Strategies adopted
On-line and high rate-> fast software	TOT filter and delays performed by FPGA, almost plain C language, multi-threading (not just parallel algorithms), lock-free, no memory allocation during runtime
Compatibility	BOOST v. 1.54
Bandwidth > 1Gbit/s	Two NIC used for acquisition, TOT filter
(Inspill rate/interspill rate)>10	Memory buffers so as to address avg. rate
Address edge cases in packets handling	Software checks
Frames fragmented in packets, packets asynchronously sent by boards	Three steps in decoding and data processing, thread-safe containers
Accurate Compton filtering vs photopeak stability vs bandwidth	Conservative TOT window on FPGA boards, coincidences TOT saved
On-line monitoring	Coincidences and single-events subset monitoring with GUI, in- and inter-spill discrimination
Data acquisition safety	GUI and coincidence finding software runs on different machines

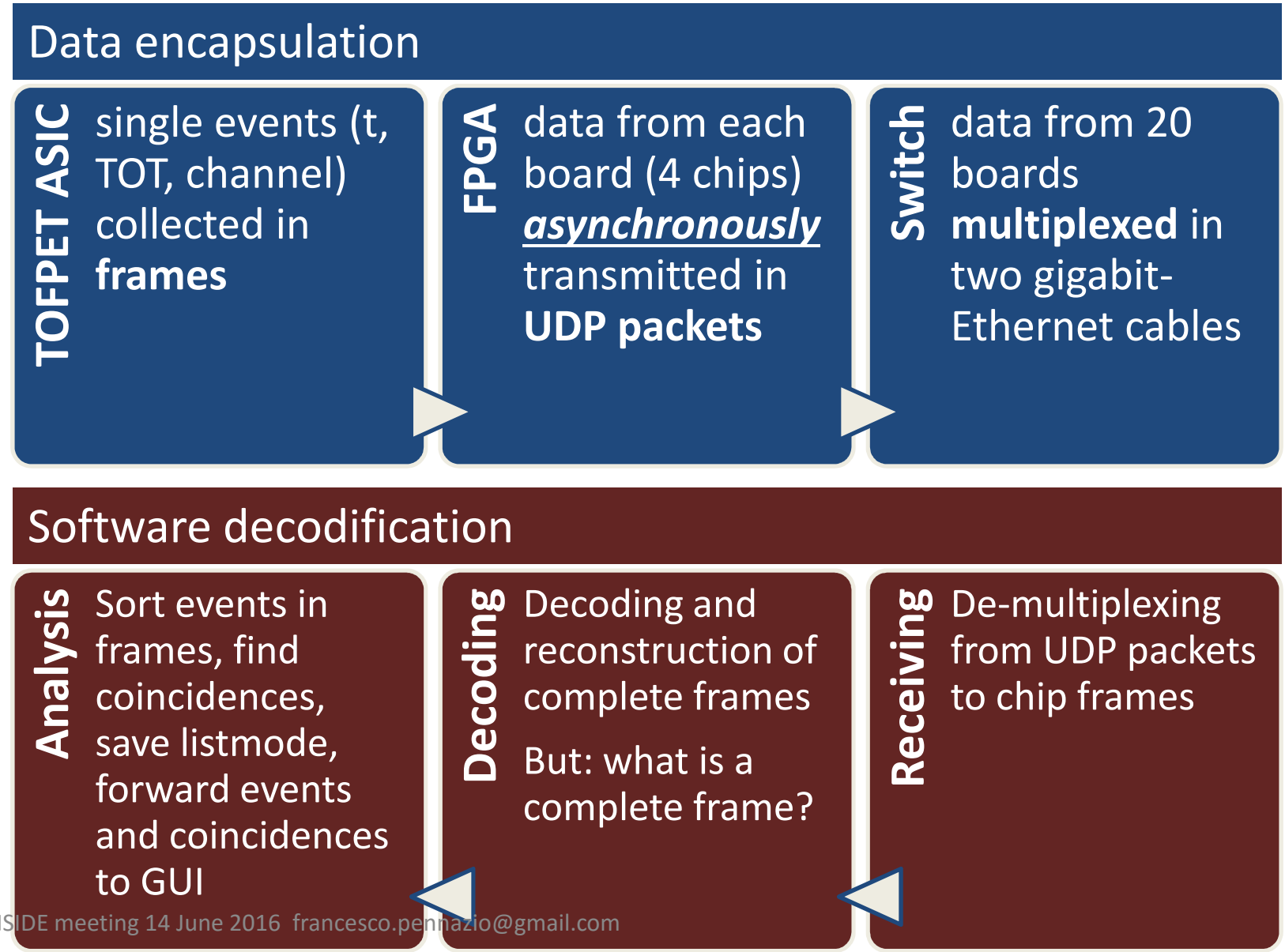
Main (new) firmware functionalities



-TOT filtering
-Data decoding from raw data to decoded format
- Application of delays channel-by-channel

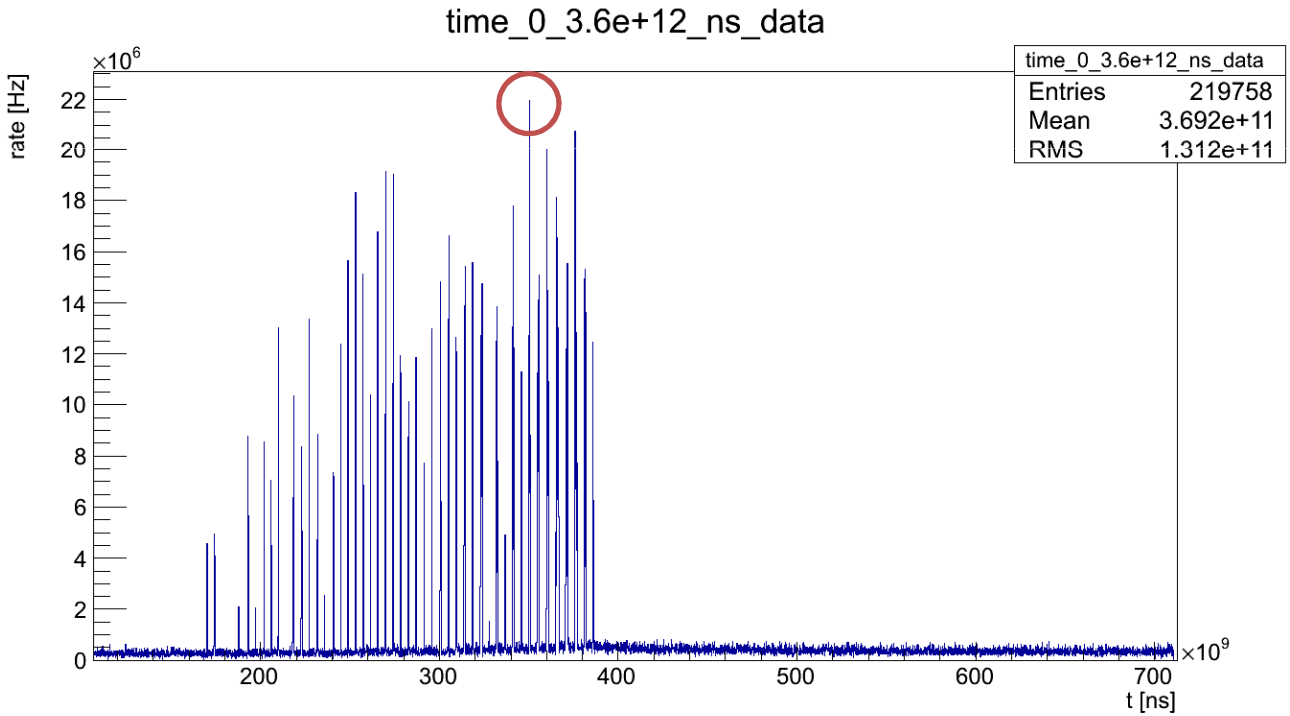


Coincidence finding software: working principle



Coincidence finding software: performance (1)

- Maximum single rate presently detected: 22 MHz, maximum coincidence rate 570 KHz



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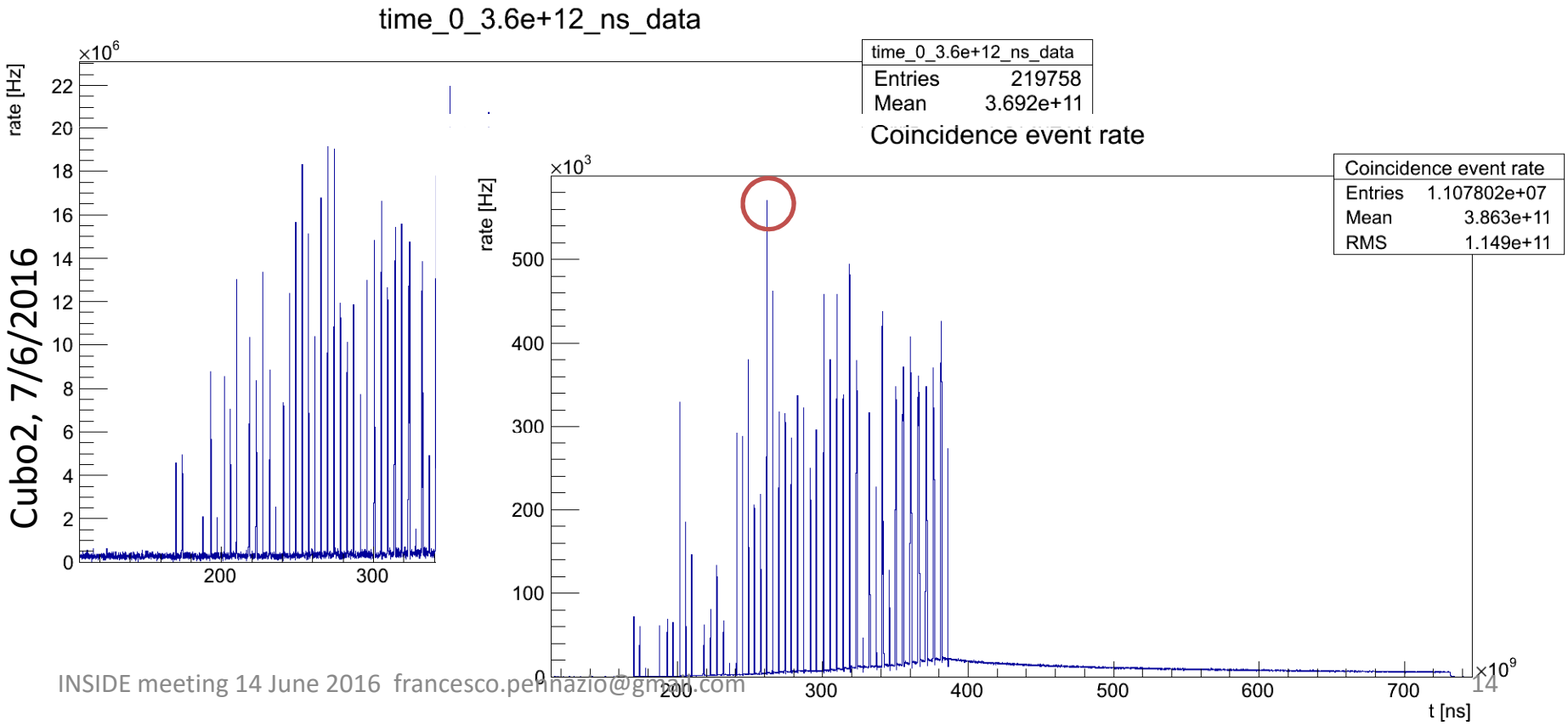


Coincidence finding software: performance (2)

- Program designed to keep running even in the event of data loss (packets-frames-events)
- Log file implemented to monitor performance
- **Data loss is presently about 0.05% (i.e. negligible)**

```
acquisition time 2806.04 s
UDP packets
    read 346738880
    catched 100%
    wrong boardID 0 0%
    lost because full buffer queue 0 0%
    (received+missed) rate 123569 pkt/s
    decoded 346738880
    bad lenght 987
    wrong header (DC check) 0

frames
    received 1119212286
    wrong boardID 18
    right boardID 1119212268
    frameID too big 15
    lost because frame buffer full 0 0%
    lost because slow sender 0 0%
    repeated 239234 0.0213752%
    old fragments missed 1 8.93486e-08%
    filled and analysed 299435877
events
    correctly decoded 1896340159
    lost 757038 0.0399051%
    Time window 2 ns
    Time window (Tfine units) = 61
    singles acquired 1896340159
    coincidences 11422994
    multiple 427830788

sent to monitoring
    frames 146192
```

Performance (3): system limits

What happens at higher rate?

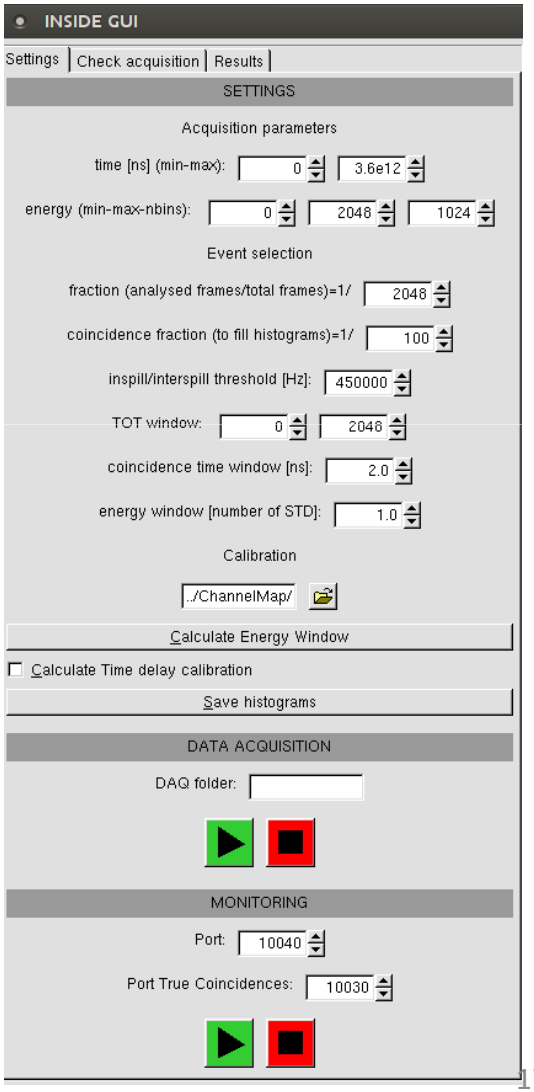
- Actual in-spill particle rate on detectors depends on
  - Projectile particle
  - Beam energy
  - Target position wrt PET heads (distance, axial position)
  - Path length of beam inside the FOV
  - Dose delivery/free beam

Limitations given by HV channels (and possibly TofPET ASIC)

- HV channels cannot provide more than 10 mA
  - With 164 MeV protons, dose delivery on -> OK (about 19cm WEPL)
  - With 218.55 MeV protons, dose delivery on -> OK (with 4 phantoms placed vertically along the beam line)
  - With 227 MeV protons, dose delivery on -> trip
  - With 145 MeV protons, free beam -> trip
- Counter of events/frames discarded inside the ASIC implemented in vi controls

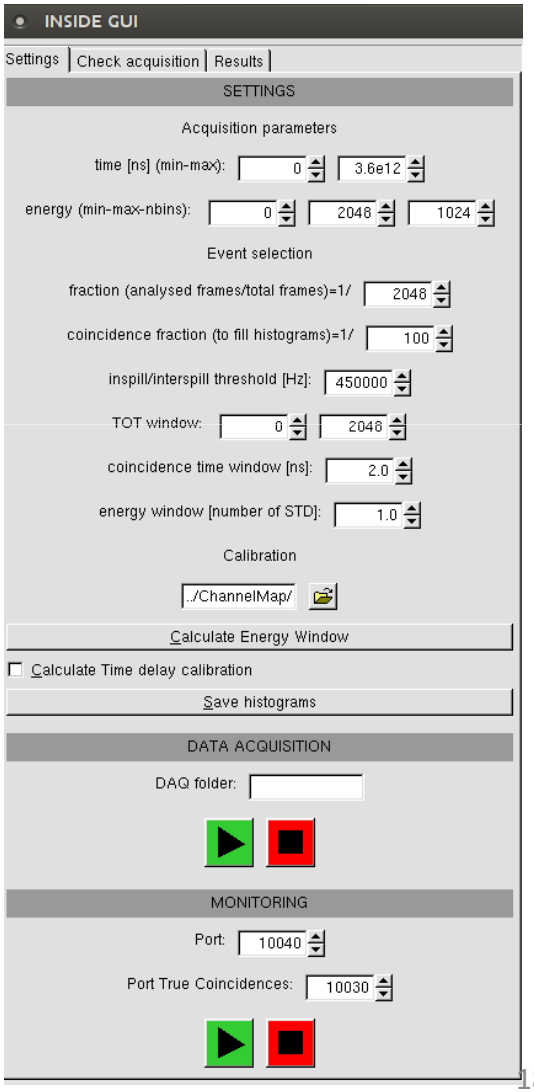
GUI-based on-line monitoring

- INSIDEDAQGui:
  - Application tested during last 5 beam tests
  - On-line in- and inter-spill discrimination
  - Coincidences saved in list-mode compatible for reconstruction



Other GUI features

- INSIDEDAQGui:
  - Calculate EoC-SoC calibration
  - Calibrate delays&TOT window and write calibration file
  - Can load saved histograms
  - >It can be used for fine TOT windows calibration off-line as soon as data are saved



Analysis programs

- INSIDEWriteLORfile :
  - Can be launched as soon as servers save LOR files
  - Reconstructs the image with all LOR available
  - Analyses all coincidences saved
  - Can apply finer coincidence windows
  - Can select the analysis time
  - Produces listmode coincidences files compatible with reconstruction program

```
francesco@mag07xl:~$ INSIDEWriteLORfile -h
Program to analise DAQ data and write LORfile for image reconstruction, usage::
  -h [ --help ]                Produce this help message
  -L [ --LORFile(s) ] arg      Input DAQ LORFile(s) (.bin)
  -G [ --RootFile ] arg        GUI root file (forwarded data) needed for
                               inspill/interspill threshold
  -C [ --ChannelMap ] arg      /ChannelMap.txt
  -w [ --coincWindow ] arg     Sets coincidence window (default: 2ns)
  -b [ --BuildHisto ]          [optional!] Creates a histogram Root file with
                               DAQ data
  -r [ --EnergyWindow ] arg    [optional!] Applies new energy window to data,
                               /EnergyWindow.txt
  -i [ --startTime ] arg       [optional!] Cuts DAQ data from time startTime (s)
  -e [ --endTime ] arg         [optional!] Cuts DAQ data to time endTime (s)
  -t [ --spillThreshold ] arg [optional!] Threshold (Hz) to discriminate in-
                               and inter-spill data, default 450000
```

Analysis programs

Other programs developed to analyze images, based Insight Segmentation and Registration Toolkit

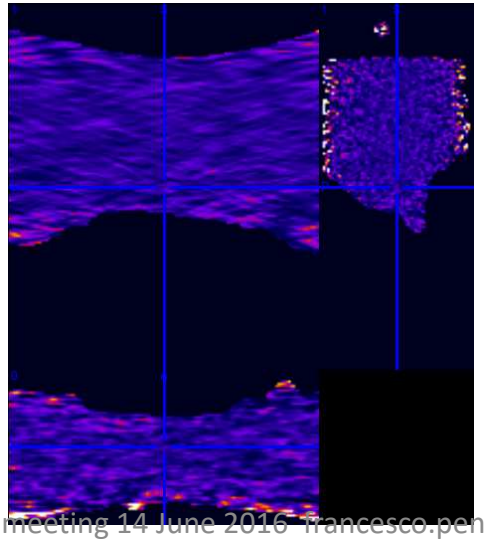
- INSIDEAnalyseImageProfile:
  - Compare several images
  - Z and Y profiles on selectable region
  - Calculate range with sigmoid in the interval specified by user

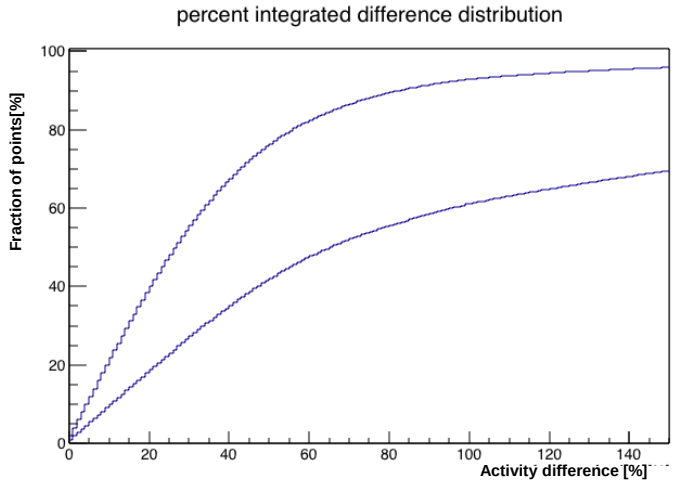
```
francesco@mag07xl:~$ INSIDEAnalyseImageProfile
Program to analyse reconstructed PET images, usage::
  -h [ --help ]                       Produce this help message
  -r [ --ReconstructedImage(s) ] arg  3D PET reconstructed image(s) (.nii)
  -l [ --Plane ]                      Profile centered in (xIndex,yIndex), along
                                      a plane in y (number of slices to be
                                      considered set by opt w)
  -p [ --Prism ]                      Profile centered in (xIndex,yIndex), prism
                                      with cubic base (number of slices to be
                                      considered set by opt w)
  -w [ --Width ] arg                  [optional!] Half number of slices to be
                                      considered in the profiles (default:
                                      ImgDimY/2)
  -v [ --VoxelSize ] arg              [optional!] Voxel dimension (default:
                                      0.16cm)
  -x [ --xIndex ] arg                 [optional!] x position (slice) to
                                      calculate profiles (default: ImgDimX/2)
  -y [ --yIndex ] arg                 [optional!] y position (slice) to
                                      calculate profiles (default: ImgDimY/2)
  -b [ --fitRangeBegin ] arg          [optional!] Initial z coordinate for
                                      sigmoid fit
  -e [ --fitRangeEnd ] arg            [optional!] Final z coordinate for sigmoid
                                      fit
```

Analysis programs

Other programs developed to analyze images, based Insight Segmentation and Registration Toolkit

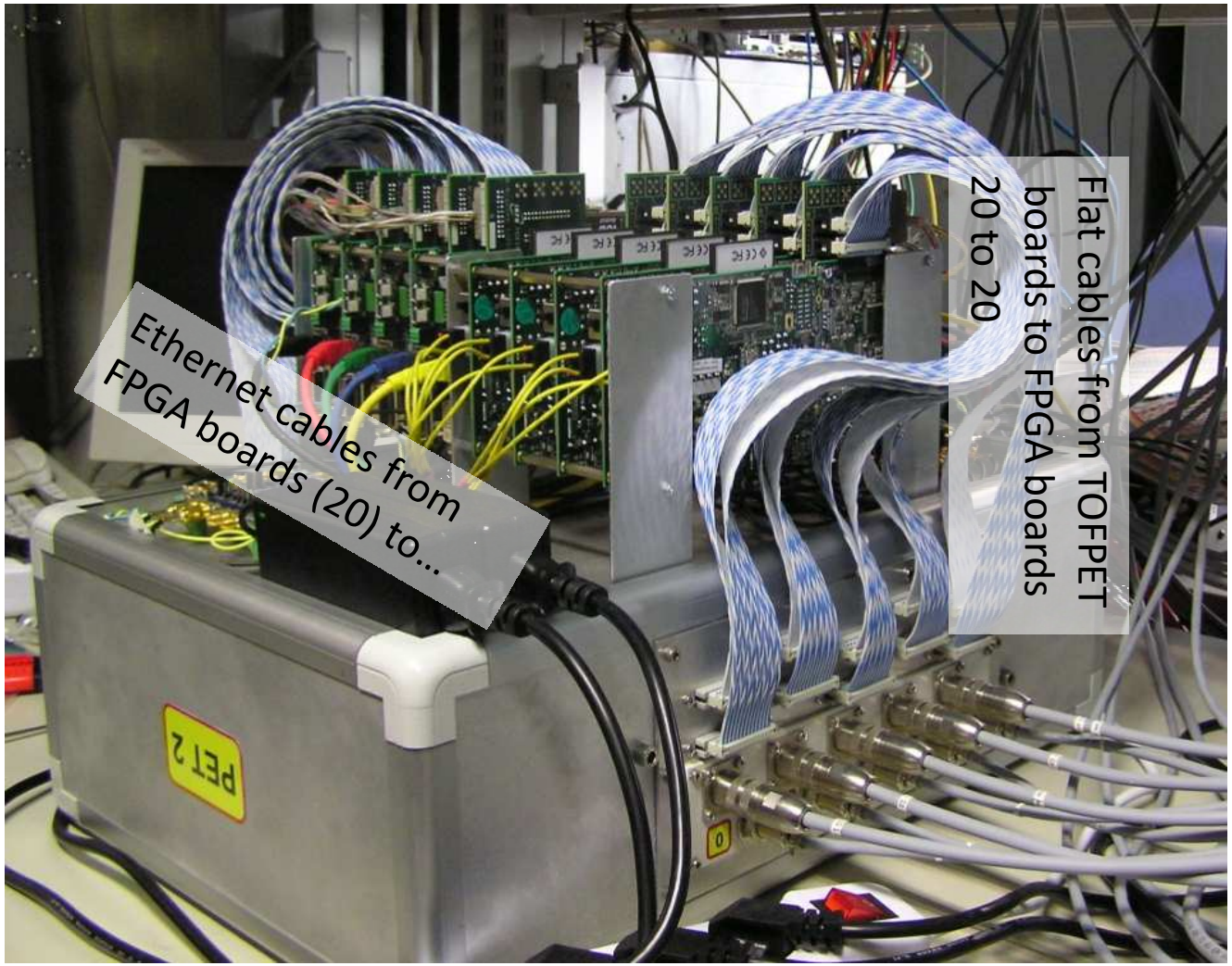
- INSIDECompareDataSim
  - Performs 3D image comparison
  - Calculate image of the difference to help visually the user
  - More features under development





Backup slides

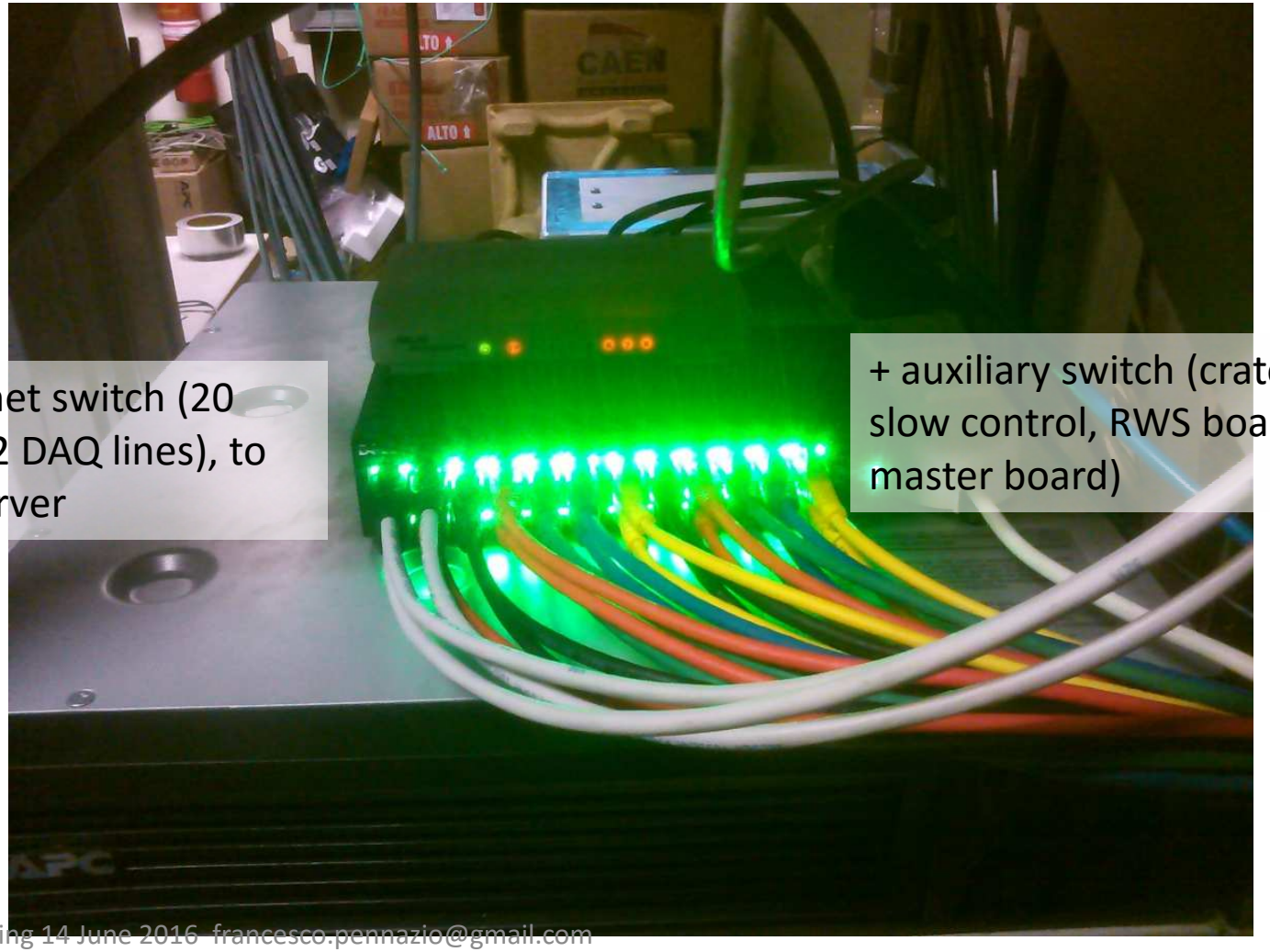
DAQ scheme


Ethernet cables from
FPGA boards (20) to…
Flat cables from TOFPET
boards to FPGA boards
20 to 20
PET 2

DAQ scheme

DAQ scheme

…to Ethernet switch (20 boards to 2 DAQ lines), to 32-core server



+ auxiliary switch (crate, slow control, RWS board, master board)