INSIDE in-beam PET
Software & Simulation

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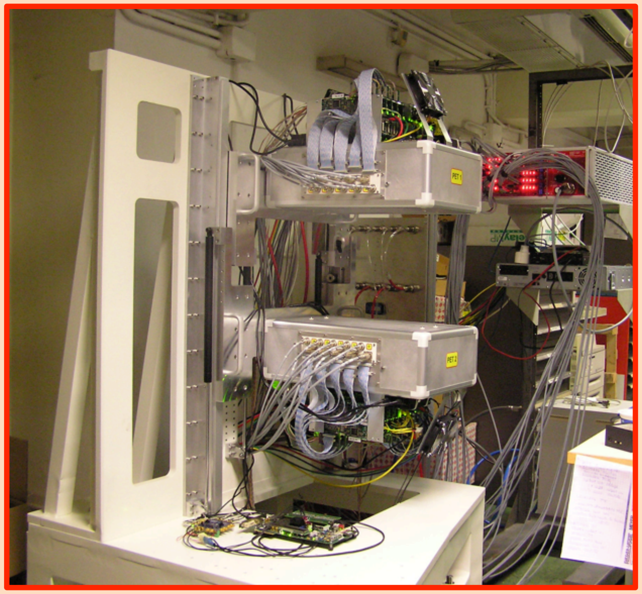
INSIDE meeting, Pisa, January 20th 2016

Torino Group's SW Tasks

INSIDE in-beam PET
10vs10 modules
was built!



JANUARY 2016

Data AcQuisition (DAQ)

Decided in the meeting in June 2015

- Acquisition of in-spill and inter-spill
- Online analysis
- Sending data to monitoring SW (singles & coincidences)

Online Monitoring - GUI

Available 1vs1 version, raw data

- Update to 10vs10 and data format
- Calibration functionalities
- Online monitoring on true coincidence data

Simulation

Distal fall off validated

-Coincidence rate validation

Data AcQuisition (DAQ)

ACQUISITION OF IN-SPILL AND INTER-SPILL DATA

① To reduce the transmitted event rate ➔ The energy window filter and the time delay calibration have been implemented in the TX boards firmware and the decoded data format has been optimized.
② To design and implement a task-dedicated SW ➔ Multi-threading and scalable approach, C/BOOST based.
③ To increase ethernet bandwidth, computational power and RAM memory ➔ Use a server with 3 Gigabit NIC, 128 GB RAM, 16 cores (32 with HyperThreading).

ONLINE ANALYSIS

① Only coincidences time-tagged are saved by the DAQ SW.
② Report on the DAQ SW performance.

SENDING DATA TO MONITORING SW VIA UDP PROTOCOL

① To send singles to verify system performance and separate in-spill/inter-spill data.
② To send time-tagged true coincidences to obtain in-spill/inter-spill images and monitor the system performance in coincidence

First decoded data format

```
UDP header
header[0] =  0xDC;
header[1] =  0xBA + boardID;
header[2] = (packetNumber & 0xff000000) >> 24);
header[3] = (packetNumber & 0x00ff0000) >> 16);
header[4] = (packetNumber & 0x0000ff00) >> 8);
header[5] = (packetNumber & 0x000000ff);
header[6] = ((eventBytes & 0xff00) >> 8);
header[7] = ((eventBytes & 0x00ff);

Data is formatted in groups of 3 bytes.
First byte is always
Bit 7 downto 4:  Not used
Bit 3 downto 1:  Chip
Bit 0:           Frame start

The remaining two bytes can be:

Frame start [case (bits 19 downto 16)]
case "0000": frame_ID(11 downto 0)
case "0001": frame_ID(23 downto 12)
case "0010": "0000" & frame_ID(31 downto 24)

Event
case "0011”: TOT(5 downto 0) & channel(6 downto 0)
case "0100": Tcoarse(6 downto 0) & TOT(10 downto 6)
case "0101": Etime > Ttime & Tfine(7 downto 0) &
     Tcoarse(9 downto 7)

Frame end
case "0110": frame_ID(4 downto 0) & num_events(6
     downto 0)
case "0111": frame_ID(16 downto 5)
case "1000": frame_ID(28 downto 17)
```

	First format
UDP header	8 bytes
Frame start	9 bytes
Event	9 bytes
Frame end	9 bytes

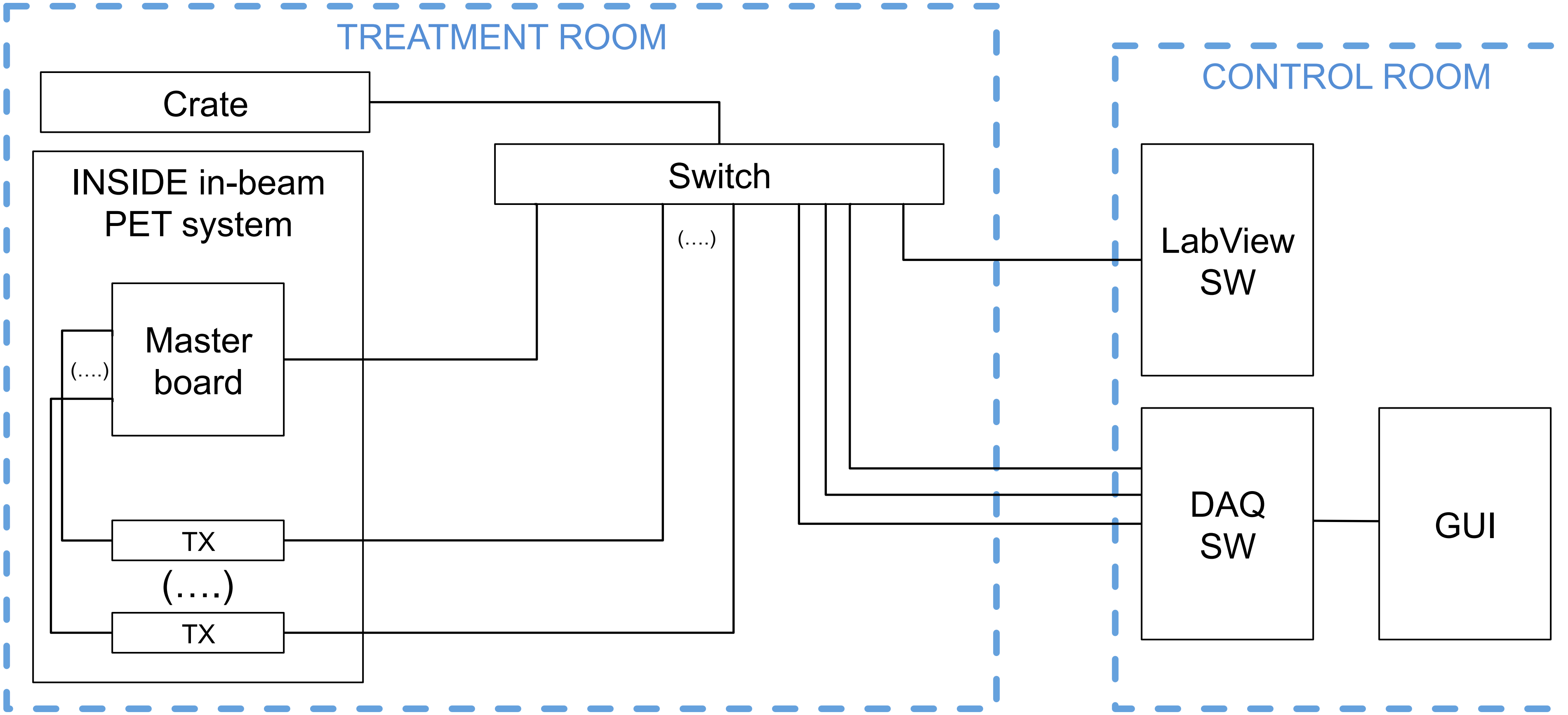
```
UDP header
header[0] =  0xBA + boardID;
header[1] =  0xDC;
header[2] = ((eventBytes & 0x00ff);
header[3] = ((eventBytes & 0xff00) >> 8);
header[4] = (packetNumber & 0x000000ff);
header[5] = (packetNumber & 0x0000ff00) >> 8);
header[6] = (packetNumber & 0x00ff0000) >> 16);
header[7] = (packetNumber & 0xff000000) >> 24);

Frame start
Byte0(7 downto 6) <= "00"
Byte0(5 downto 0) <= "000000”
Byte1(7) <= '0'
Byte1(6 downto 2) <= boardID
Byte1(1 downto 0) <= chipID
Byte2(7 downto 0) <= FrameID(7 downto 0)
Byte3(7 downto 0) <= FrameID(15 downto 8)
Byte4(7 downto 0) <= FrameID(23 downto 16)
Byte5(7 downto 0) <= FrameID(31 downto 24)

Event
Byte0(7) <= '1'
Byte0(6 downto 5) <= ”00”
Byte0(4 downto 3) <= TAC
Byte0(2 downto 0) <= TOT(10 downto 8)
Byte1(7 downto 0) <= TOT(7 downto 0)
Byte2(7 downto 6) <= chip
Byte2(5 downto 0) <= channel
Byte3(7 downto 6) <= Tfine(1 downto 0)
Byte3(5) <= Etime > Ttime
Byte3(4 downto 0) <= board
Byte4(7 downto 6) <= Tcoarse(1 downto 0)
Byte4(5 downto 0) <= Tfine(7 downto 2)
Byte5(7 downto 0) <= Tcoarse(9 downto 2)
```

New decoded data format

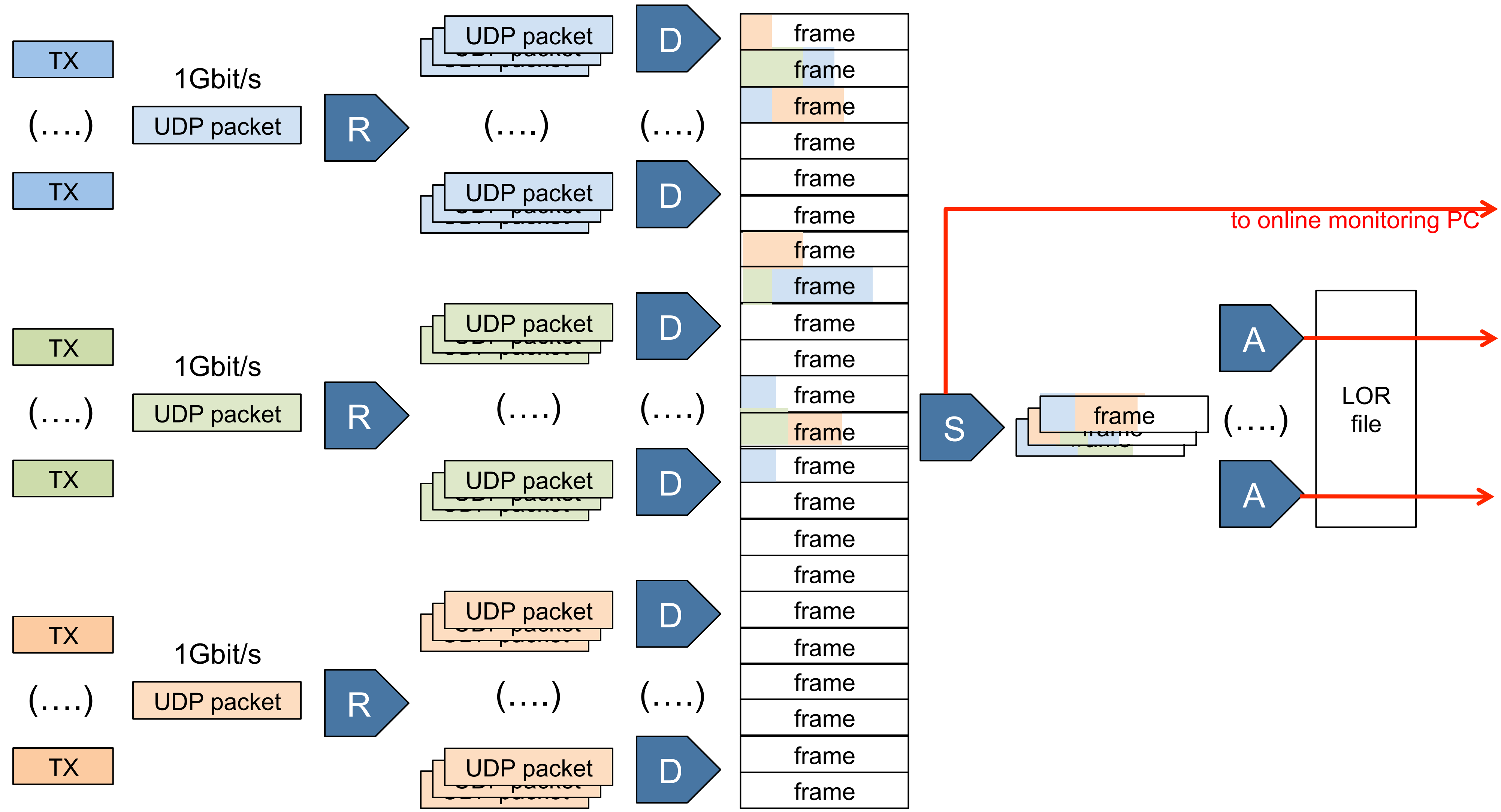
The new decoded data format was designed to:
1) Reduce the overhead.
2) Give the necessary information to sort and find coincidences as fast as possible

	First format	New format
Frame start	9 bytes	6 bytes
Event	9 bytes	6 bytes
Frame end	(9 bytes)	(6 bytes)
Bandwidth 10 evts x frame x TX	1.86Gbit/s	1.24Gbit/s
	Raw format	New format
Bandwidth 10vs10 background	208 Mbit/s	112 Mbit/s

System configuration, Data Acquisition and monitoring set up



Switch: 24-port Gigabit + 8 port Gigabit
Control PC (desktop)
DAQ Server: 32 cores HT, 128 GB RAM
Monitoring PC: 4 cores, 6 Gb RAM (desktop)



20 TX 3 RECEIVERS 20 DECODERS 1 SENDER 8 ANALYSERS

The DAQ software was tested with dummy events at a data rate of 0.7Gbit/s (partial configuration: 2 modules, 1R-2D-1A)

Data AcQuisition (DAQ)

The energy window filter and the delay time calibration has been implemented in the TX board firmware.
A new decoded data format was designed to reduce data overhead and speed up the coincidence finding.
A multi-threading DAQ software was designed and implemented to satisfy project requirements and it has been already tested with dummy events (partial geometry) and background signal.

NEXT STEPS

① FDG sources available from the IRCC (Candiolo, TO) to forward test the DAQ performance and to calibrate the INSIDE in-beam PET system
② Test DAQ performance at very high rate with dummy events

Online Monitoring - GUI

UPDATE SW TO 10VS10 GEOMETRY AND TO DECODED DATA FORMAT

① To check acquisition parameters and analyse singles.
② To analyse true coincidences.

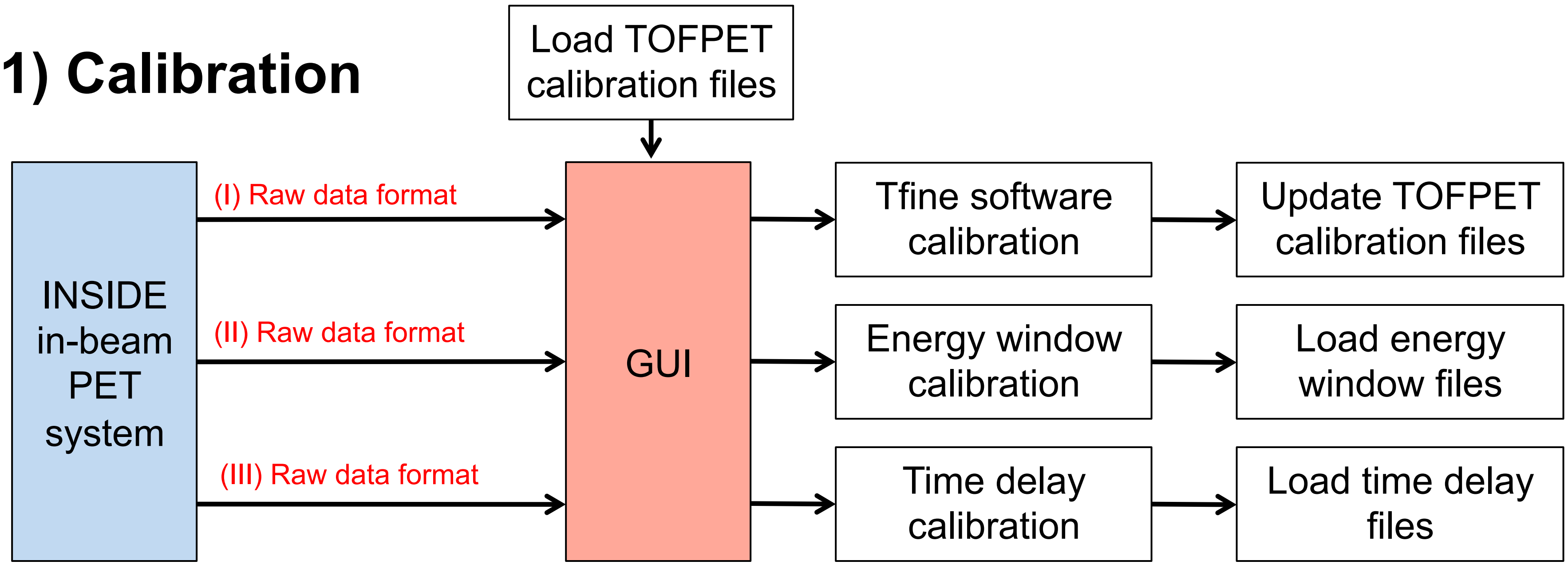
AUTOMATIC CALIBRATIONS

① To calibrate via software T fine, TAC by TAC, raw data format.
② To select energy window, channel by channel, raw data format.
③ To calibrate time delay, channel by channel, raw data format.

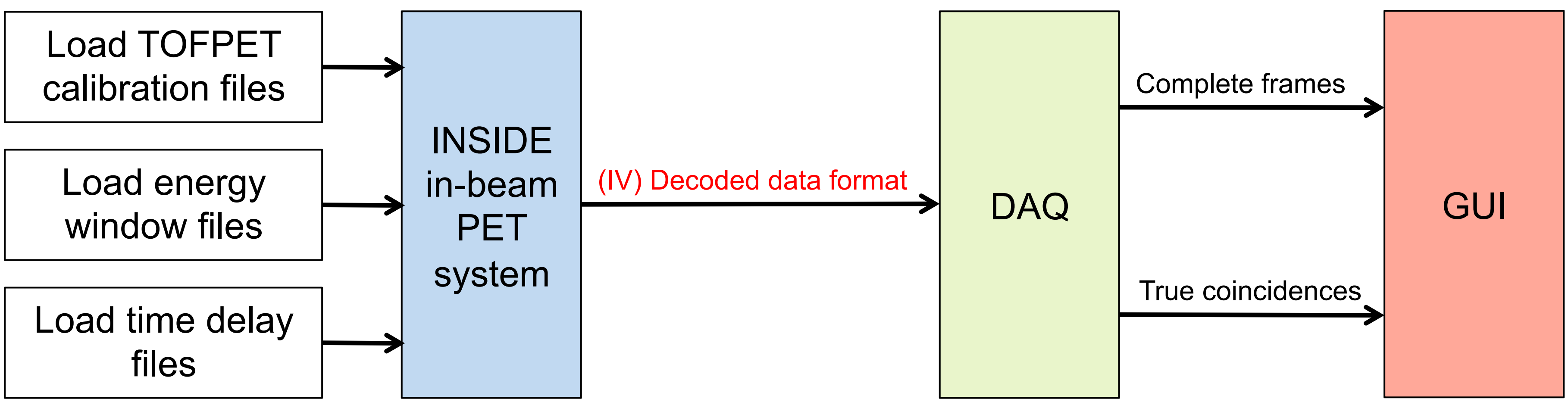
ONLINE MONITORING ON TRUE COINCIDENCE DATA

① To divide true coincidences by using single event rate distribution
② To evaluate system performance in coincidence (e.g. CTR)

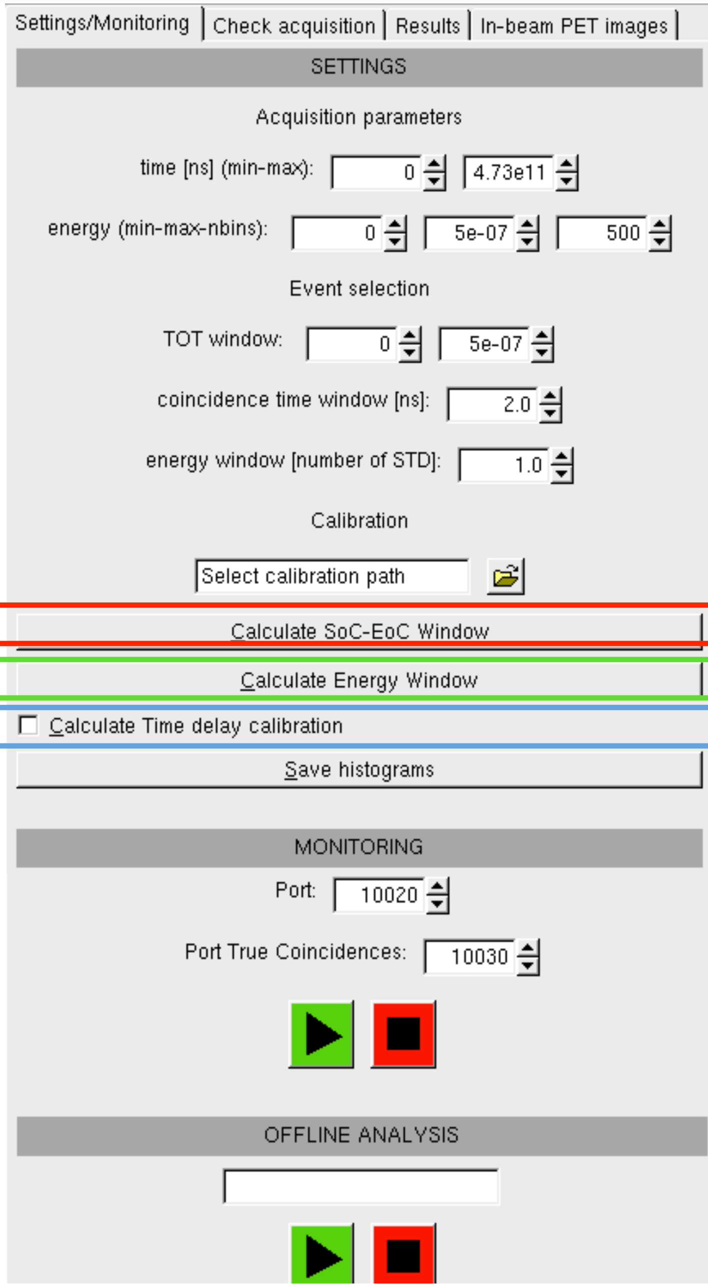
1) Calibration



2) Acquisition



Raw data format



Monitored quantities

Check acquisition
(chip by chip)
Frame multiplicity

(channel by channel)
Inspill/Interspill Tcoarse
Inspill/Interspill Ecoarse
Inspill/Interspill Tfine
Inspill/Interspill Efine
Inspill/Interspill Tcoarse in coincidence
Inspill/Interspill Tfine in coincidence

(TAC by TAC)
EoC-SoC T
EoC-SoC E

Results
(general)
Single distribution
Single event rate
Coincidence event rate
Coincidence Time Resolution (CTR)
Inspill/Interspill Coincidence Time Resolution (CTR)
Coincidence map on head

(channel by channel)
CTR
TOT (not calibrated)
Inspill/Interspill TOT
TOT in coincidence
Inspill/Interspill TOT in coincidence

Online Monitoring - GUI

The monitoring software was updated to the 10vs10 geometry and to new decoded data format.
An automatic calibration procedure was implemented to obtain fully calibrated decoded data from the final system configuration.

NEXT STEPS

① To test the GUI performance with the FDG source.
② To calibrate the INSIDE in-beam PET system.

Simulation

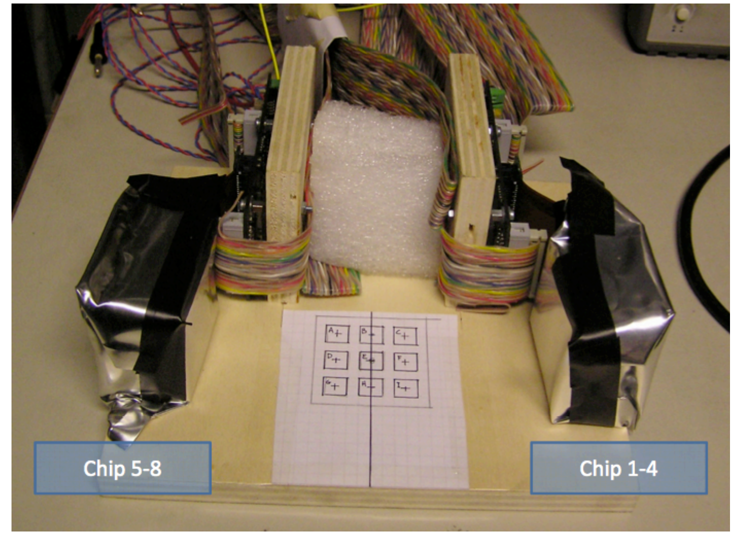
COINCIDENCE RATE VALIDATION

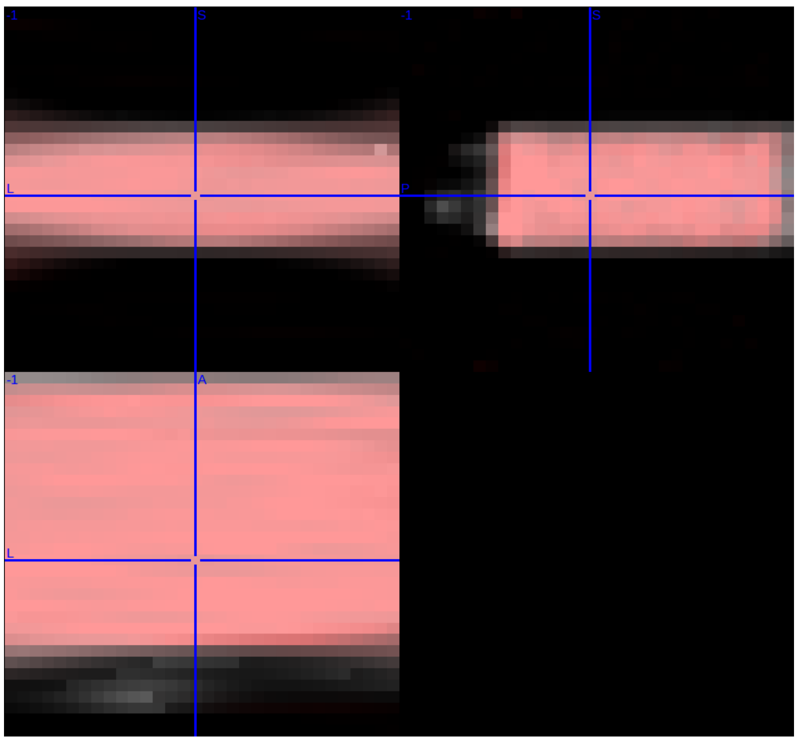
① To check Lutetium Fine Silicate (LFS) formula.

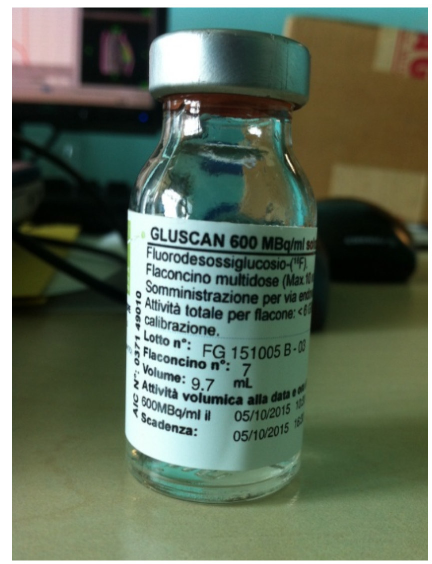
② Results for F18-FDG and 1vs1 INSIDE geometry (data acquired at the CNAO in May 2015)

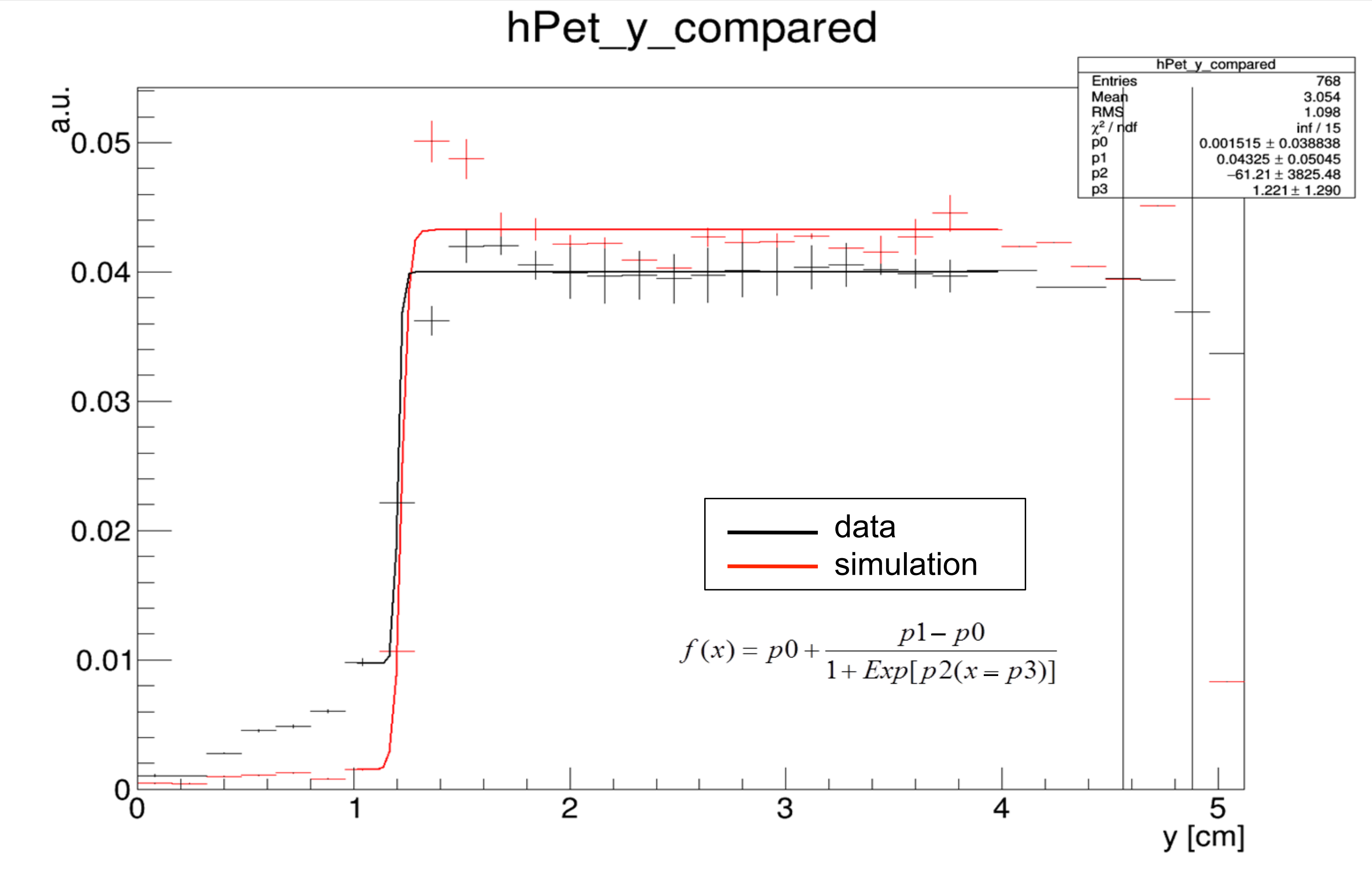
F18-FDG measurement validation – Candiolo 2015

Problems:
- Vial characteristics
- LFS atomic composition



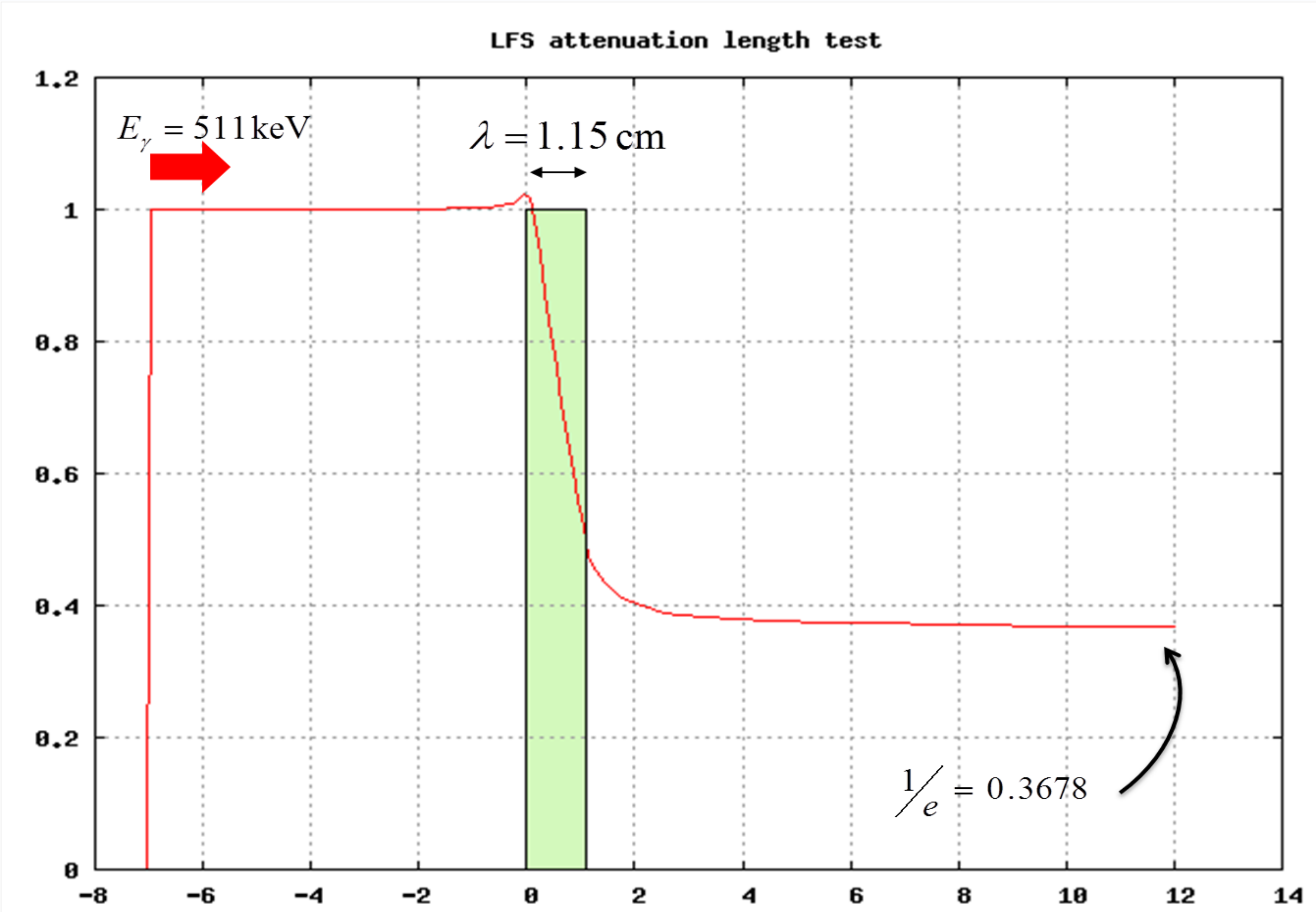


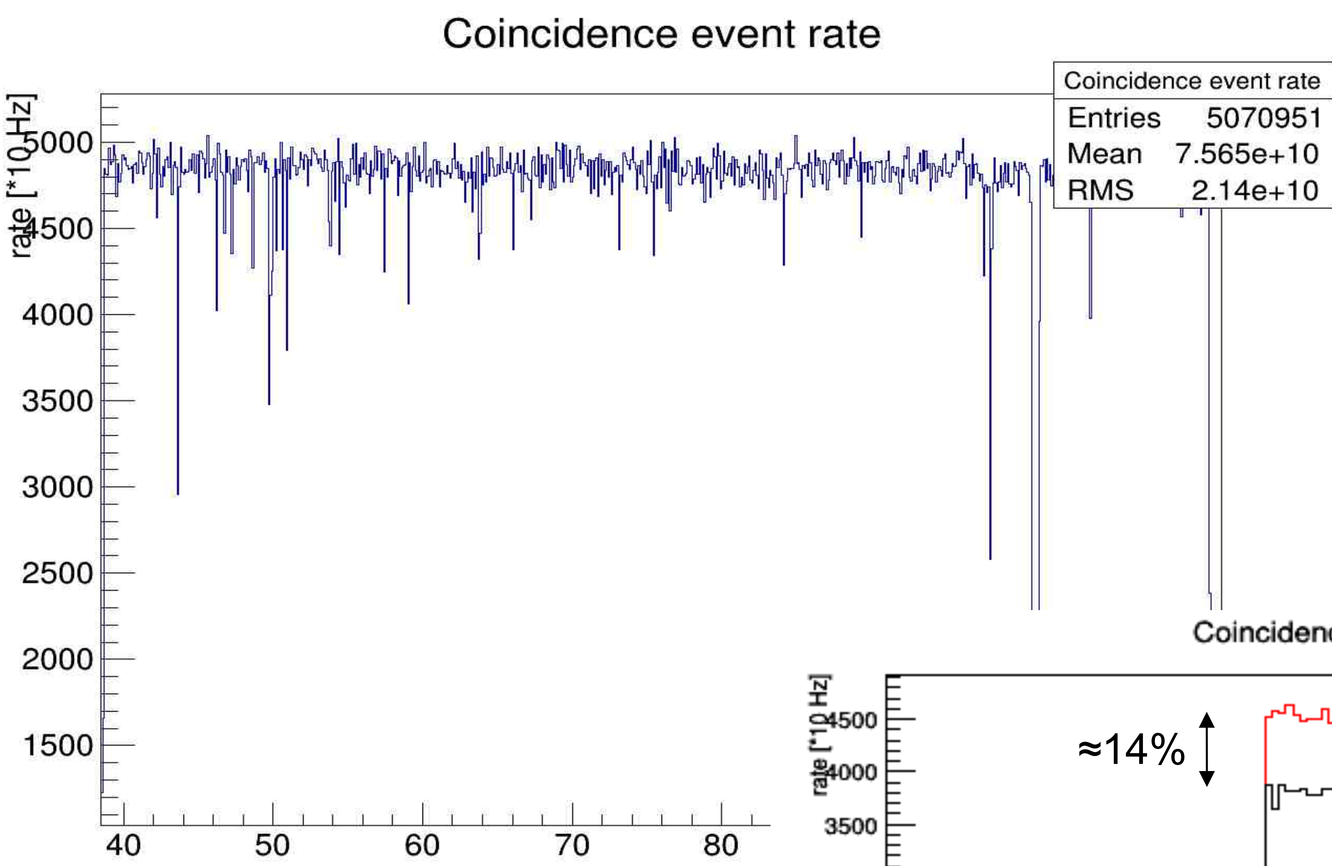


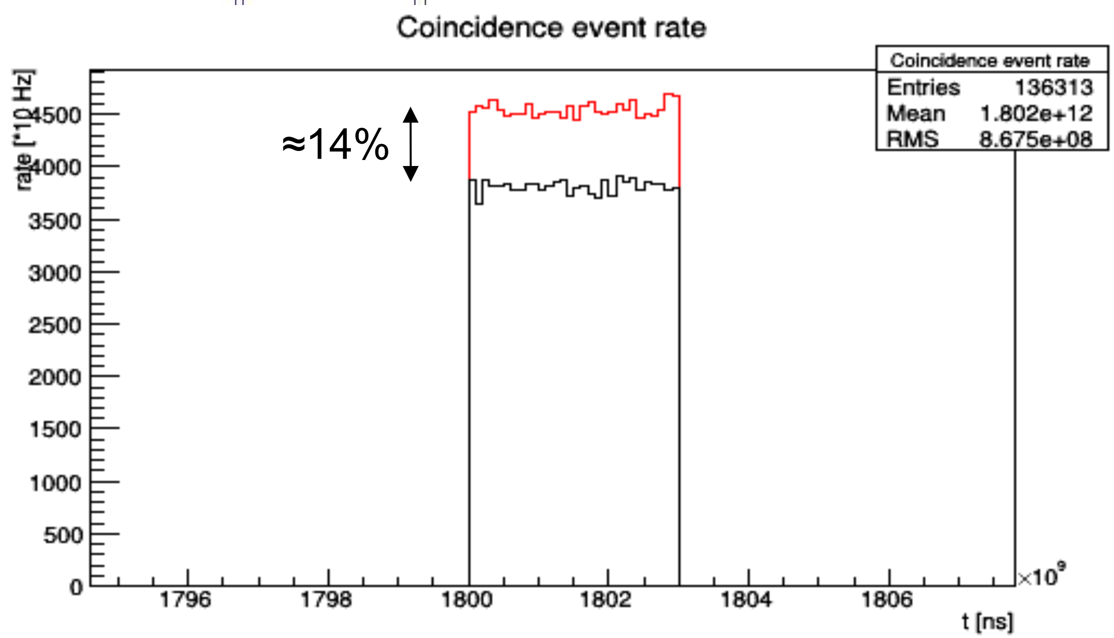

hPet_y_compared
a.u.
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
y [cm]
hPet_y_compared
Entries 768
Mean 3.054
RMS 1.098
χ² / ndf inf / 15
p0 0.001515 ± 0.038838
p1 0.04325 ± 0.05045
p2 −61.21 ± 3825.48
p3 1.221 ± 1.290
data
simulation
$f(x) = p0 + \frac{p1 - p0}{1 + Exp[p2(x = p3)]}$

- LFS atomic composition: photoelectric effect evaluation (FLUKA)

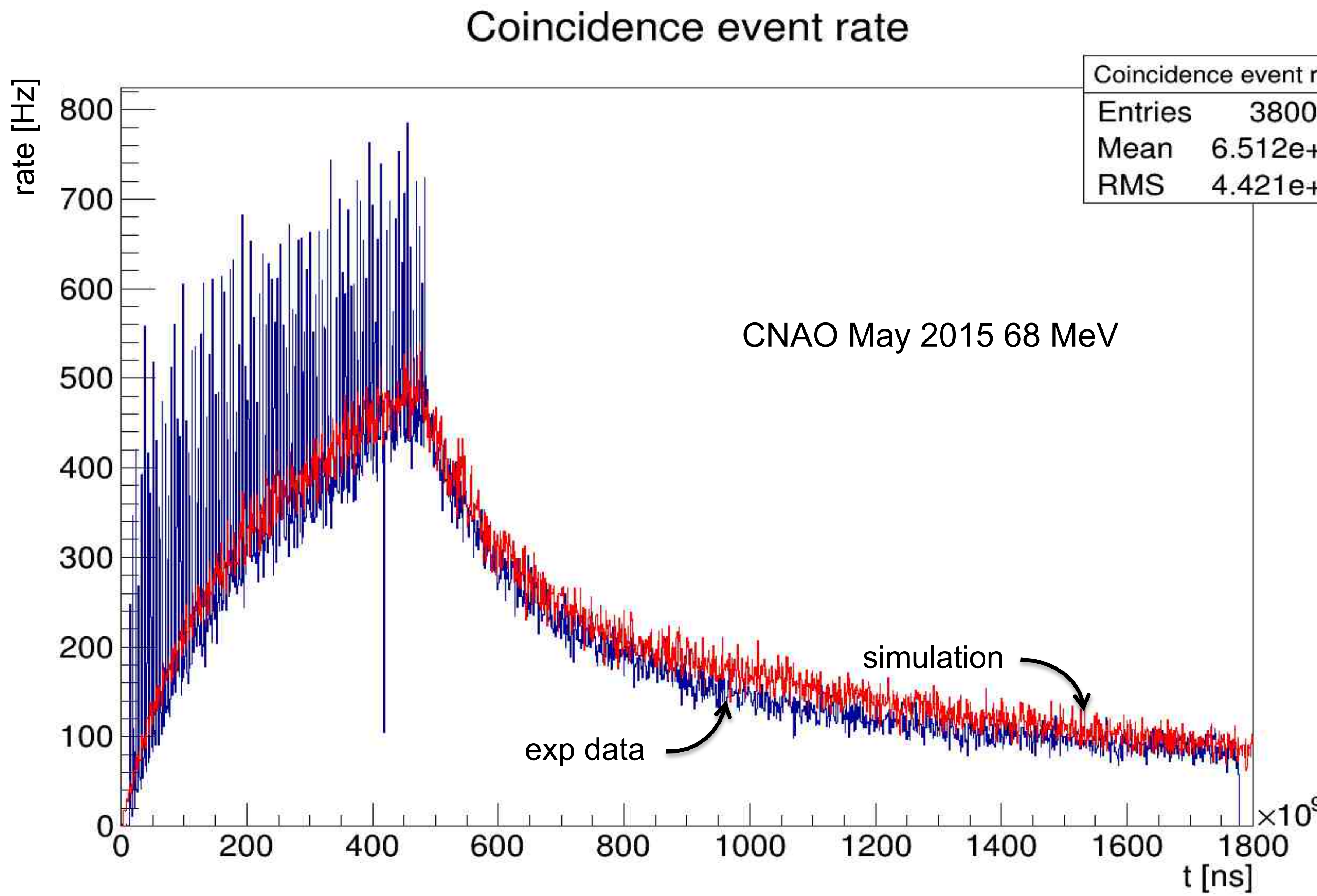
	LSO	LFS
ρ (g cm**-3)	7.4	7.35
Attenuation length (cm)	1.15	1.15
LUTETIUM	2.0	4.0
OXYGEN	5.0	3.0
SILICON	1.0	0.2


LFS attenuation length test
$E_\gamma = 511\,\mathrm{keV}$
$\lambda = 1.15\,\mathrm{cm}$
$1/e = 0.3678$
1.2
1
0.8
0.6
0.4
0.2
0
-8
-6
-4
-2
0
2
4
6
8
10
12
14





6% discrepancy w/ exp. data: vial characteristics (approximations), unknown glass composition, possible FDG drop



Coincidence event rate
Coincidence event rate
Entries 380008
Mean 6.512e+11
RMS 4.421e+11
rate [Hz]
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
1800
×10^9
t [ns]
CNAO May 2015 68 MeV
simulation
exp data

Simulation

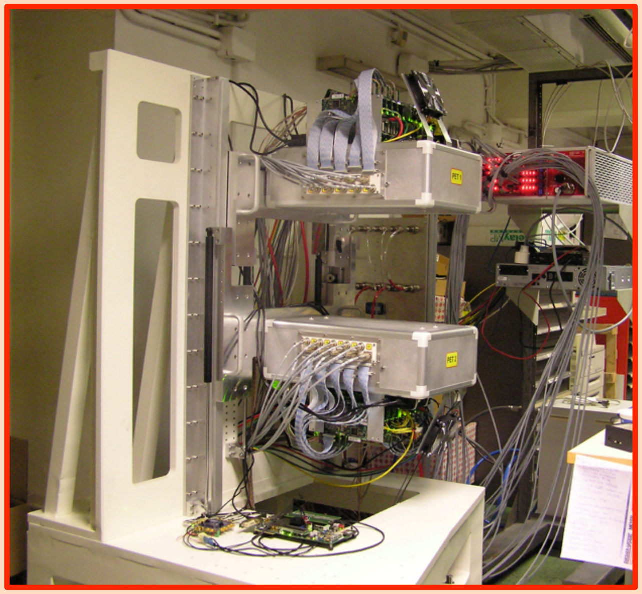
Both the profile distal fall-off in the final in-beam PET image and the coincidence event rate have been validated.

NEXT STEPS

① Next beam test simulations.
② Simulation of carbon beams.

Torino Group's SW Tasks

INSIDE in-beam PET
10vs10 modules
was built!



JANUARY 2016

Data AcQuisition (DAQ)

- ✓ Decoded data format
- ✓ Multi-threading DAQ software
- ✓ Online data analysis
- ✓ Monitoring via UDP protocol

Online Monitoring - GUI

- ✓ Updated GUI sw (10vs10)
- ✓ Improved automatic calibrations
- ✓ Online monitoring on singles
- ✓ Online monitoring on true coincidence data

Simulation

- ✓ Coincidence rate validation