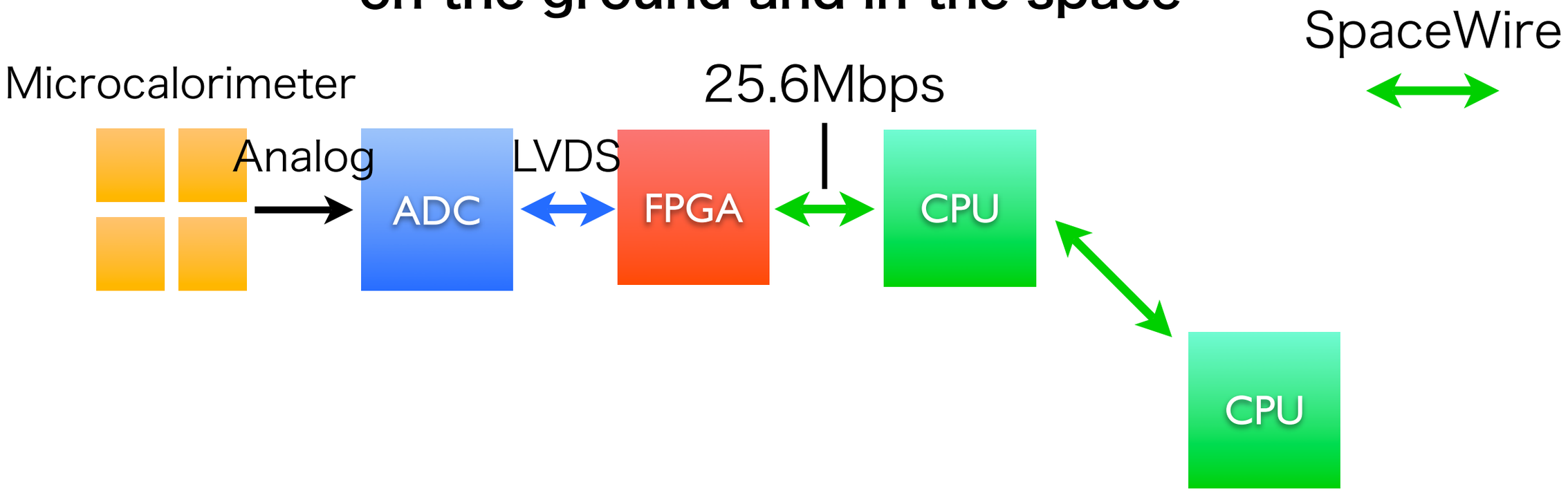
Digital signal processing systems of an X-ray microcalorimeter array for ground and space applications

T. Hagihara,
K. Mitsuda, N. Y. Yamasaki, Y. Takei, H. Odaka(ISAS/JAXA)
M. Nomachi(Osaka University), T. Yuasa(University of Tokyo)

Overview

Microcalorimeter DAQ system adapted to high count rate

on the ground and in the space



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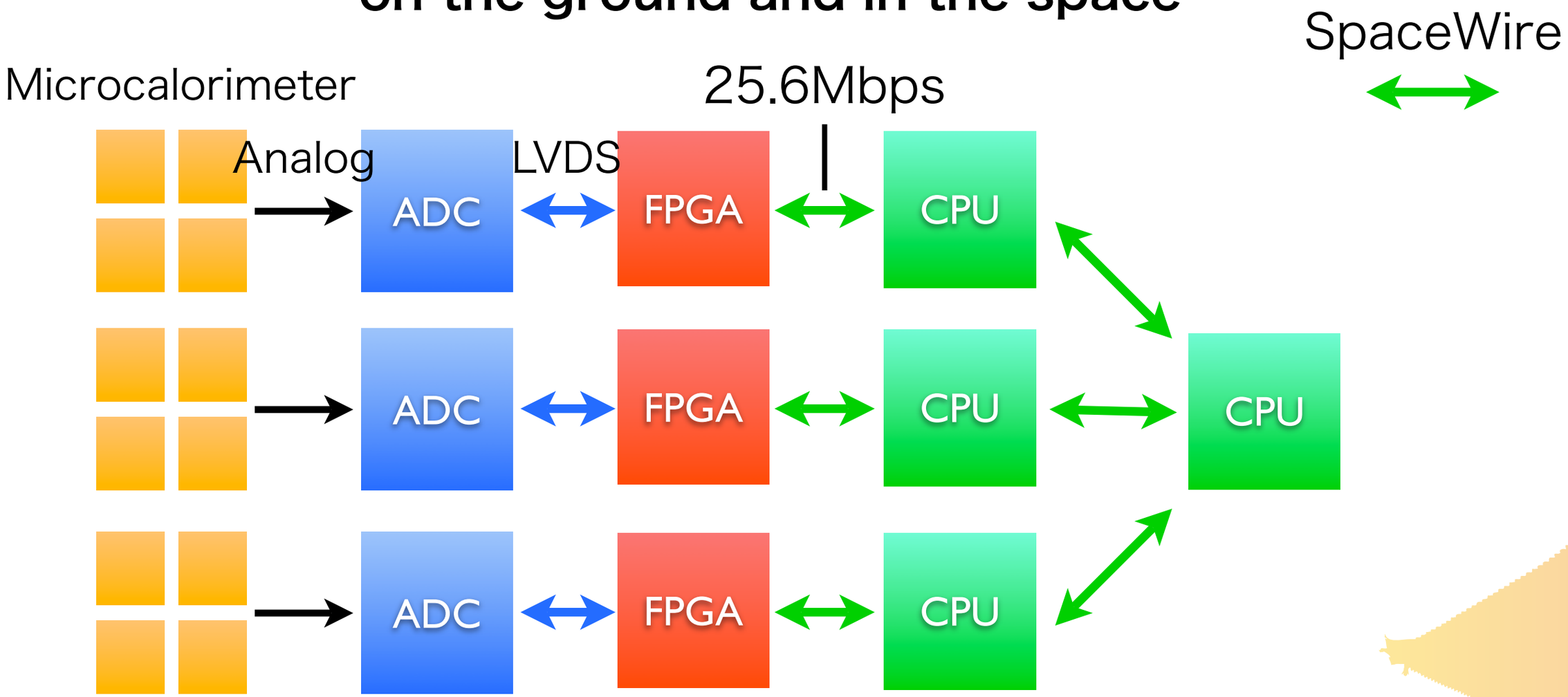

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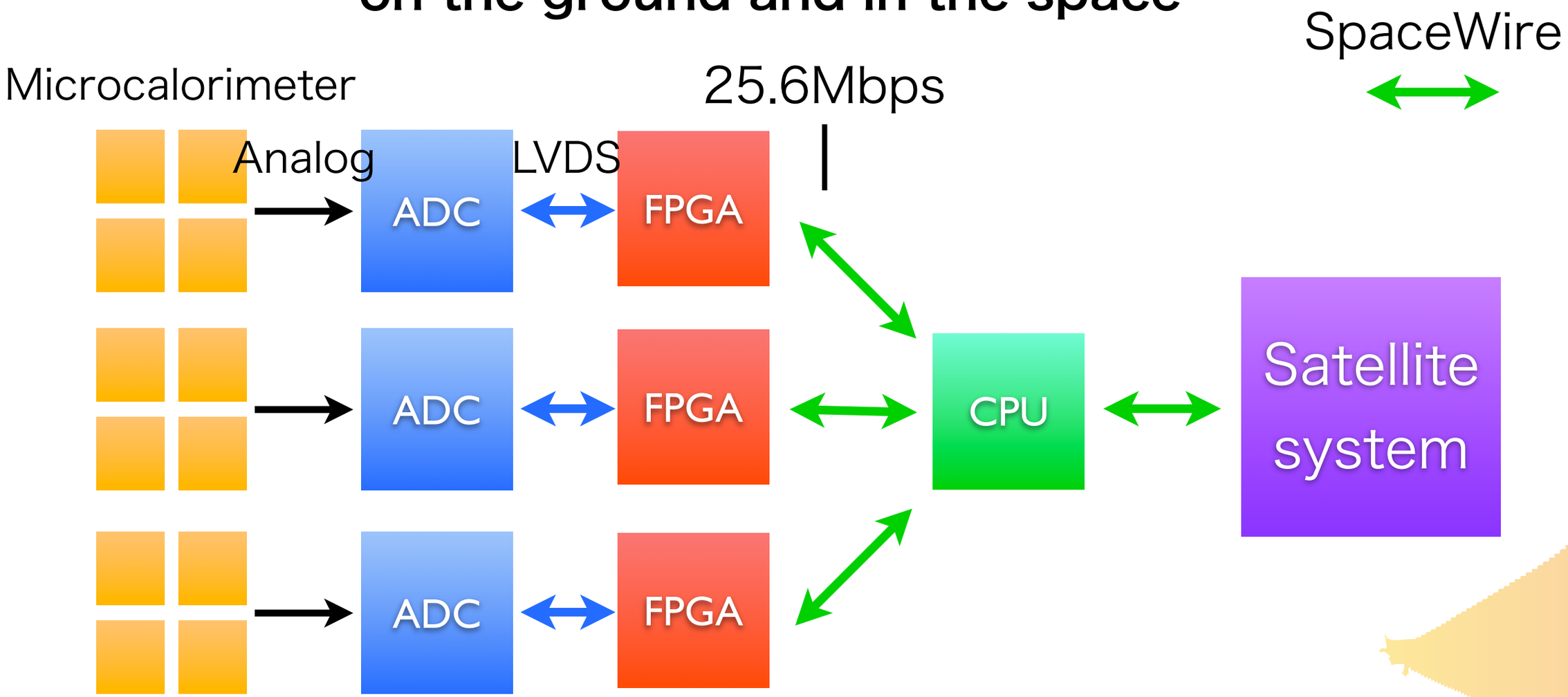
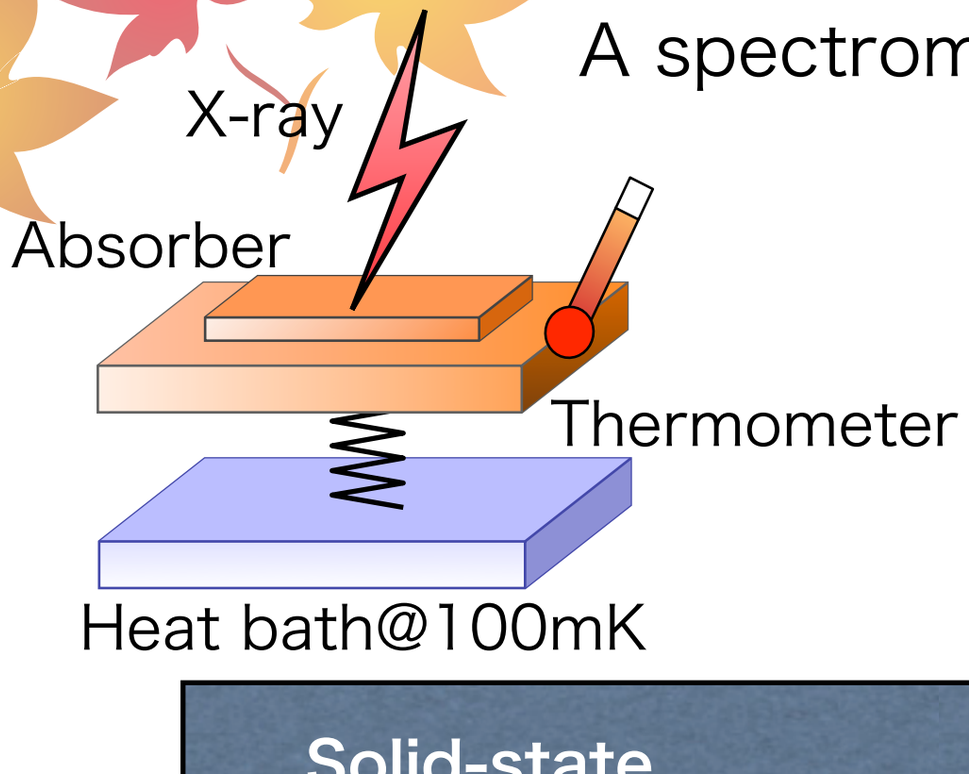


Microcalorimeter

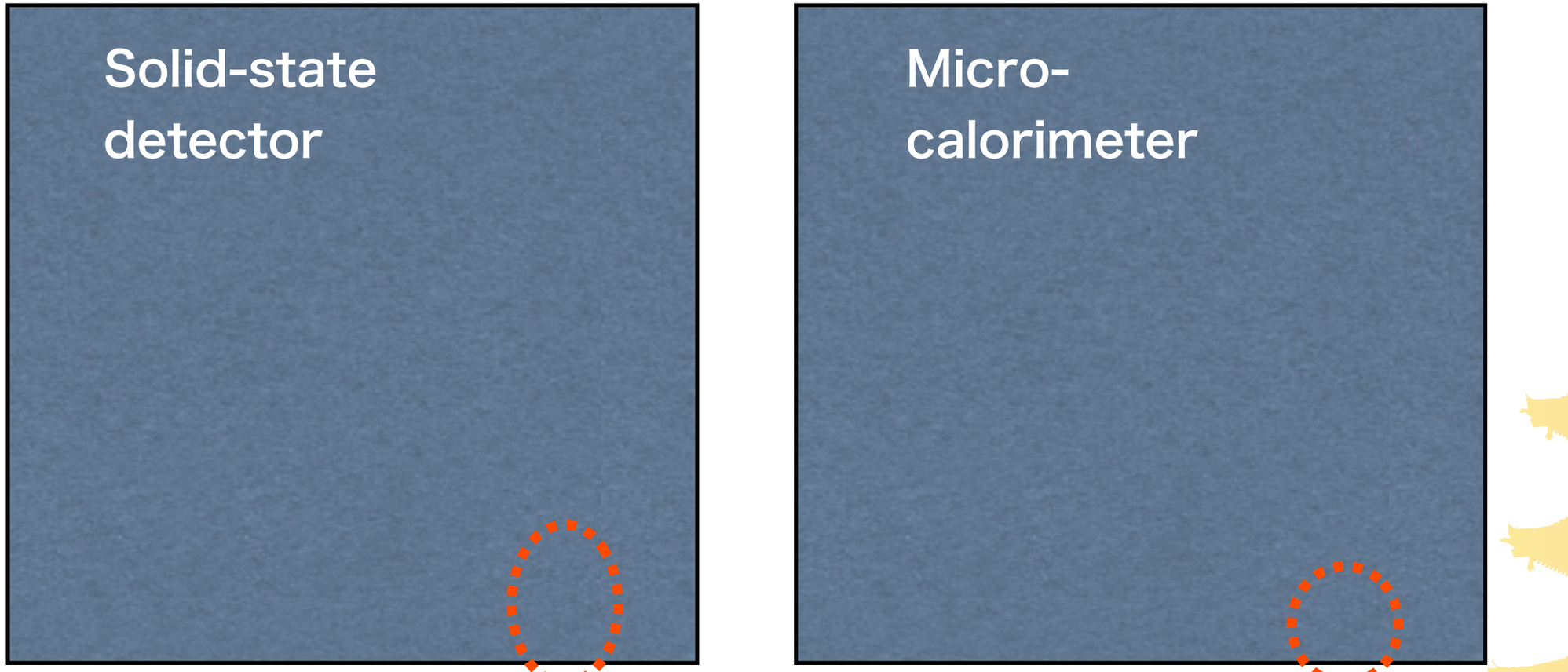
A spectrometer that measures photon energy as heat



X-ray application:

Energy range : 0.1~10 keV

Energy resolution : <10eV



Hara et al. 2008

Applications with high count rate

Microcalorimeter system has great application possibilities,
if it can be **adapted to high count rate.**

In the space
with lager telescope,
count rate becomes >100 counts/s/pixel

On the ground
for quick (1 min) inspection, total count rate becomes >10k counts/s

For now, Microcalorimeter system can deal with only few counts/s.

Microcalorimeter system for TEM (Transmission Electron Microscope)

PI: T. Hara (NIMS)

MEXT project "Development of elementary techniques for electron microscope in next generation"

Development team

Hara* et al.

(*NIMS, SIINT, Kyushu Univ., JOEL, ISAS/JAXA)

Development goal

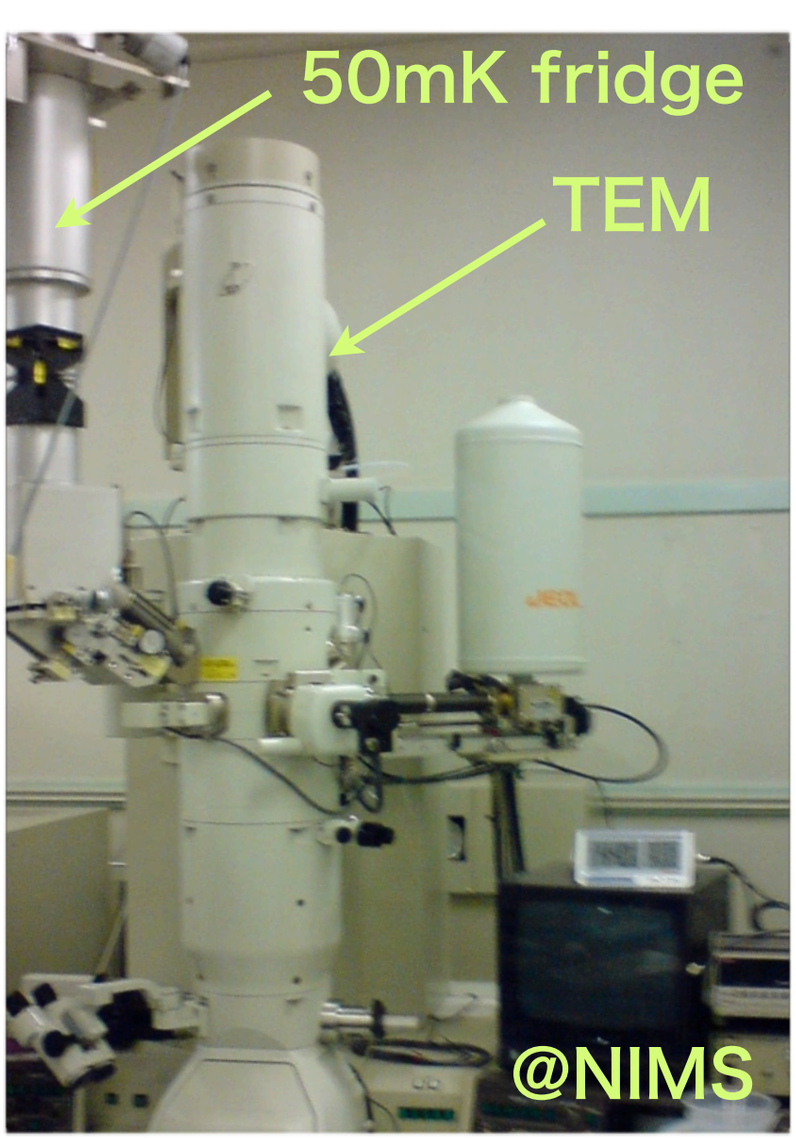
Energy range: 0.5 – 10 keV

Energy resolution:

FWHM ≤ 10 eV

Counting rate: ≥ **2k counts/s**

200 counts/s/pixel



Microcalorimeter DAQ system

Scope of this presentation

~100mK 4K 300K

X-ray

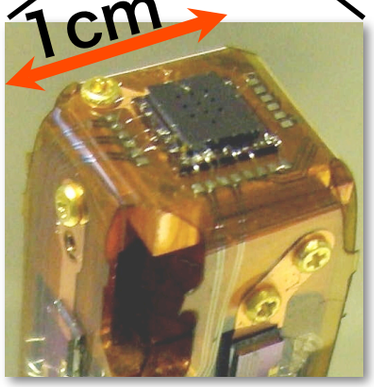
Calori-meter

Low noise amplifier

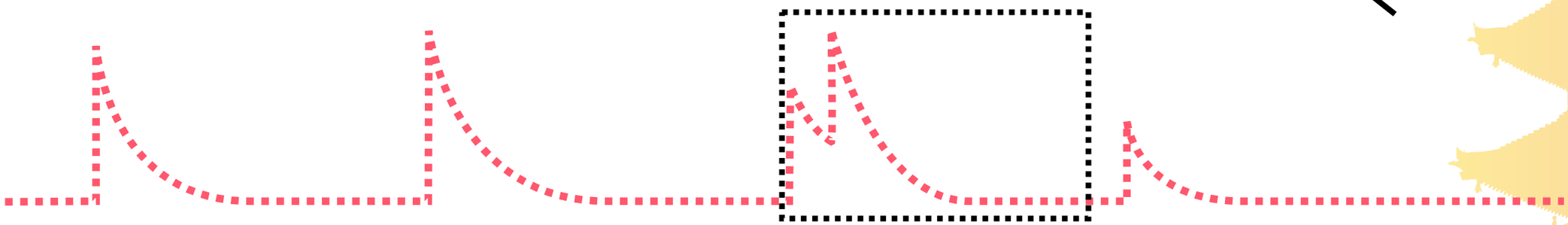
ADC continuous sampling

Digital process

X-ray energy



event triggering
optimal filtering
->next slide



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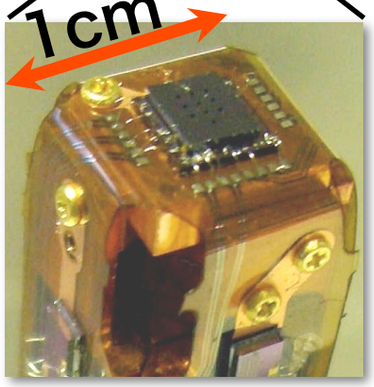

event triggering
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trigger

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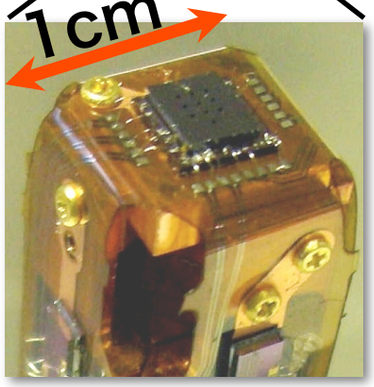


event triggering
optimal filtering
->next slide

trigger

record length

event

event

event

event

event

Optimal filtering

for higher energy resolution

Whole waveform contains X-ray information

-> Chi square fitting in frequency domain can maximize S/N ratio

$$D(f) = A \times M(f) + N(f)$$

---- Premise

event: $D(f)$ — deposited energy: A — ideal pulse: $M(f)$ — ideal noise: $N(f)$

$$\chi^2 \equiv \int \frac{|\, D(f) - A \times M(f) \,|^2}{|\, N(f) \,|^2} df \rightarrow \frac{\partial \chi^2}{\partial A} = -2A \int D \frac{M^*}{|\, N \,|^2} df + 2 \int \frac{|\, M \,|^2}{|\, N \,|^2} df$$

$\frac{\partial \chi^2}{\partial A}$ → 0

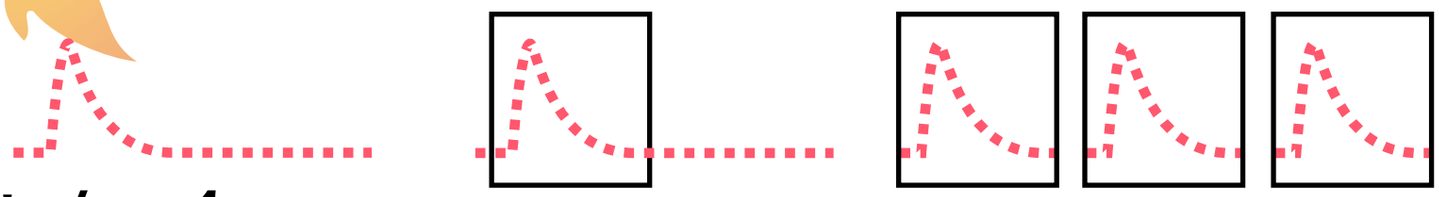
$$A = \frac{\int D(f) \frac{M^*(f)}{|N(f)|^2} df}{\int \frac{|M|^2}{|N|^2} df} = \int D(f) T(f) df = \int D(t) T(t) dt$$

deposited energy

template, T

cross correlation between event and template in time domain

System design



X-ray energy

200 events/s x4
= 800 events/s

=25.6 Mbps/s(32 kbit/event)

LVDS

ADC

ADC

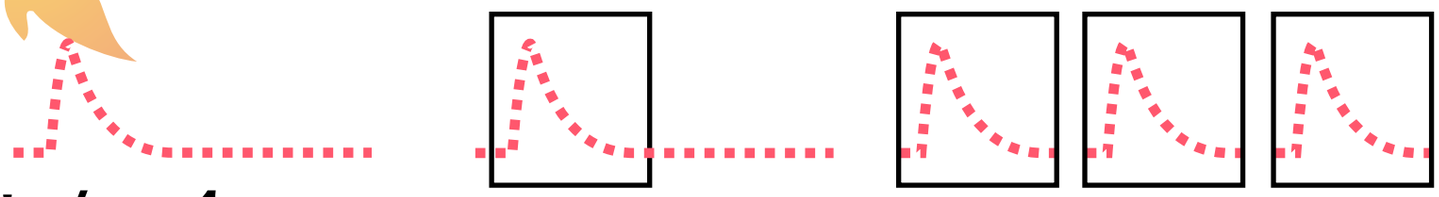
ADC

ADC

Digital process
event triggering &
optimal filtering

1.2MS/s 14 bits

System design



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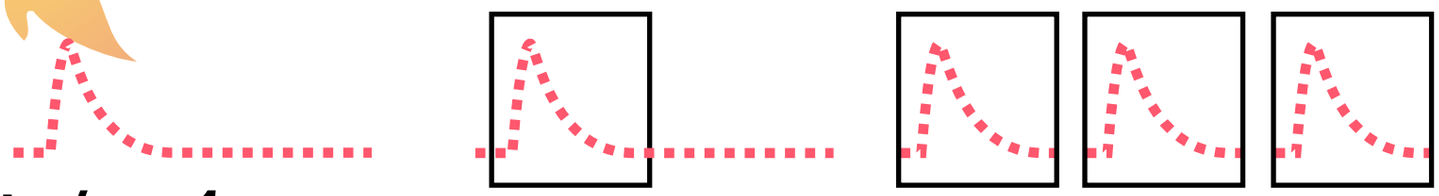
Digital process for event triggering

Digital process for optimal filtering

System design



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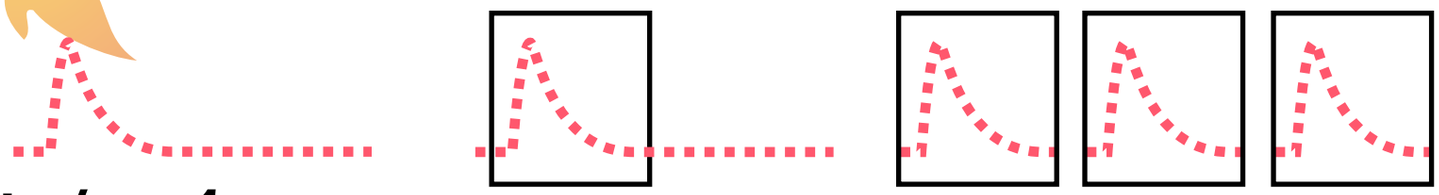
Digital process for event triggering

Digital process for optimal filtering

We adopted SpaceWire

System design



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FPGA for User logics

FPGA for SpW I/F

SDRAM

SpW I/O Board

User FPGA
Xilinx XC3S400FTG256

SpW

FPGA for SpW I/F

CPU

TCP/IP I/F

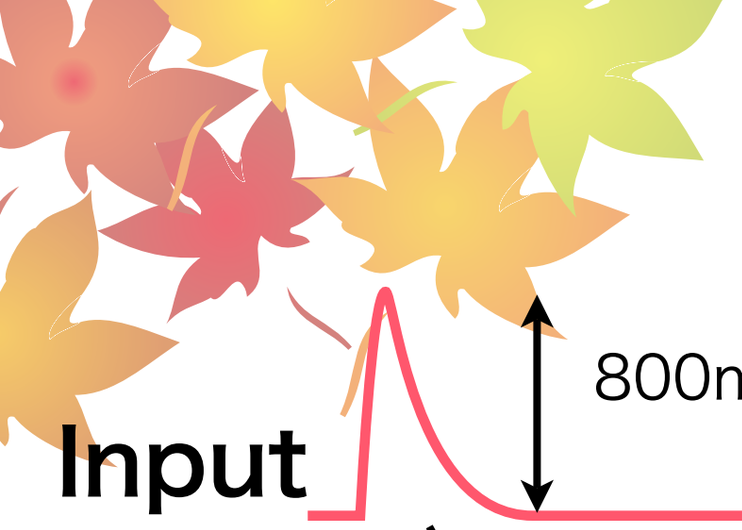
SpaceCube

CPU
VR5701
OS
T-kernel

SpW

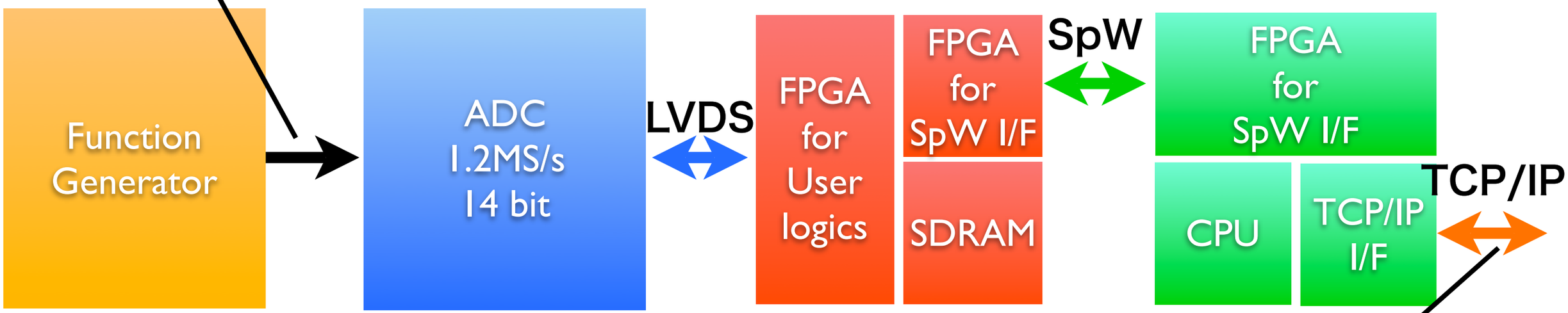
TCP/IP

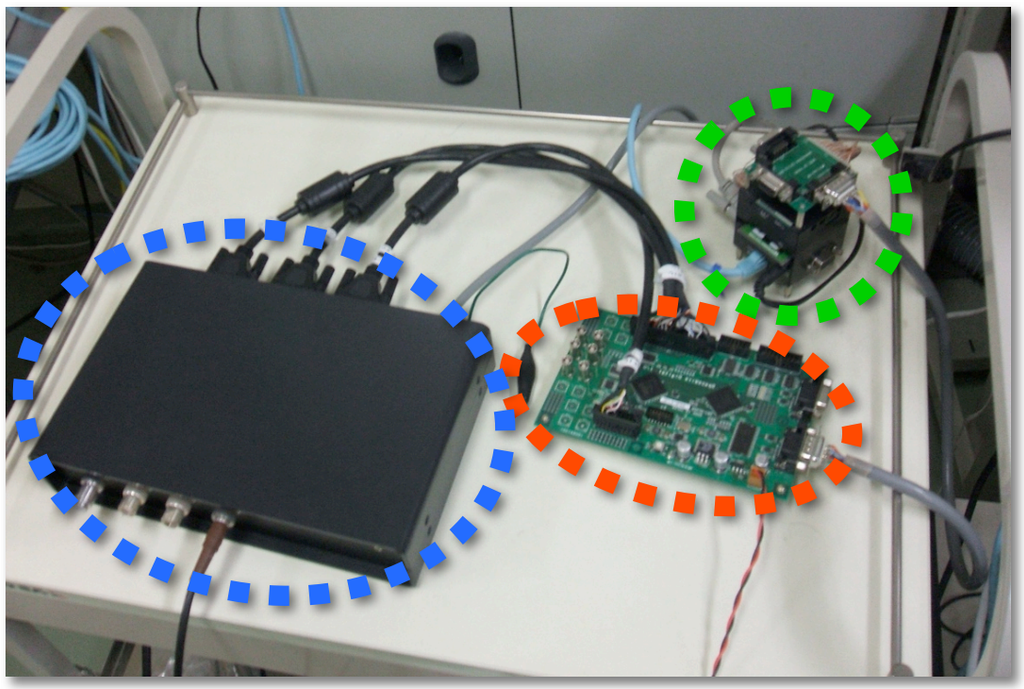
Function test



800mV ~ 10 keV X-ray

Input

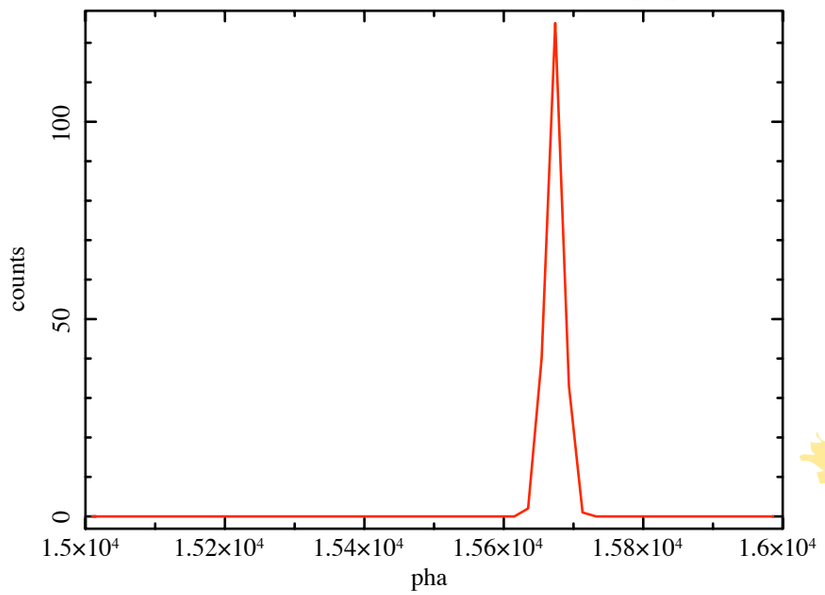




Output

event by event information

(time, energy, event grade)



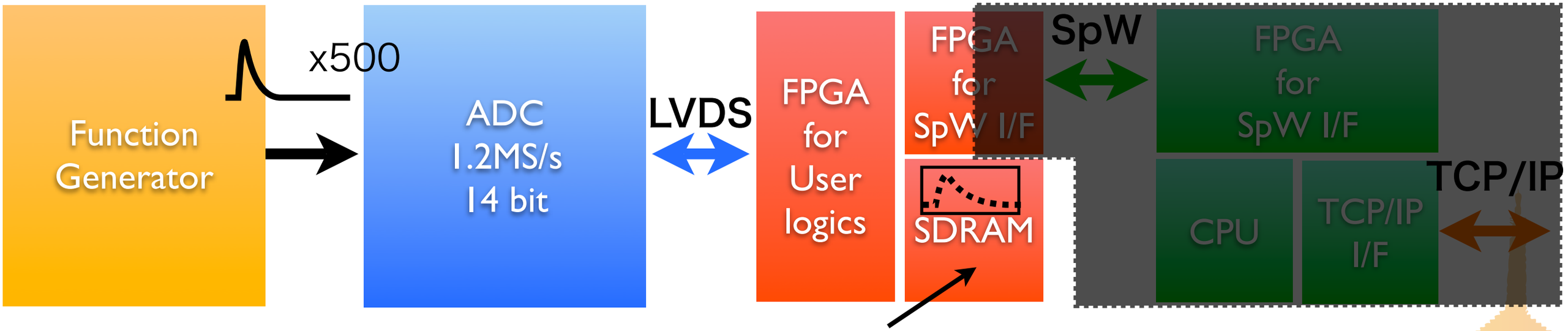
Performance evaluation

Event triggering speed

Method:

Input ideal 500 events periodically at an event rate and measure acquired events in SDRAM

Requirements
800 events/s



event rate [events/s]	acquired events [events]	ratio
500	500/500	100%
1000	500/500	100%
2000	270/500	54%

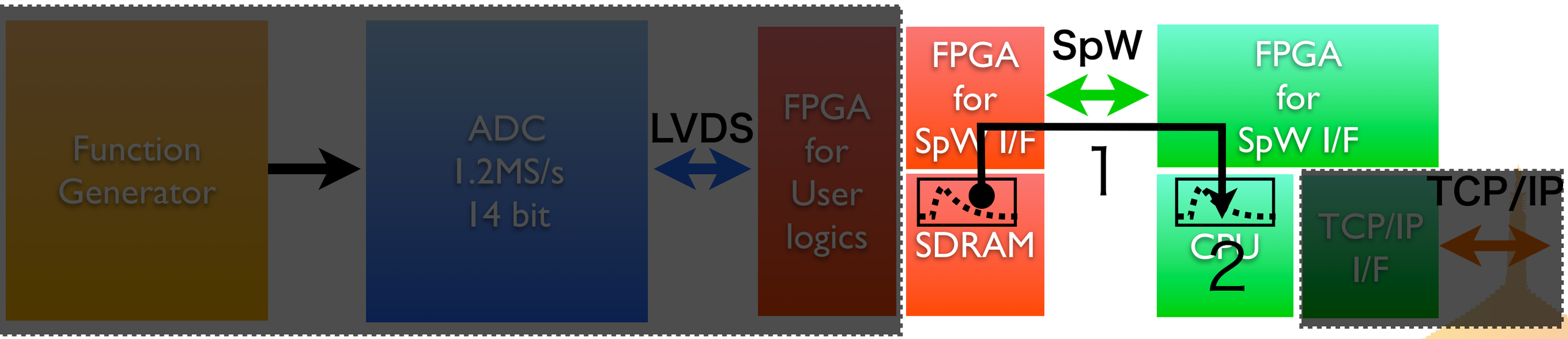
at ~1 k events/s, all events are acquired -> OK

Performance evaluation

Event transfer and filtering speed

Method:
transfer 1000 events in SDRAM to CPU
and filter them

Requirements
800 events/s



1. event transfer speed via SpW = 32 events/s
2. filtering speed in CPU = 2k events/s

-> SpW speed will be improved using a new SpW IP core
(Yuasa et al. this conference)

Summary

- We designed and assembled a high count-rate adapted digital processing system for micro-calorimeter array using SpaceWire.

- Whole system works as we intended and evaluation tests started.
- Event triggering and optimal filtering speed are sufficient for 800 events/s/4pixels(= 2k events/s).
- Data transfer speed via SpaceWire is not sufficient.
- New version SpaceWire interface will improve this speed.

- Test of the full TEM system with a 10 pixel array will start in January 2009.