Laboratory of Radiation Detectors and Nuclear Electronics (RADLAB)

(2 staff, 8 PhD students and post-doc, 8-10 master thesis positions)

Topics for Master Thesis: (for both ELN and BIO strudents)

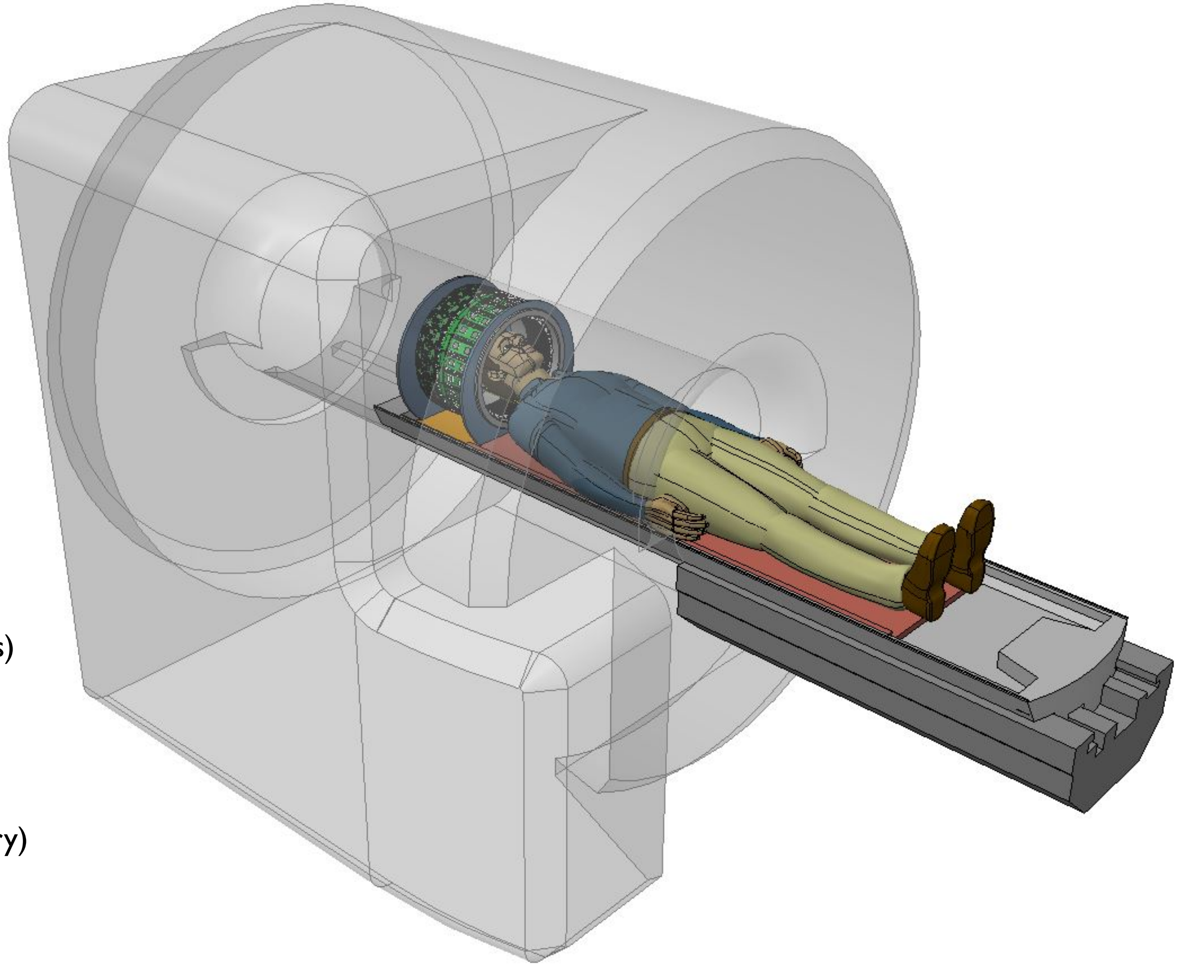
- Detectors, electronics and instrumentation for X and gamma rays applications in medical imaging, X-ray astronomy, nuclear physics, study of matter and industrial applications
- Integrated circuits for signal processing of detector signals in scientific and industrial applications

Pre-requisites:

- interest/attitude to experimental activity in laboratory
- basic background on electronics (in particular, for thesis in integrated circuits design)
- motivation, curiosity

INSERT: INtegrated SPECT/MRI for Enhanced Stratification in Radio-chemo Therapy

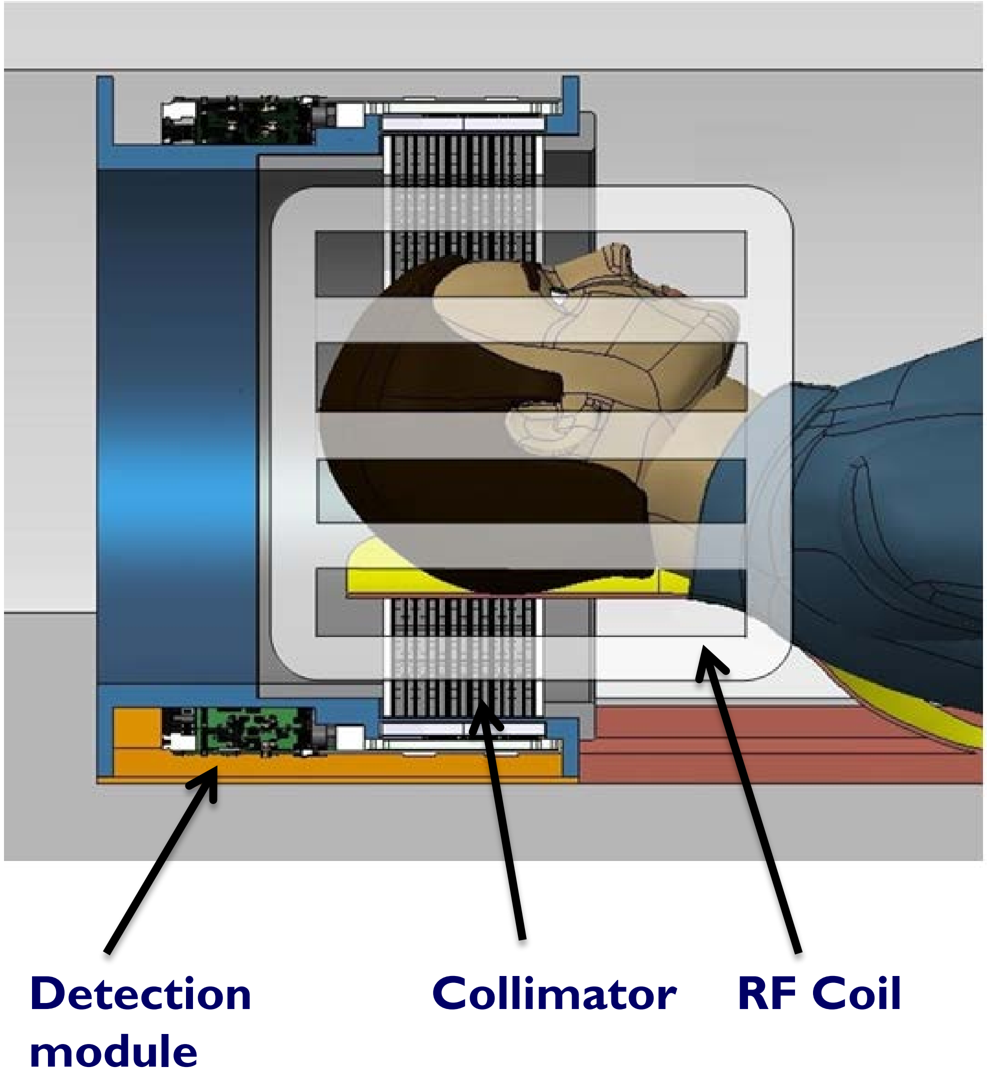
GA n. 305311
Kickoff: 01/03/13
Duration: 4 years



INSERT members

- Politecnico di Milano (Italy)
- Mediso Medical Imaging Systems (Hungary)
- Fondazione Bruno Kessler (Italy)
- Nuclearfields International BV (Netherlands)
- MRI.Tools GmbH (Germany)
- University College London (UK)
- Universita Vita-Salute San Raffaele (Italy)
- Universita Degli Studi di Milano (Italy)
- Cromed Research and Services ltd. (Hungary)
- CF Consulting srl. (Italy)

Goal: to provide improved personalized radio-chemo therapies for brain tumour (<u>Glioma</u>) patients using a specifically developed multi-modality imaging tool



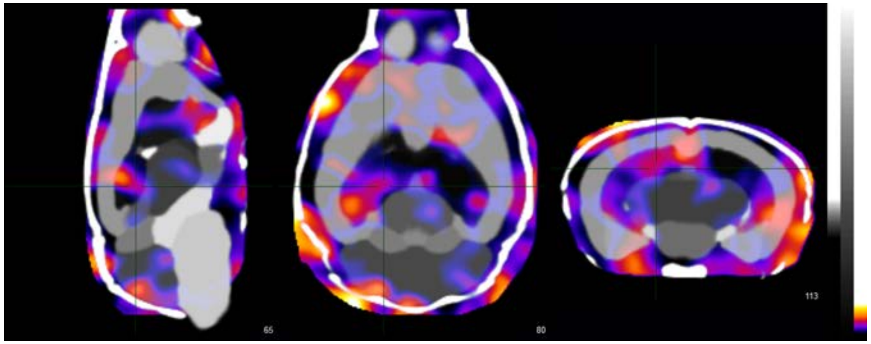
MRI:

- 3 T MRI
 (internal bore diameter ~60 cm)
- Customized RF coil

SPECT:

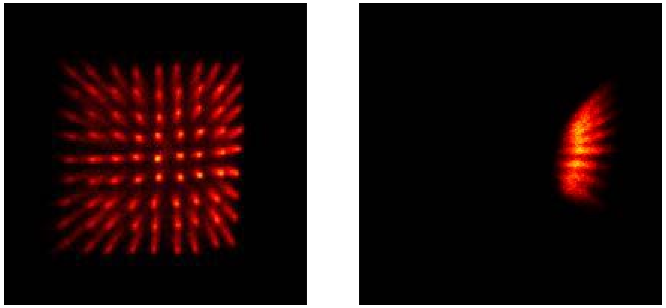
- Stationary system
- Multi Slit-Slat collimator
- 20 independent detection modules
 (FOV ~ 10x5 cm^2)

Example of coregistration of **non-simultaneous** SPECT (colourscale) – MRI (grayscale) acquisitions



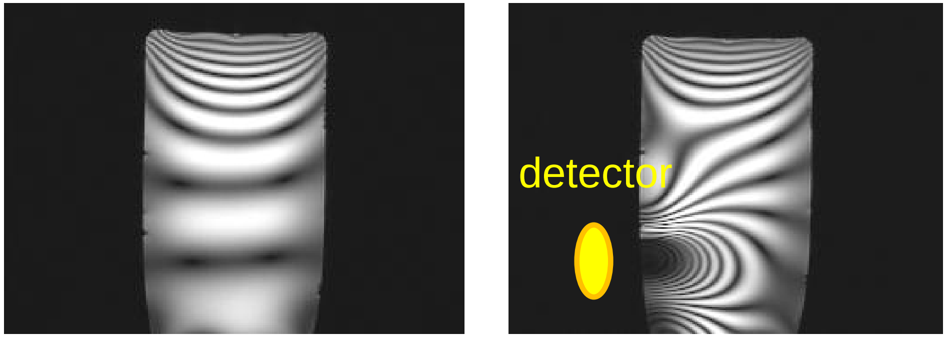
MRI compatibility tests

- The MRI field and signals should not interfere with the detection module
- The detection module should not produce artifacts on the MRI images



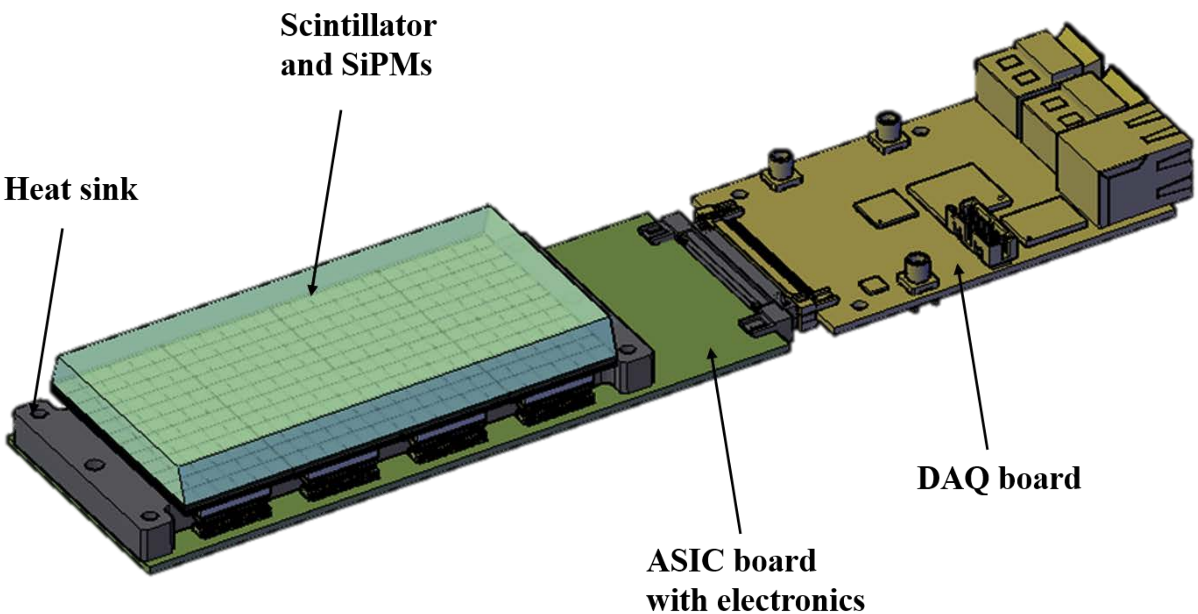
MRI off   MRI on

with PMT

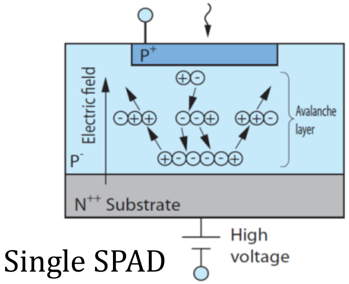


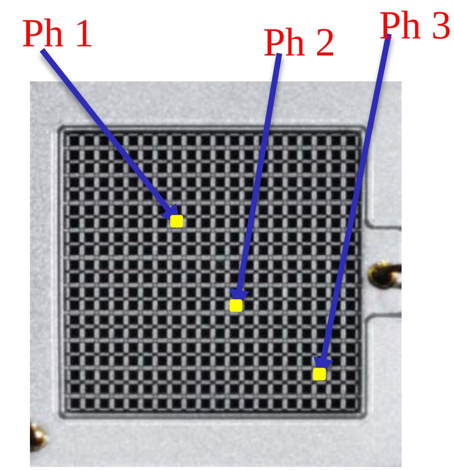
Detection module (Anger camera):

1. Monolithic slanted scintillator (CsI:Tl. Area~10x5 cm^2. Thickness 8 mm)
2. Silicon PhotoMultipliers matrix
3. ASIC readout and Data Acquisition System



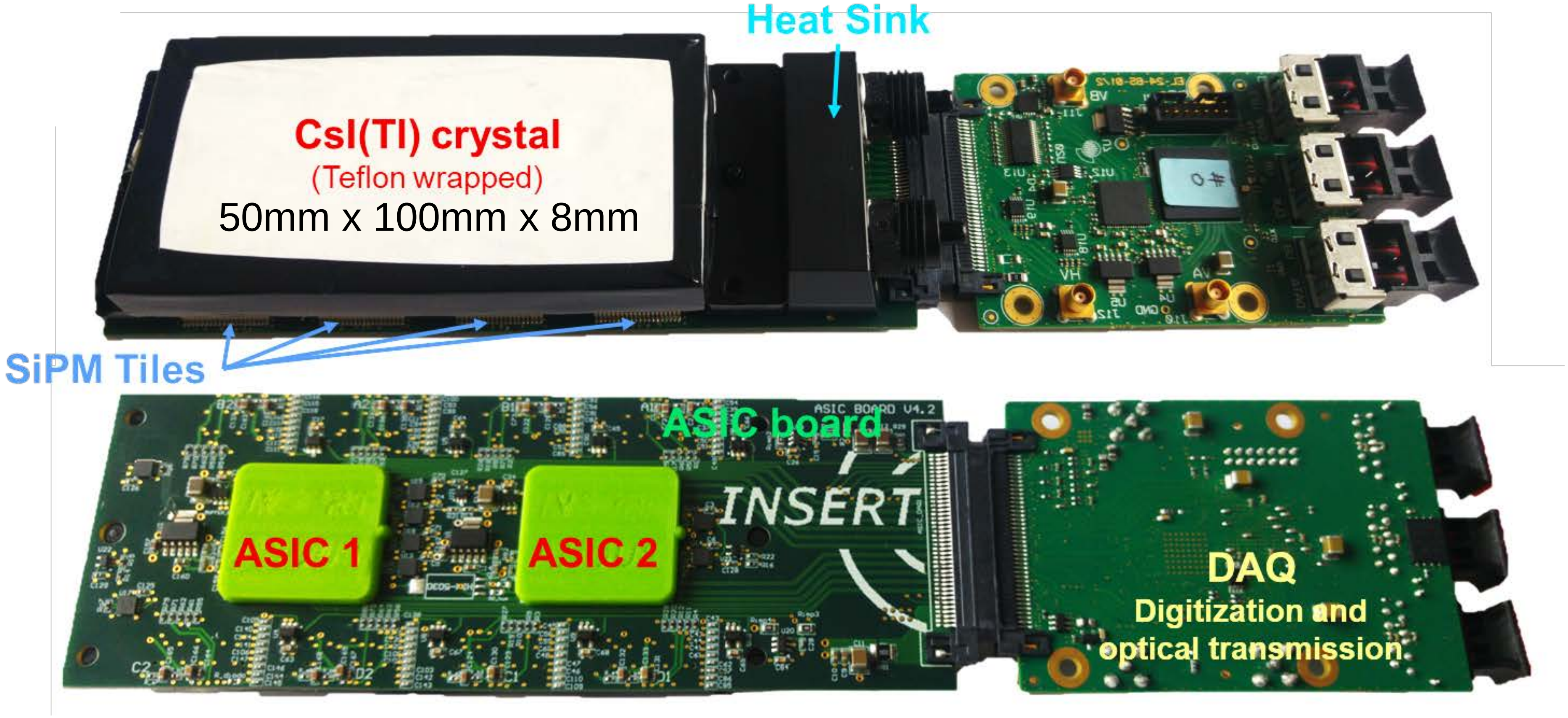
Silicon PhotoMultiplier (SiPM)



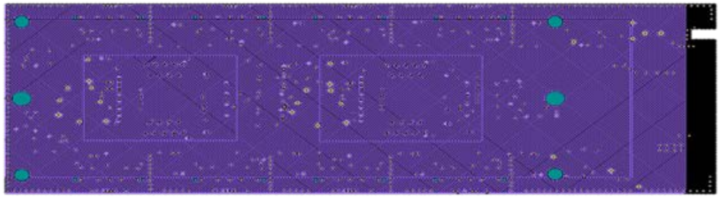


Expected performance from Monte Carlo simulations:

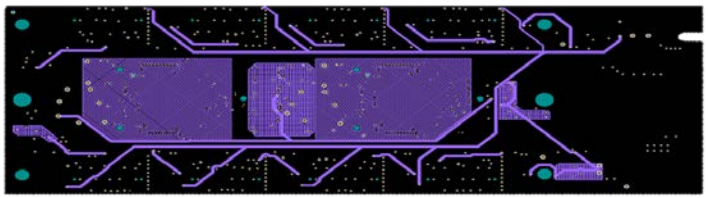
- **Spatial resolution:** between 0.8 and 1 mm
- **Energy resolution:** between 11% and 15% (Tc-99m - 140 keV)



Standard design

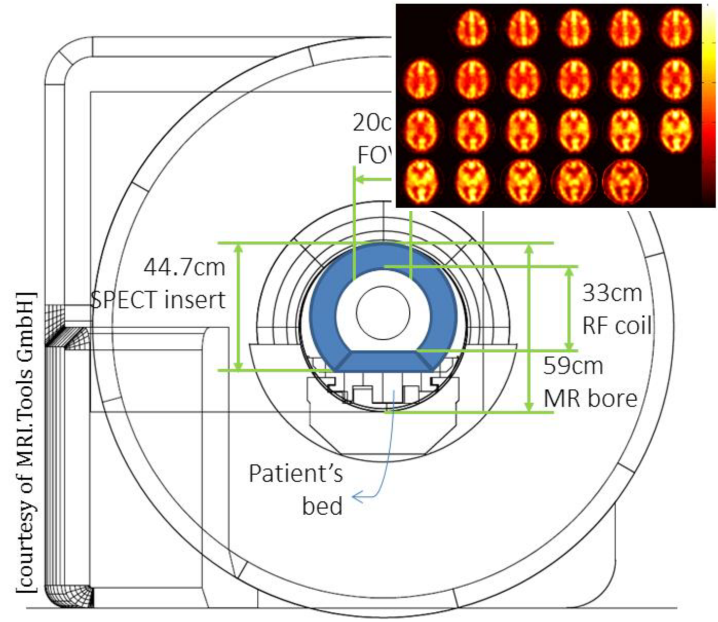


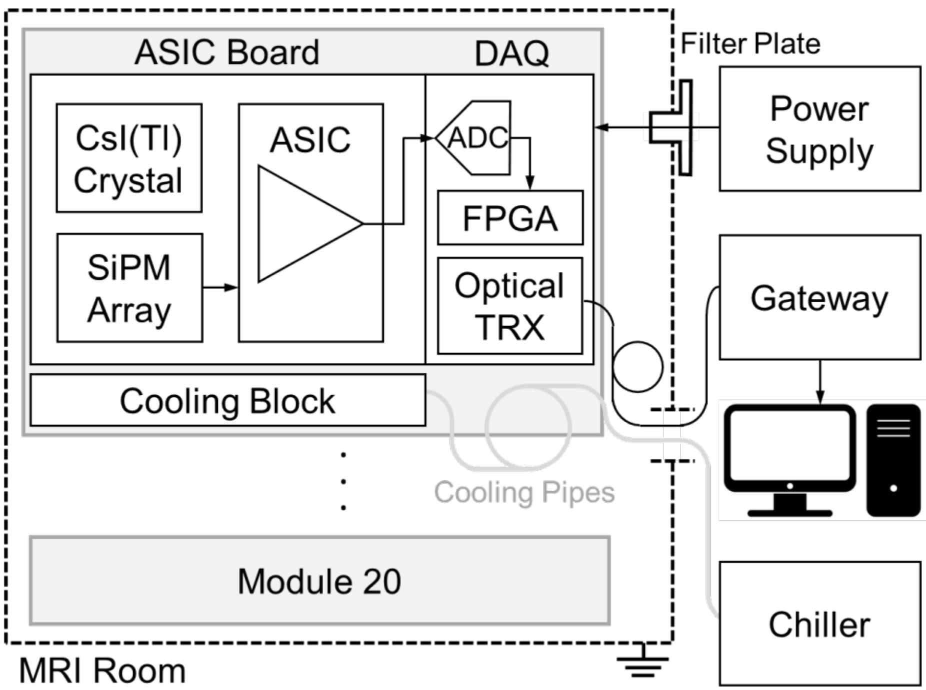
MRI-Compatible design

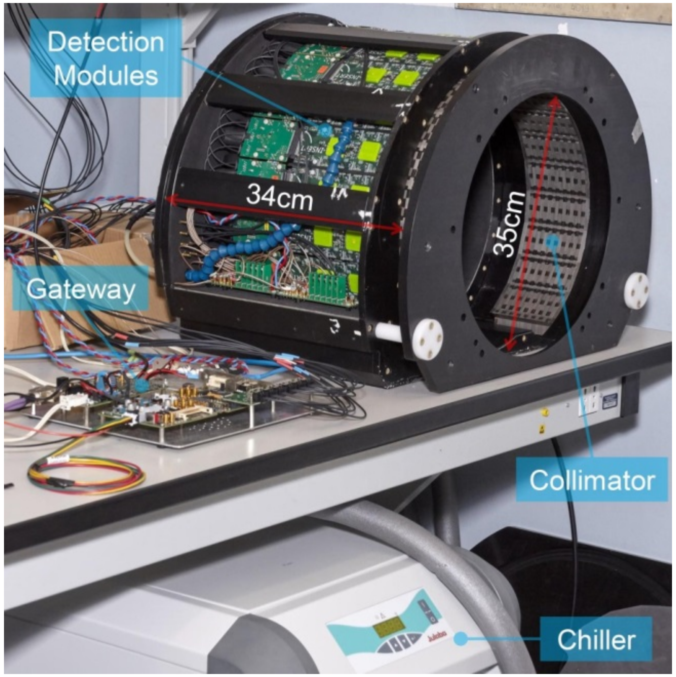


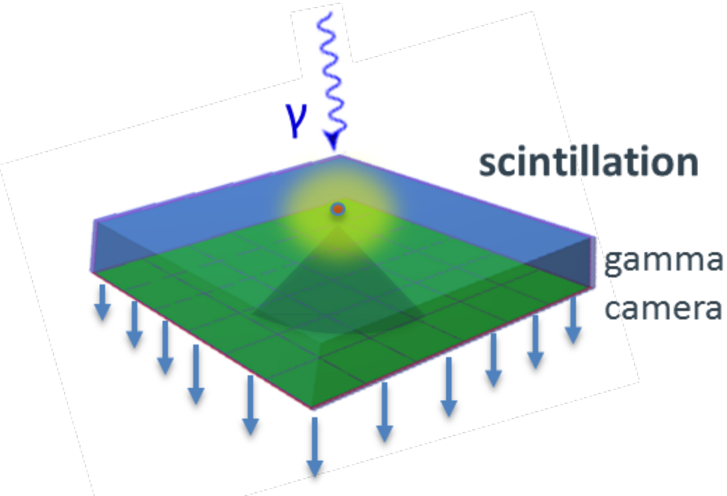
thesis topics:

- detection module: development and experimentation of new reconstruction algorithms (Depth-Of-Interaction, reconstr. of edge events, Multiplexing, ..)
- experimentation of clinical SPECT, in collaboration with University College London









Multiplexing Strategies for Monolithic Crystal PET Detector Modules

Phys Med Biol. 2014 September 21; 59(18): 5347–5360. doi:10.1088/0031-9155/59/18/5347.

A machine learning method for fast and accurate characterization of depth-of-interaction gamma cameras

Stefano Pedemonte *et al* 2017 *Phys. Med. Biol.* **62** 8376

event reconstruction is made through processing of ALL photodetector signals (e.g. 64 in a 8x8 array)

⇒ can we achieve the same results with subsets of data (multiplexing)?

⇒ can we implement on-chip X,Y reconstr.?

1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8

9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16
9	10	11	12	13	14	15	16

The RC16 row/column summation. There are 8 signals from row summation (left) and 8 from column summation (right) for 16 total output channels.

1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3

6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8
6	7	8	9	10	6	7	8

The RC10 row/column summation. Note that some row and column channels are repeated so that only 10 output channels are shown.

1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4

5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8
5	6	7	8	5	6	7	8

The RC8 row/column summation. Note that some row and column channels are repeated so that only 8 output channels are shown.

1	6	3	8	5	2	7	4
2	7	4	1	6	3	8	5
3	8	5	2	7	4	1	6
4	1	6	3	8	5	2	7
5	2	7	4	1	6	3	8
6	3	8	5	2	7	4	1
7	4	1	6	3	8	5	2
8	5	2	7	4	1	6	3

9	12	15	10	13	16	11	14
10	13	16	11	14	9	12	15
11	14	9	12	15	10	13	16
12	15	10	13	16	11	14	9
13	16	11	14	9	12	15	10
14	9	12	15	10	13	16	11
15	10	13	16	11	14	9	12
16	11	14	9	12	15	10	13

The MOD 3-5 multiplexing scheme. Each column of the left figure is a +3 rotational shift of the previous column. A rotational shift of -3 is applied to the columns of the figure on the right for an additional 8 output channels.

	1	1	1	1	1	1	
	2	2	2	2	2	2	
	3	3	3	3	3	3	
	4	4	4	4	4	4	
	5	5	5	5	5	5	
	6	6	6	6	6	6	

	7	8	9	10	11	12	
	7	8	9	10	11	12	
	7	8	9	10	11	12	
	7	8	9	10	11	12	
	7	8	9	10	11	12	
	7	8	9	10	11	12	

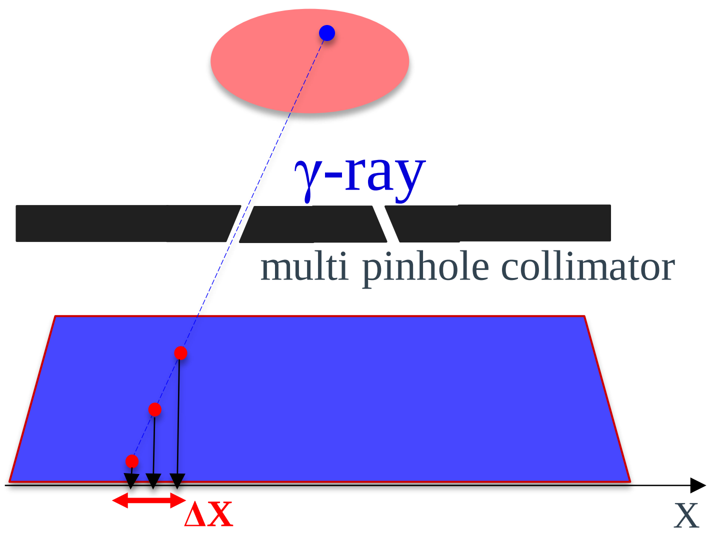
13	19	18	17	16	15	14	13
14							19
15							18
16							17
17							16
18							15
19							14
13	14	15	16	17	18	19	13

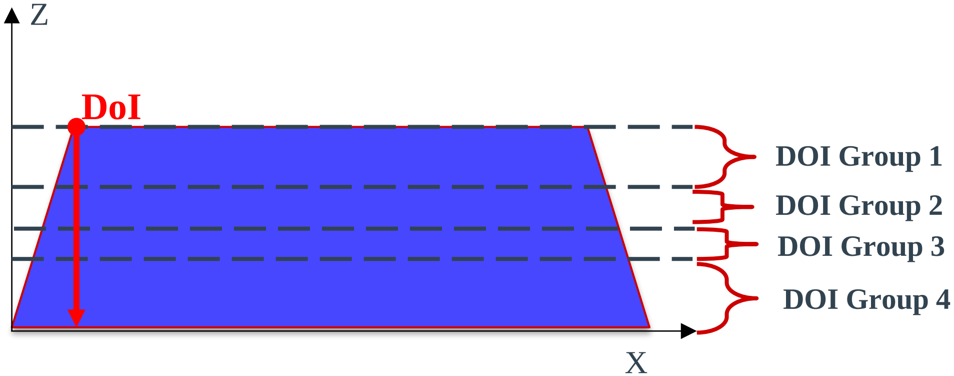
The MOD RC+edge multiplexing scheme. The left figure shows the six channels that sum the interior rows. The center figure shows the six channels that sum the interior columns. The figure at right shows seven additional channels in a ring around the edge of the detector module for a total of 19 output channels.

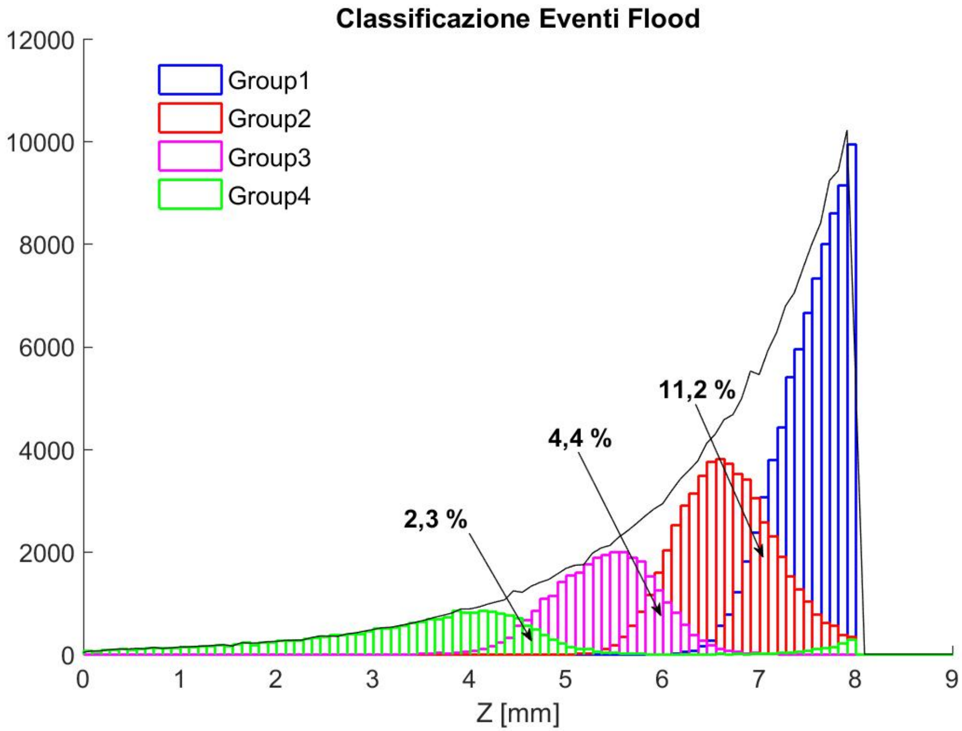
Figure 2.

Illustrations of the various multiplexing schemes used. Each image shows an 8 × 8 array representing the PMT output channels. For each scheme, the channels with the same numbered label are summed together for multiplexing. Thus, each number represents a single output channel for the multiplexing scheme.

Events clustering for different DOI

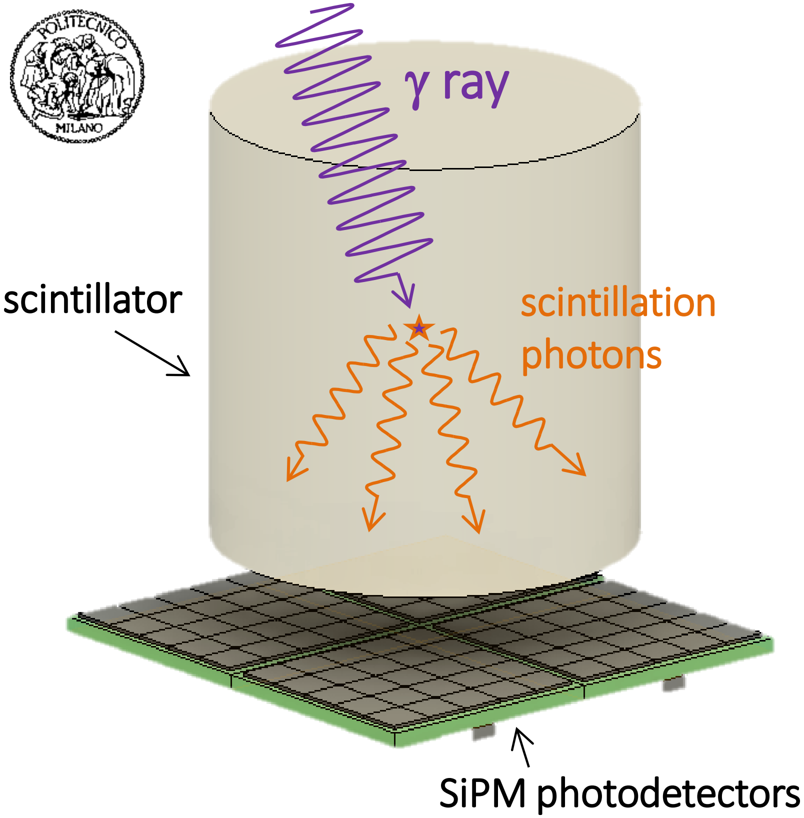






⇒ different DOI (Depth Of Interaction) produces an error in X and Y reconstruction

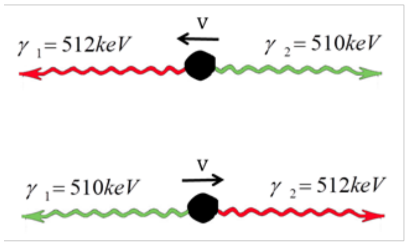
GAMMA project (Spectroscopy and imaging of wide-range gamma rays)

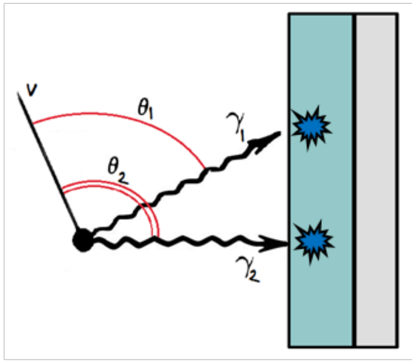


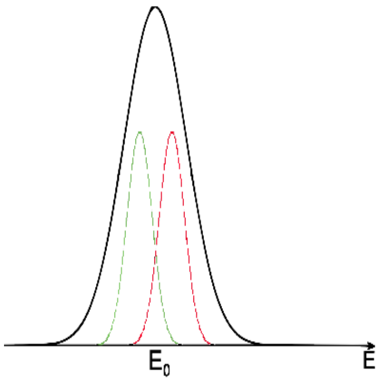
thesis topics:

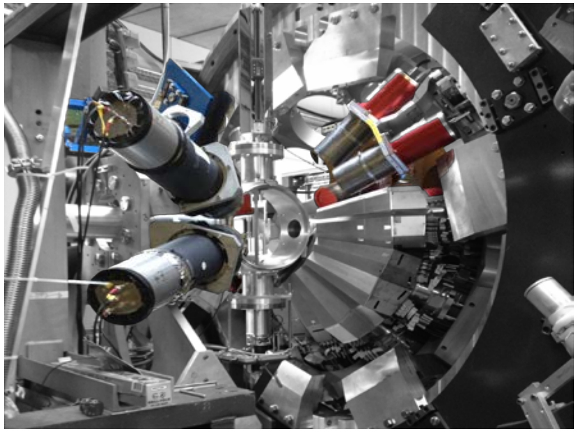
- development and experimentation of a gamma-ray detector based on 3" $LaBr_3$ scintillator
- development of imaging algorithms for Doppler broadening correction
- development of an ultra high (10.000) dynamic range ASIC
- study and experimentation of timing properties of the detector+electronics

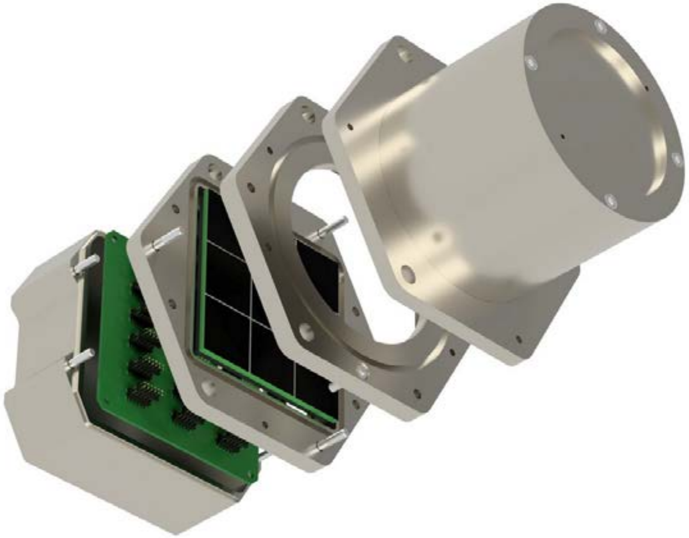
Radionuclides traveling at relativistic speeds

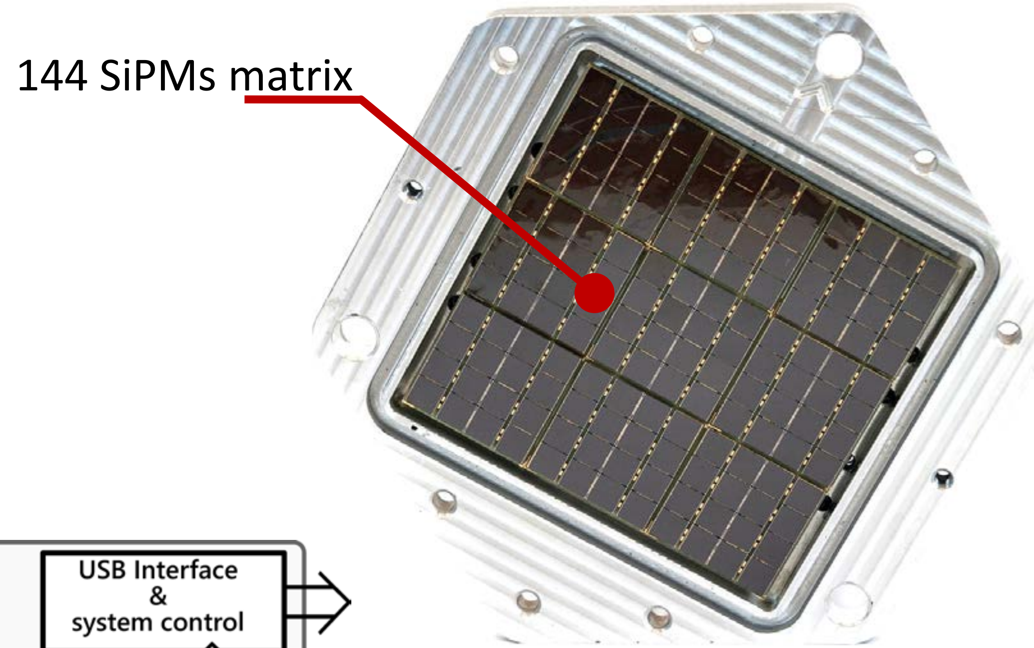


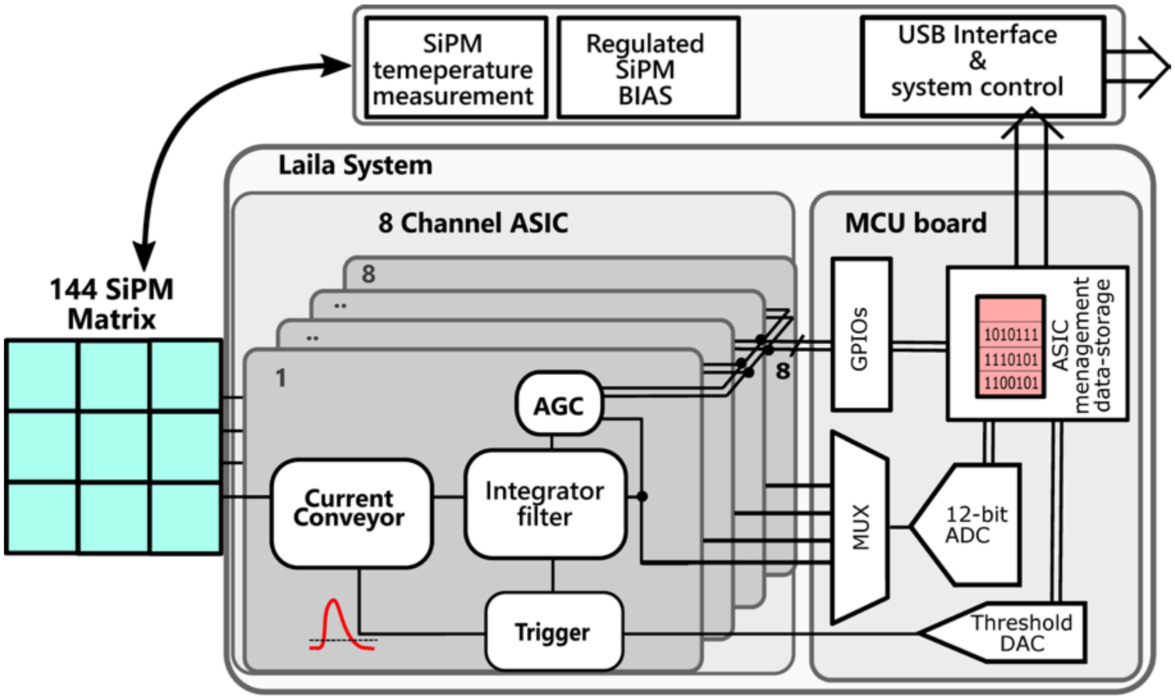




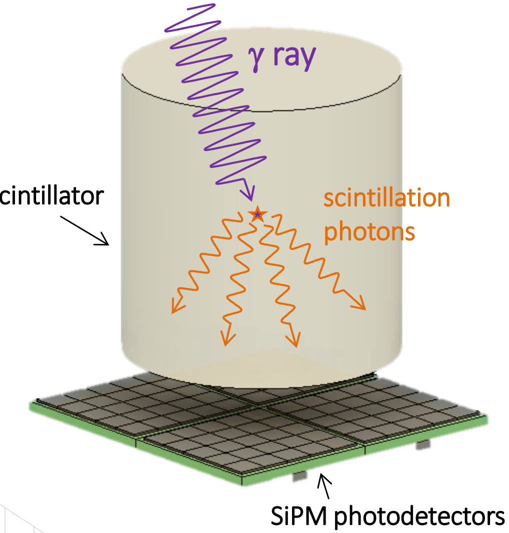




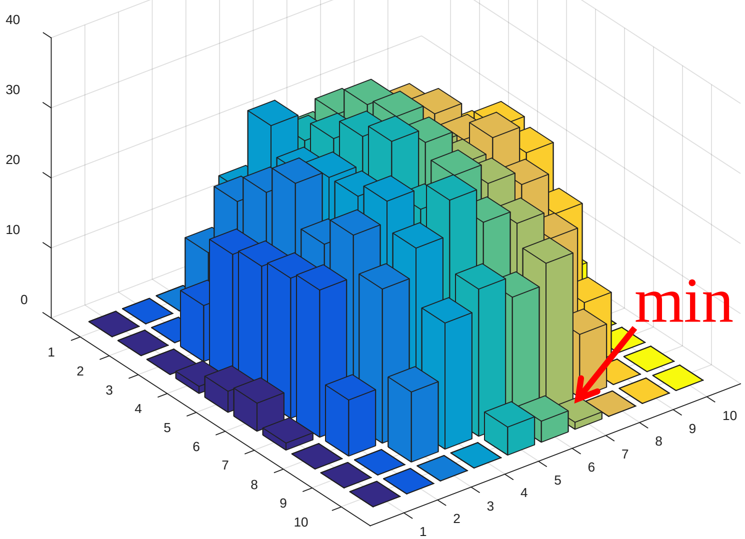

144 SiPMs matrix


SiPM temeperature measurement
Regulated SiPM BIAS
USB Interface & system control
Laila System
8 Channel ASIC
MCU board
144 SiPM Matrix
8
..
..
1
AGC
Current Conveyor
Integrator filter
Trigger
8
GPIOs
1010111
1110101
1100101
ASIC menagement data-storage
MUX
12-bit ADC
Threshold DAC

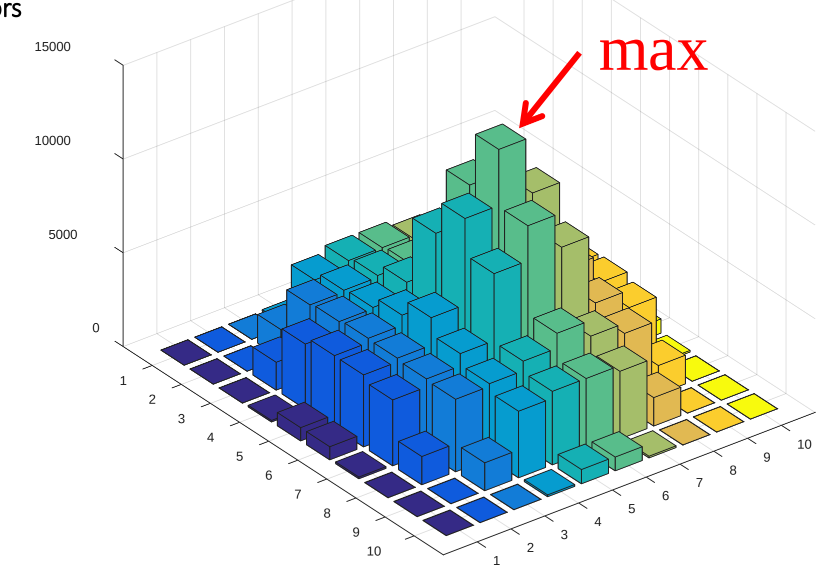
GOAL: design of a readout ASIC able to cover a high dynamic range (1ph → ~10.000ph)



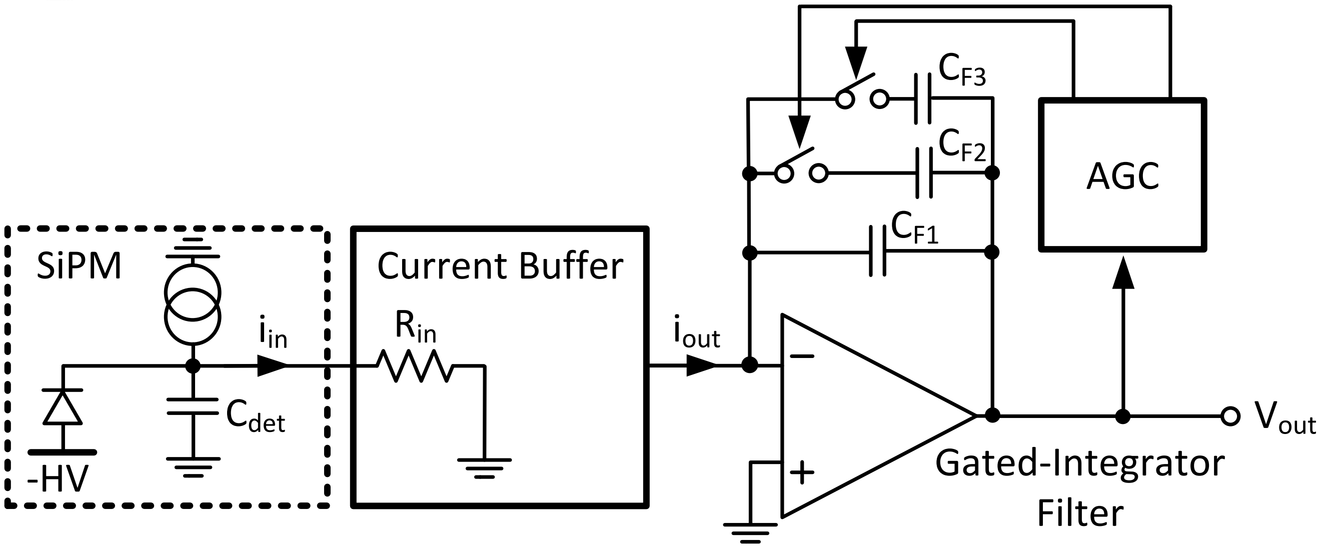
200keV gamma ray:
SiPm signals



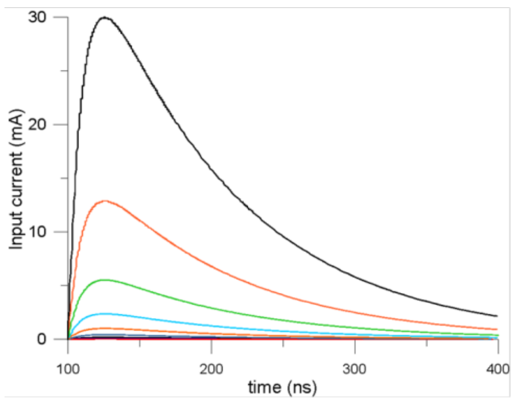
20MeV gamma ray:
SiPm signals

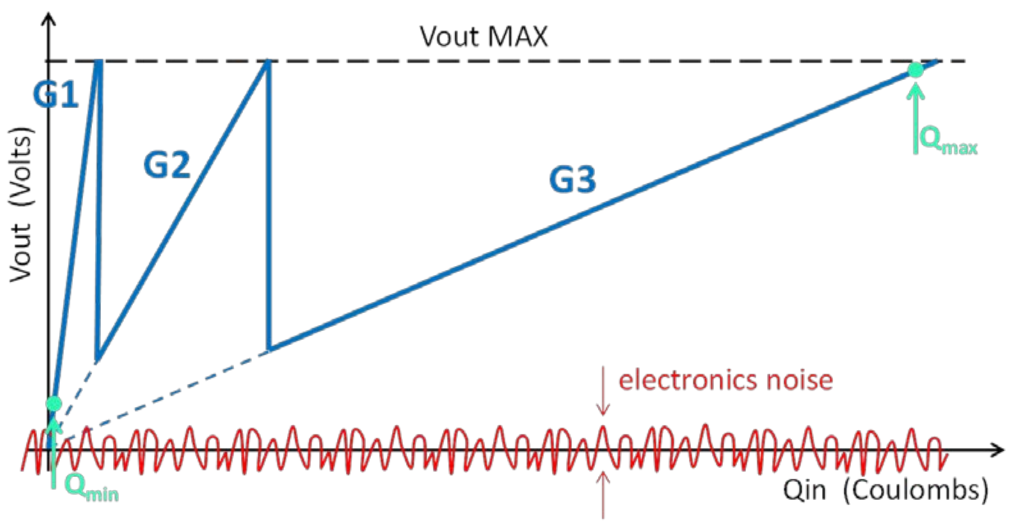


Adaptive-Gain Control ASIC

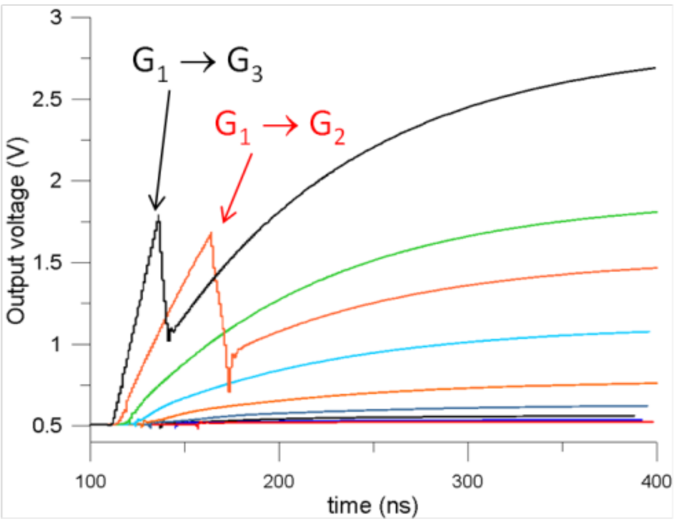


SiPM signal

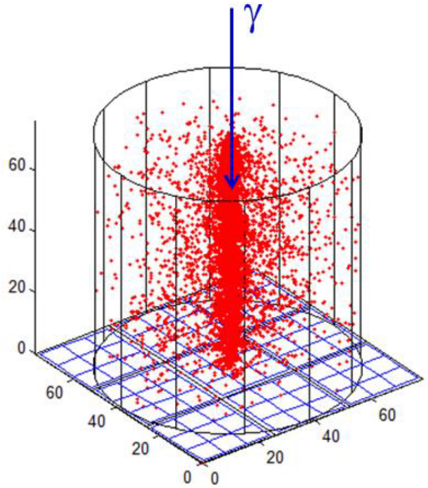




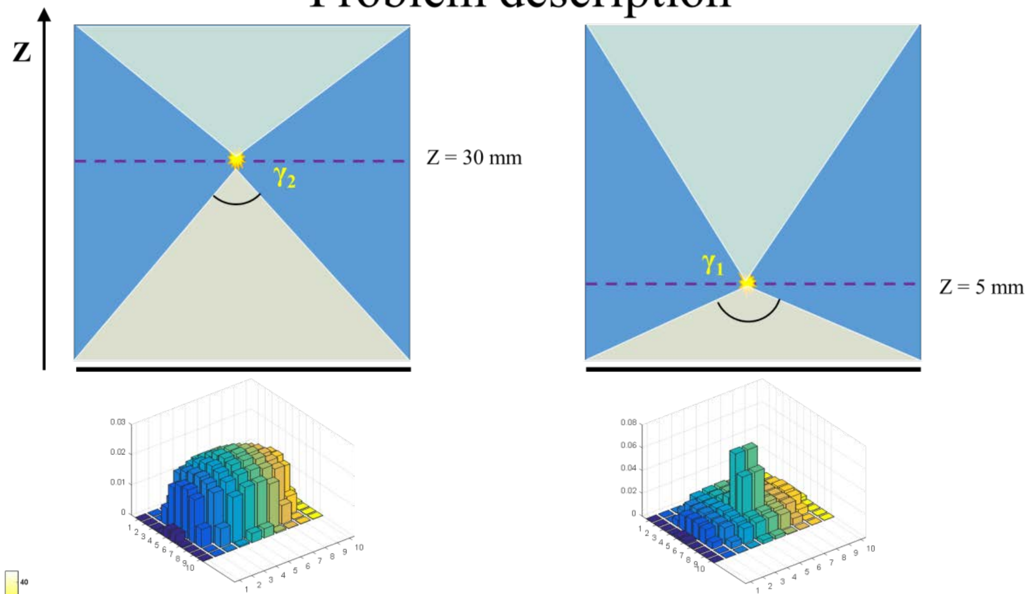
filter output



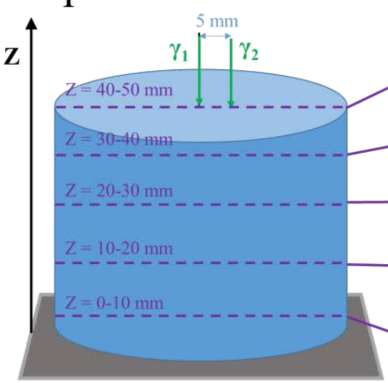
Position sensitivity in large scintillators

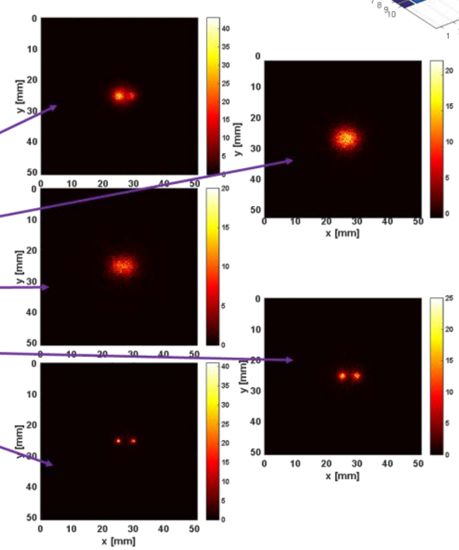


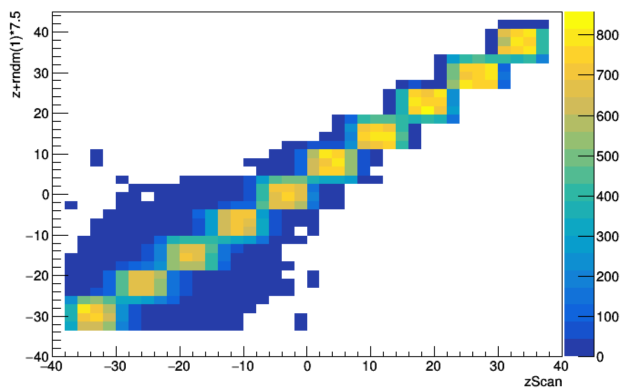
Problem description



Spatial Resolution





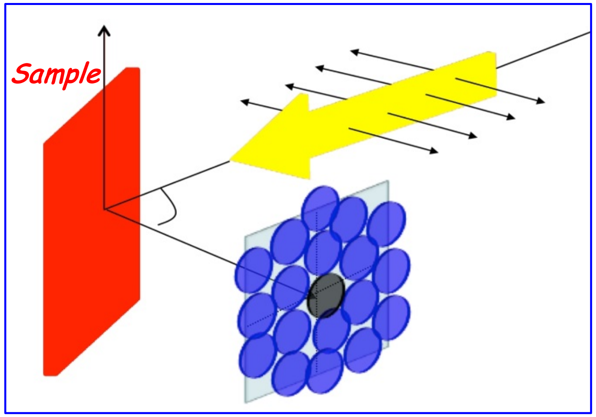


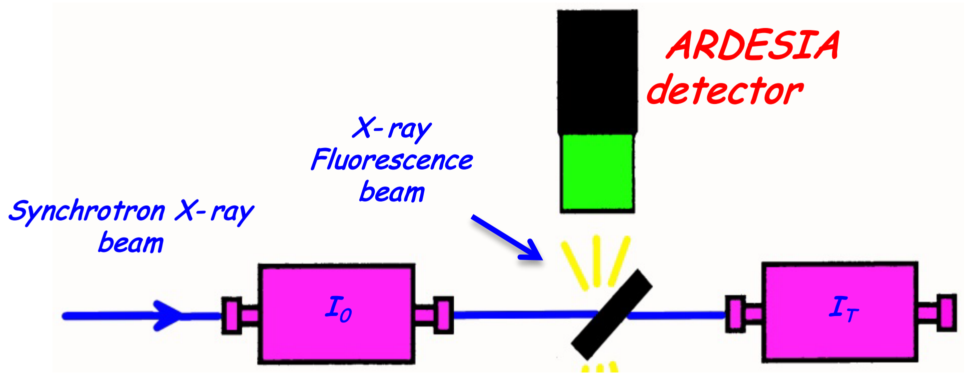
Reconstructed Z of irradiated points along the depth of the scintillator: horizontal axis is the true Z, vertical axis is the reconstructed Z.

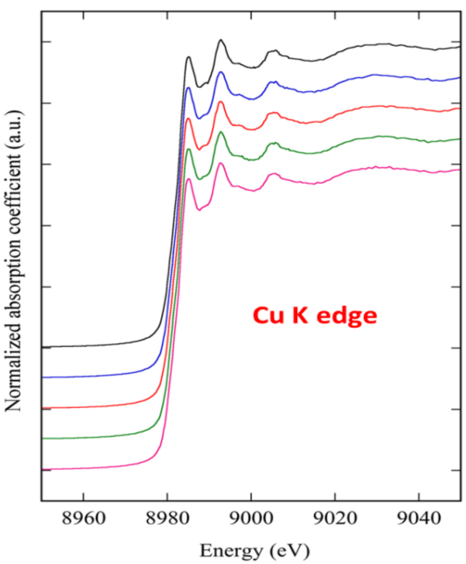
ARDESIA

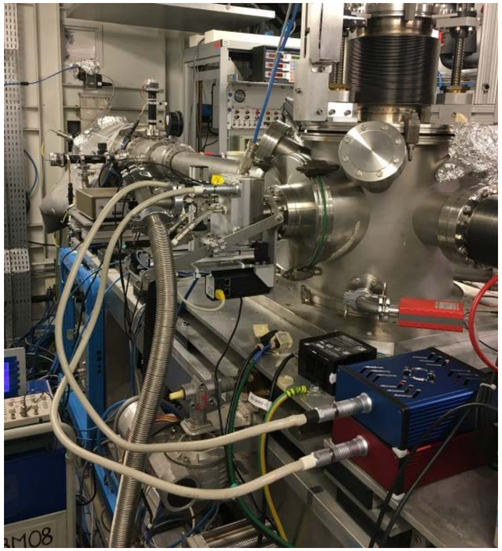
ARRAY of DETECTORS for SYNCHROTRON RADIATION APPLICATIONS

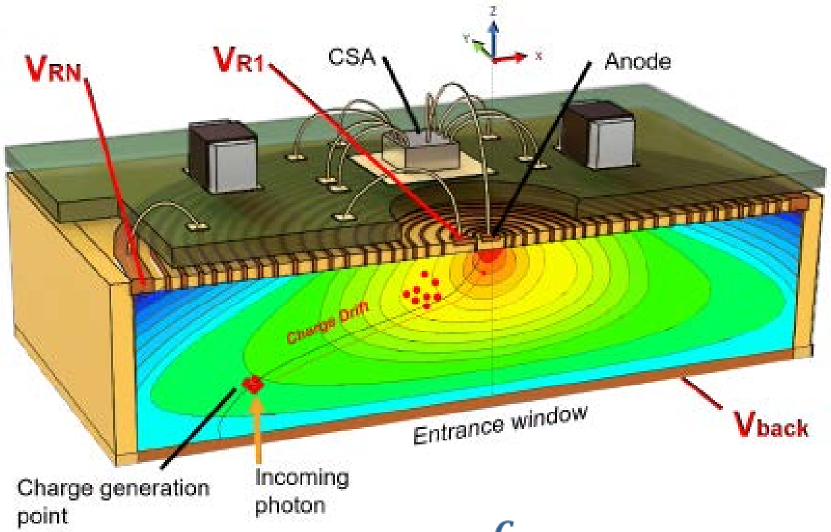
Goal: Development of a **versatile detector** based on **arrays of Silicon Drift Detectors** and **low-noise electronics** for **Synchrotron applications**

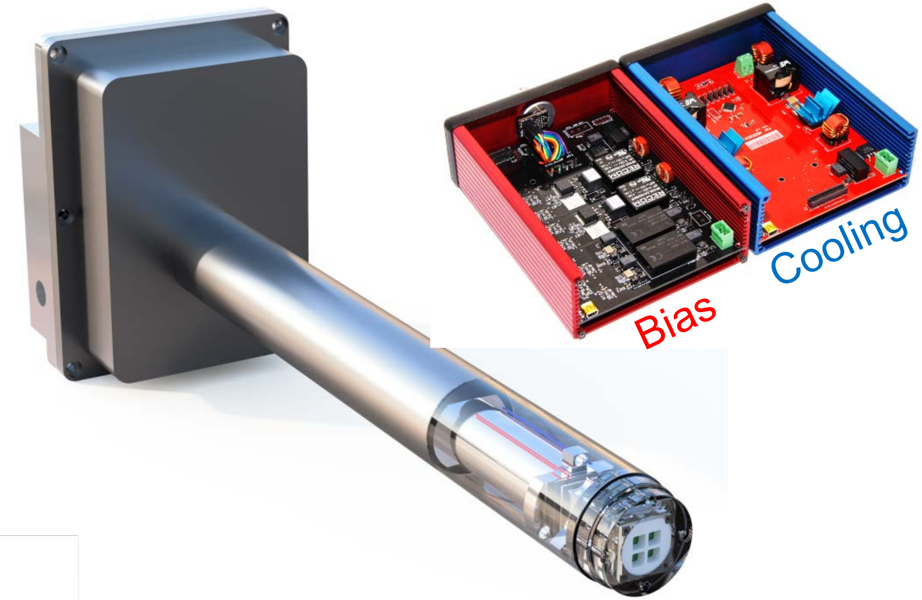


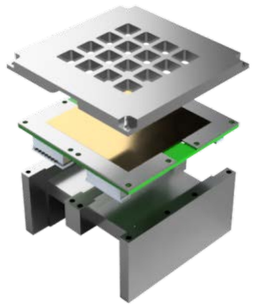


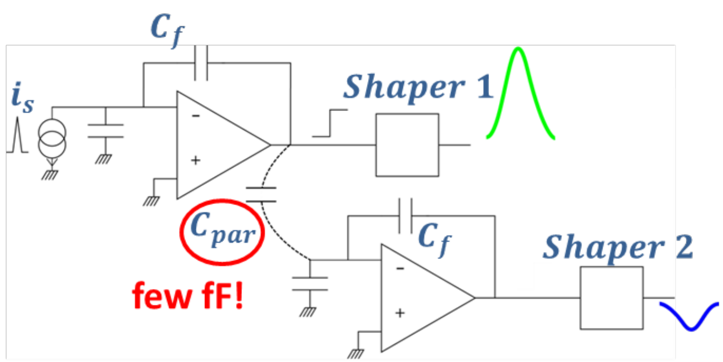


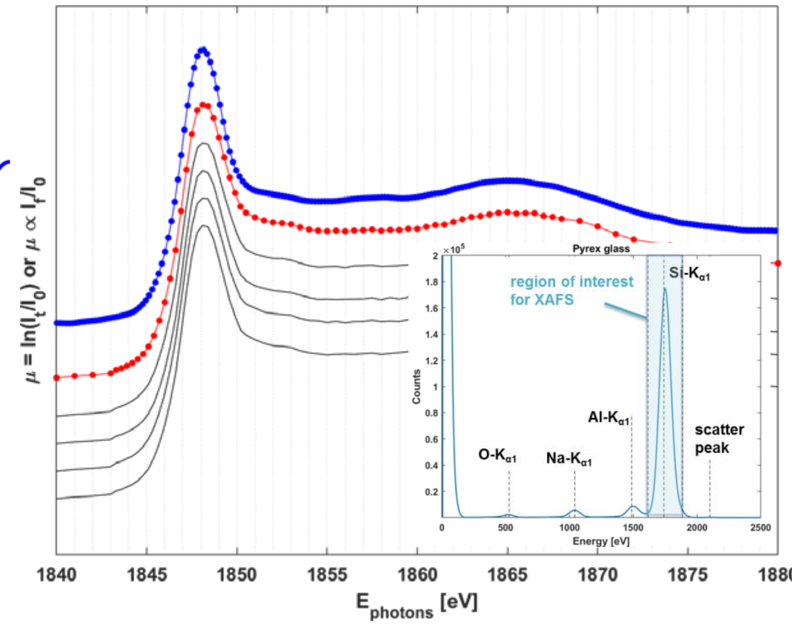






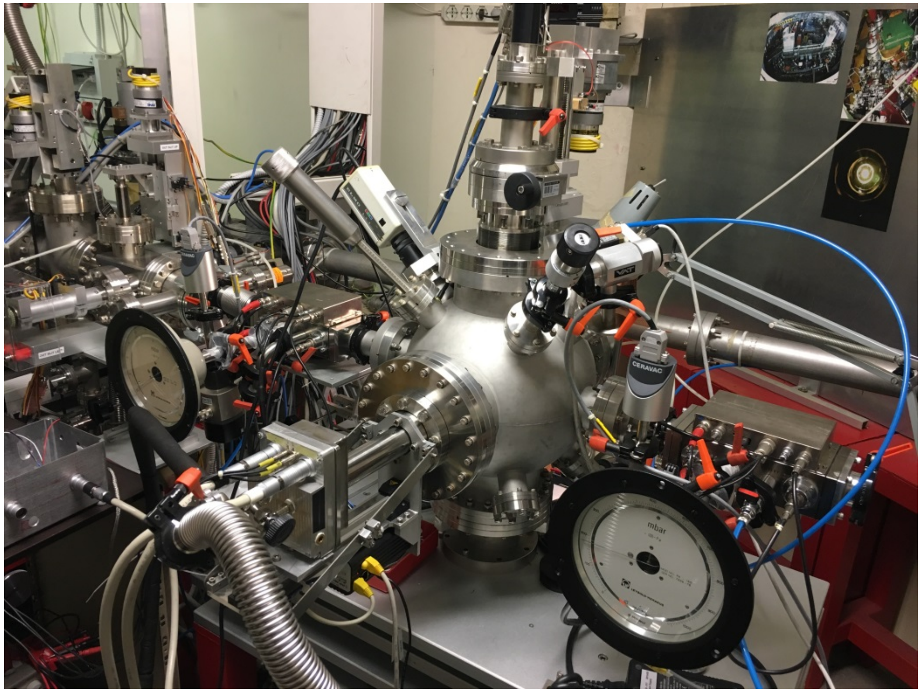


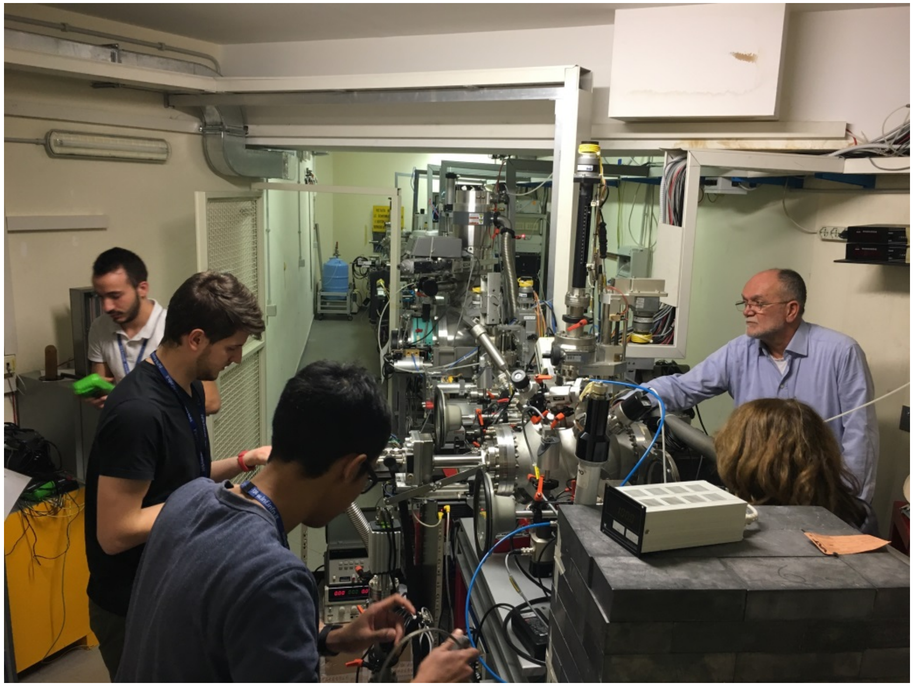


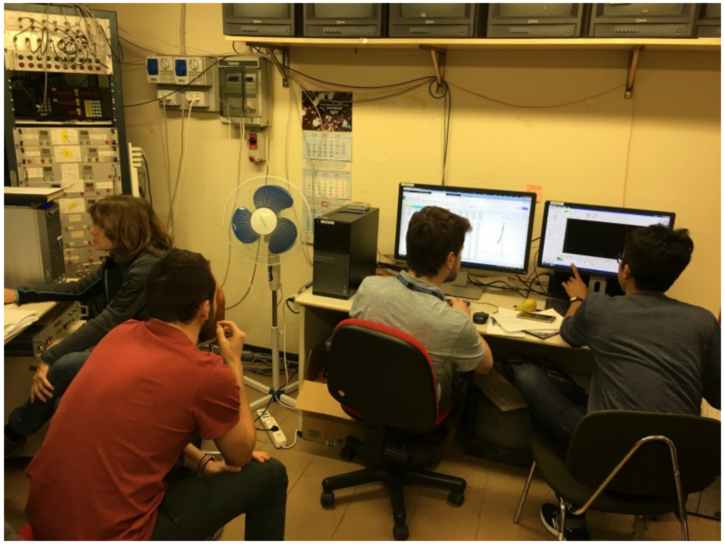


thesis topics:

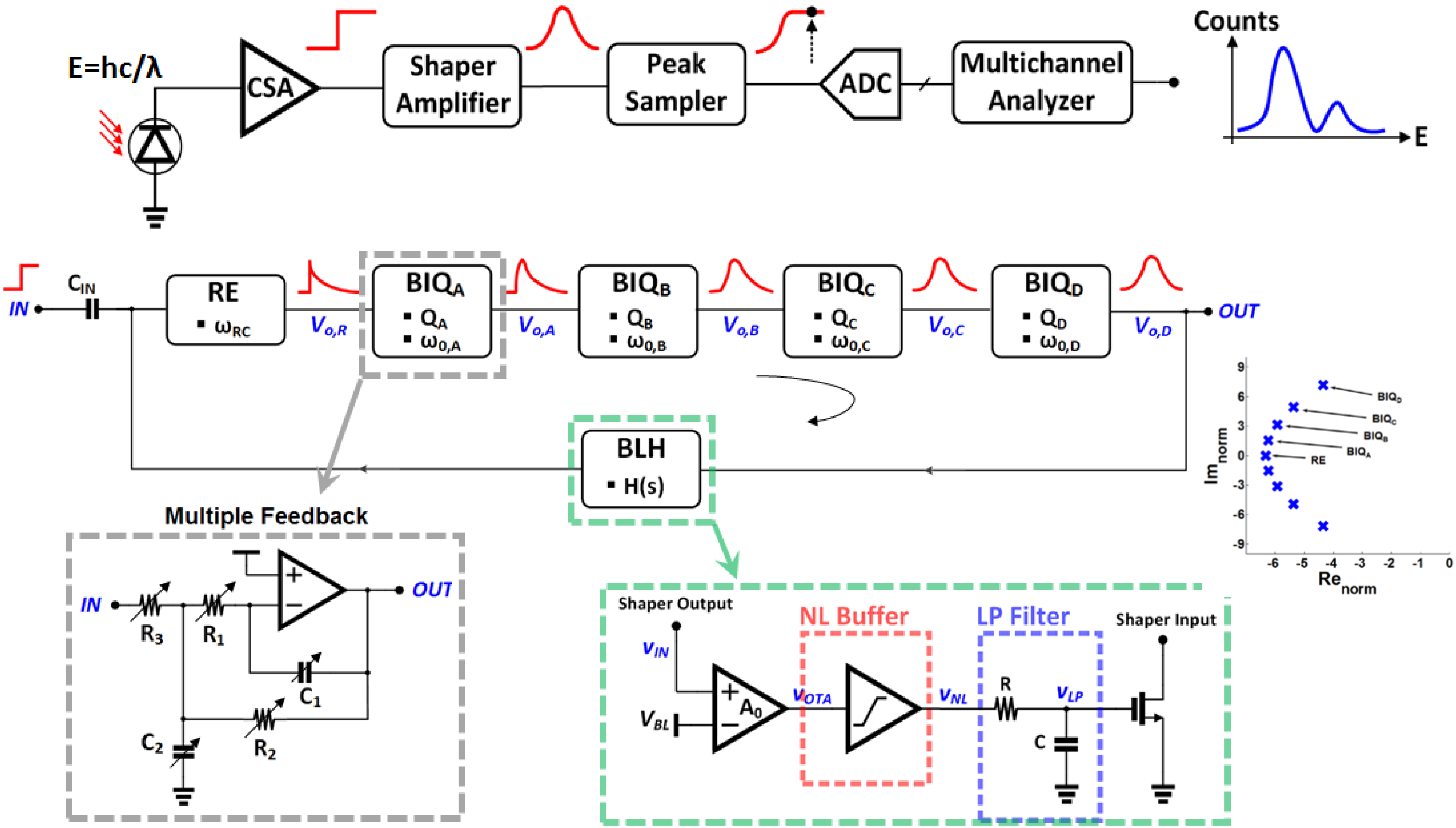
- development of detectors and instruments to be installed at synchrotrons, measurements and beam tests
- development and test of a high-rate readout ASIC (TERA)
- Development of an ultra-fast detector (SCARLET)


CERAVAC
mbar

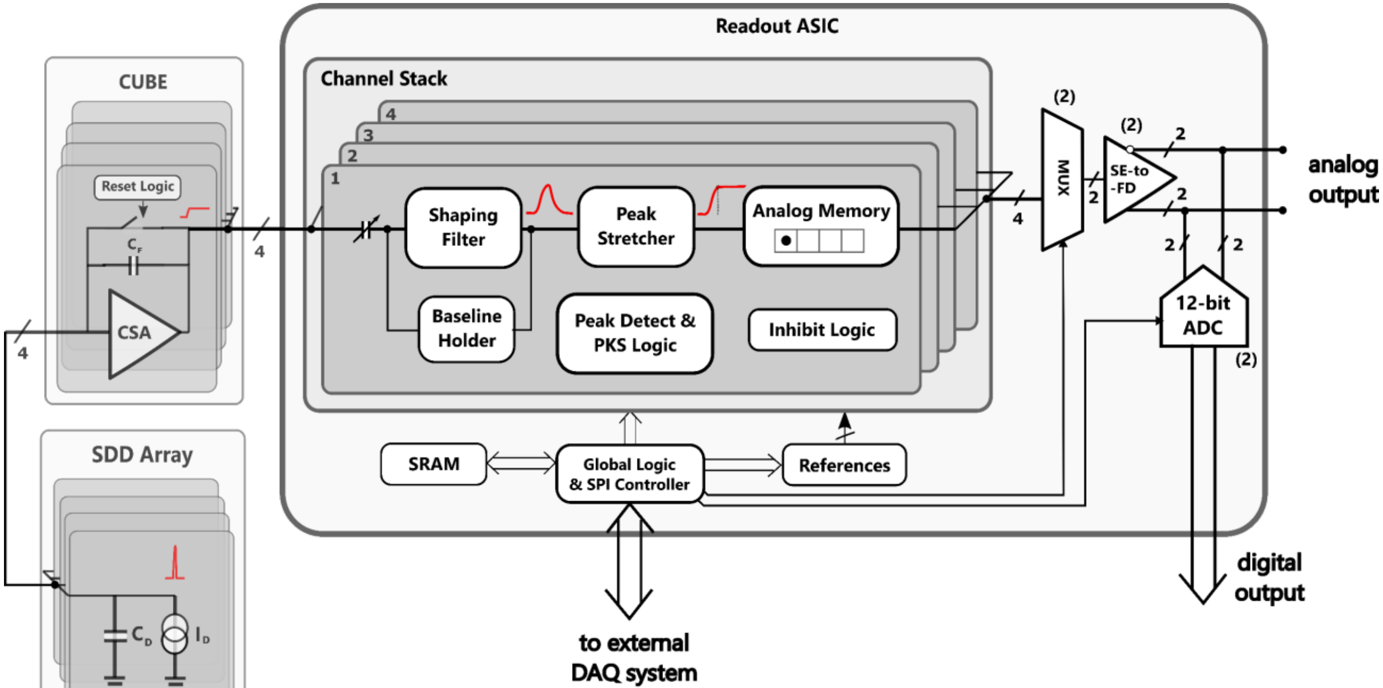


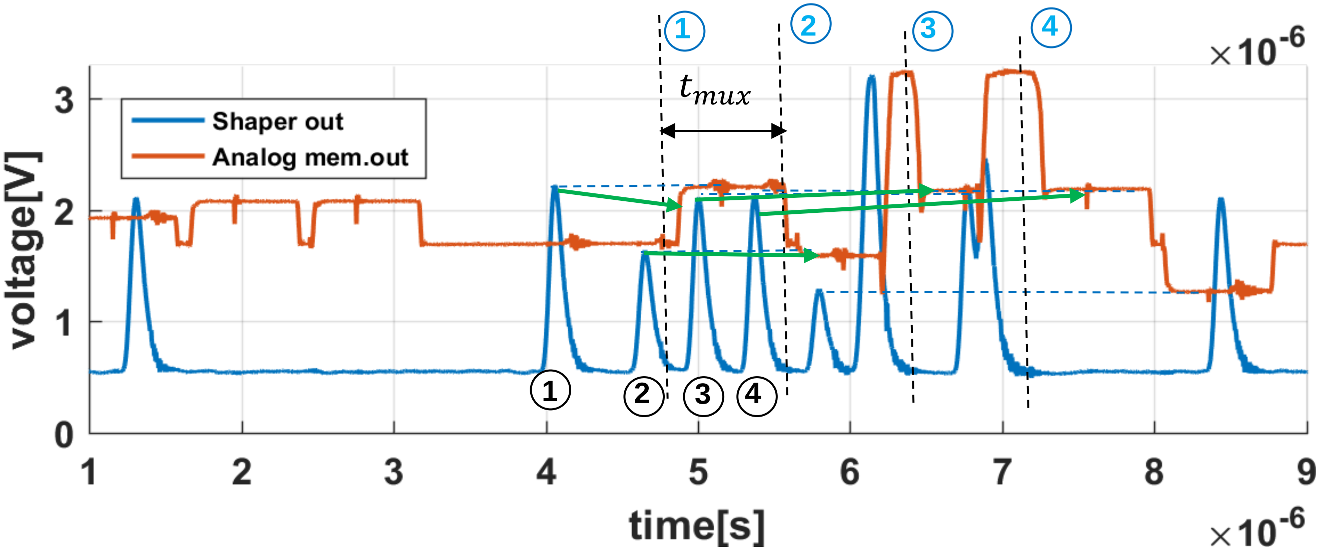


Example of readout ASIC architecture



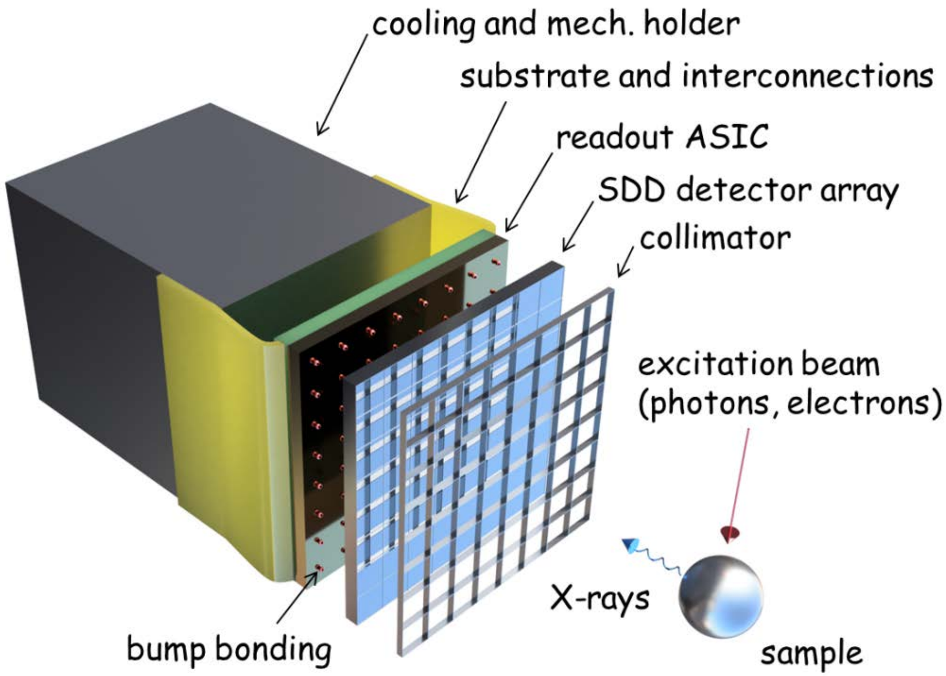
TERA: A Readout ASIC for Ultra High Rate X-ray Detection Applications





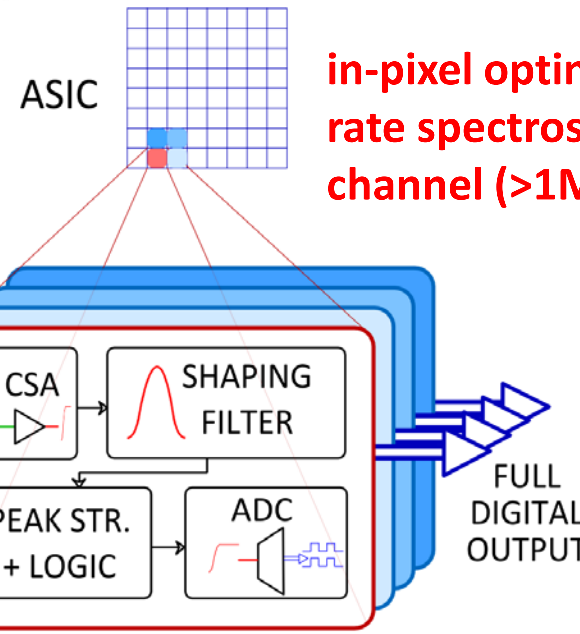
can analog approach get close to digital processing?

SCARLET: Monolithic pixellated spectroscopy detector



thesis topics:

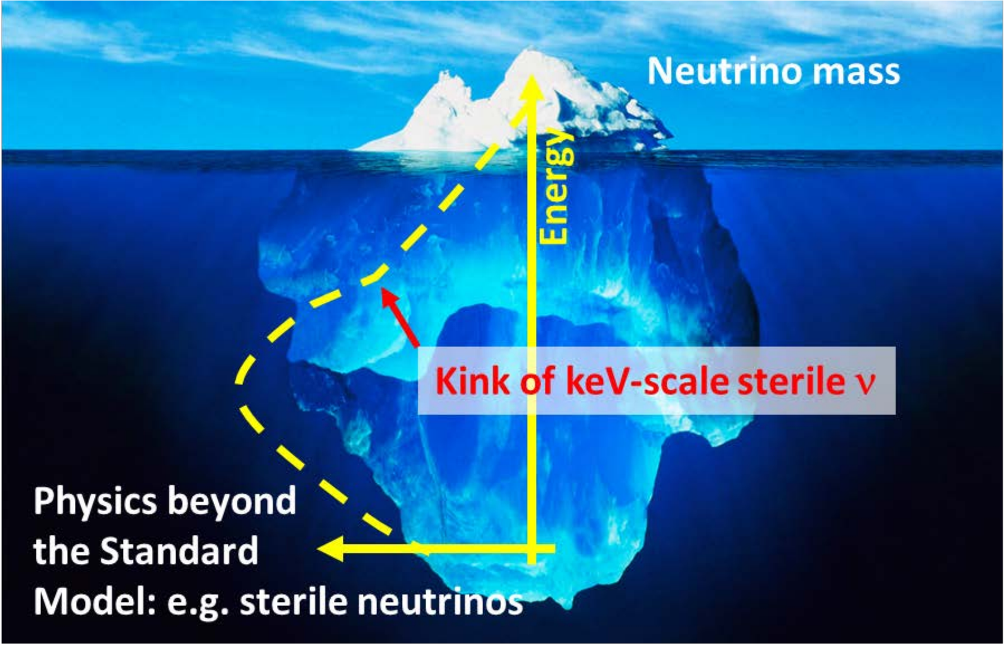
- study of a new detector: pixel of the ASIC (pre+shaper+ADC, power, area,..);
- technology (bump-bonding); detector performances evaluation; mask for charge sharing



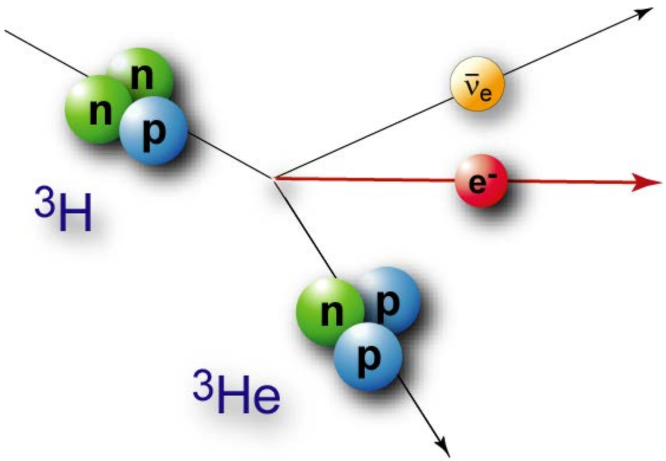
in-pixel optimum, high-rate spectroscopy channel (>1Mcount/ch.)

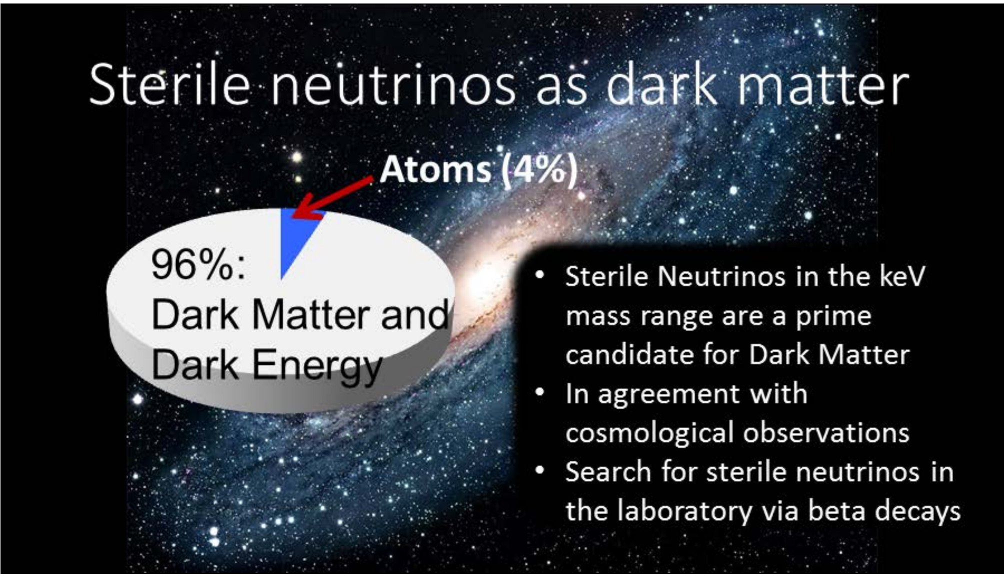
features:

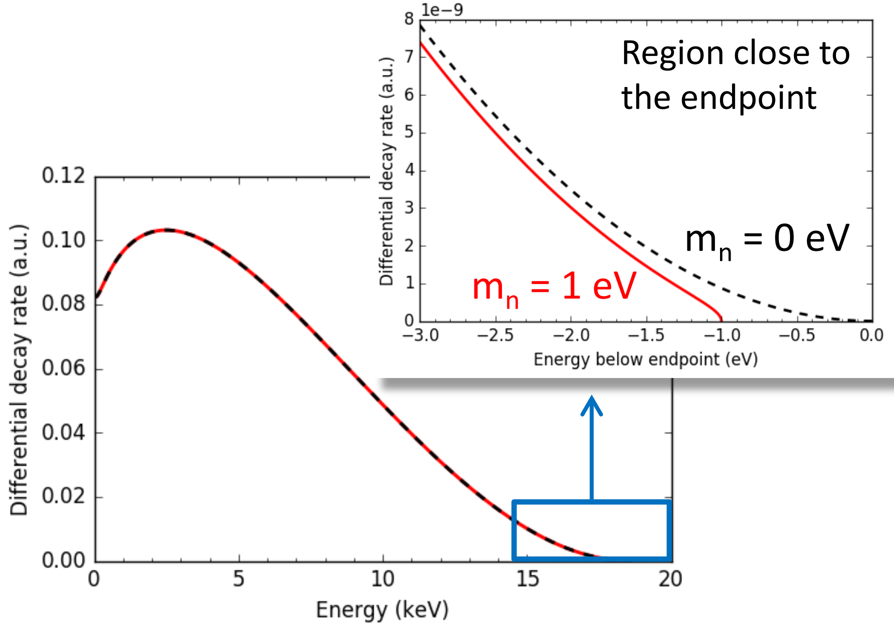
- 1Mcps/SDD (with 200ns analog shaping)
- ~ 64 Mcps total counting rate
- full analog processing (preamp.+filter) in the ASIC pixel
- E.Res. <150eV @200ns peak. time
- ADC integrated in the ASIC (1 for 4 ch.)


Neutrino mass
Energy
Kink of keV-scale sterile ν
Physics beyond
the Standard
Model: e.g. sterile neutrinos

TRISTAN

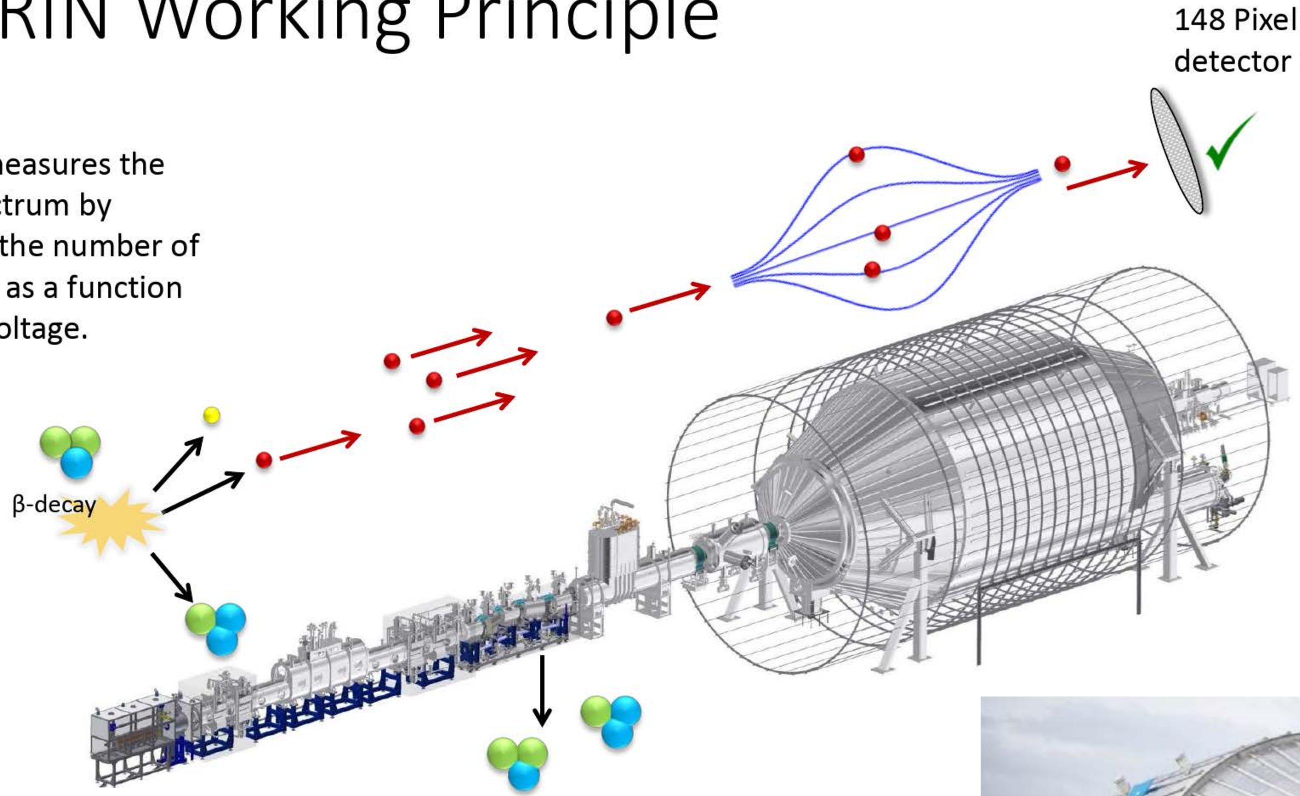

n
n
p
^3H
$\bar{\nu}_e$
e^-
n
p
p
^3He


Sterile neutrinos as dark matter
Atoms (4%)
96%:
Dark Matter and
Dark Energy
Sterile Neutrinos in the keV mass range are a prime candidate for Dark Matter
In agreement with cosmological observations
Search for sterile neutrinos in the laboratory via beta decays


Differential decay rate (a.u.)
Energy (keV)
Region close to
the endpoint
m_n = 0 eV
m_n = 1 eV
1e−9
Differential decay rate (a.u.)
Energy below endpoint (eV)

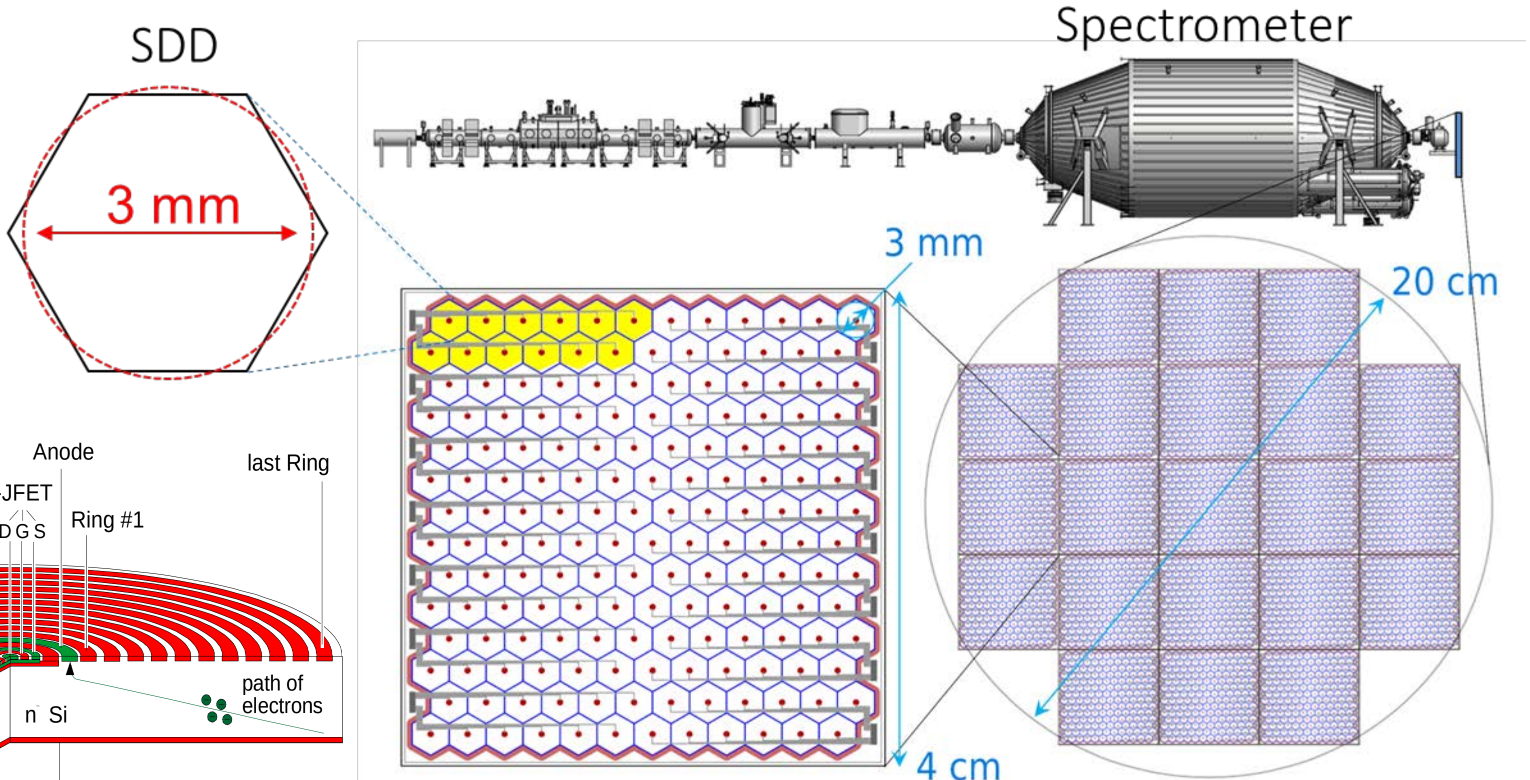
KATRIN Working Principle

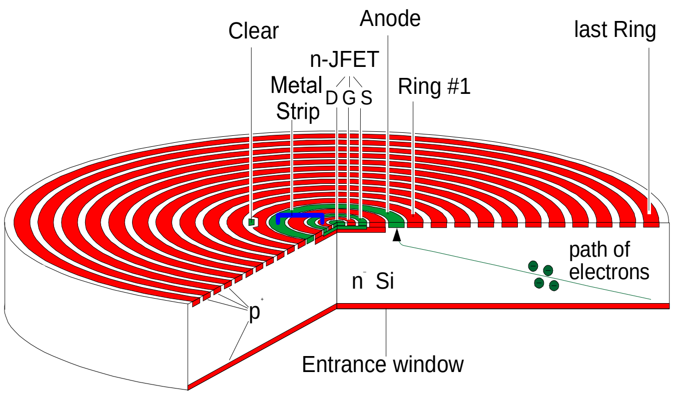
KATRIN measures the beta spectrum by counting the number of electrons as a function of filter voltage.



Dublin
IRELAND
Irish Sea
Man (U.K.)
Leeds
Manchester
Liverpool
KINGDOM
Birmingham
Cardiff
London
Celtic Sea
Amsterdam
NETH.
Rotterdam
Brussels
BEL.
Lille
Guernsey (U.K.)
Hamburg
Bremen
Berlin
Essen
Cologne
Bonn
GERMANY
Leipzig
Frankfurt am Main
Luxembourg
LUX.
Stuttgart
Munich
Strasbourg
300km
Zürich
Bern
Vaduz
SWITZ.
Geneva
Lyon
Bornholm
Gdansk
Poznań
Oder
Elbe
Łódź
Prague
CZECH REPUBLIC
Brno
Bratislava
Danube
Vienna
AUSTRIA
Budapest
HUNGARY
Cluj-Napoca
Iaşi
MOLDOVA
ROMANIA
Bucharest
Constanţa
Black Sea
Mykolayiv
Ljubljana
SLOVENIA
Zagreb
CROATIA
BOSNIA AND HERZEGOVINA
Belgrade
Serbia
Sarajevo
Danube
Varna
BULGARIA
Sofia
Istanbul
Bursa
Thessaloniki
TURKEY
Izmir
Aegean Sea
Athens
Rhodes
Crete
Milan
Venice
Turin
Genoa
MONACO
SAN MARINO
Ligurian Sea
Corsica
Sardinia
Cagliari
Sicily
Toulouse
Andorra la Vella
ANDORRA
PYRENEES
Marseille
Bilbao
Porto
Zaragoza
Madrid
Barcelona
PORTUGAL
Lisbon
Tagus
SPAIN
Valencia
Balearic Sea
BALEARIC ISLANDS
Sevilla
Gibraltar (U.K.)
Málaga
Strait of Gibraltar
Ceuta (SPAIN)
Alborán Sea
Mediterranean Sea
Melilla (SPAIN)
Oran
Algiers
Rabat
Tunis
Valletta
MALTA
Scale 1: 19,500,000
Lambert Conformal Conic Projection, standard parallels 40°N and 56°N

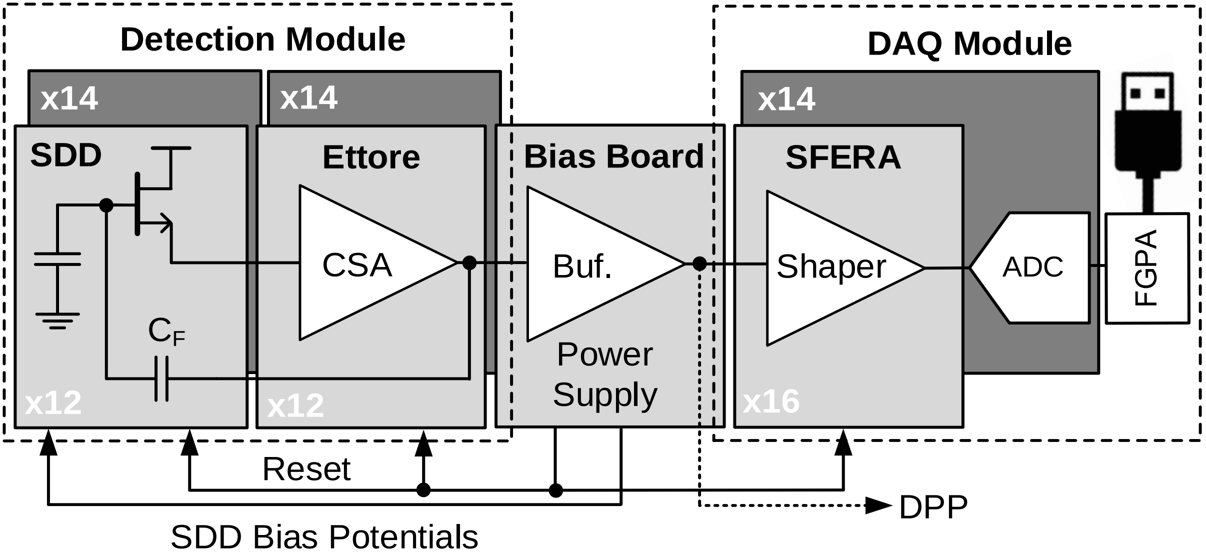
THE TRISTAN DETECTION SYSTEM

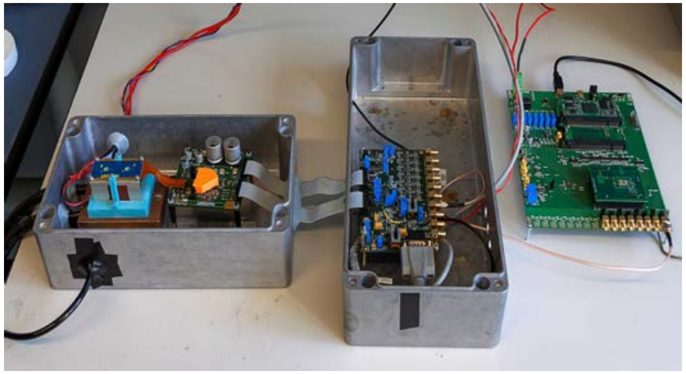


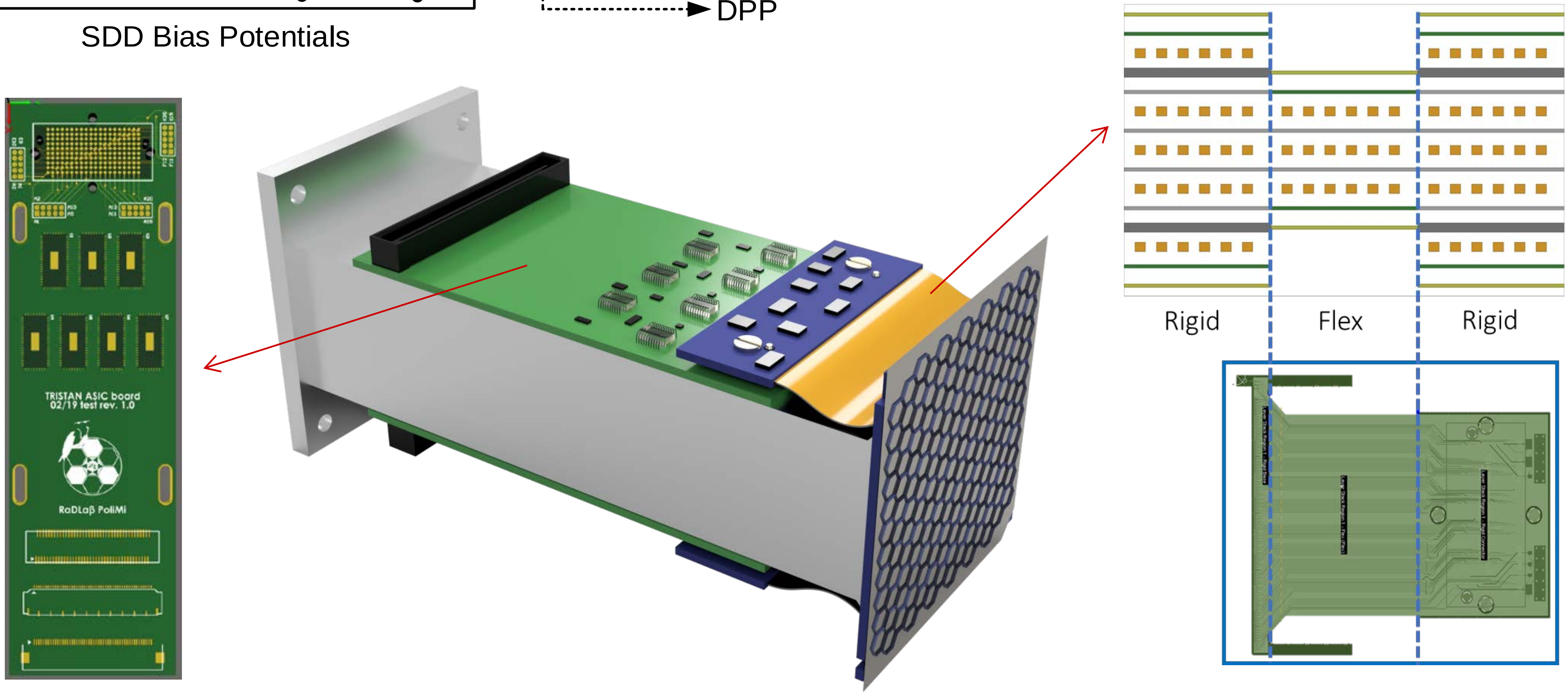


small output capacitance (thanks also to JFET integration on the detector)
⇒ very good energy resolution at fast processing times

- 21 juxtaposed modules
- 166 channels per module
- ~3500 total channels
- 100kcps per channel

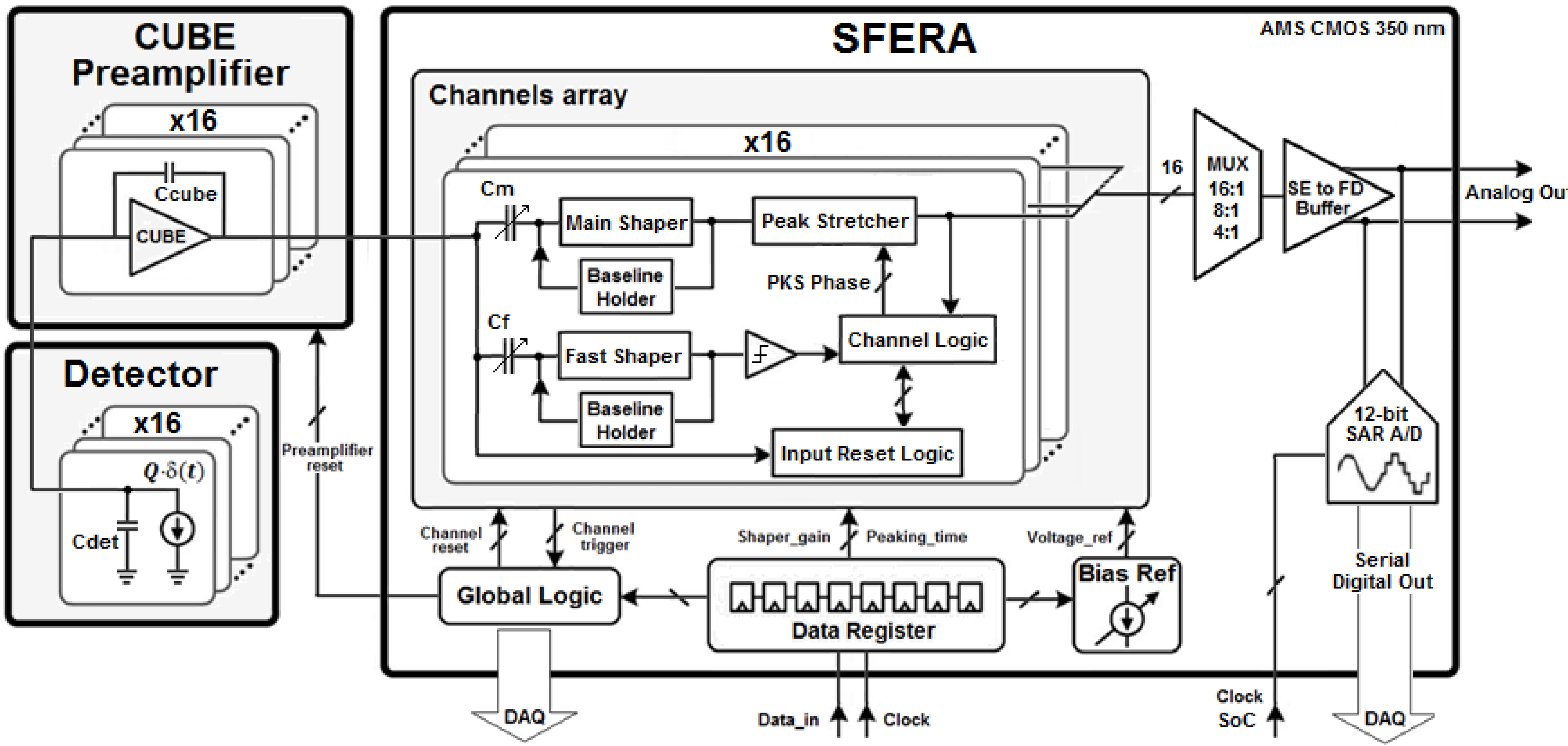

Detection Module
x14
x14
SDD
Ettore
CSA
C_F
x12
x12
Bias Board
Buf.
Power Supply
DAQ Module
x14
SFERA
Shaper
ADC
FGPA
x16
Reset
SDD Bias Potentials
DPP

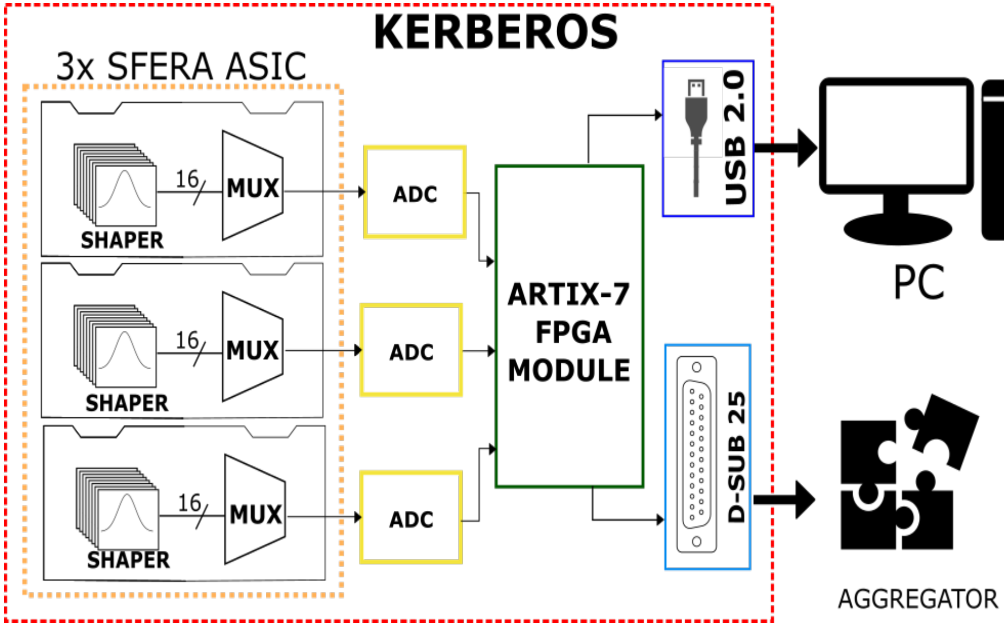


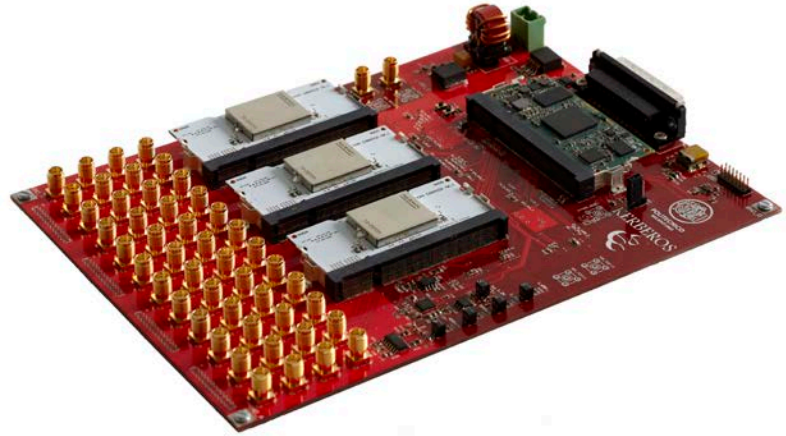

TRISTAN ASIC board 02/19 test rev. 1.0
RaDLaβ PoliMi
Rigid
Flex
Rigid

Another challenge is the scalability to 3500 channels of a DPP solution (1k€/ch.)

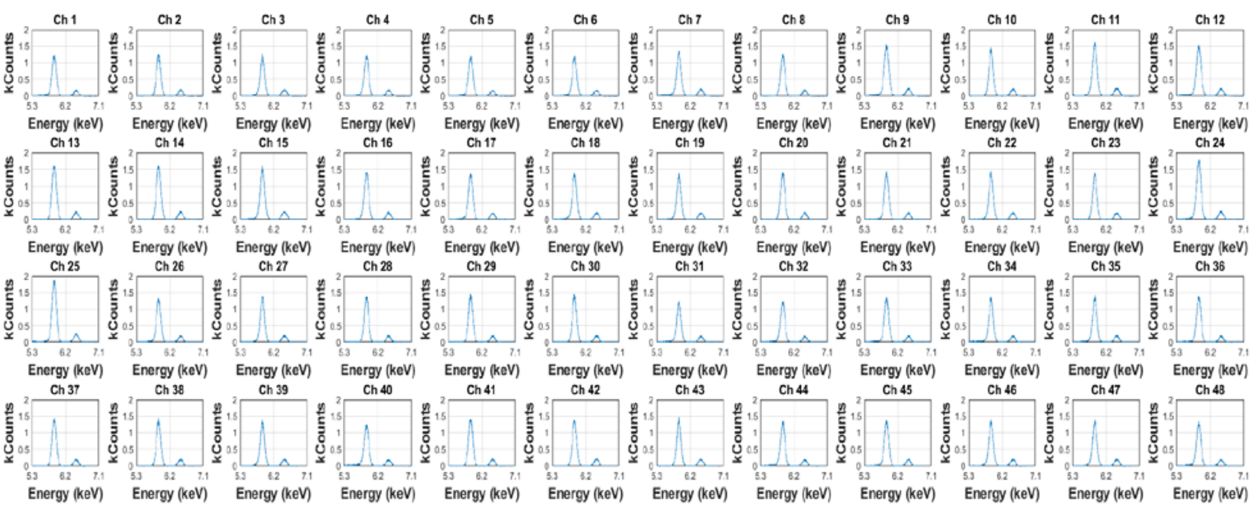
Solution: **integrated multi-channel analog signal processor**

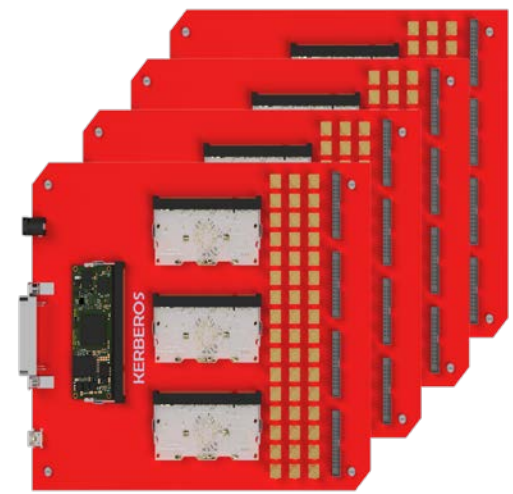



KERBEROS
3x SFERA ASIC
SHAPER
16
MUX
SHAPER
16
MUX
SHAPER
16
MUX
ADC
ADC
ADC
ARTIX-7
FPGA
MODULE
USB 2.0
D-SUB 25
PC
AGGREGATOR


KERBEROS

192 Ch.


Ch 1
Ch 2
Ch 3
Ch 4
Ch 5
Ch 6
Ch 7
Ch 8
Ch 9
Ch 10
Ch 11
Ch 12
Ch 13
Ch 14
Ch 15
Ch 16
Ch 17
Ch 18
Ch 19
Ch 20
Ch 21
Ch 22
Ch 23
Ch 24
Ch 25
Ch 26
Ch 27
Ch 28
Ch 29
Ch 30
Ch 31
Ch 32
Ch 33
Ch 34
Ch 35
Ch 36
Ch 37
Ch 38
Ch 39
Ch 40
Ch 41
Ch 42
Ch 43
Ch 44
Ch 45
Ch 46
Ch 47
Ch 48
kCounts
Energy (keV)

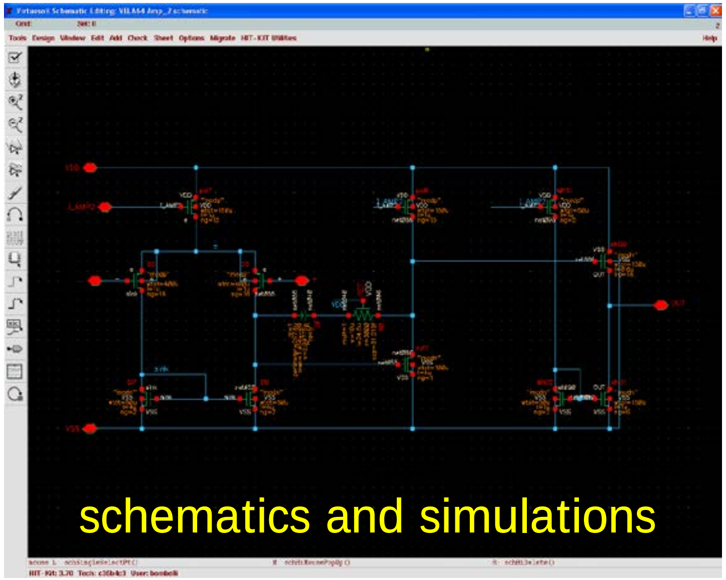

KERBEROS

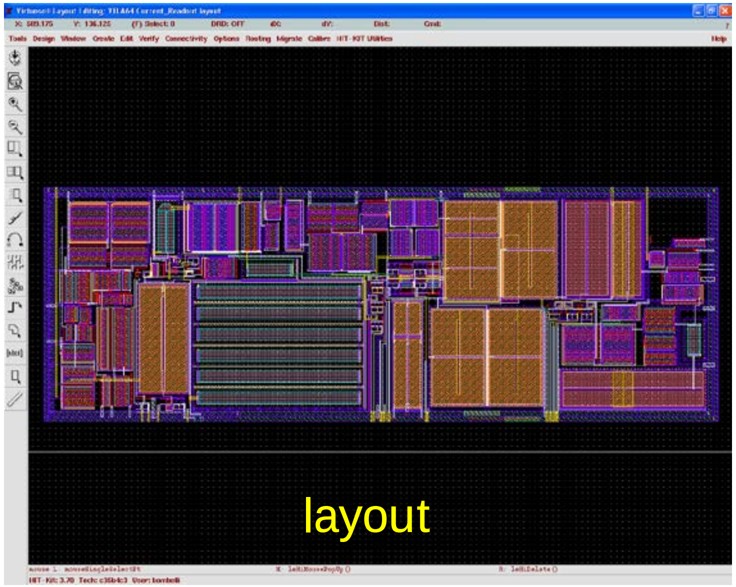
TRISTAN collaboration
(MPP-Munich, KIT Karlsruhe,..)

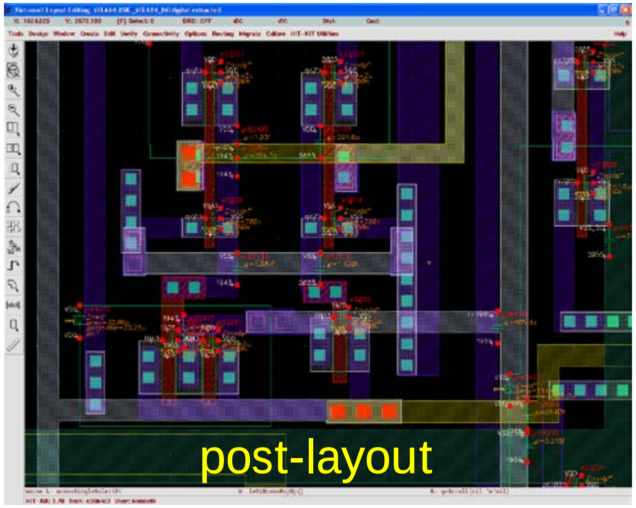
thesis topics:

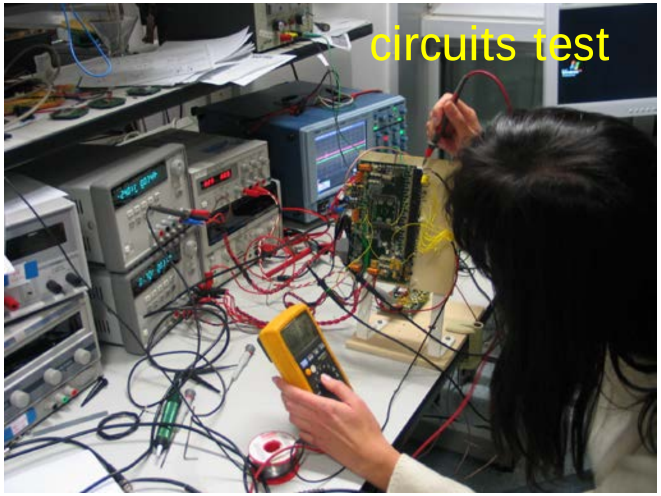
- Development of the TRISTAN detector module
- Development of the ASIC-based readout platform and DAQ
- Experimentation of detector with electrons

Design of integrated circuits:









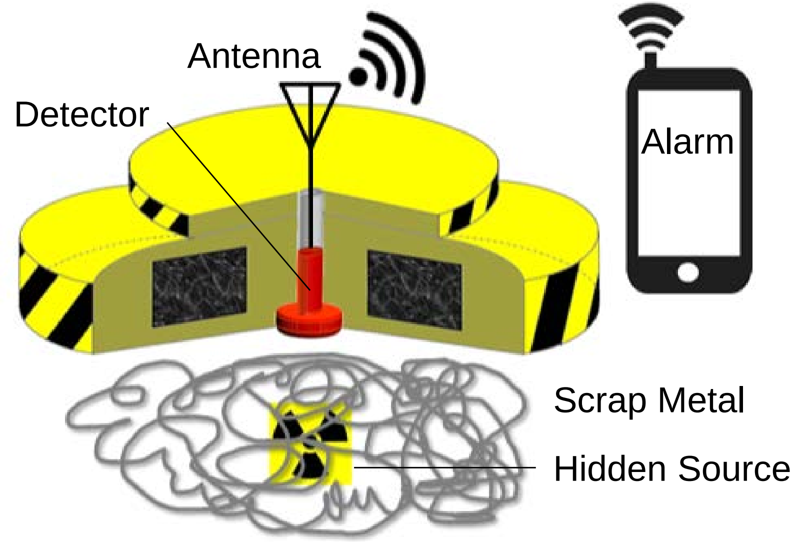
and finally….

← presentation of the thesis

↓ diploma delivery

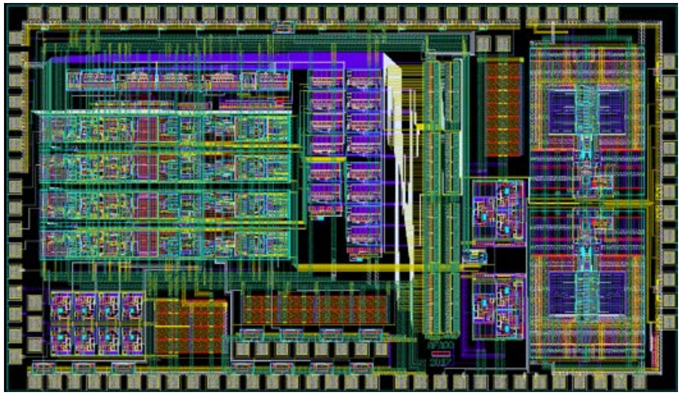
← and party…

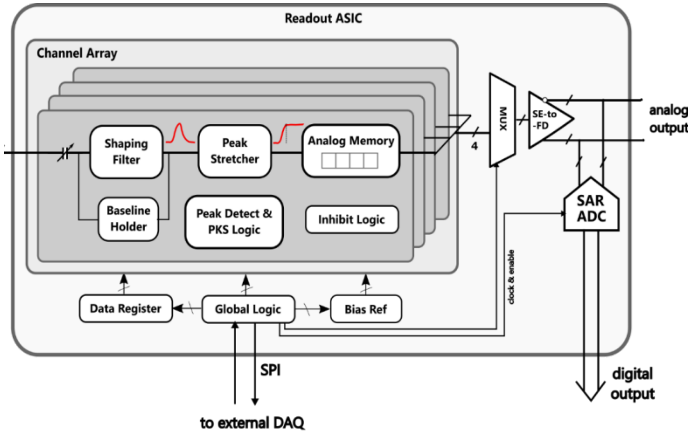
and it is not over: Awards…!



Innovation Day - Design Contest, 18 ottobre 2018, Museo della Scienza e Tecnologia di Milano. Emanuele Lavelli, premio per miglior tesi di laurea sul lavoro: "Spettrometro di raggi gamma basato su fotorilevatori SiPM per rilevazione sorgenti radioattive".

Awards…!





Idham Hafizh, student at the Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, has been awarded with the first edition of the Prof. Emilio Gatti Best Master Thesis Award from the Istituto Lombardo Accademia di Science e Lettere.

Preliminary list of available thesis

1) INSERT

- detection module: innovative event reconstruction techniques (machine learning), e.g. DOI, MUX…;
- experimentation of the clinical SPECT in measurements at University College London

2) ARDESIA

- development of a 16ch. detector + ASIC readout, thicker silicon substrate, development of a complete instrument, installation and beam tests at DESY synchrotron (Hamburg)
- development and test of the new high-rate TERA readout ASIC

3) SCARLET

- study of a new detector: pixel of the ASIC (pre+shaper+ADC, power, area,..);
  technology (bump-bonding); detector performances evaluation; mask for charge sharing

4) SIDDHARTA

- characterization of the detection modules and new SFERA ASIC vs. experiment specifications; installation in the experiment and beam tests at LNF-INFN in Frascati

5) TRISTAN

- development of new multi-element detector, readout ASICs and DAQ for TRISTAN experiment for neutrino-mass measurement and dark matter search

6) GAMMA

- development and experimentation of the detector based 3" LaBr3 scintillator and beam tests
- development of imaging algorithms for Doppler broadening correction
- development of an ultra high (10.000) dynamic range ASIC
- study and experimentation of timing properties of the detector+electronics

7) SMART FOUNDRY

- development of a new radiation sensors and systems for portable and areal (on board of drones) applications in environmental radiation monitoring

8) PAIRED-X

- development of electronics readout (ASIC+DPP) for microstrip detector for a portable XRF+XRD analyzer of material for mining

9) ESQUIRE

- development of innovative gamma-ray detectors based on nanocristal scintillators (quantum dots) readout by SDDs (Silicon Drift Detectors)

10) NEW ASICs design

- development of innovative readout preamplifiers and ASICs for ultra-low noise and special applications

You are very welcome to visit our lab, to talk with master students and PhD students and spend some time to see what they are doing…..

For visiting the lab and looking to research and development activities (not necessarily only for thesis interest),
please organize youself in small groups (4-5 max.) and provide me by mail desired time slot (day and time) to organize the visit (1-2 hours)