ARDENT

Advanced Radiation Dosimetry European Network Training

THE ARDENT PROJECT AND NEUTRON DETECTION WITH TIMEPIX DEVICES

ERLANGEN CENTER FOR ASTROPARTICLE PHYSICS, DECEMBER, 20TH 2012

OVERVIEW

The ARDENT project

- What is the ARDENT project?
- Why is it interesting for students?
- Examples of work done within this project
- Impressions of the first workshop in Vienna

Neutron detection with MPX/TPX devices

- Working principle of hybrid pixel detectors
- Neutron detection and conversion layers
- The ATLAS-Medipix detector network
- Proposed upgrade from MPX to TPX

THE ARDENT PROJECT

ARDENT

February 2012 – January 2016

Advanced Radiation Dosimetry European Network Training initiative

Marie Curie Initial Training Network under EU FP7 – 4 M€

7 Full Partners and 5 Associate Partners

Coordinator: CERN, Scientist-in-Charge: Dr. M. Silari

CERN (coordinator), Switzerland
AIT Vienna, Austria / Siebersdorf Laboratories
CTU- IAEP Prague, Czech Republic
IBA Dosimetry, Schwarzenbruck, Germany
Jablotron, Prague, Czech Republic
MI.AM, Milano, Italy
Politecnico, of Milano, Italy

ST Microelectronics, Italy
University of Erlangen, Germany
University of Houston, USA
University of Ontario, Canada
University of Wollongong, Australia

Development of advanced instrumentation for radiation monitoring…

Three main technologies

- Gas detectors [e.g., gas electron multipliers (GEM), tissue equivalent proportional counters (TEPC)]
- Solid state detectors [e.g., Medipix, silicon micro-dosimeters]
- Track detector techniques [e.g., CR-39, nano-dosimeters]

We can still add detectors / technologies we think are worth investigating!

OBJECTIVES & APPLICATIONS

- Main objectives
  - Radiation dosimetry
  - Micro- and nano-dosimetry
  - Photon and neutron spectrometry

- Applications
  - Characterization of radiation fields at particle accelerators (research, industry, medical)
  - Characterization of radiation fields on-board aircrafts and in space
  - Assessment of secondary dose to RT patient
  - Measurement of properties of clinical hadron beams

RESEARCHER RECRUITMENT

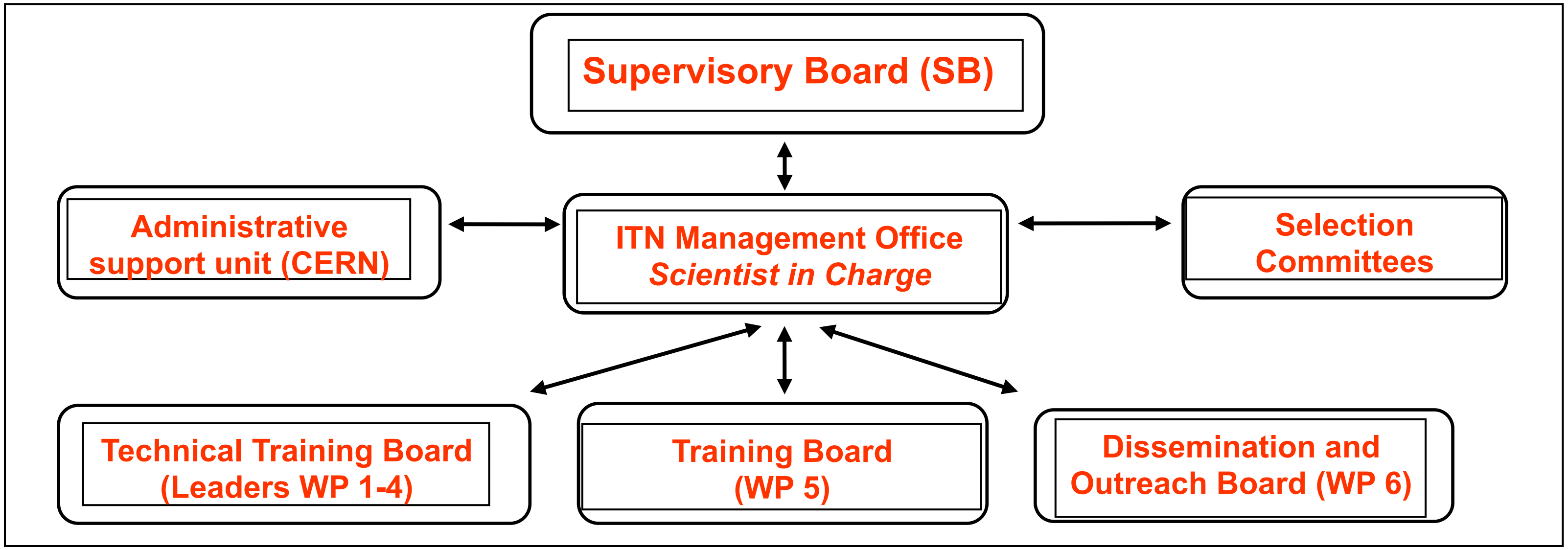
- 15 Early Stage Researchers (ESR), 9 already recruited
  - 4 at CERN: Eleni Aza (Gr), Erik Frojd (Se), Stuart George (GB), Silvia Puddu (It)
  - 2 ait AIT / SL, Vienna: Andrej Sipaj (Sl)
  - 3 at CTU, Prague: Benedikt Bergmann (DE), Kevin Loo (AU)
  - 2 at IBA Dosimetry, Schwarzenbruck
  - 1 at Jablotron, Prague: Vijayaragavan Viswanathan (India)
  - 1 at MI.AM, Milano: Alvin Sashala Naik (Mauritius)
  - 2 at the Politecnico, Milano: Chris Cassell (AU), Eleni Sagia (Gr)

- Up to 1/3 of time can be spent on secondments
- Work performed within the project to be used for PhD
- Generous training allowance for researchers

WORK PACKAGES

- Seven Work Packages
  - WP1: gas detectors *(Sofia Rollet, AIT, Vienna)*
  - WP2: solid state detectors *(Zdenek Vykydal, CTU, Prague)*
  - WP3: track detectors *(Marco Caresana, Politecnico, Milano)*
  - WP4: instrument inter-comparison *(Matteo Magistris, CERN)*
  - WP5: training
  - ❖ Individual training programs
  - ❖ Network-wide training
  - WP6: dissemination and outreach
  - WP7: ITN management

ARDENT Structure



http://cern.ch/ardent

ERIK FRÖJDH – ESR 2

- **28 Years old**
- **Born in Sundsvall, Sweden**
- **Education**
  - Master of Science degree in Physics from Mid Sweden University Jan 2010
  - Admitted as a PhD student at Mid Sweden University (Feb 2010)
- **Work within ardent**
  - Application of Timepix as a dosimeter in space and around accelerators
  - Characterization of Medipix3RX and Timepix 3
  - Medipix support for the other ESRs

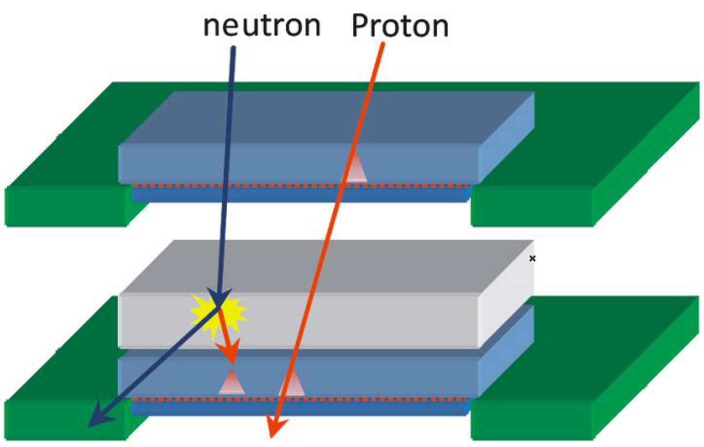
STUART GEORGE – ESR4

- I'm 24 and from the UK
- Completed a Masters degree in physics from the University of Sheffield in computational stat mech.
- My project focuses on the medical applications of the Medipix device as well as other active detector systems (for example GEM's).

stuart.george@cern.ch

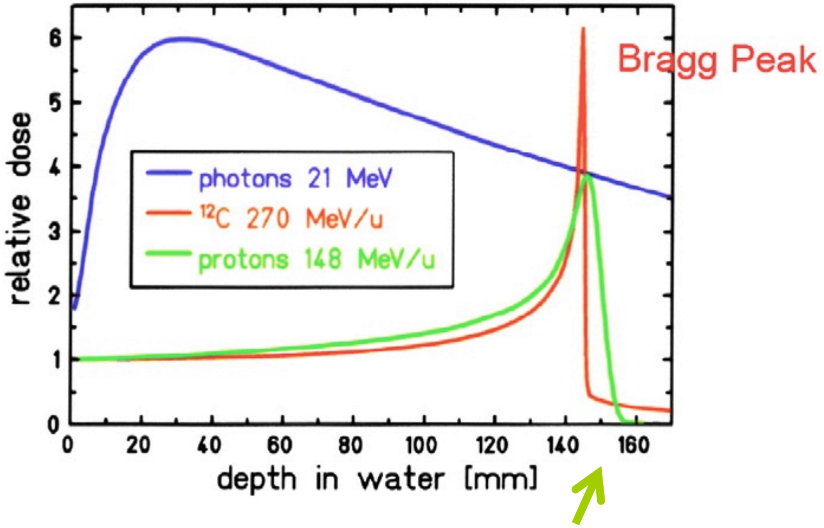
UNDUE RADIATION TO THE (CONVENTIONAL) RADIOTHERAPY PATIENT

- In-phantom measurement of out-of-field radiation doses.
- Some work has been done on characterising doses outside of phantoms and in-phantom with *passive* dosimeters.
- In addition, neutrons are generated for electron energies E > 10 MeV.
- Medipix2 with converter layers should allow us to measure neutrons inside the phantom out-of-field and in-field, actively discriminating against the intense photon field.
- We plan to carry out similar measurements in particle therapy.

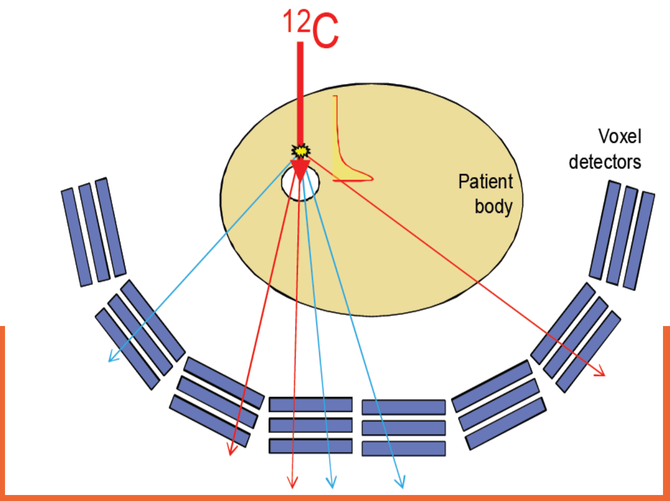


ION FRAGMENTS IN CARBON ION THERAPY

- During therapy with carbon ions the carbon beam suffers high levels of fragmentation before the Bragg Peak.
- The small size of the timepix chip allows us to measure these fragments inside the phantom.
- In addition we plan to continue the work done at CTU on vertex imaging from secondary radiation (0.1 secondaries/carbon)



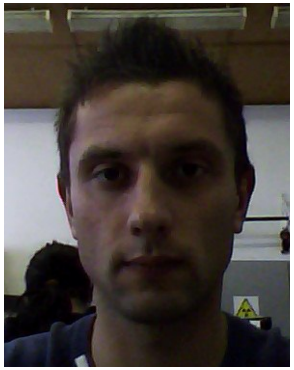
Biochimica et Biophysica Acta **1796** (2009) 216–229



^{55}FE WASTE CHARACTERISATION

- CERN has lots of low level radioactive waste stored at the old ISR site.
- Some of this waste may be suitable for free release depending amongst other radionuclides, on ^{55}Fe levels (2.7 year half life).
- ^{55}Fe is hard to detect with conventional spectrometry due to its low energy of emission (5.9 keV x-ray).

BENEDIKT BERGMANN – ESR9



Benedikt Bergmann

Germany, Pressig

12^{th} February 1987

X-mas Concert (2011)

Work in the ARDENT program

- Evaluation of data taken by the ATLAS-MPX detector network focussing on neutron dosimetric issues
- ATLAS MPX to TPX upgrade

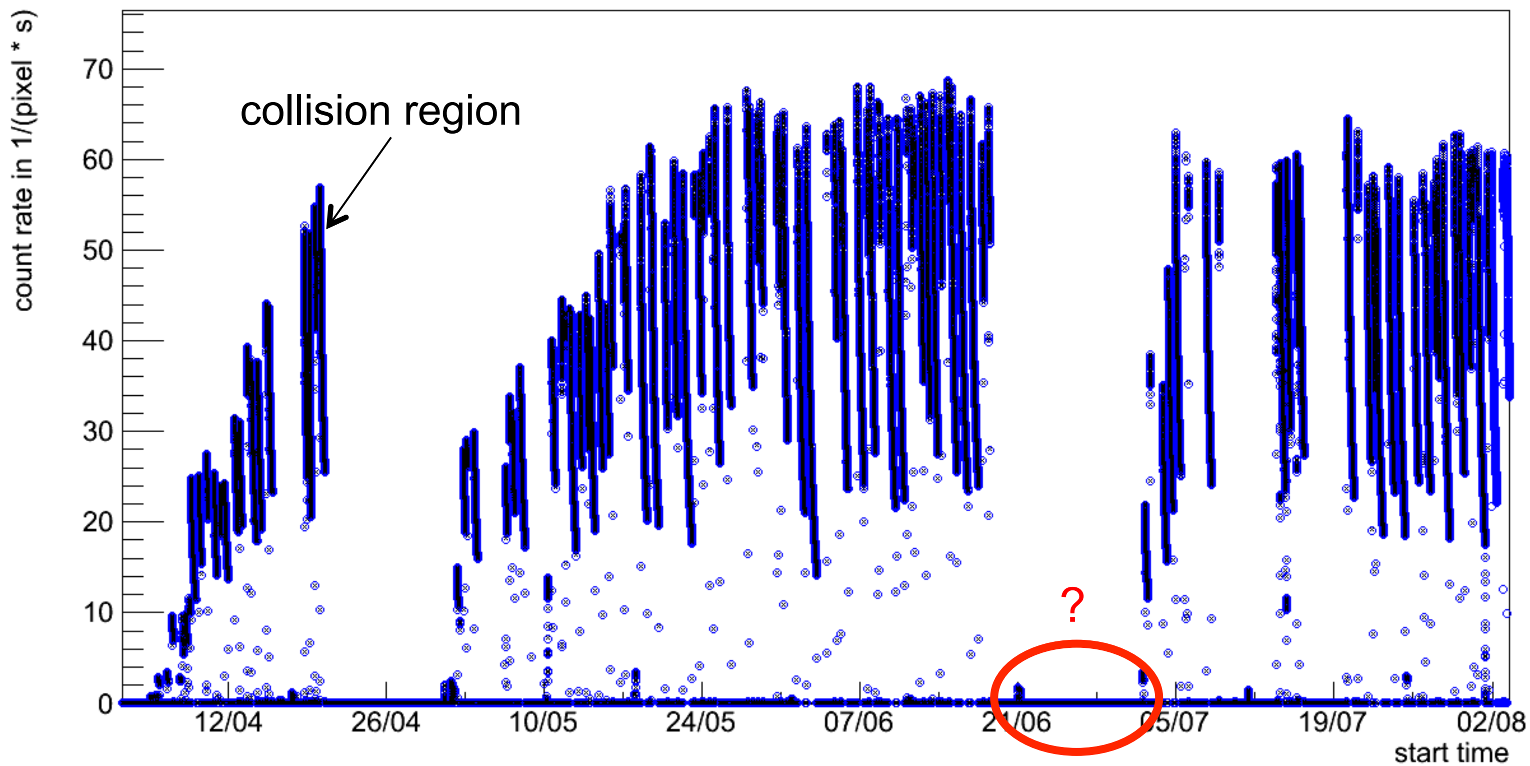
Bavarian Beach Soccer Champion (2010)

ECAP vs. Theory 4:1 (2012)

STUDIES ON ACTIVATION IN THE ATLAS CAVERN

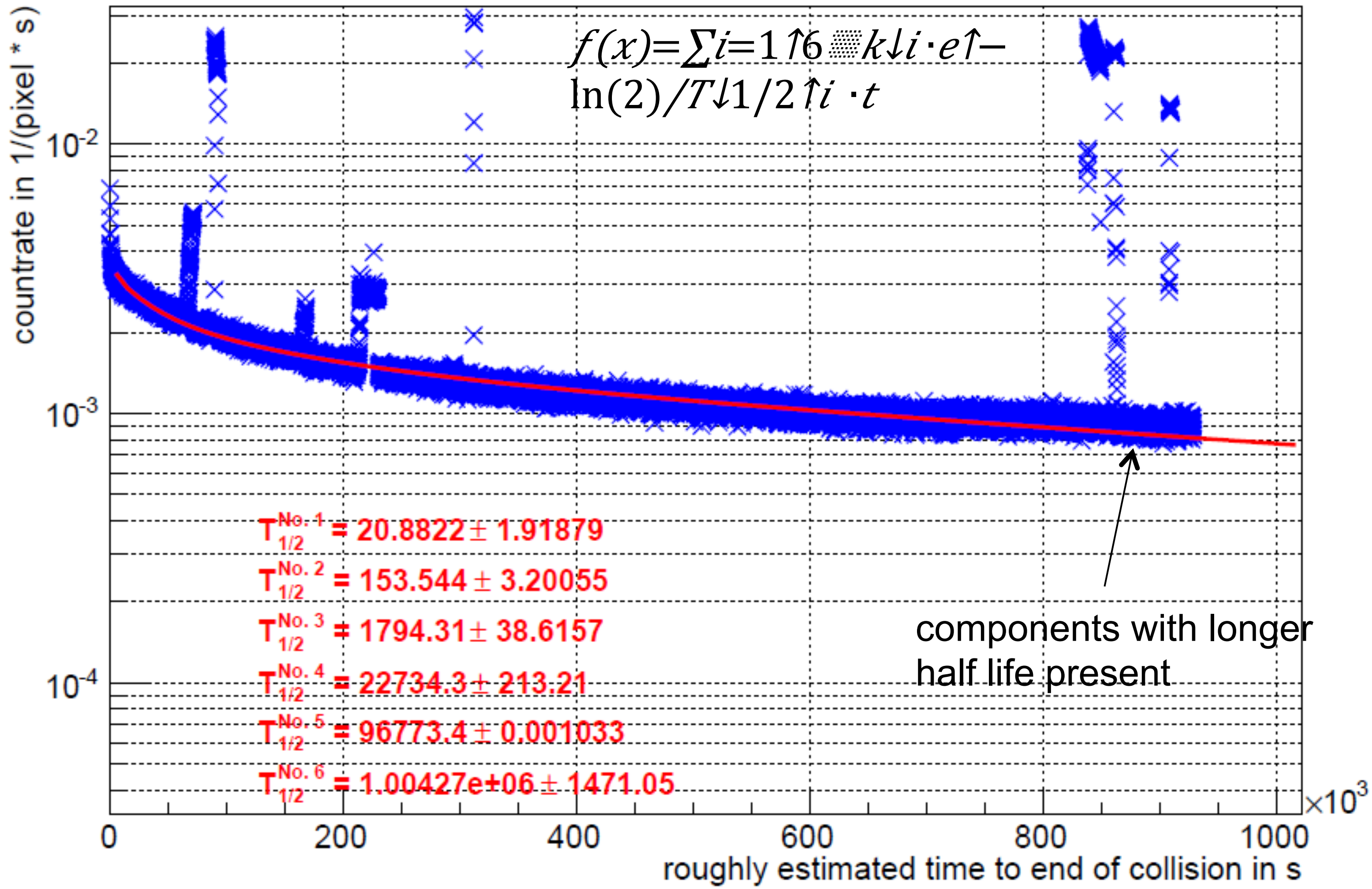
Activation of surrounding material during collisions in the ATLAS detector

- Luminosity monitoring with MPX devices: Background contribution
- Dosimetric aspect: What is the time dependency of the equivalent dose rate after the collisions?



MODELLING THE DECAY OF ACTIVATION PRODUCTS

$$f(x)=\sum_{i=1}^{6} k_i \cdot e^{-\ln(2)/T_{1/2}^{i} \cdot t}$$



IMPRESSIONS OF THE 1ST ANNUAL WORKSHOP IN VIENNA

Hard work: lectures from 9:00 to 18:30 (3 days)

Getting to know other countries and cultures

Visiting institutes on the cutting-edge of technology

DOSIMETRY: AN ARDENT TOPIC

The first annual ARDENT workshop took place in Vienna from 20 to 23 November. The workshop gathered together the Early-Stage Researchers (ESR) and their supervisors, plus other people involved from all the participating institutions.

"Article in CERN Bulletin about the 1st annual ARDENT workshop" taken from http://cdsweb.cern.ch/journal/CERNBulletin/2012/49/News%20Articles/1496550?ln=en

"The meeting, which was organised with the local support of the Austrian Institute of Technology, was a nice opportunity for the ESRs to get together, meet each other, and present their research plans and some preliminary results of their work," says Marco Silari, a member of CERN Radiation Protection Group and the scientist in charge of the programme. Two full days were devoted to a training course on radiation dosimetry, delivered by renowned experts. The workshop closed with a half-day visit to the MedAustron facility in Wiener Neustadt.

ARDENT (Advanced Radiation Dosimetry European Network Training) is a Marie Curie ITN project funded under EU FP7 with €4 million. The project focuses on radiation dosimetry exploiting several detector technologies for various applications: the characterization of the stray radiation field around particle accelerators, on board commercial flights and in space, in the medical field (radiation therapy), and for the characterization of radioactive waste.

All the information and slides from the training course are accessible from the ARDENT web site.

by CERN Bulletin

SUMMARY

The ARDENT project offers:

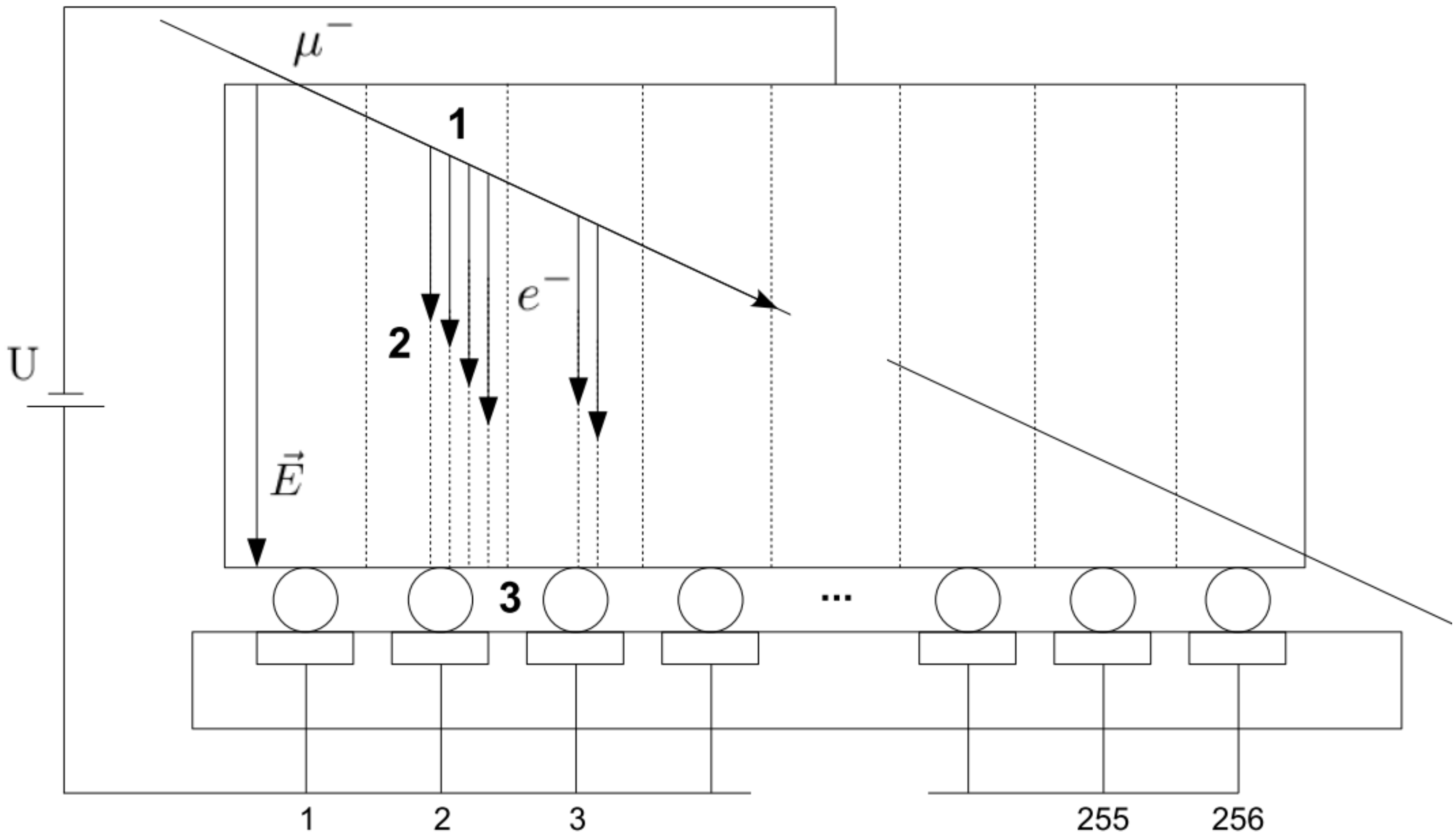
- The possibility to spend some time abroad
- Working on the cutting-edge of technology
- Getting to know people from other institutes
- Really good training possibilities

There are still vacant jobs!

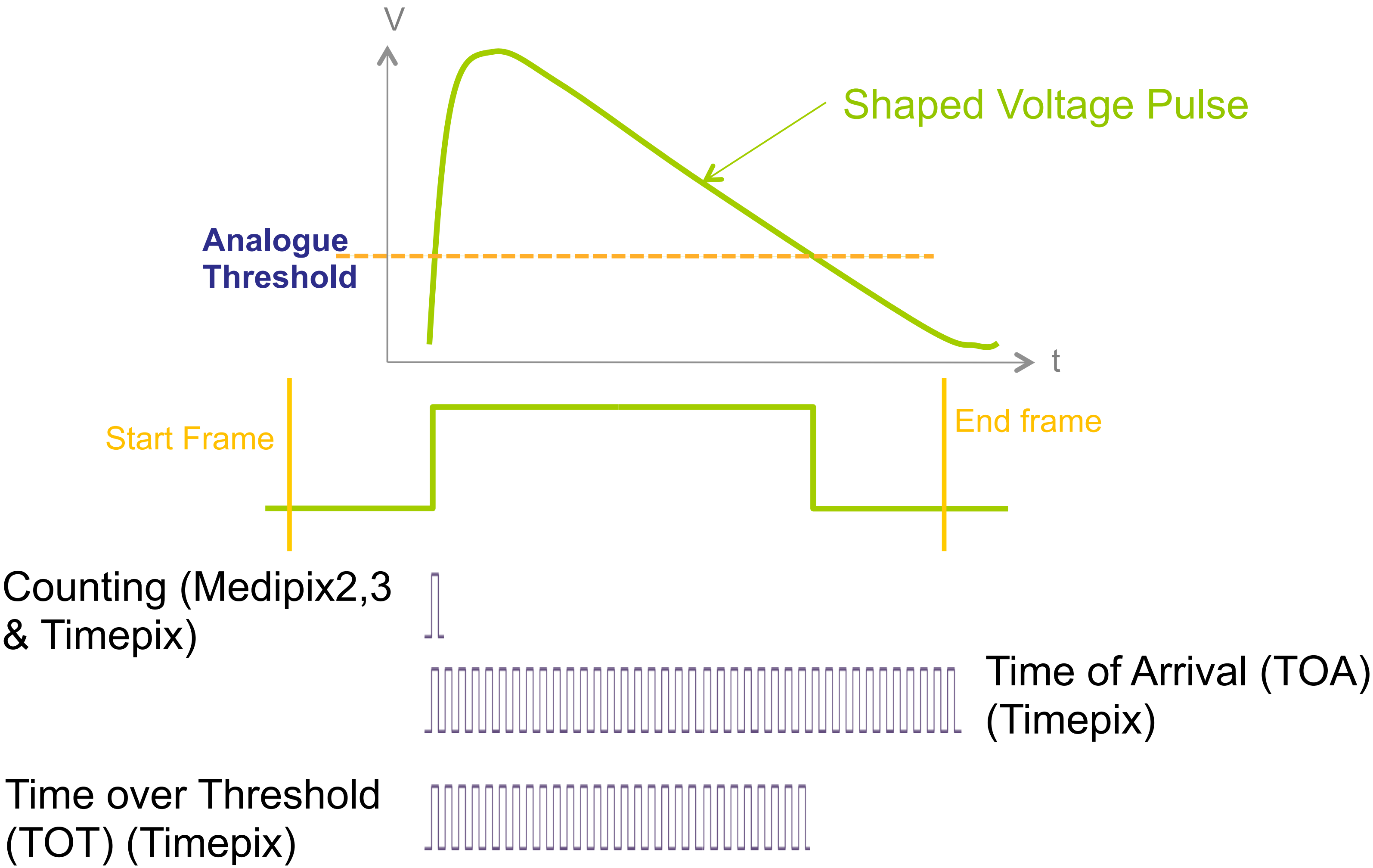
http://ardent.web.cern.ch/ardent

NEUTRON DETECTION WITH TIMEPIX DETECTORS

DETECTION PRINCIPLE OF A HYBRID PIXEL DETECTOR



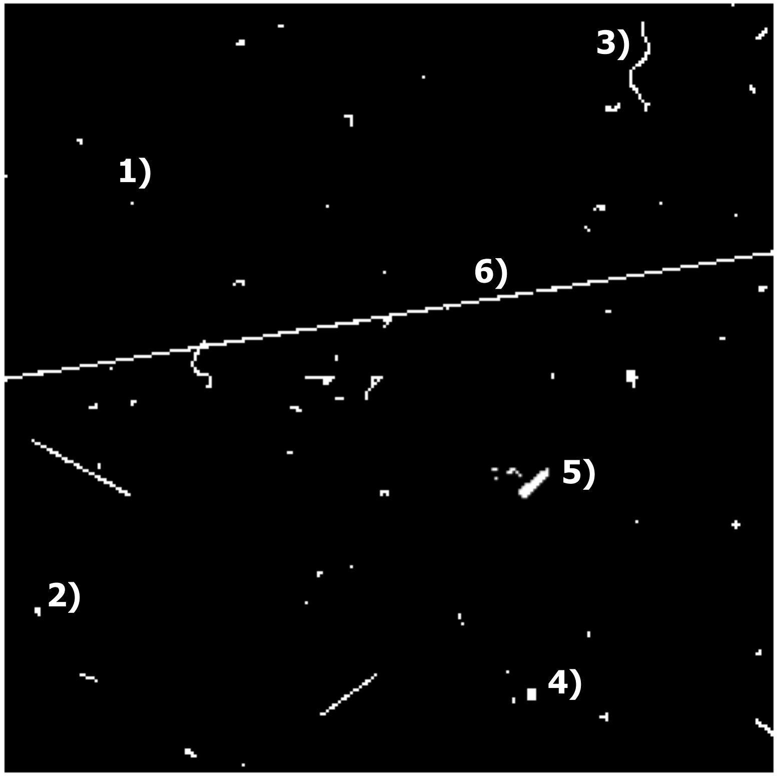
THREE MODES OF OPERATION



CLUSTER ANALYSIS AND PATTERN RECOGNITION ALGORITHM

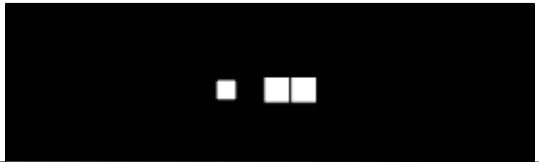
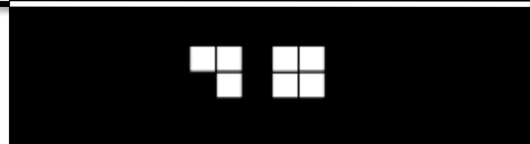
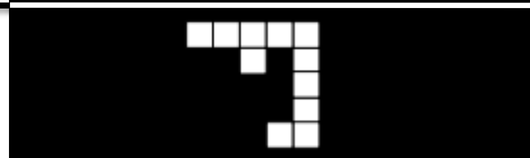
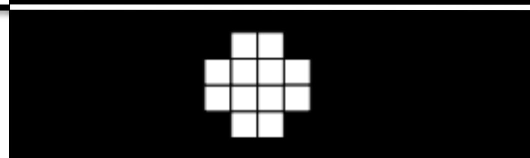
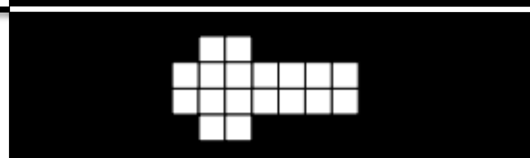
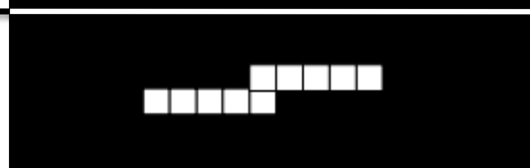
Set of criteria can be established in order to resolve those different shapes:

- Area (number of pixel) in the cluster
- Roundness (surface compared to length of the border)
- Linearity (possibility to interleave track with line)
- Thickness of the straight track



Typical frame recorded in a mixed radiation field

TRACKING CAPABILITY – CHARACTERISTIC PATTERN

1) Dot		Photons and electrons (10keV)
2) Small blob		Photons and electrons
3) Curly track		Electrons (MeV range)
4) Heavy blob		Heavy ionizing particles with low range (alpha particles,…)
5) Heavy track		Heavy ionizing particles (protons,…)
6) Straight track		Energetic light charged particles (MIP, Muons,…)

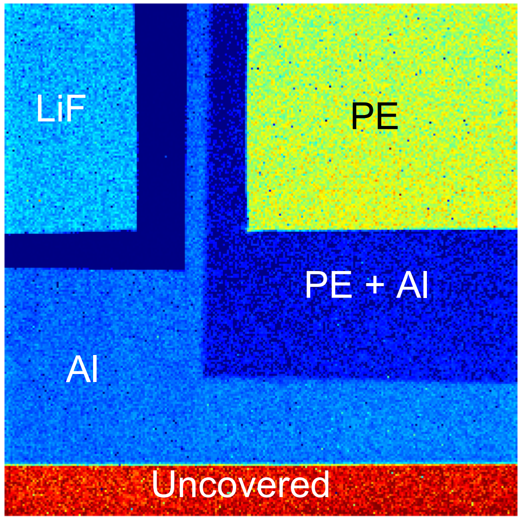
NEUTRON DETECTION WITH MPX DEVICES

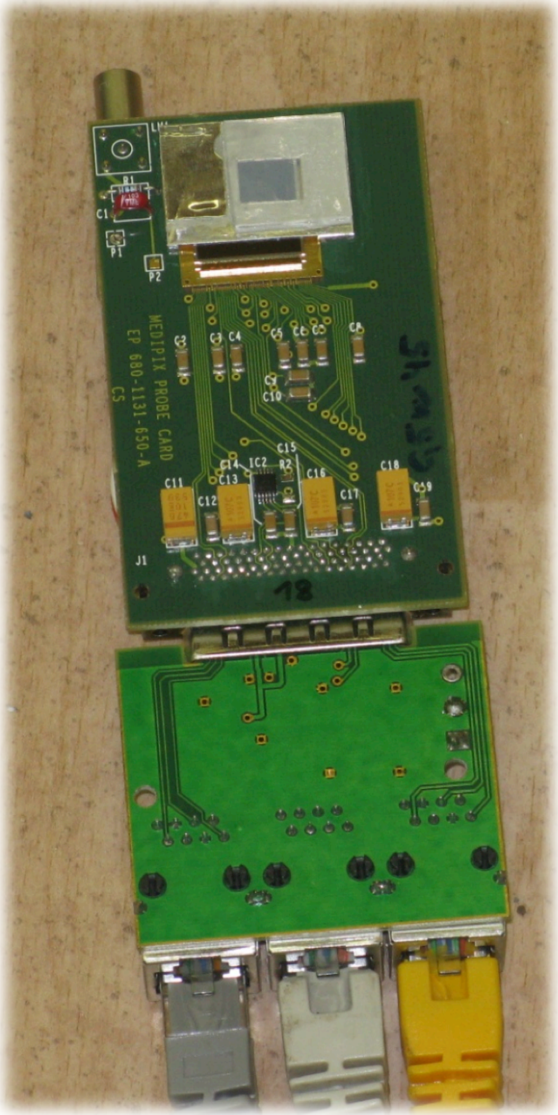
Medipix 2 ASIC with 300µm Silicon layer

- 256 x 256 pixel with 55µm pixel pitch

Converter foils:

- $^{6}Li(n,\alpha)^{3}H$ -> thermal neutrons
- PE: recoiled protons -> fast neutrons





DETECTION EFFICIENCIES

Efficiencies for non charged particles are reduced by the conversion efficiency to detectable charged particles and geometry factors to following:

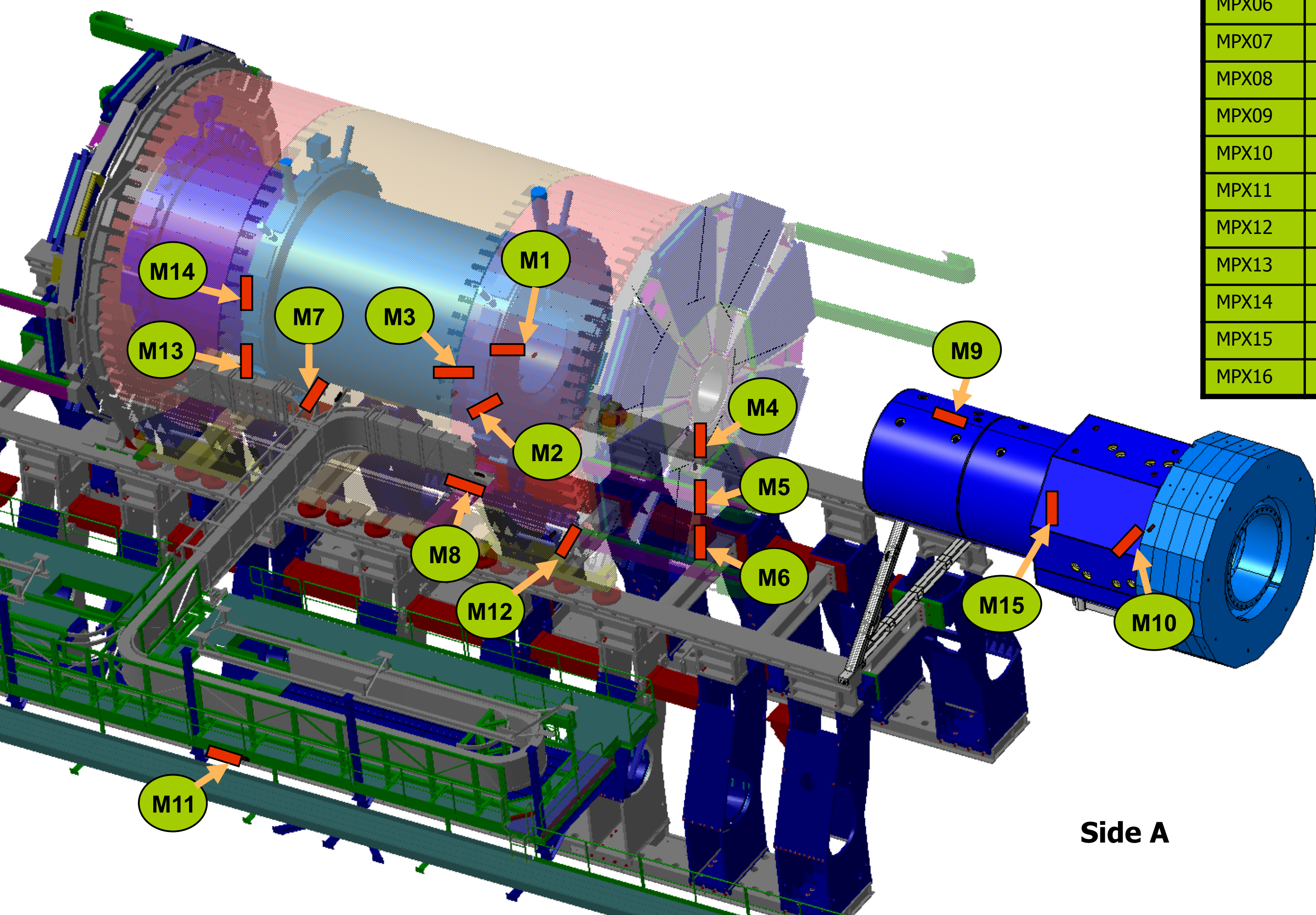
- Charged particles (above 8 keV): 100%
- X-rays (10 keV): ~80%
- Gamma-rays (above 1 MeV): ~0.01%
- Thermal neutrons (energy < 1 eV): ~1%
- Fast neutrons (MeV range): ~0.5%

Device lifetime expectancy:

It is expected that the device will survive up to neutron fluences of about 10^{13} neutrons/cm^2 (tested up to 1.5×10^{12} neutron/cm^2).

ATLAS – CURRENT MPX DETECTOR NETWORK

MPX01	between ID and JM plug
MPX02	between ID, LARG and JM
MPX03	between LARG and LARG EC
MPX04	between FCAL and JT
MPX05	between LARG and JT wheel
MPX06	between LARG and JT wheel
MPX07	top of TILECAL barrel
MPX08	top of TILECAL EXT. barrel
MPX09	corner between JF cyl. and hexagon
MPX10	cavern wall A or C side
MPX11	cavern wall USA side
MPX12	small wheel
MPX13	between ID and JM plug
MPX14	between ID, LARG and JM
MPX15	at the back of Lucid detector
MPX16	ATLAS-MPX rack in USA15



INSTITUTES AND PEOPLE WORKING ON THIS PROJECT

Institute for Experimental and Applied Physics at Czech Technical University in Prague (IEAP CTU)

- Stanislav Pospisil
- Jan Jakubek
- Michal Suk
- Andrè Sopczak
- Zdenek Vykydal
- Daniel Turecek
- Jaroslav Solc
- Bartolomej Biskup
- Vìt Sopko
- Benedikt Bergmann

Université de Montrèal, Canada

- Claude Leroy
- Paul Soueid
- Nedaah Asbah

PROPOSED ATLAS UPGRADE FROM MPX TO TPX DEVICES 2013 - 2014

Usage of the Timepix chip

- Per pixel energy deposition measurement (TOT)
  - Particle identification using dE/dx information
  - Better selectivity with the pattern recognition algorithm (see next slides)
- Time of arrival of the particles (TOA)

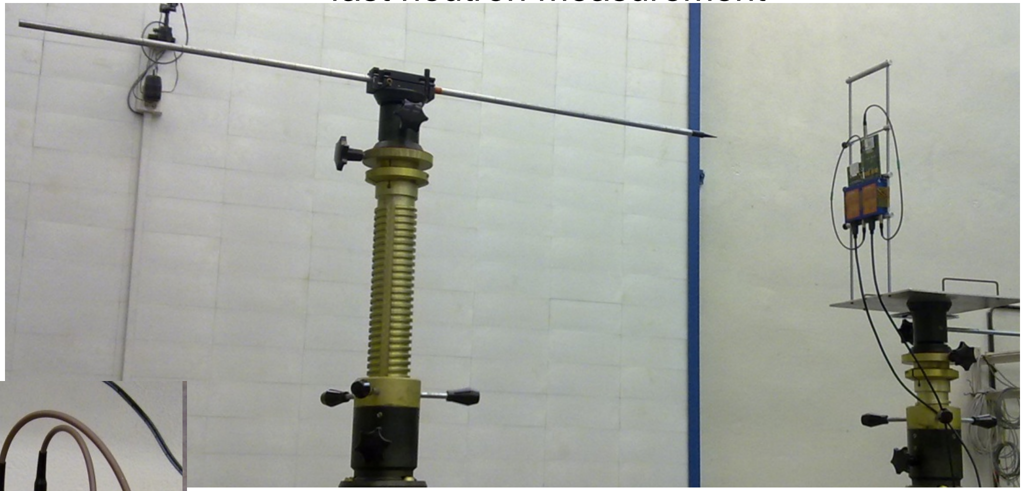
Faster readout electronics

- Reduce dead-time caused by device read-out by factor 50 (from 0.17 fps with one detector to 10 fps with two detectors (20 MHz readout frequency)
- Simplification of cabling – from 5 cables per device to 1 cable (one serial link + power)
- Possibility of trigger signal in USA15 to run the whole or part of the network in coincidence

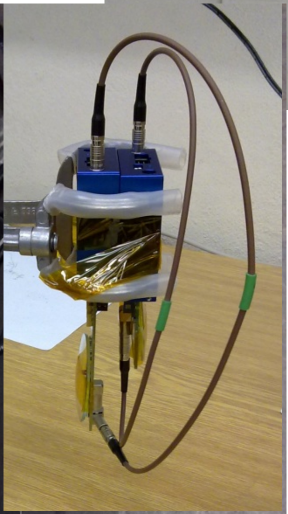
MEASUREMENT AT CZECH METROLOGICAL INSTITUTE

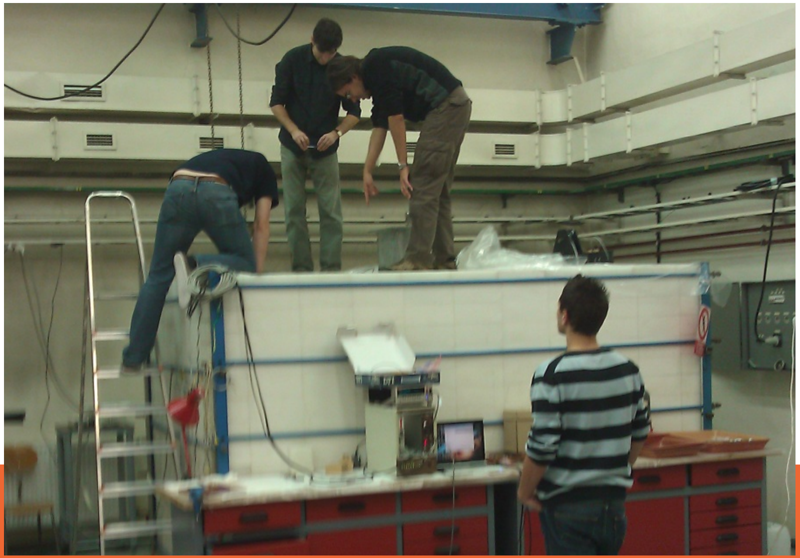
- Upgrade from MPX to TPX
- Comparison of response of MPX and TPX to thermal neutron and fast neutron impact (Cf, AmBe)
- Calibrate TPX

fast neutron measurement

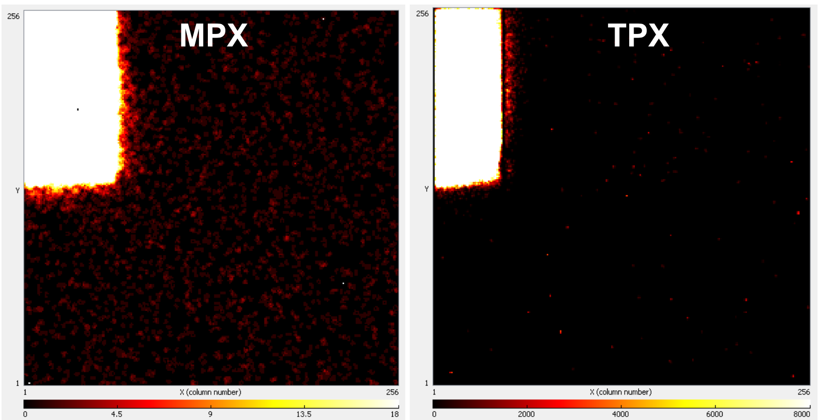


thermal neutron measurement



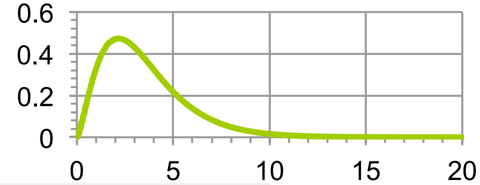


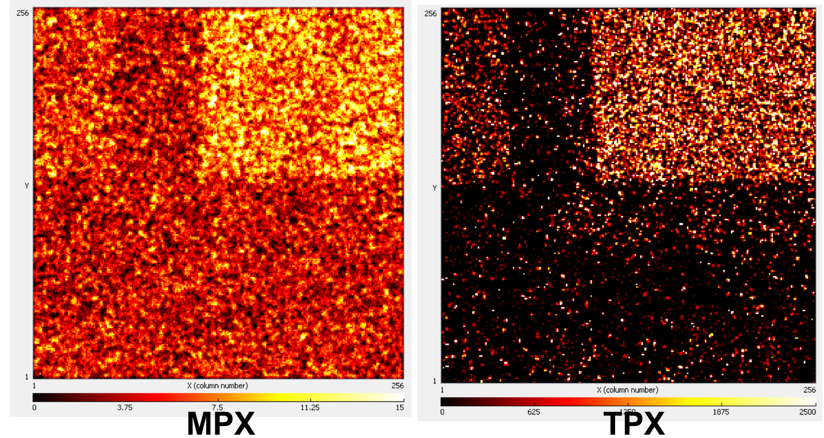
COMPARISON: MPX VS. TPX

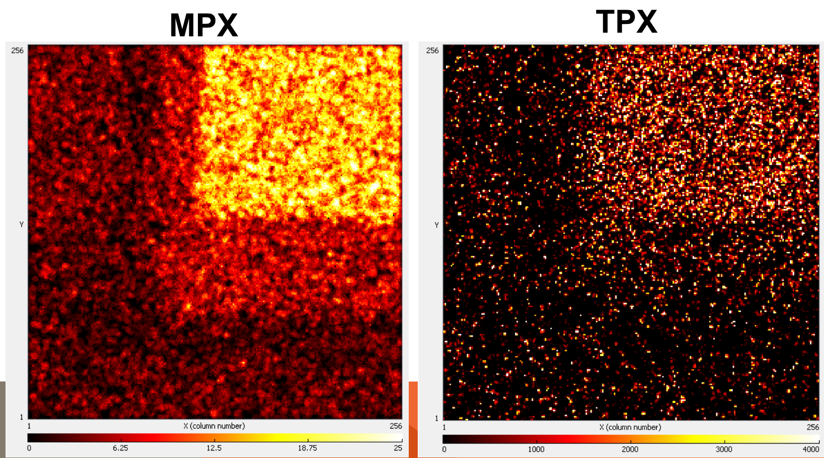


thermal neutrons ($E < 0.5$eV)

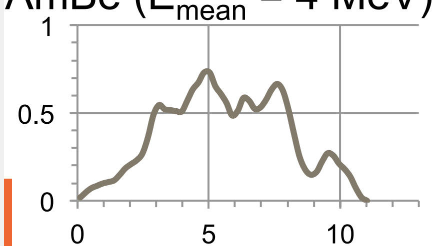
^{252}Cf (E_{mean} = 2 MeV)







AmBe (E_{mean} = 4 MeV)



MEASURED ENERGY SPECTRUM FOR THE THERMAL NEUTRON MEASUREMENT – ONLY TPX

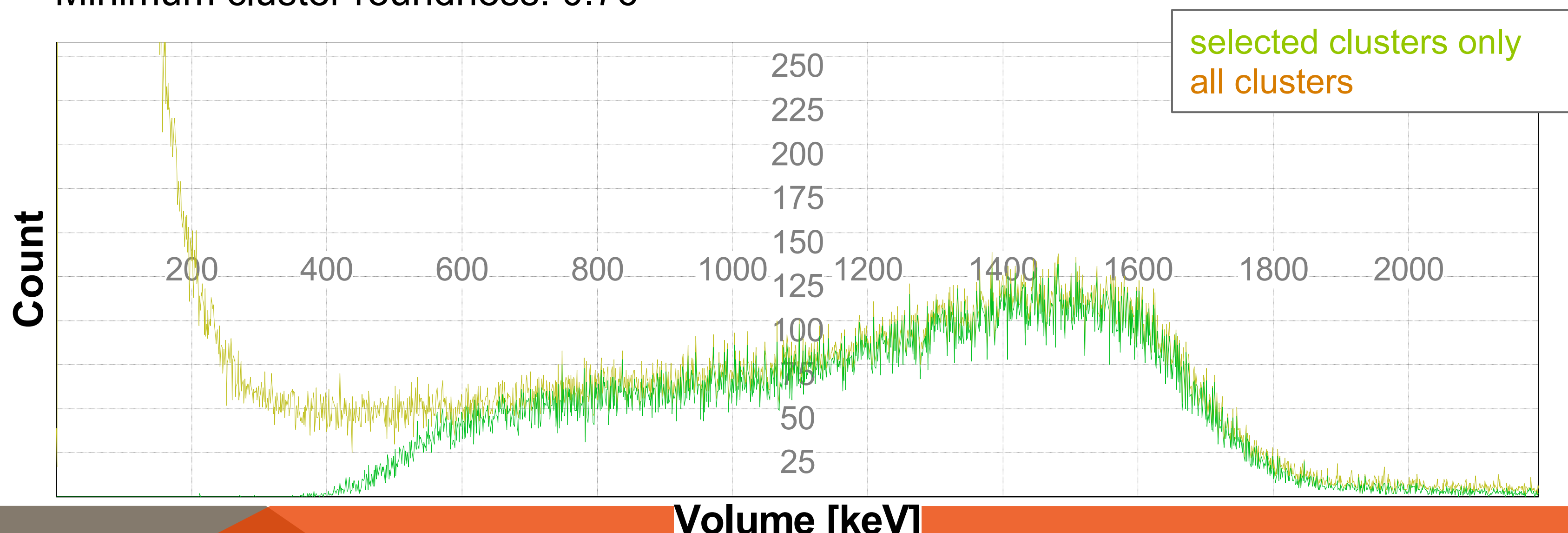
Consists of Tritium and α-Peak smeared out due to different interaction depths in the convertor

Criteria used (pattern recognition algorithm):

- Minimum cluster size: 8 pixel
- Minimum cluster height: 100 keV
- Minimum cluster roundness: 0.76

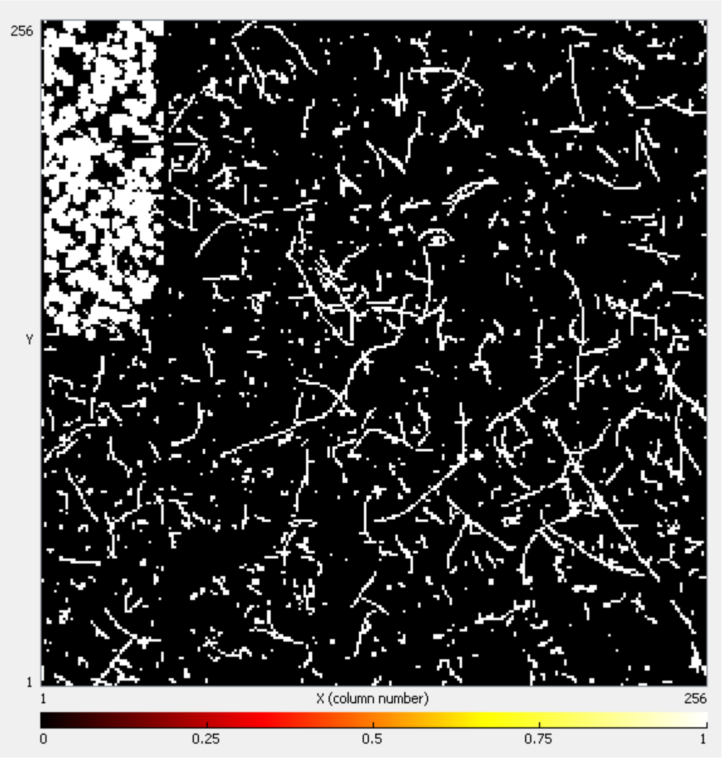
$N_{selected} = 97799$

$N_{all} = 618657$

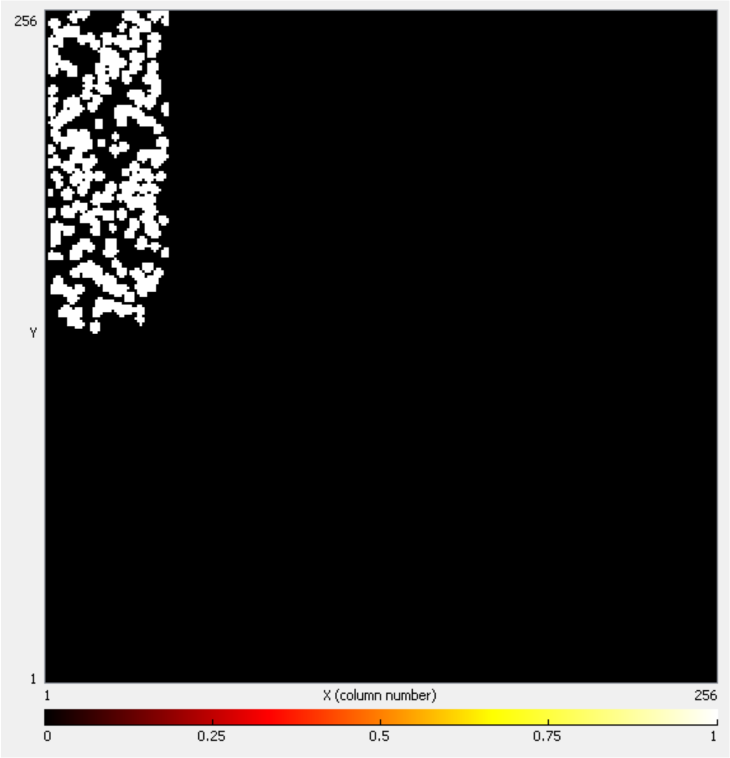


TPX: THE POWER OF PATTERN RECOGNITION – THERMAL NEUTRONS

50 frames with acquisition time 0.1s in a nearly isotropic thermal neutron field



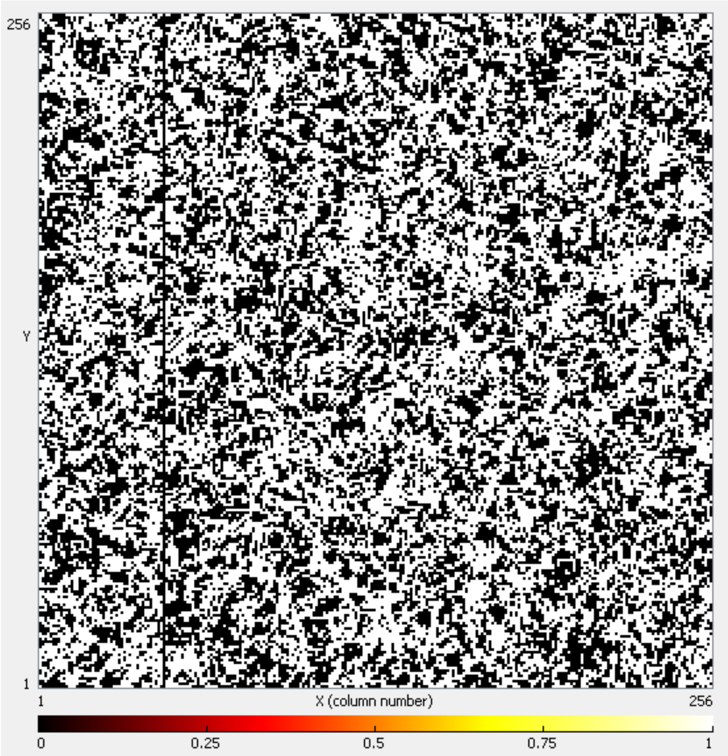
Integrated picture of raw data



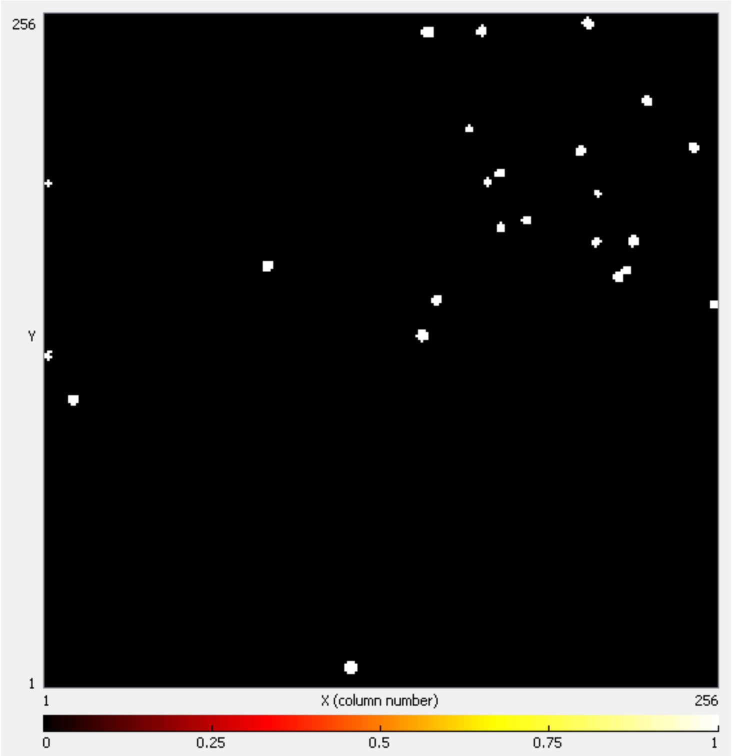
Integrated picture of selected events

TPX: THE POWER OF PATTERN RECOGNITION – FAST NEUTRONS

70 frames with acquisition time 0.1s in neutron field of ^{252}Cf source



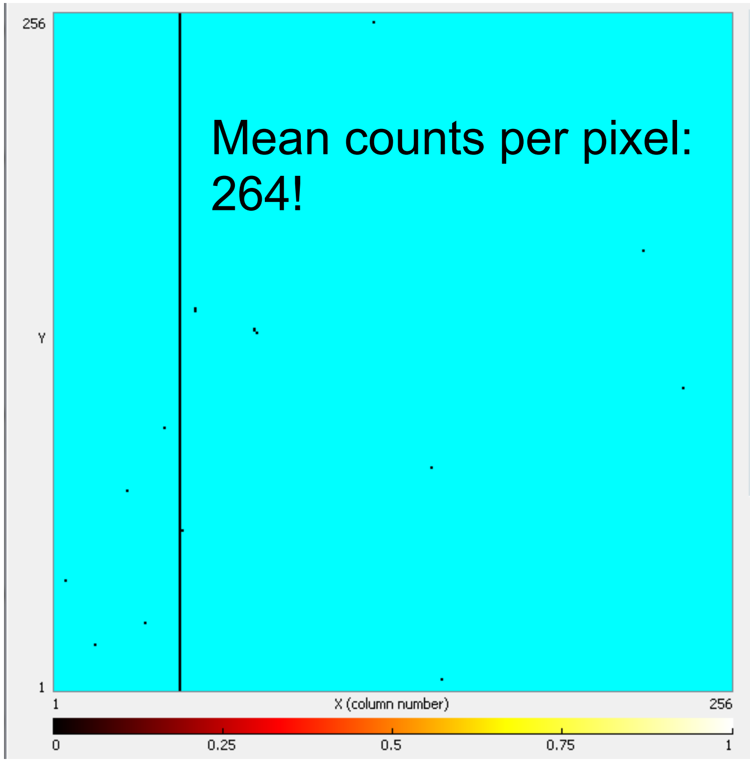
Integrated picture of raw data



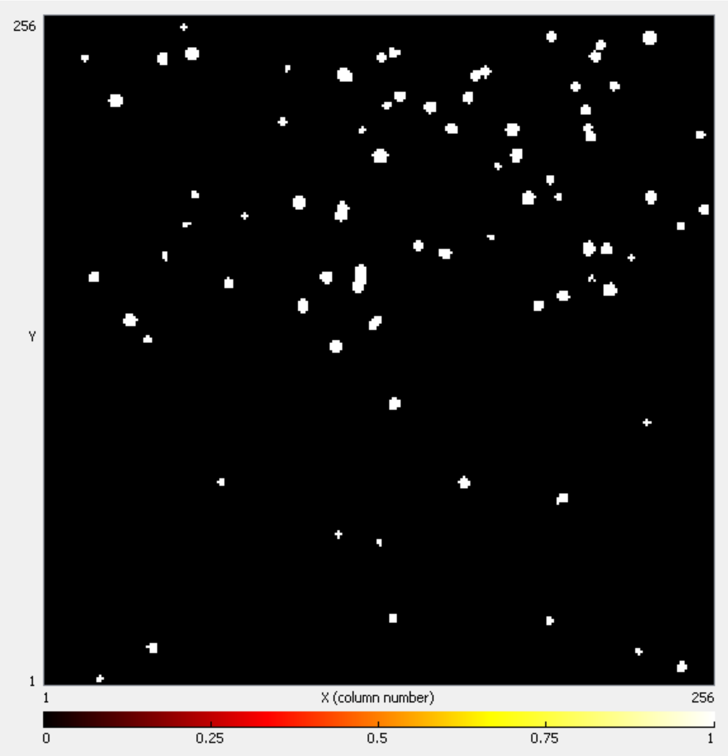
Integrated picture of selected events

TPX: THE POWER OF PATTERN RECOGNITION – FAST NEUTRONS

1000 frames with acquisition time 0.04s in neutron field of AmBe source



Integrated picture of raw data

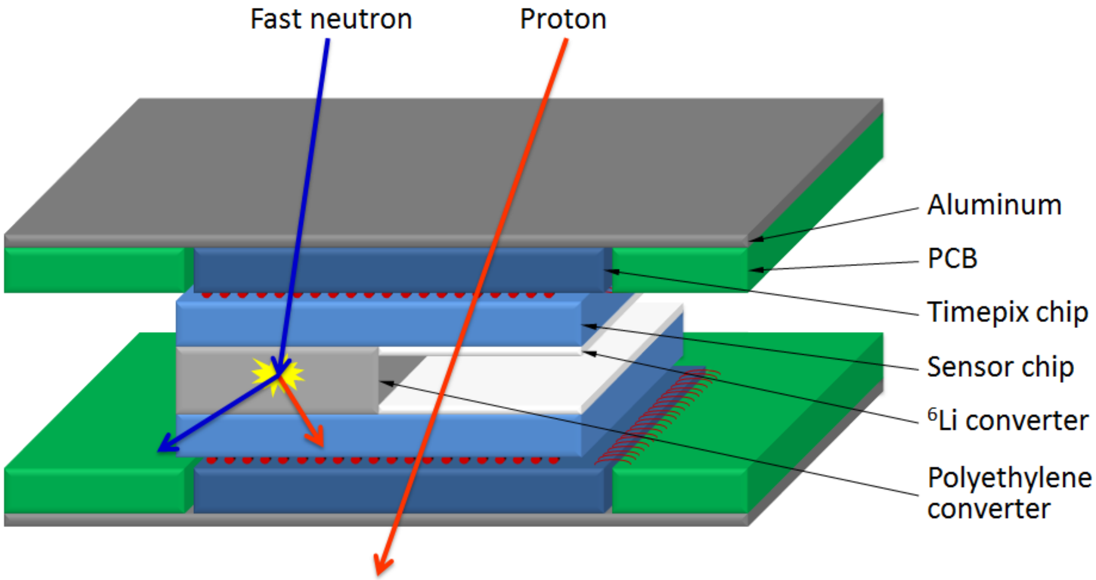


Integrated picture of selected events

FROM SINGLE DEVICES TO HODOSCOPES

Two layer face-to-face structure

- Better particle identification (anticoincidence between detectors)
- Directional sensitivity



Neutron converters in between

- 4 regions? – LiF, PE1, PE2, uncovered

500 µm thick silicon

- Bias voltage < 100 V

APPLICATIONS OF MIXED FIELD DATA ACQUISITION AND EVALUATION

From high energy physics to ….

… dosimetric applications

- Space (NASA, ESA)
- Airplanes
- Accelerators (LHC, etc.)
- Cancer treatment with Proton or Carbon Ion beam

…

MERRY X-MAS

Thank you for your attention ….