A short summary of “ARDENT”

Advanced Radiation Dosimetry European Network Training

www.cern.ch/ardent

Marco Silari (DGS-RP)
ARDENT
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Marie Curie Initial Training Network under EU FP7 – 4 M€

8 Full Partners and 6 Associate Partners

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

CERN (coordinator), Geneva, Switzerland
AIT Vienna, Austria
CTU - IAEP Prague, Czech Republic
IBA Dosimetry, Schwarzenbruck, Germany
Jablotron, Jablonec nad Nisou, Czech Republic
MI.AM, Piacenza, Italy
Politecnico of Milano, Italy
Seibersdorf Laboratories, Austria

INFN Legnaro National Laboratories, Italy
ST Microelectronics, Italy
University of Erlangen, Germany
University of Houston, USA
University of Ontario, Canada
University of Wollongong, Australia
The 18 ARDENT researchers

Stefan Gohl – ESR 16
Eleni Aza – ESR 1
Andrej Sipaj – ESR 6
Elena Sagia – ESR 14
Alvin Sasha Naik - ESR 13
Stepan Polansky – ESR 18
Benedikt Bergmann  
ESR 9
Silvia Puddu – ESR 3
Michele Togno - ESR 11
Natalia Kostiukhina  
ESR 17
Jayasimha V. BAGALKOTE  
ESR 5
Vijayaragavan Viswanathan  
ESR 12
Kevin Loo – ESR 8
Stuart George – ESR 4
Ivan Caicedo – ESR 7
Francesca Bisello – ESR 10
Erik Frojd – ESR2
Chris Cassel – ESR 15
Development of advanced instrumentation for radiation monitoring

Three technologies

• Gas detectors: gas electron multipliers (GEM), ion chambers
• Solid state detectors: Medipix, silicon detectors
• Combined silicon-gas detector
• Track detector techniques: CR-39
Main objectives
• Radiation dosimetry
• Microdosimetry
• Neutron and photon spectrometry

Applications
• Characterization of radiation fields at particle accelerators
• Characterization of radiation fields on-board aircrafts and in space
• Medical applications: diagnostics and therapy
GEM/Timepix measurements at CERF

Eleni Aza and Silvia Puddu (GEM), Stuart George (Timepix)

- CERF @ CERN: mixed field of secondary particles (p, π, e⁻, γ, n) from spallation reactions
- Measurements with Timepix:
  - mixed field analysis
- Measurements with GEM:
  - beam monitoring
  - measurements of individual radiation components
The Triple GEM detector as beam monitor

Experimental set-up

Beam image
0.6 ± 0.1% efficiency

Beam profile comparison to a MWPC during an intensity scan

GEM
MWPC (saturates)

Good correlation with IC reference monitor
Fast neutron detection with GEM

Fast neutrons:
• Head on detector
• Converter: PE + Al
• Low sensitivity to $\gamma$ background at chosen WP
Thermal neutrons:

- Converter: series of slices of $^{10}$Bo
- Delay: 12 ms
- Low sensitivity to $\gamma$ background at chosen WP
- Beam image reconstructed from several step positions
Characterization of neutron time-of-flight facility with the GEM detector (nTOF, CERN)

Slow and fast neutron profile at 200 m

20 GeV/c protons on lead target
Neutron detectors placed at EAR1 and Beam dump (185 and 200 m)
Active area 10x10 cm² and pad size 8x8 mm²

Energy spectrum measured at 200 m
The GEMPix - An Ultra Pixellated Gas Detector

Stuart P. George (CERN)

The Gempix combines two CERN developed technologies, GEM detectors and the Timepix to produce a gas detector with 55 µm readout granularity.

Sensitive area = 3 x 3 x 1.2 cm³

(1) Gas Supply
(2) High Voltage
(3) Entrance Window
(4) GEM Foils
(5) FITPix Readout
GEMPix: two working modes

The detector is a **naked quad Medipix**:  
The active area is 9 cm\(^2\)  
The particle track is analysed with 512 pixel in 3 cm length  
This is equivalent to 30 microns of tissue ... with 17 samples/micron
Determination of $^{55}$Fe in radioactive waste

Silvia Puddu and Stuart George (CERN)

The sample is reduced to a powder with a milling machine.

Filtered at 50 mm grain with a mesh.

Finally the sample is put below the detector for the measurement.

Next the powder is attached to a double-side tape in a small plastic box 3x3 cm$^2$. 
Results: GEMPix versus radiochemical analysis
GEMPIX: detector for tissue samples

The detector is a quad naked medipix:
The active area is 9 cm²
The particle track is analysed with 512 pixel in 3 cm length
This is equivalent to 30 microns of tissue ... with 17 samples/microns
Track reconstruction (Microdosimetry?)

3D Path

Spatial resolution of track reconstruction is ~120 µm, should be further improvable in the future.
Neutron conversion board read-out by a GEM detector
Active area $35 \times 21 \text{ cm}^2$
and pad size $22 \times 13 \text{ mm}^2$ (256 pads)

Regions defined for different energy ranges
Reg 1-4 employ $\text{B}_4\text{C}$ and PE for $1 \text{ meV} – 5 \text{ MeV}$
Reg 5 & 6 employ PE and Al for $3 – 100 \text{ MeV}$
LUPIN

Chris Cassell (POLIMI)

Proportional counter

$^{3}$He or BF$_3$

Moderator

(response function reproduces the curve of the neutron fluence to $H^*(10)$ conversion coefficients)

Innovative front end electronics
Measurements in pulsed neutron fields at CERN (just two examples)

Access to the PS tunnel

HiRadMat

Detectors mounted on carousel

Example of signal acquired with the LUPIN

- Prompt Neutrons
- Thermalized Neutrons
- Scattered Neutrons

CERN Medical Applications, 2 December 2015

Marco Silari for
Neutron spectrometry with the BSS (Proton Therapy Centre, Essen)

Eleni Aza (CERN) and Chris Cassell (POLIMI)

230 MeV/c protons on water phantom
Spectrum measured inside the treatment room

Neutron fluence per unit lethargy (/cm²/proton)

Neutron energy [MeV]
Neutron dosimetry with structured plastic converters

Stuart P. George (CERN)

• Multilayer plastic converters should be able to provide an energy independent response for fast neutron dosimetry

• Experimental evaluation of 3D printer prototypes over fast energy range
Development of low cost radiation monitor

Vijayaragavan Viswanathan (JabloTron)

- Czech Radiation Protection Institute (SURO)
  - Low cost radiation monitors
  - Deploy all across the country
  - Wired or wireless based device
  - Cloud connectivity to monitor remotely

- Prototype
  - Raspberry-Pi based device
  - First prototype ready
  - Ongoing experiments and calibration activity

- Next steps
  - Include other blocks like Temperature, Humidity, Pressure
  - Ensure the device environment
  - Mechanical design
  - Testing and deployment

Remote monitoring
BrachyView – Medipix in cancer treatment

Kevin Loo (CTU Prague)

• Use Medipix to develop brand new, ultra-functional, in-body imaging probe

• Currently, doctors use a combination of ultrasound, X-rays, CT for implant verification
Ionization Chamber Array for External Beam Radiotherapy

Michele Togno (IBA Dosimetry)

Development and characterization of a new air vented ionization chamber array technology for machine & patient quality assurance in external beam radiotherapy.

MV X-Rays

~100÷230 MeV protons
Ionization Chamber Array for External Beam Radiotherapy

Proton beams characterization: example of measured Pristine Bragg peak at different energies

Example of patient plan verification for an Intensity Modulated PT treatment of prostate tumor.
Scattered radiation in a CT room

Erik Frojdh (CERN)

- **Dosepix** and **Timepix** detectors with a 300 μm Si sensor
- Measurements performed at CHUV in Lausanne
- Ge Medical Systems Discovery CT750 HD CT-scanner
  - at 80 kVp and 120 kVp
- Measured scattered radiation during scan of an abdomen phantom
Silicon microdosimeter

Monolithic silicon telescope

• Segmented \(\Delta E\) stage

Silicon telescope:
- a thin \(\Delta E\) stage (1.9 \(\mu\)m thick)
- coupled to a residual energy stage \(E\) (500 \(\mu\)m thick)

on the same silicon wafer.

• 7000 pixels in parallel
• Sensitive area 0.5 mm\(^2\)
• Minimum detectable energy limited to about 20 keV by the electronic noise
62 MeV proton – Distal part of SOBP

Event-by-event TE correction!!!
GEMPix: 3D energy deposition in water phantom

Stuart George (CERN)

CNAO 3D motorized water phantom
GEMPix: 3D energy deposition in water phantom

23 depths in water with the CNAO (Pavia Italy) clinical carbon ion beam ($5.10^8$ ions/depth).
Neutron dosimetry with CR-39 detectors

Alvin Sashala Naik (MI.AM)

Intercast CR-39
track detector

Fast neutron dosimeter based on the
intercast CR-39

The Politrack™ instrument was developed by the Politecnico di Milano and commercialised by Mi.am SRL.
Spectrometry using CR-39 detectors for hadron therapy beam diagnostics (Carbon ions)

Experiment at CNAO hadron therapy centre in Pavia, Italy

Irradiation of CR-39 detectors with Carbon ions of 108.4 MeV/nucleon
In-beam LET spectrometry and dosimetry of heavy ions

Preliminary results from measurements of the fragmentation of Carbon ions in a stack of CR-39 detectors at CNAO. (a) Fluence to depth curve, (b) Dose to Depth curve, (c) mean lineal energy of the Carbon beam with respect to depth in the CR-39 stack.
In-beam LET spectrometry and dosimetry in proton beam

Dose Equivalent 2D map along the beam path

Detector 1
Detector 2
Detector 3
Detector 4
Detector 5
Detector 6
Objective: Measure dose to moving lung tumor (online and offline) in order to validate treatment planning system.
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