Highlights from the Advanced Radiation Dosimetry European Network Training initiative (ARDENT)

Marco Silari (CERN)

on behalf of the ARDENT consortium

ARDENT

February 2012 – January 2016

Advanced Radiation Dosimetry European Network Training initiative

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), Switzerland
AIT Vienna, Austria
CTU- IAEP Prague, Czech Republic
IBA Dosimetry, Schwarzenbruck, Germany
Jablotron, Prague, Czech Republic
MI.AM, Milano, 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

Development of advanced instrumentation for radiation monitoring

Three technologies

- gas detectors [gas electron multipliers (GEM), tissue equivalent proportional counters (TEPC), ionization chambers]
- solid state detectors [Medipix, silicon micro-dosimeters]
- track detector techniques [CR-39]

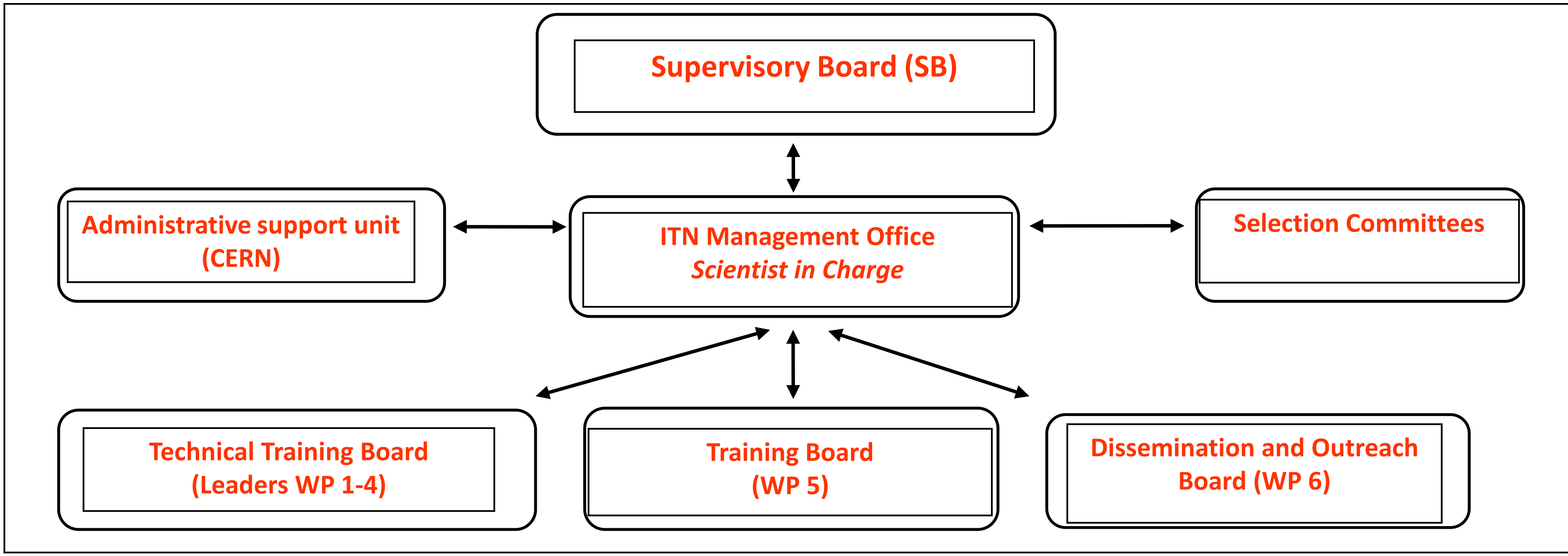
Main objectives

- Radiation dosimetry
- Micro- (and maybe sub-micro-) dosimetry
- Neutron spectrometry

Applications

- Characterization of radiation fields at particle accelerators
- Characterization of radiation fields on-board aircrafts and in space
- Assessment of secondary dose to RT patient
- Measurement of properties of clinical hadron beams

ARDENT management structure



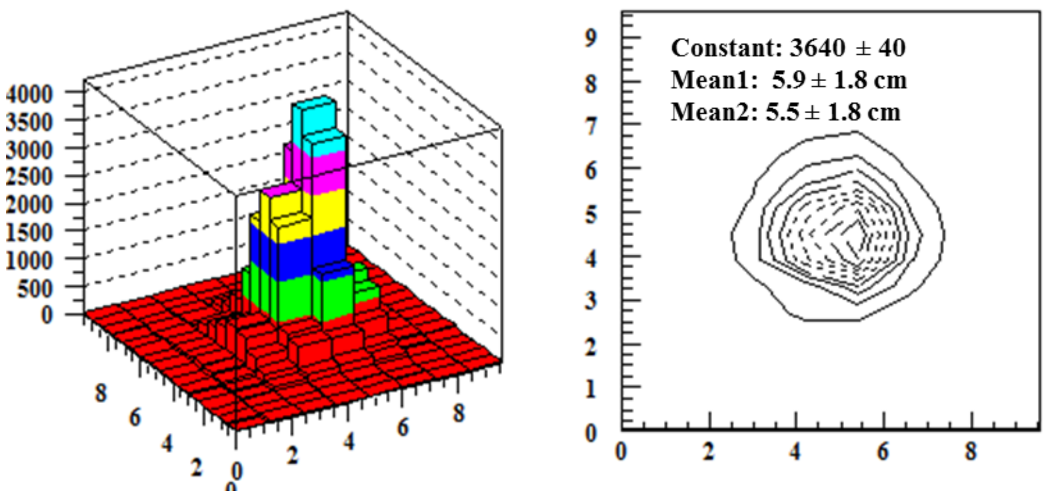
- WP1: gas detectors
- WP2: solid state detectors
- WP3: track detectors
- WP4: instrument inter-comparison

http://cern.ch/ardent

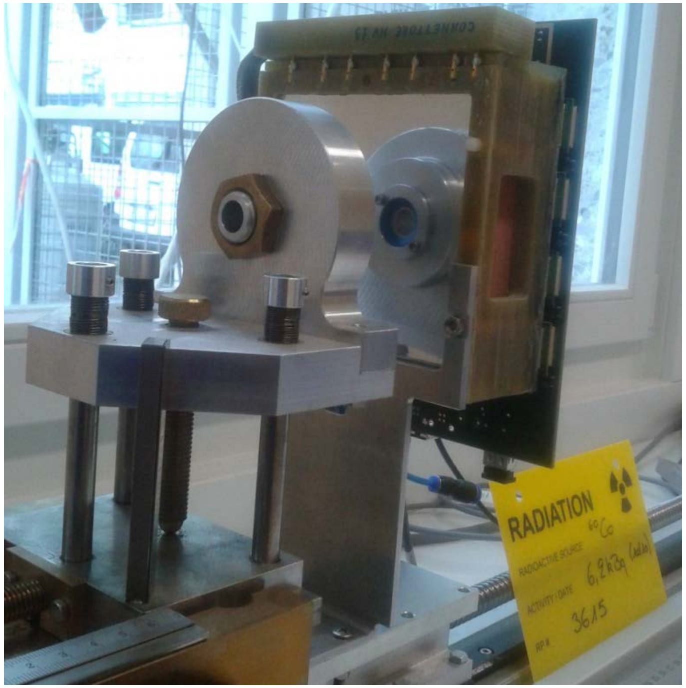
Gas Electron Multiplier

Silvia Puddu (CERN) – *PhD with Uni Bern*

Application of **G**as **E**lectron **M**ultiplier (**GEM**) in dosimetry and microdosimetry around particle accelerators, space and environment, beam monitoring for experimental and medical particle beams



Beam profile measured at CERN n_TOF facility



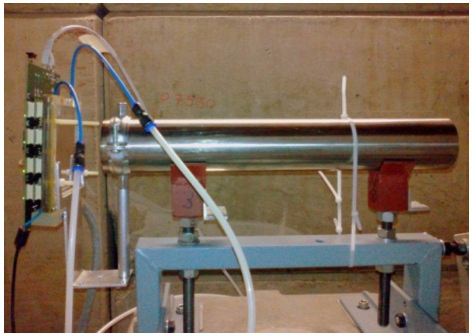
GEM set-up in the ARDENT laboratory at CERN

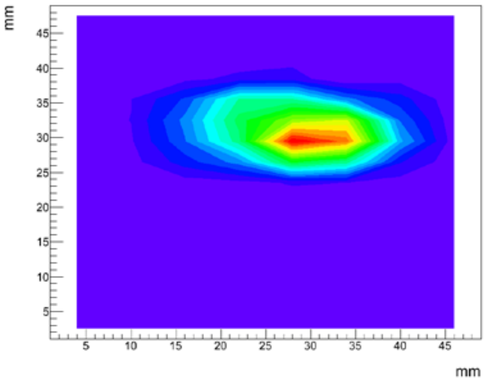
GEM-based Neutron Spectrometer

Eleni Aza (CERN) – *PhD with Uni Thessaloniki*

Measurements with neutron detectors

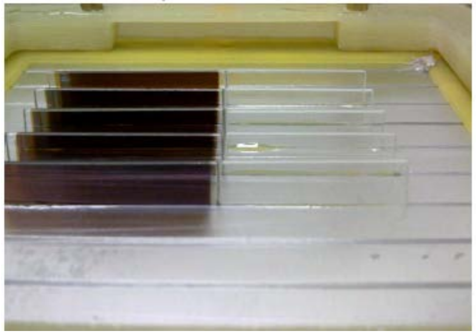
Test of GEM as a beam monitor at CERF (CERN)

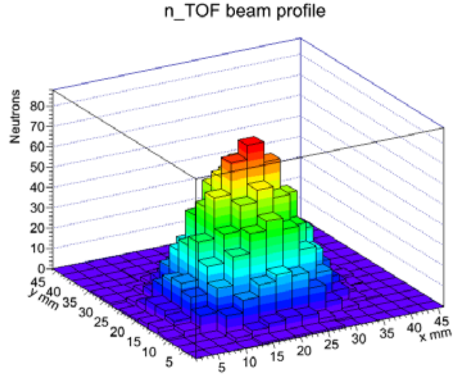




- Intercomparison of neutron detectors in neutron pulsed fields in the HiRadMat facility and around the PS ring at CERN
- Measurements with BSS around the PS ring

With Boron converter, at n_TOF





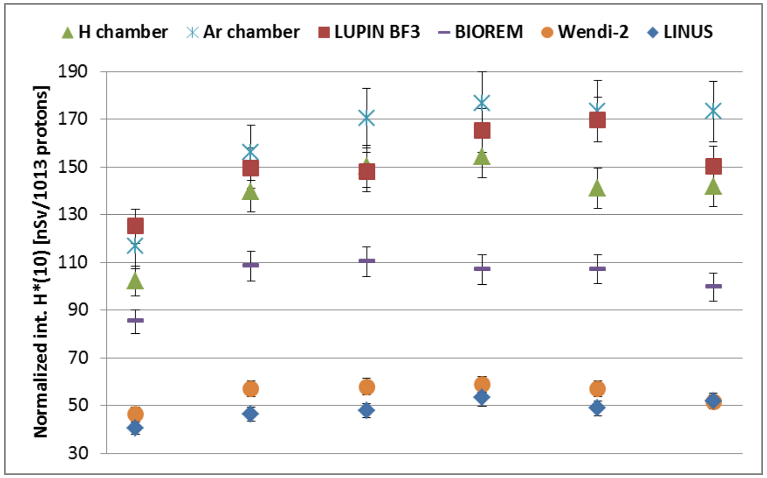
FLUKA simulations

For the study of the physical phenomena inside GEM and the design of the new neutron spectrometer

LUPIN

Chris Cassell (POLIMI) – *PhD with Uni Wollongong*

- Characterisation of LUPIN (**L**ong-interval, **U**ltra-wide dynamic, **PI**le-up free **N**eutron rem counter
- Instrument designed for use in Pulsed Neutron Fields (bursts of high-dose radiation over very short time periods) without saturation
- Experiments conducted at the Proton Synchrotron (PS) and Super Proton Synchrotron (SPS) at CERN, and at the SwissFEL (Swiss free-electon laser) at the Paul Scherrer Institute in Switzerland



Plot of normalised H*(10) from 6 detectors around the Proton Synchrotron at CERN.

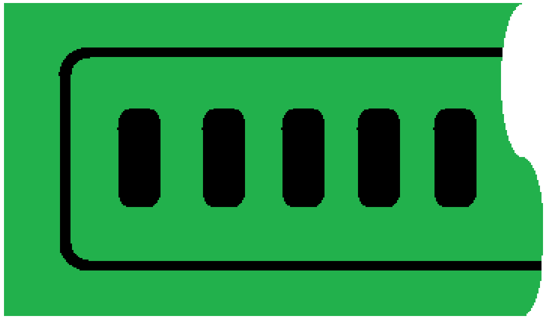
The intercomparison plot shows that the LUPIN presents almost no saturation effects, whereas most of the other detectors show a marked underestimation

2D Ion Chamber Array for Clinical Applications

Michele Togno (IBA Dosimetry) – *PhD with* TU Munich

Development and characterization of a new generation of ionization chambers arrays aimed at radiotherapy applications, particularly at the measurement of absorbed dose from photon, electron and proton radiation

Goal	Benefit
Test new solutions for IC arrays (improve MatriXX detector)	Better future products
Reduce pitch and sensor size	Improved spatial resolution
Reduce chamber sensitive volume	Improved efficiency at high rate
Studies on materials and geometry	Improved stability
Simple assembling	Improved yeld, cost, service



Sketch of a simple 1D array

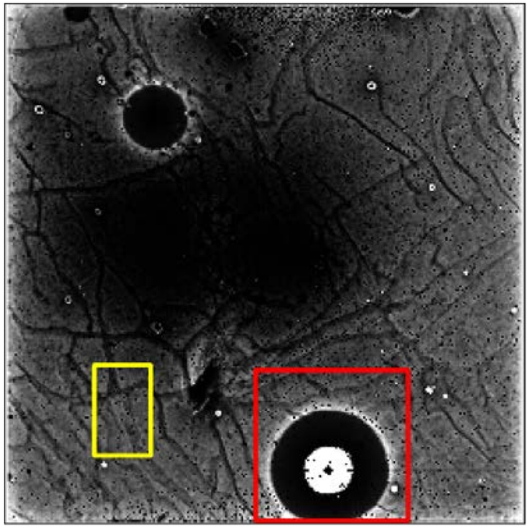
Current activities:

- Iterative improvement of prototype design (first simple prototype is a small 1D array – picture beside shows an example sketch
- Measurements under gamma beam (^{60}Co) and MV X-rays
- Studies on materials and geometry
- Monte Carlo simulations

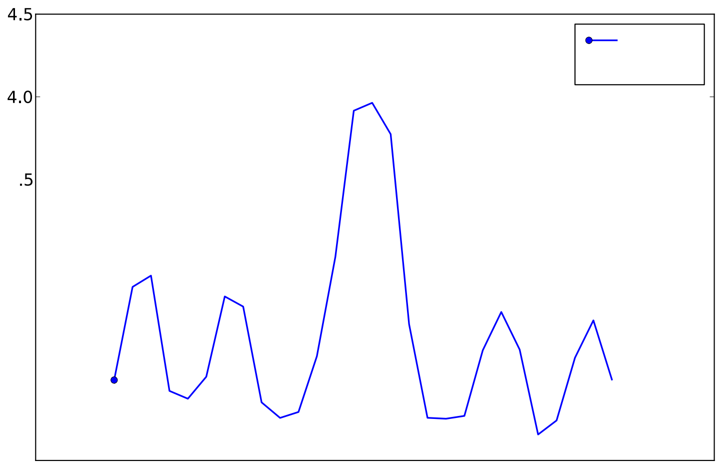
Characterization of Timepix and Medipix3RX

Erik Fröjdh (CERN) – *PhD with Mid-Sweden Uni*

- Working together with the Medipix team
- Characterization of Timepix and Medipix3RX
- CdTe Sensor characterization
- Measurements of scattered radiation around clinical CT
- Medipix support to other ARDENT ESRs



CdTe Sensor Defects flood exposure with X-rays



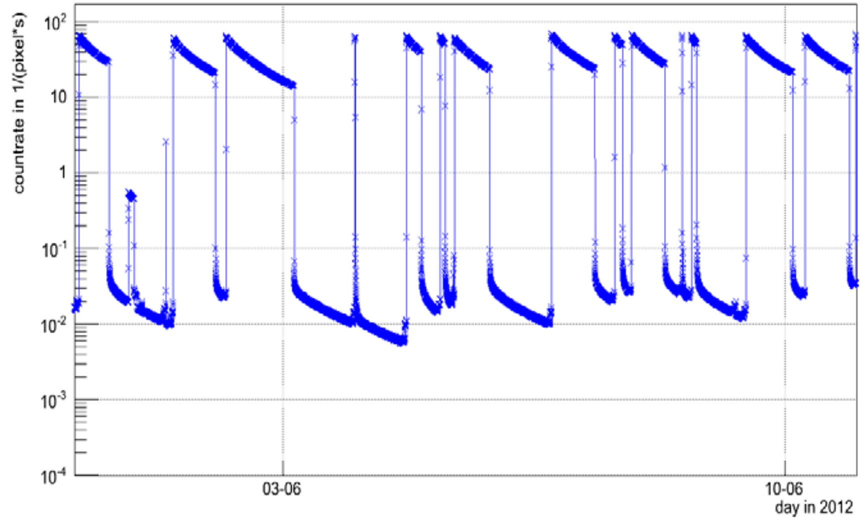
Cluster size as a function of beam position

Evaluation of data in mixed radiation fields

Benedikt Bergmann (CTU) – *PhD with Uni Erlangen*

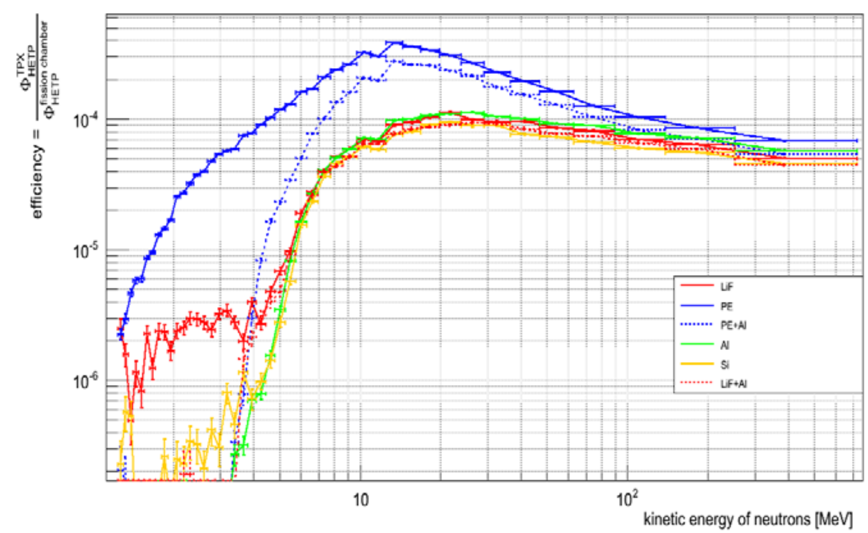
Evaluation of data taken by the ATLAS-MPX detector network

- Luminosity studies
- Studies of activation and dose rates at different sites in the ATLAS cavern
- Example: measured count rate vs time for detector MPX01



Calibration of MPX and TPX detector responses to different particle types

- Measurements in well known radiation fields (gamma, alpha, proton, neutron, …)
- Example: detection efficiency vs energy obtained in a pure neutron field with a TPX device and different converter foils



Medipix-based radiation monitoring system

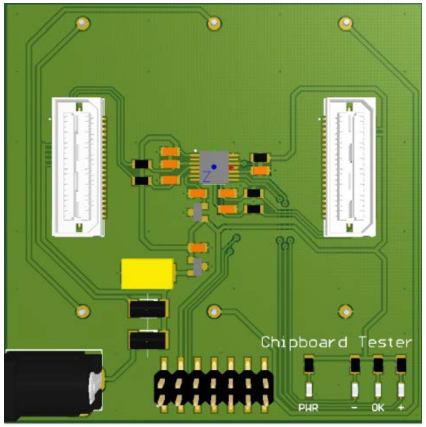
Vijayaragavan Viswanathan (Jablotron)

(PhD from the Ecole Centrale de Lyon)

- Overall aim of the project
  - Market study
  - Investigation of possible applications in radiation monitoring
  - Design and development
  - Testing and prototype verification
  - Certification and production

PCB design training – GM counter

- Development of Medipix-based radiation monitoring system
  - Design of Medipix/Timepix monitoring system
    - Interface development for hand held device
    - Educational kit for high schools and universities
- Progressed on
  - PCB schematics and design
  - Market study on application areas
  - Medipix communication protocol
  - Interface development (ongoing)



Medipix – Voltage regulator – PCB layout -3D view

Medipix in medical imaging

Kevin Loo (CTU) – *PhD with Uni Wollongong*

1. Development of novel in-body imaging system: *BrachyView*

   Utilises Medipix technology in prostate cancer low dose rate brachytherapy procedures

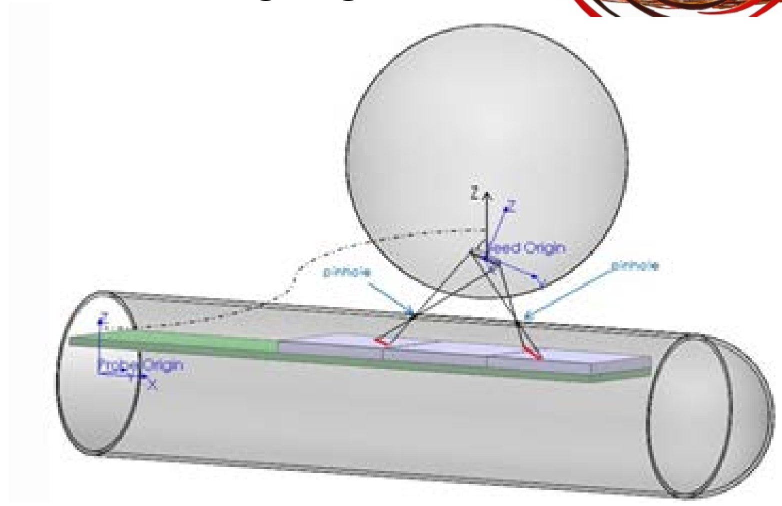
   Two main aspects:

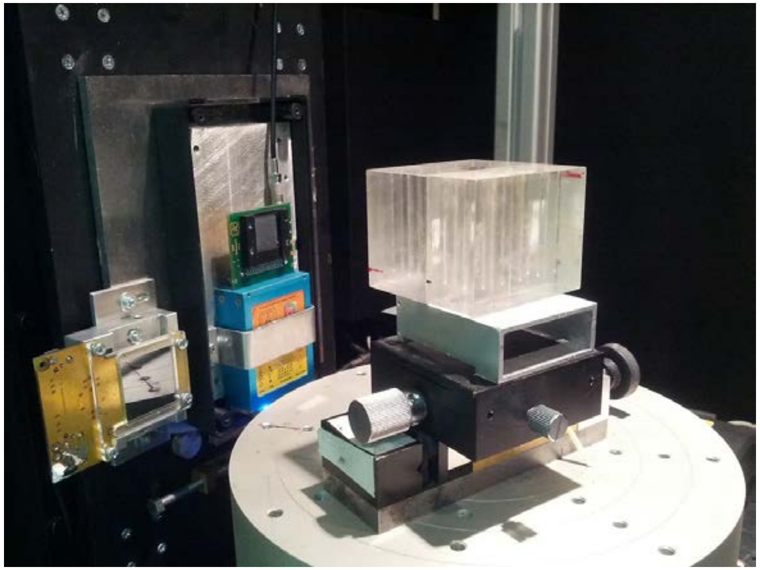
   a) Intraoperative dose planning to avoid critical structures and allow for implant adjustments *as they occur.* Dynamic quality assurance for patient dosimetry

   b) Use of Medipix as imaging plane for post-implant CT dosimetry.

2. Further development of Medipix in use for mixed field radiation dosimetry, with possible applications in homeland security and radiation safety

   In conjunction with Jablotron Alarm Systems (CZ)



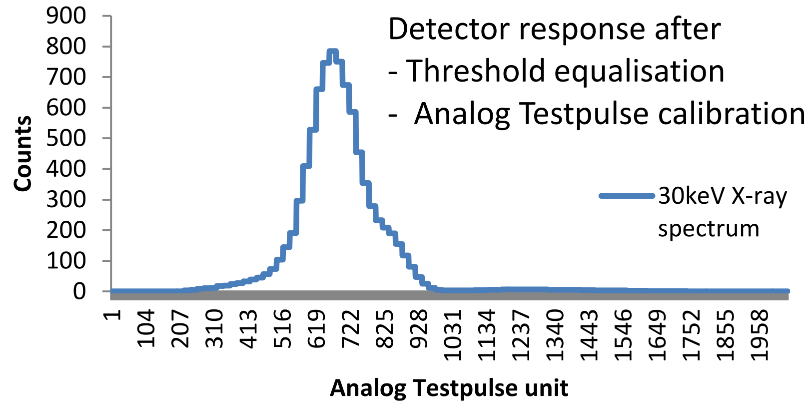


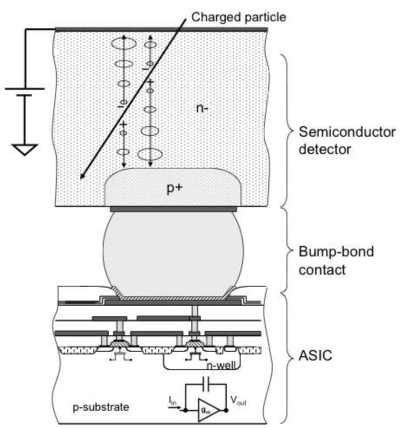
Dosepix

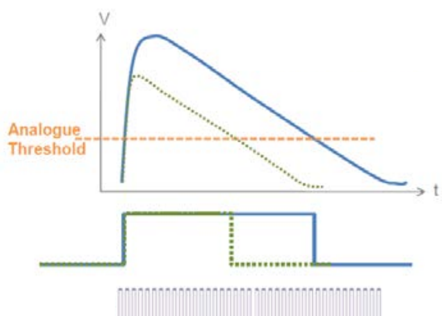
Francesca Bisello (IBA Dosimetry) – *PhD with Uni Erlangen*

Hybrid Pixel Detector with read-out electronics
256 pixels of 220 µm pitch

Photon radiation measurement using Si detector by Time over Threshold (ToT) calculation for each incoming photon

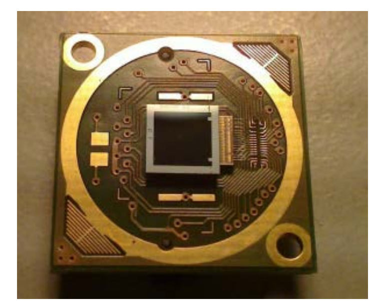






Project development:

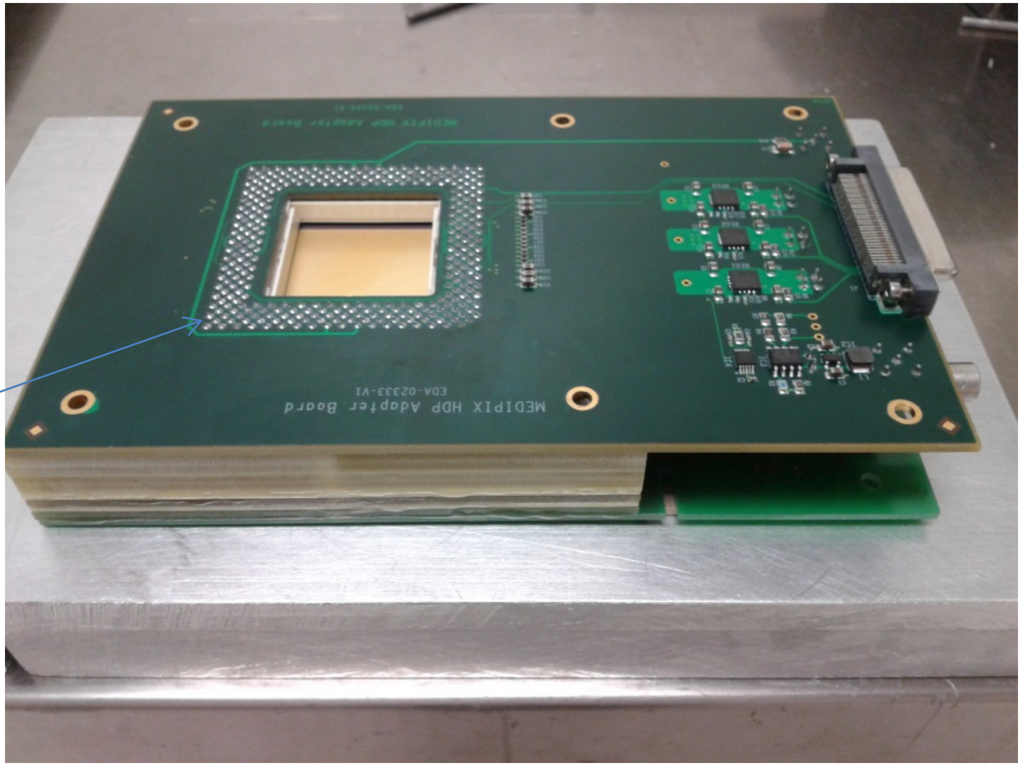
- Chip Calibration Method
- Chip Operation Mode (Dosi mode, ToT mode)
- Chip evaluation at different radiation energy
- Reconstruction and analysis of radiation spectra
- Monte Carlo simulations



GEMPIX at CERN

F. Murtas and J. A. Alozy

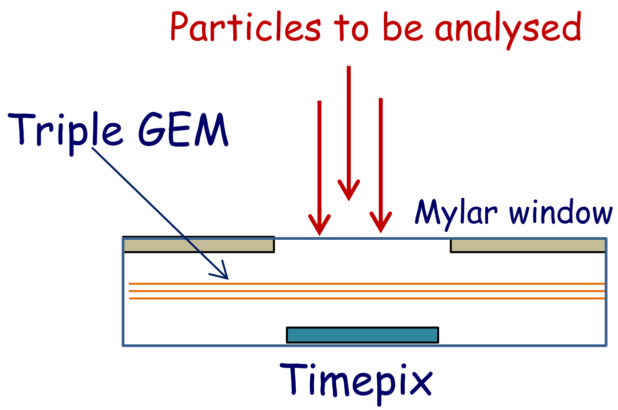
A new detector concept where a GEM gas detector is coupled with a 260,000 Medipix “quad” readout of 55 µm x 55 µm area



Timepix readout card

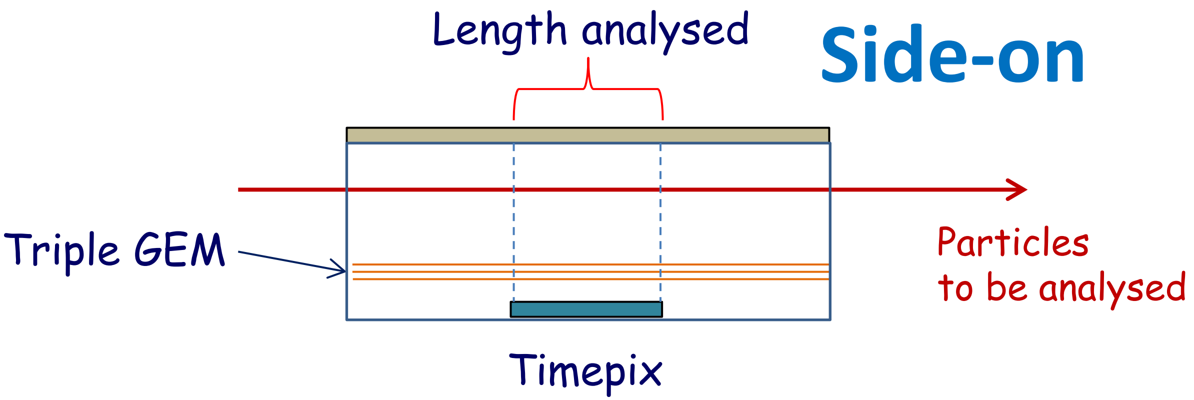
Potential patent

GEMPIX: two working modes



Head-on

Side-on



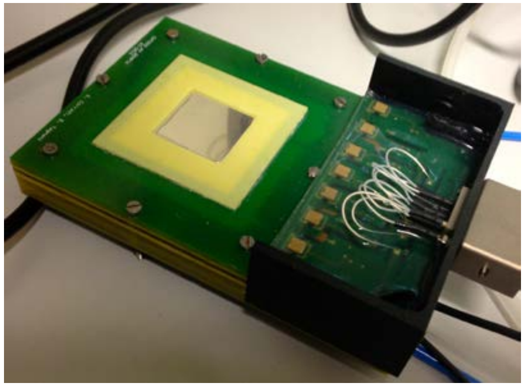
The readout is made with a Timepix chip
The active area is 9 cm^2
The particle track is analysed with 512 pixel in 3 cm length
This is equivalent to 30 microns of tissue … with 17 samples/micron

Medipix and GEMPIX

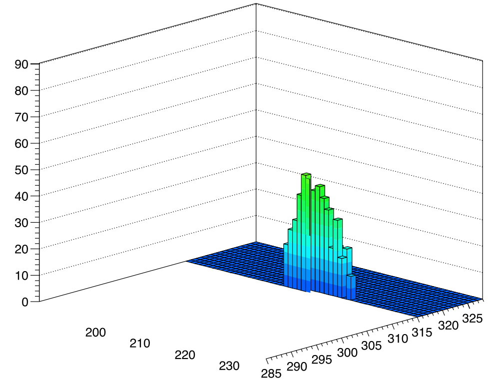
Stuart George (CERN) – *PhD with Uni Wollongong*

Individual particles leave highly detailed tracks in the GEMPIX

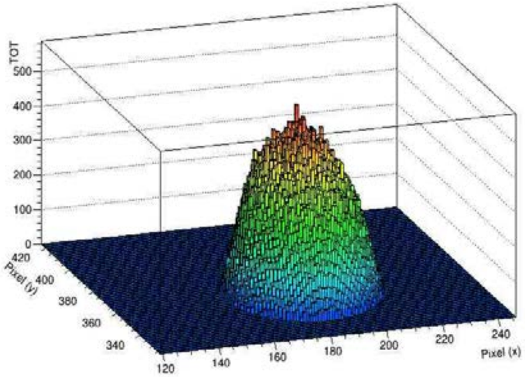
We are investigating its potential for microdosimetric measurements



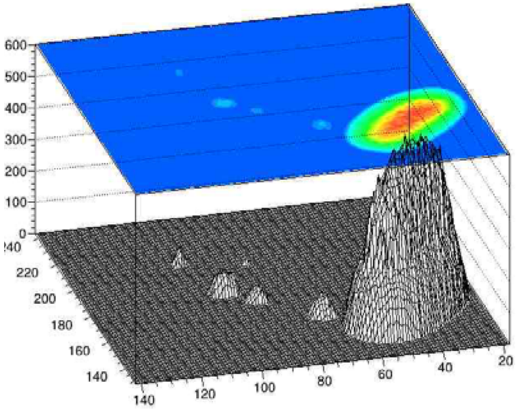
The GEMPIX



5.5 keV photoelectron

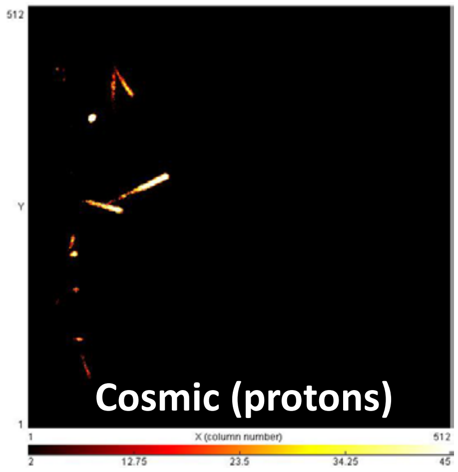


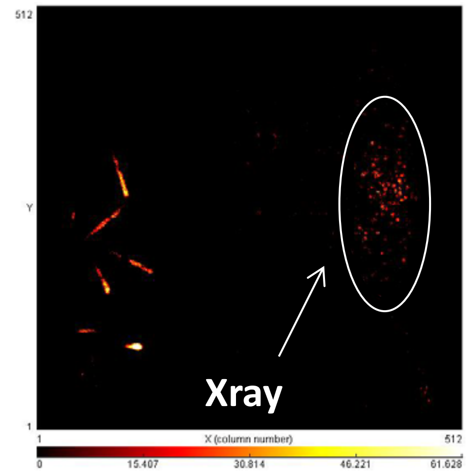
6 MeV alpha-particle

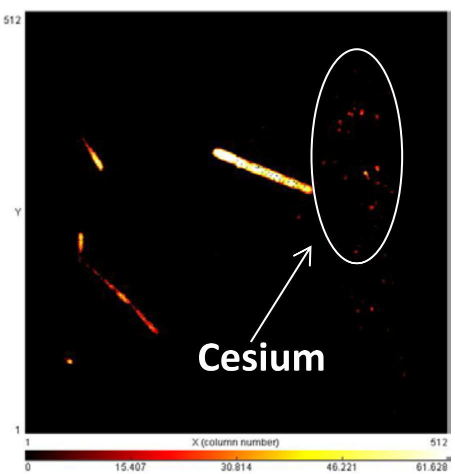


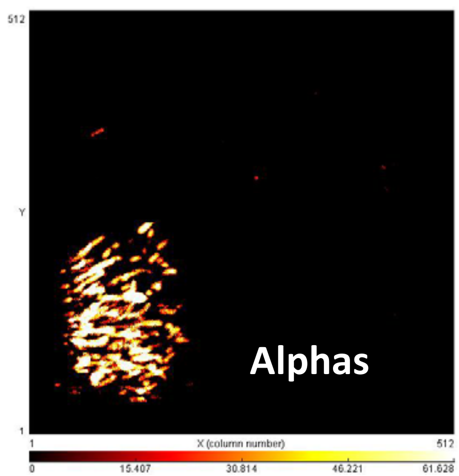
Cosmic-ray

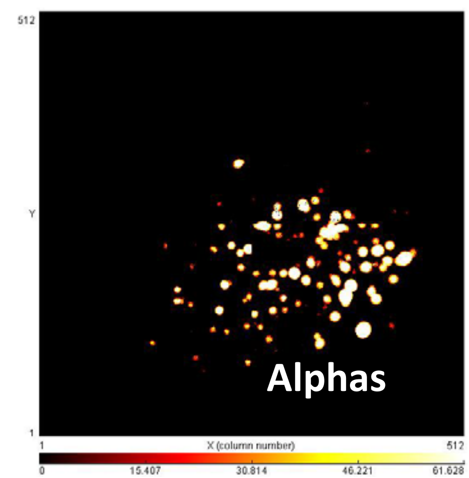
Some events taken with GEMPIX









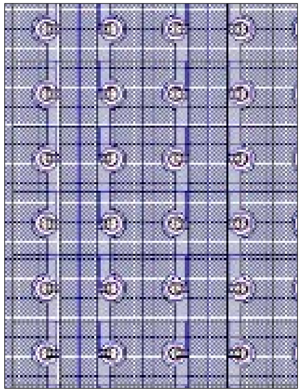


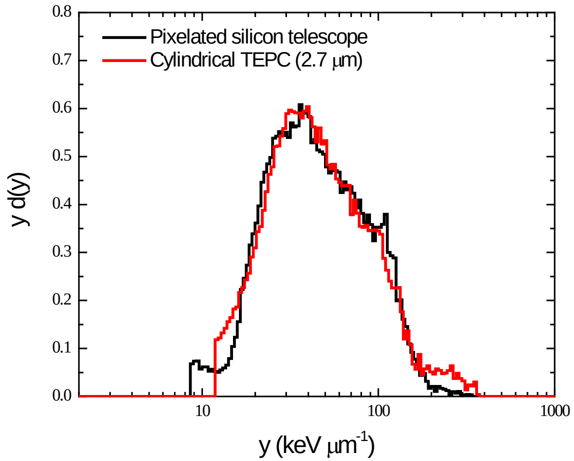
Silicon microdosimeter at POLIMI

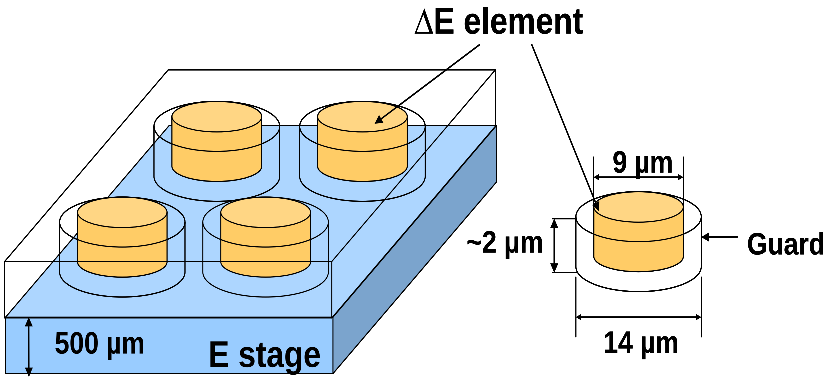
(S. Agosteo and A. Pola)

SEGMENTED SILICON TELESCOPE

- ✓ Constituted by a matrix of cylindrical ΔE elements (about 2 µm in thickness) and a single residual-energy E stage (500 µm in thickness)
- ✓ Nominal diameter of the ΔE elements about 9 µm, the width of the pitch separating the elements about 41 µm
- ✓ Minimum detectable energy limited to about 20 keV by the electronic noise



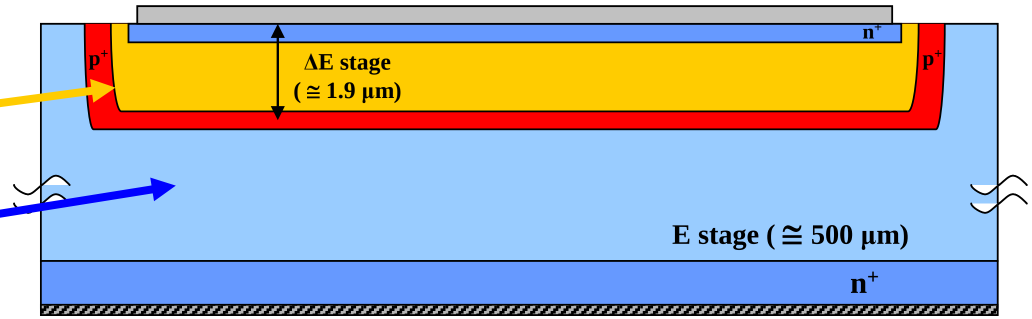




Silicon microdosimeter

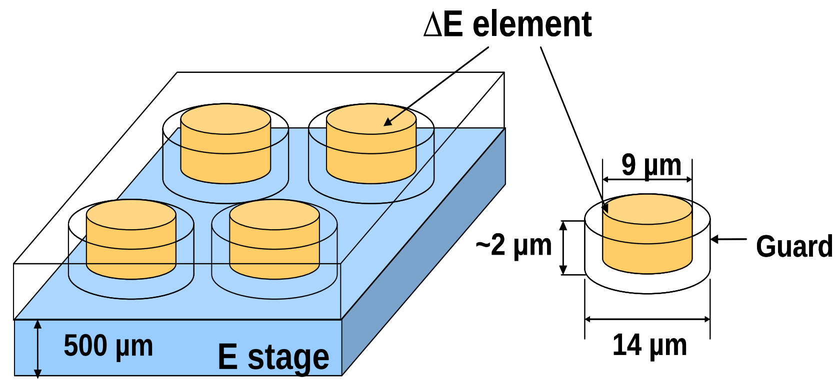
Eleni Sagia (POLIMI) – *PhD with POLIMI*

<u>Silicon telescope</u>:
a thin ΔE stage (1.9 µm thick)
coupled to a residual energy E stage (500 µm thick)
on the same silicon wafer.



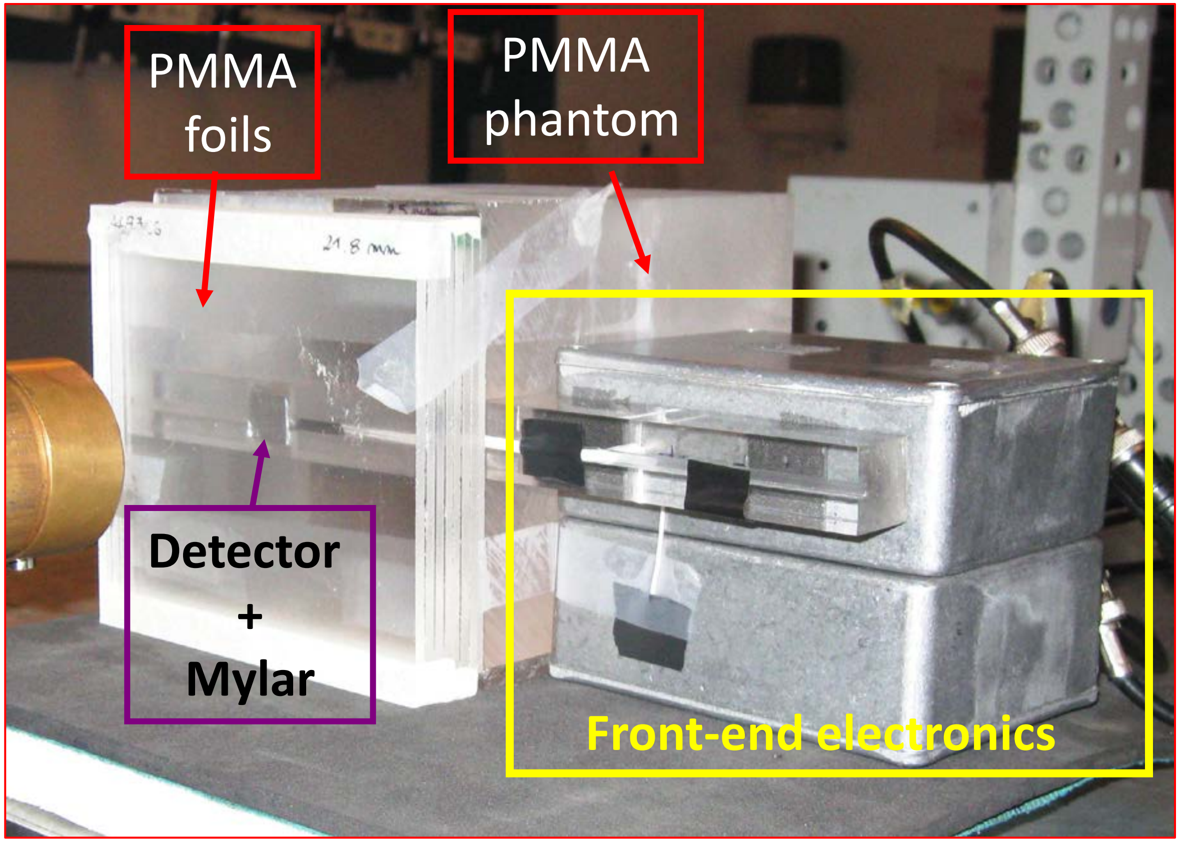
More than 7000 pixels are connected in parallel to give an effective detection area of the ΔE stage of about 0.5 mm^2

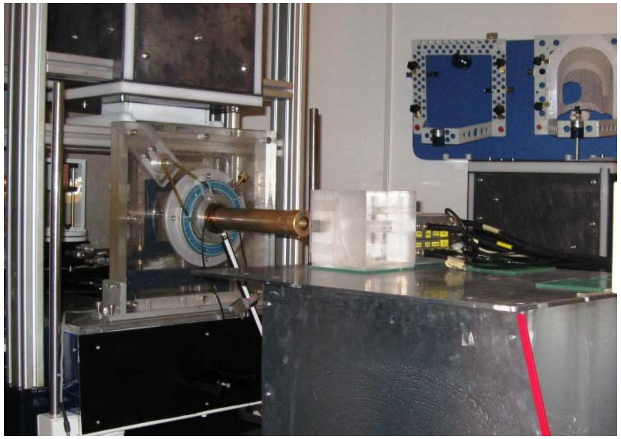
The ΔE stage acts as a microdosimeter while the E stage allows assessing the full energy of the recoil-protons, providing the LET-dependent correction for tissue-equivalency



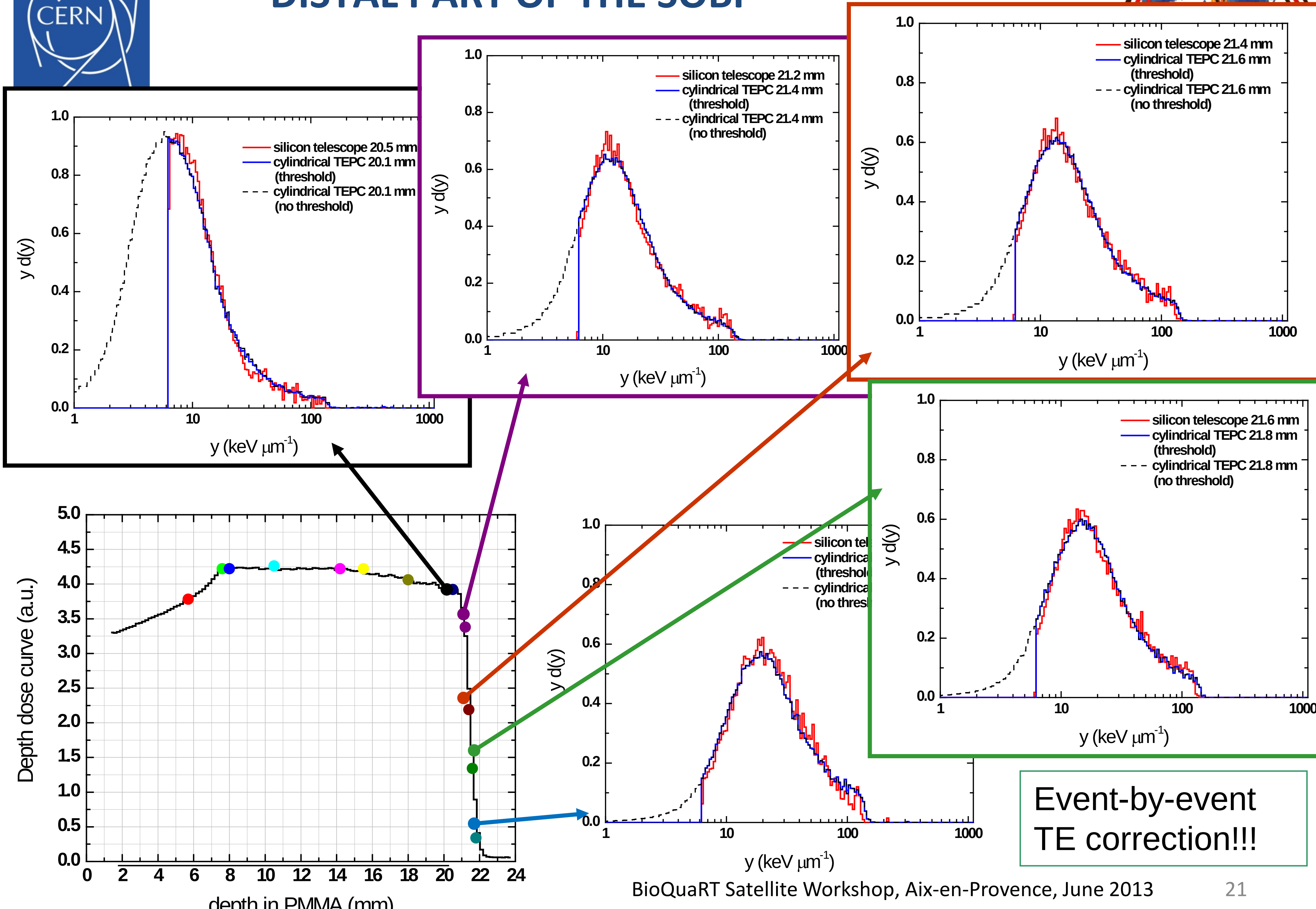
Silicon microdosimeter at POLIMI

Segmented silicon telescope irradiated inside a PMMA phantom exposed to the 62 MeV proton beam at the INFN-LNS CATANA facility.





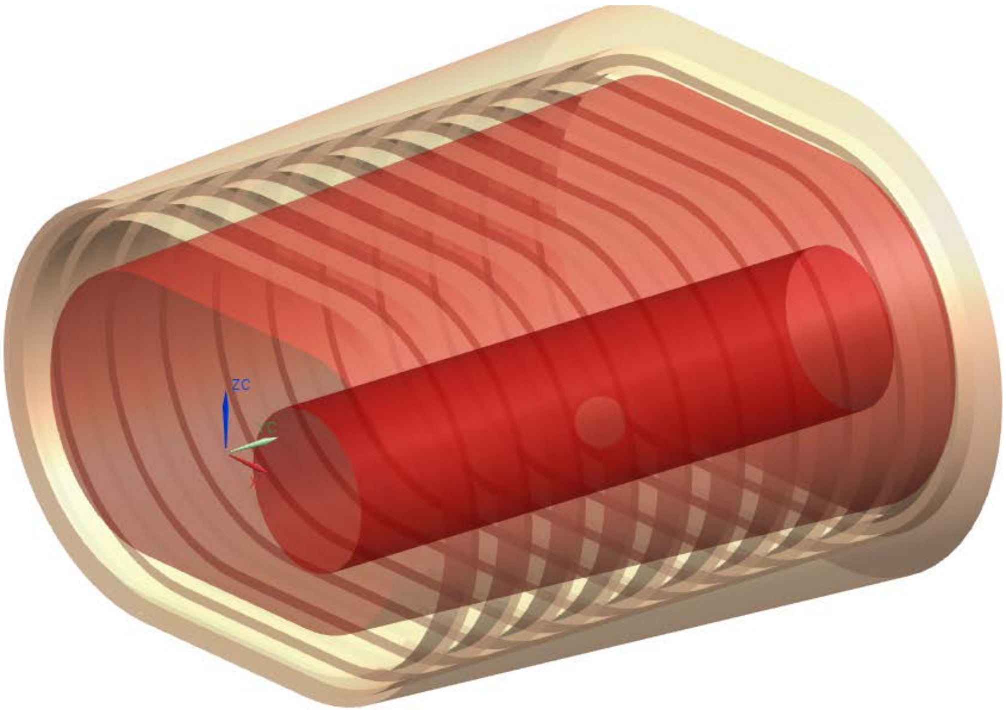
DISTAL PART OF THE SOBP



Event-by-event TE correction!!!

Treatment planning verification

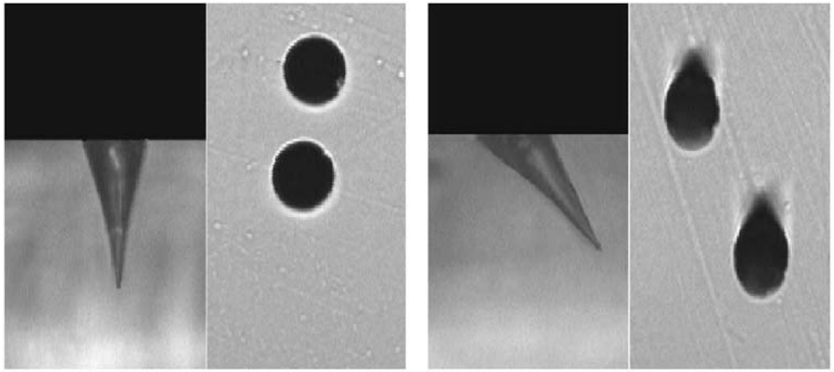
Andrej Sipaj (AIT) – *PhD with Medical University of Vienna*



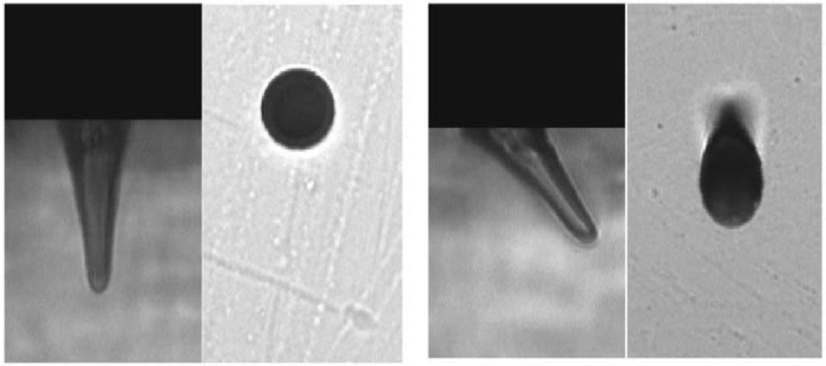
Development of a heterogeneous, breathing thorax phantom with moveable tumor for treatment planning system verification. Different types of passive/active detectors will be selected

LET reconstruction with CR39 at POLIMI
(M. Caresana)

B. Dorschel et al.
Radiation Measurements 37 (2003) 563 – 571



(a)

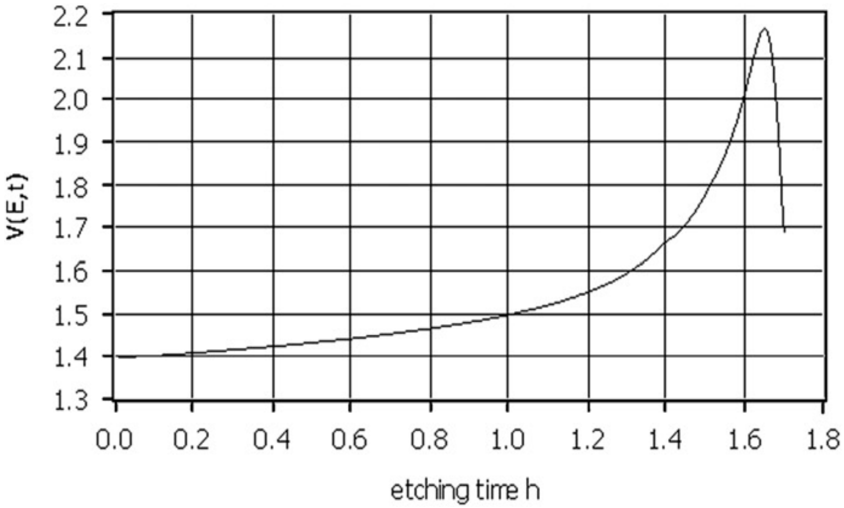


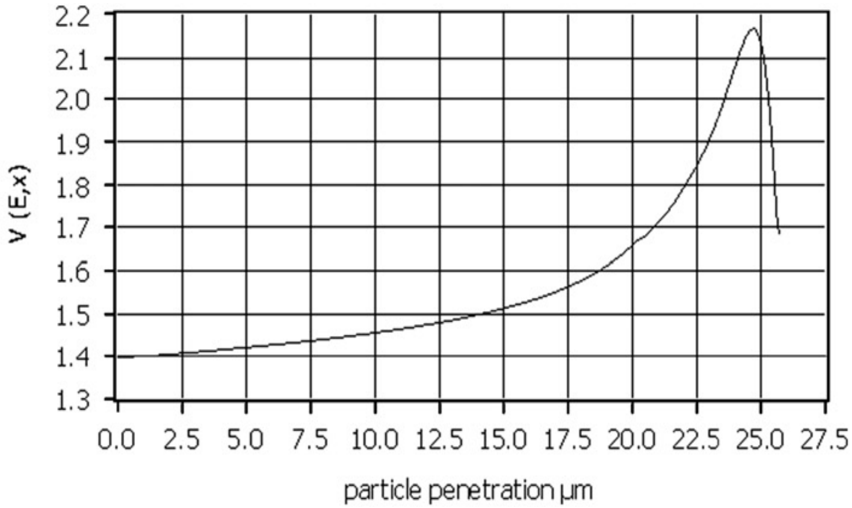
(b)

Longitudinal section and top view of etched tracks of 90 MeV 7-Li ions entering the detectors at 0° (left) and 40◦ (right) for diferent etching times, t (a) t = 3:5 h, (b) t = 4:33 h. Magnification: 950.

LET reconstruction with CR39 at POLIMI

Ratio V of the track attack velocity to bulk attack velocity as a function of the etching time and the particle penetration in CR39



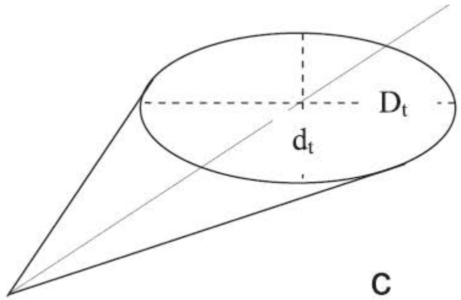


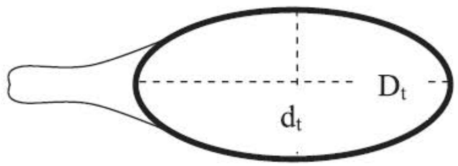
V = V(E,t) and *V = V(E,x)* functions calculated through the ***V = V(LET(E,x))*** function for 1.2 MeV protons impinging perpendicularly on the detector surface. The simulated etching conditions are Vb=9.8 µm h^{-1} and 1.5 h of etching time.

LET calculation

$$V = V_t/V_b = f[LET_{mean}(E,x)]$$

$V = (D_t, d_t)$ where D_t and d_t are the track major and minor axis





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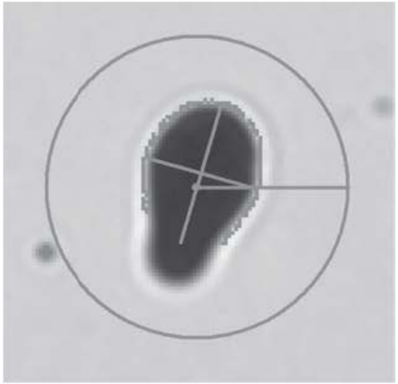
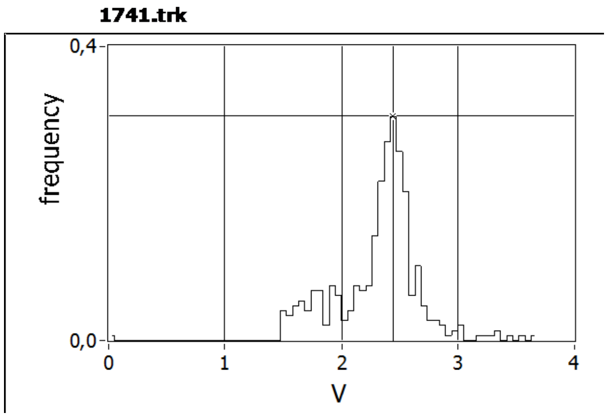
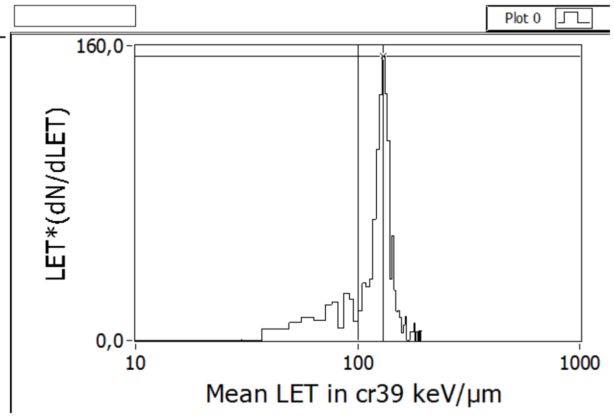


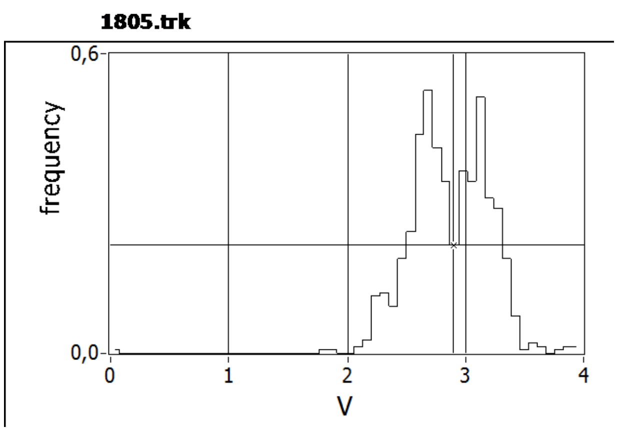
LET reconstruction with CR39 at POLIMI

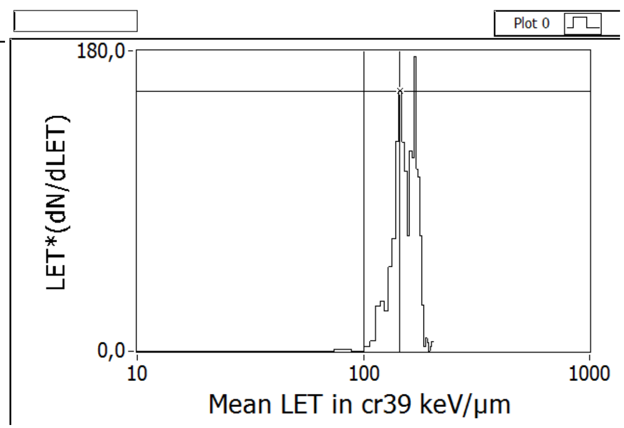




Am-241 E=5.5 MeV
Etching time 60’
Removed layer 10 µm

Mean LET measured 130 keV/µm
Mean LET calculated 140 keV/µm





U_{nat} E_1=4.2 MeV E_2=4.77 MeV
Etching time 40’
Removed layer 6.7 µm

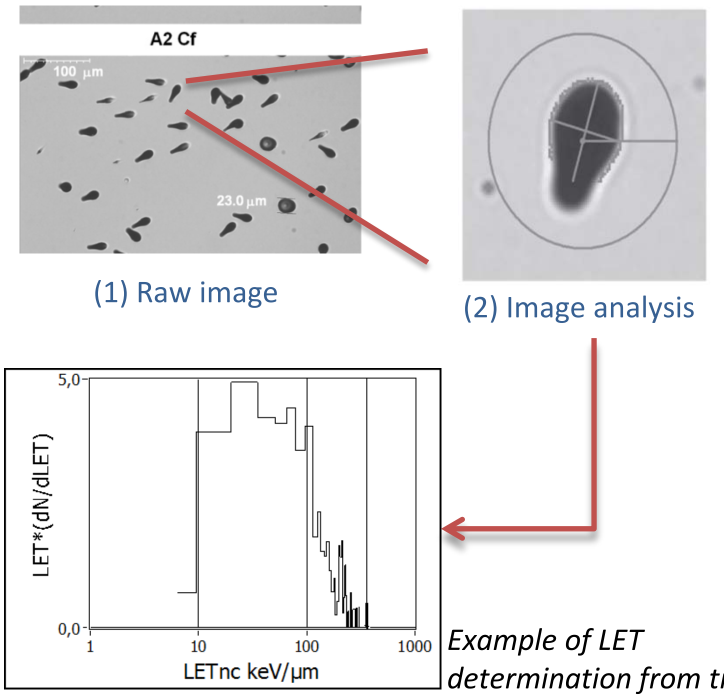
Measurement LET alfa Am-241 and U_{nat}

Source	Mean LET measured	Mean LET calculated
U-234	145 keV/µm	148 keV/µm
U-338	170 keV/µm	187 keV/µm

Dosimetry and spectrometry in complex neutron fields using CR-39 track detectors

Alvin Sashala Naik (MI.AM) – *PhD with POLIMI*

- LET measurements in quasi-monoenergetic neutron beams at the PTB (Germany) and Ithemba labs (South Africa) calibration facilities
- Development of personal and area neutron dosimeters with Monte Carlo simulations (MCNPX, FLUKA)
- Development of the POLITRACK™ automatic detector reader for precision track image analysis in CR-39
- Applications:
  - stray radiation measurement in Ion beam therapy
  - complex neutron fields in high-altitude flights and in space due to cosmic rays



(1) Raw image

(2) Image analysis

(3) LET distribution

Example of LET determination from track image parameters

THANK YOU FOR YOUR ATTENTION

Highlights from the Advanced Radiation Dosimetry European Network Training Initiative (ARDENT)

Marco Silari (CERN)

on behalf of the ARDENT consortium