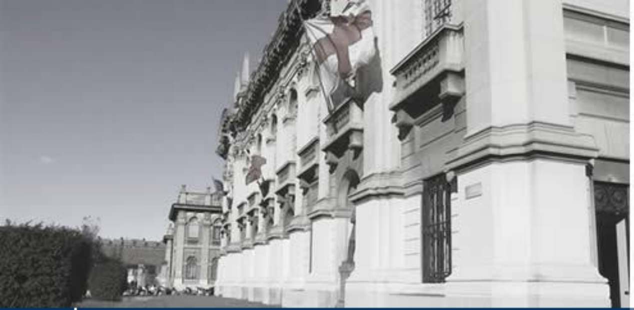

POLITECNICO DI MILANO

Neutron Dosimetry and Spectrometry in Complex Radiation Fields using CR-39 Track Detectors

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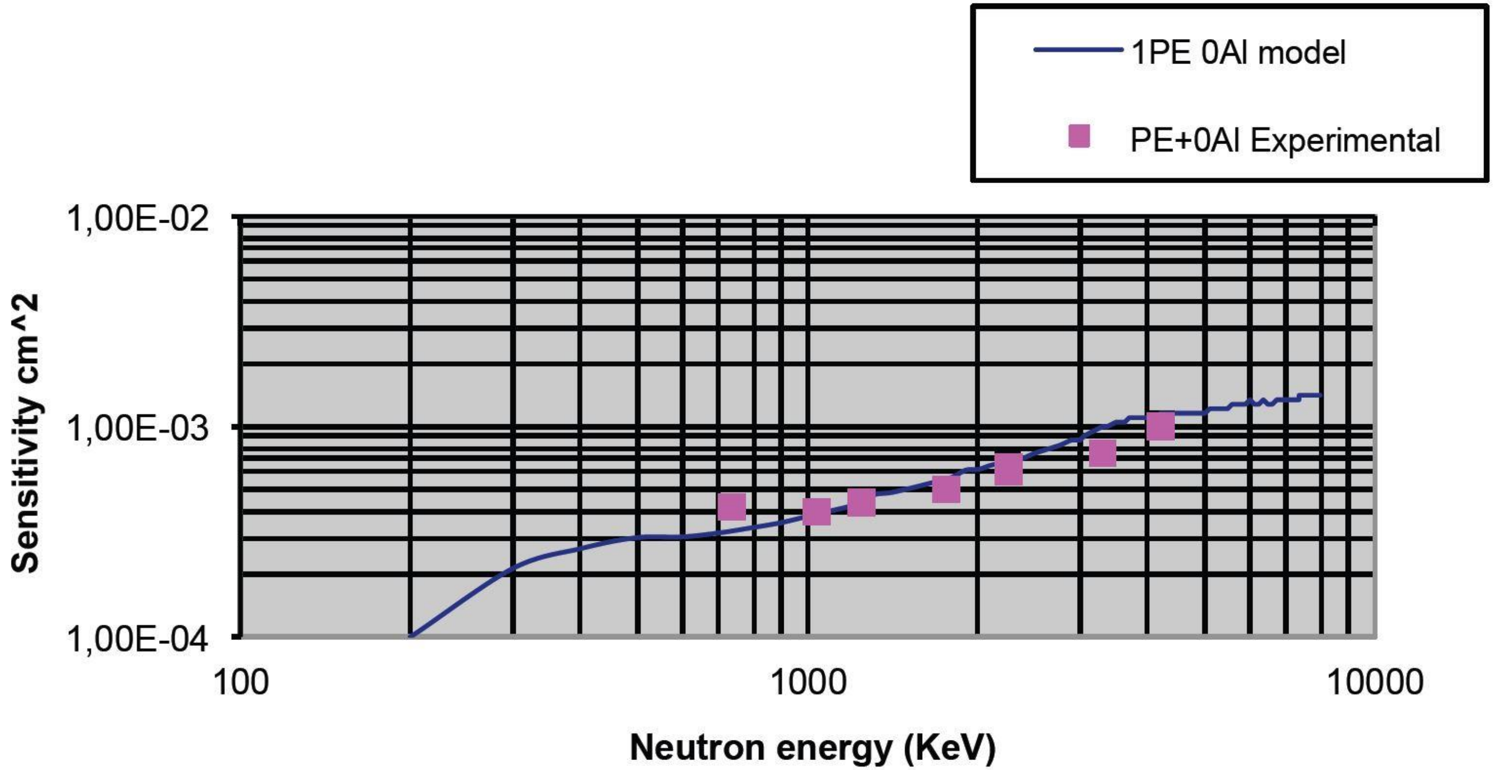
Outline

- State of the art in neutron dosimetry using CR-39 track detectors
- Our innovative approach: Concept of Dose calculations using the LET_{nc} spectra
- Measurements in Neutron fields
- In-beam LET Spectrometry in hadron-therapy applications
- Monte Carlo simulations for validation of measurements (FLUKA, MCNPX, SRIM)
- Achievements so far
- Conclusion

State of the art in neutron dosimetry using CR-39 track detectors

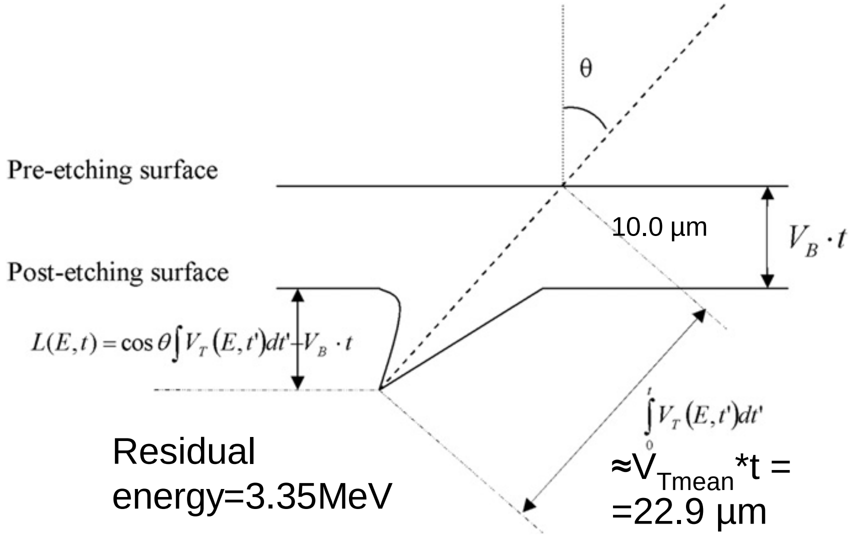
Most of the present European dosimetry services (IRSN France, LANDAUER Europe, PSI Switzerland, ENEA Bologna in Italy) correlate the neutron dose with the track density. This results in a detector sensitivity that can vary by a factor 10 according to the neutron energy. Thus a prior knowledge of the energy composition of the neutron field is required.



M. Caresana et al.

What is LET_{nc} measured in CR-39?

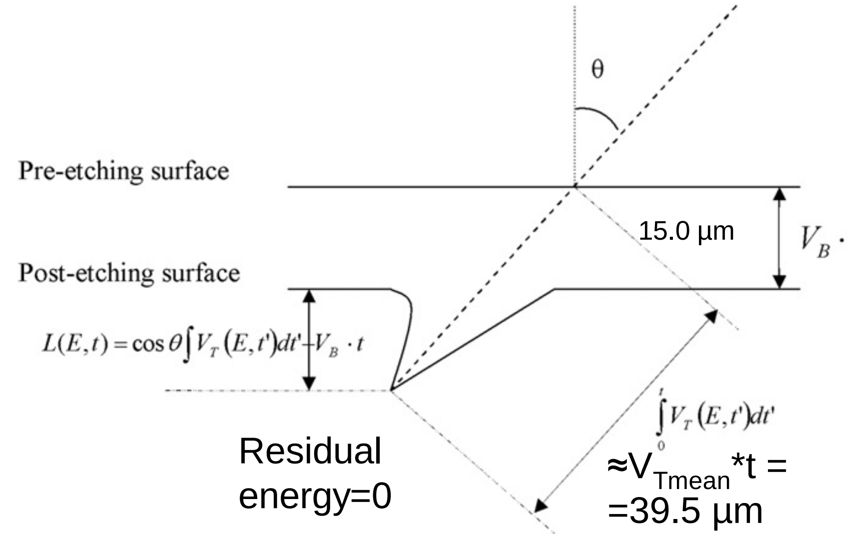
Etching time 60 min
Alpha energy 6.1 MeV (Cf-252)



Residual energy=3.35MeV

$\approx V_{Tmean}$*t =
=22.9 µm

Etching time 90 min
Alpha energy 6.1 MeV (Cf-252)



Residual energy=0

$\approx V_{Tmean}$*t =
=39.5 µm

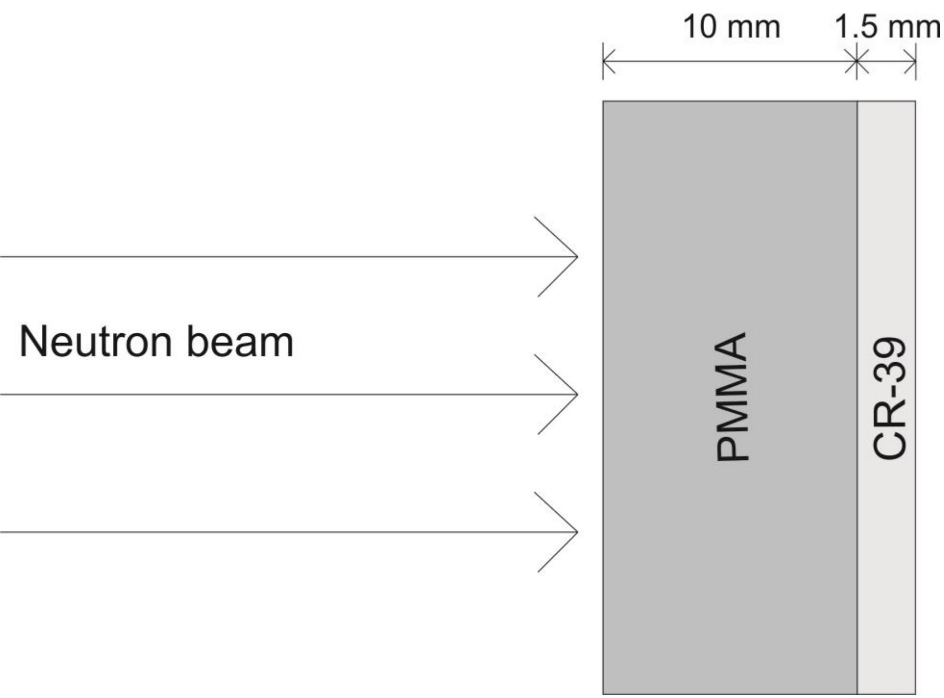
$$LET_{nc} = \frac{E_i - E_r}{x} = \frac{6100 - 3350}{22.9} = 120\left[keV/\mu m \right]$$

$$LET_{nc} = \frac{E_i - E_r}{x} = \frac{6100 - 0}{39.5} = 154\left[keV/\mu m \right]$$

LET_{nc} is the calculated from the V ratio (V_t /Vb)

M. Caresana et al. 2010

State of the art in neutron dosimetry using CR-39 track detectors



In the PMMA radiator, the type of secondary particles produced is strongly dependent on the neutron beam energy (E_n):

E_n < 20 MeV : elastic scattering = recoils protons

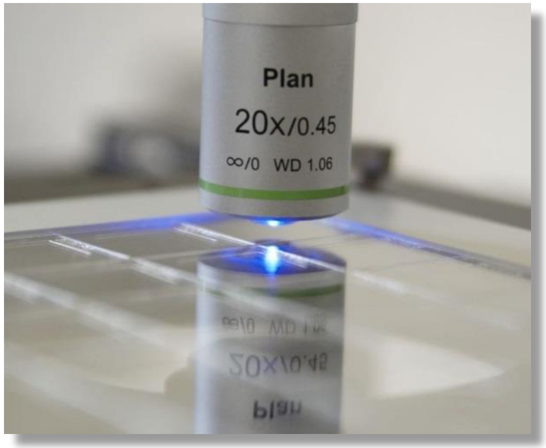
E_n > 20 MeV : (n,p) reactions
+ (n,α) reactions
+ (n,d) reactions
+ (n,t) reactions

http://www.oecd-nea.org/janis/

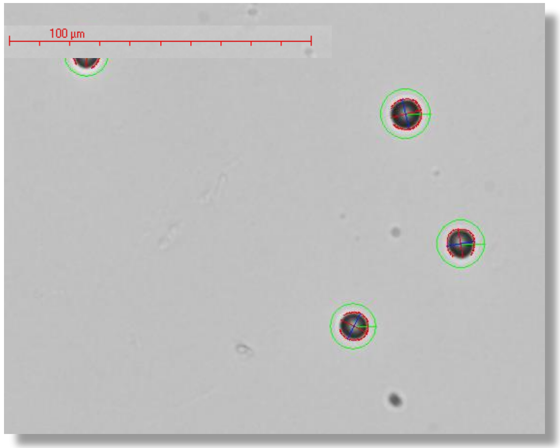
Fragmentation of O and C atoms occur due to spallation reactions when E_n > 20 MeV

CR-39 detector analysis with POLITRACK™

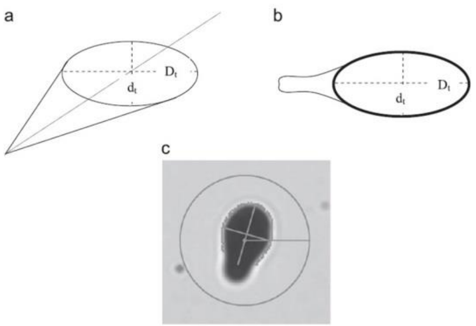
- Automatic counting and geometrical analysis of the tracks by POLITRACK (a)
- Track filtering (account for dust particles or surface defects) (b)
- V_t and LET_{nc} and impinging angle determination (c)
- LET_{nc} distribution (d)



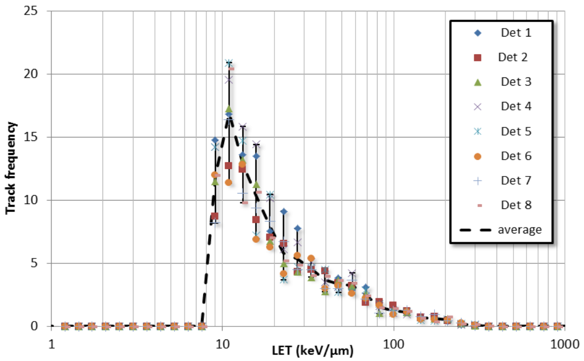
(a)



(b)



(c)



(d)

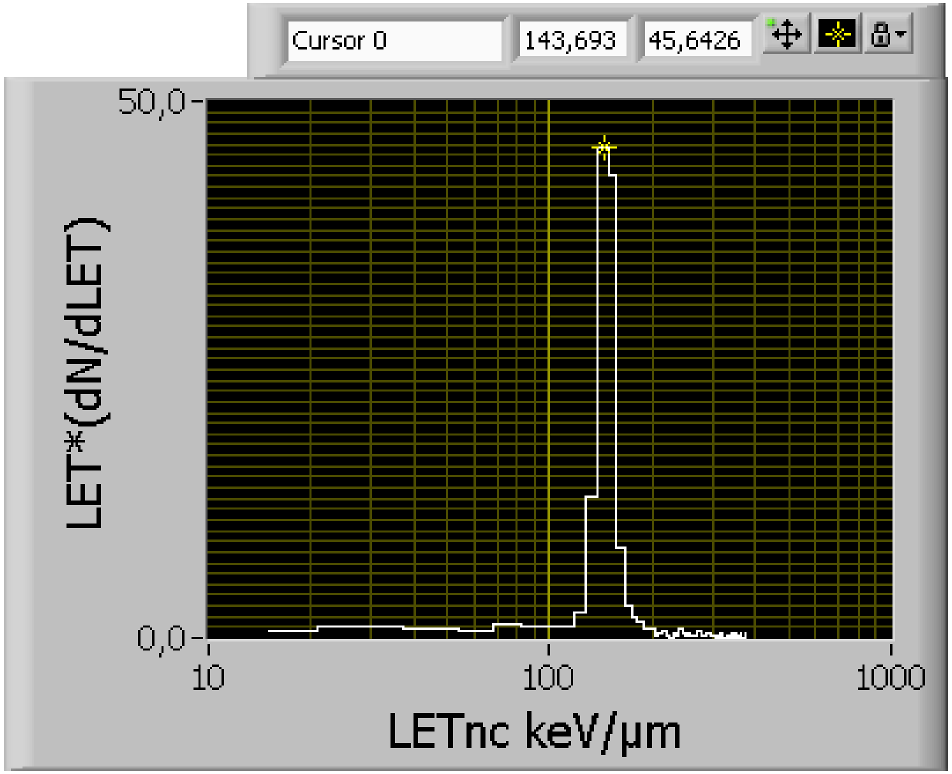
- <u>Dose Equiv. Calculation (mSv)</u>

$$H = \frac{1}{\rho} \cdot 1.602 \cdot 10^{-6} \cdot \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos \vartheta_i} \cdot Q\left(\overline{LET}_i\right)$$

ICRP 60

Calibration of CR-39 dosimeters

Determination of V ratio through the fission fragment technique.



LET spectrum of alpha particles measured in the Detector 3060 irradiated with an electroplated Cf source. The LET peak for a V_b of 10 µm/h is at 146 keV/µm.

Novel approach using the LET_{nc} spectrometry

- Our approach is based on the capability of CR-39 to evaluate the average Linear Energy Transfer (LET) and the possibility to assess the dose from the average LET. (*M. Caresana et al.*)

- The results is that when using this approach the detector response is more stable on a wide neutron energy range.

Beam	Measured Dose (mSv)	Reference Dose(mSv)	Detector Response
PTB 565 KeV	1.79	3.67	0.49
PTB 8 MeV	1.75	4.90	0.36
PTB 14 MeV	3.49	6.90	0.51
PTB 19 MeV	1.84	2.90	0.64
iThemba 66 MeV 0°	2.38	4.44	0.54
iThemba 66 MeV 16°	1.72	3.20	0.54
iThemba 100 MeV 0°	1.52	2.36	0.64
iThemba 100 MeV 16°	1.75	2.83	0.62
Average Sensitivity			0.54 ± 0.09

- No or little prior knowledge of the neutron field is needed with this technique. The neutron field can thus be investigated directly with the average LET measurements done using the CR-39 detectors, acting as a low-resolution spectrometer.

Dose measurement in a simulated workplace field at CERF facility at CERN

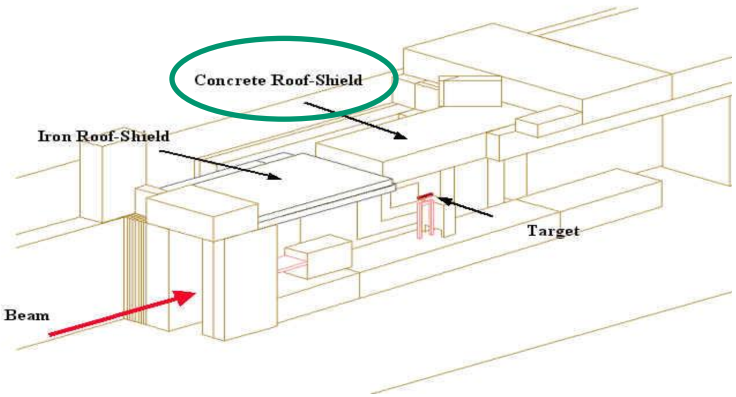


Fig 1a. *CERF irradiation facility*

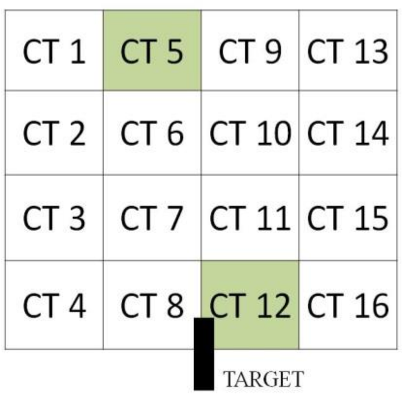


Fig 1b. *Detector position on the concrete roof of CERF*

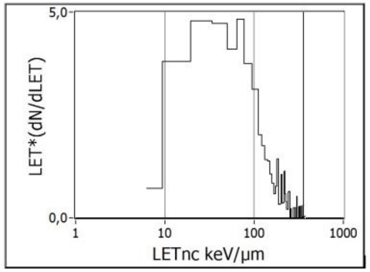


Fig 2a. *LET* distribution measured for the position CT 5

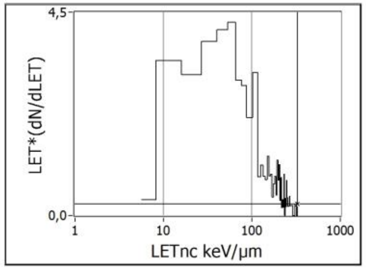


Fig 2b. *LET* distribution measured for the position CT12

Position	Reference Dose (mSv)	Measured Dose in CR-39 (mSv)
CT-5	5.17	3.8 ± 1.4
CT-12	4.85	4.1 ± 0.5

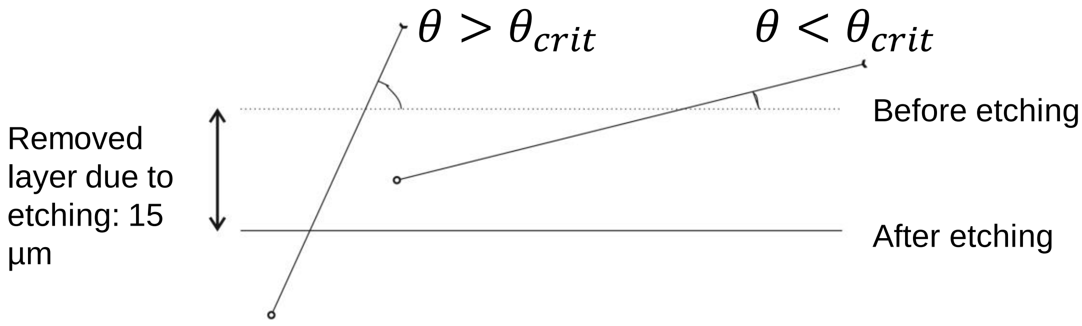
The results obtained for the dose measured at position CT5 and CT12 at CERF, are based on the average sensitivity measured in calibration campaigns using quasi-monoenergetic neutron beams (M. Caresana et al., Neudos 12 proceedings) and confirms the suitability of this detection system for dosimetry in workplace fields.

Response Calibration in mono-energetic neutrons

Beam	Measured Dose (mSv)	Reference Dose(mSv)	Detector Response
PTB 565 KeV	1.79	3.67	0.49
PTB 8 MeV	1.75	4.90	0.36
PTB 14 MeV	3.49	6.90	0.51
PTB 19 MeV	1.84	2.90	0.64
iThemba 66 MeV 0°	2.38	4.44	0.54
iThemba 66 MeV 16°	1.72	3.20	0.54
iThemba 100 MeV 0°	1.52	2.36	0.64
iThemba 100 MeV 16°	1.75	2.83	0.62
Average Sensitivity			0.54 ± 0.09

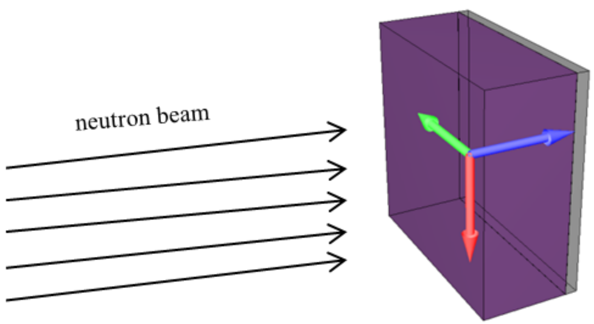
A stable response of 0.54 ± 0.09 is measured for the whole range of neutron energies

Caresana, M. et al. Radiat. Prot. Dosim., submitted in the proceeding of Neudos12 conference

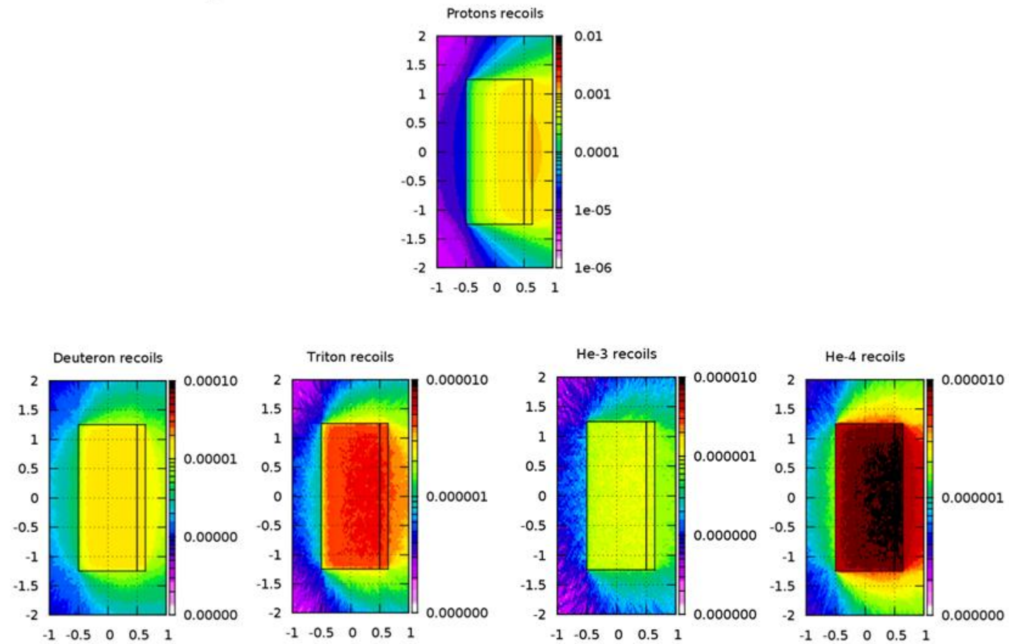


- Around 50% of the dose is not measured because:
  - Hadrons impinging at a low angle with respect to the detector surface are not detected due to etching.
  - Hadrons having a low LET, e.g. protons with energy > 5 MeV are not detected due to etching
  - Etching removes the first 15 µm of the surface of the detector.

Monte Carlo simulations (FLUKA)



Simulation of the CR-39 based neutron dosimeter irradiated in a quasi-monoenergetic 100 MeV neutron beam at Ithemba labs

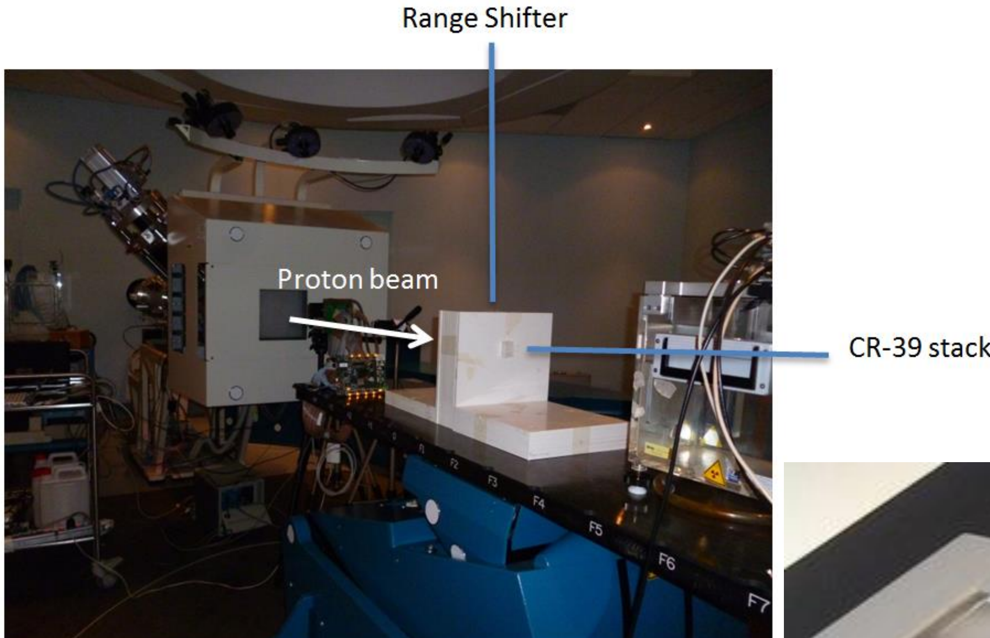


Spatial distribution and fluence of secondary heavy charged particles producing tracks in the CR-39 detectors

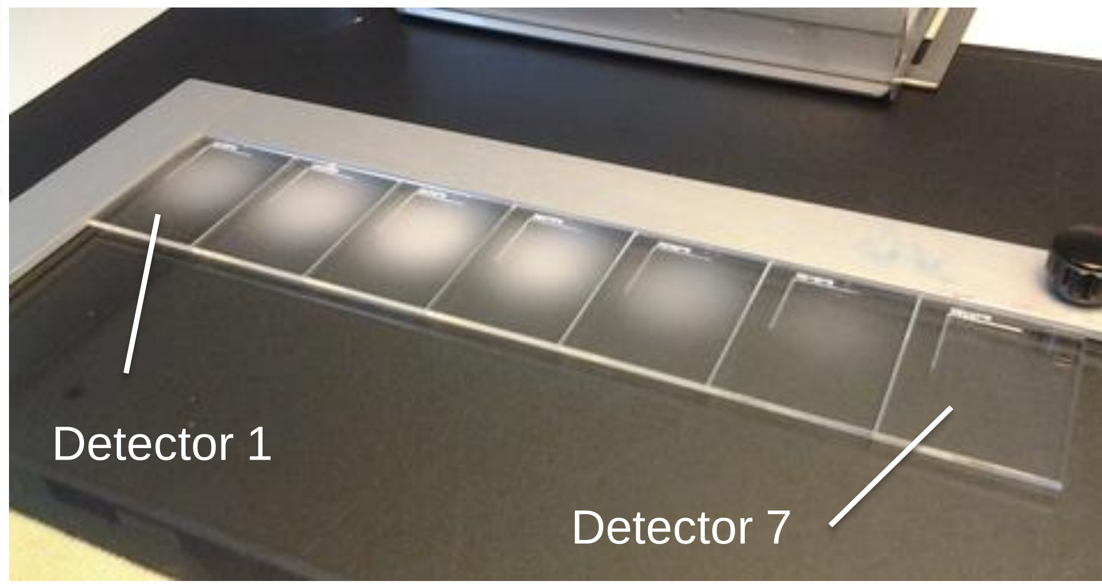
Monte Carlo simulations allows us to identify and quantify the secondary hadrons which contributes to the dose delivered to the CR-39 dosimeter.

Research work performed at the Austrian Institute of Technology – AIT, under the coordination of Sofia Rollet

Spectrometry using CR-39 detectors for hadron therapy beam diagnostics (Proton and Carbon beams)



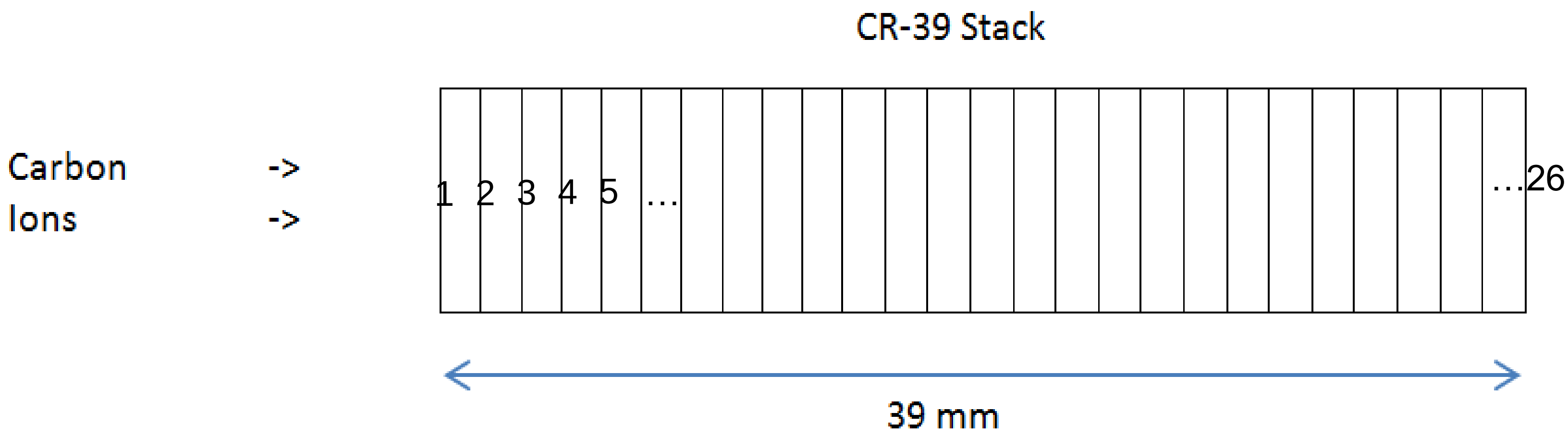
Experiment at setup with 180 MeV proton beam at CNAO, Pavia



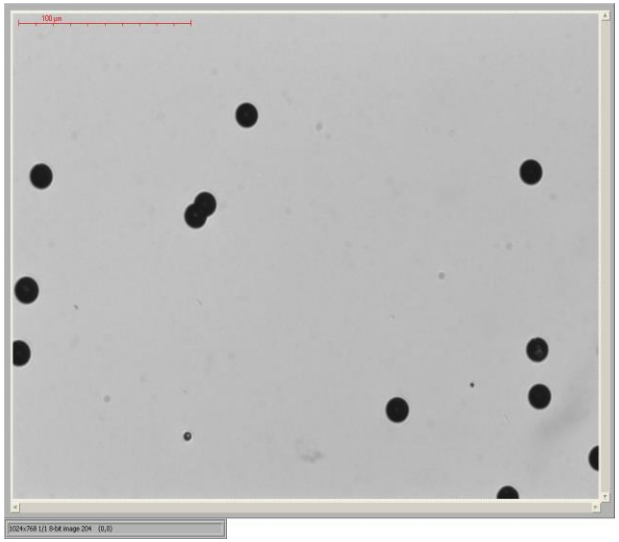
Beam shape marked in the CR-39 due to track overlap

In experiment 4, a stack of 26 CR-39 detectors (1.5 mm each) were used and irradiated without using any phantom. The stack was placed directly in the Carbon beam. E = 108.4 MeV/nucleon (30mm H_2O

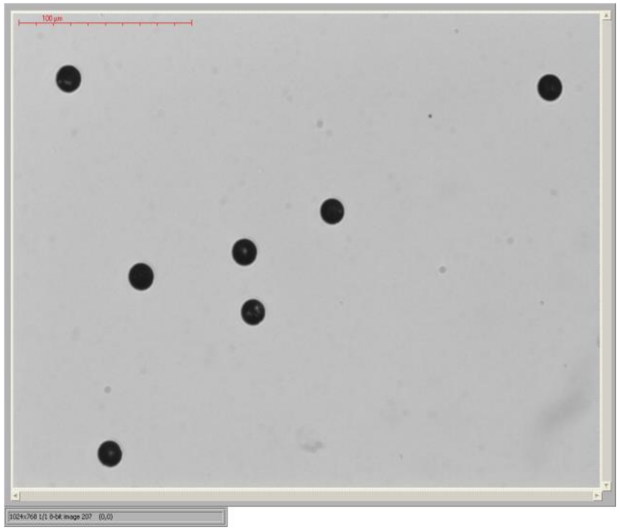
A fluence of $7*10^4$ particles was calculated for this experiment.



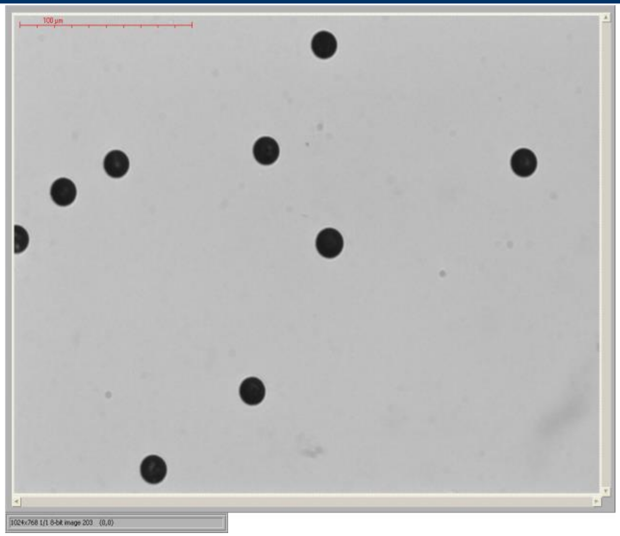
Spectrometry using CR-39 detectors for hadron therapy beam diagnostics



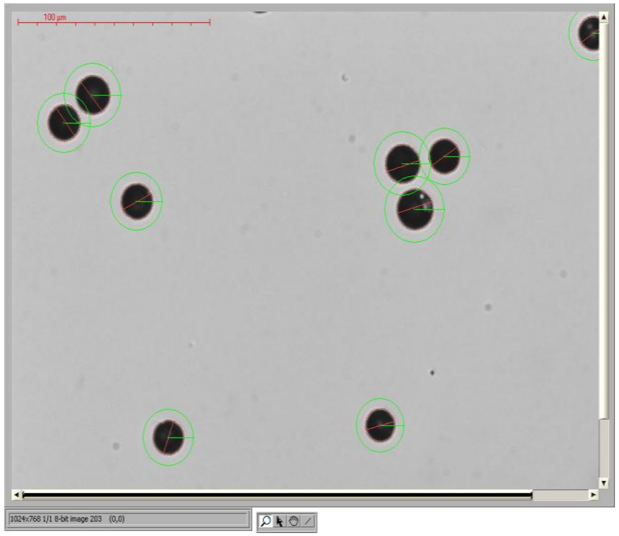
Detector10



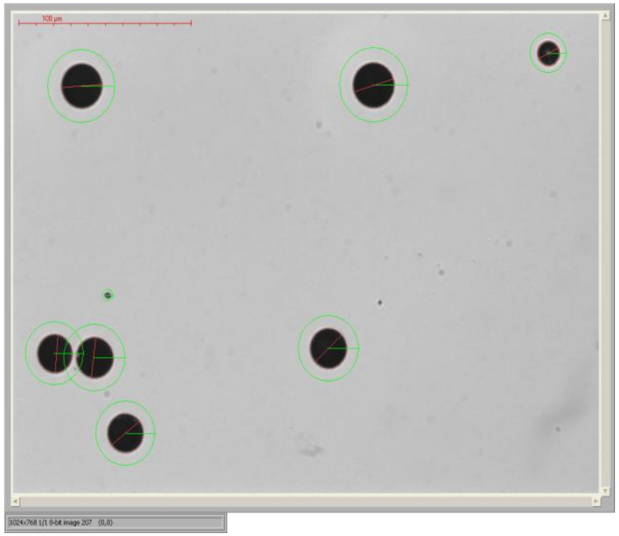
Detector11



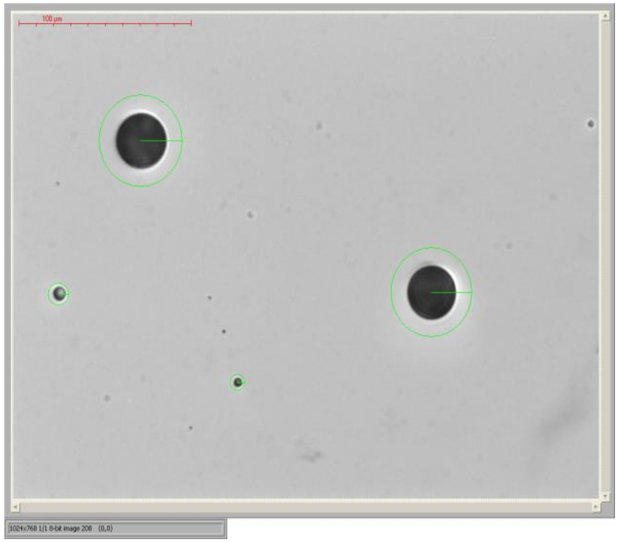
Detector12



Detector13



Detector14



Detector15

Achievements so far

- 4 publications in major journals
  - M. Caresana et al. (Nov 2013), Rad. Prot. Dosimetry
  - F. Trompier et al. (Dec 2013), Rad. Prot. Dosimetry
  - M. Caresana et al. (April 2014), Rad. Measurements
  - M. Caresana et al. (July 2014), Rad. Measurements
- Conferences attended
  - EURADOS, NEUDOS, SSD 17, IEEE NSS-RSTD, PSND Jülich.
- Workshops/training courses attended
  - ESARDA, B&A course at CERN, FLUKA, LabView
  - 40 compulsory Credits already validated for the PhD school
    - 8 courses (management, engineering, communication skills, radiation physics, etc.)
- Secondments
  - AIT Vienna (supervisor: Sofia Rollet) on Monte Carlo simul. - completed
  - CERN (B&A project, Jan & Feb 2015)

Conclusion

- CR-39 acts as a low resolution spectrometer and a dosimeter at the same time
- It has a very low cost
- It can be used as a tissue equivalent personal and environmental dosimeter
- It is insensitive to stray radiation such as intense gamma ray pulses which are parasites to all active detection instruments

- However, the limits are its insensitivity to hadrons having a low-LET or high angle of incidence on the detector; thus reducing the response of the detector