Pitfalls in calculating charge response parameter from etch pit

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Outline of talk

- Motivation.
- Formation of etch pit inside Nuclear Track Detector.
- Estimation of the region of applicability of two widely used methods of calculating charge response parameter.
- Experimental confirmation.
- Conclusion.

Motivation

Nuclear Track Detectors (NTDs) are used to detect particles (size ~ nucleus) by observing their tracks inside detector material.

Currently two major experiments use NTDs as their detecting tool

Magnetic Monopole search (MoEDAL experiment) at LHCb, CERN

Strangelet search at mountain altitude at Bose Institute

In these two experiments, people use two different methods to calculate charge response parameter. Our aim is to study the region of applicability of these two methods.

Technical Design Report of the MoEDAL experiment CERN-LHC-2009-006, MoEDAL-TDR-1.1, September 21,2009

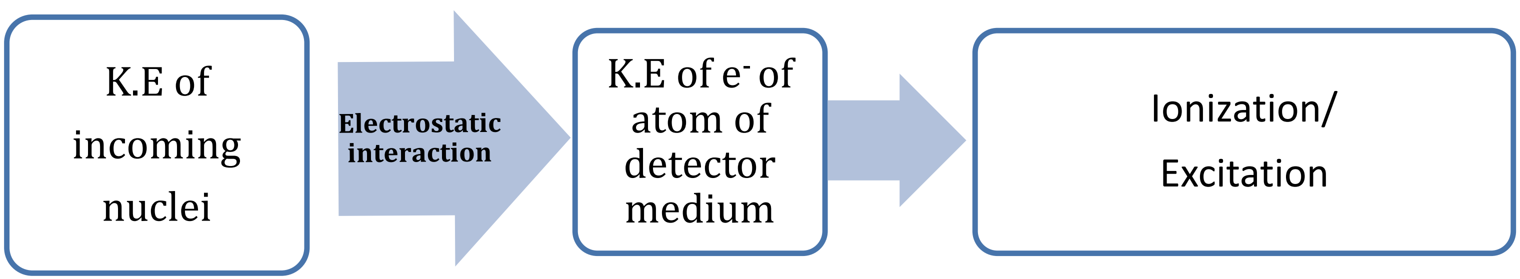
Strangelet Search at Mountain Altitude by R Bhattacharyya, S Dey, Sanjay K Ghosh, A Maulik, Sibaji Raha and D Syam. *Proc Indian Natn Sci Acad* **81** No. 1 February 2015 Special Issue, pp. 165-168.

Formation of etch pit inside Nuclear Track Detector (NTD)

NTDs belong to a class of passive detectors.

Solid State Nuclear Track Detectors are dielectric solids.

Organic polymer : Polyethylene Terephthalate (PET)
CR-39
Makrofol



Electronic energy loss of charged particles follows Bethe-Bloch formula

$$-\frac{dE}{dx} = \frac{4\pi n Z^2}{m_e v^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\ln\left(\frac{2m_e v^2}{I}\right)\right]$$

Ionizing particle produces 'permanent' damage trail along its direction of motion.
Latent Track (diameter 3-10 nm)

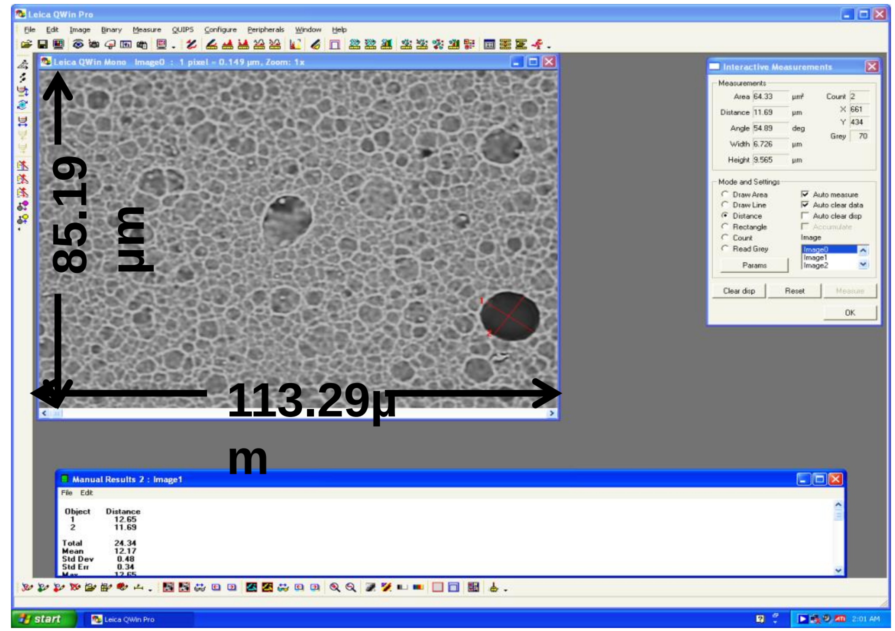
Etching : to make "latent track" visible under Optical Microscope

- Damaged region contains more chemically active zones than surrounding undamaged portion.
- Applying some chemical reagent (here we use 6.25 N aqueous solution of NaOH) makes the damaged portion etched out at a faster rate V_T (Track etch rate) than the undamaged portion V_B (Bulk etch rate) and after that size of the damaged portion increased to ~ µm.
- **Charge response parameter** :: (V_T/V_B) :: Necessary condition for the formation of etch-pit : $V_T/V_B > 1$
- Now if the Detector (transparent) is kept under the microscope we can observe the etch pits.

Calibration of a solid state nuclear track detector (SSNTD) with high detectionthreshold to search for rare events in cosmic rays by S. Dey, D. Gupta, A. Maulik, Sibaji Raha, Swapan K. Saha, D. Syam, J. Pakarinen, D. Voulot, F. Wenander. *Astroparticle Physics 34, 805-808 (2011).*

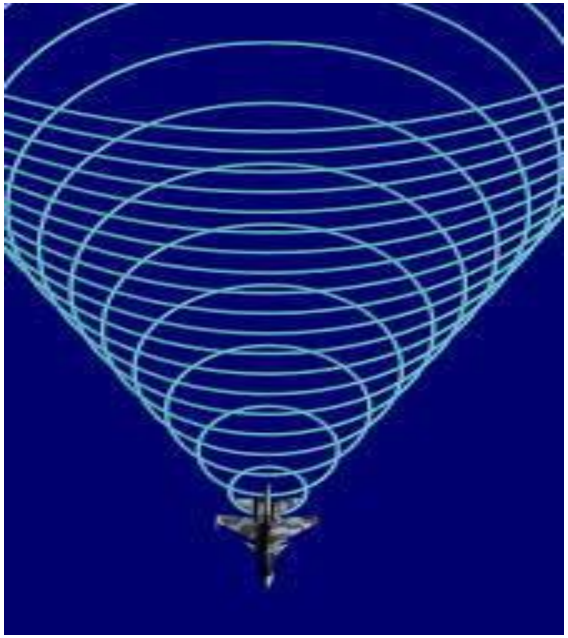
Images of etch pit

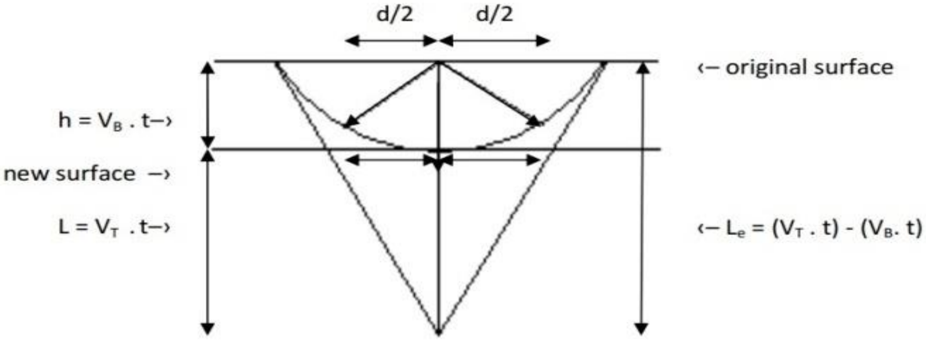
Leica DM 4000 optical microscope



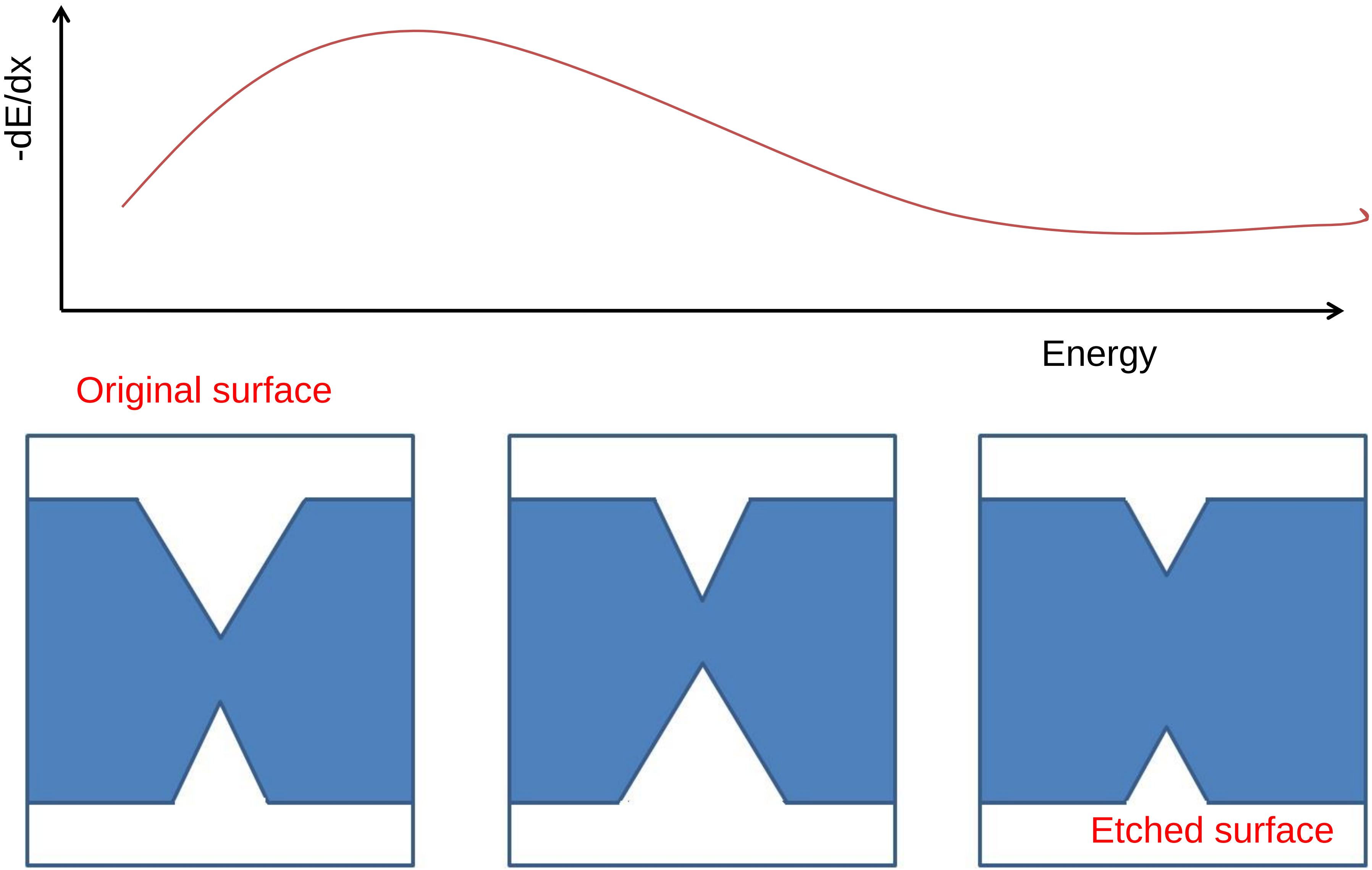
Screenshot during observation using QWin software under x100 dry objective

Why the shape of the etch pit is conical

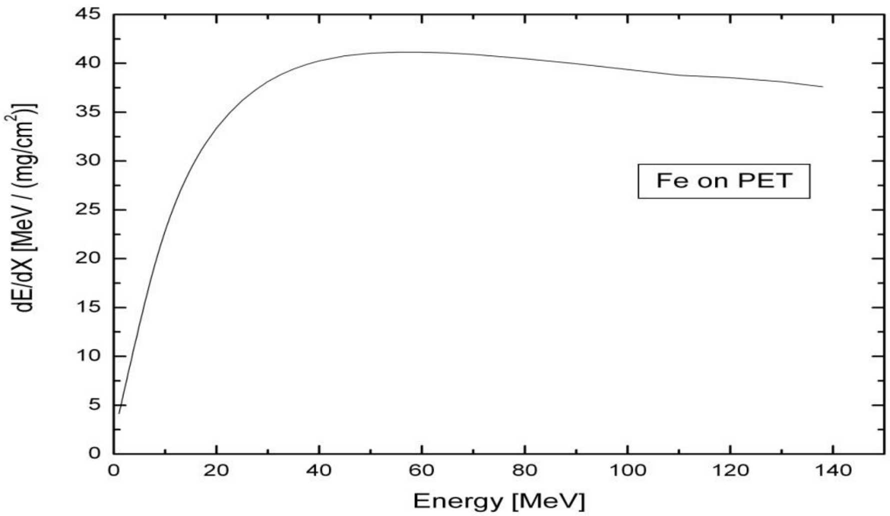


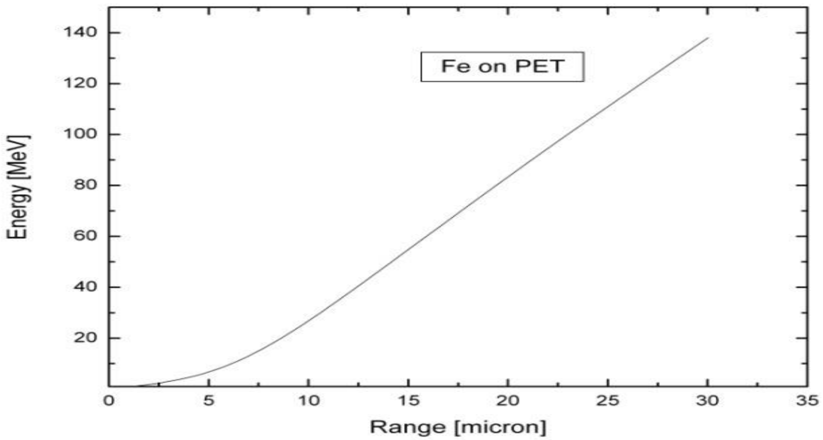


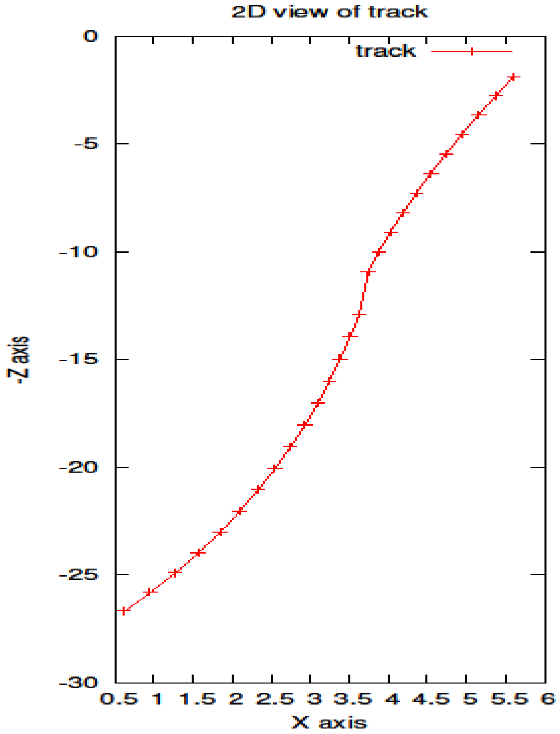
Geometry of etch pit



Simulation of etch pit

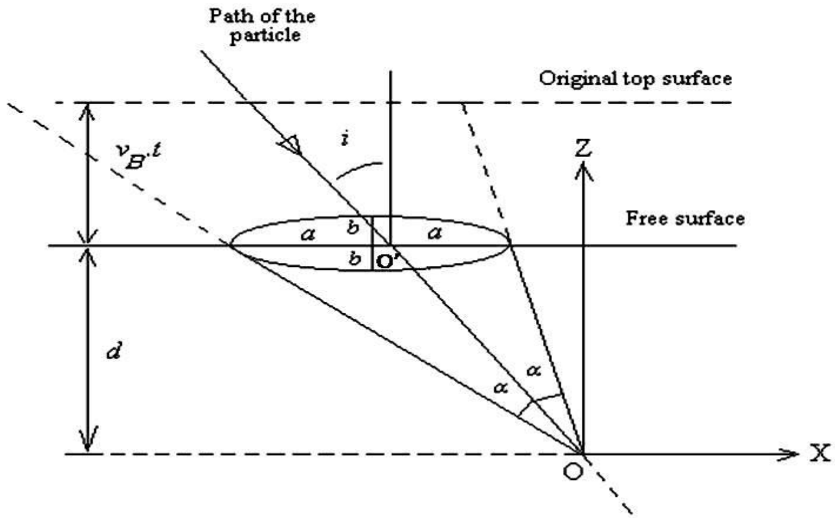






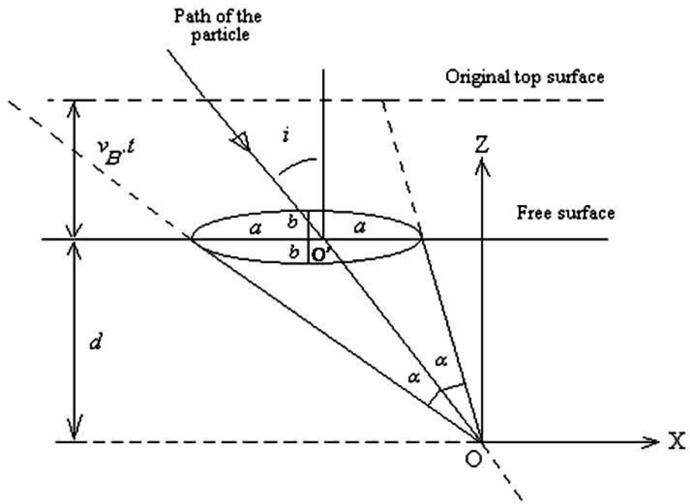
J.F. Ziegler, J.P. Biersack, The Stopping and Range of Ions in Matter (SRIM Computer Code), Version: 2008.04

Schematic diagram of etch pit inside the detector



Measurable quantities	Precision of measurement
Major axis diameter[2a]	0.4 µm
Minor axis diameter [2b]	0.4 µm
Height of the cone [d]	1.0 µm

Formulae for calculating V_T/V_B



From depth measurement

$$p = \frac{V_t}{V_b} = \frac{OO'/t}{V_b} = \frac{\mu d + V_b \times t}{V_b \times t \times \cos i}$$

From diameter measurement

$$p = \frac{V_t}{V_b} = \sqrt{1 + \frac{4D^2}{(1-E^2)^2}}$$

Where,

$$E = \frac{b}{V_b \times t} \qquad D = \frac{a}{V_b \times t}$$

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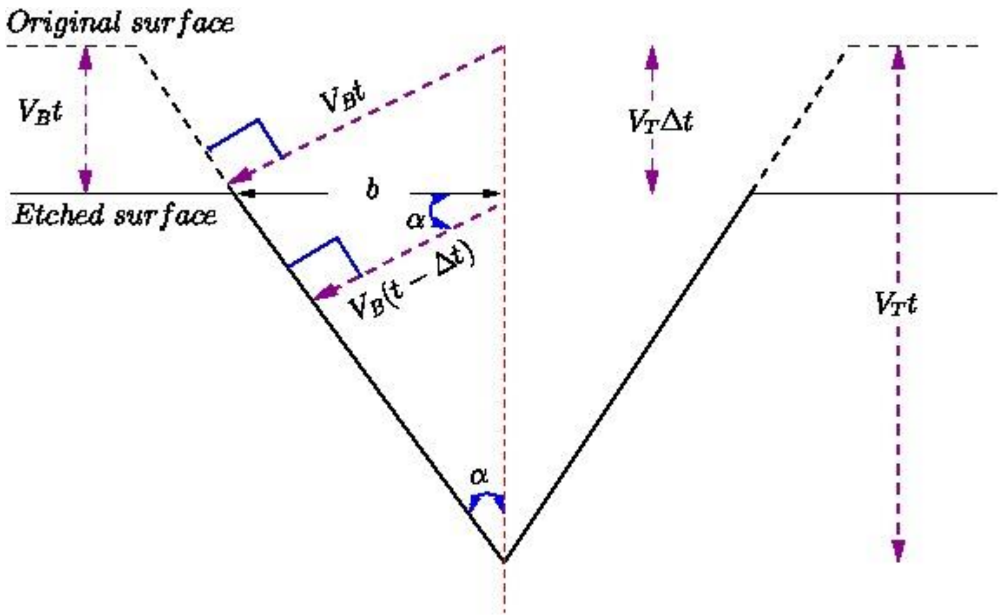
Condition for conical etch pit



$$V_B t = V_T \Delta t$$

$$\sin\alpha = \frac{V_B}{V_T} \qquad \cos\alpha = \sqrt{1-\left(\frac{V_B}{V_T}\right)^2}$$

$$b = \frac{V_B(t-\Delta t)}{\cos\alpha}$$

$$E = \frac{b}{V_B t} = \frac{V_B\left(t - \frac{V_B t}{V_T}\right)}{V_B t \cos\alpha} = \frac{\left(1-\frac{V_B}{V_T}\right)}{\sqrt{\left(1+\frac{V_B}{V_T}\right)\left(1+\frac{V_B}{V_T}\right)}} = \sqrt{\frac{\left(1-\frac{V_B}{V_T}\right)}{\left(1+\frac{V_B}{V_T}\right)}} < 1$$

Ions on PET

Ion	Incident energy (MeV)	Energy at the surface after etching (MeV)	dE/dx after etching [MeV/(mg /cm^2)]	$E=2b/2V_Bt$	V_T/V_B from depth measurement (eqn.1)	V_T/V_B from diameter measurement (eqn.2)
^{238}U	1724.5	2590.0	146.3	1.88±0.04	15.29±0.71	1.79±0.79
	2641.8	1680.0	136.6	1.31±0.03	14.32±0.67	3.89±0.29
^{129}Xe	363.8	350.0	88.2	1.35±0.03	14.96±0.54	4.97±3.35
^{78}Kr	220.0	194.5	53.6	1.25±0.05	12.21±0.42	6.7±7.2
^{56}Fe	113.0	94.0	39.7	1.22±0.07	8.61±0.29	113±145
	129.8	111.2	38.7	1.24±0.05	8.53±0.27	28.7±67.4
	134.4	116.0	38.6	1.36±0.04	8.12±0.29	25.5±46.1
^{49}Ti	138.2	130.0	30.2	1.14±0.03	6.26±0.24	12.5±24.7
^{32}S	67.4	62.0	21.1	0.79±0.02	4.54±0.14	3.78±0.49
	70.4	63.8	20.9	0.73±0.05	4.23±0.19	3.63±0.50
	110.2	105.4	17.4	0.72±0.02	3.66±0.16	3.21±0.26
	115.6	110.0	17.1	0.61±0.07	3.29+0.18	3.08±0.21
^{12}C	8.0	5.0	7.7	0.51±0.04	2.09+0.10	1.84±0.15
	11.0	5.7	7.6	0.34±0.04	1.78+0.19	1.40±0.08

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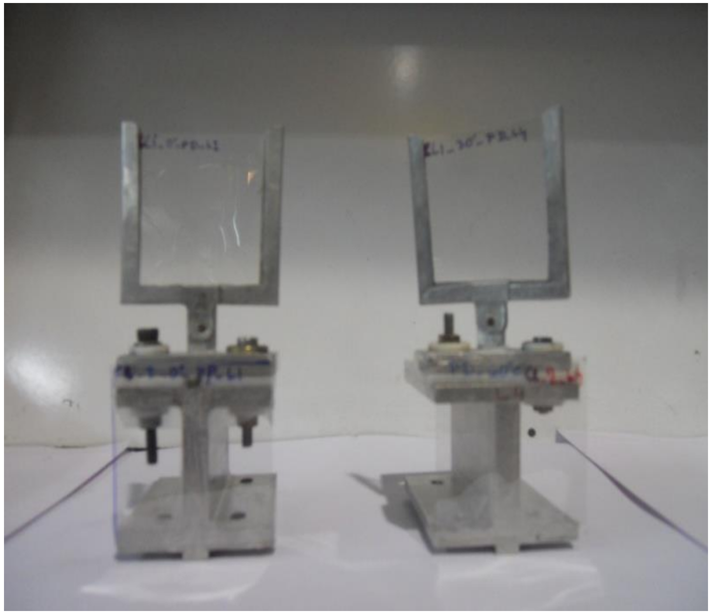
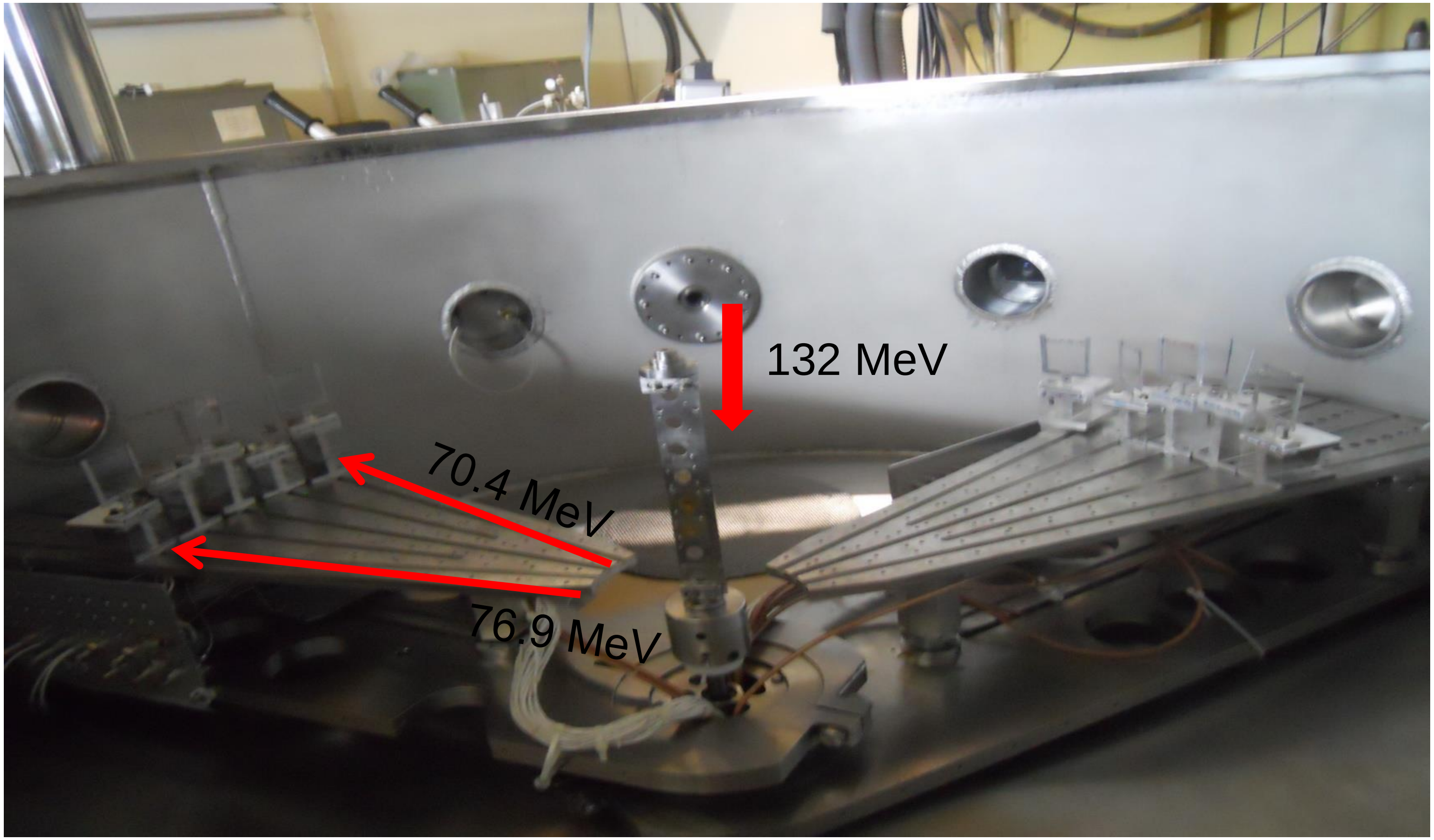
Experiment at IUAC

General Purpose Scattering Chamber (GPSC) at IUAC



PET films (5 cm × 5 cm) inside aluminium holders

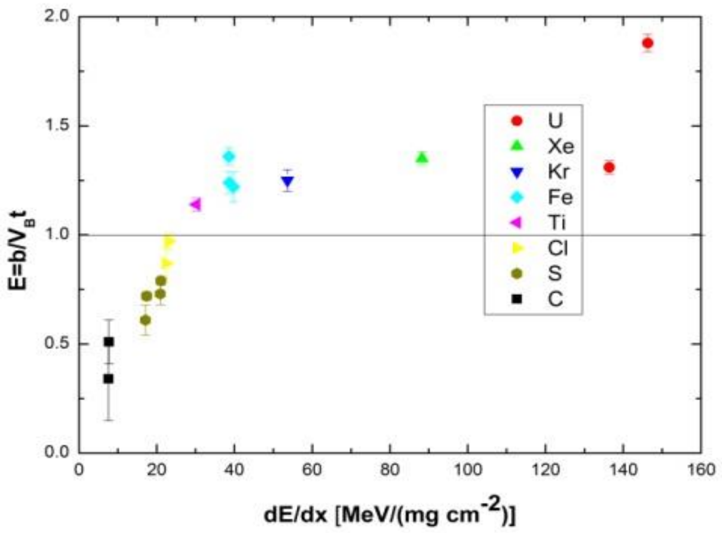
Beam details



Ion	Energy (MeV)	Charge state	Beam current (pnA)
^{35}Cl	132	10^{+}	1.5

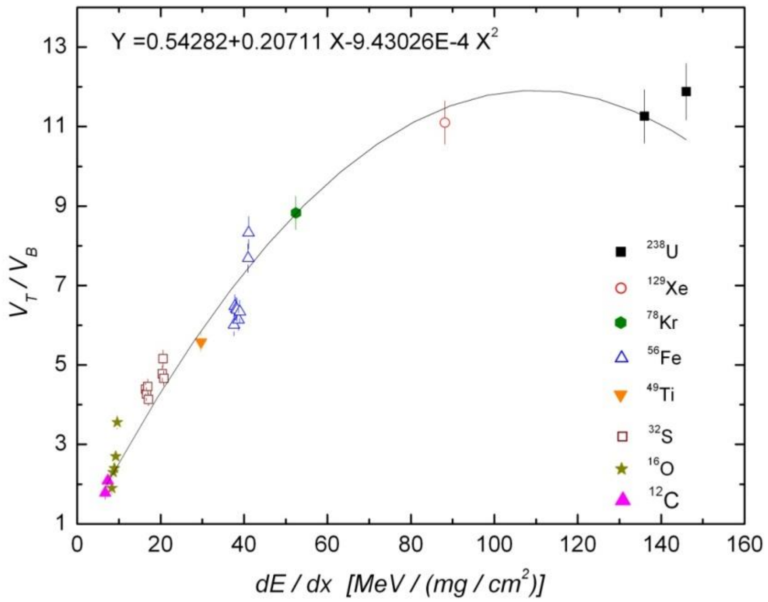
Updated table of PET

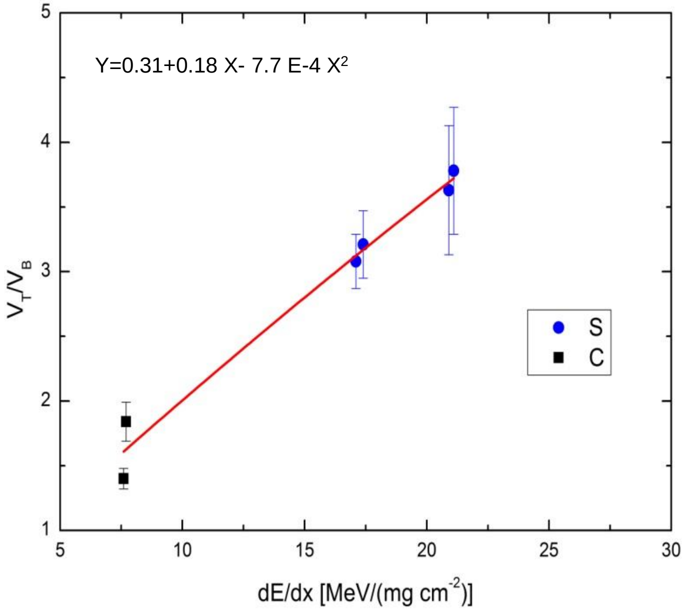
Ion	Incident energy (MeV)	Energy at the surface after etching (MeV)	dE/dx after etching [MeV/(mg/cm^2)]	$E=2b/2V_Bt$	V_T/V_B from depth measurement	V_T/V_B from diameter measurement
^{49}Ti	138.2	130.0	30.2	1.14±0.03	6.26±0.24	12.5±24.7
^{35}Cl	70.4	61.00	23.1	0.97±0.04	5.08±0.13	56.9±58.5
	76.9	67.50	22.4	0.87±0.07	4.58±0.19	7.97±1.68
^{32}S	67.4	62.0	21.1	0.79±.02	4.54±0.14	3.78±0.49



E vs. dE/dx plot for PET

Calibration curve of PET

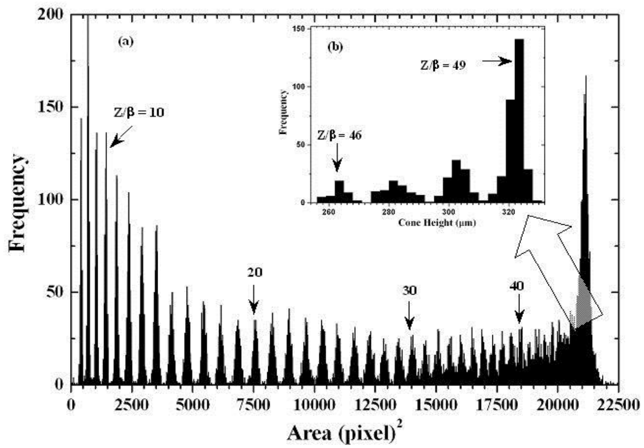




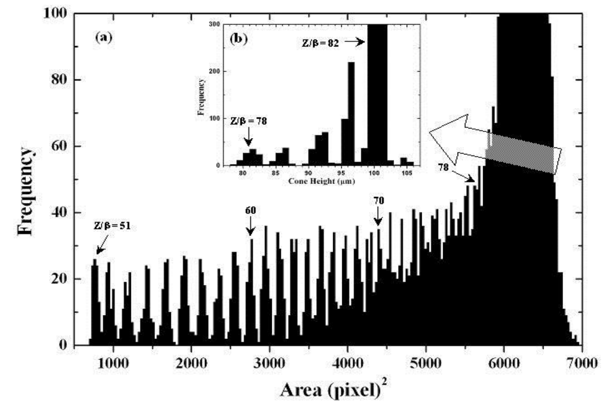
Using depth measurement method

Using diameter measurement method

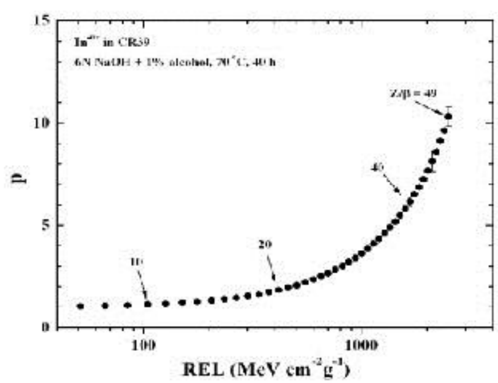
Results from CR-39 and Makrofol detectors



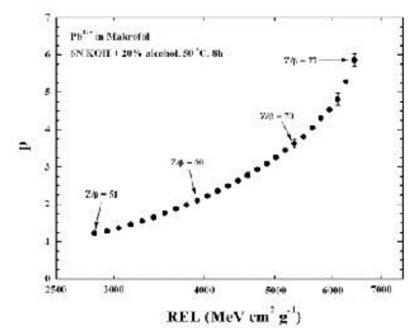
Base area distribution of etched cones in CR39 from 158 A GeV In^{49+} ions and their fragments



Base area distribution of etched cones in Makrofol from158 A GeV Pb^{82+} ions and their fragment



p versus REL for CR39



p versus REL for Makrofol

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Conclusion

- Although by diameter measurement, one can easily get the value of 'p' at the surface we found that this formula can't be used blindly.

- For *dE/dx > 23* [MeV/(mg/cm2)] we observe that $b>V_B\times t$ (so $E>1$); So in this region conical approximation of etch pits doesn't hold good. Moreover near E~1 this formula started giving absurd results and value of 'p' diverges.

- Above p~4 from diameter measurement method or above p~5 from depth measurement method, depth measurement method provides more reliable results.

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thank you!