Developments in the determination of the charged particle LET threshold of the HPA-RPD neutron PADC dosemeter, and its relevance to the estimation of neutron doses on the International Space Station.

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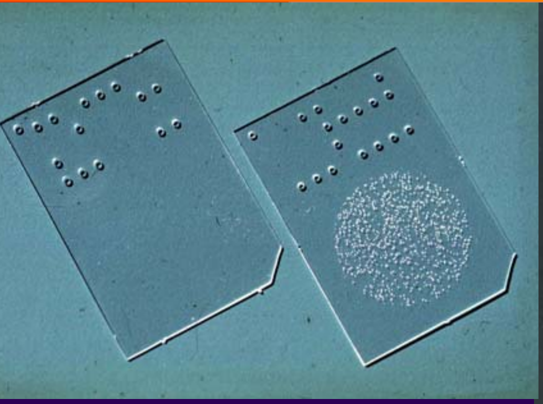
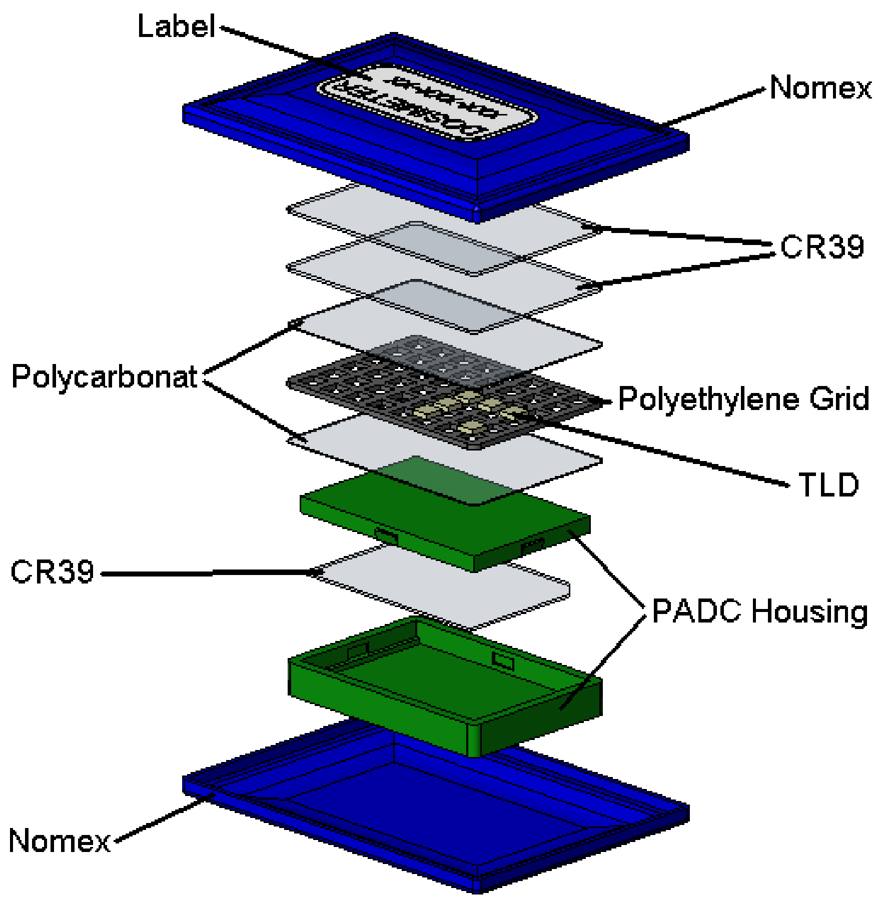
WRMISS 13, Krakow, September 2008

HPA PADC dosemeter & EuCPD



- Routine issue for neutron personal dosimetry – electrochemical etch rear face
- Calibrated for neutrons ≤ 173 MeV
- Electrochemical etch produces indistinguishable tracks for neutrons, direct protons, and heavy ions
- Forms a component of European Crew Personal Dosemeter – to assess neutron dose equivalent only

EuCPD



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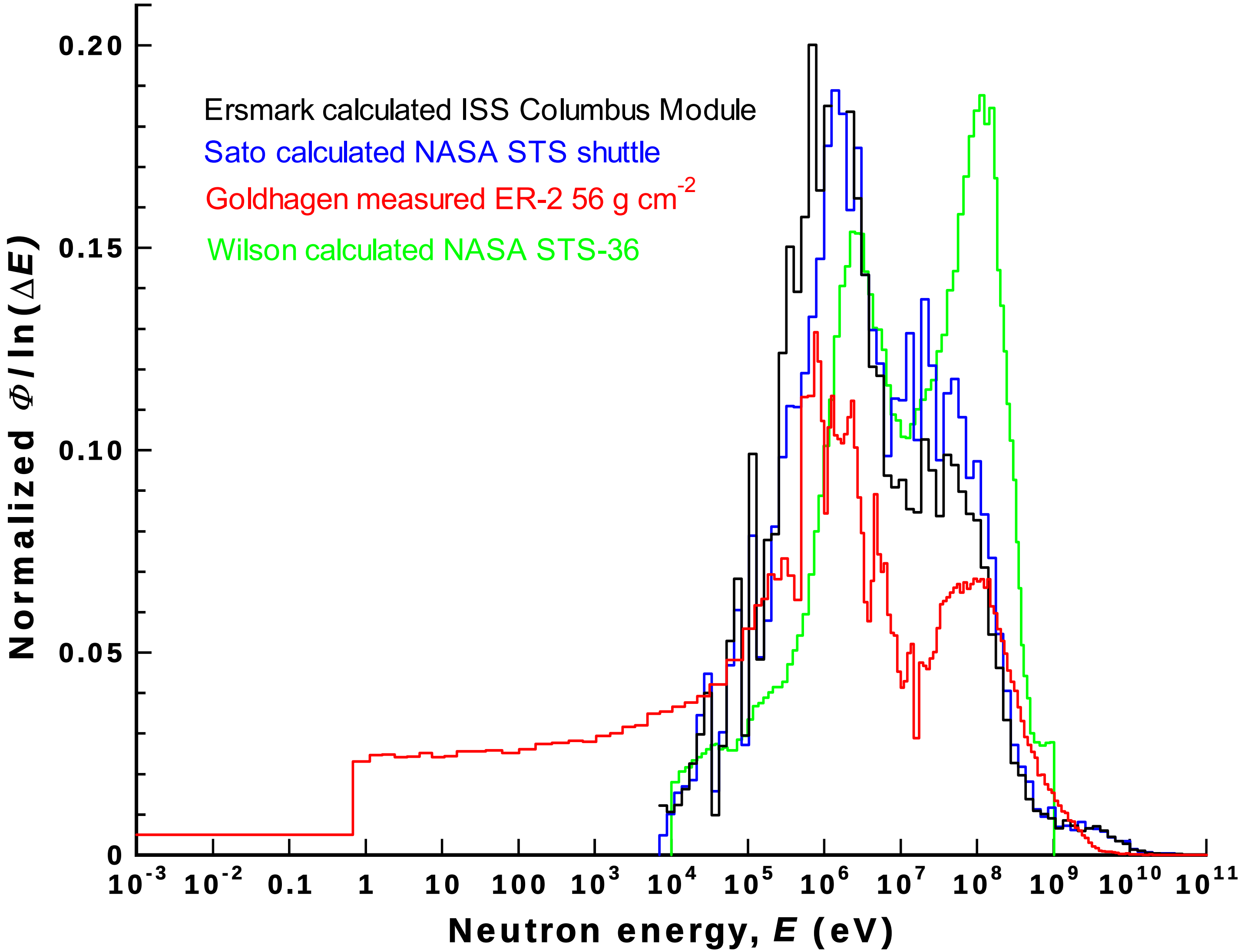
Representative neutron energy distributions



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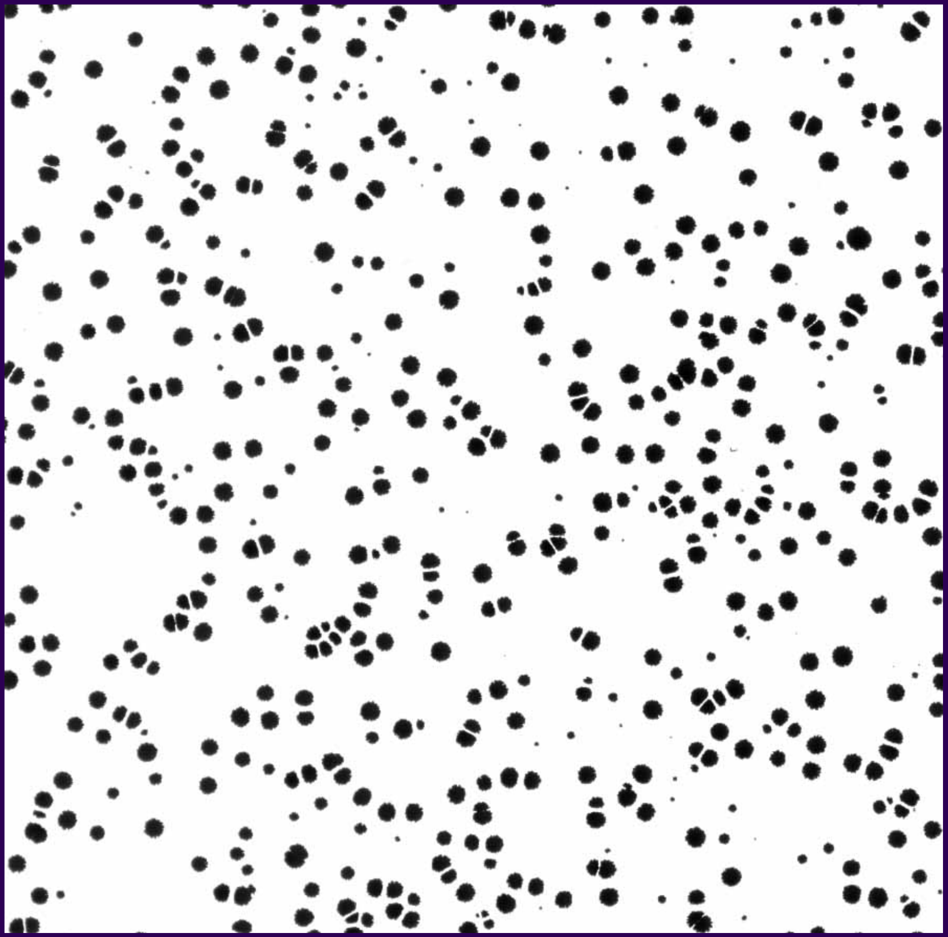
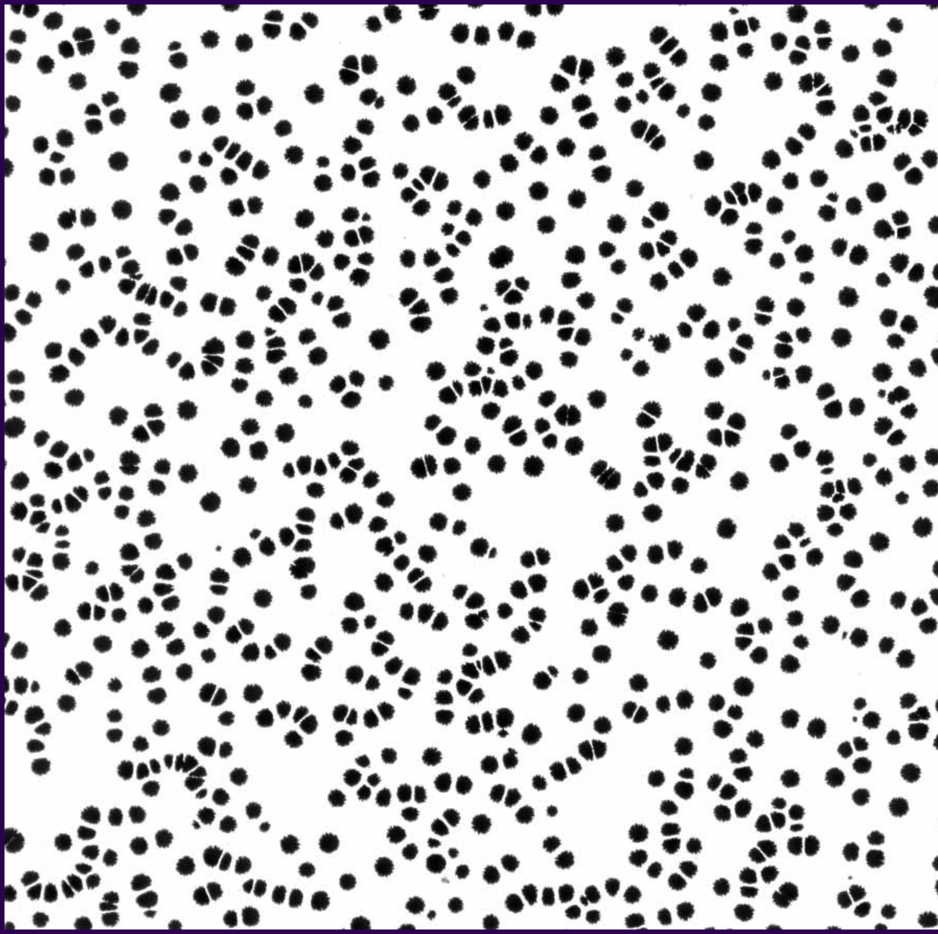
ELECTROCHEMICAL etch problem - Tracks similar for all charged particle types



^{241}Am-Be Neutron tracks



^{12}C tracks

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Methods – need to get rid of the charged particles

Simple method to get neutron dose

$$H = \frac{N - \overline{B}}{R_{\mathrm{ISS}}}$$

H = Dose equivalent

N = Total Tracks counted

B = Background tracks

R_{ISS} = Dosemeter dose equivalent response for ISS

But, unwanted charged particles are also recorded by the PADC dosemeter – these need to be removed

$$H = \frac{N - N_{CP} - \overline{B}}{R_{\mathrm{ISS}}}$$

N_{CP} = Tracks from charged particles

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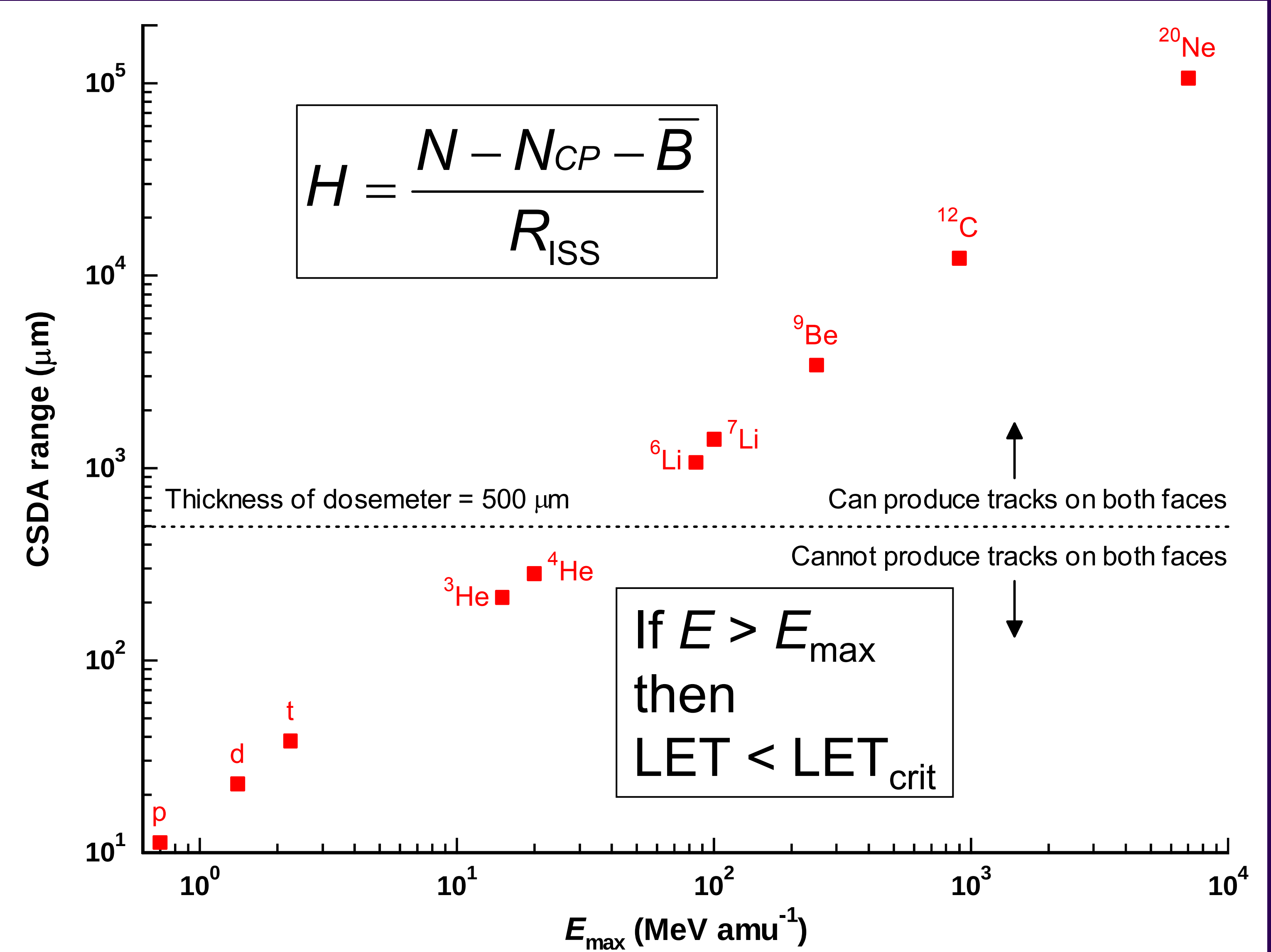
Residual range vs E_{max} in PADC



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The problem

- We want to measure the neutron dose, but a correction is required to account for the unwanted response to charged particles
- $Z \geq 3$ particles can be excluded by detection of entry and exit tracks
- $Z < 3$ particles can be estimated if we know the LET_{crit} and the fluence energy distribution….
  - Protons: assume LET_{∞} PADC ~ 30 keV μm^{-1}
    α-particles: measured LET_{∞} PADC ~ 60 keV μm^{-1}

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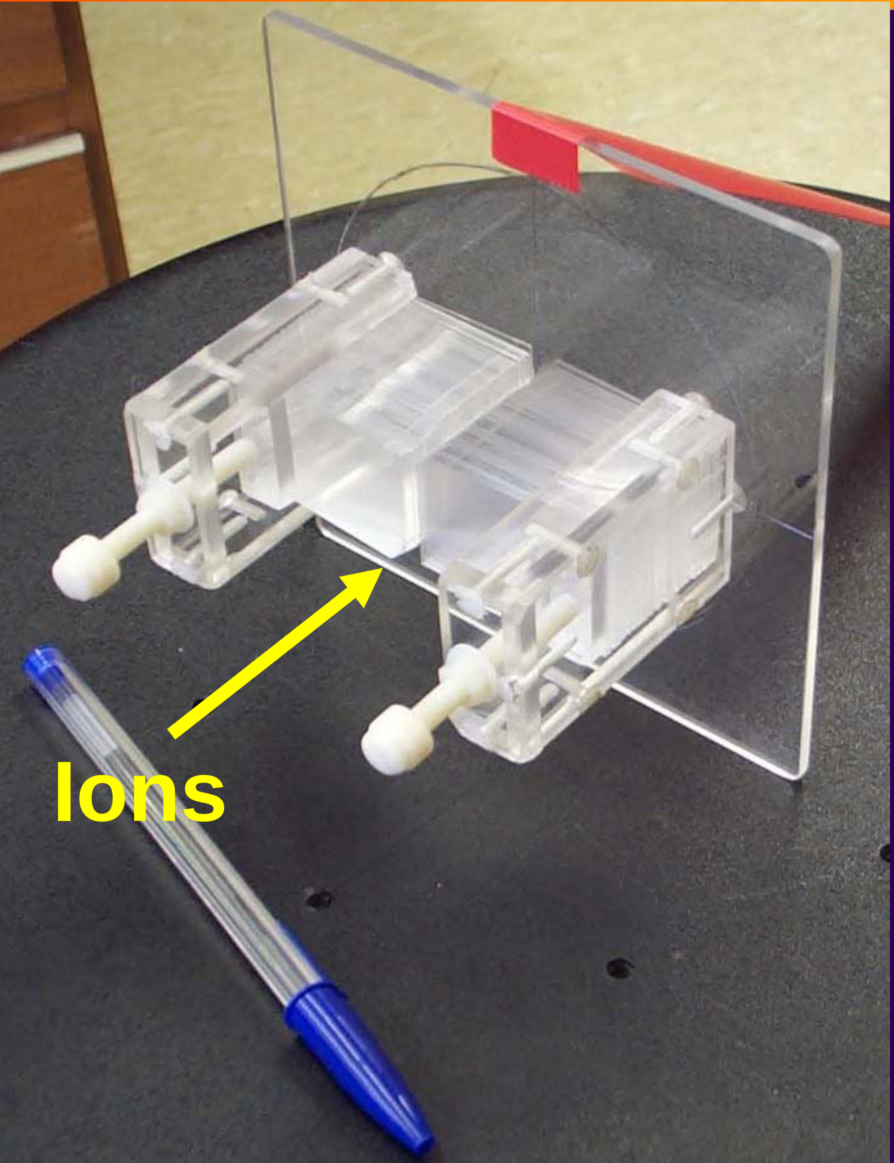
Detector stack arrangement for HIMAC irradiations



- HIMAC irradiations provided data for ^{4}He, ^{12}C and ^{56}Fe in May 2008
- Prior data for ^{20}Ne
- PMMA block in the beam to ensure ions stop in the PADC stack
- Data allow etchable range of an ion to be estimated
- LET_{crit} can be inferred

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HIMAC irradiation of PADC stacks

	Water equivalent thickness of PMMA	PADC stack
^{4}He 577.14 MeV →	139.08 mm →	
^{12}C 4581.9 MeV →	220.37 mm →	
^{56}Fe 23.331 GeV →	56.70 mm →	

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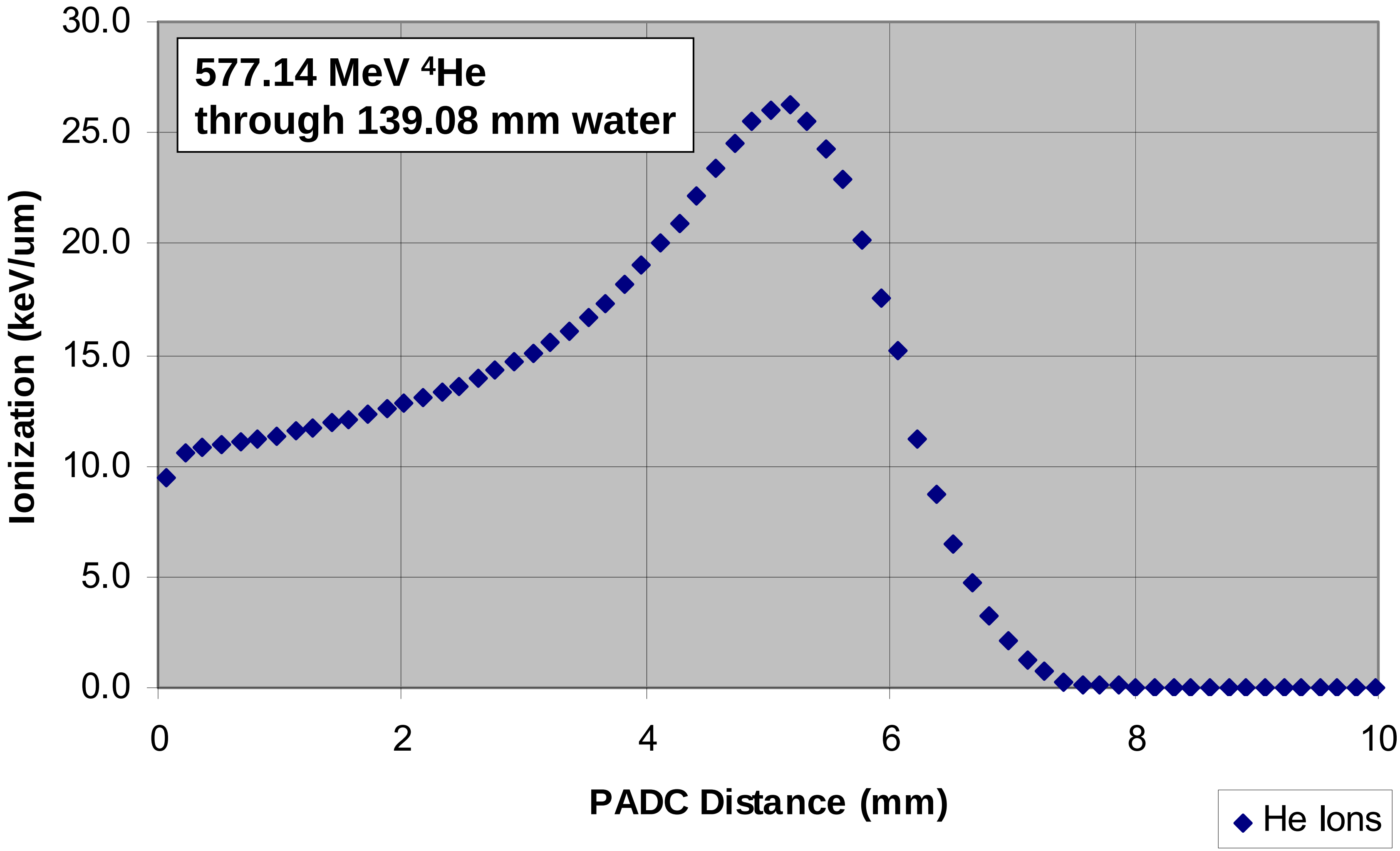
TRIM calculation of ionization ^{4}He



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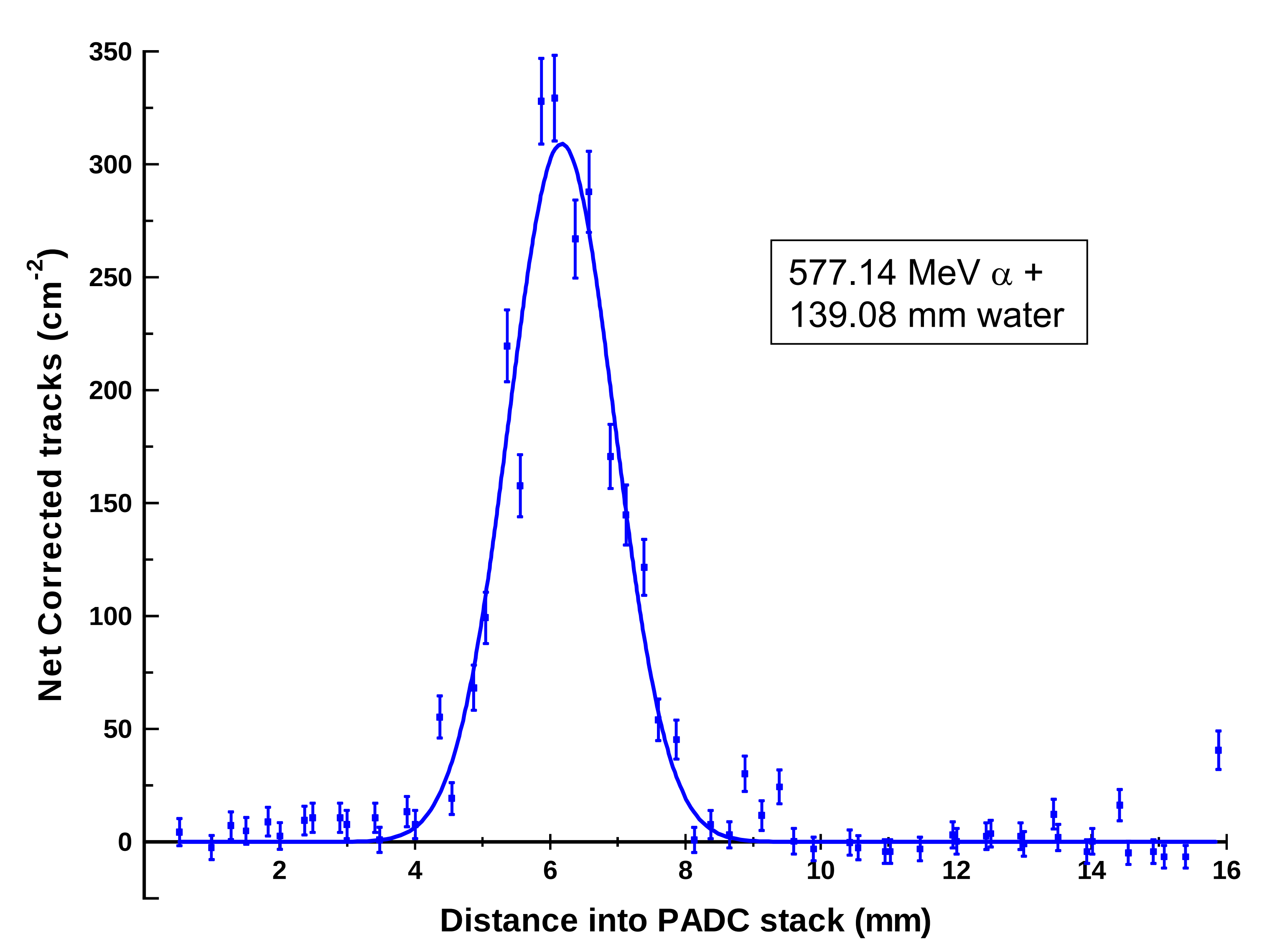
HIMAC ^{4}He: 577.14 MeV

+ 139.08 mm water equiv PMMA

Health Protection Agency



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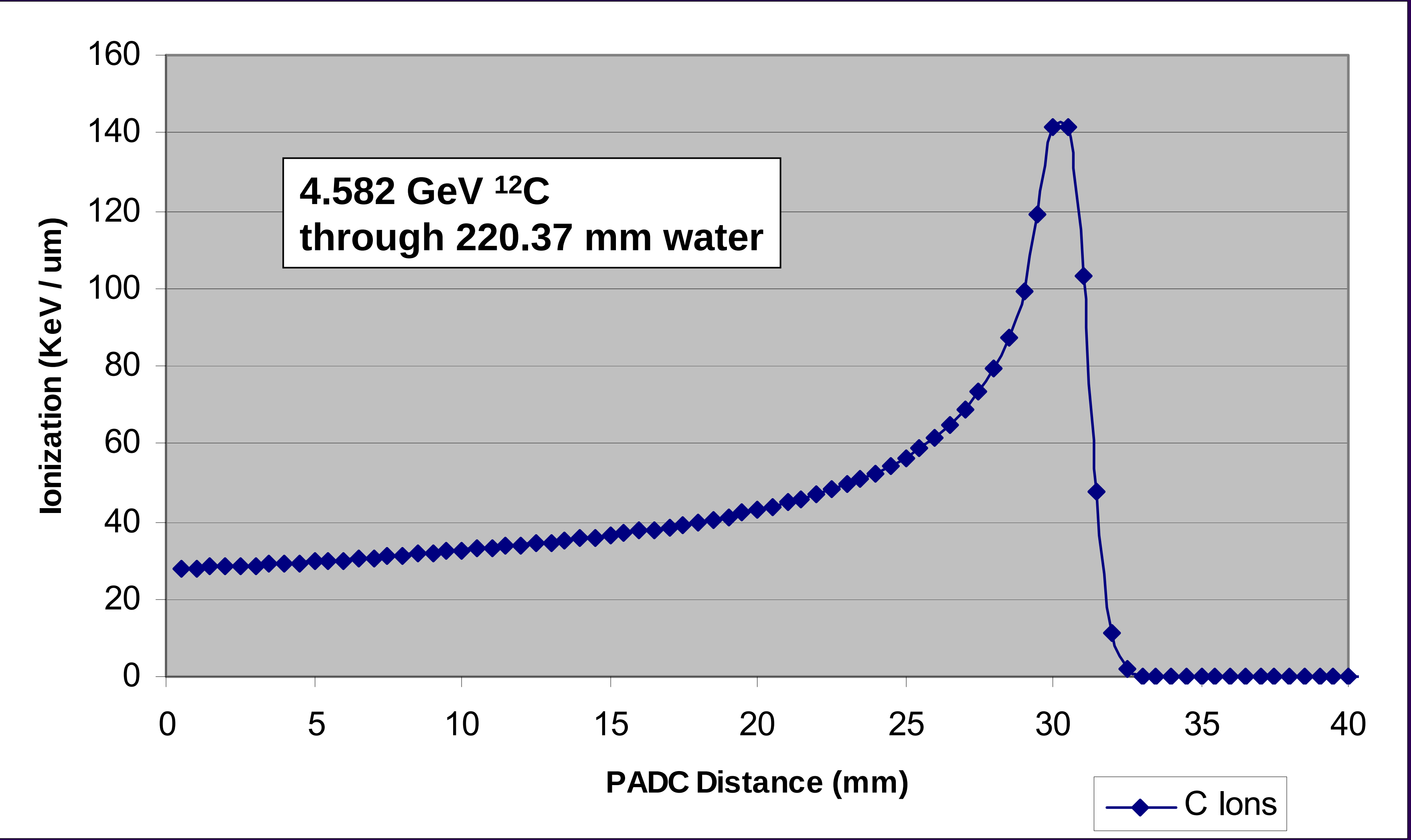
TRIM calculation of ionization ^{12}C



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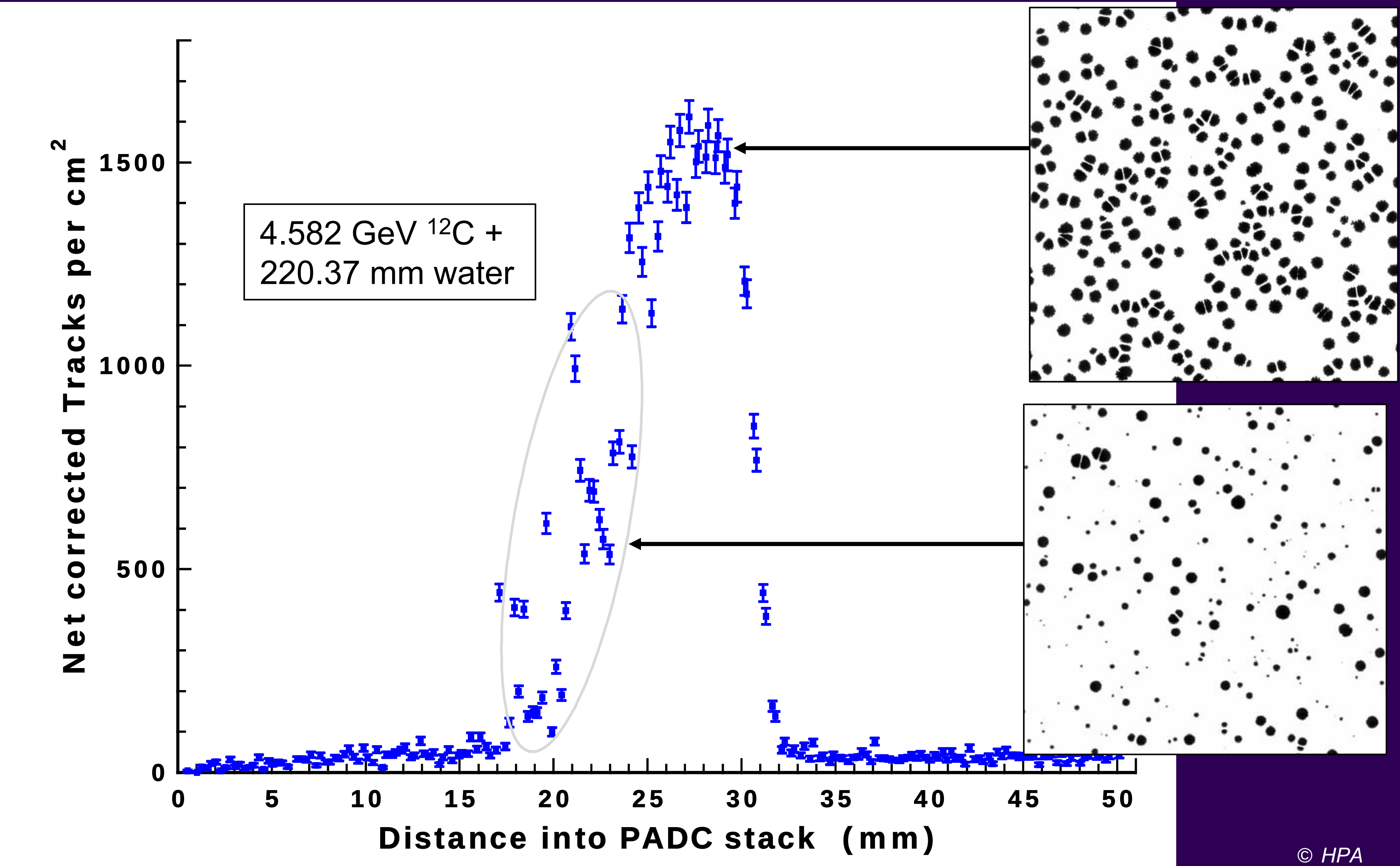
HIMAC ^{12}C: 4.582 GeV
+ 220.37 mm water equiv PMMA



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HIMAC ^{12}C: 4.582 GeV
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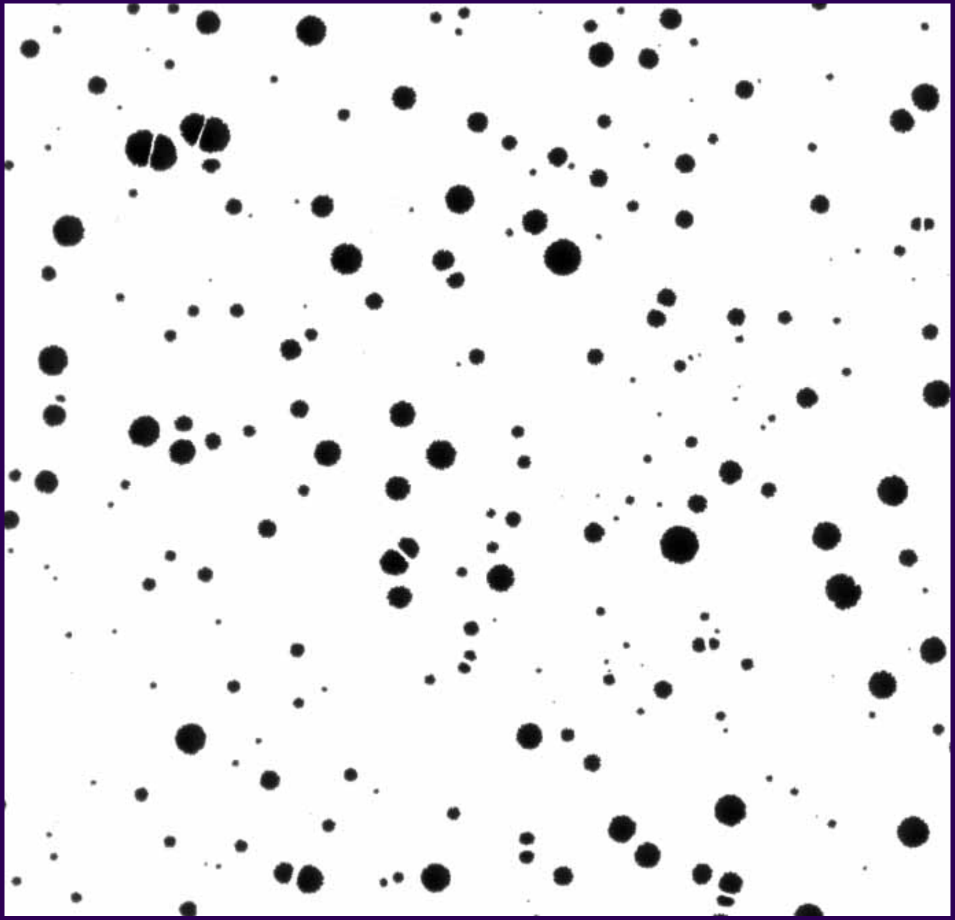
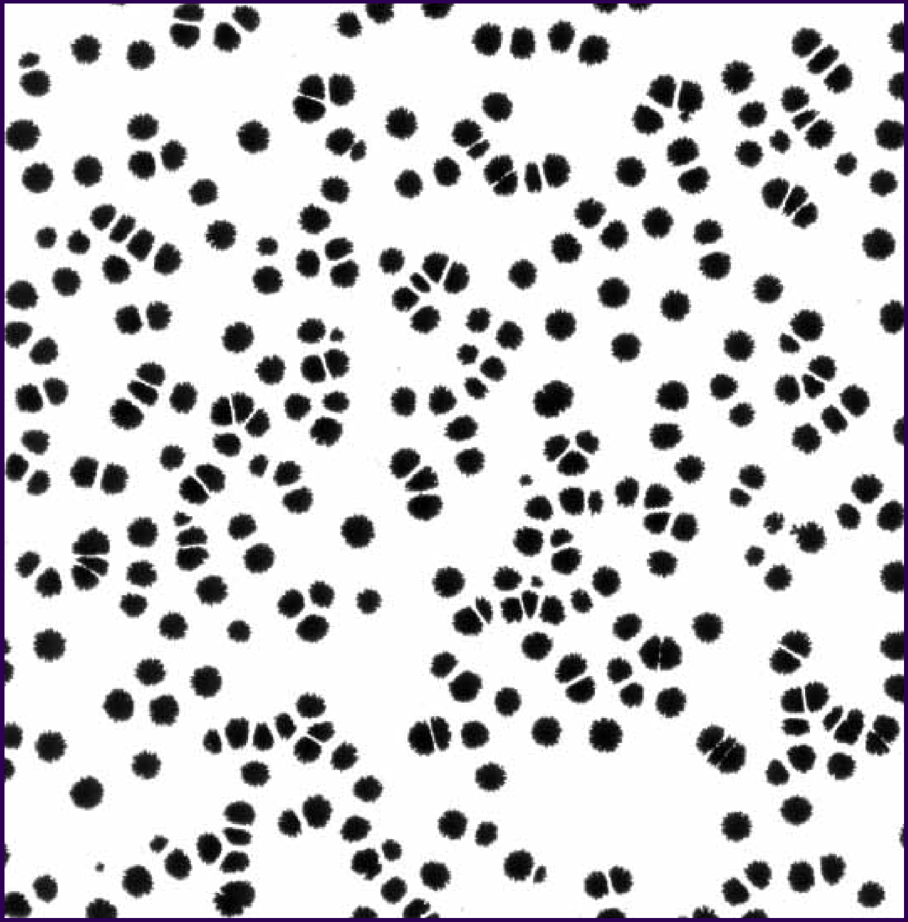


BEFORE PEAK of measured response - highly variable track sizes



AT PEAK of measured response - uniform track sizes

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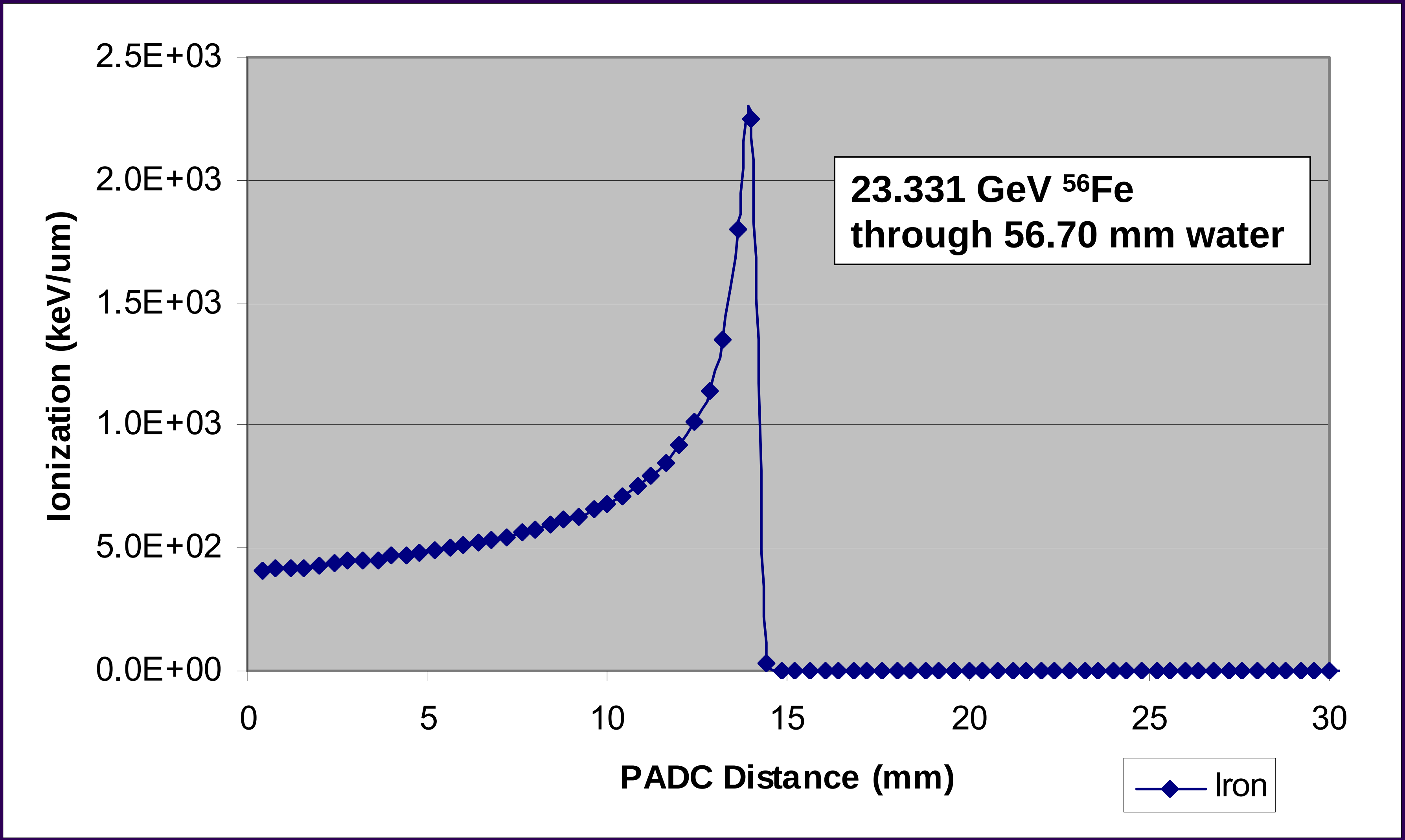
TRIM calculation of ionization ^{56}Fe



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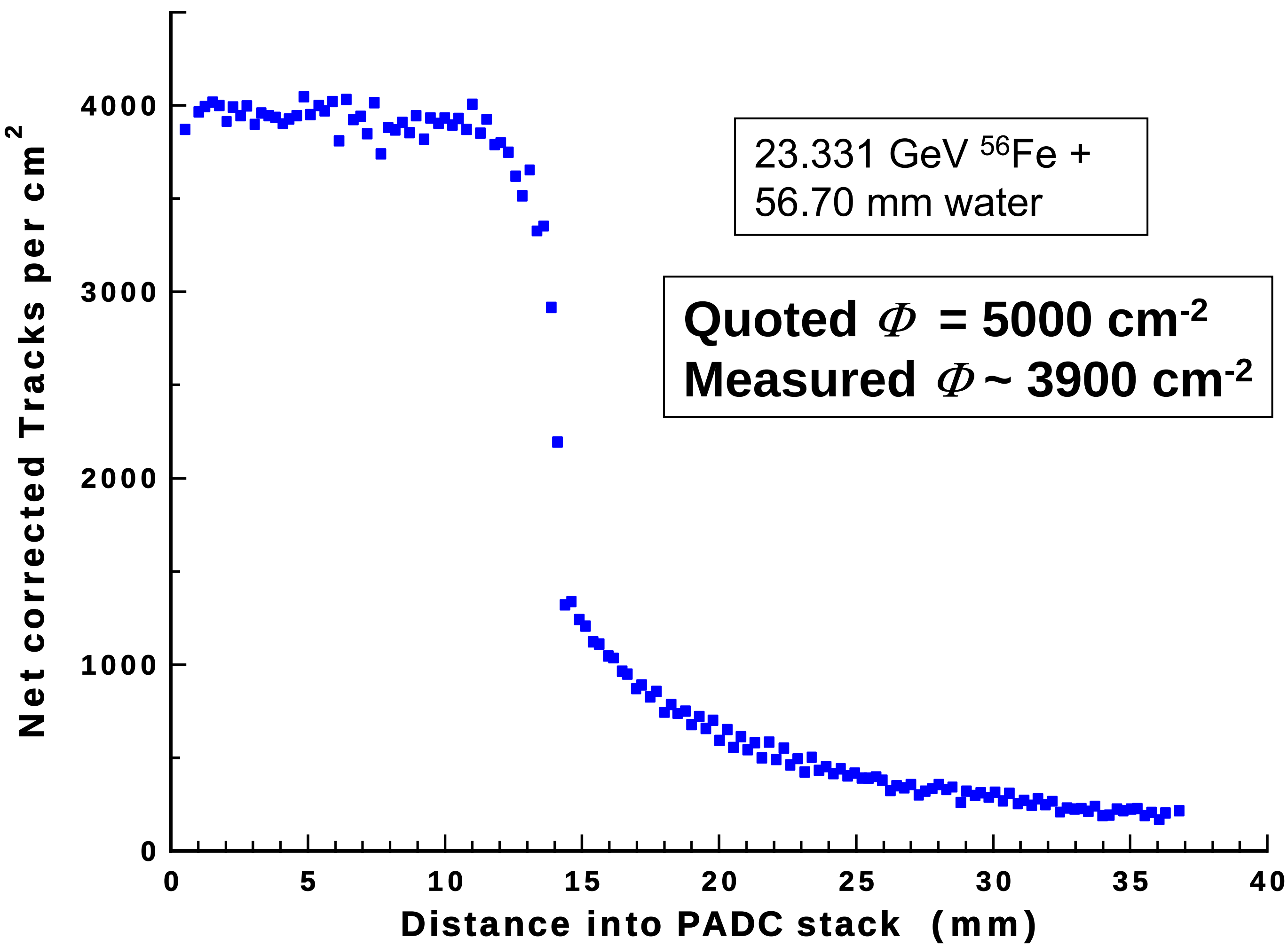
HIMAC ^{56}Fe: 23.331 GeV

+ 56.70 mm water equiv PMMA



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^{4}He: Etchable range in PADC

$$R_{crit} = \frac{DN}{\Phi}$$

D = dosemeter thickness

N = measured tracks summed for all dosemeters

Φ = fluence

R_{crit} = etchable length of track (i.e. LET > LET_{crit})

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LET thresholds in PADC

Ion	Etchable track length R_{crit}	Energy, *E* (MeV)	LET_{∞} PADC (keV/μm)	LET_{∞} water (keV/μm)	#LET_{200} PADC (keV/μm)
^{4}He	130 μm	12.75	58	47	33
^{12}C	2.886 mm	403.6	77	62	44
^{56}Fe	> 3 m	-	-	-	-
^{20}Ne	-	6020	44	35	25

Using: $\log(LET_{\infty}\ water) = 0.1689 + 0.984\log(LET_{200}\ CR\text{-}39)$

^{56}Fe always exceeds the etching threshold, at any energy, therefore the ^{56}Fe measurement is an estimate of the total fluence.

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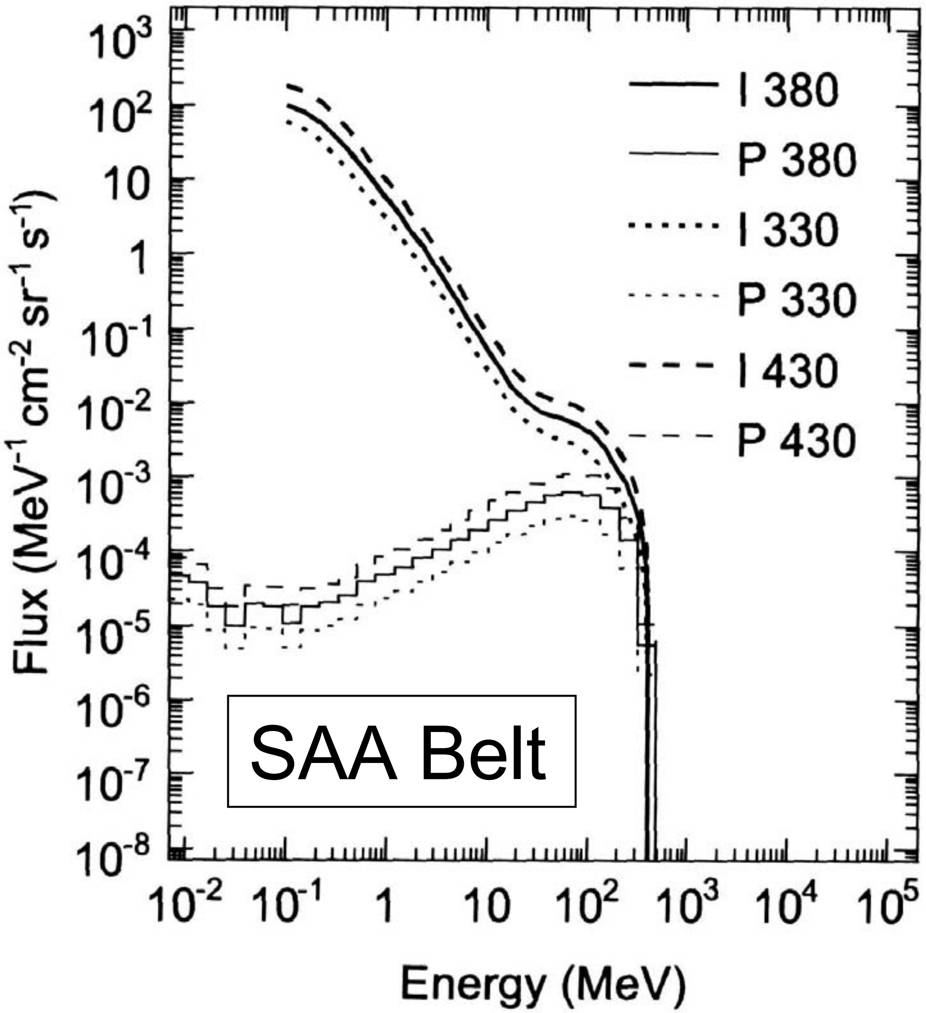
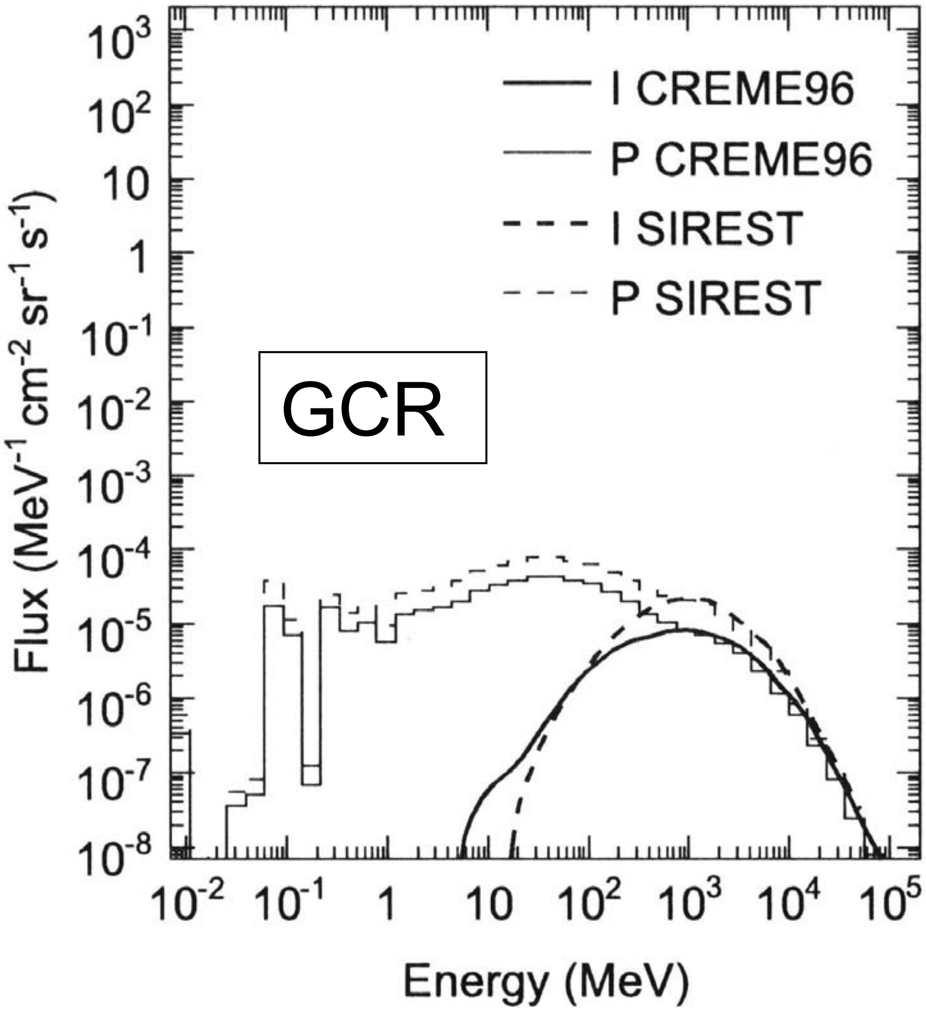
Calculated protons inside ISS Columbus module (GEANT4)





(T Ersmark PhD thesis, June 2006, Royal Institute of Technology, Stockholm)

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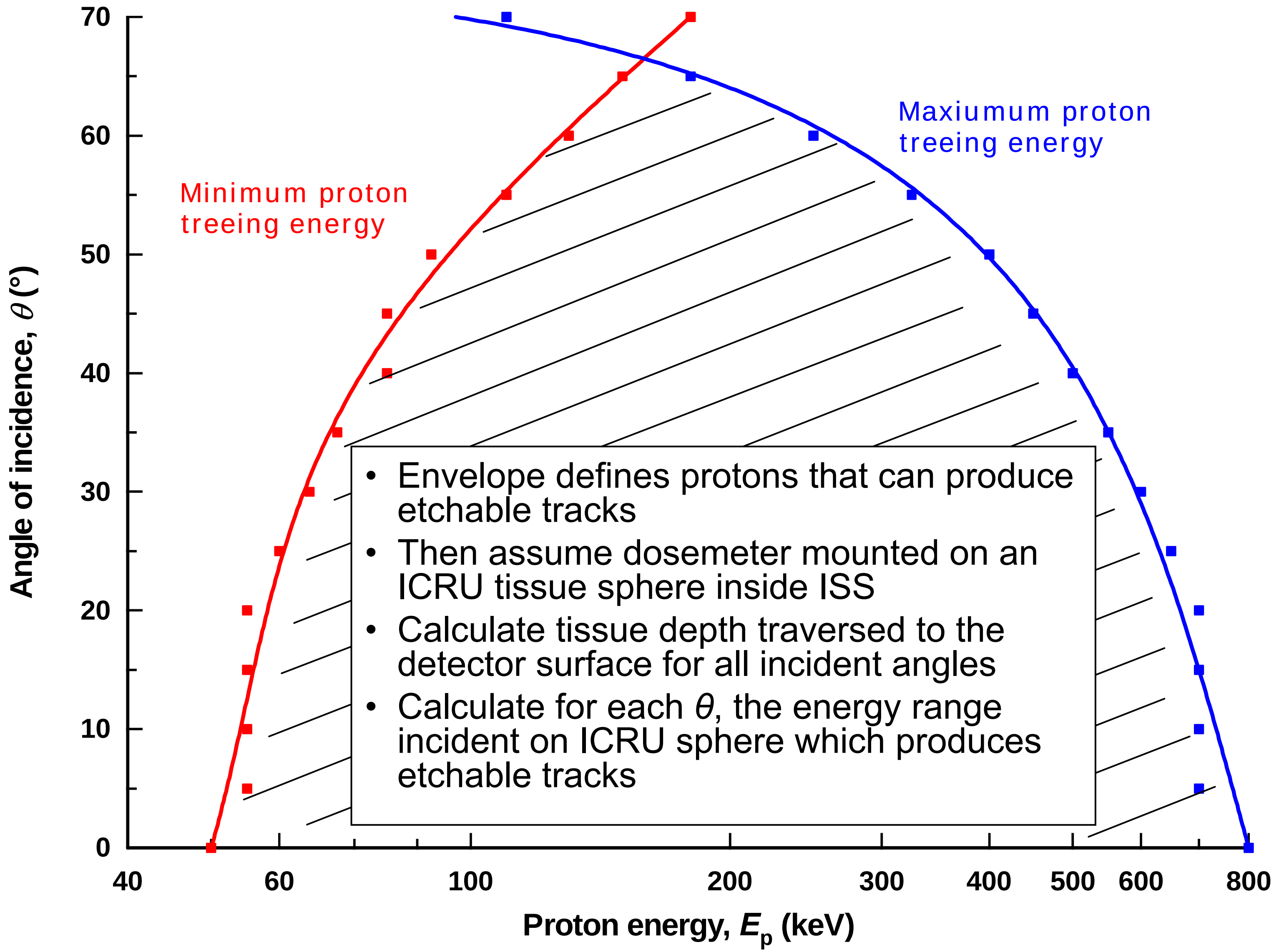
Angle of incidence, *θ* vs E_p to produce etchable tracks



- Envelope defines protons that can produce etchable tracks
- Then assume dosemeter mounted on an ICRU tissue sphere inside ISS
- Calculate tissue depth traversed to the detector surface for all incident angles
- Calculate for each *θ*, the energy range incident on ICRU sphere which produces etchable tracks

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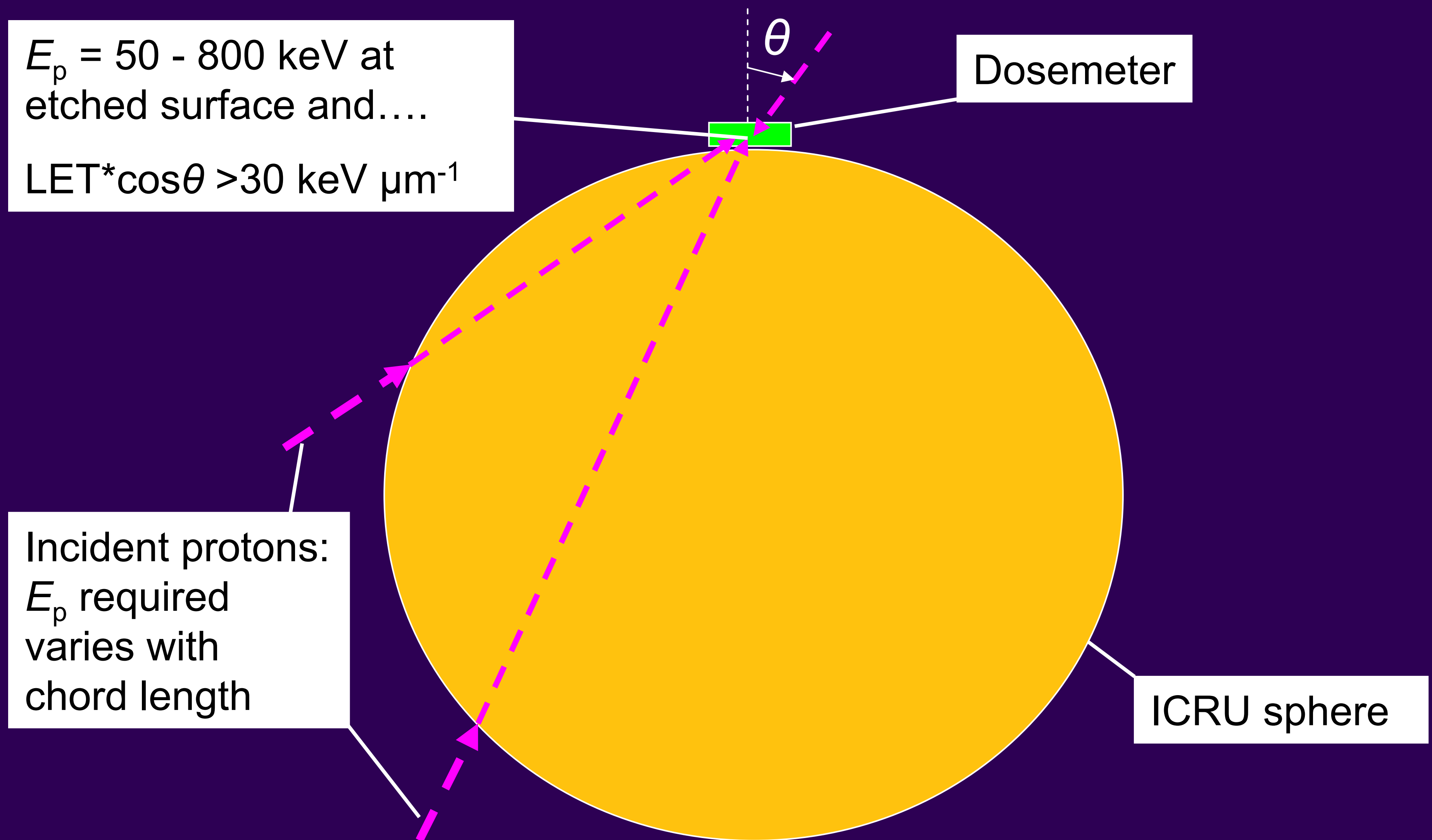
Dosemeter mounted on 30 cm diameter ICRU tissue sphere



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Estimated etchable proton tracks

Origin	Φ_p TOTAL ($cm^{-2}\,d^{-1}$)	Φ_p Etchable ($cm^{-2}\,d^{-1}$)	Ratio
SAA belt	1.24×10^5	1.79	1.44×10^{-5}
GCR	5.50×10^4	0.17	3.09×10^{-6}
TOTAL		1.96	

$1.96\ cm^{-2}\,d^{-1} \sim 3.5\ d^{-1}$ (read area = $1.767\ cm^2$)

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Neutron dose estimate MATROSHKA 2A

Total tracks	$Z \geq 3$ (17%)	Protons (14%)	Neutrons (69%)
9349	1589	1285	6475

Neutron tracks	$H_p(10)$ (mSv)	E_{ISO} (mSv)	$H_p(10)$ rate (mSv d^{-1})	E_{ISO} rate (mSv d^{-1})
6475	70.4	53.1	0.19	0.14

i.e. 31% lower than the uncorrected doses

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Summary

- The HPA PADC dosemeter is being used for the determination of the neutron dose in low earth orbit, but requires:
  - subtraction of high energy ions with $Z \geq 3$
  - direct protons & α-particles
- So far the assessment has considered subtraction of:
  - $Z \geq 3$ ions by measurement after secondary chemical etch ~ 17%
  - Direct protons by calculation ~ 14%
- Still to be considered:
  - α-particles

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Future Work

- Determine experimentally the proton LET threshold for the electrochemical etch
- Determine experimentally the critical angle for protons as a function of energy
- Calculate α-particle contribution to response
  - needs α-particle fluence energy spectrum

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Acknowledgements

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- Staff at DLR, Cologne, Germany for assistance in arranging the measurement programme
- Tore Ersmark formerly of Royal Institute of Technology, Stockholm, for the calculated proton spectra

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Galactic Cosmic Radiation at top of atmosphere

Protons	86 %
Helium nuclei	12 %
Electrons Positrons	2 %
Heavier nuclei	< 1%

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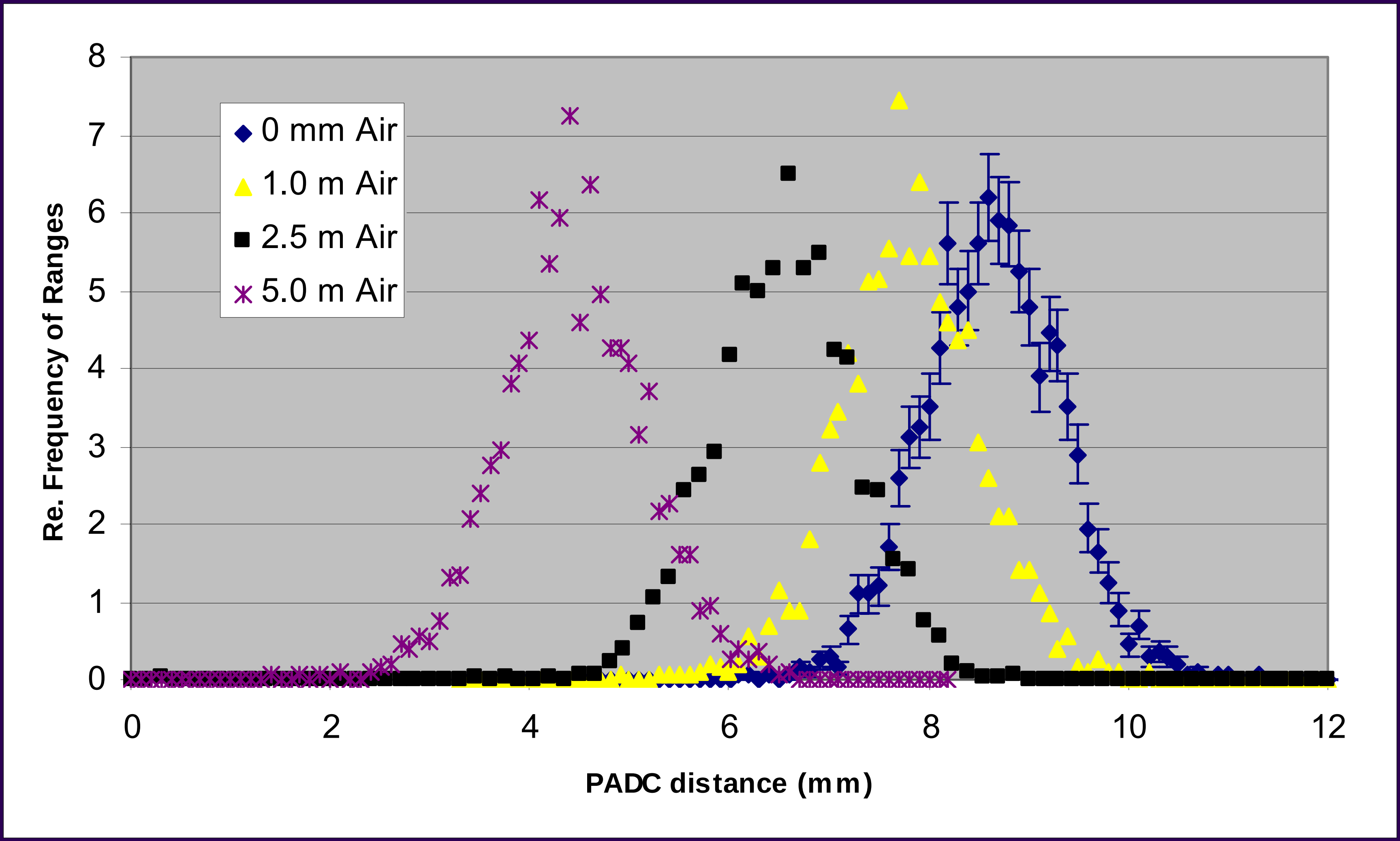
Ranges of ^{4}He ions in PADC for different air build-up

Air build up before PMMA



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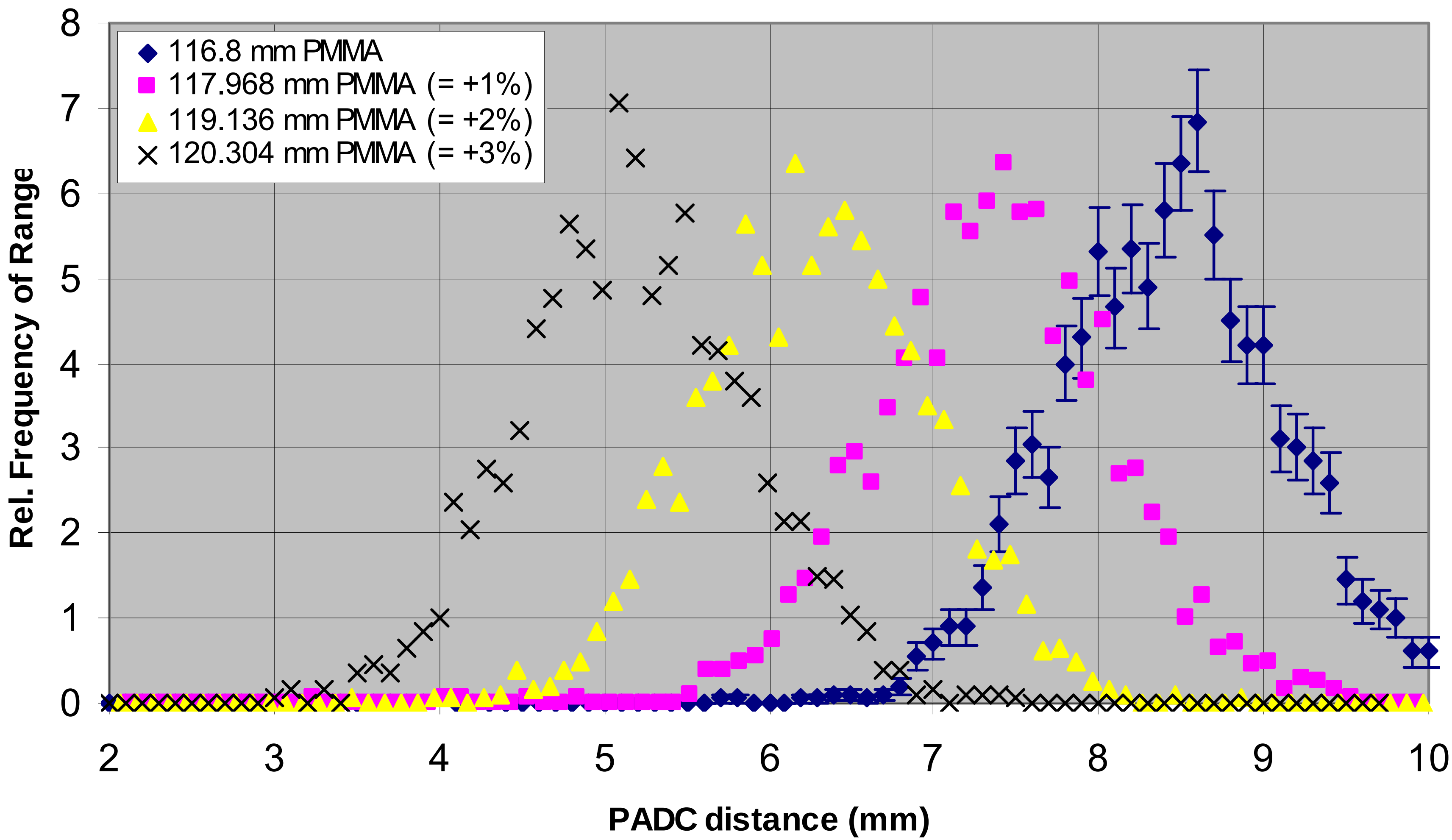
Ranges of ^{4}He ions in PADC for different PMMA thicknesses

TRIM calculation



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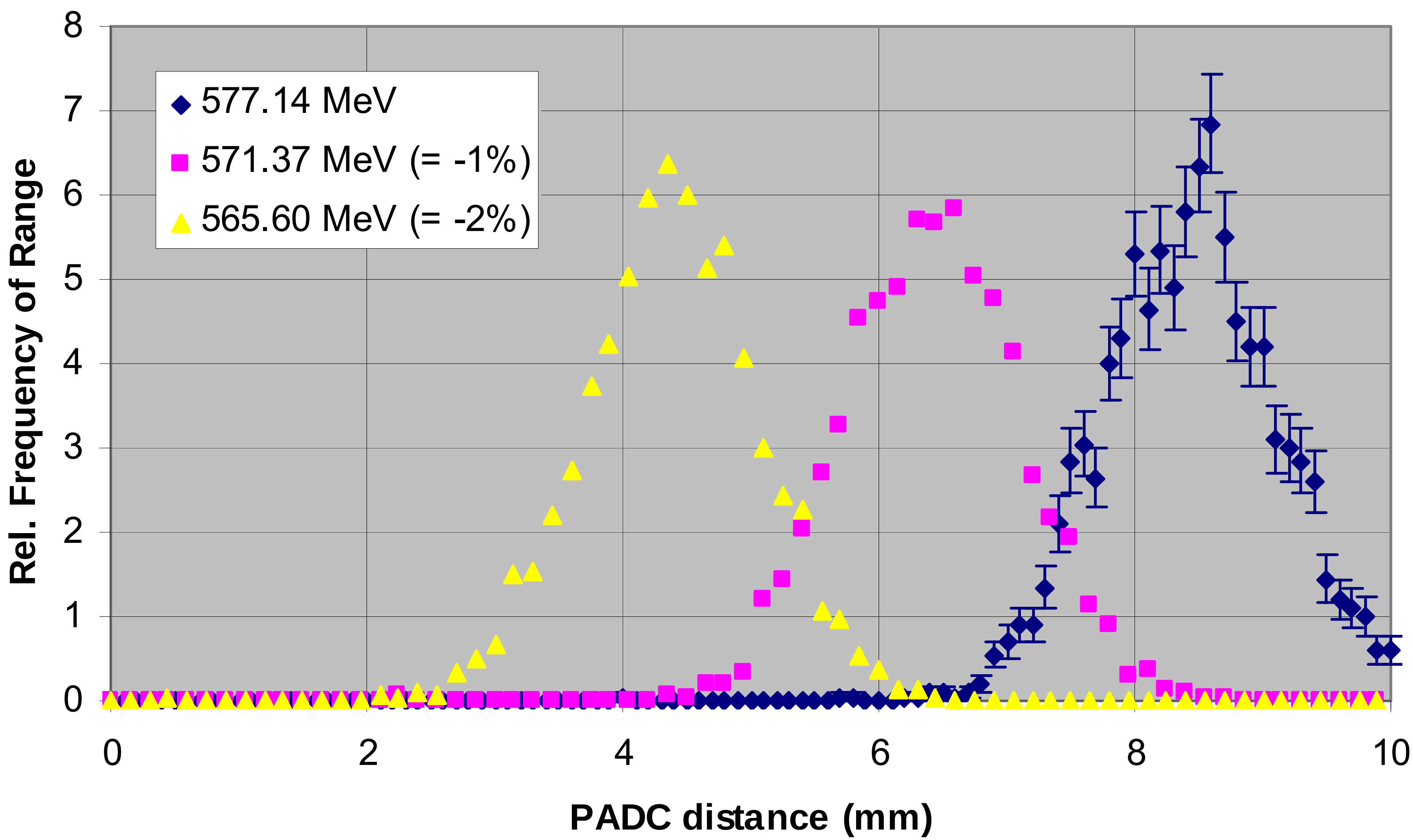
Ranges of ^{4}He ions in PADC for different initial energies

TRIM calculation



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