



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

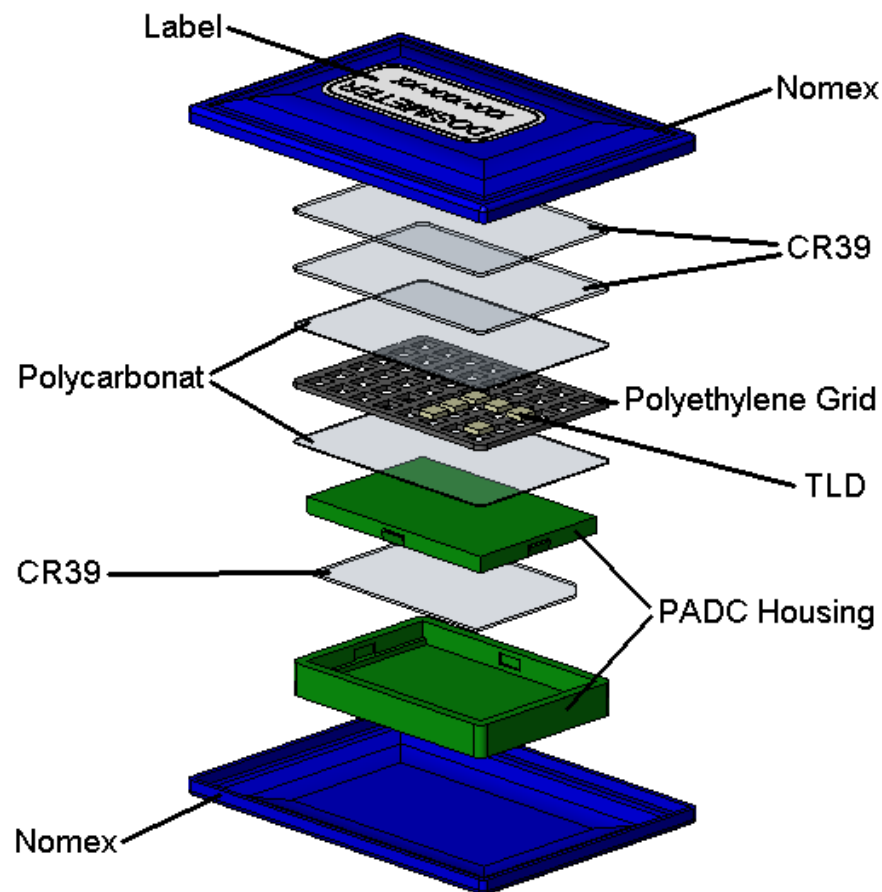
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WRMISS 13, Krakow, September 2008

HPA PADC dosimeter & EuCPD

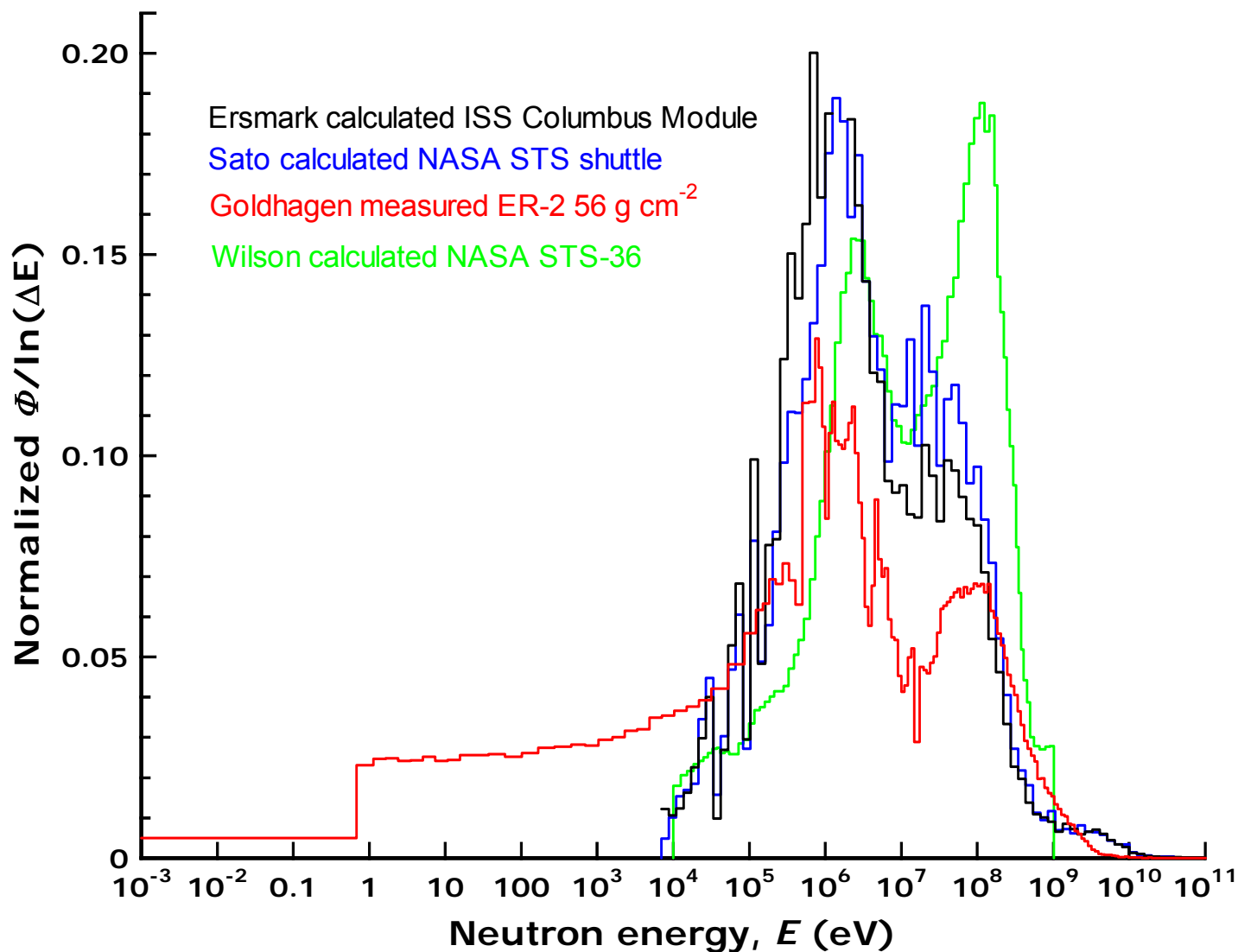


EuCPD



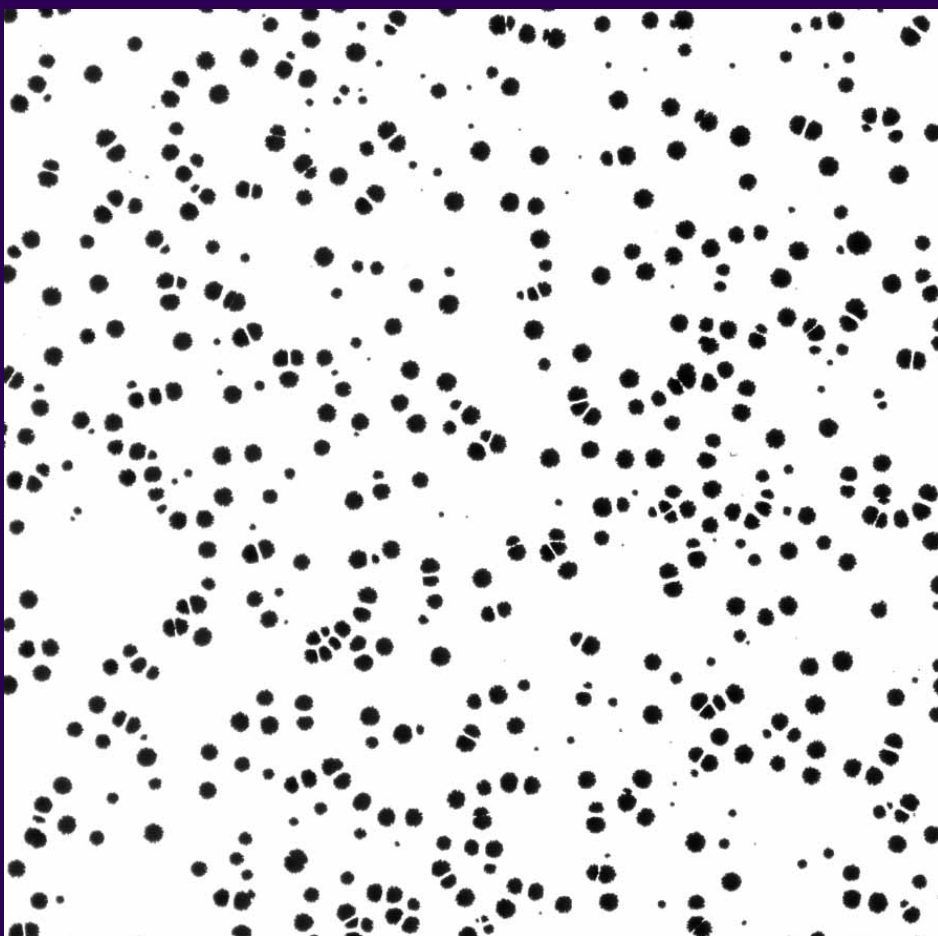
- Routine issue for neutron personal dosimetry – electrochemical etch rear face
- Calibrated for neutrons ≤ 173 MeV
- Electrochemical etch produces indistinguishable tracks for neutrons, direct protons, and heavy ions
- Forms a component of European Crew Personal Dosimeter – to assess neutron dose equivalent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

Representative neutron energy distributions

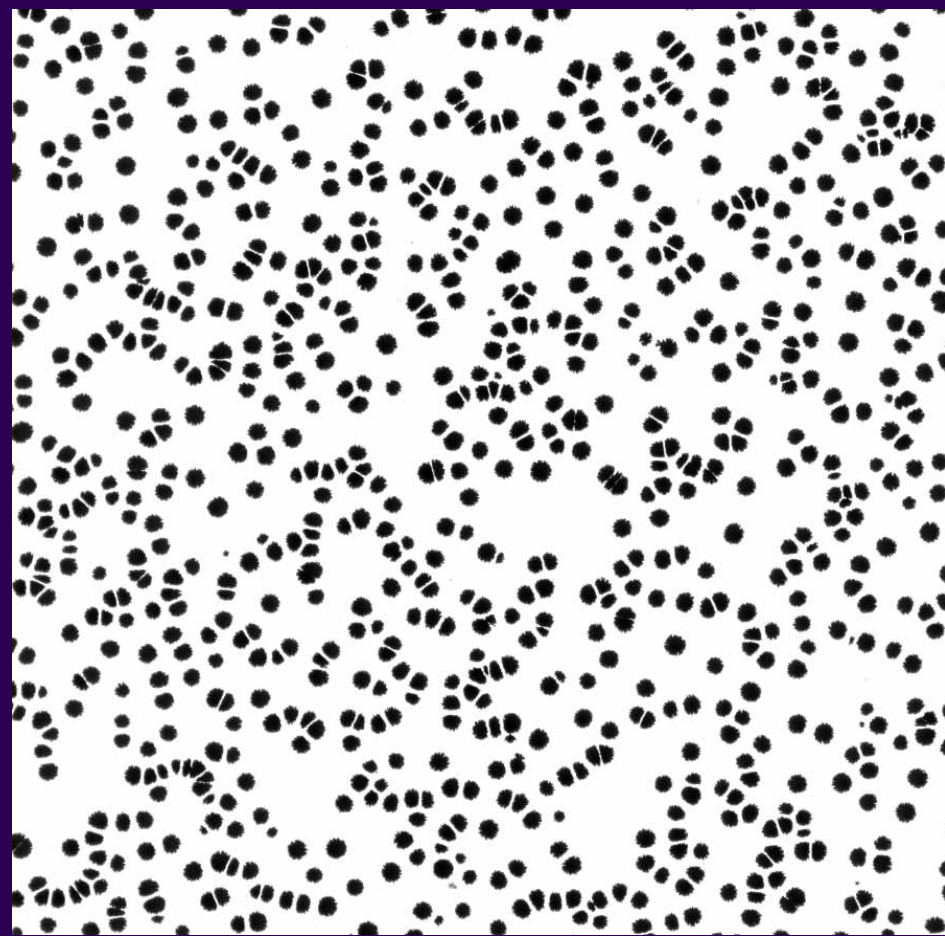


ELECTROCHEMICAL etch problem

- Tracks similar for all charged particle types



$^{241}\text{Am-Be}$ Neutron tracks



^{12}C tracks

Methods – need to get rid of the charged particles



Simple method to get neutron dose

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

H = Dose equivalent

N = Total Tracks counted

B = Background tracks

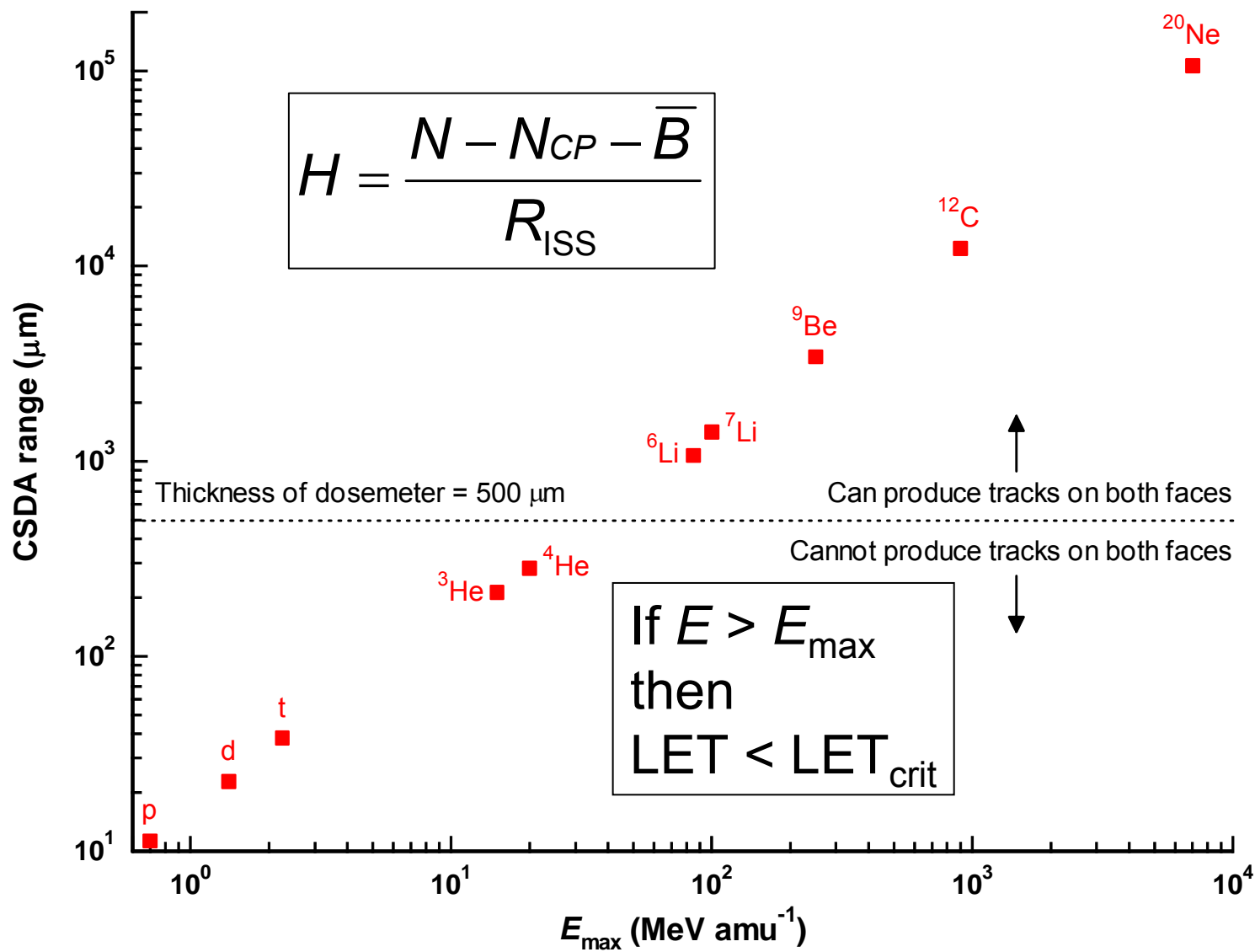
R_{ISS} = Dosimeter dose equivalent response for ISS

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

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

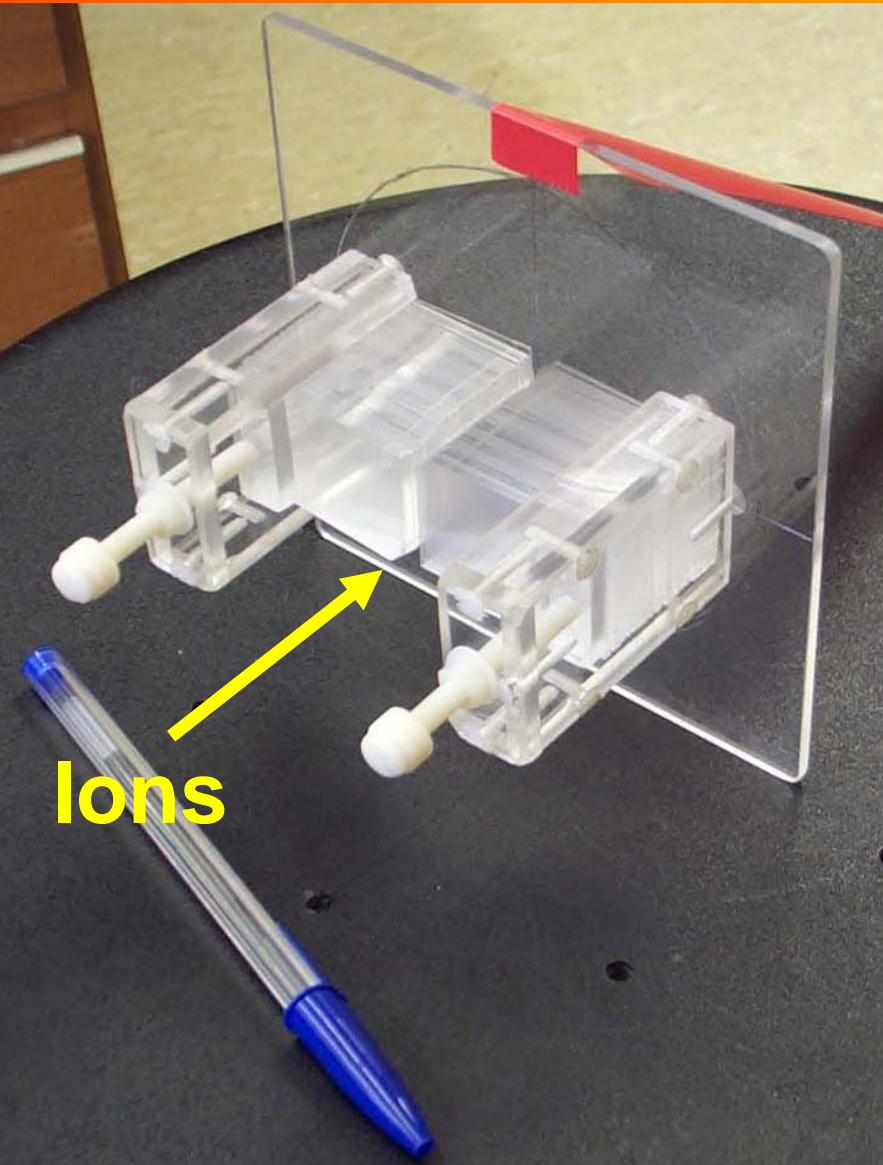
N_{CP} = Tracks from charged particles

Residual range vs E_{\max} in PADC



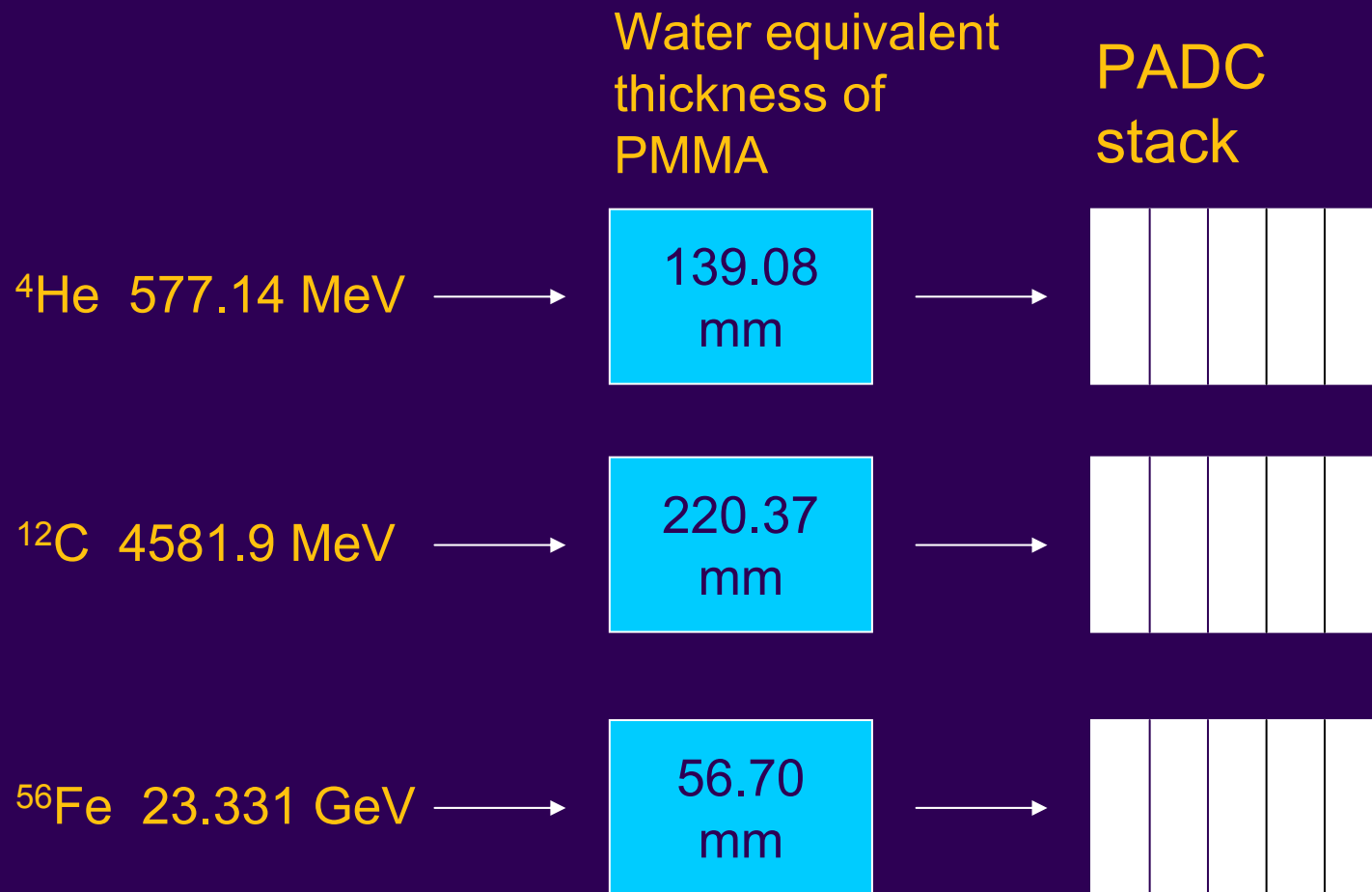
- We want to measure the neutron dose, but a correction is required to account for the unwanted response to charged particles
- $Z \geq 3$ particles can be excluded by detection of entry and exit tracks
- $Z < 3$ particles can be estimated if we know the LET_{crit} and the fluence energy distribution....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

Detector stack arrangement for HIMAC irradiations

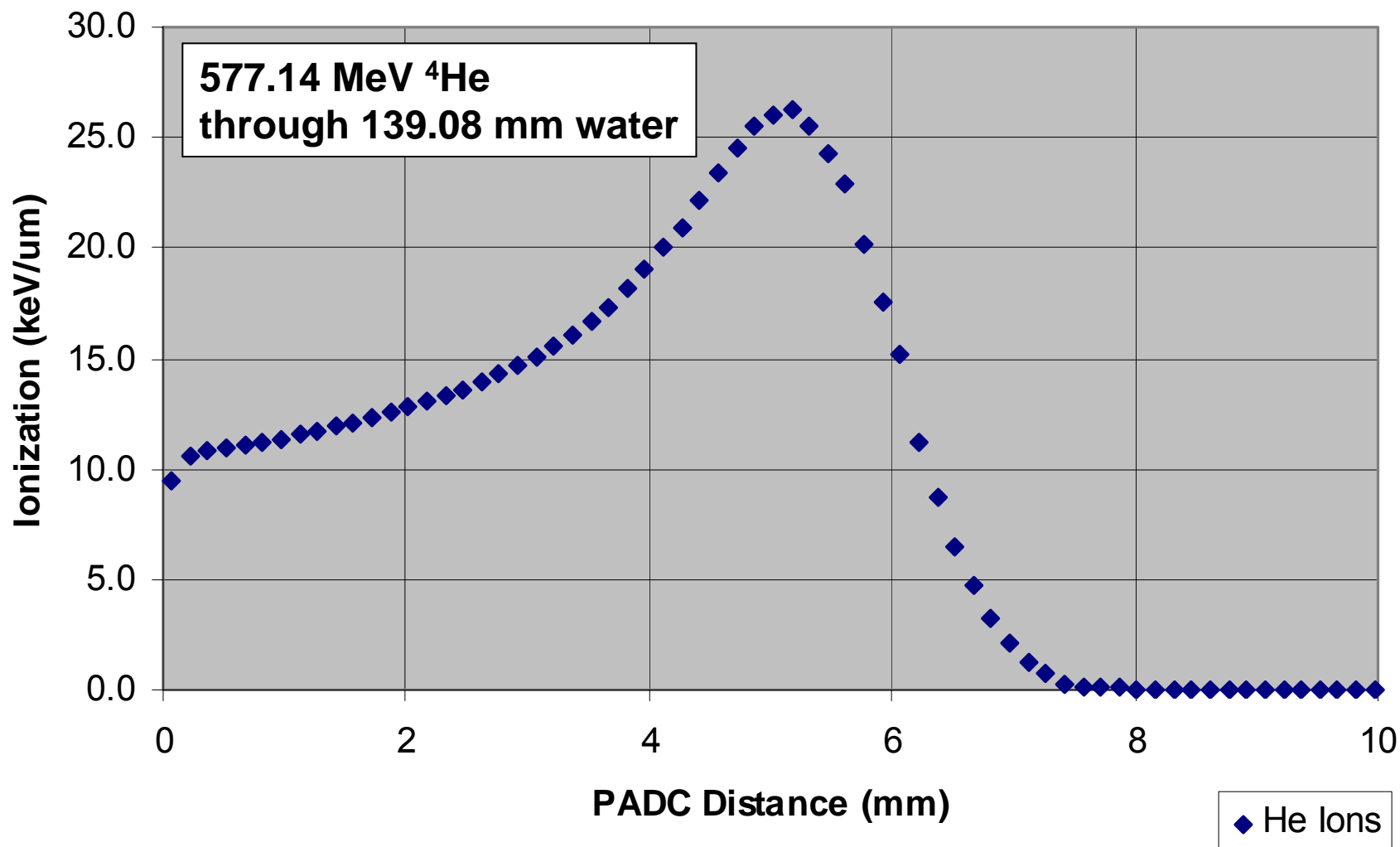


- HIMAC irradiations provided data for ^4He , ^{12}C and ^{56}Fe in May 2008
- Prior data for ^{20}Ne
- PMMA block in the beam to ensure ions stop in the PADC stack
- Data allow etchable range of an ion to be estimated
- LET_{crit} can be inferred

HIMAC irradiation of PADC stacks

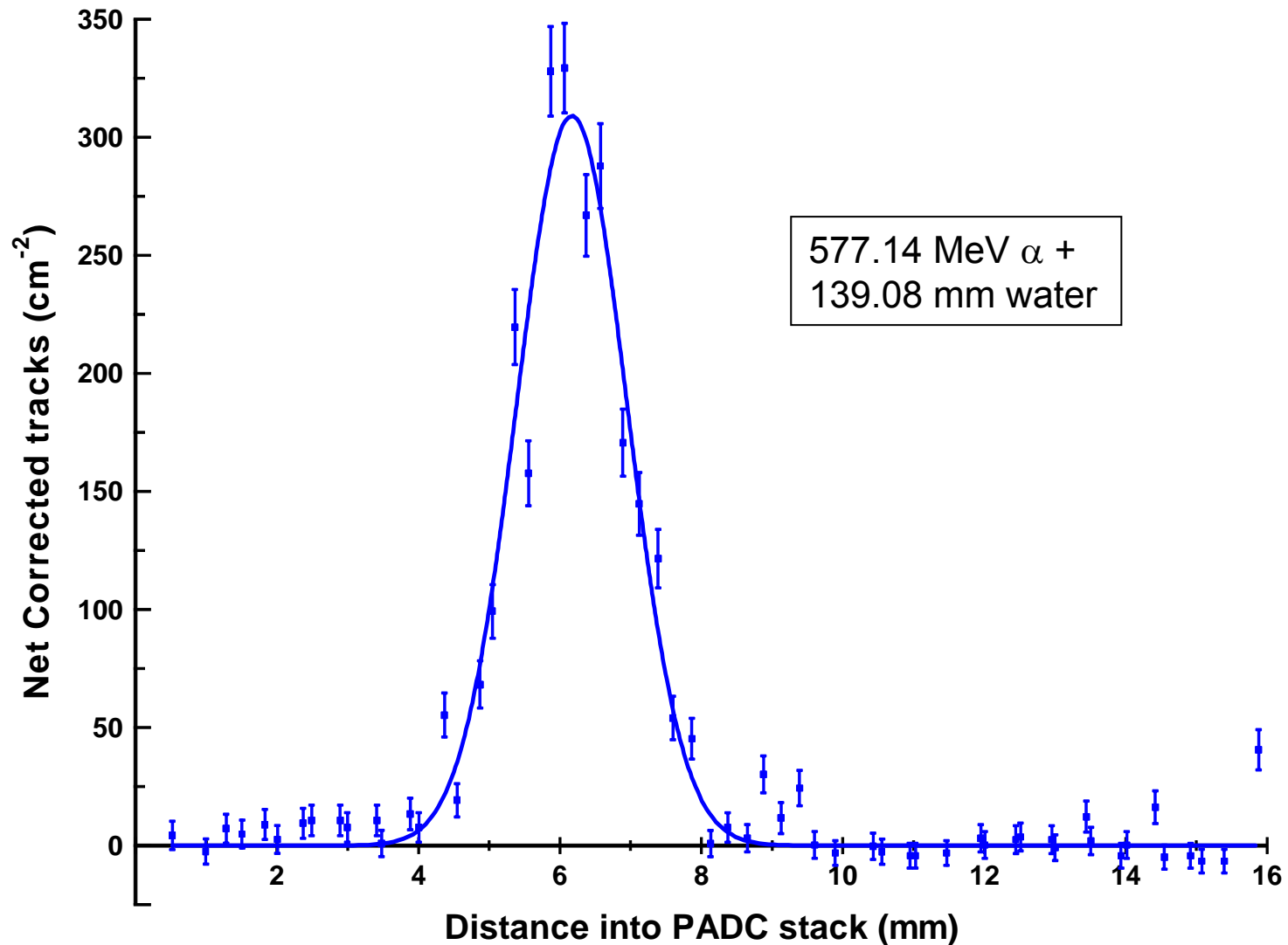


TRIM calculation of ionization ^4He

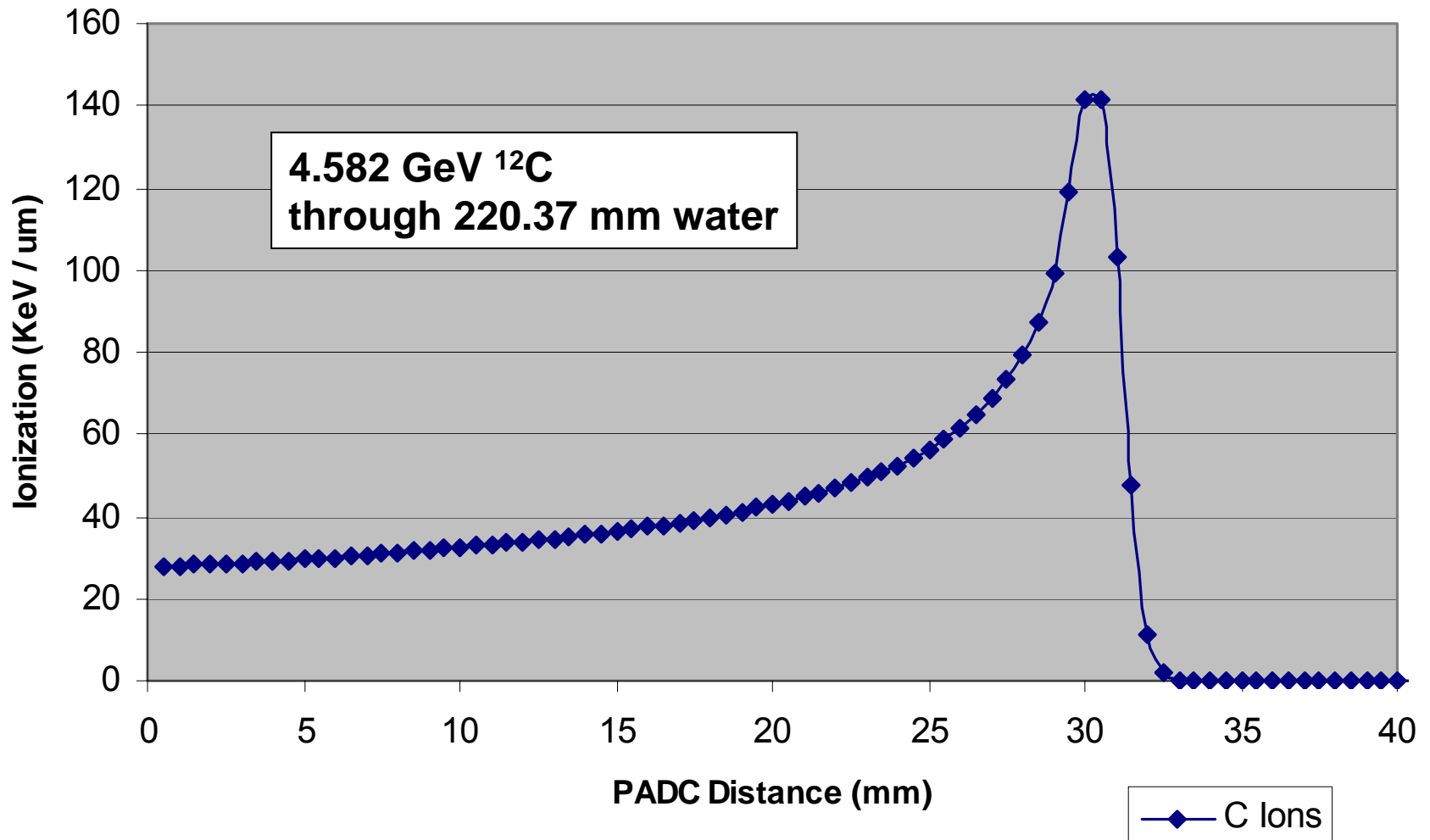


HIMAC ^4He : 577.14 MeV

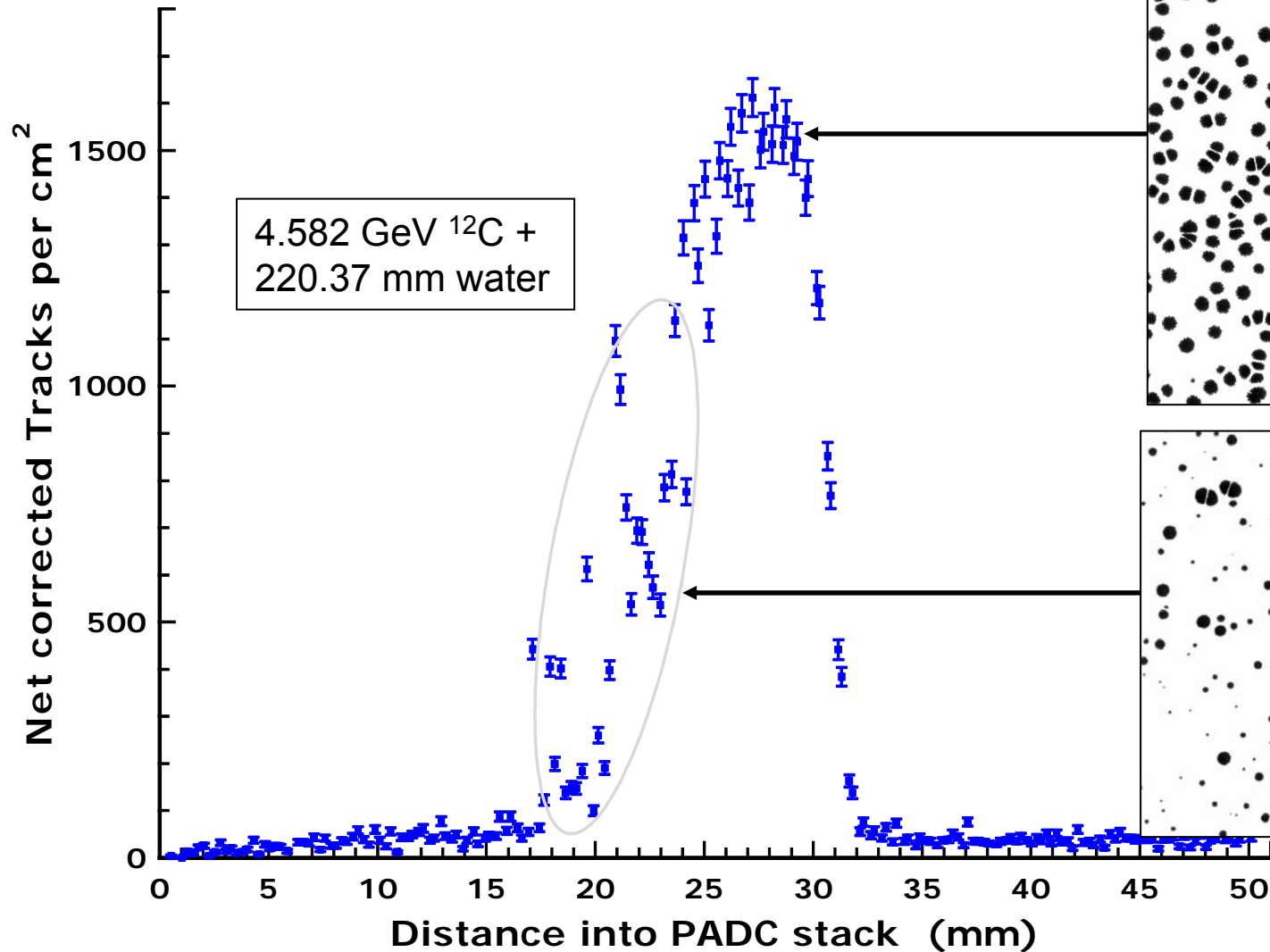
+ 139.08 mm water equiv PMMA



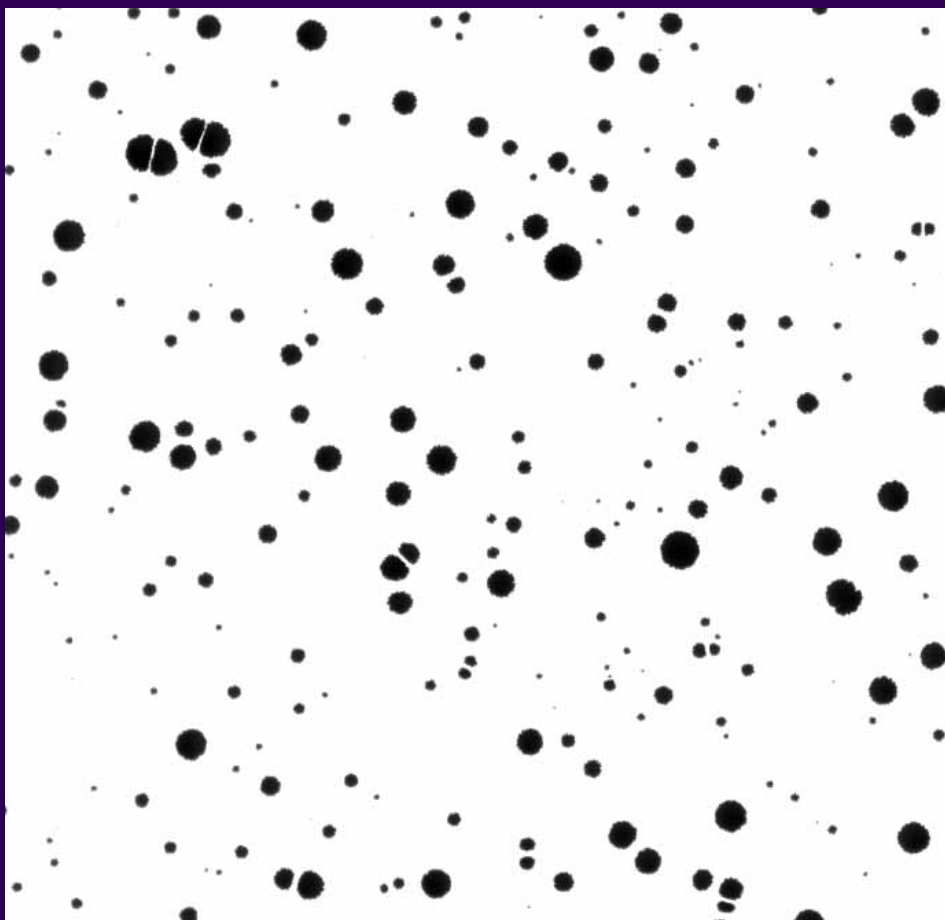
TRIM calculation of ionization ^{12}C



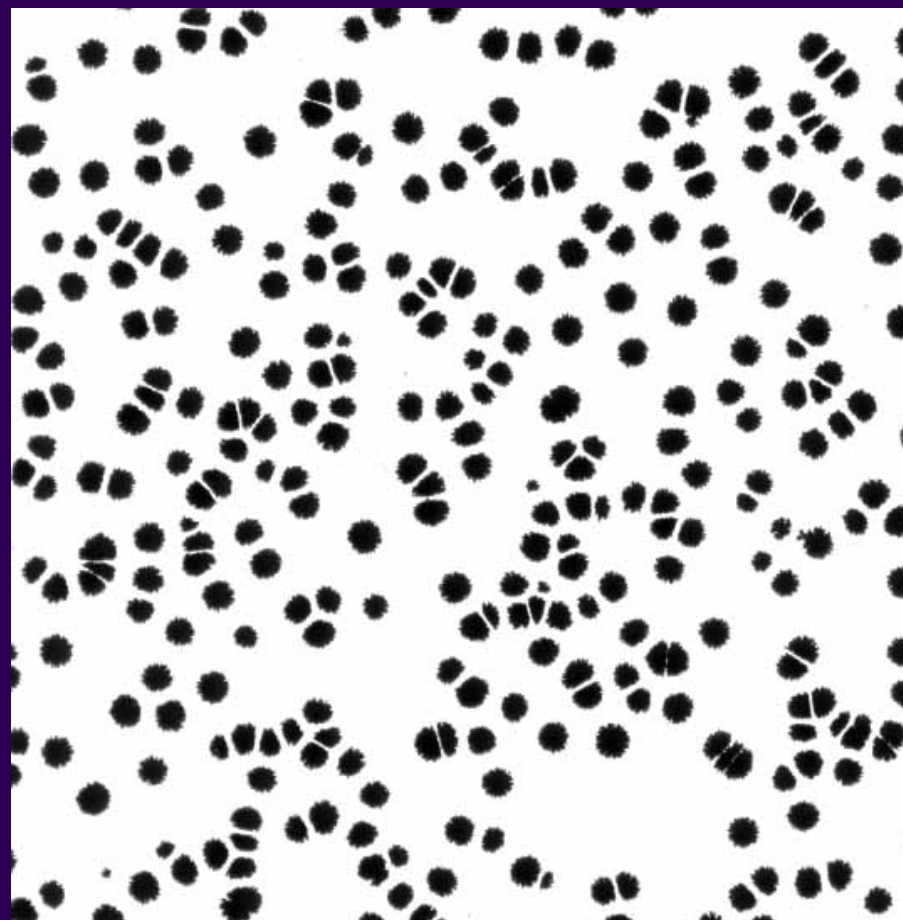
HIMAC ^{12}C : 4.582 GeV + 220.37 mm water equiv PMMA



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

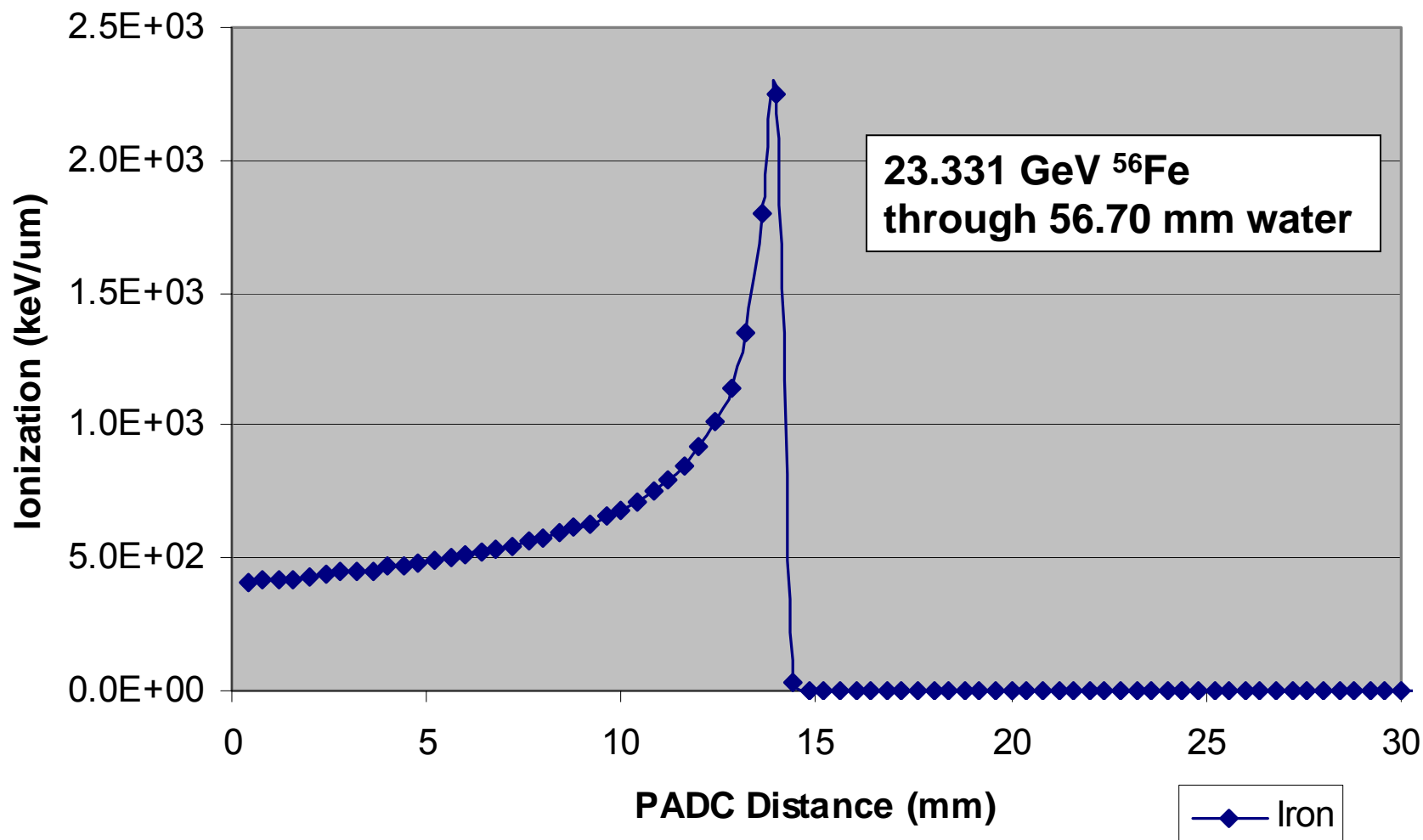


BEFORE PEAK of measured response - highly variable track sizes

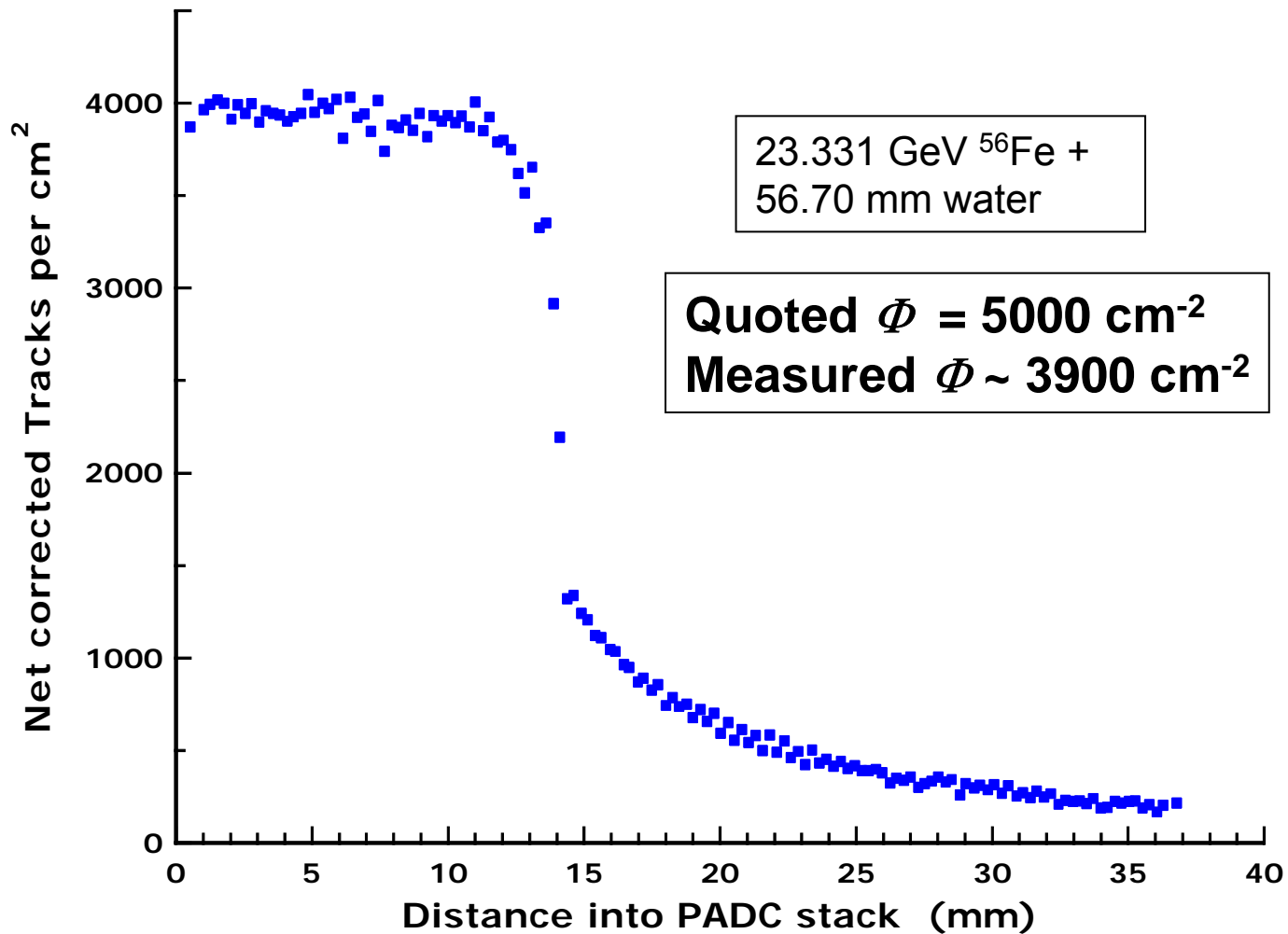


AT PEAK of measured response - uniform track sizes

TRIM calculation of ionization ^{56}Fe



HIMAC ^{56}Fe : 23.331 GeV + 56.70 mm water equiv PMMA



^4He : Etchable range in PADC



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

D = dosemeter thickness

N = measured tracks summed for all dosemeters

Φ = fluence

R_{crit} = etchable length of track (i.e. $\text{LET} > \text{LET}_{\text{crit}}$)

LET thresholds in PADC

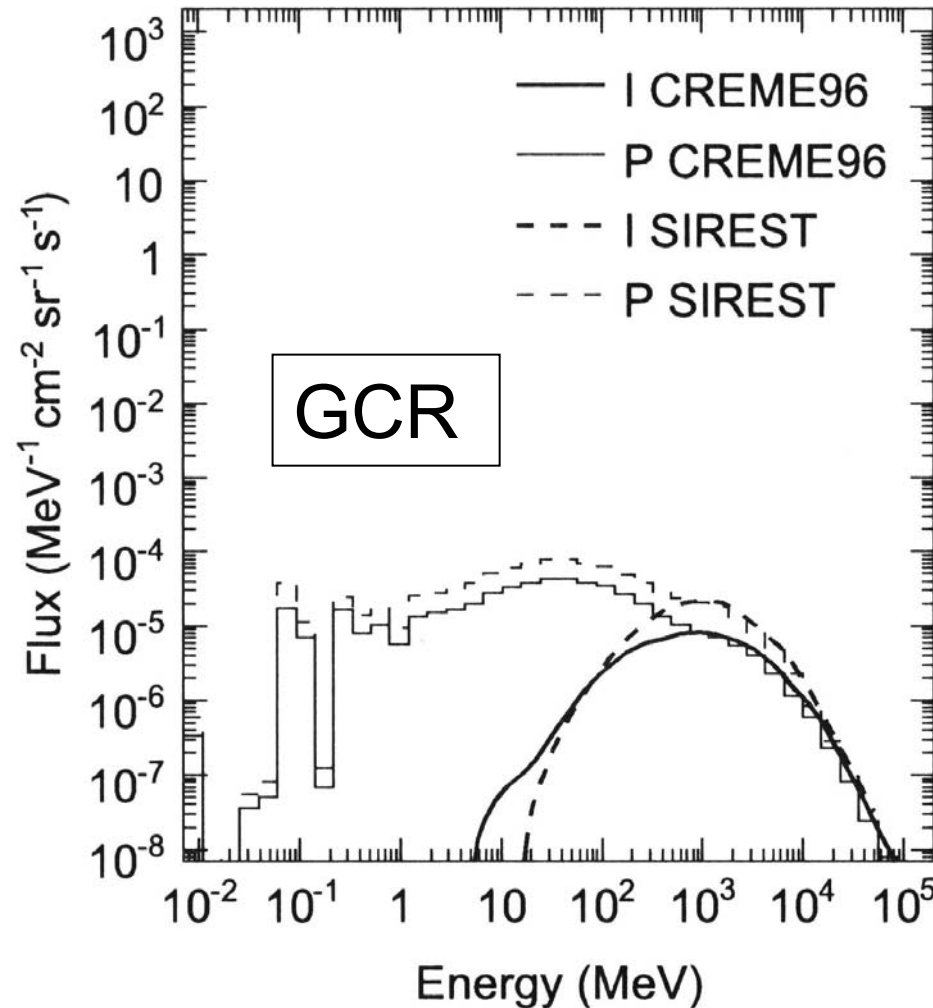
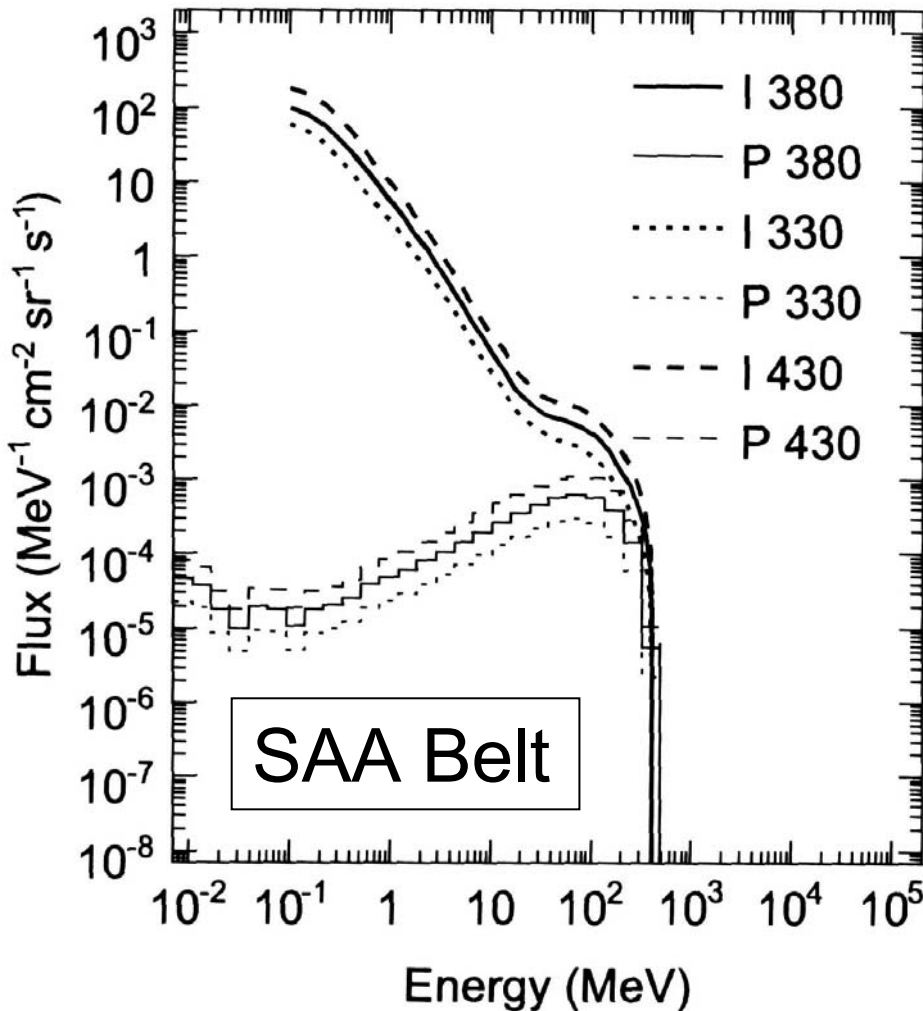


Ion	Etchable track length R_{crit}	Energy, E (MeV)	$\text{LET}_{\infty \text{ PADC}}$ (keV/ μm)	$\text{LET}_{\infty \text{ water}}$ (keV/ μm)	# $\text{LET}_{200 \text{ PADC}}$ (keV/ μm)
^4He	130 μm	12.75	58	47	33
^{12}C	2.886 mm	403.6	77	62	44
^{56}Fe	> 3 m	-	-	-	-
^{20}Ne	-	6020	44	35	25

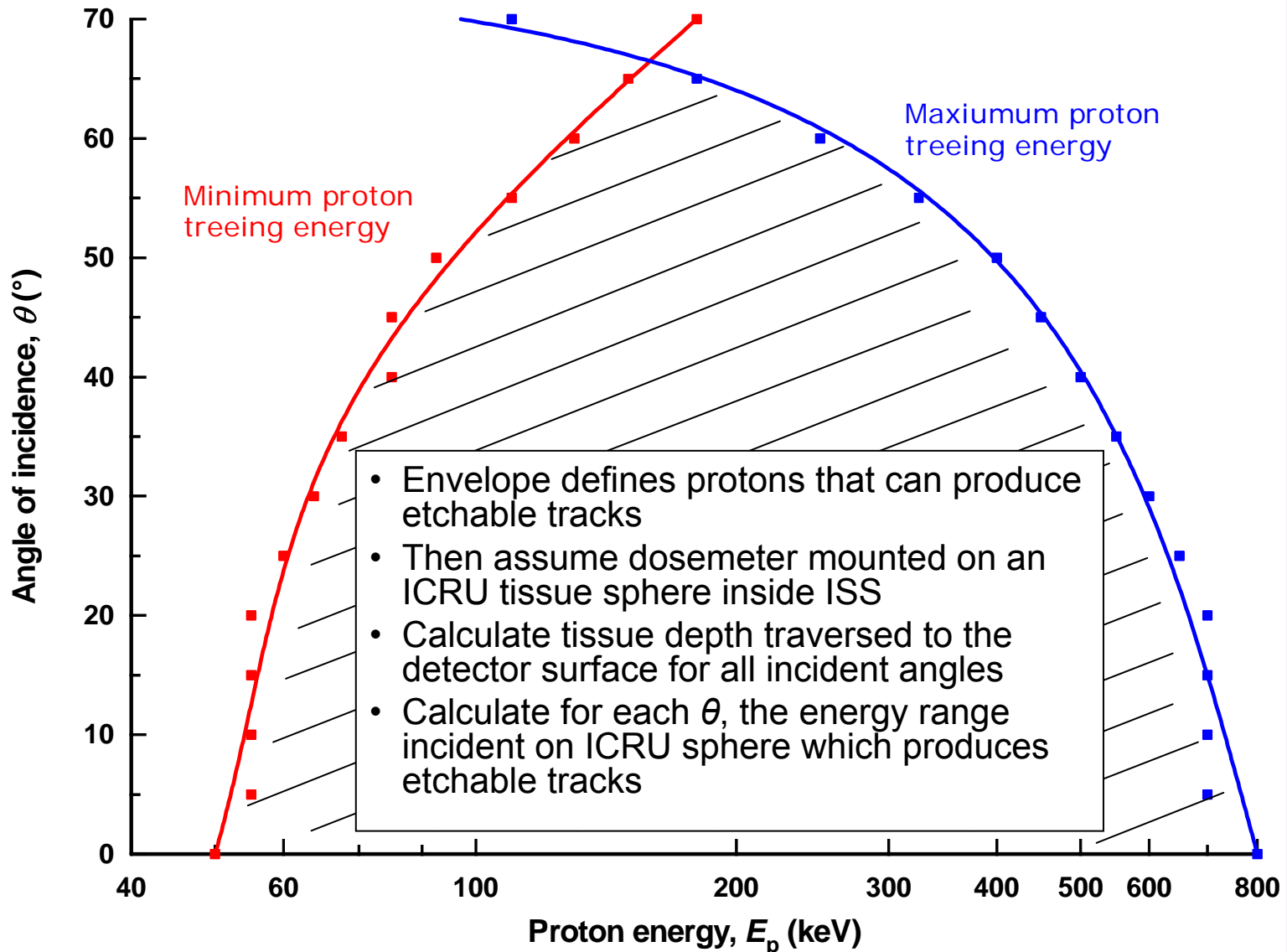
Using: $\log(\text{LET}_{\infty \text{ water}}) = 0.1689 + 0.984\log(\text{LET}_{200 \text{ CR-39}})$

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

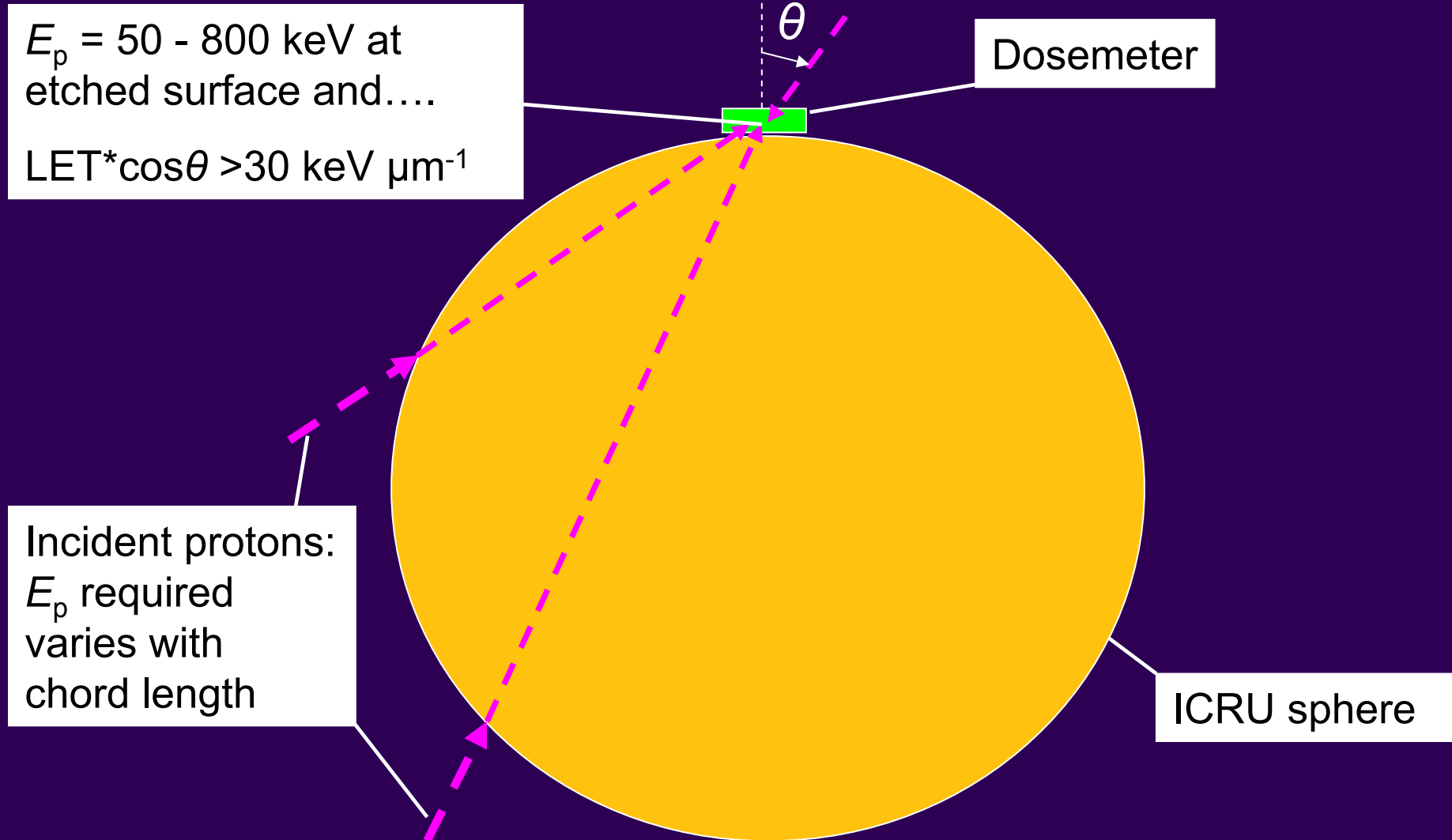
Calculated protons inside ISS Columbus module (GEANT4)



Angle of incidence, θ vs E_p to produce etchable tracks



Dosemeter mounted on 30 cm diameter ICRU tissue sphere



Estimated etchable proton tracks



Origin	Φ_p TOTAL ($\text{cm}^{-2} \text{d}^{-1}$)	Φ_p Etchable ($\text{cm}^{-2} \text{d}^{-1}$)	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	

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

Neutron dose estimate MATROSHKA 2A



Total tracks	Z ≥ 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

- The HPA PADC dosimeter 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

- 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

We would like to acknowledge the help of:

- Staff at HIMAC, Chiba, Japan for providing the irradiation facilities
- 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

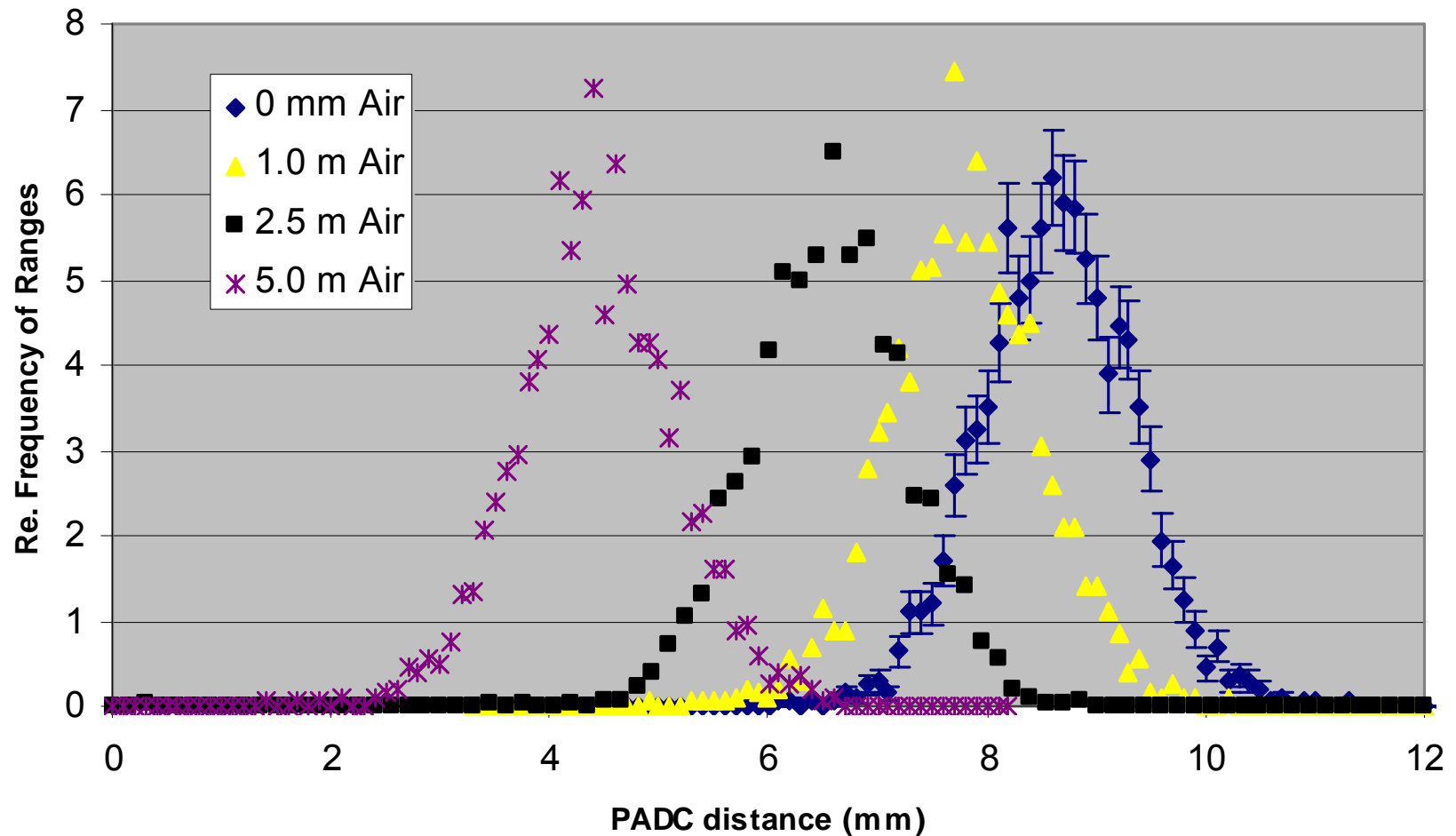
Galactic Cosmic Radiation at top of atmosphere



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

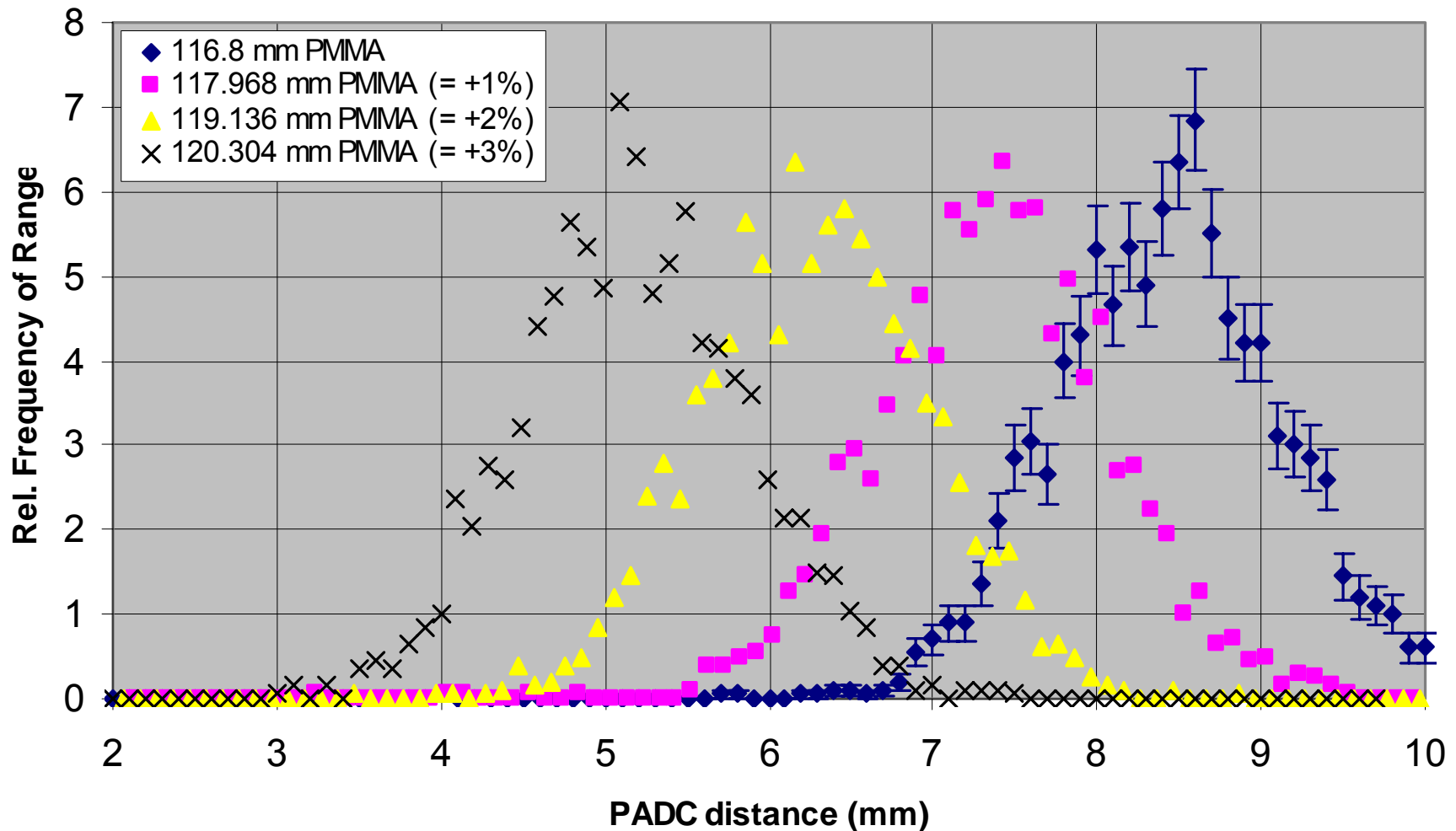
Ranges of ^4He ions in PADC for different air build-up

Air build up before PMMA



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

TRIM calculation



Ranges of ^4He ions in PADC for different initial energies TRIM calculation

