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HSERLAB
Human Space Exploration Radiation LAB

New methods for space radiation field characterisation: LET and ToF for the first z^2/β^2 and kinetic energy spectrum inside a space habitat

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SCIENTIFIC PROBLEM

- The radiation environment inside a space habitat has never been described in terms of **particles' kinetic energy**

- Current risk models, e.g. NASA's, suggest the necessity of the knowledge of each impinging particle characteristics expressed in terms of kinetic energy (β) and charge (z) → $\boldsymbol{z^2/\beta^2}$

↓

Need for a detector capable of particle-by-particle measurements → LIDAL (Light Ion Detector for ALtea)

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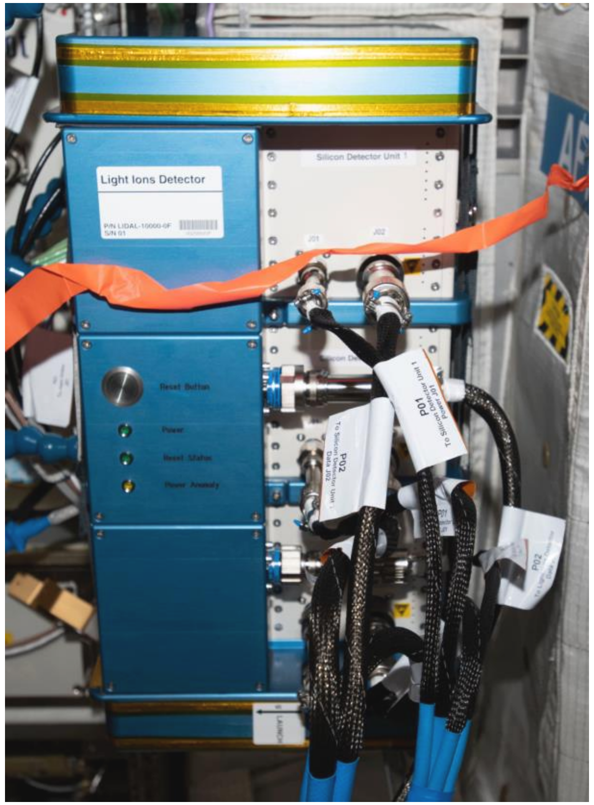
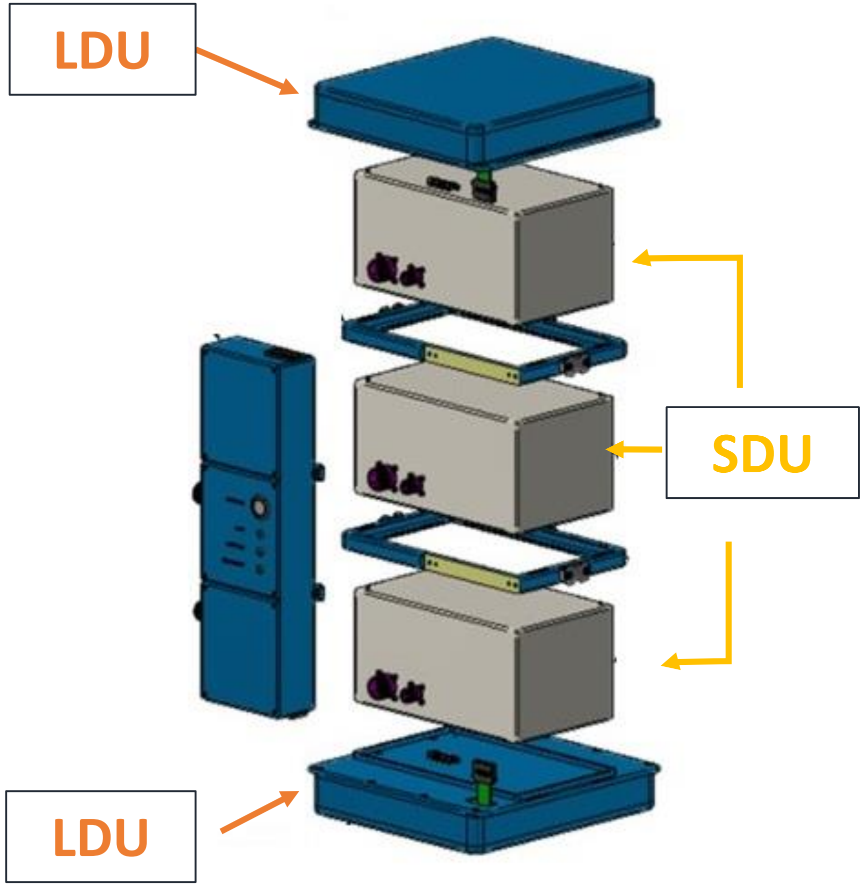
LIDAL (Light Ion Detector for ALtea)

Operative between January 2020 and, at least, 2024



LIDAL detector on board the ISS



Scheme of LIDAL system

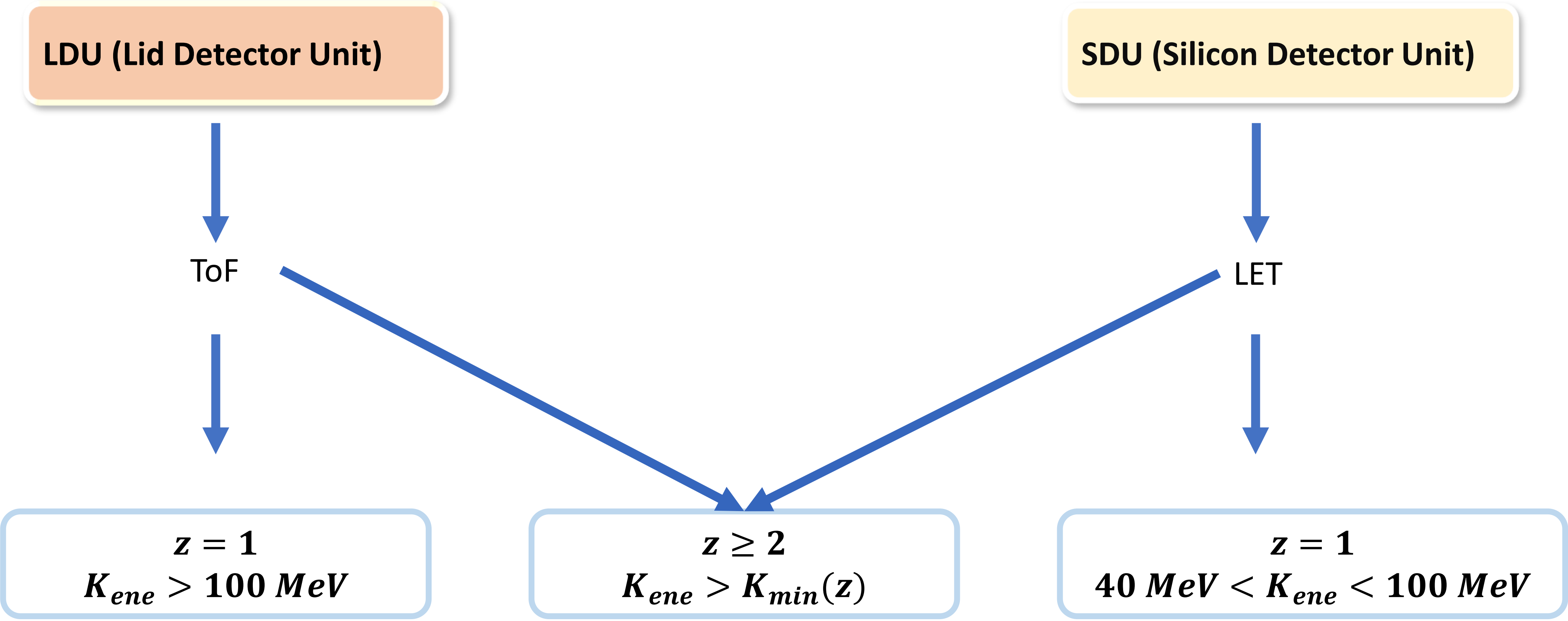
SDU (Silicon Detector Unit):

- 6 Silicon planes
- **LET measure**, Tracking
- Self-trigger at 3 keV/µm

LDU (Lid Detector Unit):

- Plastic scintillators
- **Time of Flight (ToF) measure**
- SDU under threshold measurements (2.3 keV/µm)

LIDAL – Nuclear Identification



Nuclear Identification – ToF + LET

Bethe-Bloch simulation

$z = \{1\,,26\}$

Initial kinetic energy $= \{25\,,2000\}\; MeV/n$

$\beta = \{0.2\,,0.95\}$

Particle properties

z, β

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2}\left(\frac{N_A Z \rho}{A M_u}\right)\left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{z^2}{\beta^2}\left[\ln\left(\frac{2 m_e c^2 \beta^2}{I(1-\beta)}\right) - \beta^2\right]$$

LET

ToF

Layer name	Density ρ (g/cm³)	Z/A	Thickness x (cm)	Mean ionization potential I (MeV) $\times 10^{-4}$
Aluminum	2.70	0.482	0.13	1.66
Air	0.0012	0.498	Variable	0.86
Tape	0.92	0.466	0.03	0.60
Bakelite	1.45	0.533	0.6	0.33
Silicon	2.33	0.498	0.038	1.73

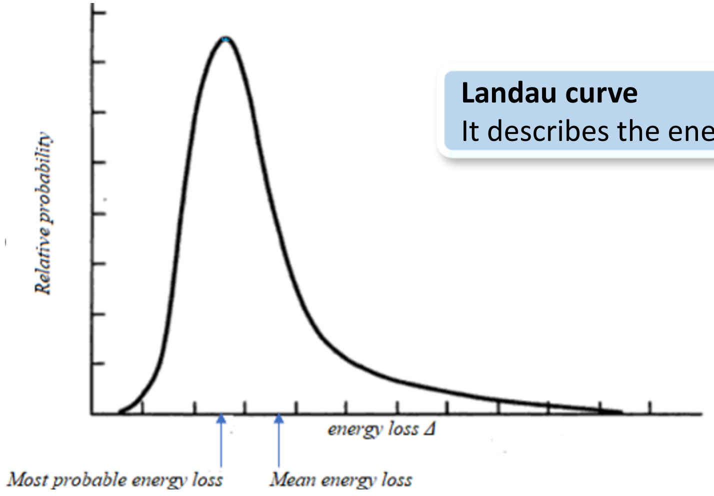
Layers properties

Chemical composition

Thickness

Nuclear Identification – ToF + LET

Straggling Evaluation



Landau curve
It describes the energy straggling

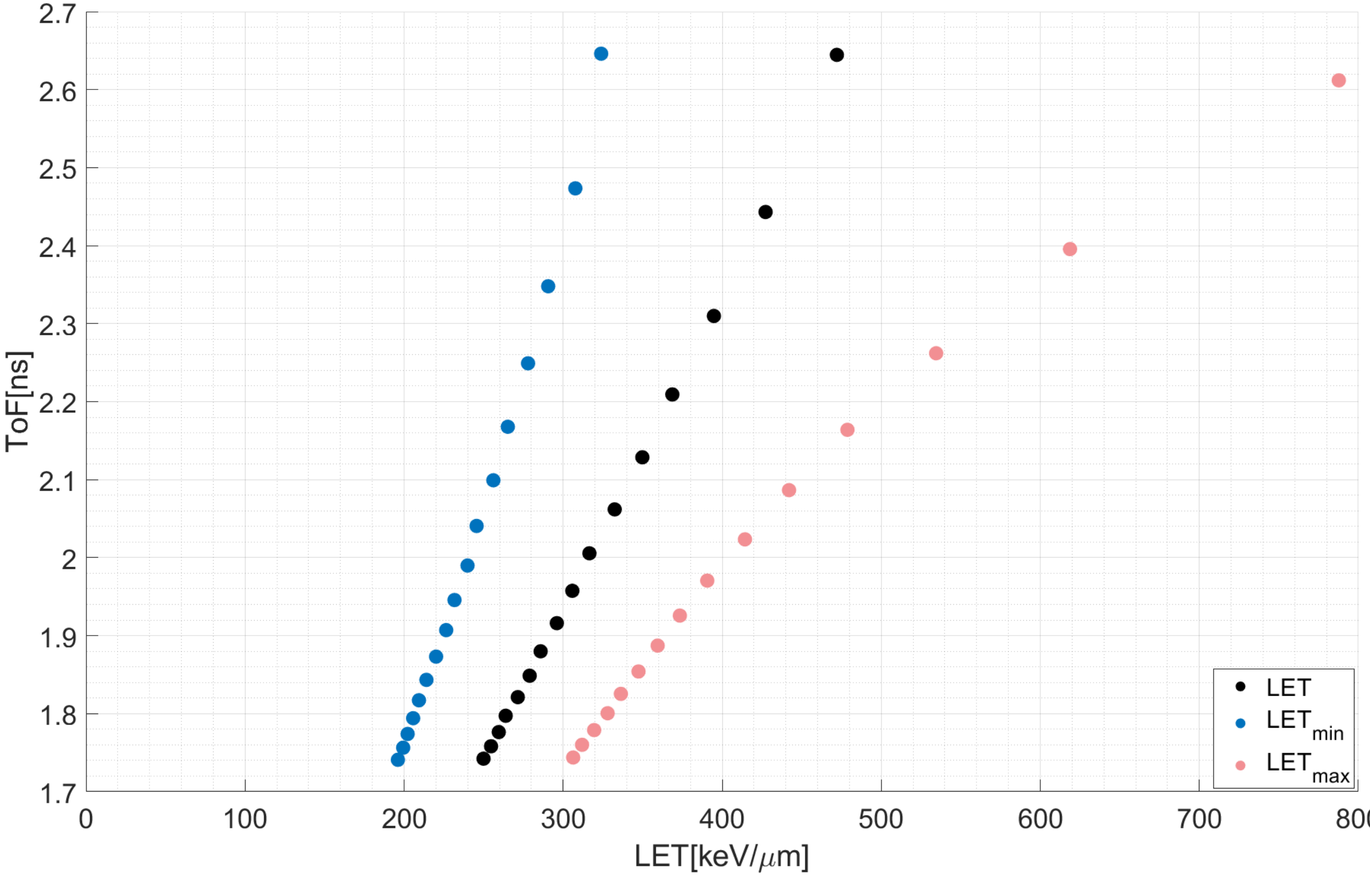
$$\epsilon = FWHM = 4\xi$$

where $\xi = 0.1535 \frac{Zz^2}{A\beta^2} \rho x$

Two extra simulations:

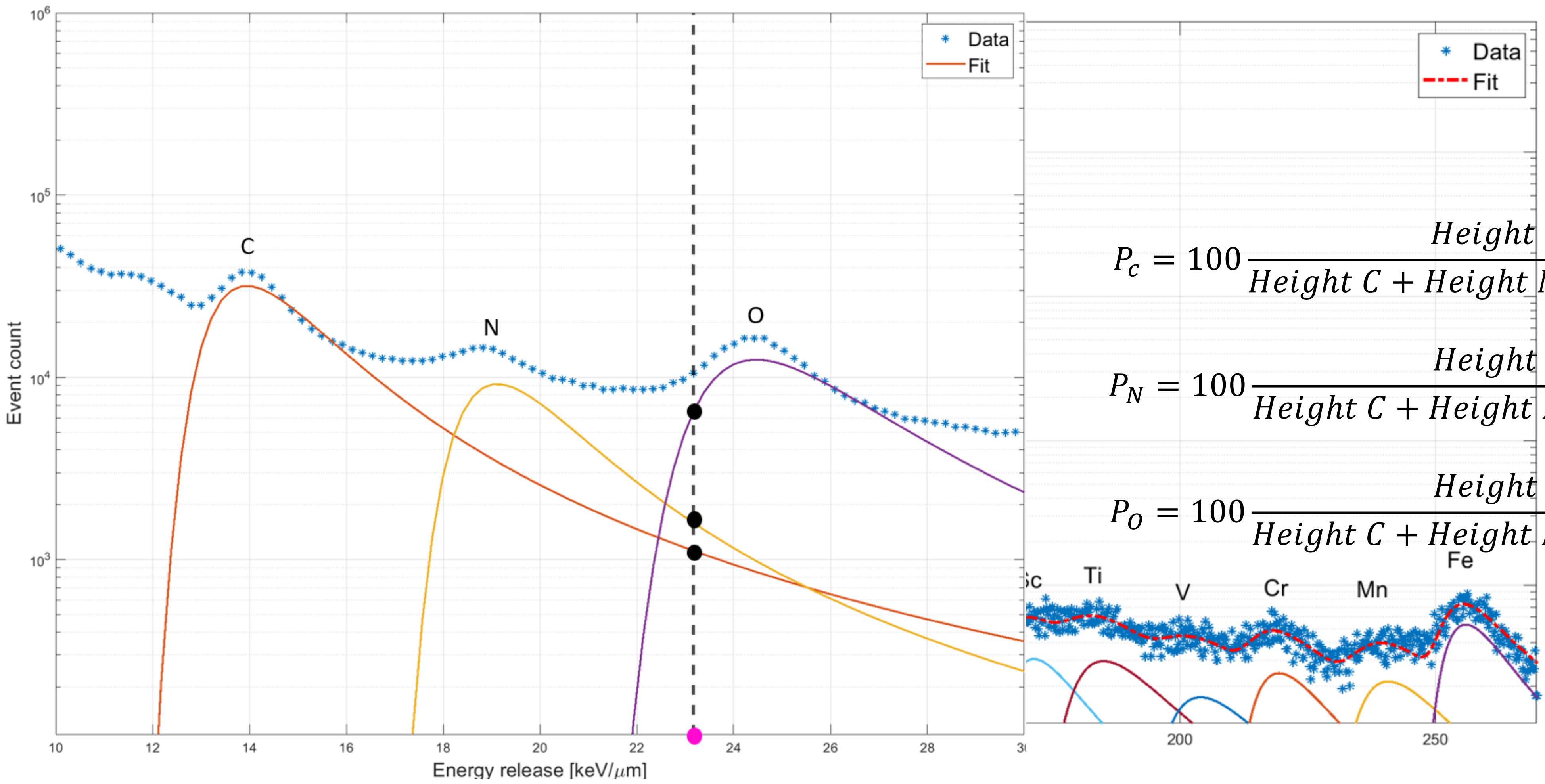
$$LET^{-} = LET - \epsilon$$

$$LET^{+} = LET + \epsilon$$



Nuclear Identification – ToF + LET

Landau recognition



$$P_c = 100\frac{Height\ C}{Height\ C + Height\ N + Height\ O}$$

$$P_N = 100\frac{Height\ N}{Height\ C + Height\ N + Height\ O}$$

$$P_O = 100\frac{Height\ O}{Height\ C + Height\ N + Height\ O}$$

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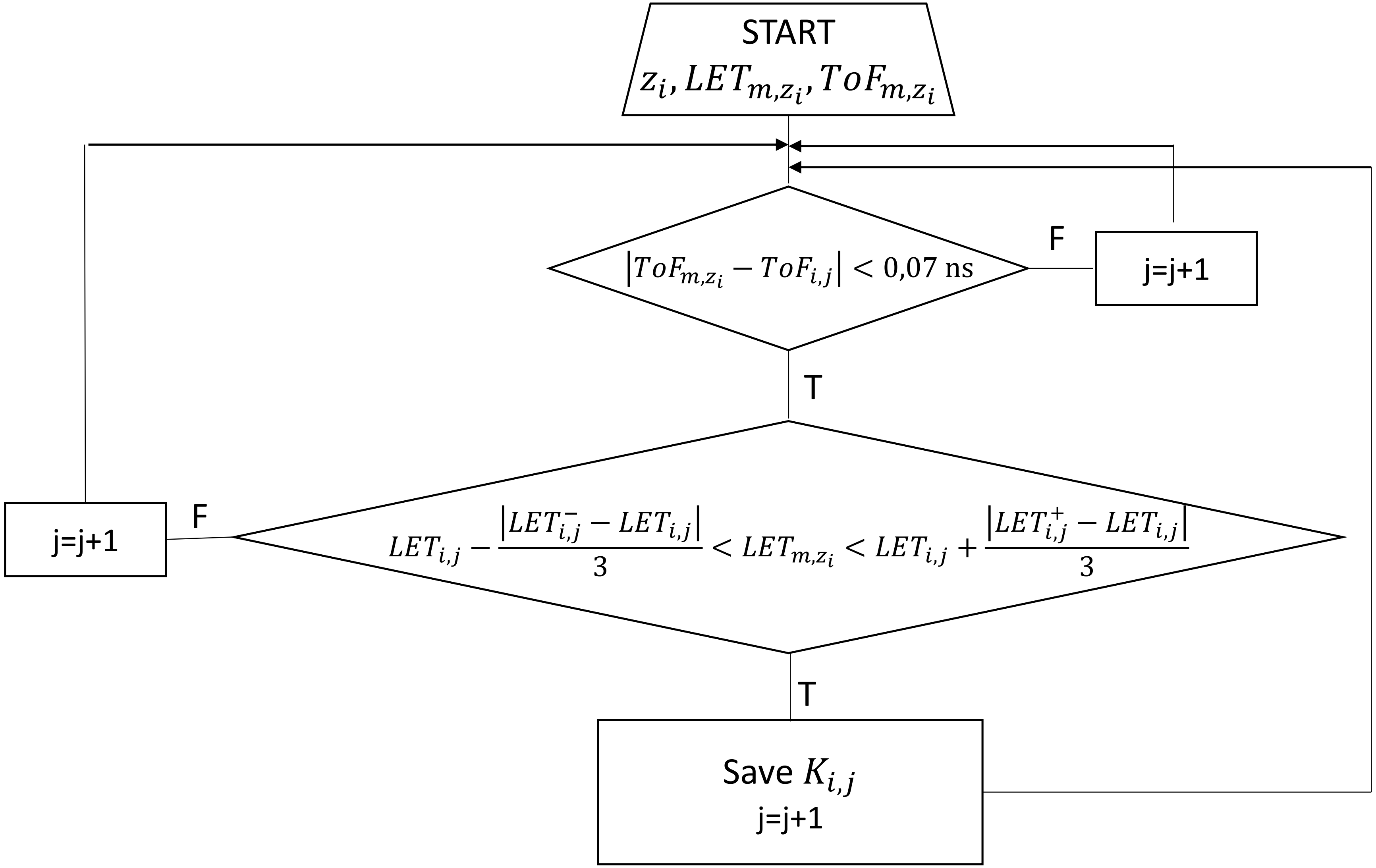
Nuclear Identification – ToF + LET

From the Landau Recognition	From the Bethe Bloch Simulation
z_1, P_1	$K_{1,1}, ToF_{1,1}, LET_{1,1}, LET^+_{1,1}, LET^-_{1,1}$ … $K_{1,l}, ToF_{1,l}, LET_{1,l}, LET^+_{1,l}, LET^-_{1,l}$
…	…
z_N, P_N	$K_{N,1}, ToF_{N,1}, LET_{N,1}, LET^+_{N,1}, LET^-_{N,1}$ … $K_{N,l}, ToF_{N,l}, LET_{N,l}, LET^+_{N,l}, LET^-_{N,l}$

Nuclear Identification – ToF + LET



Nuclear Identification – ToF + LET

z_1, P_1	$K_{1,1}$ $K_{1,2}$ … $K_{1,m}$
z_2, P_2	$K_{2,1}$ $K_{2,2}$ … $K_{2,l}$
…	…
z_N, P_N	$K_{N,1}$ $K_{N,2}$ … $K_{N,p}$

$ToF_{1,min} = \min(|ToF_{m,z_1} - ToF_{1,j})$ → $z_1, K_{ToF_{1,min}}$

$ToF_{2,min} = \min(|ToF_{m,z_2} - ToF_{2,j})$ → $z_2, K_{ToF_{2,min}}$

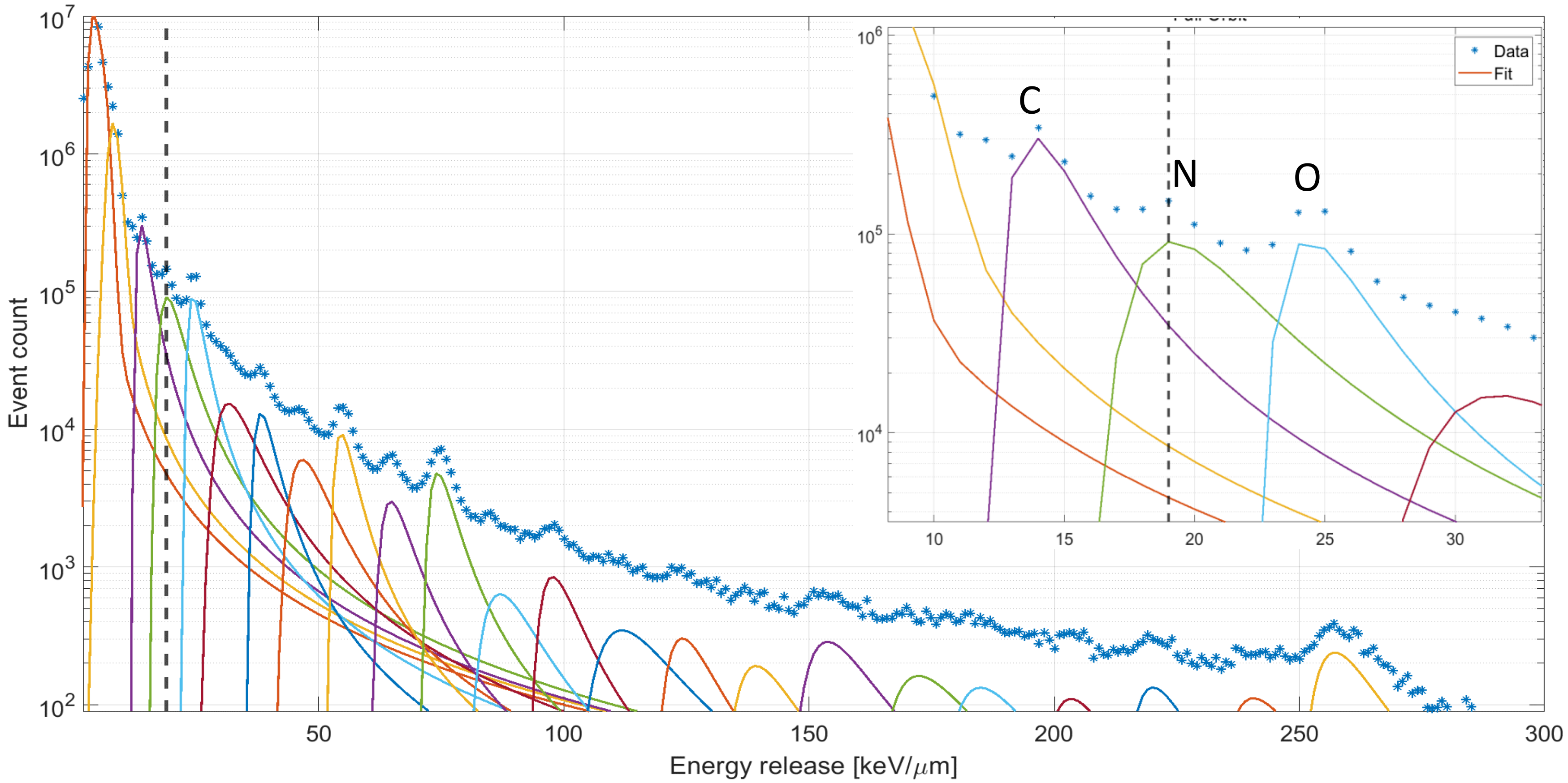
$ToF_{N,min} = \min(|ToF_{m,z_N} - ToF_{N,j})$ → $z_N, K_{ToF_{N,min}}$

$\max\{P_1, P_2, \dots, P_N\}$ → z, K

Nuclear Identification – ToF + LET

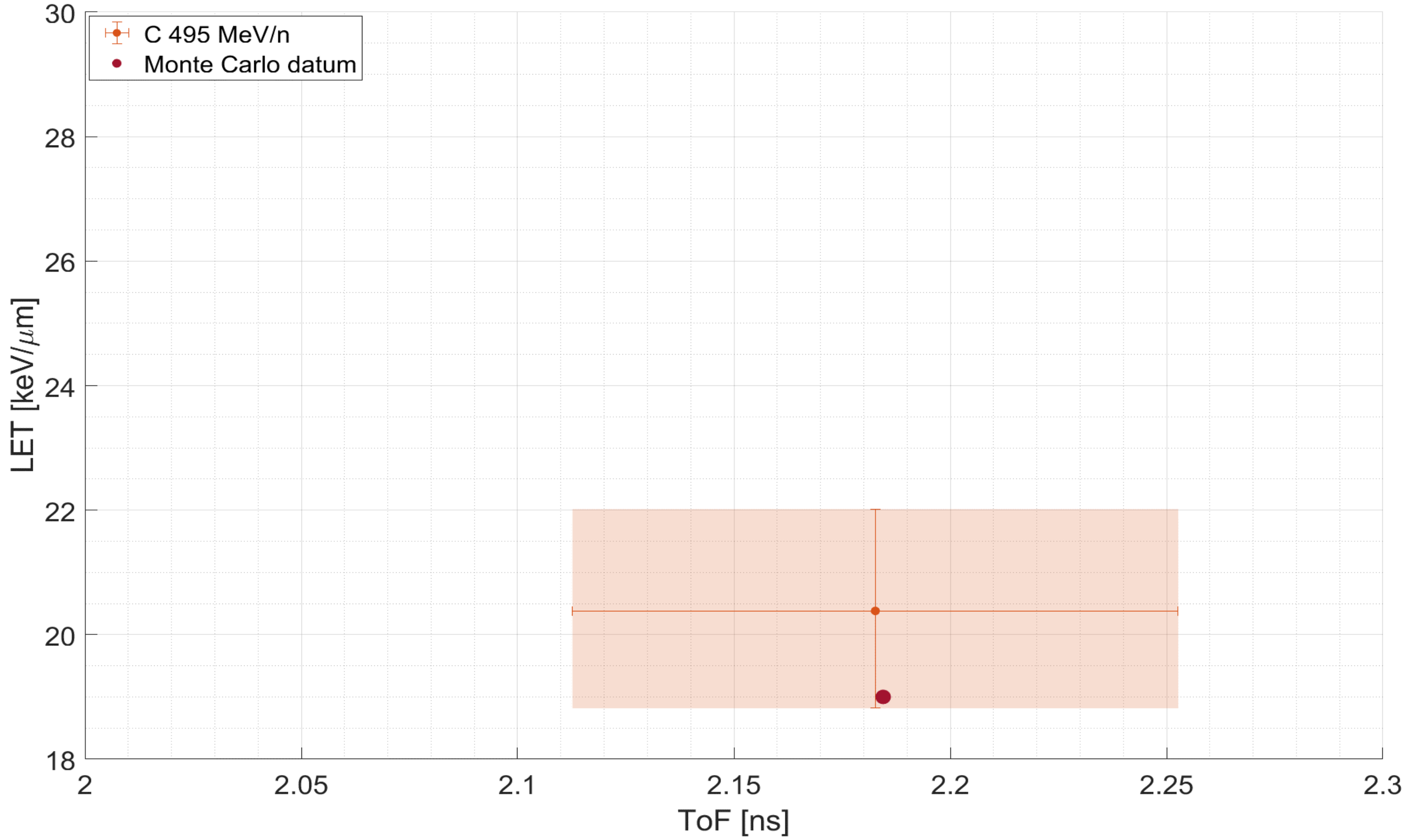
Let's see an example…

$$LET = 19 keV/\mu m$$
$$ToF = 2{,}18\ ns$$



Ions Probability at Energy Release $19\ keV/\mu m$
H or He or Li or Be (0.16 %)
B (4.4%)
C (14.6 %)
N (80.3%)

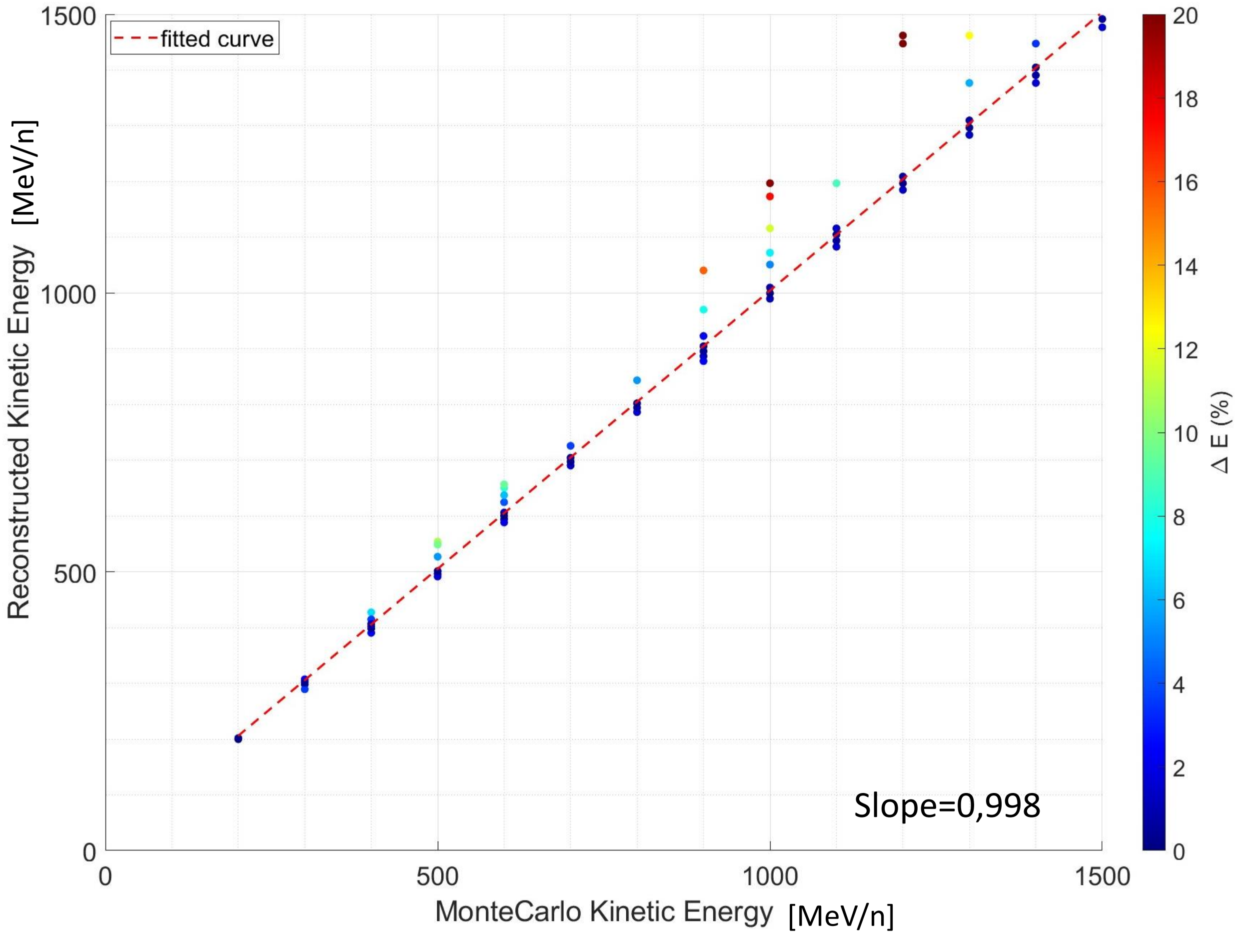
Nuclear Identification – ToF + LET

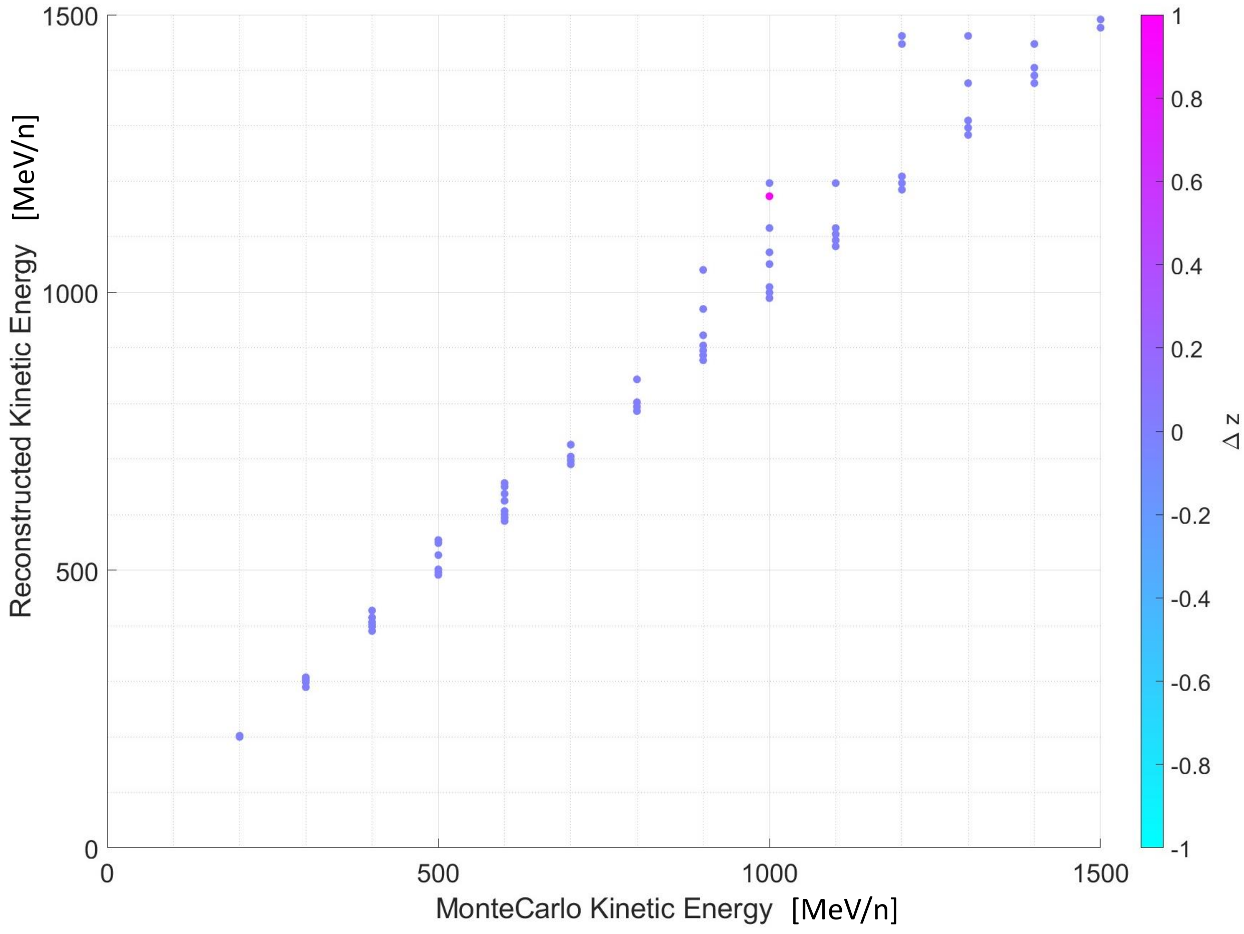


Input data from PHITS simulation: C @ 500MeV/n

Nuclear Identification – ToF + LET

Validation





Nuclear Identification – ToF

It works only for **Protons** with **K> 100MeV**

Assumptions:

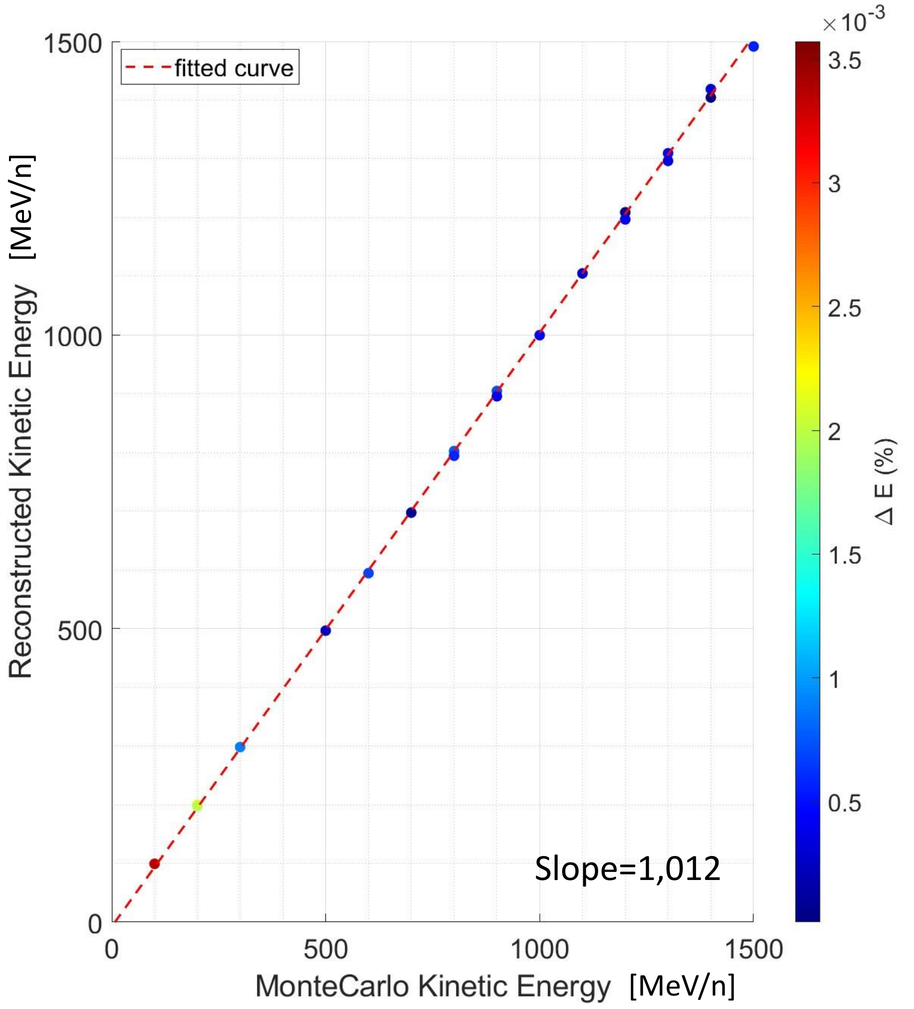
- We consider only the events where there is **no LET measurement**→ *«Fast»* protons (K>100) do not have a measurable LET
- Even *«fast»* He nuclei may not have a measurable LET, BUT! From **nuclear abundances** it is known that protons are much more abundant than He ions

The kinetic energy is selected as the one for which

$$\min\left(\left|ToF_{meas} - ToF_{sim,j}\right|\right)$$

$$\&\&$$

$$\left|ToF_{meas} - ToF_{sim,j}\right| < 0{,}07\ ns$$



Validation

Nuclear Identification – LET

It works only for **Protons** with **40MeV<K< 100MeV**

Assumptions:

- We consider only the events where there is **no ToF measurement**→ *«Slow»* protons tend to stop inside the detector
- Even *«slow»* He nuclei may not have ToF measure, BUT! From **nuclear abundances** it is known that protons are much more abundant than He ions

The kinetic energy is selected as the one for which

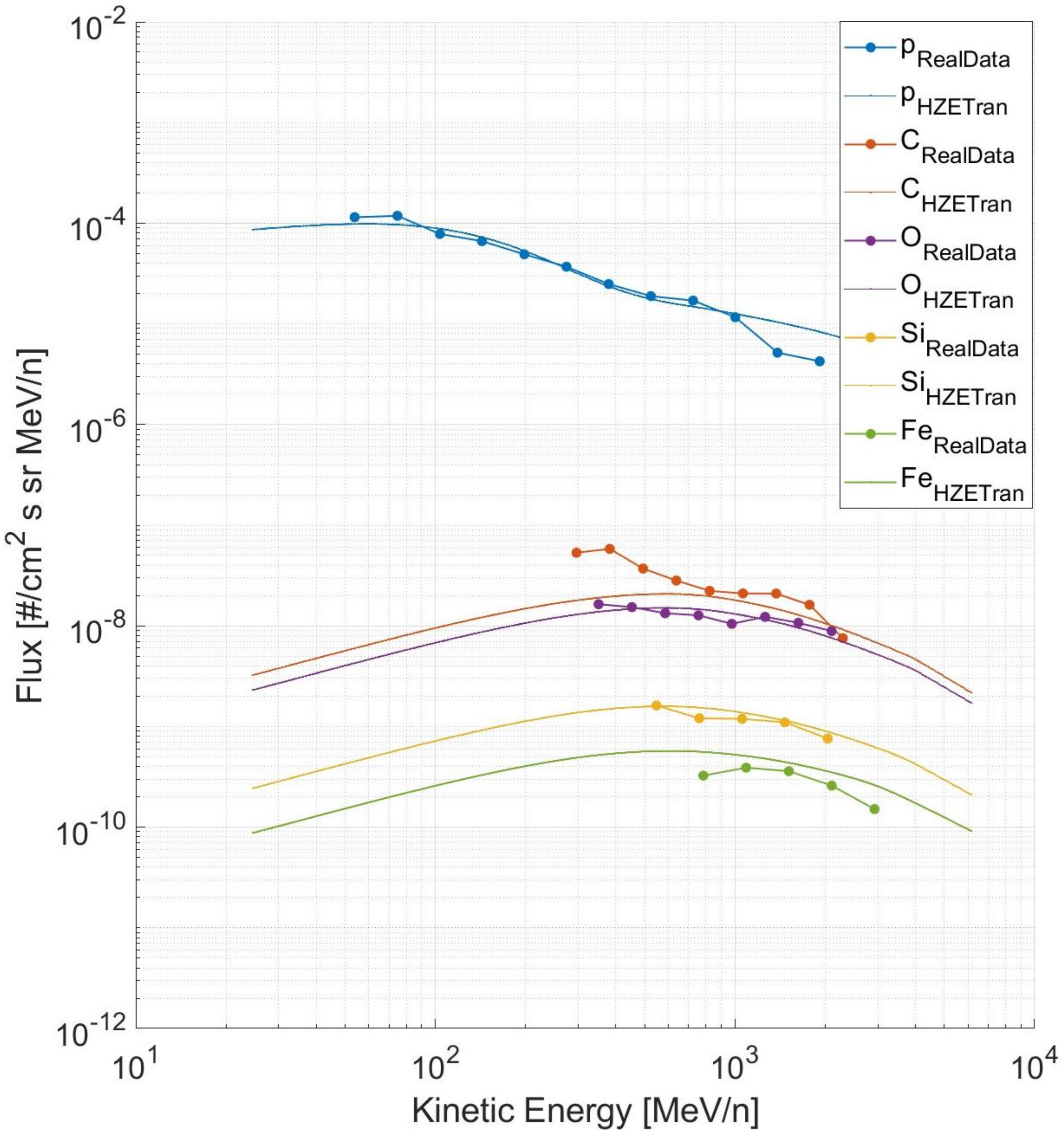
$$LET_{sim,j} - \frac{\left|LET^{-}_{sim,j} - LET_{sim,j}\right|}{3} < LET_{meas} < LET_{sim,j} + \frac{\left|LET^{+}_{sim,j} - LET_{sim,j}\right|}{3}$$

&&

$$\min(|LET_{meas} - LET_{sim,j})$$

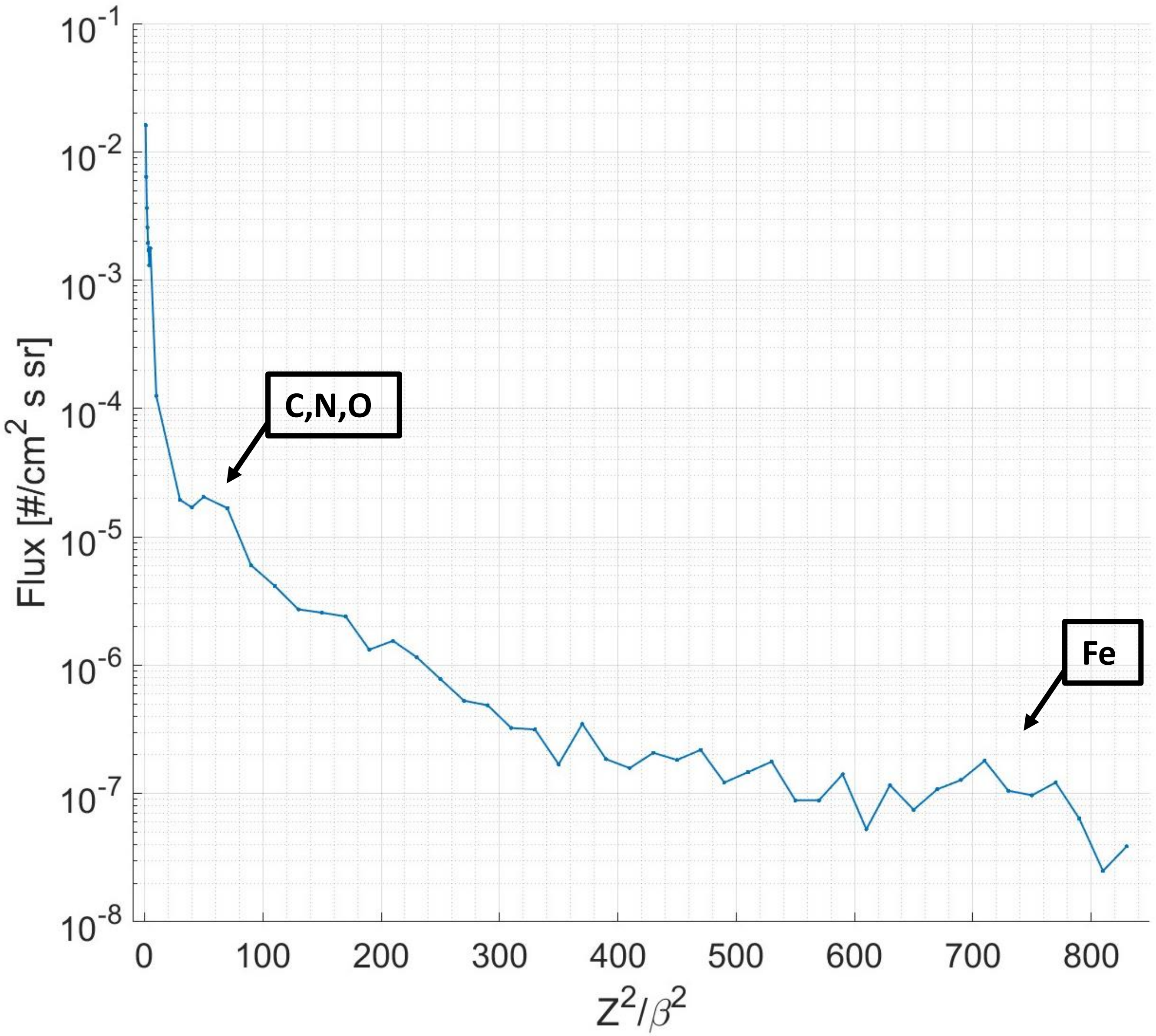
To be validated…

Results – Kinetic Energy spectrum



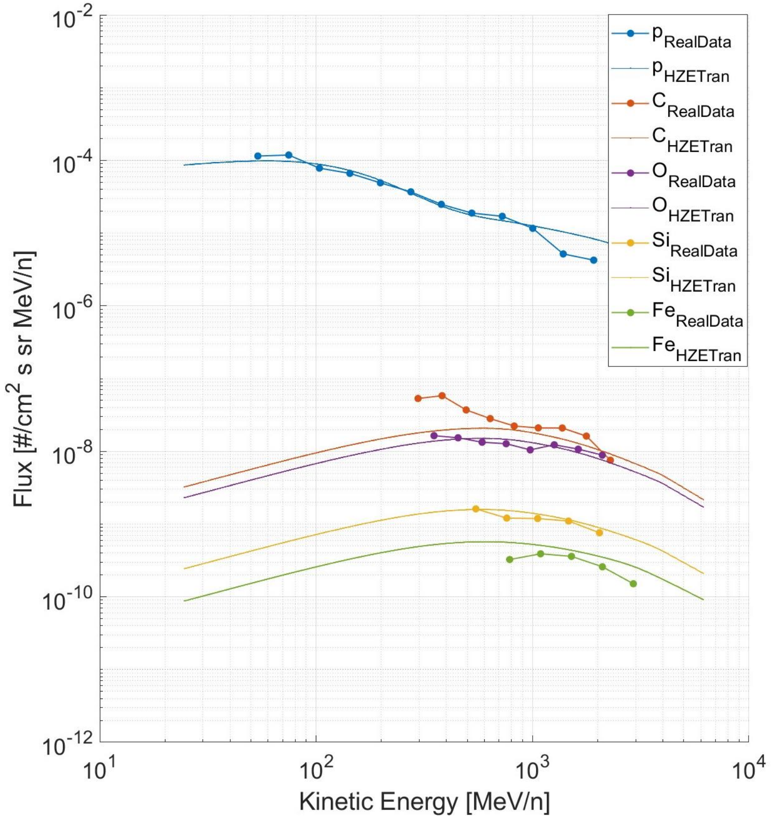
HZETran simulation with a **40** g/cm^2 Aluminum shielding

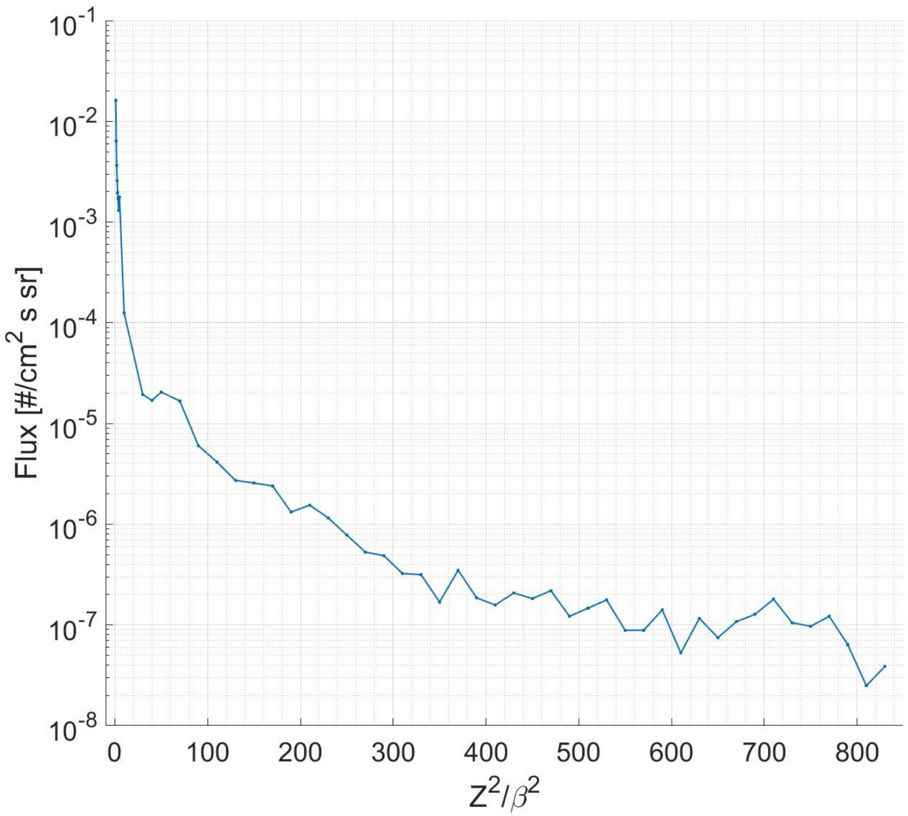
Results – z^2/β^2 spectrum



Conclusions

- Characterisation of the radiation environment in terms of the kinetic energy of particles
- Using measured data as input to risk models
- Tools to validate models





THANK YOU FOR THE ATTENTION!

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