Unique particle beams and energies at CERN applied to radiation testing of electronics

17-19 May, 2021
RADSAGA Final Conference and Industrial event

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RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators (RADSAGA) is a project funded by the European Commission under the Horizon2020 Framework Program under the Grant Agreement 721624.
RADSAGA began in Mars 2017 and will run for 5 years.

Presentation outline

- ❑ Introduction, Motivation & Background

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- ❑ Monte Carlo Simulations & Experiments

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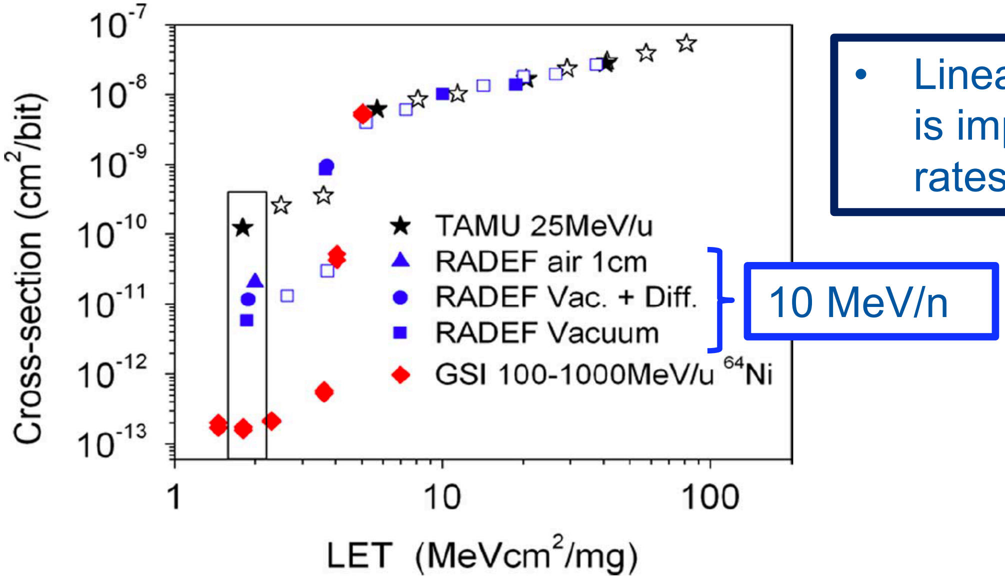
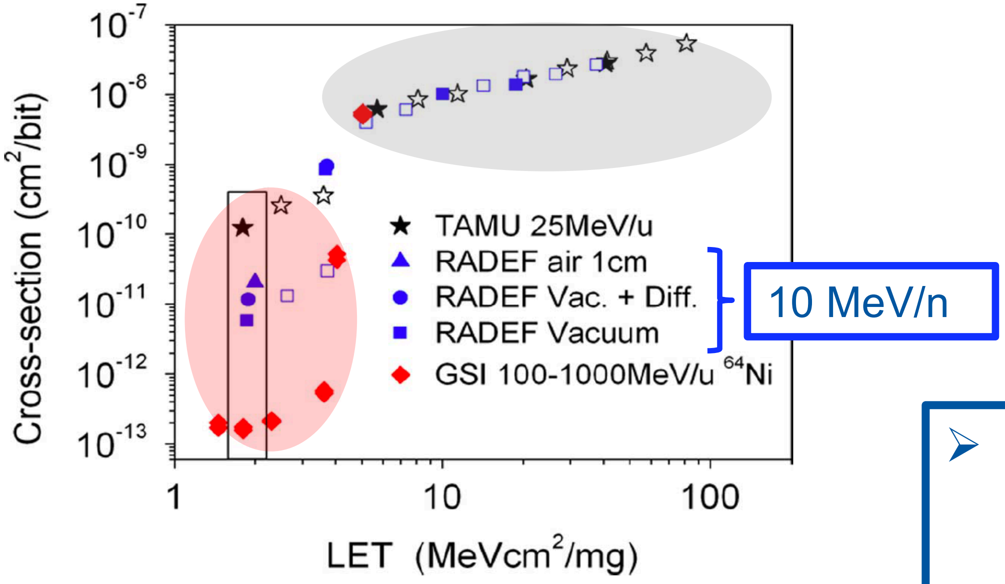
Overview of SEU cross section of same device



- Linear Energy Transfer (LET) is important to estimate SEE rates in modern devices

Ferlet-Cavrois et al., 2012

Overview of SEU cross section of same device



Ferlet-Cavrois et al., 2012

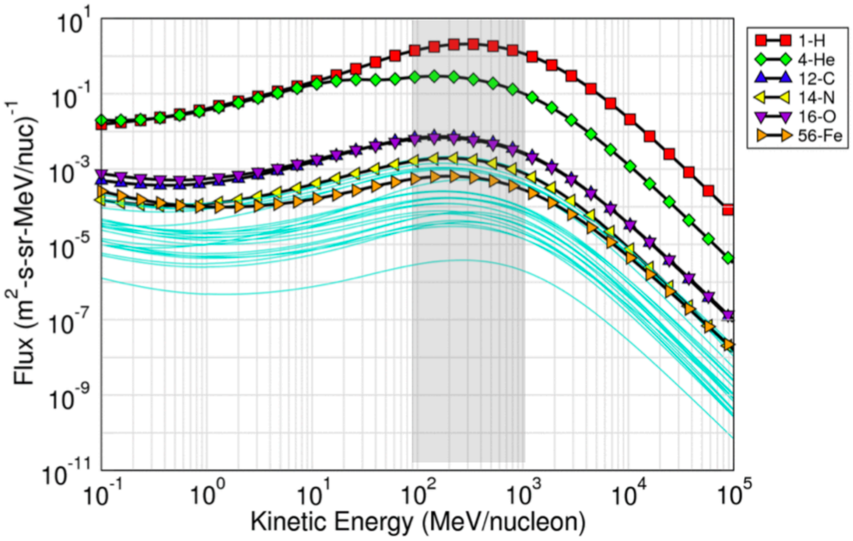
in high LET region-> similar behavior

in sub-LET region -> varying cross sections for similar LET

- Hence, sub-LET region has to be better understood especially for high energies

The Challenge of Space Application Tests

~ 0.1 - 1 GeV/nucleon



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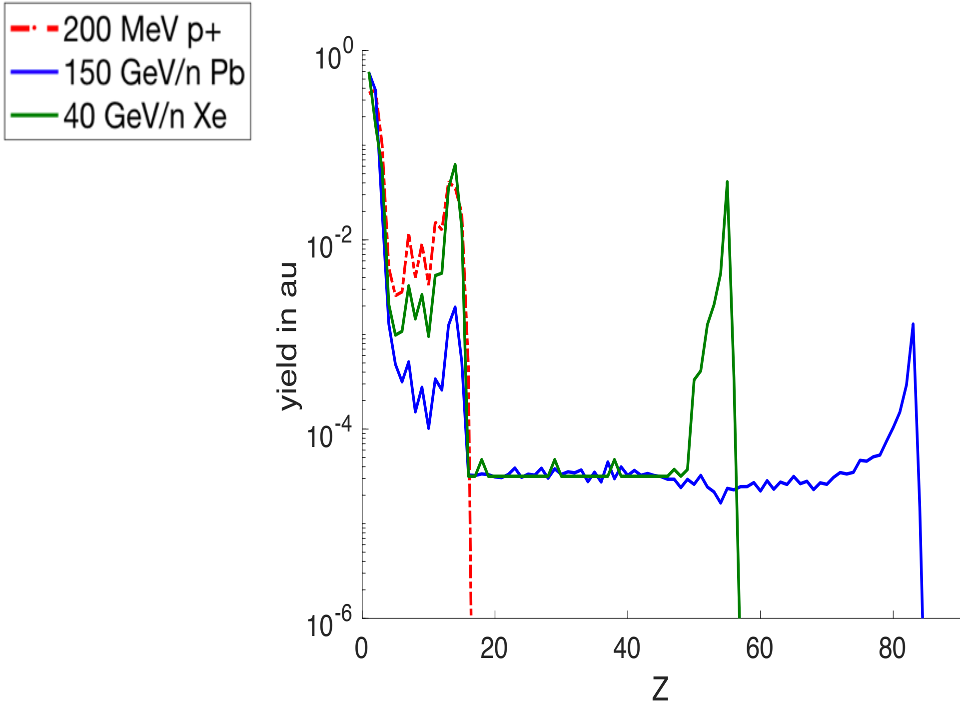
Simulation of full Z fragmentation distribution on silicon

1. Step: understanding the influence of Z



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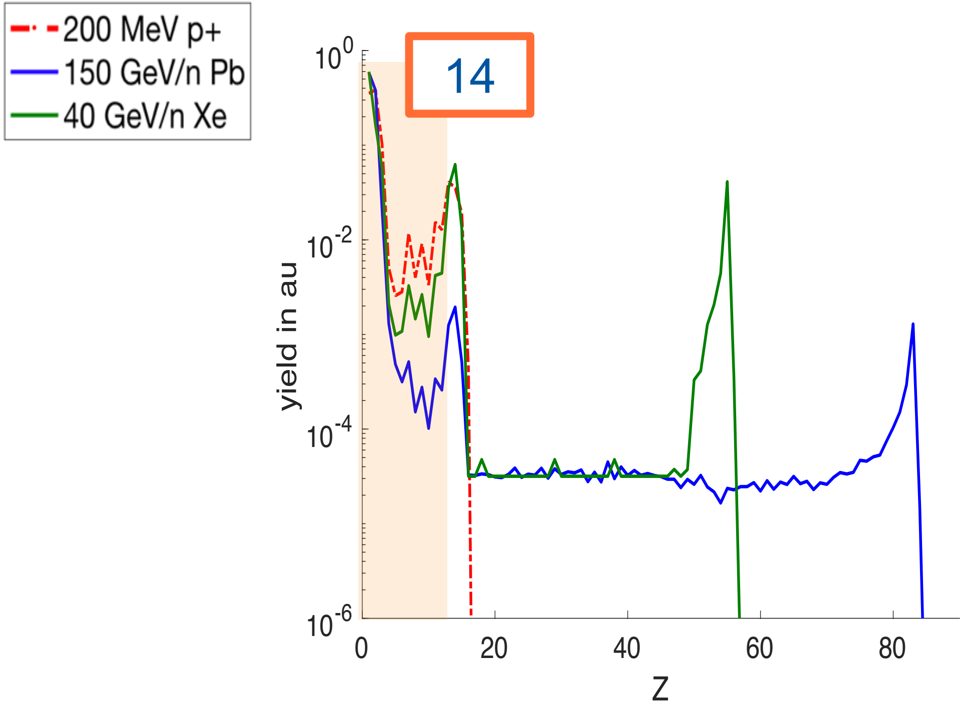

Z distribution similar only for target-like fragments Z ~14

Simulation of full Z fragmentation distribution on silicon

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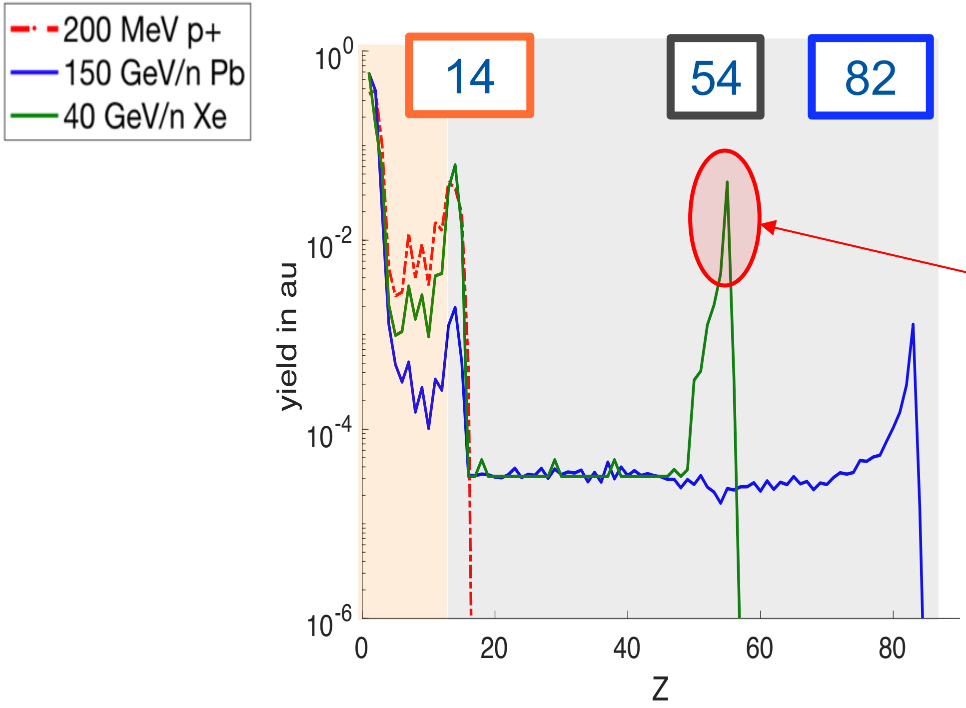


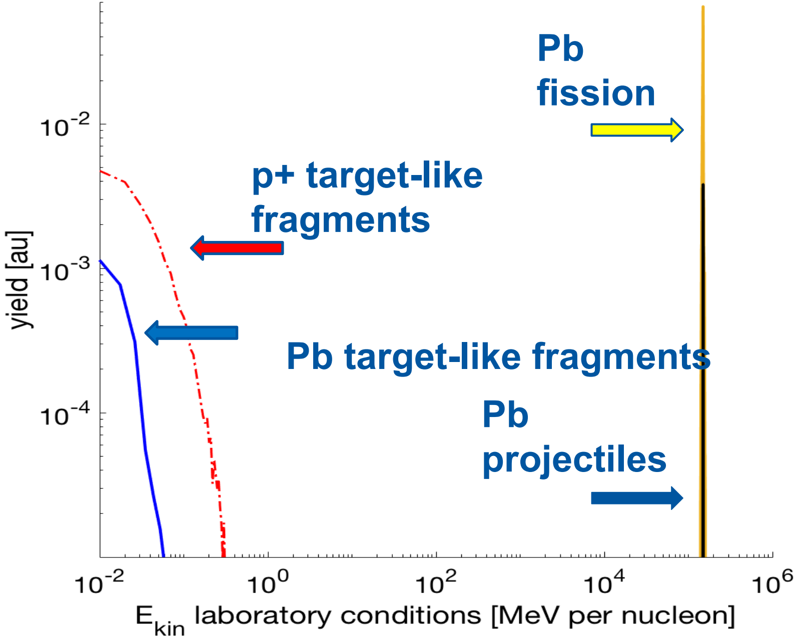
Z distribution similar only for target-like fragments Z ~14

Xe projectile-like peak

no fusion for UHE ions

Simulation of E_{kin} distribution on silicon

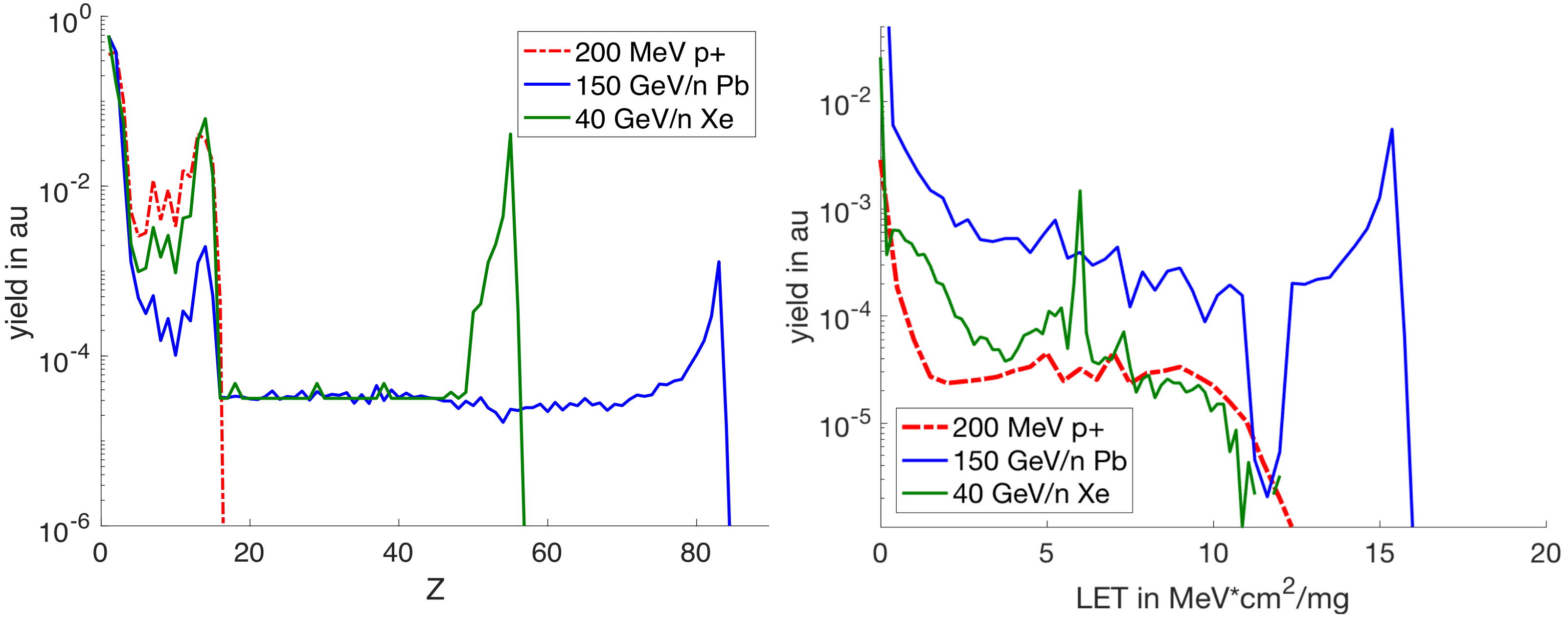
2. Step: The relation between LET, energy and Z



- kinetic energy for target-like fragments for UHE ions and protons very low!
- fission for 150 GeV/n Pb: $16.5 < Z < 80.5$
  - very high kinetic energy (comparable to the primary beam one)
- leading to a low LET, even if the primary ion is very heavy

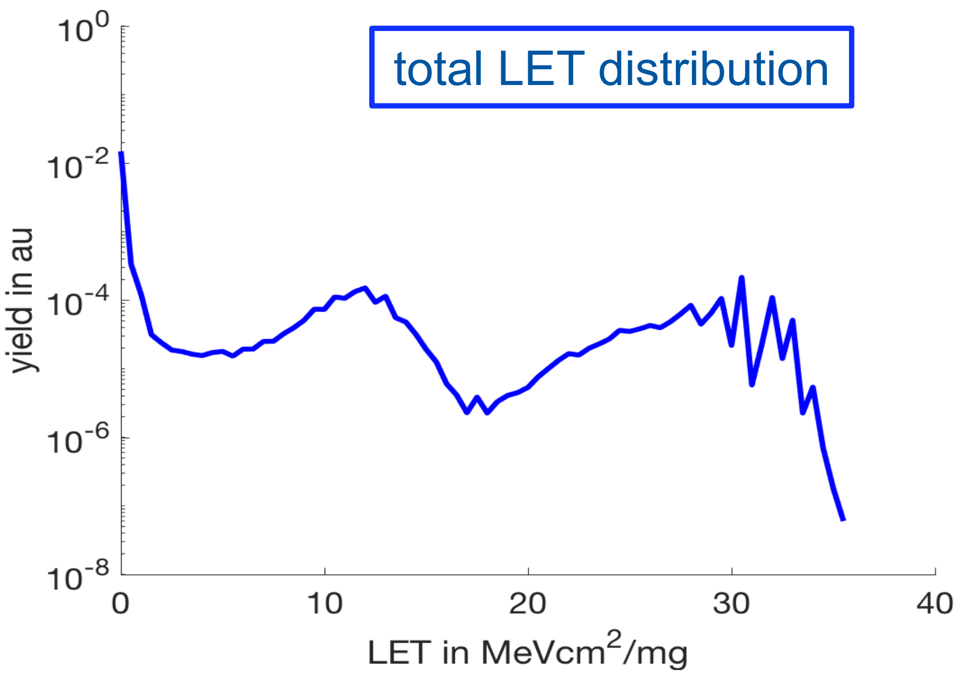
Simulation of full Z and LET distribution on silicon

2. Step: The relation between LET, energy and Z



Simulation of LET distribution of 9.3 MeV/n ^{40}Ar on silicon

3. Step: Different energy and Z but same LET



- Ar has a LET of 7.2 MeVcm^2/mg, but produces fragments with LETs over 30 MeVcm^2/mg
- double peak behavior stemming from:

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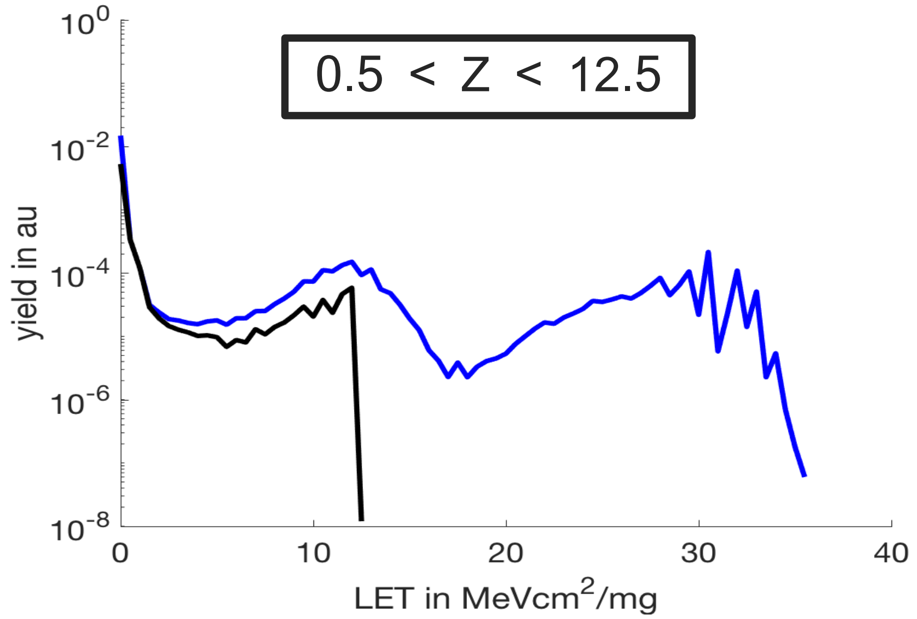

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  - light fragments (0.5 < Z < 12.5)

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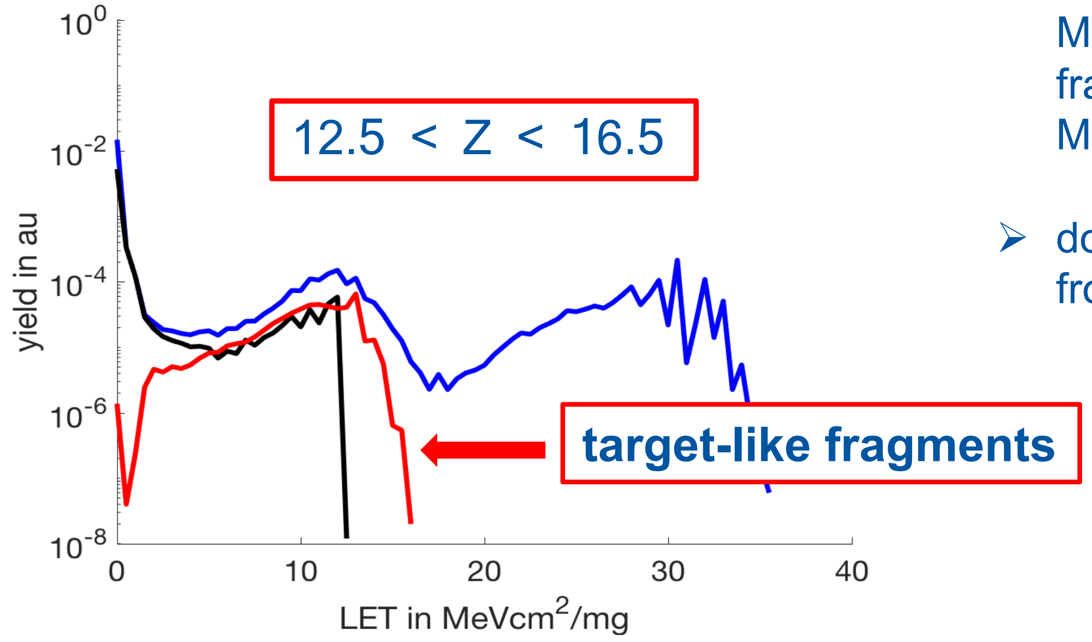

- Ar is having a LET of 7.2 $MeVcm^2/mg$, but produces fragments with LETs over 30 $MeVcm^2/mg$
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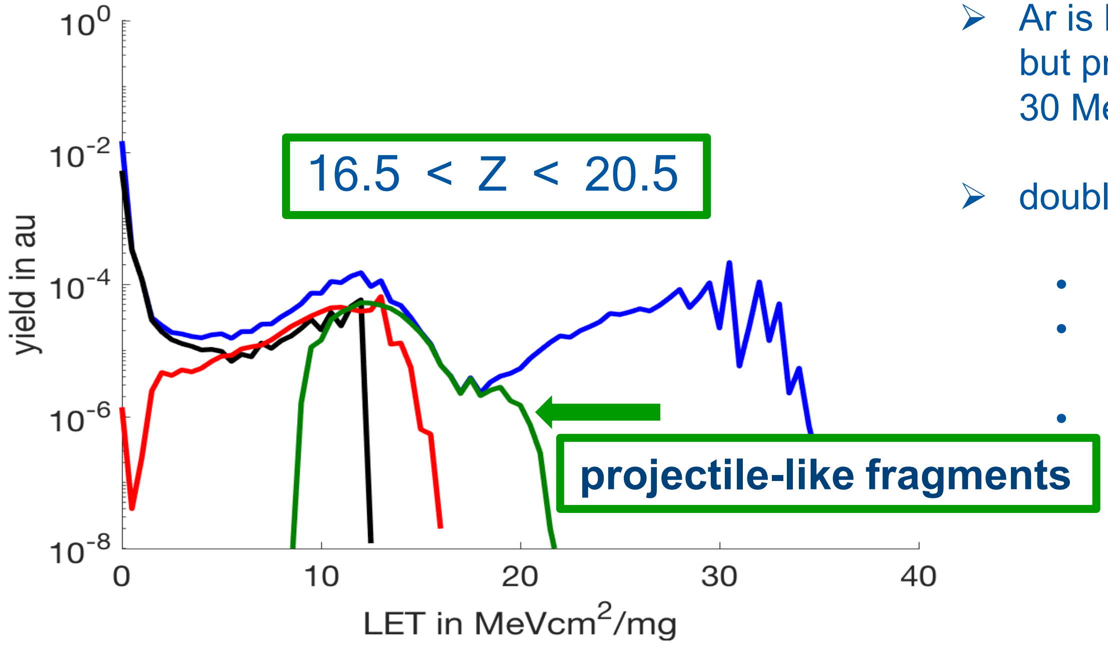

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  - projectile fragments (16.5 < Z < 20.5)

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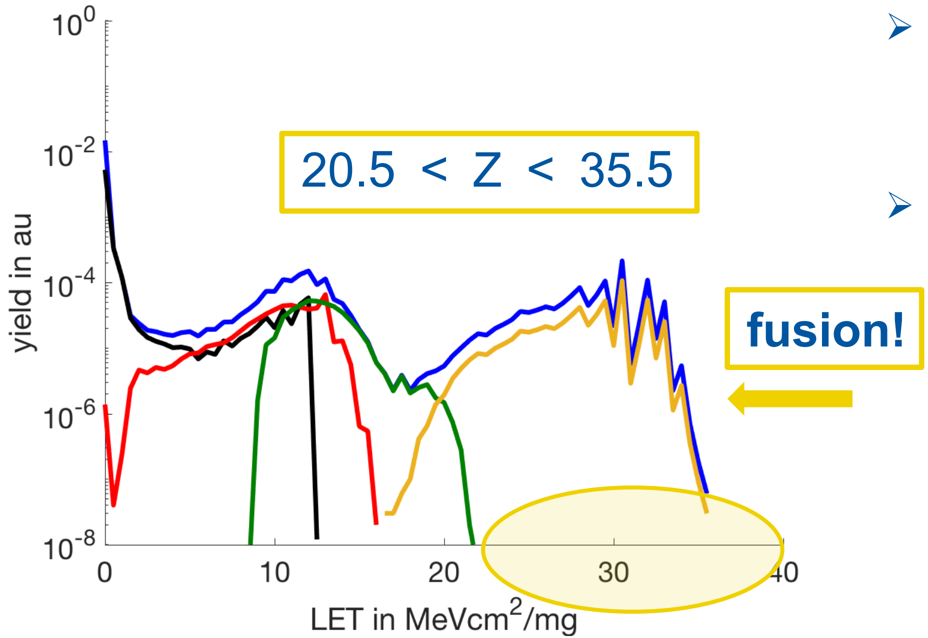

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- double peak behavior stemming from:
  - light fragments (0.5 < Z < 12.5)
  - target-like fragments (12.5 < Z < 16.5)
  - projectile fragments (16.5 < Z < 20.5)
  - fusion products (20.5 < Z < 35.5)

Simulation of LET distribution of 9.3 MeV/n ^{40}Ar on silicon

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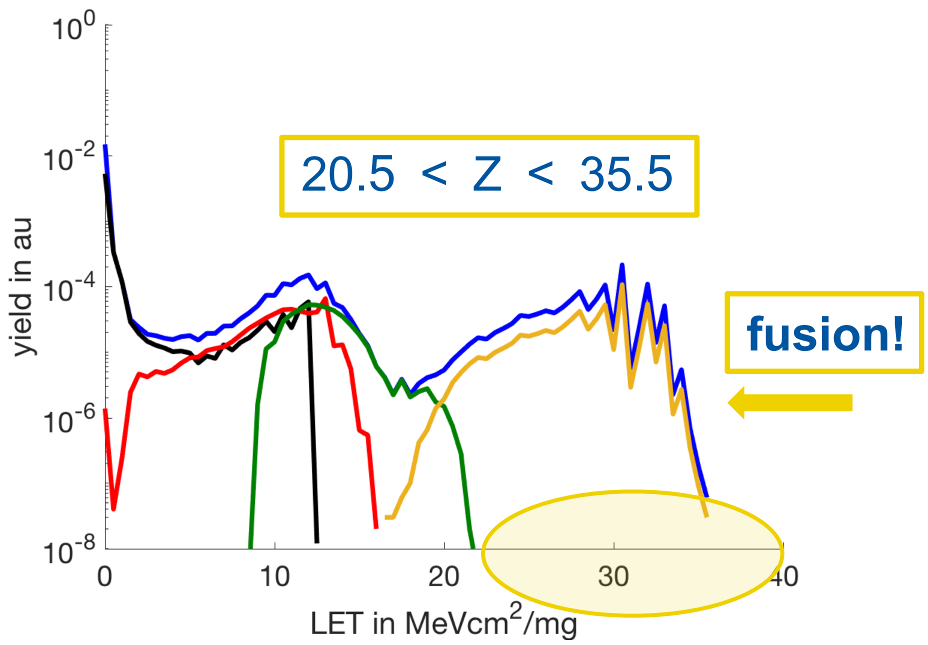

- Ar is having a LET of 7.2 MeVcm^2/mg, but produces fragments with LETs over 30 MeVcm^2/mg
  - fusion products (20.5 < Z < 35.5)
  - which present a LET value (> 30 MeVcm^2/mg) significantly above the possible LET of silicon fragments in silicon

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Calculation of the simulated heavy ion cross section

4. Step: Convolution of experimental cross section and simulated probability

$$\sigma_p\left(E_p\right) = \int \sigma_{HI}(E_d)p\left(E_p, E_d\right)dE_d$$

Experiment:
heavy ion cross section
as a function of
deposited energy

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heavy ion cross section as a function of deposited energy

Simulation:
probability that a particle of energy E_p deposits an energy E_d in the sensitive volume (FLUKA)

Calculation of the simulated heavy ion cross section

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4. Step: Convolution of experimental cross section and simulated probability

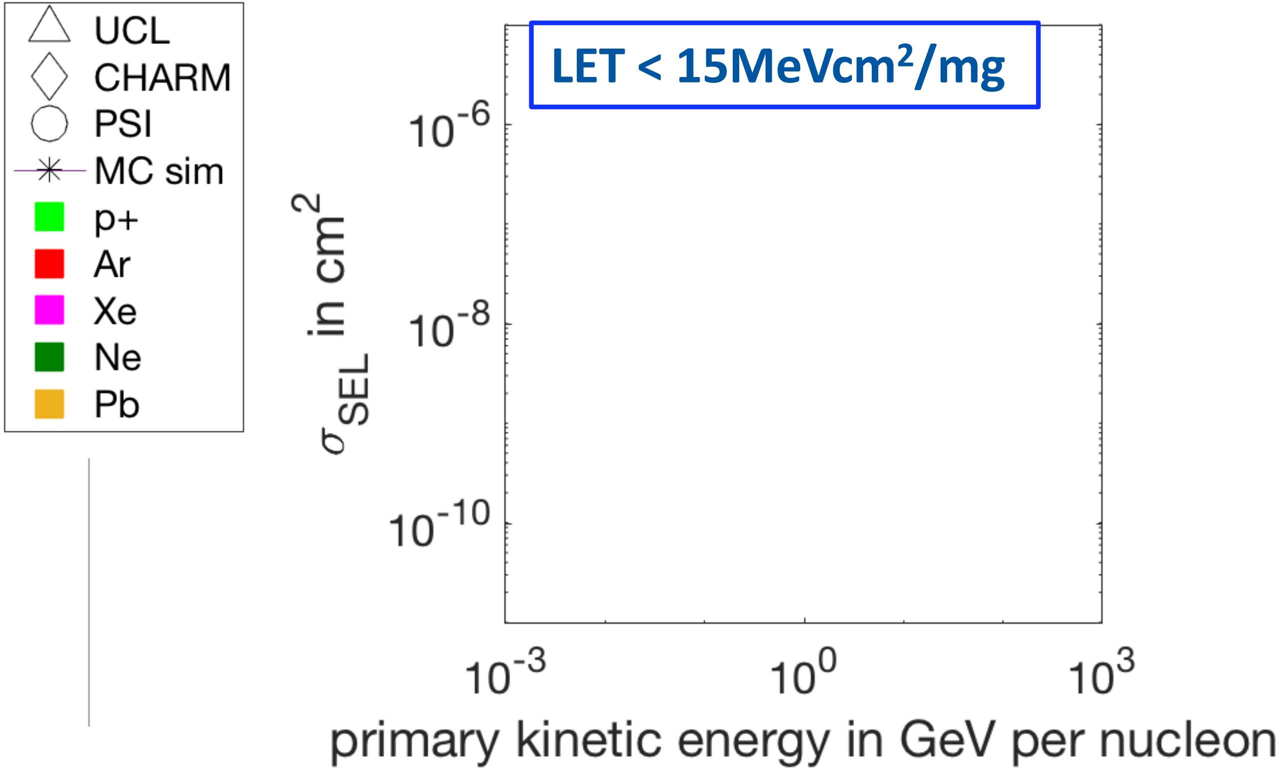
$$\sigma_p\left(E_p\right) = \int \sigma_{HI}(E_d)p\left(E_p, E_d\right)dE_d$$

Result:
particle SEE cross section

Experiment:
heavy ion cross section as a function of deposited energy

Simulation:
probability that a particle of energy E_p deposits an energy E_d in the sensitive volume (FLUKA)

Sub-LET for heavy ions and proton SEL cross section for a SRAM memory



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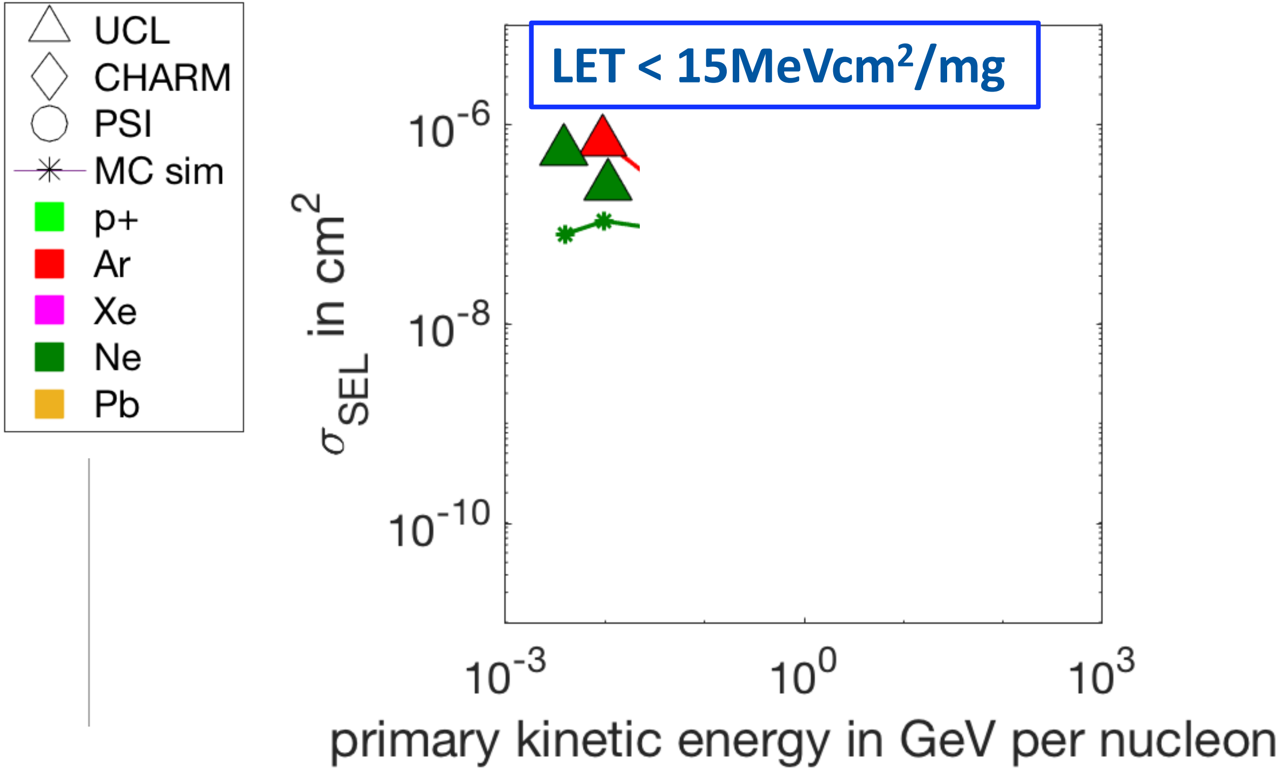

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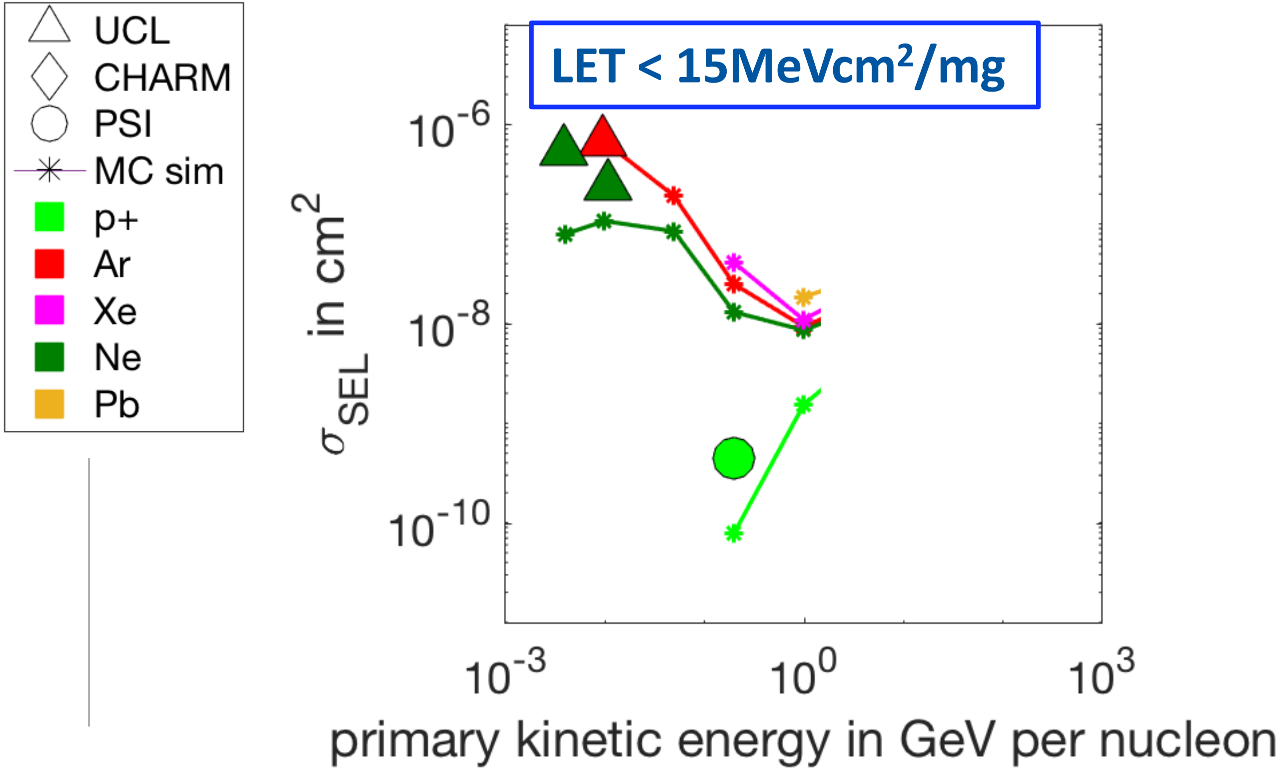

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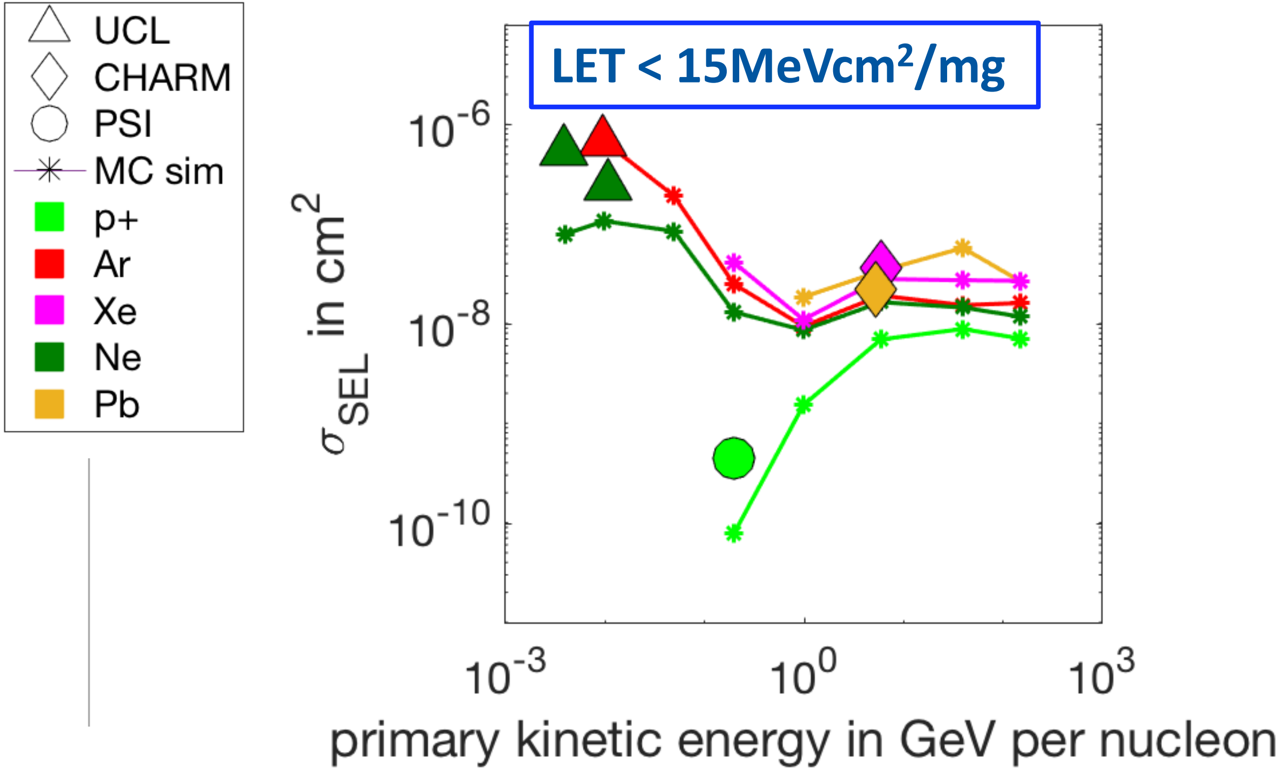

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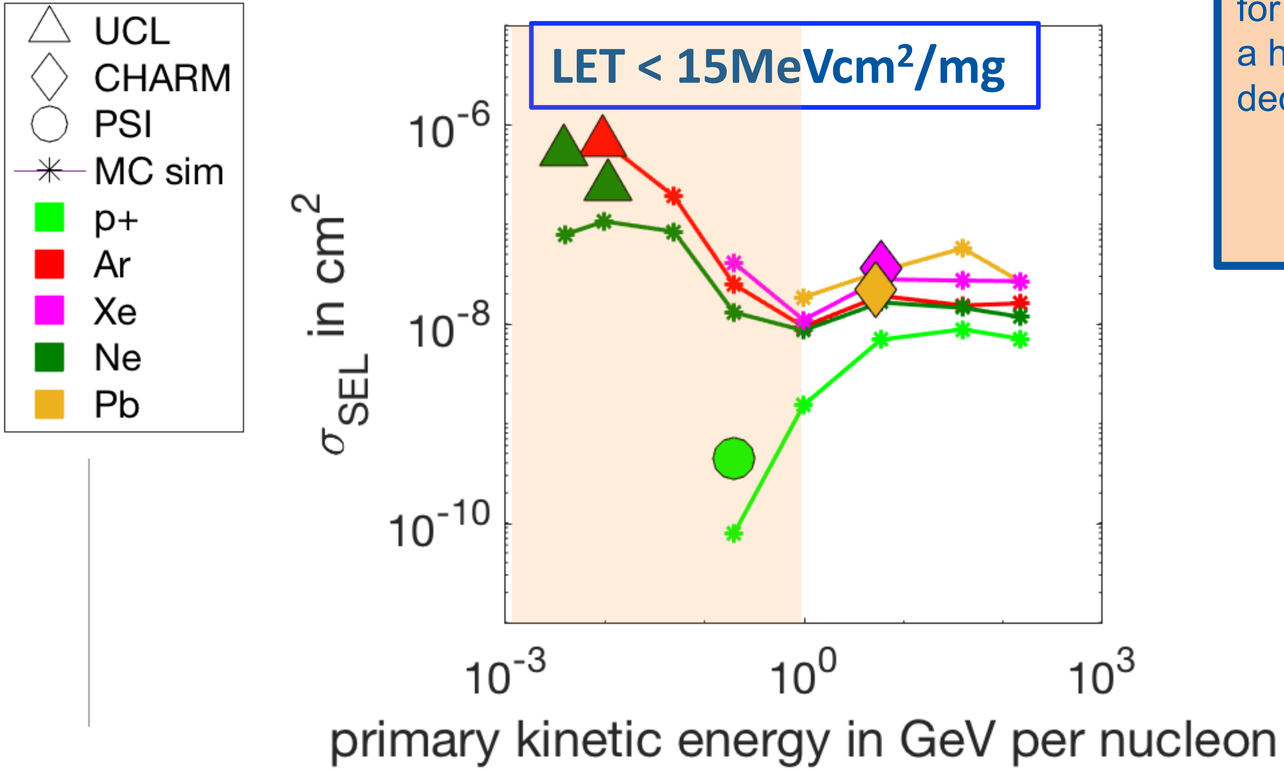

for low energies, heavy ions have a higher cross sections, which decreases with increasing energy

- caused by a decreasing fusion probability with energy

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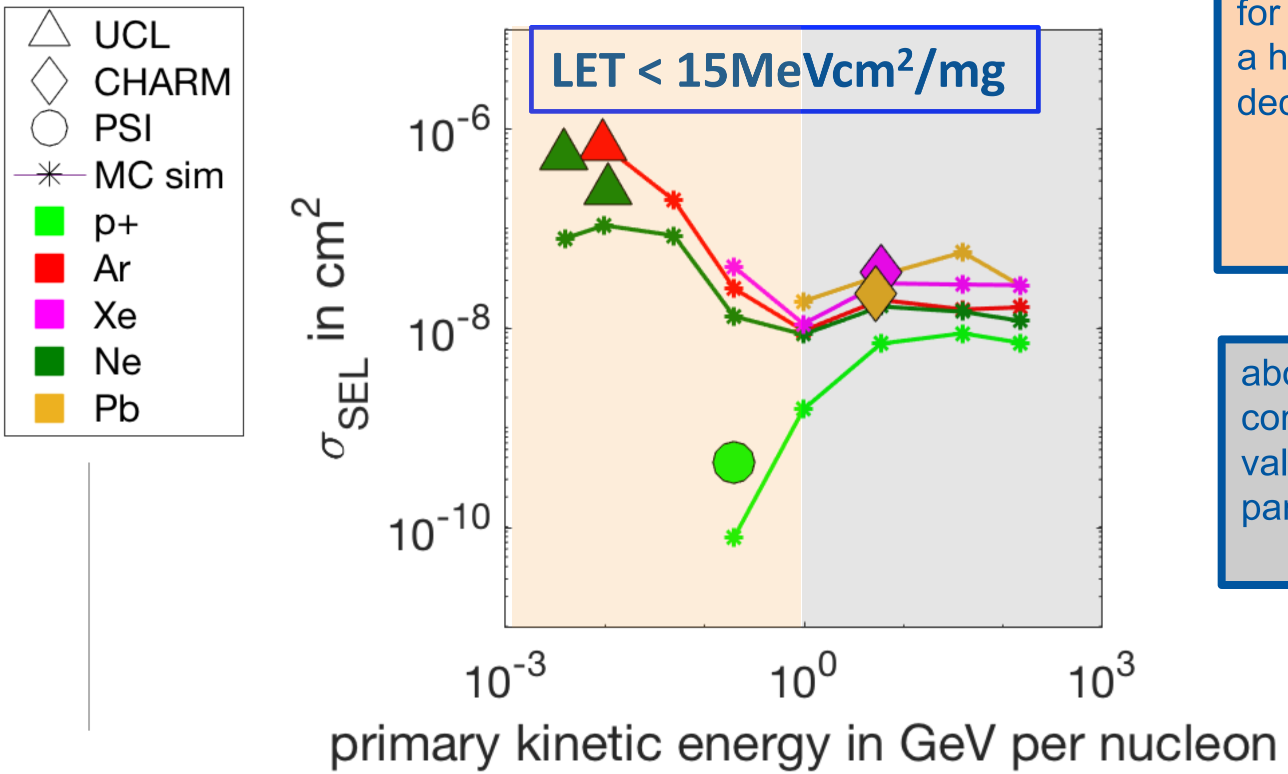

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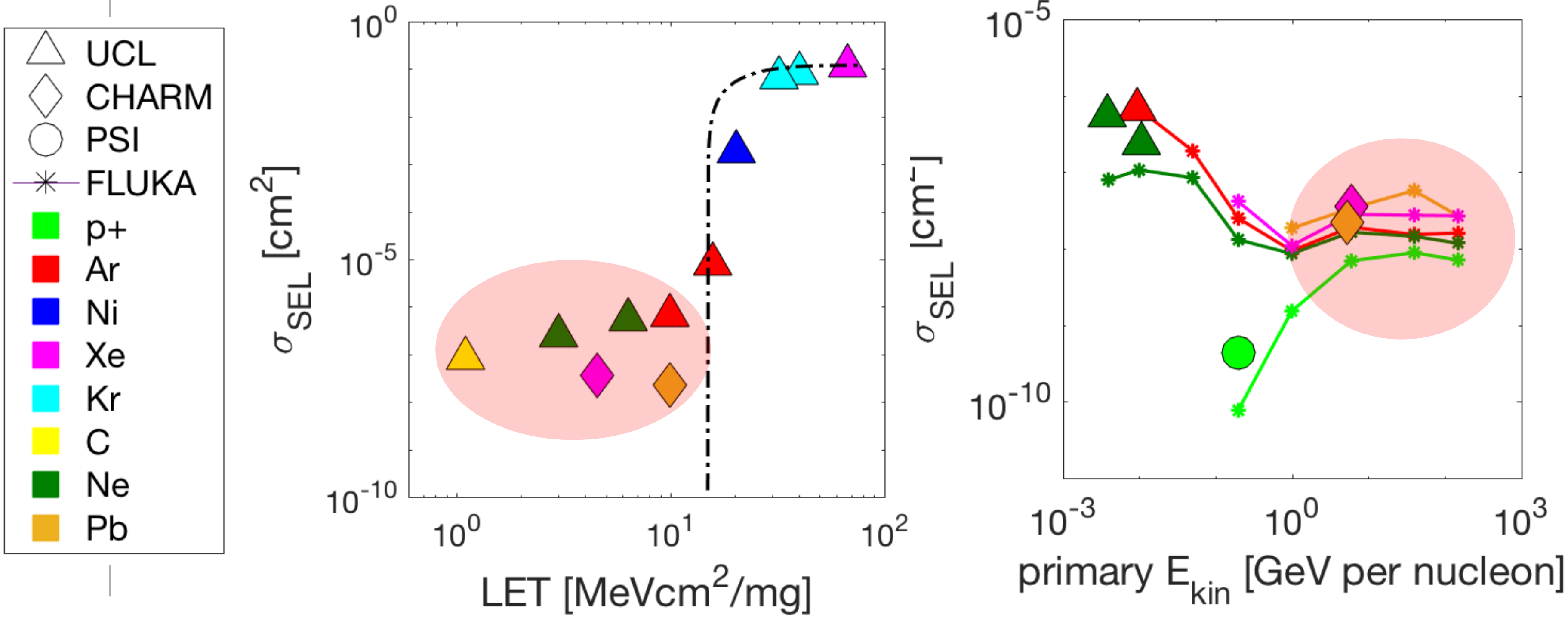
above 1 GeV/n: distributions are comparable and the saturation value is very similar for all particle species including protons

Coming back to the original hypothesis:



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Main Take-Aways:

- **For projectile E $_{kin}$ > 1 GeV/n**
  - UHE ions & high energy proton sub-LET SEE cross sections are similar
- **Fusion products:**
  - significant sub-LET impact, especially for low energy heavy ion beams (common for SEE space component tests)
- **Monte Carlo tools and associated SEE models** enables simulation of a broad variety of
  - particle species
  - energies

  ➢ highly relevant for estimations of SEE in space and high-energy accelerators

Main Take-Aways:

- **Very-high energy ions mainly produce:**

    i. target-like fragments, with LETs similar to those produced in proton interactions

    ii. fission-like fragments, lighter and with an energy per nucleon similar to the projectile's one, and hence a lower LET

- **Lower energy ions** can induce fusion reactions, generating larger LET products

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Other aspects of my work

- Longitudinal energy deposition mechanisms
- Dosimetry work
  - related to the heavy ion test campaign 2018 using a medical QA ionization chamber array and gafchromic films
- Very High Energy Electron tests at CLEAR (CERN):
  - Dosimetry purposes with different medical ionization chambers
  - Flash SEE experiments with an ESA SEU monitor
  - Gafchromic film measurements
- Contribution to other publications, related to the heavy ion test campaigns

Outlook:
UHE beams around the world

Thank you!

It was a great journey