Linear Energy Transfer of Heavy Ions in Silicon

by

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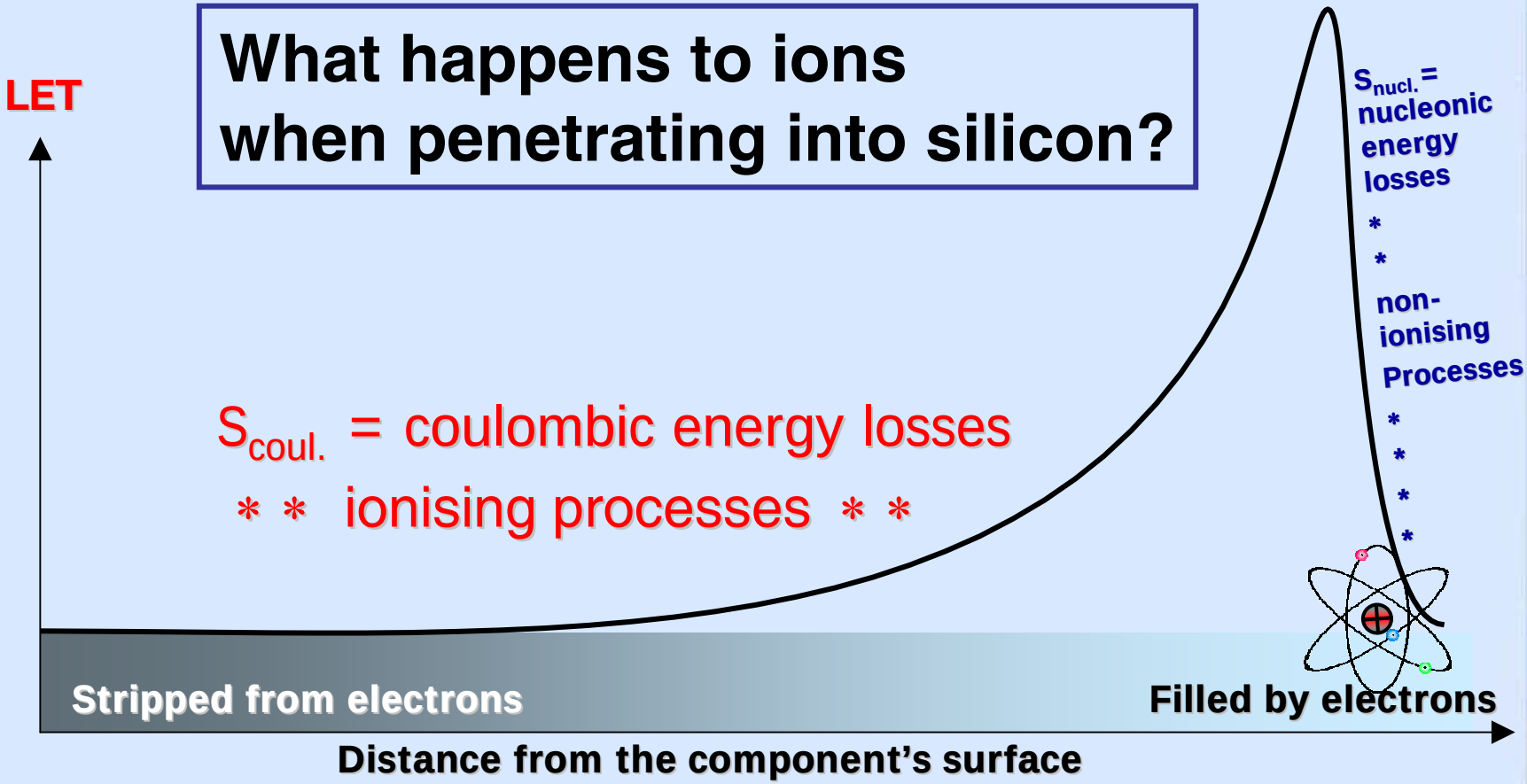
What happens to ions when penetrating into silicon?



$$S_{stopping\ power} = S_{coul.} + S_{nucl.} \approx LET + NIEL$$

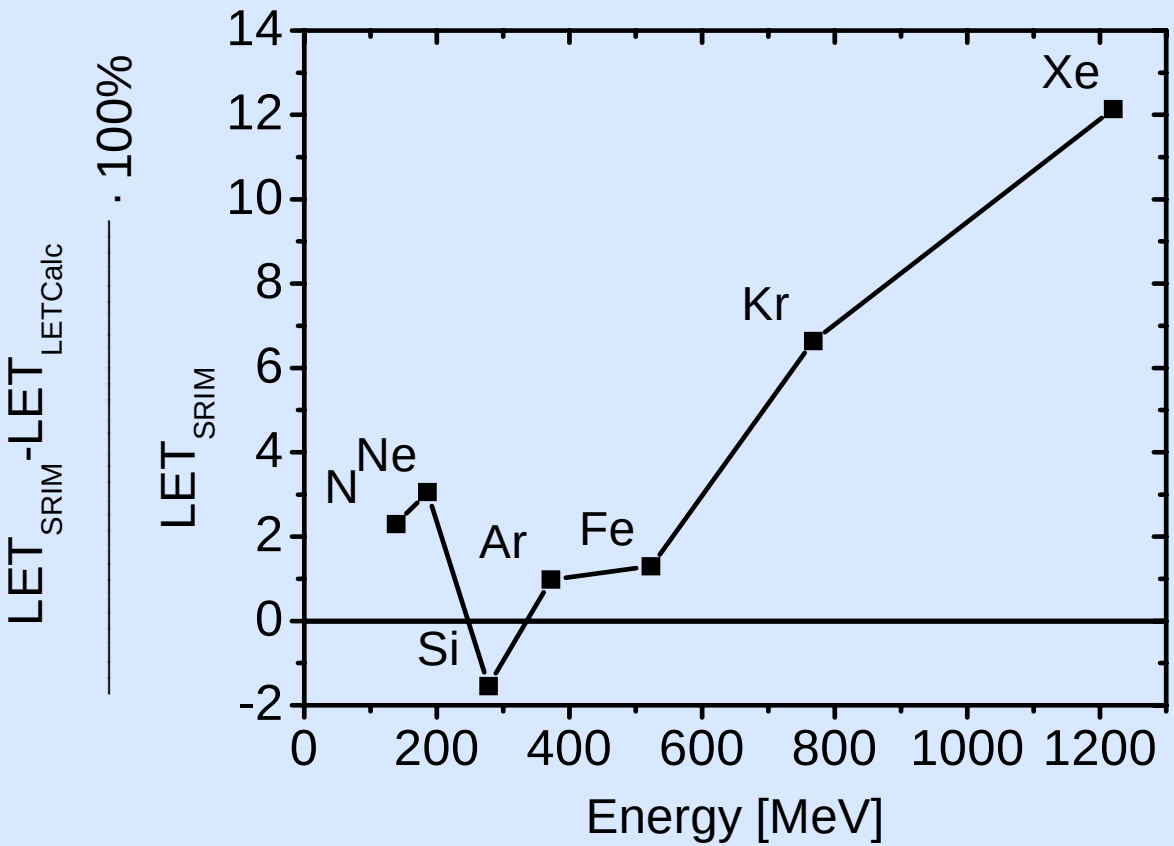
Described by semi-empirical codes based on Bethe-Bloch formula

Different codes give different LET values

For example, the two most commonly used codes are:

SRIM……The Stopping and Range of Ions in Matter by Ziegler et al., *http://www.srim.org*

LETCalc..LET Calculator developed by Brookhaven National Laboratory, *http://www.tvdg.bnl.gov*



Break points of the study project

May 2005: The question was picked up in the 1st RADECS Thematic Workshop in Jyväskylä → a workgroup to find ways for harmonising LET and range values in different test laboratories was formed…

September 2005: The group met in RADECS2005, Cap d'Agde, and decided to consult the stopping power experts in Jyväskylä.

Spring 2006: A research proposal was submitted and the experiment carried out in March

September 2006: Results were introduced in RADECS2006, Athens

January 2007: The paper accepted to IEEE-TNS

- Linear Energy Transfer of Heavy Ions in Silicon, A. Javanainen*, T. Malkiewicz, J. Perkowski, W. H. Trzaska, A. Virtanen*, G. Berger*, W. Hajdas*, R. Harboe-Sørensen*, H. Kettunen, V. Lyapin, M. Mutterer, A. Pirojenko, I.Riihimäki, T. Sajavaara, G. Tyurin, H. J. Whitlow, Proc. RADECS2006 Workshop, September 27-29, 2006, Athens, Greece

** = workgroup member*

Experimental setup

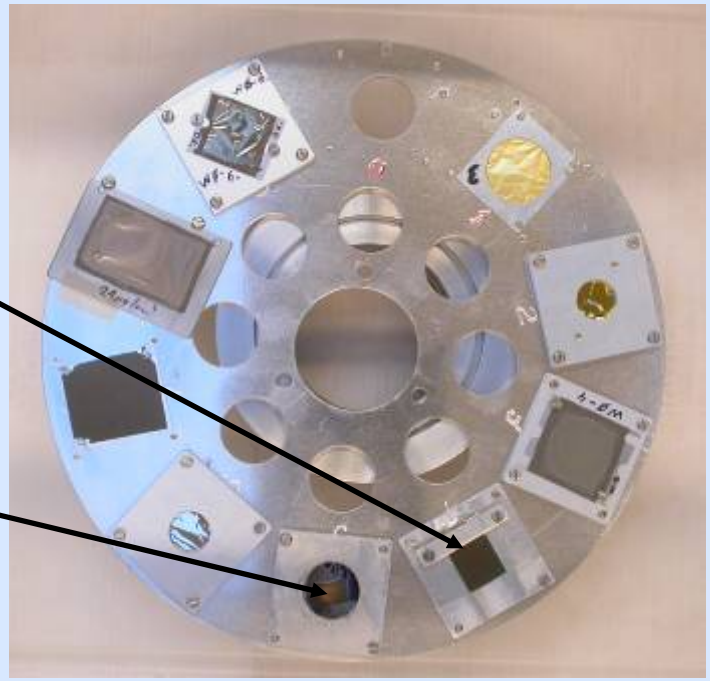
Time-of-flight spectrometer used to determine energies with and without target foils

Targets used

Two silicon foils:

- CHICSi*)-type ΔE-detector with evaporated layers removed:
d = (2.92 ± 0.03)mg/cm^2 = 12 µm

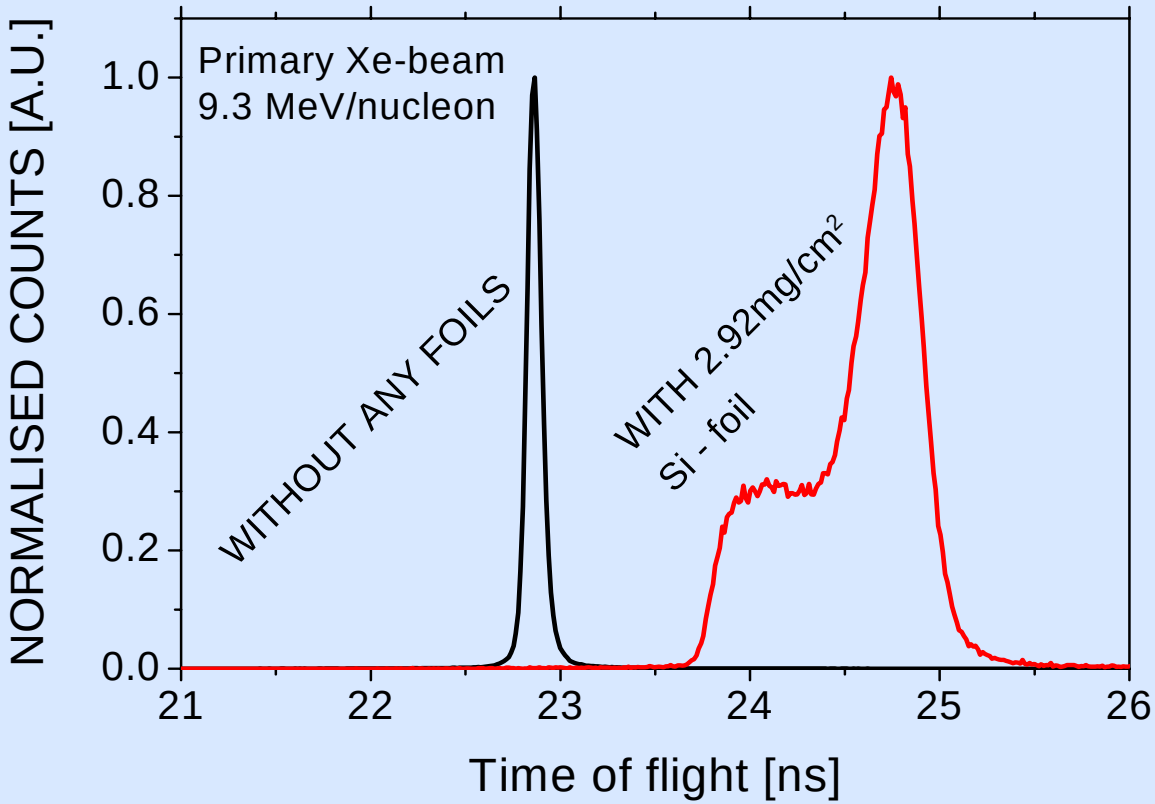
- self-supporting sample made by etching from single crystalline Si<110> wafer
d = (0.300 ± .003)mg/cm^2 = 1.2 µm



*)CELSIUS Heavy Ion Collaboration Silicon

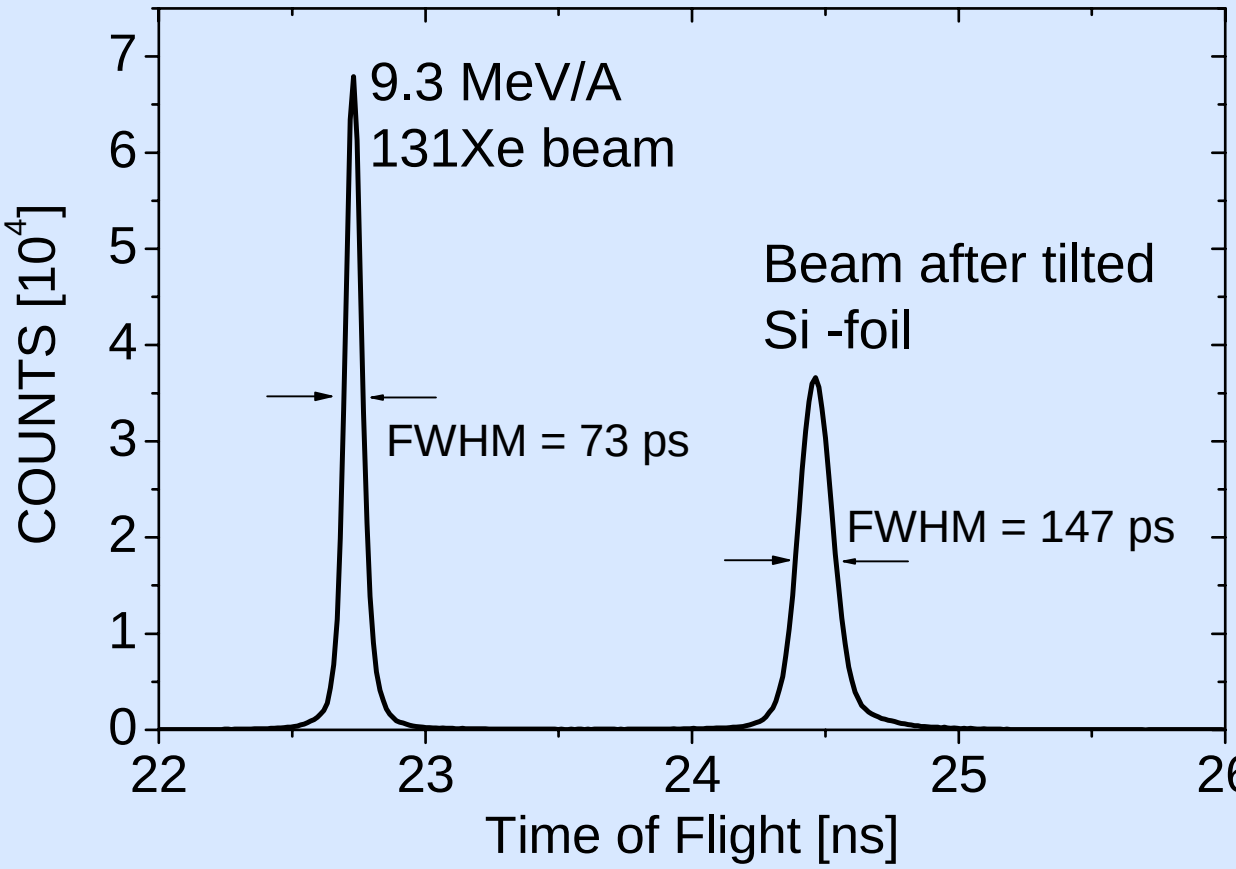
Channeling effect

- Strong channeling effect was observed in both samples



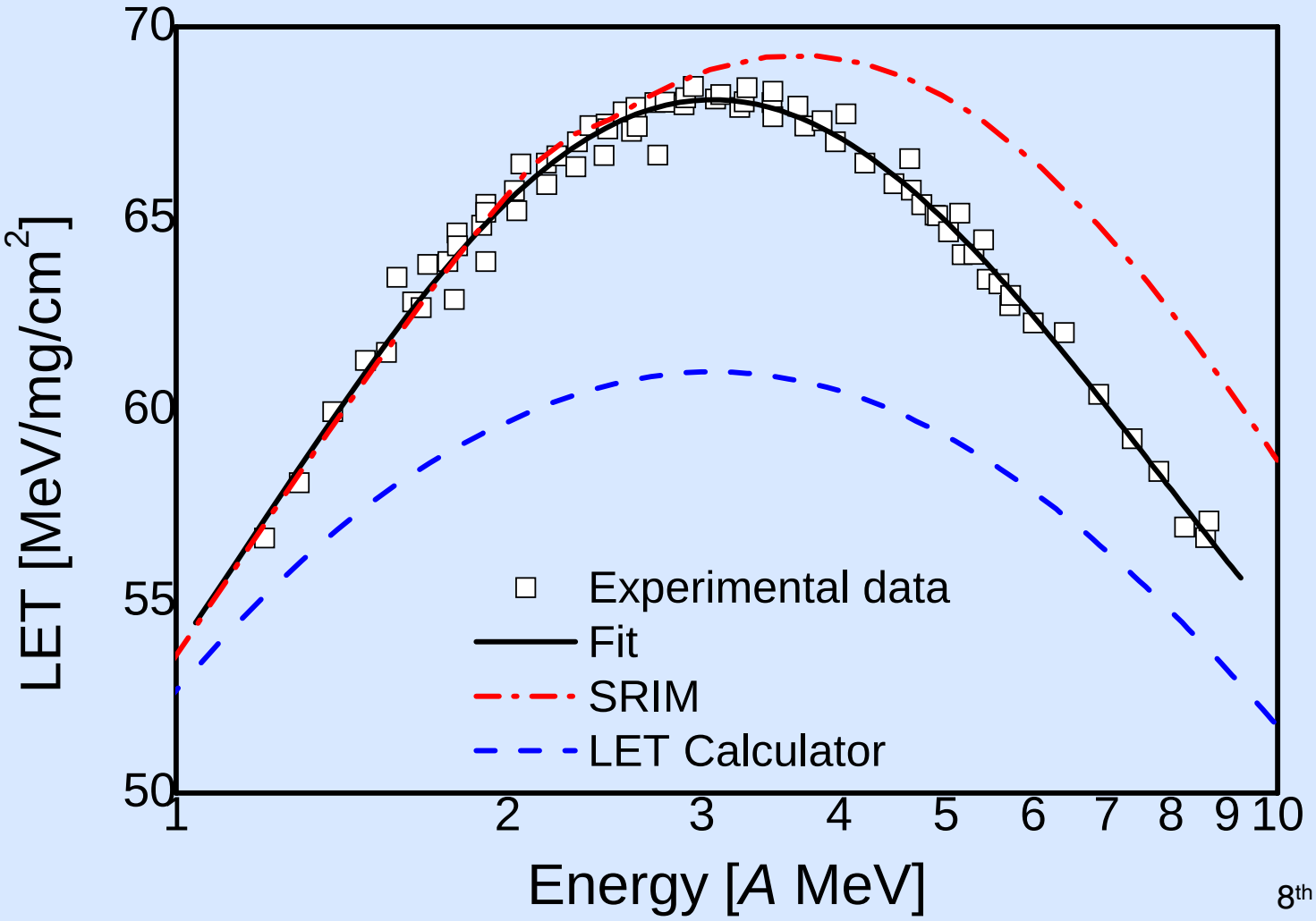
- Problem solved by tilting the foils few degrees

Resolution of the measurement setup



24.1.2007
8th QCA Days
Louvain-la-Neuve

Results: ^{131}Xe in Si



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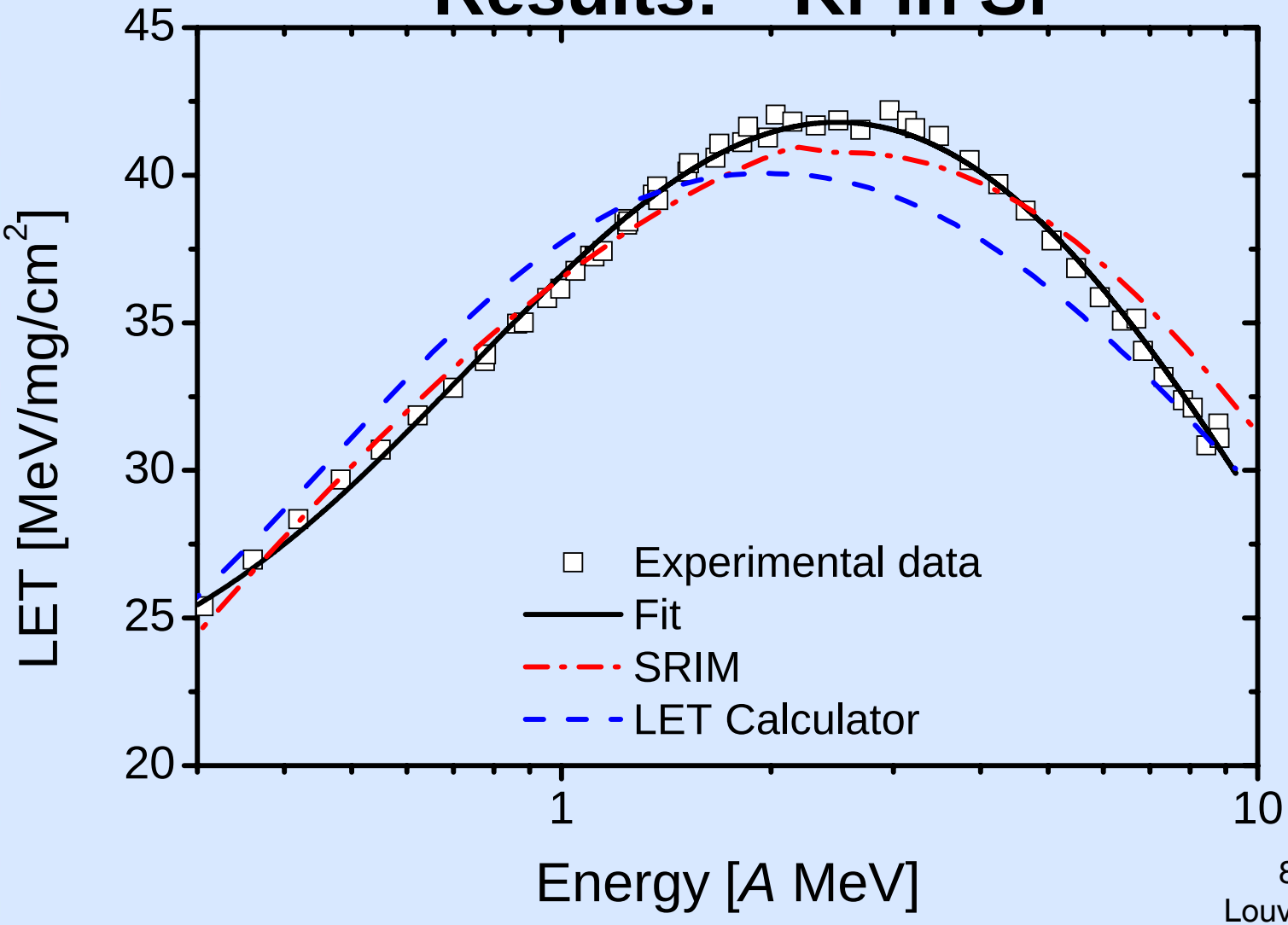
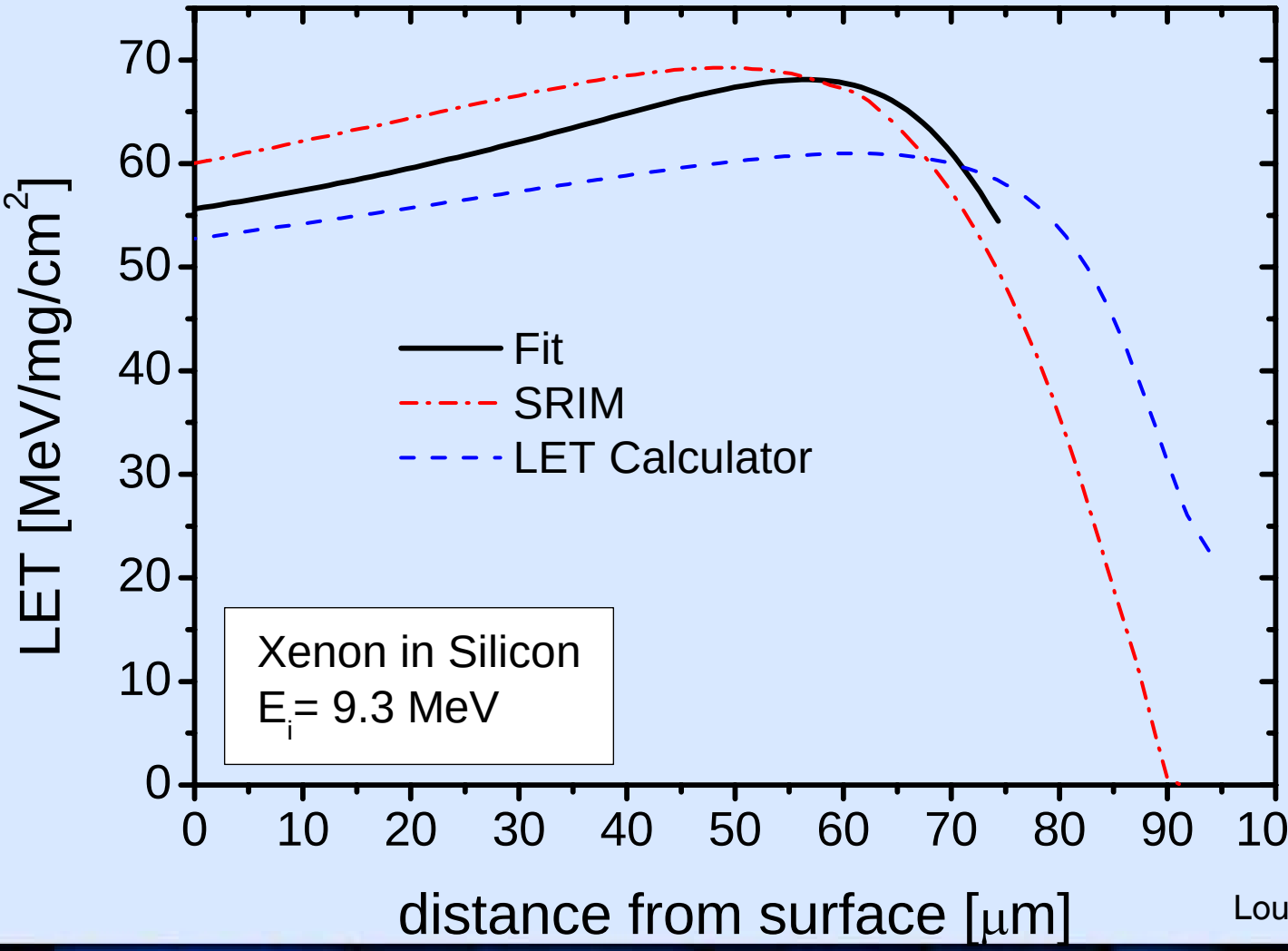
Results: ^{82}Kr in Si



LET vs. penetrated distance



Comments and recommendations

Reviewer 1 Comments:

This paper describes very important subject to the community … **will provide excellent base line towards developing good simulation code for the common LET estimation**…, the referee supports the publication of the current draft.

Reviewer 2 Comments:

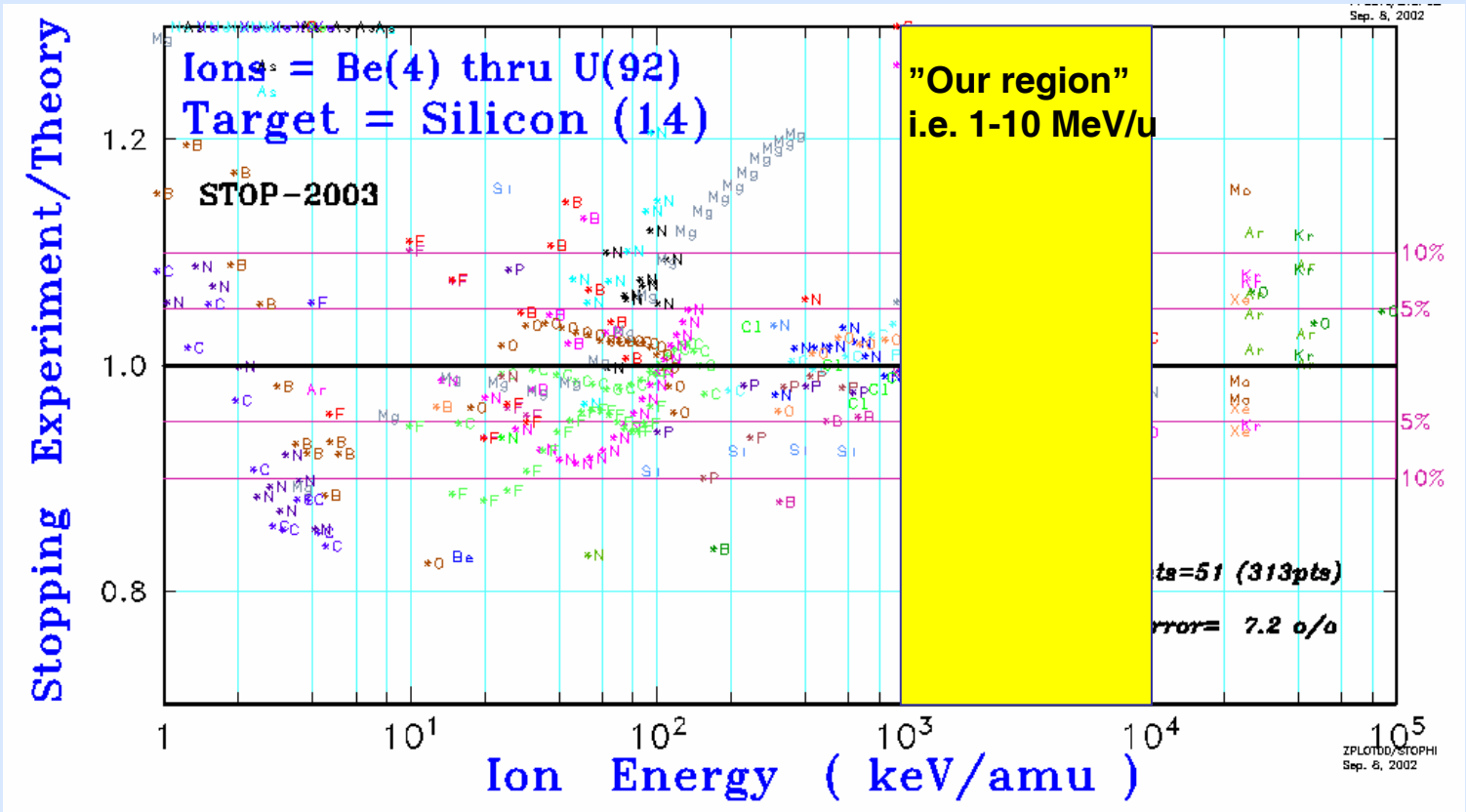
Your paper is the beginning of an interesting analysis about the ion LET in silicon ICs. The paper shows a significant discrepancy between the predicted LET (simulated with SRIM and the LET Calculator) and your experimental measurements.

…

MA: **How do you interpret the differences between the simulated results and your experimental data?** What do you think is not correctly modeled in the codes (SRIM, LET Calculator). You only mention the fact that SRIM and LET Calculator assume **an amorphous target** instead of a crystalline structure. It I would like you to develop **does not explain the difference between the two codes themselves**. the interpretation of your observations. This point is important. It will give a real value to your paper.

MI: **I suggest that if you have additional results (another ion), it might be good to include them in the paper.**

SRIM data base for silicon target



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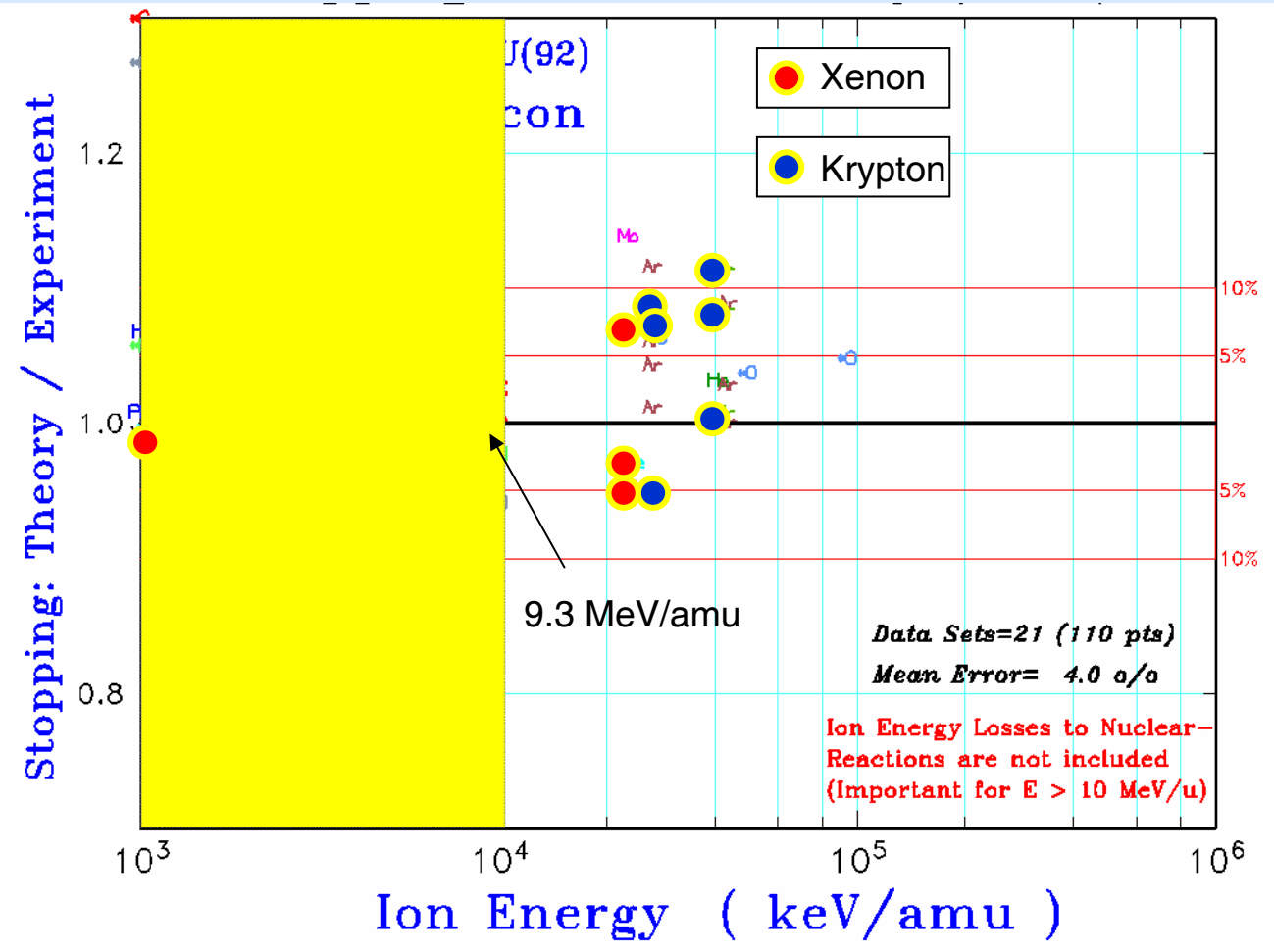
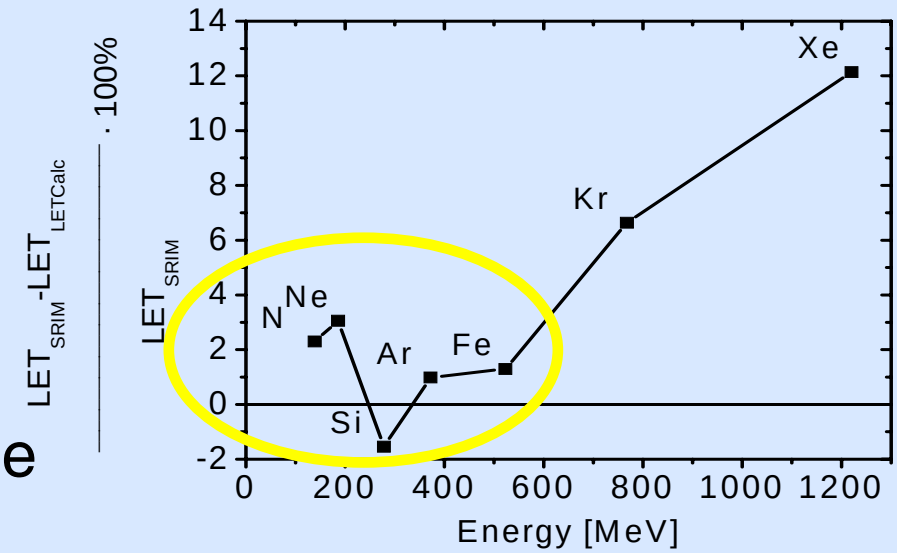


http://www.srim.org

FUTURE ACTIONS?

Still five ions to go

If our data would be implemented in SRIM code, will the accuracy be good enough?



Or is there a need for community's own LET-calculator for the proper energy range (E > 1 MeV/u) and ions?

Conclusions

Experimental LET for Xe and Kr in Si defined at 1-10 MeV/u
- –differs from simulated estimates; e.g. Xe 8% for SRIM

Recent simulation tools only ”indicative” when E > 1 MeV/u
- –especially important when irradiating from rear and DUT’s exact thickness not known accurately
- –more energetic ions would also help this

Community has clear need for more accurate LET and range estimates at proper energy range for certain ions
- –whether the recent codes will be improved
- –or we make our own LET/range calculator

THANK YOU FOR YOUR ATTENTION!

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