Heavy ion LET in Silicon

Workgroup Final Report

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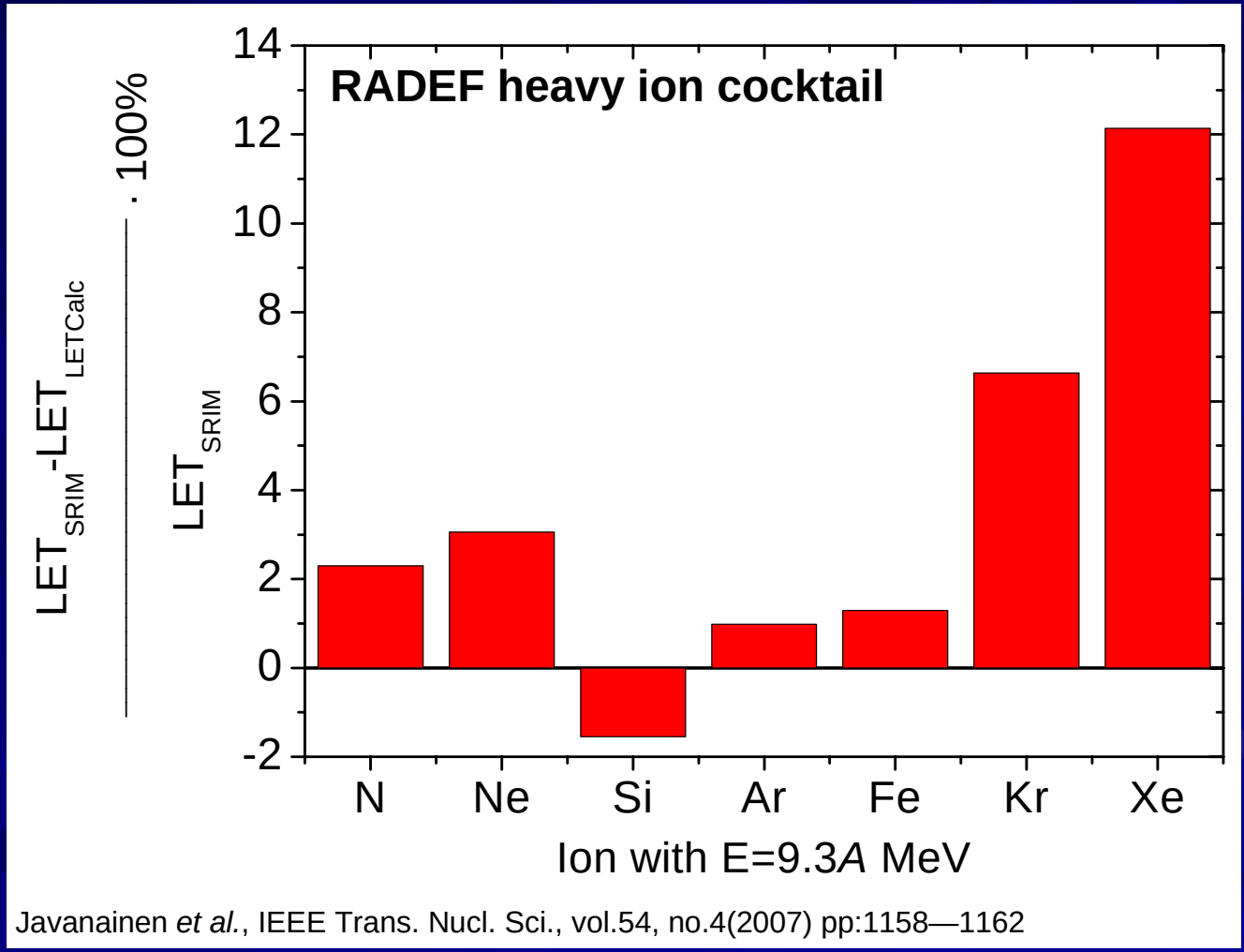
RADECS Thematic Workshop on European SEE Accelerators

- 26th of May 2005 in Jyväskylä
- In the Round Table discussions, questions were raised about the inconsistence in LET values
- Workgroup was formed
  - **Members**: *Reno Harboe-Sørensen, Ari Virtanen, Wojtek Hajdas, Guy Berger and Arto Javanainen*
  - Due to the stopping power expertise, JYFL/RADEF was chosen to run the experiments

Estimated LET values

- Inconsistent LET values (may) have been used in the past
- Values are estimated mainly by using semi-empirical codes:
  - SRIM (various versions)
  - BNL LET Calculator (modified version of older TRIM/SRIM)
    - + Easy access (www), user-friendly interfaces, variety of different energy/ion/target combinations with reasonable accuracy
    - ± Semi-empirical → some experimental data and the rest is derived from the parameterized theory
    - – Due to coarse experimental database, the heavy ion estimates may give inconsistent values
- Maximum deviation of ~10% between code estimates
  - "The heavier the ion, the higher the divergence"

Inconsistence in the estimations



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Heavy ion LET Experiments

- Series of experiments: 2006-2008
  - Beam times were applied from the PAC
- New method developed for stopping measurements
  - B-TOF: Time-Of-Flight (res. <100ps) combined with magnetic dipole
- 7 ions measured:
  - **^{15}N, ^{20}Ne, ^{30}Si, ^{40}Ar, ^{56}Fe, ^{82}Kr, ^{131}Xe**
  - RADEF heavy ion cocktail species
- Two Si-samples: ~**1 µm** and ~**12 µm**
- Energy range: from 0.2*A* MeV to 9.3*A* MeV
- Previously *unpublished* experimental data at this energy range for: *Ne, Ar, Fe, Kr and Xe*
- "Scientific outcome" … so far:
  - 2 presentations in RADECS2006 (oral) and RADECS2008 (poster)
  - 2 publications in IEEE TNS

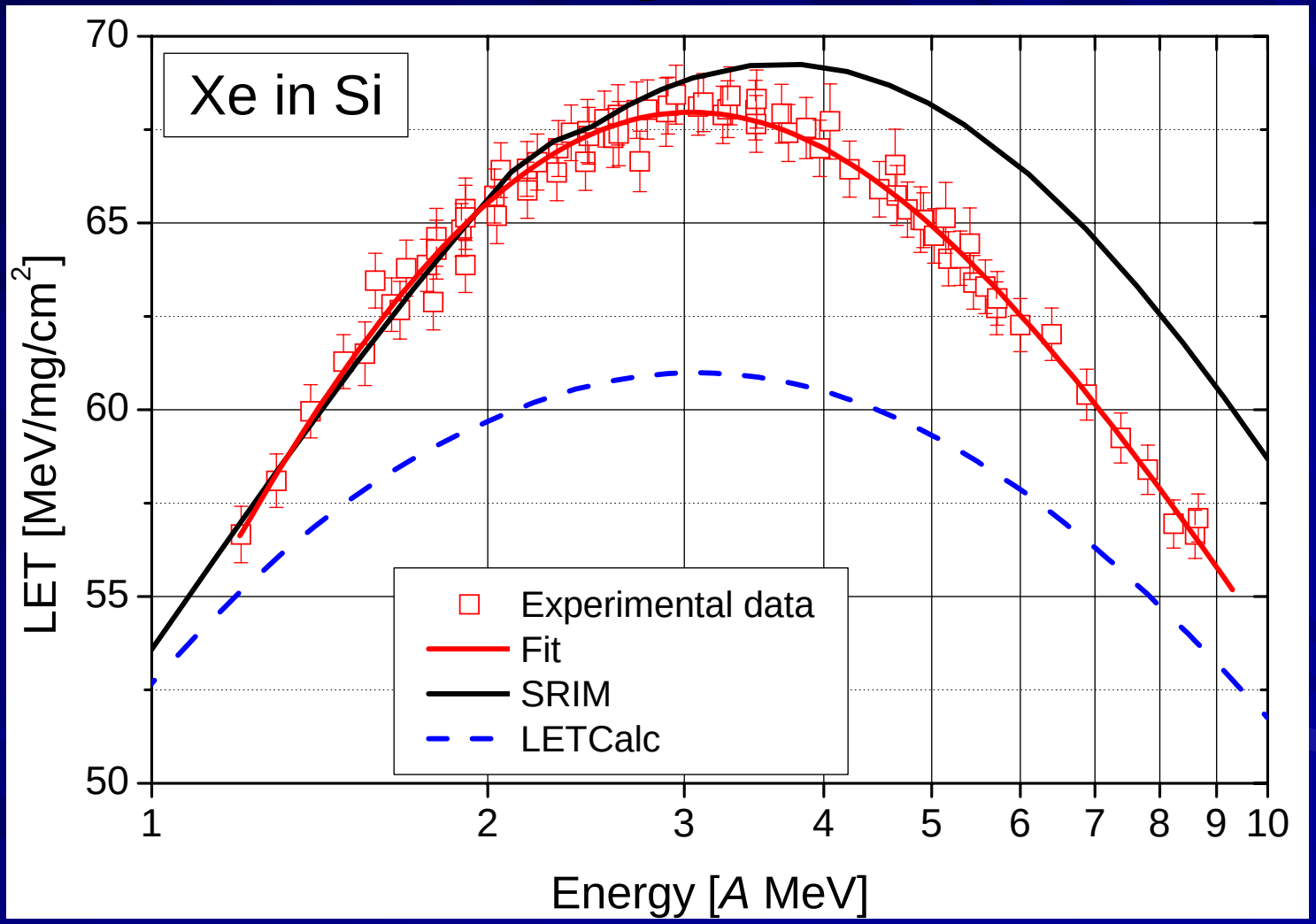
LET in Si

– Results and Comparison -

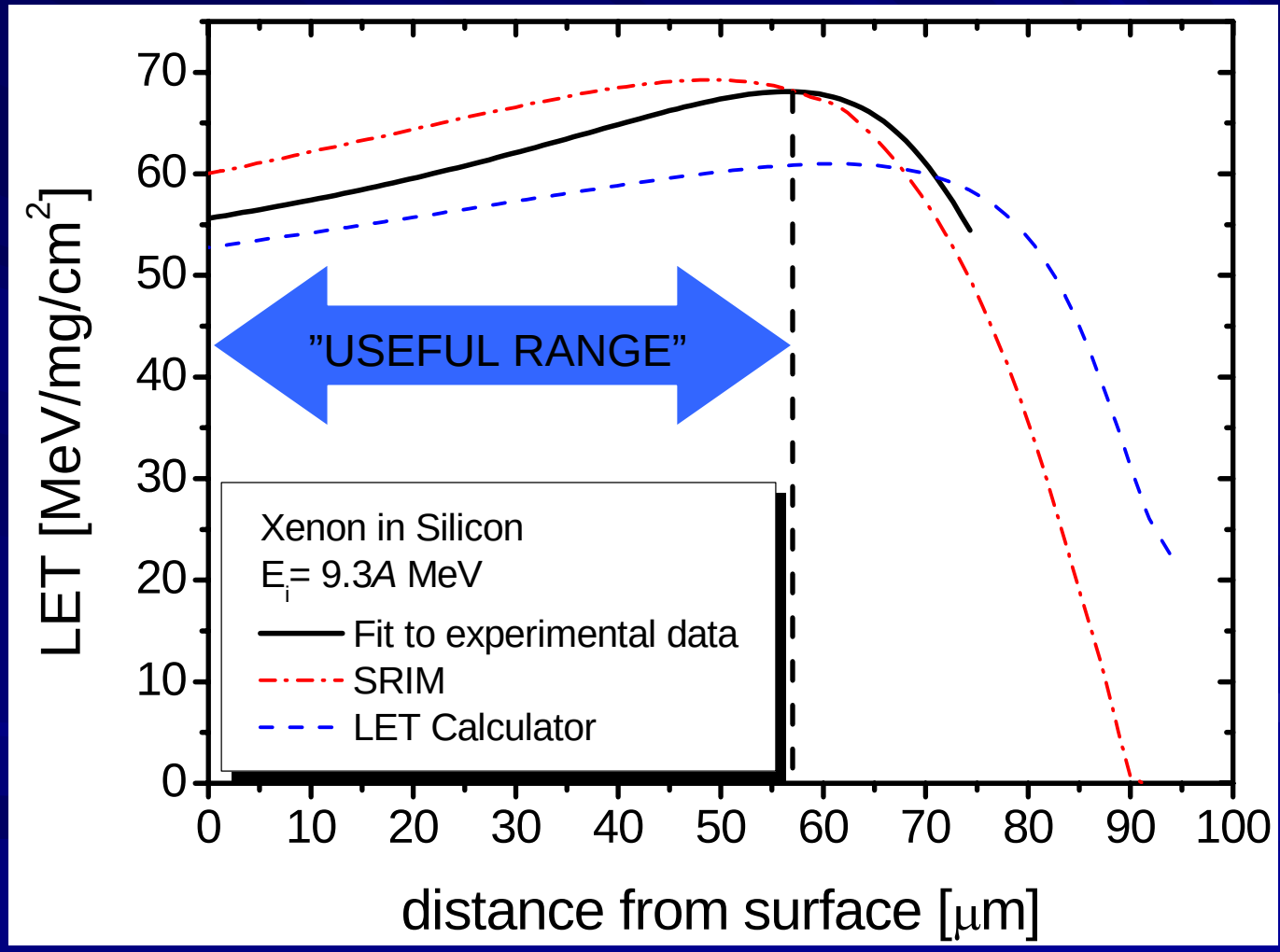
Energy = 9.3*A* MeV; $\sigma LET_{MEAS} < 3\%$

ION	LET_{MEAS} [MeV/mg/cm^2]	LET_{SRIM} [MeV/mg/cm^2]	LET_{LETC} [MeV/mg/cm^2]
^{15}N	**1.88**	**1.83** (-2.7%)	**1.78** (-5.3%)
^{20}Ne	**3.64**	**3.63** (-0.3%)	**3.52** (-3.1%)
^{30}Si	**6.73**	**6.40** (-4.9%)	**6.50** (-3.3%)
^{40}Ar	**10.1**	**10.2** (+1.0%)	**10.0** (-1.0%)
^{56}Fe	**18.5**	**18.6** (+0.5%)	**18.3** (-1.1%)
^{82}Kr	**30.2**	**32.2** (+6.6%)	**30.0** (-0.7%)
^{131}Xe	**55.3**	**60.0** (+8.5%)	**52.8** (-4.5%)

Example data



LET behavior inside the Si-substrate - The Bragg curve -



”Enhanced” LET in Bragg peak

derived from the experimental data

ION	LET@ surface [MeV/mg/cm²]	LET @ Bragg peak [MeV/mg/cm²]	“Enhancement” factor
^{15}N	**1.88**	**5.89** (192 µm) -6µm	3.13
^{20}Ne	**3.64**	**9.47** (139 µm) ±0µm	2.60
^{30}Si	**6.73**	**13.9** (116 µm) -4µm	2.07
^{40}Ar	**10.1**	**19.0** (99 µm) -6µm	1.88
^{56}Fe	**18.5**	**29.9** (75 µm) -2µm	1.62
^{82}Kr	**30.2**	**42.2** (68 µm) -1µm	1.40
^{131}Xe	**55.3**	**68.0** (57 µm) +9µm	1.23

Conclusions

- LET values for various heavy ions (RADEF cocktail) in silicon has been experimentally defined
  - Previously unpublished data
- Values will be available in the RADEF website
  - http://www.jyu.fi/accelerator/radef
- Differences between “new” and “old” values up to 8.5%
- Future?
  - Simple calculator based on these results…
  - Measurements:
    - High energy heavy ions @ GANIL (Kr, Xe @ 40-70*A* MeV?)
    - More ions?, Other targets?, SiO_2, Ge, etc.? Need?

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