Altitude and underground real-time SER characterization of SRAM memories

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2nd LSM-EXTENSION WORKSHOP - OCTOBER 16th 2009 - Modane, France

Acknowledgments

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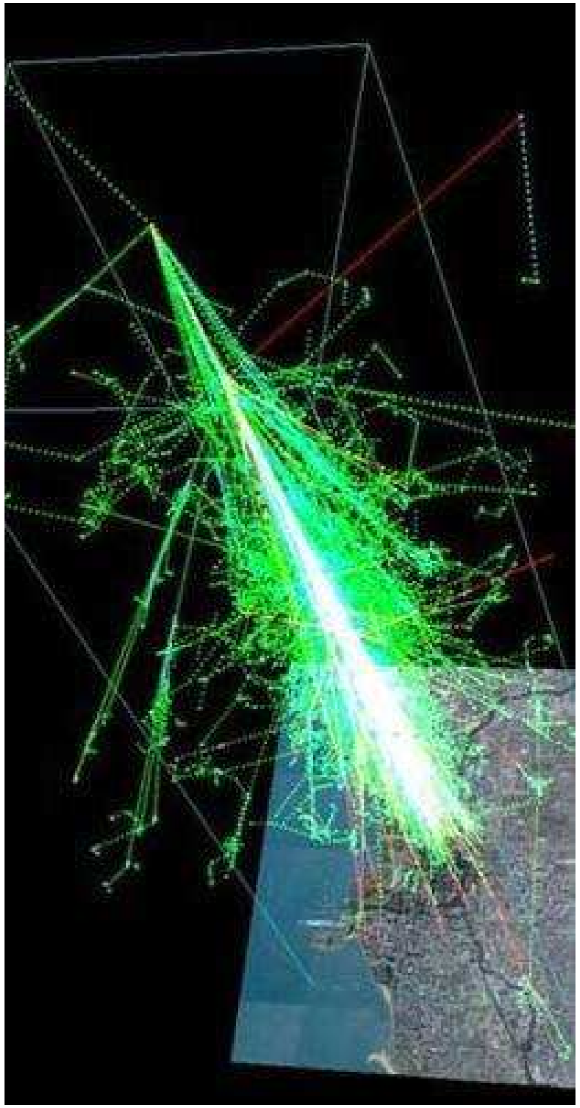
Outline

- *Introduction - Context*
- *Test platforms – Characteristics*
- *Current experiments*
- *Experimental results (2006-2009)*
- *Plateau de Bure Neutron Monitor*
- *Future experiments*

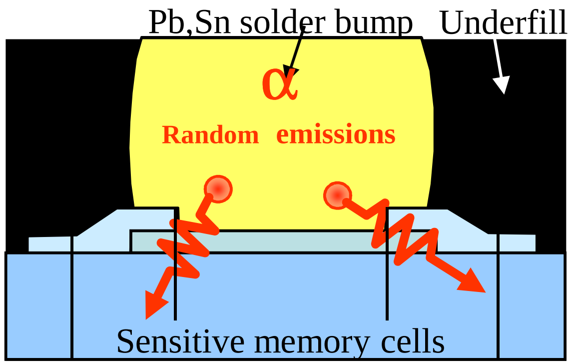
Introduction – Context

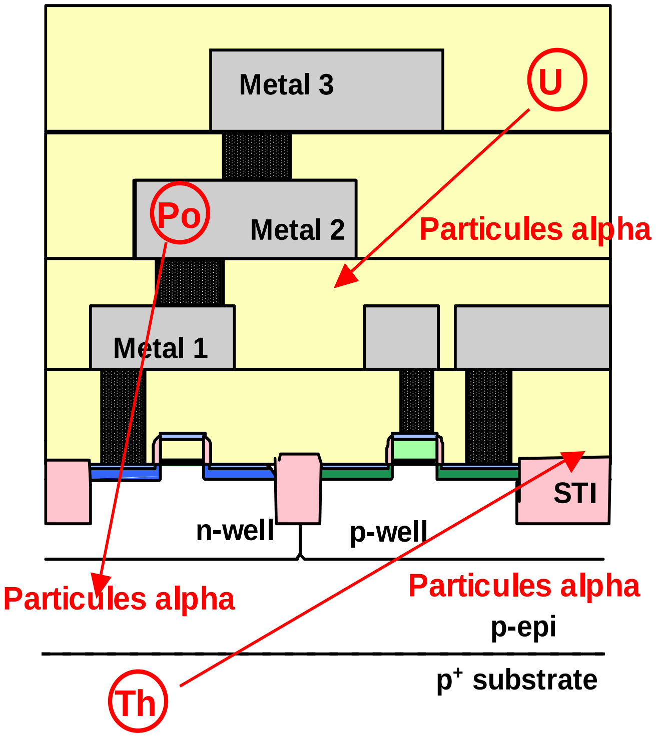


Electronic devices at ground level
are primilarly impacted by:

- ✓ Secondary cosmic rays in the Earth atmosphere (atmospheric neutrons)
- ✓ Telluric ray produced directly inside ICs due to residual traces of radioactive elements (alpha-particles)

Neutrons and alpha particles are the main aggressors playing a major role in the occurrence of SEE in chips at ground level





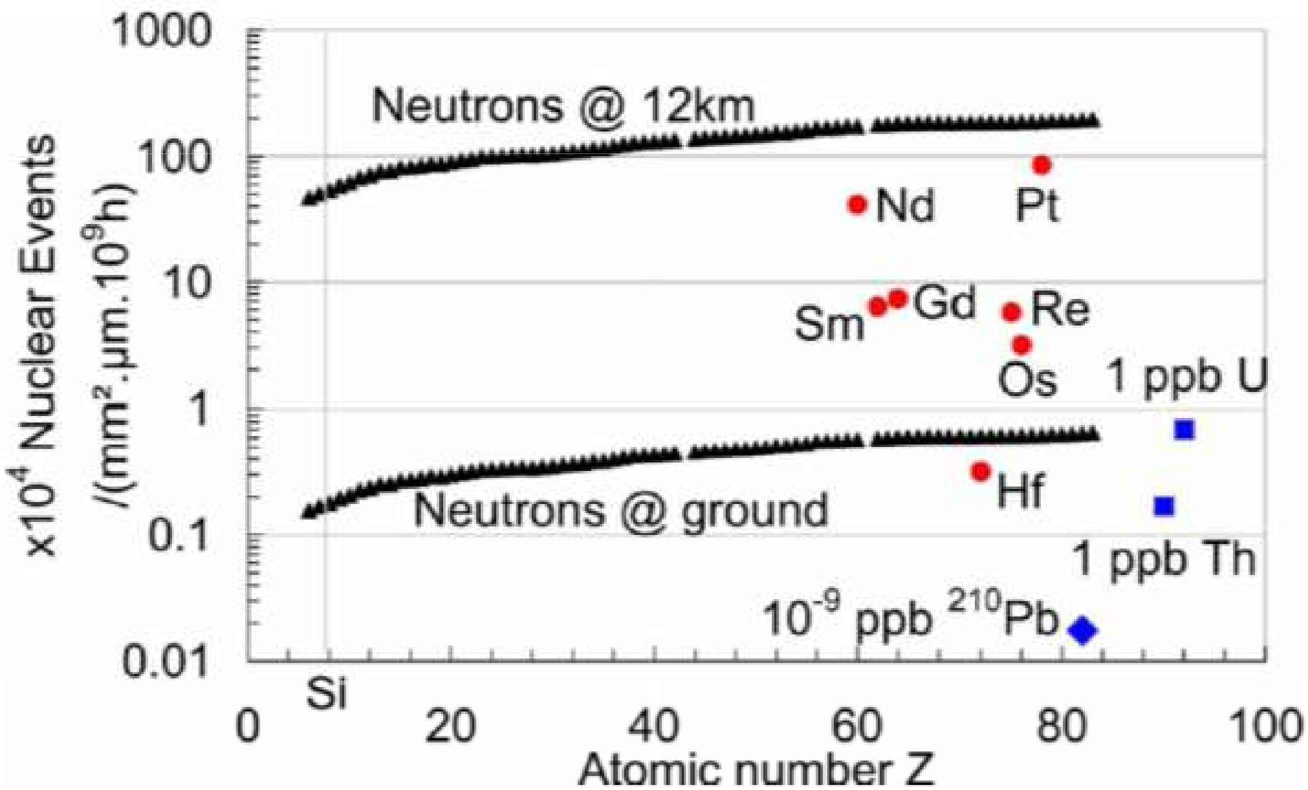
Appl. Phys. Lett. 93, 064105 (2008)

TABLE I. Disintegration rates of radioactive materials. Concentrations of radioactive nuclei are deduced from natural abundances.

Element	$T_{1/2}$ (s)	Natural abundance (%)	Disintegration rate $[(\mathrm{mm}^2\ \mu\mathrm{m}\ 10^9\ \mathrm{h})^{-1}]$
^{190}Pt	2.05×10^{19}	0.014	85.21×10^{4}
^{144}Nd	7.23×10^{22}	23.8	41.07×10^{4}
^{152}Gd	3.41×10^{21}	0.2	7.31×10^{4}
^{148}Sm	2.21×10^{23}	11.24	6.35×10^{4}
^{187}Re	1.37×10^{18}	62.6	5.70×10^{4}
^{186}Os	6.31×10^{22}	1.59	3.14×10^{4}
^{174}Hf	6.31×10^{22}	0.16	0.32×10^{4}

After F. Wrobel et al.

Appl. Phys. Lett. **93**, 064105 (2008)



Number of nuclear events

in a layer of material of 1 $mm^2 \times 1\ \mu m$

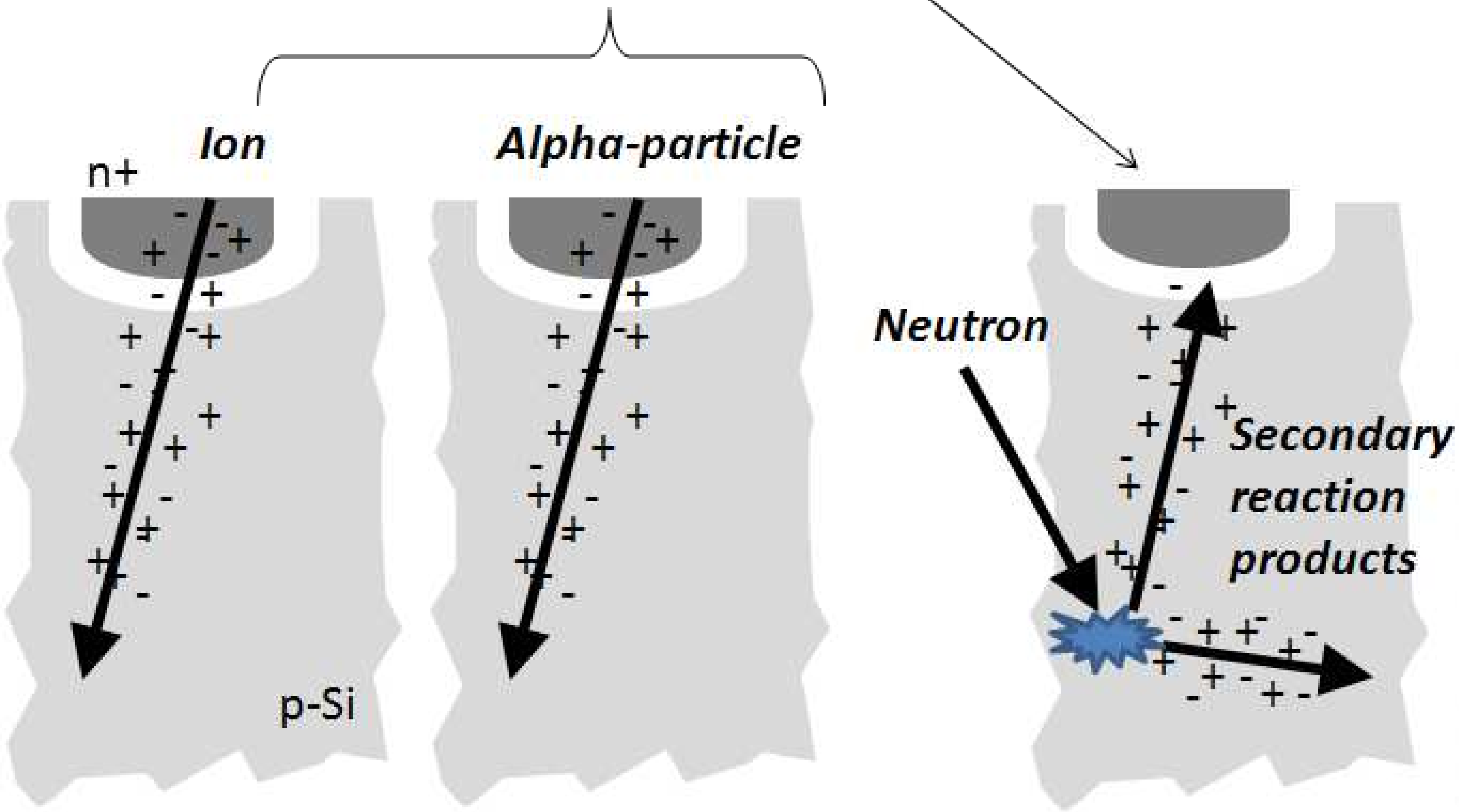
during 10^9 h

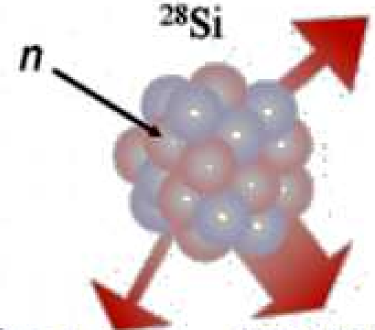
After Fréderic Wrobel et al.

(IES Montpellier)

Main steps of SEE production in microelectronic devices (1/2)

Direct and indirect matter ionization

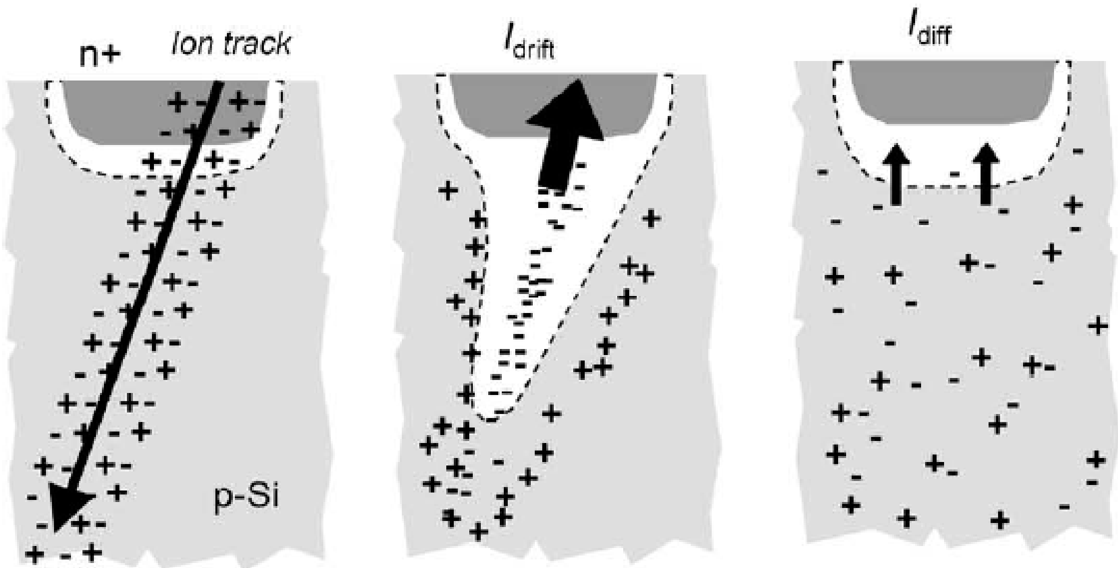




$^{25}Mg + \alpha$	2.75 MeV
$^{28}Al + p$	4.00 MeV
$^{27}Al + d$	9.70 MeV
$^{24}Mg + n + \alpha$	10.34 MeV
$^{27}Al + n + p$	12.00 MeV
$^{26}Mg + {}^{3}He$	12.58 MeV
$^{21}Ne + 2a$	12.99 MeV

Reaction table from F. Wrobel et al., IEEE Trans. Nucl. Phys., Vol. 47, No. 6, Dec. 2000

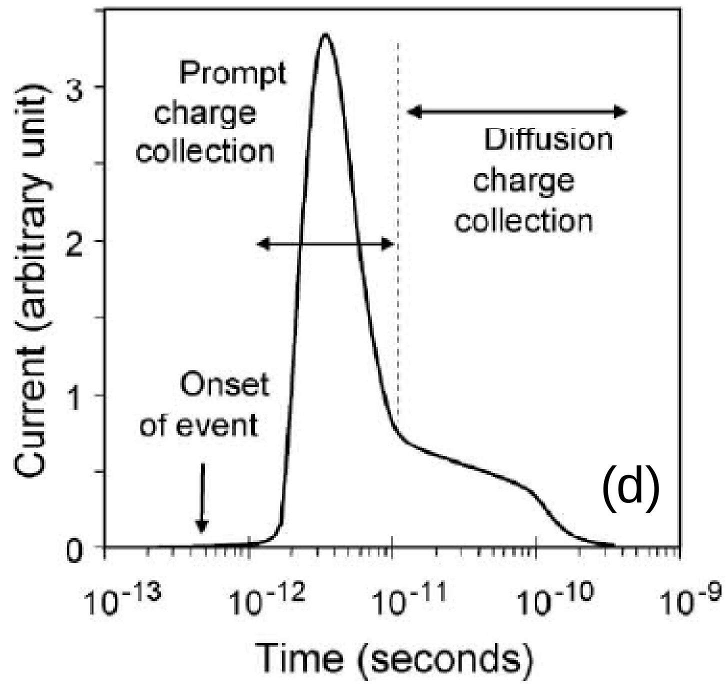
Main steps of SEE production in microelectronic devices *



1 *Charge deposition by the energetic particle striking the sensitive region*

Transport of the released charge into the device (drift and diffusion mechanisms) 2

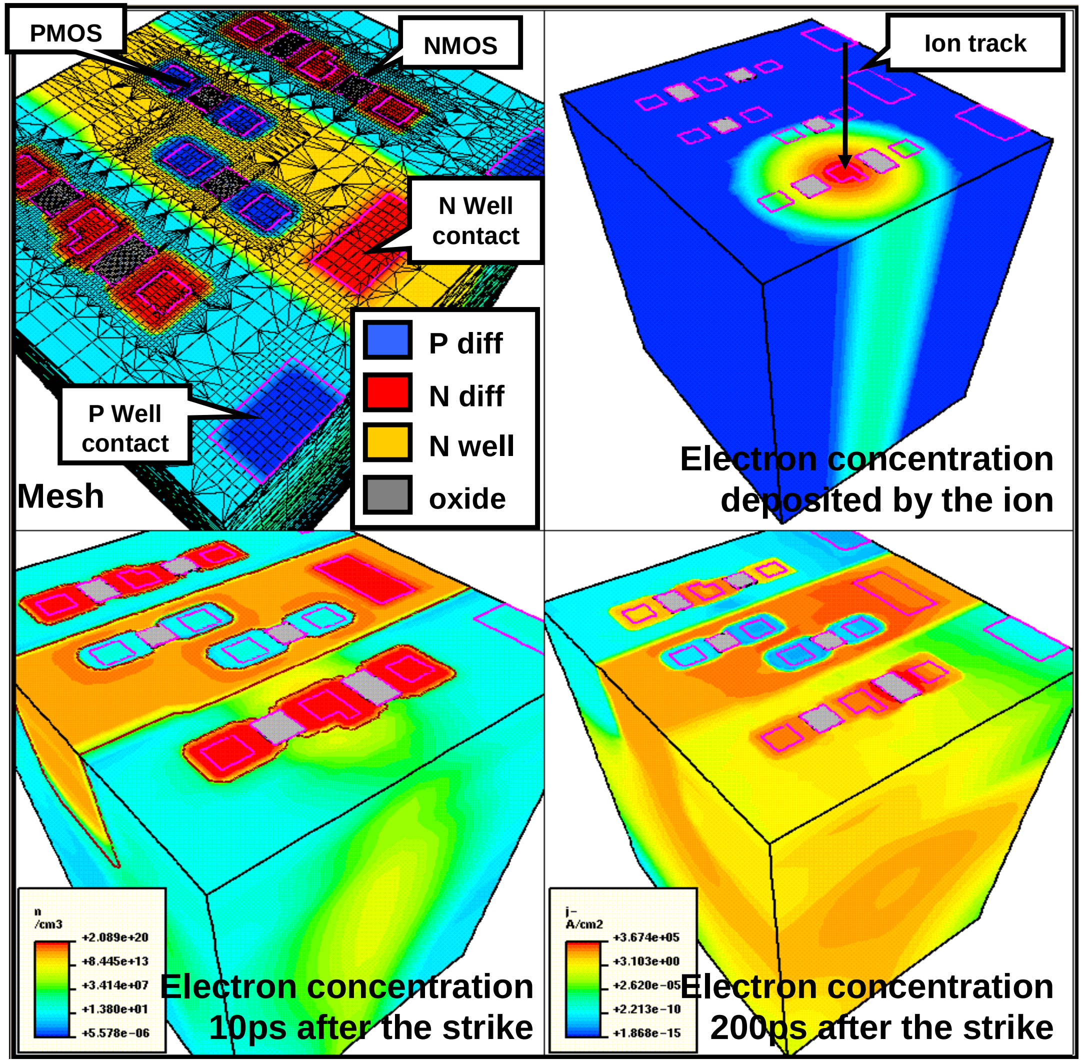
Charge collection in the sensitive region of the device 3

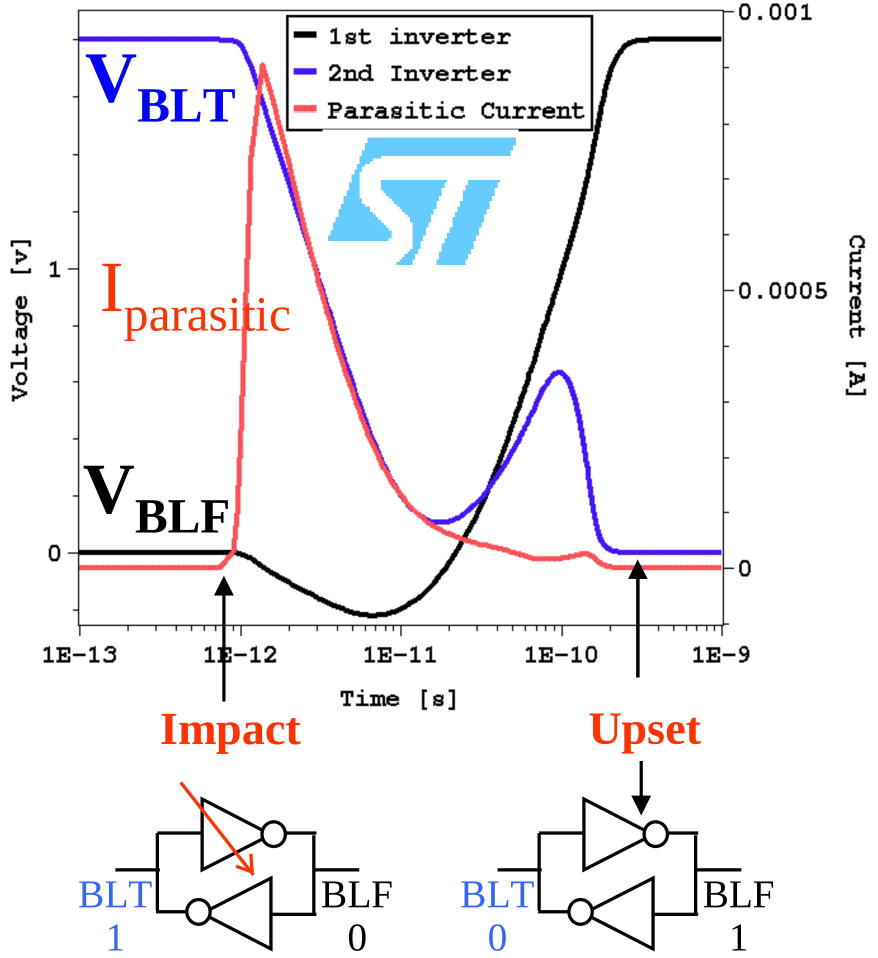


Current pulse caused by the passage of the energetic particle

* After R. C. Baumann, ***IEEE Trans. Device Mater. Reliab.***, vol. 5(3), p. 305-316, Sept. 2005.

SEU in SRAM memory

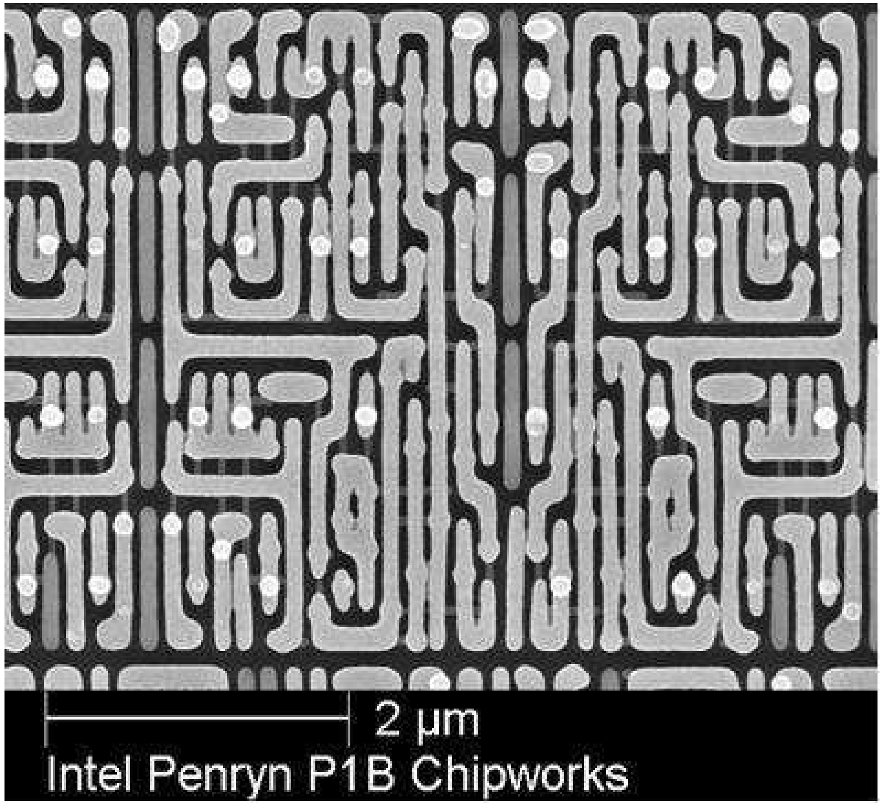




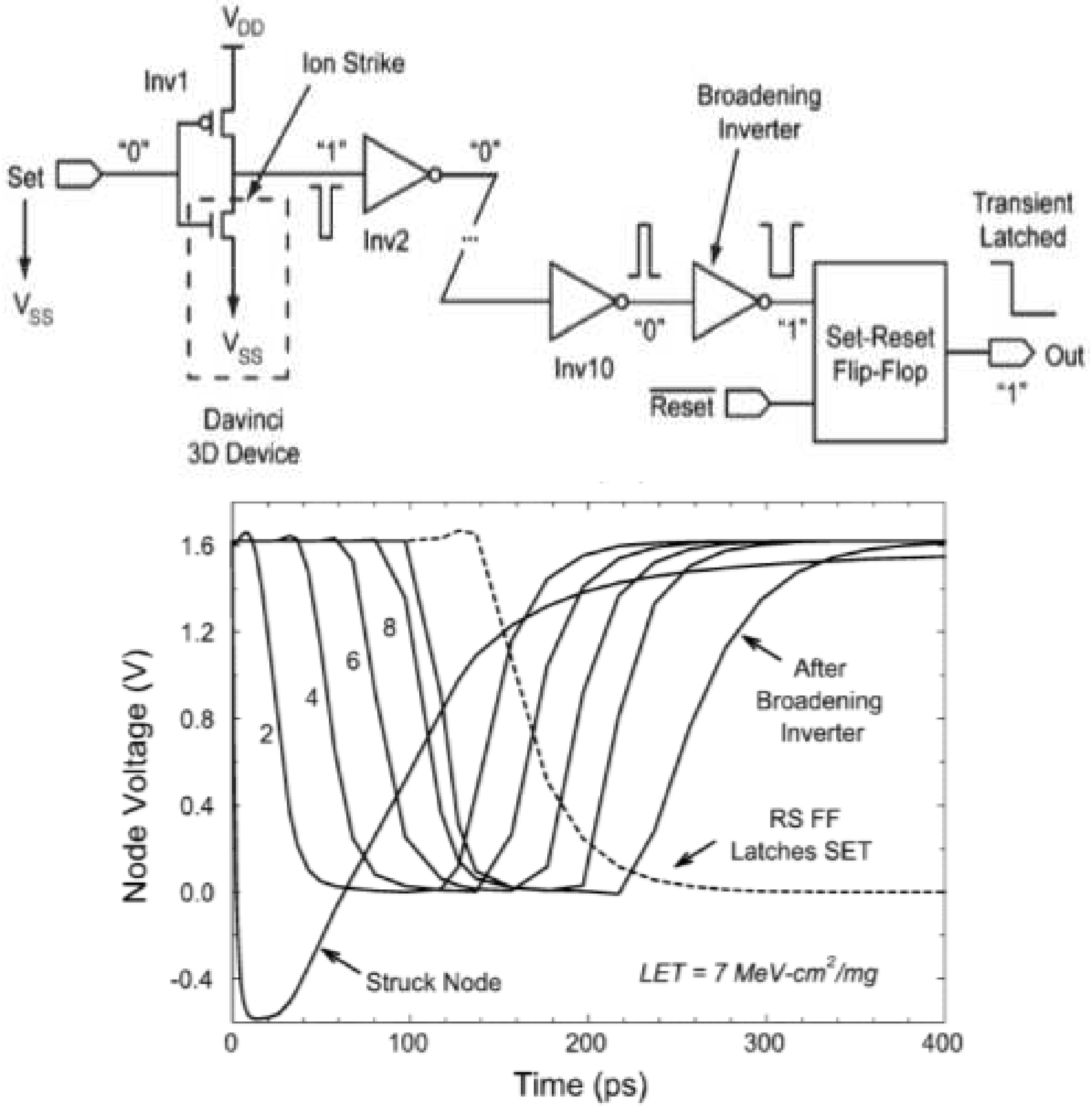
Snapshots courtesy of P. Roche

SET in digital circuits

SET propagation



Plan-View SEM of Metal 1 in Logic Area



P. Dodd et al., ***IEEE Trans. Nucl. Sci***., vol. 51 (6), pp. 3278-3284, Dec. 2004.

Test platforms

-1700 m
under rock

Altitude SEE Test European Platform

+2552 m in Alp
mountains

iram
Institut de Radioastronomie Millimétrique

Altitude SEE Test European Platform

The Altitude SEE Test European Platform

Altitude SEE Test European Platform

August 2008

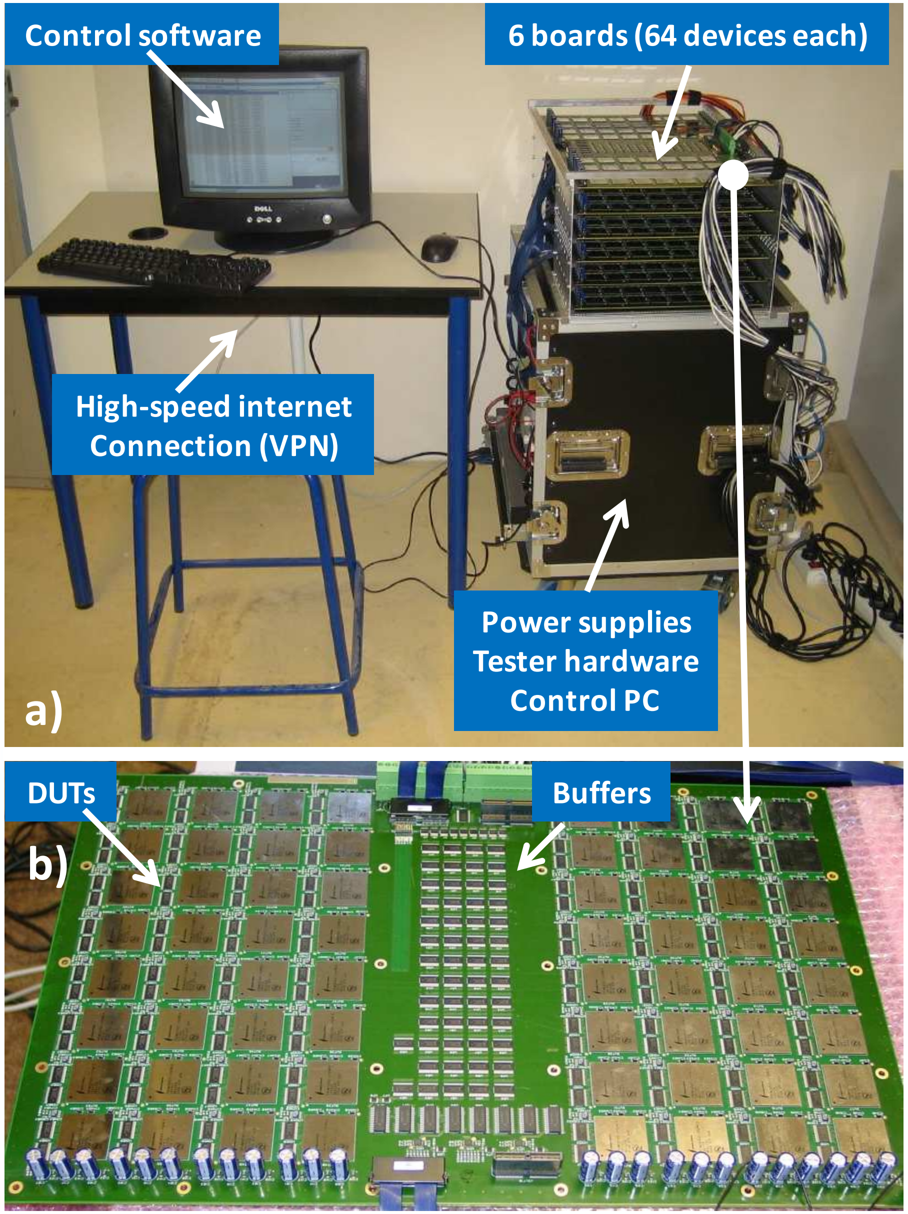
Experiments currently in progress

- STMicroelectronics – SRAMs 65nm
- Xilinx – FPGA 130 nm
- EADS-ATMEL – SRAMs 130nm
- UCL – ISEEM monitor (CCD)
- IM2NP – PdBNM + CCD experiment

- STMicroelectronics – SRAMs 130nm
- STMicroelectronics – SRAMs 65nm

- 2nd neutron monitor (version 2)
- CCD experiment
- Muon detector (to be constructed)

ASTEP Main Research Experiment



Hosted Experiments

XILINX/Rosetta
130nm FPGA (Virtex II)

ATMEL-EADS
130nm SRAMs

Academic Experiments (3/3)

University of Central Lancashire
Imaging SEE Monitor

LSM Main Research Experiments

STMicroelectronics
65nm SRAMs

STMicroelectronics
130nm SRAMs

Neutron flux measurements

Measurements performed on ***October 2008*** by ***Evgeny Yakushev*** using a He^3 neutron detector

=> **Neutron flux (E>0.5 MeV) ~1.2×10^{-6} neutron/cm^2/s**

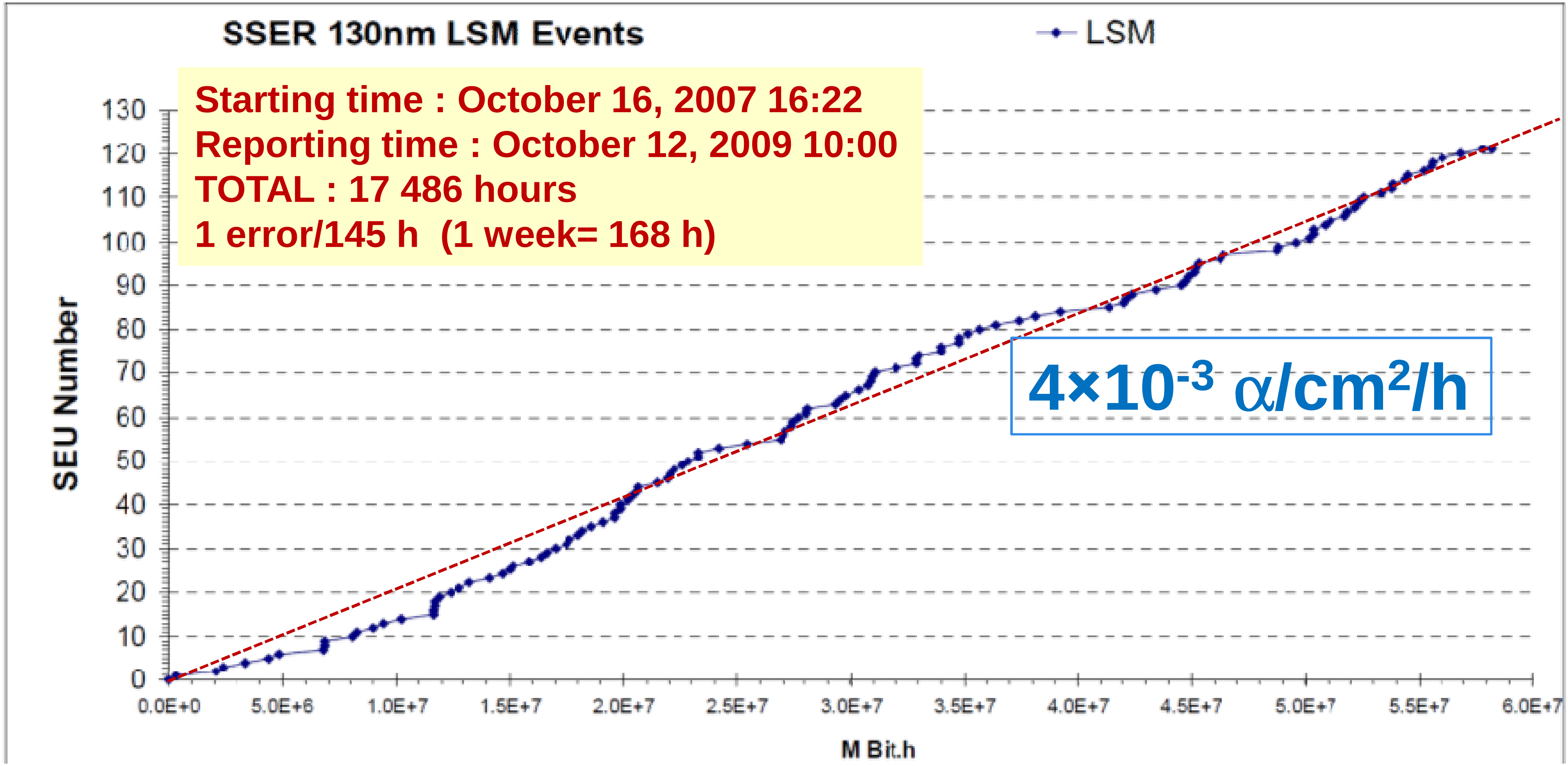
For memory on the Plateau de Bure, **Neutron flux > 3.5×10^{-2} neutron/cm^2/s**

Reduction factor > 30,000

Reporting SSER ST 130nm at LSM
12/10/2009

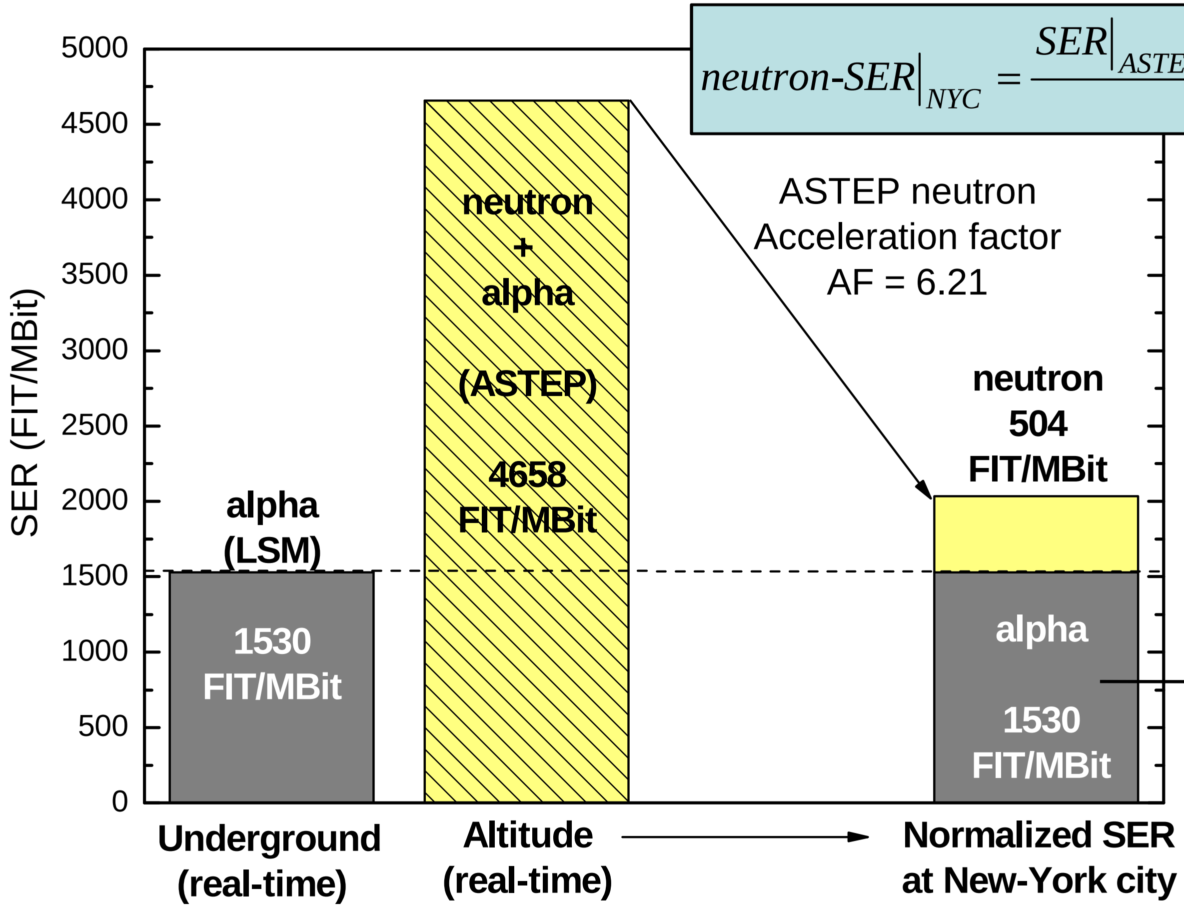
Cumulated results during ~17 500 h

Graphics:



Experimental Results - 130nm SRAM

Neutron and alpha-SER extraction

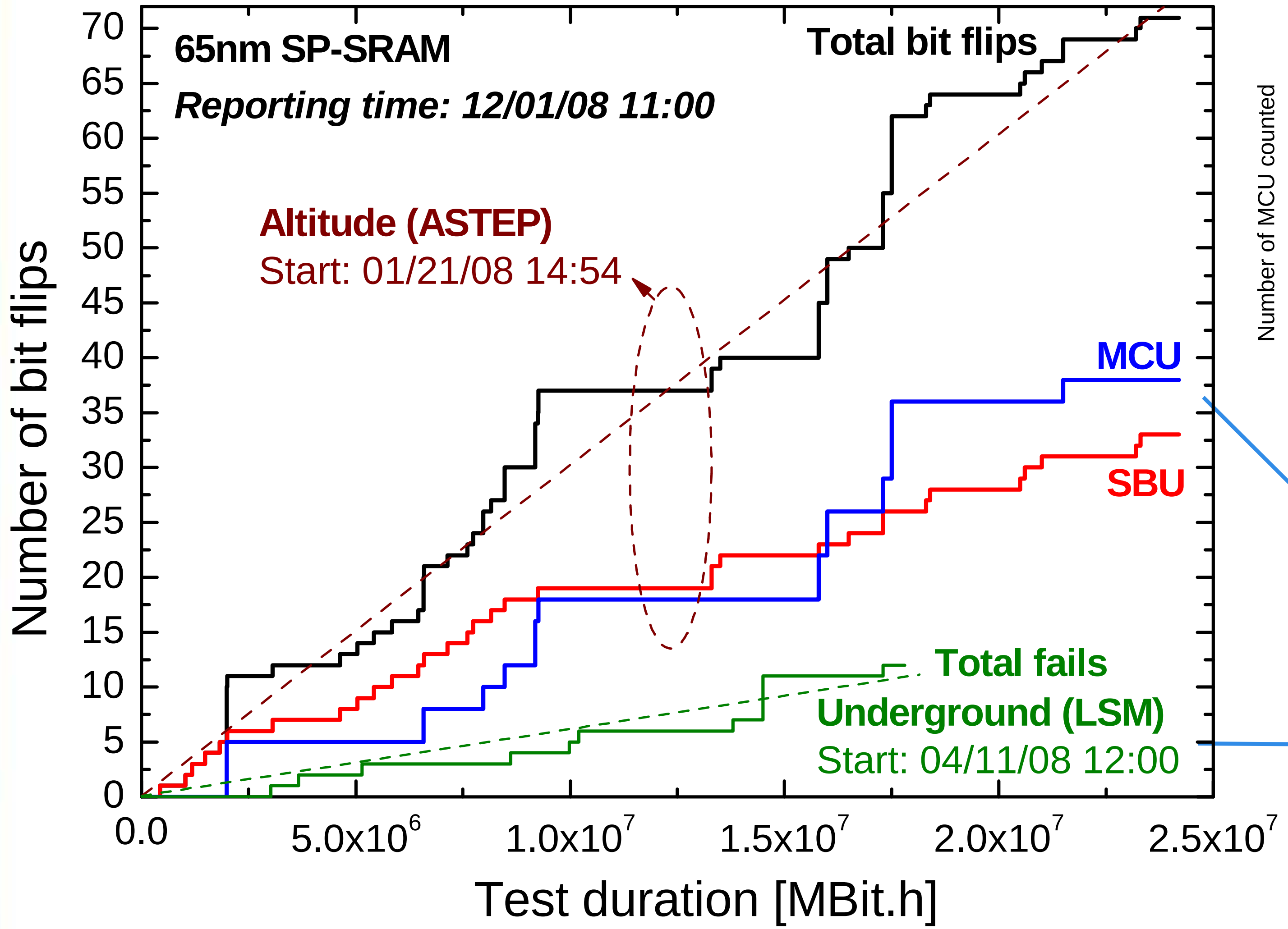


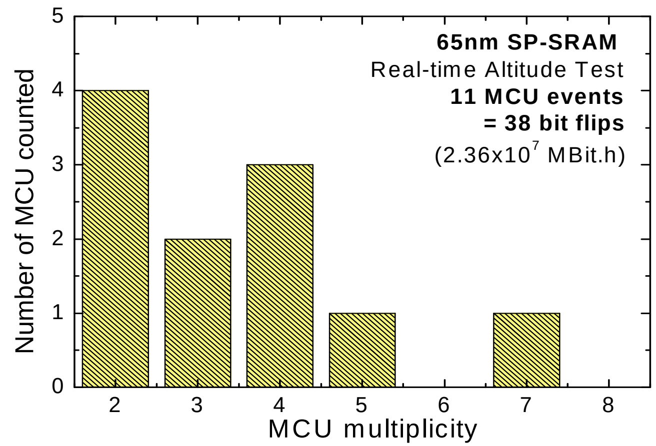
$$neutron\text{-}SER\big|_{NYC} = \frac{SER\big|_{ASTEP} - SER\big|_{LSM}}{AF}$$

⇒ α-SER > neutron-SER at sea-level for 130nm technology

Corresponds to an α-emission rate for the chip materials of 4×10^{-3} α/cm²/h

Experimental Results - 65nm SRAM

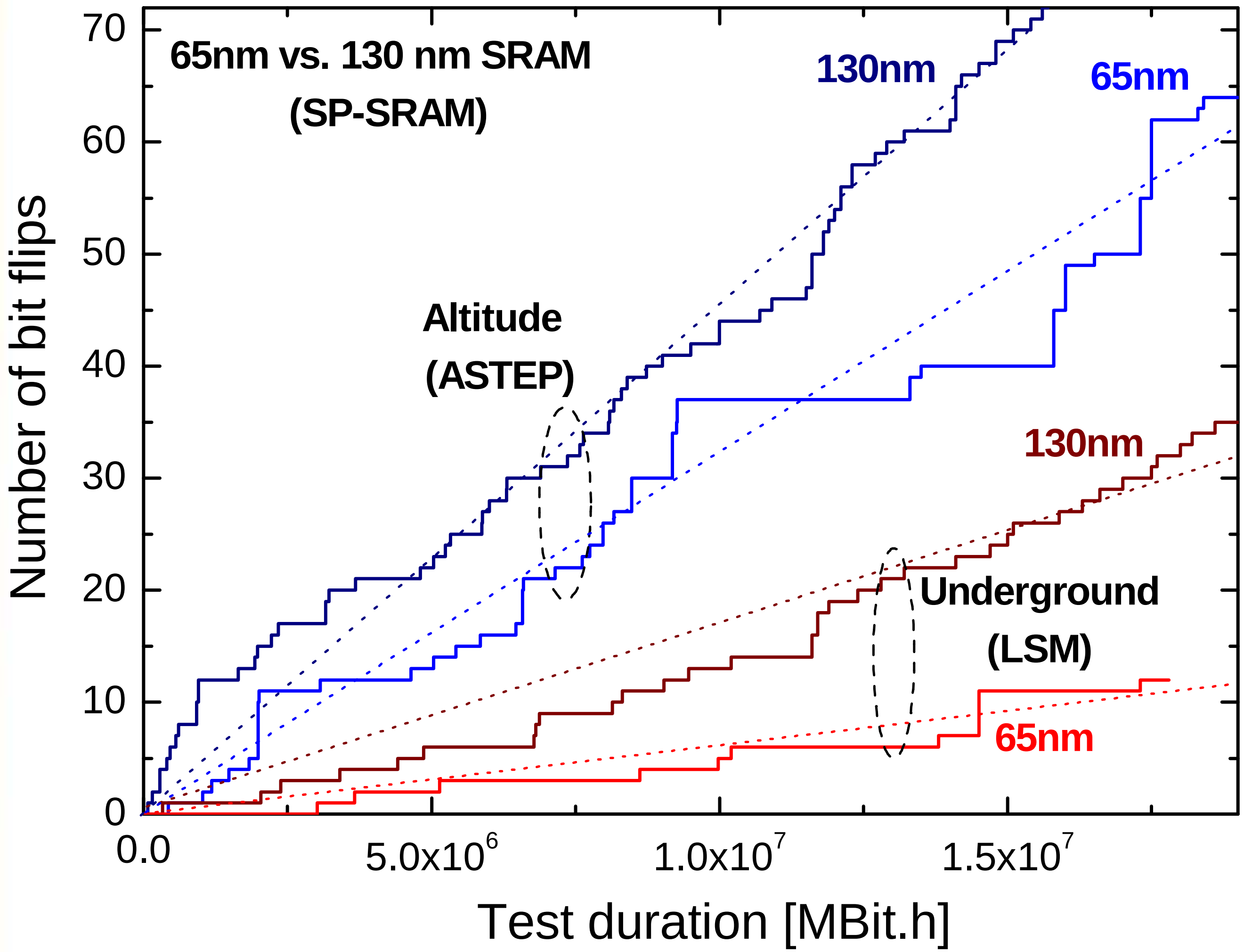




Importance of Multi-Cell Upsets (>52%)

Reduction of alpha-particle SEUs

65nm versus 130nm technologies

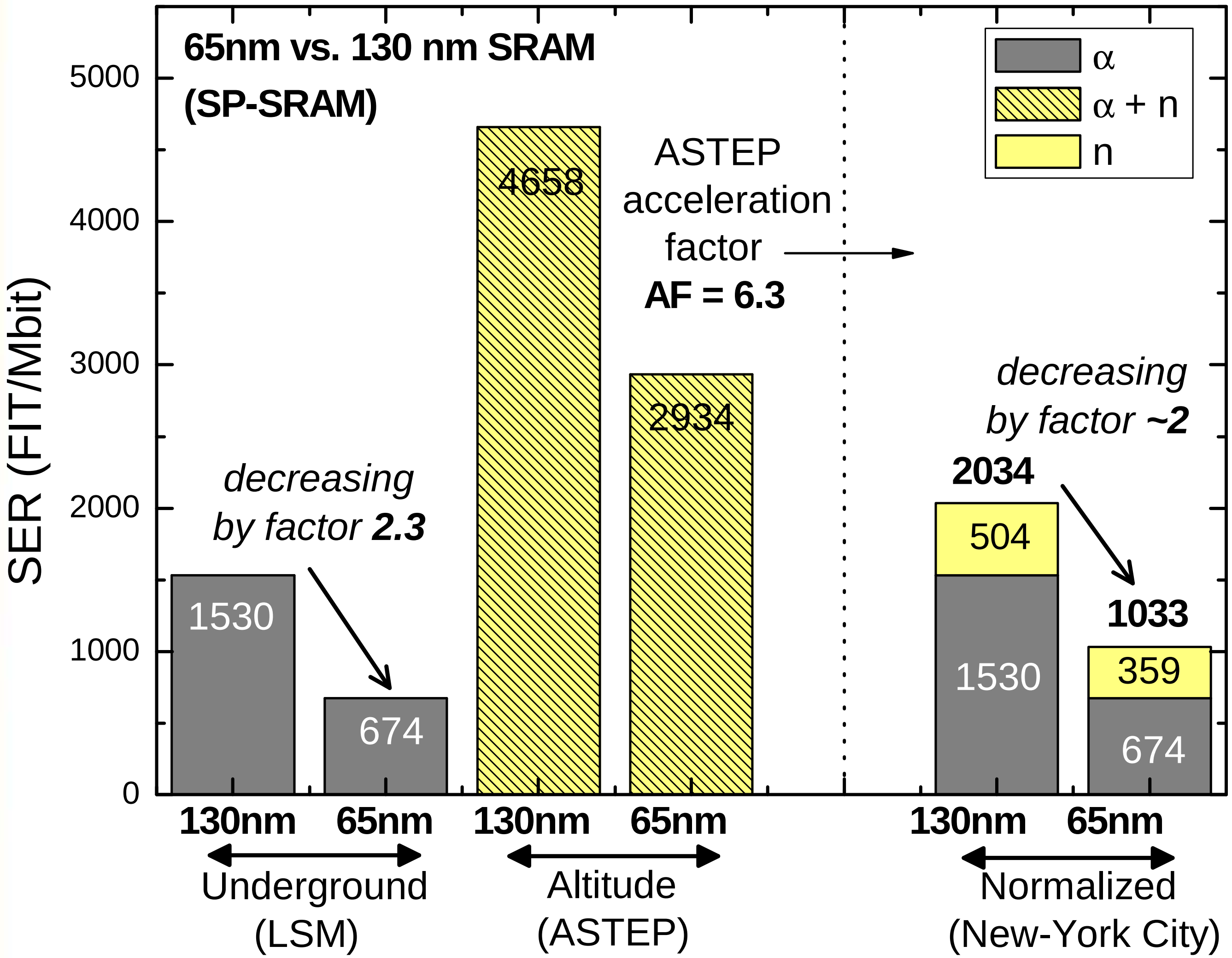


$4\times10^{-3}\ \alpha/cm^2/h$

$9\times10^{-4}\ \alpha/cm^2/h$

= result of a substantive work performed at technological process integration level (elimination of some materials subjected to alpha emitter contamination).

65nm versus 130nm technologies



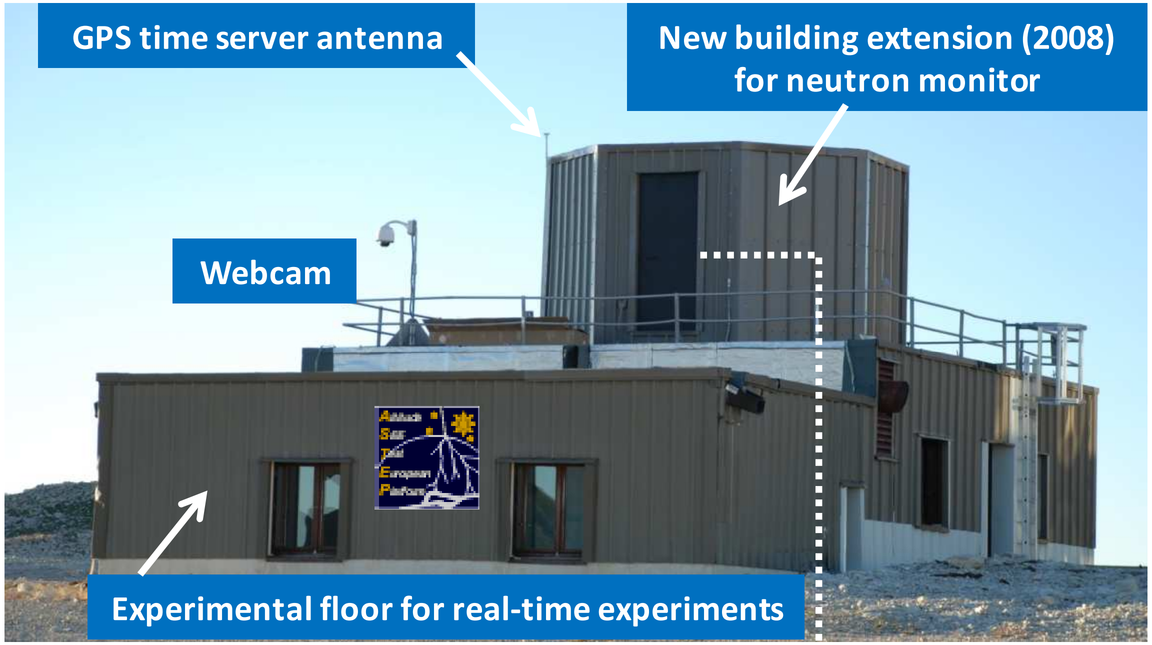
⇒ **Alpha-SER is decreasing by a factor 2.3 for the 65nm technology with respect to the 130nm**

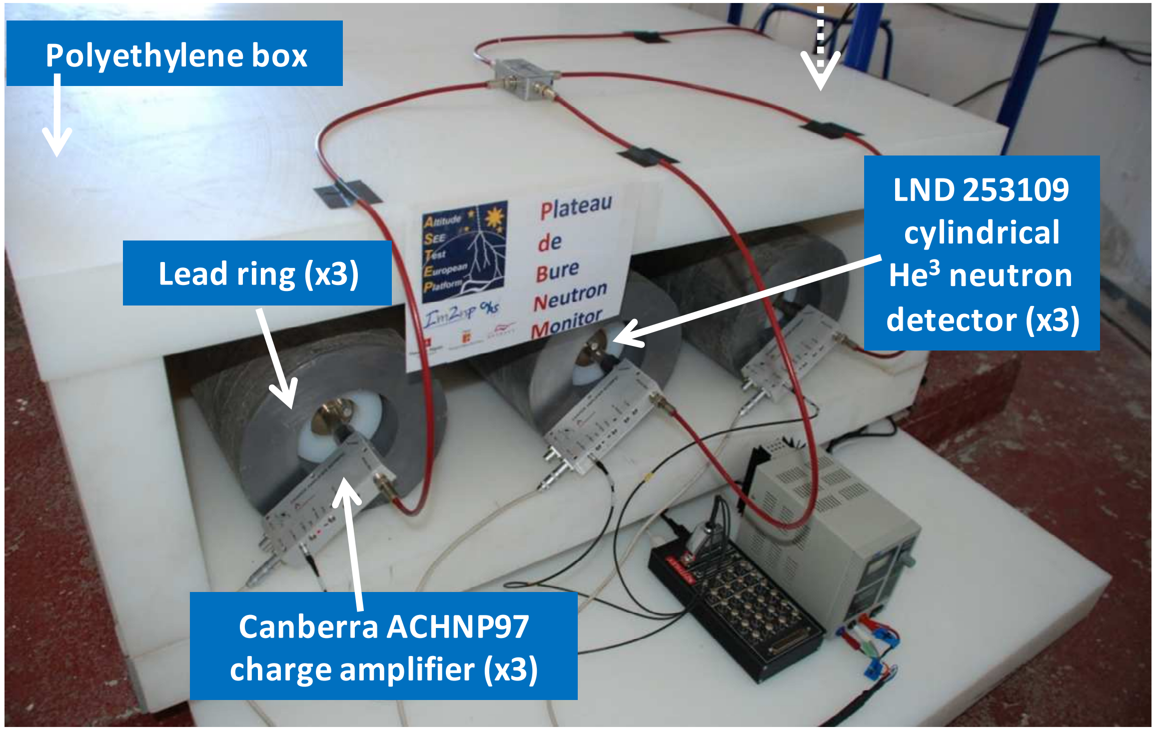
⇒ **neutron-SER is reducing by a factor 1.4,**

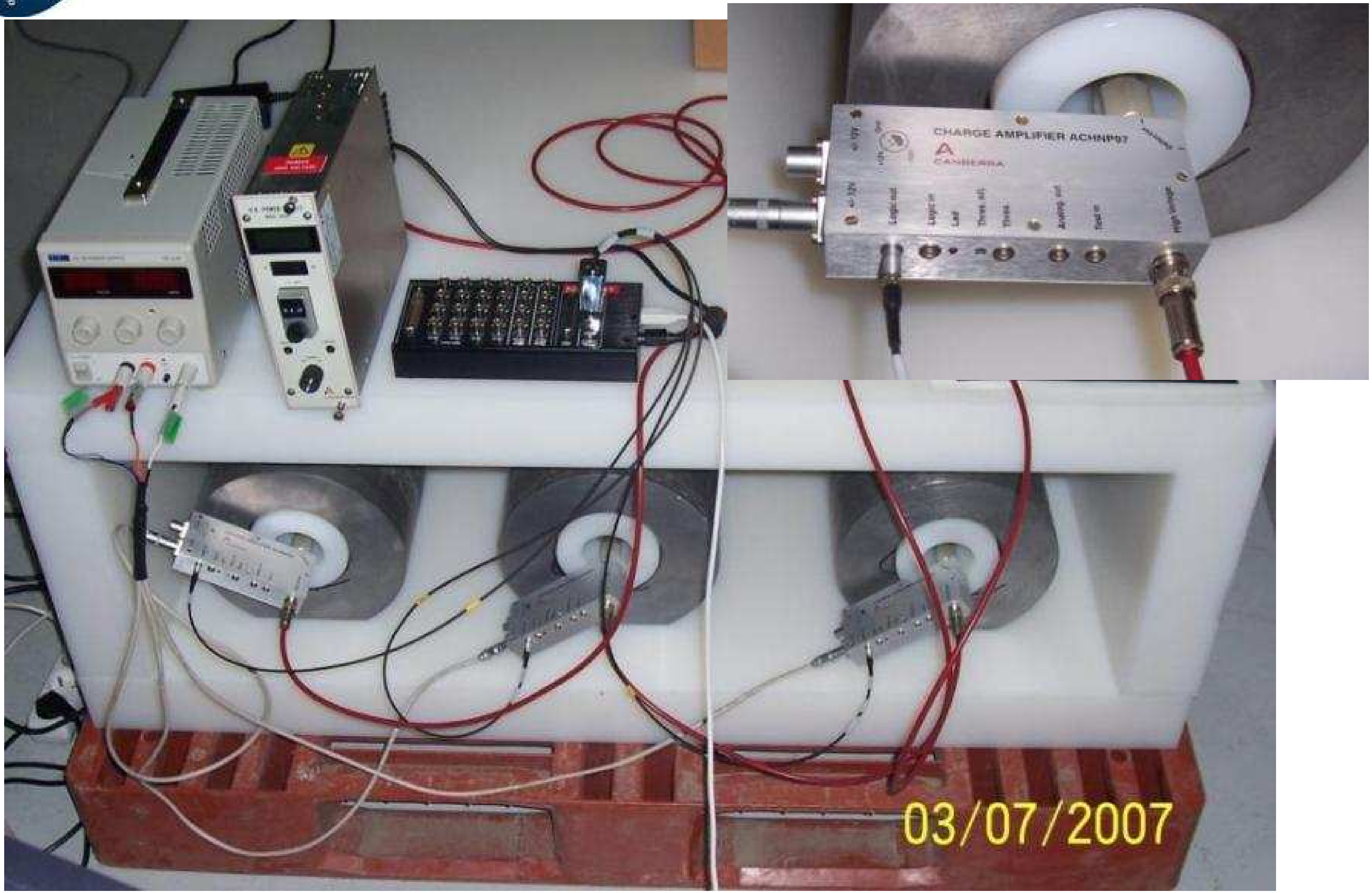
⇒ **resulting in a net improvement of the total SER by a factor 2.**

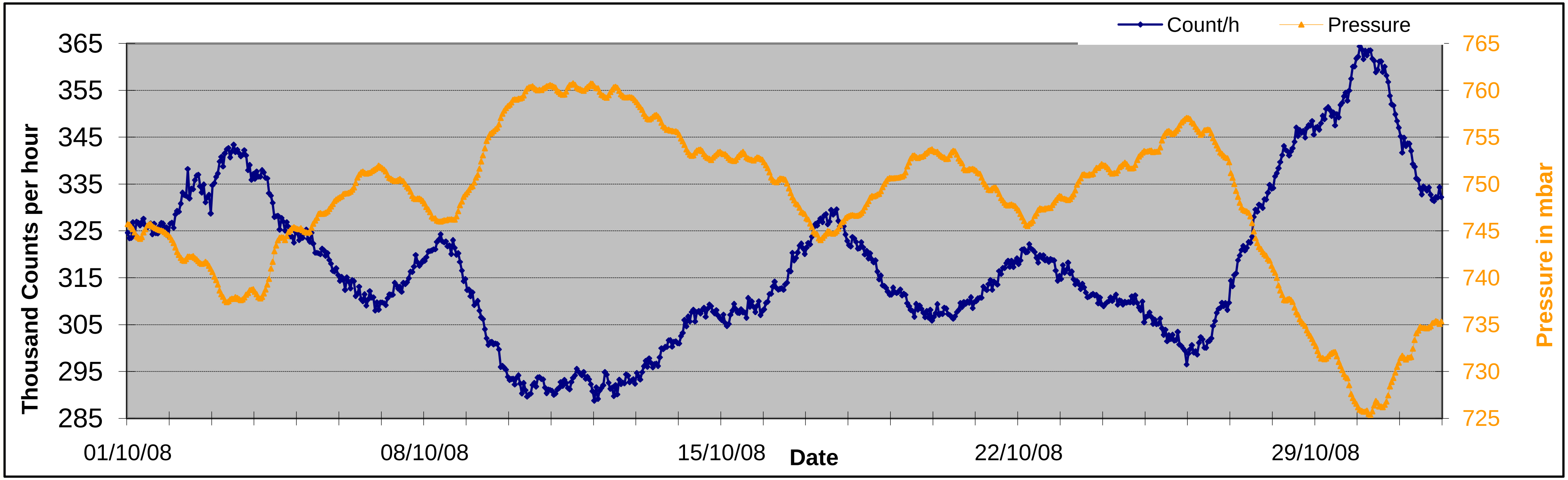
The Plateau de Bure Neutron Monitor (PdBNM)

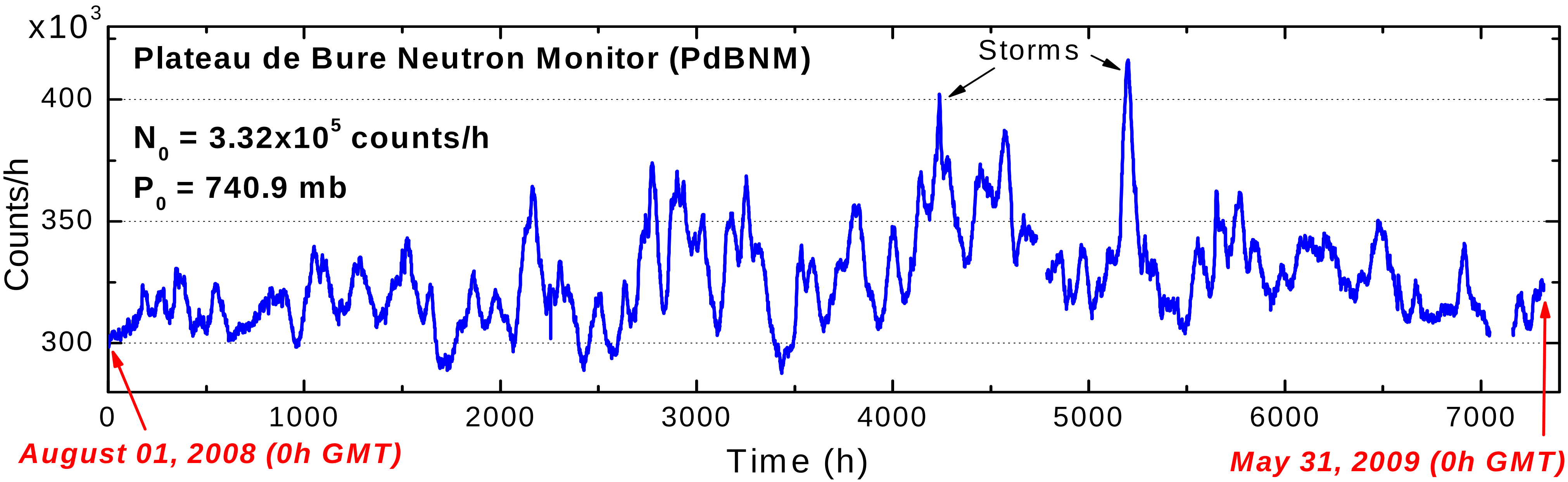
- Installed on ASTEP: July 23, 2008
- 1 year operation (test) in Marseille (2007-2008)
- 3 LND253109 high pressure He^3 (3 atm.) detection tubes
- 2.65 tons (lead rings), $2m^2$, $\sim 3\times10^5$ counts/hour
- Data available online: www.astep.eu





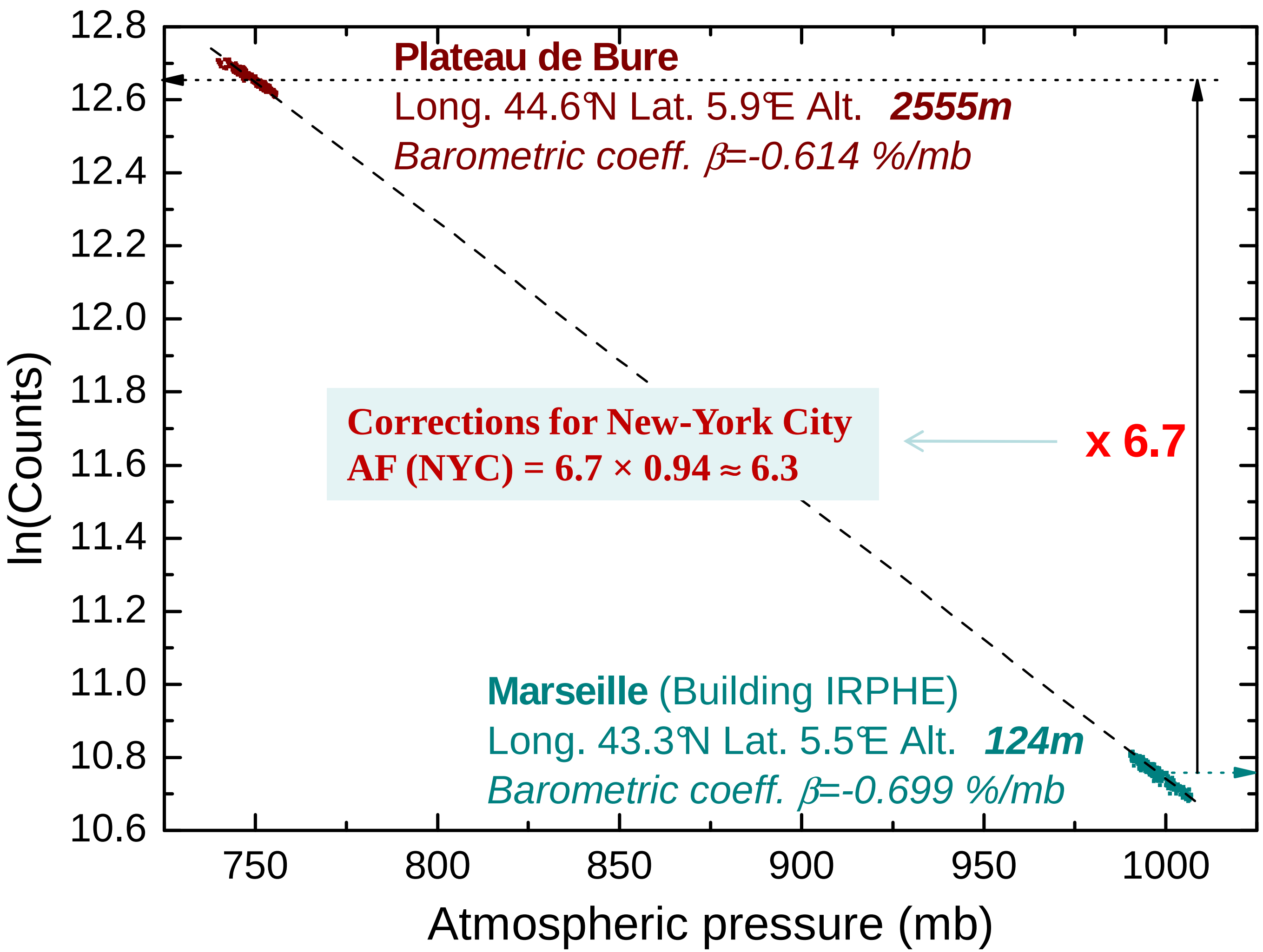

03/07/2007
CHARGE AMPLIFIER ACHNP97
CANBERRA
Logic out
Logic in
Thres
Analog out
Test in
High Voltage


Count/h
Pressure
Thousand Counts per hour
Pressure in mbar
365
355
345
335
325
315
305
295
285
765
760
755
750
745
740
735
730
725
01/10/08
08/10/08
15/10/08
Date
22/10/08
29/10/08

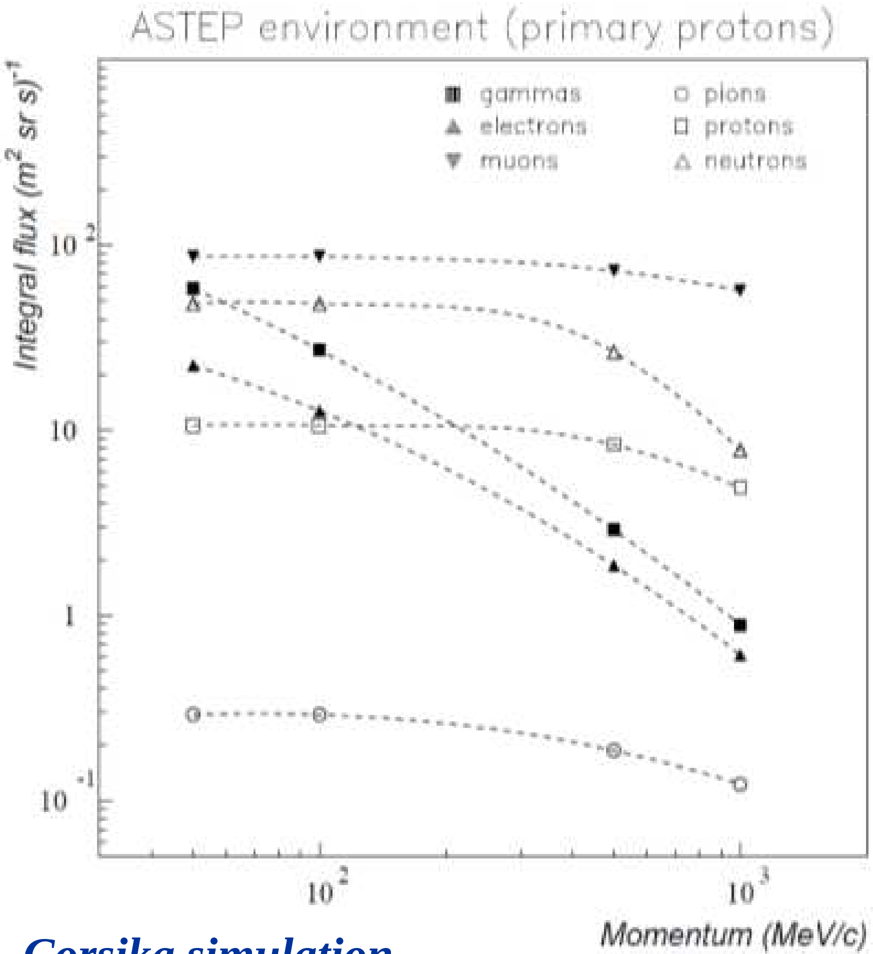

x10^3
Plateau de Bure Neutron Monitor (PdBNM)
Storms
N0 = 3.32x10^5 counts/h
P0 = 740.9 mb
Counts/h
400
350
300
0
1000
2000
3000
4000
5000
6000
7000
Time (h)
August 01, 2008 (0h GMT)
May 31, 2009 (0h GMT)

www.astep.eu

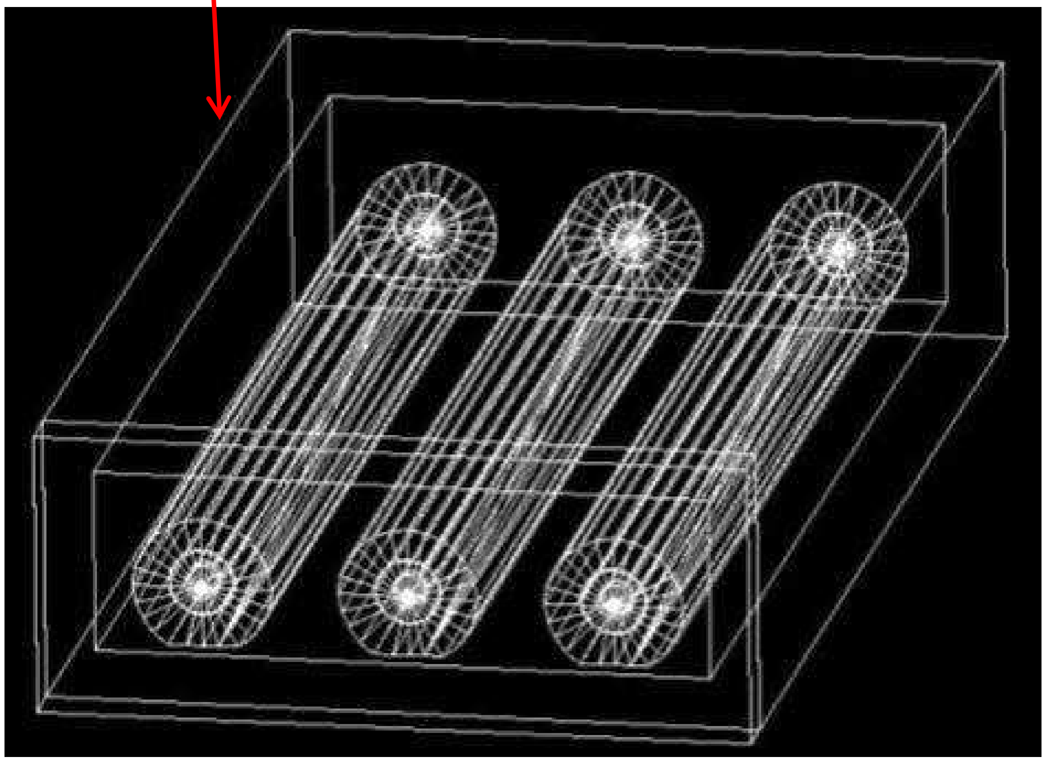
Experimental determination of the (neutron flux) acceleration factor of the ASTEP location



PdBNM: Modeling and Geant4 Simulation



Corsika simulation



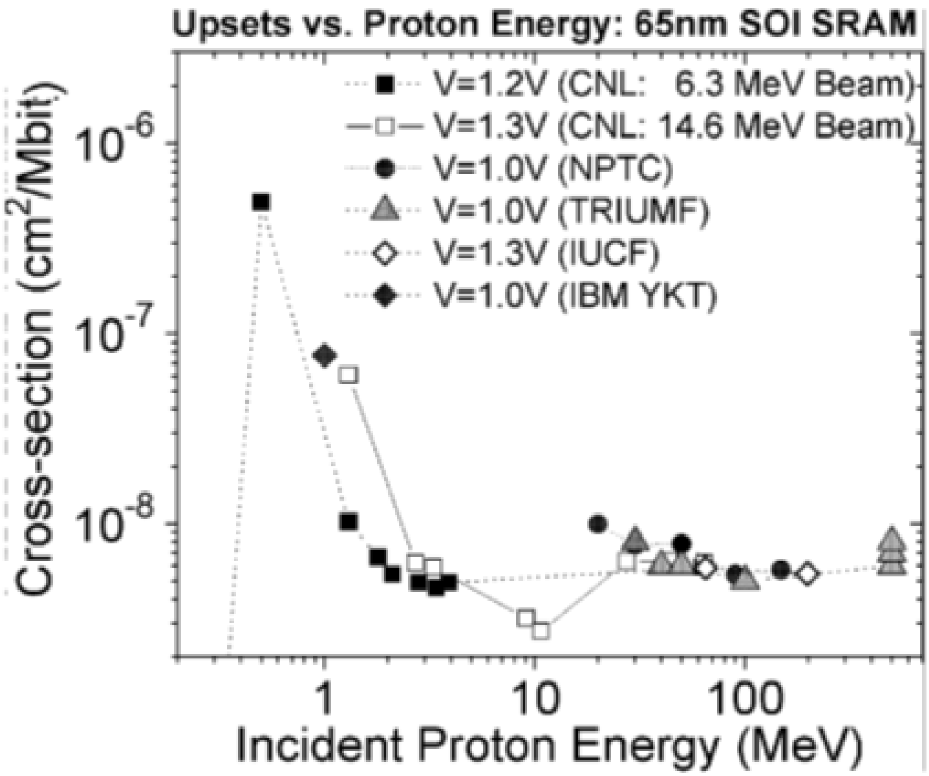
- **Work performed by Sergey Semikh (JINR) in Marseille (October-November 2009)**
- **Calculate the instrument response in the natural radiation environment (n, p, μ)**

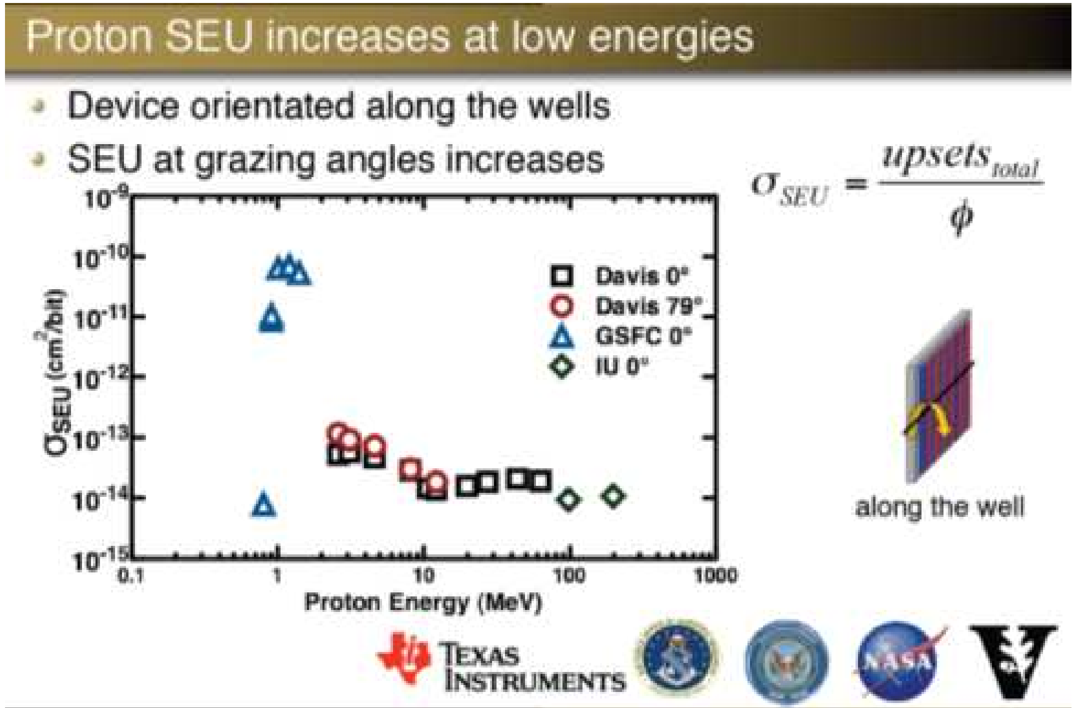
Altitude experiments: impact of low energy protons

3394 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 55, NO. 6, DECEMBER 2008

Low Energy Proton Single-Event-Upset Test Results on 65 nm SOI SRAM

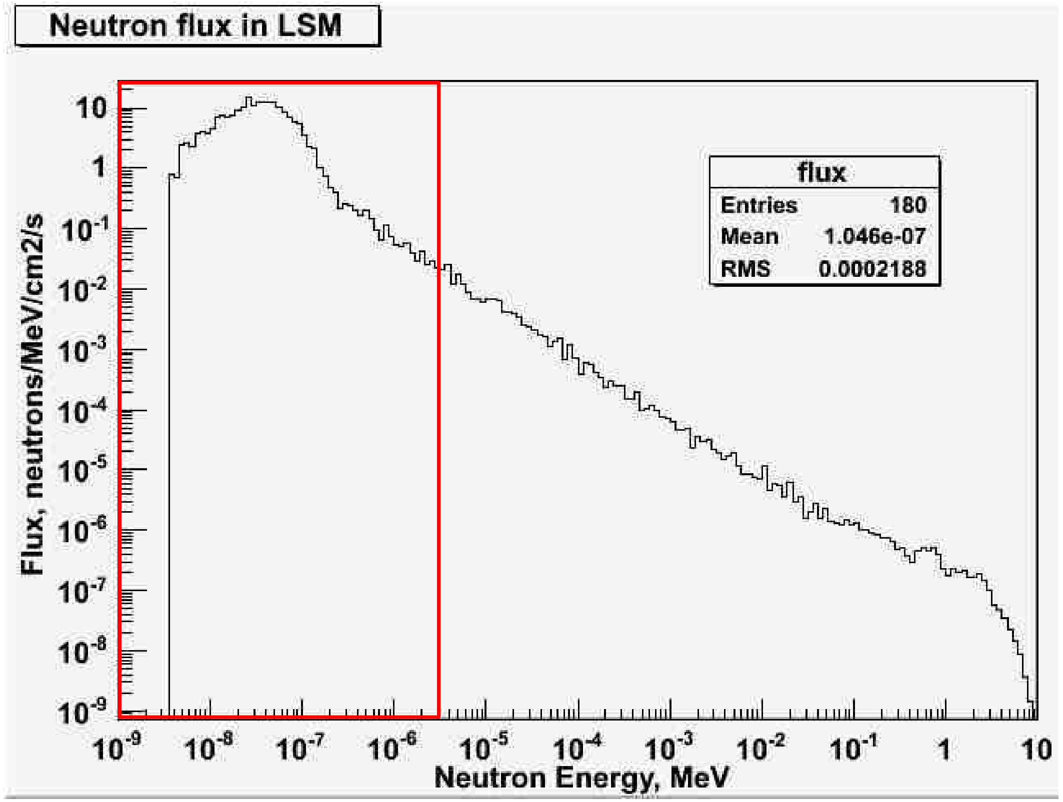
David F. Heidel, *Senior Member, IEEE*, Paul W. Marshall, *Member, IEEE*, Kenneth A. LaBel, *Member, IEEE*, James R. Schwank, *Fellow, IEEE*, Kenneth P. Rodbell, *Member, IEEE*, Mark C. Hakey, Melanie D. Berg, *Member, IEEE*, Paul E. Dodd, *Senior Member, IEEE*, Mark R. Friendlich, Anthony D. Phan, Christina M. Seidleck, Marty R. Shaneyfelt, *Fellow, IEEE*, and Michael A. Xapsos, *Senior Member, IEEE*





Underground experiments: impact of thermal neutrons

Shielding of the 65nm experiment with borated HD Polyethylen box (8-10 cm thickness)



After R. Lemrani

Recent references

J.L. Autran, P. Roche, J. Borel, C. Sudre, K. Castellani-Coulié, D. Munteanu, T. Parrassin, G. Gasiot, J.P. Schoellkopf, "Altitude SEE Test European Platform (ASTEP) and First Results in CMOS 130nm SRAM", ***IEEE Transactions on Nuclear Science***, 2007, Vol. 54, n°4, p. 1002-1009. http://dx.doi.org/10.1109/TNS.2007.891398

J.L. Autran, P. Roche, S. Sauze, G. Gasiot, D. Munteanu, P. Loaiza, M. Zampaolo, J. Borel, "Real-Time Neutron and Alpha Soft-Error Rate Testing of CMOS 130nm SRAM: Altitude versus Underground Measurements", ***IEEE International Conference on IC Design and Technology*** (ICICTD 2008), June 2-4, 2008, Grenoble, France, p. 233-236. http://dx.doi.org/10.1109/ICICDT.2008.4567284

J.L. Autran, P. Roche, S. Sauze, G. Gasiot, D. Munteanu, P. Loaiza, M. Zampaolo, J. Borel, "Altitude and Underground Real-Time SER Characterization of CMOS 65nm SRAM", ***IEEE Transactions on Nuclear Science***, Vol. 56, 2009, Vol. 56, N°4, p. 2258-2266. http://dx.doi.org/10.1109/TNS.2009.2012426

J.L. Autran, P. Roche, S. Sauze, G. Gasiot, D. Munteanu, P. Loaiza, M. Zampaolo, J. Borel, S. Rozov, E. Yakushevn "Combined Altitude and Underground Real-Time SER Characterization of CMOS Technologies on the ASTEP-LSM Platform *(invited)",* ***IEEE International Conference on IC Design and Technology*** (ICICTD 2009), May 18-20, 200, Austin (TX), USA, p. 113-120.

Thank you for your attention

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