Radiation Test Results and 3D TCAD Simulations in UTBB FD-SOI 28nm

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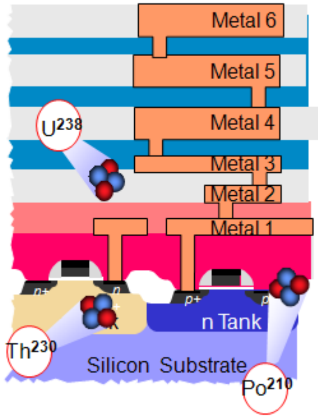
- **Background on SER and FDSOI28**

- **Experimental radiation test results**
  - heavy ions
  - Multiple Cell Upsets
  - alpha particles and neutrons
  - SRAMs and microprocessors

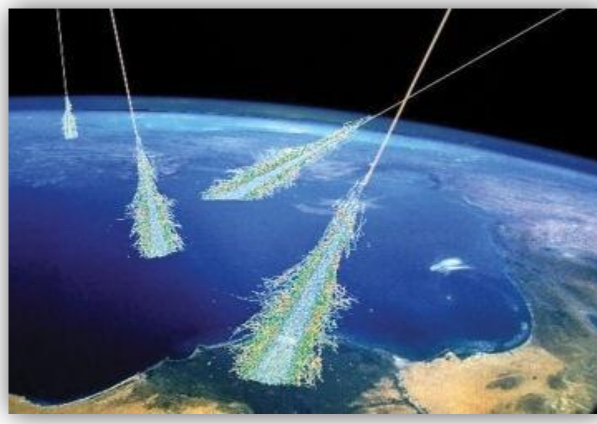
- **3D TCAD simulations for key SEU parameters**
  - sensitive volume for charge collection
  - charge amplification with parasitic bipolar

- **Take-aways**

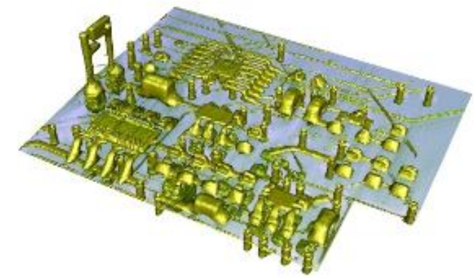
- **Bit flips, latch-up, leakage currents**



Alpha contaminants

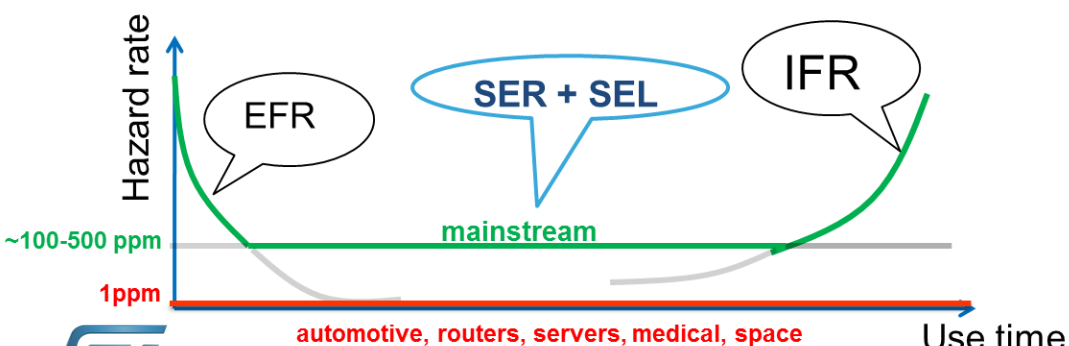


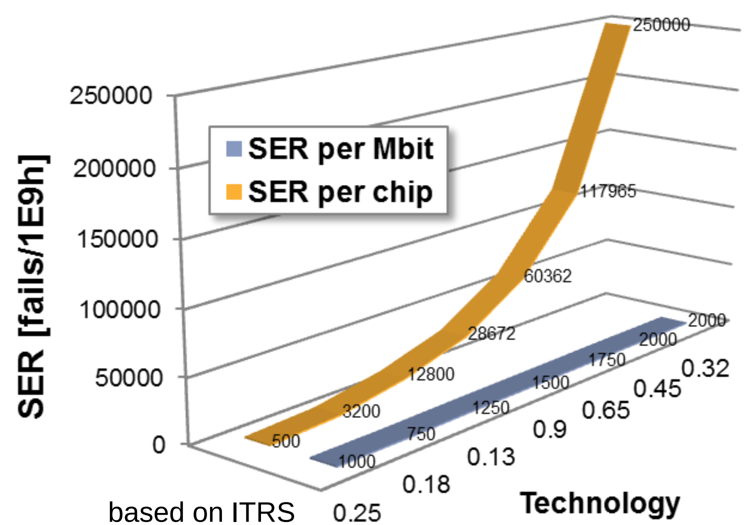
Atmospheric neutrons



X-ray IC inspections

- **Soft Error Rate now higher than all other reliability mechanisms**
  - constant evolution of SER/Mb
  - SER/chip increase when left unmitigated





based on ITRS roadmap 2011

ST, Central CAD and Design Solutions, SER FDSOI28, P.Roche et al.

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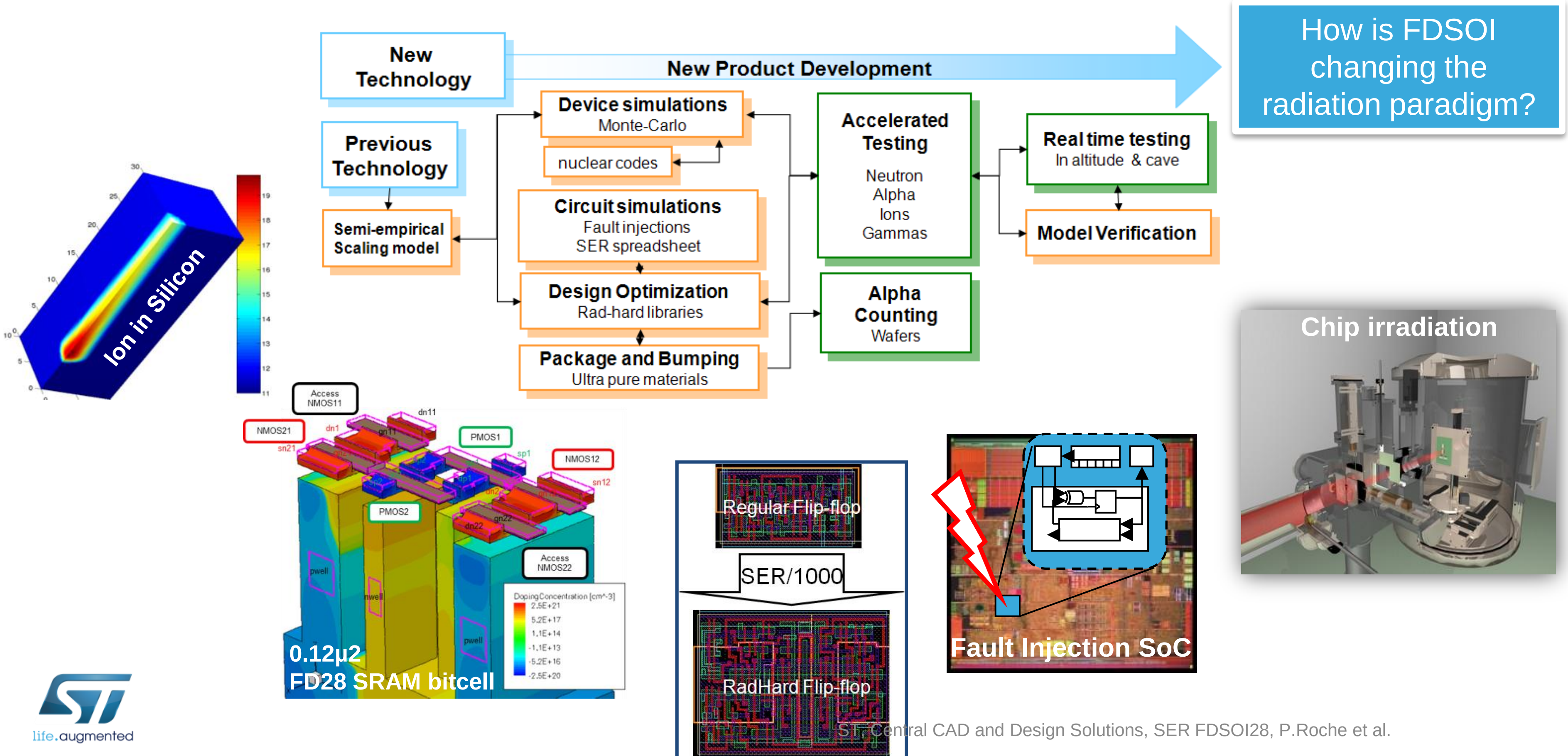
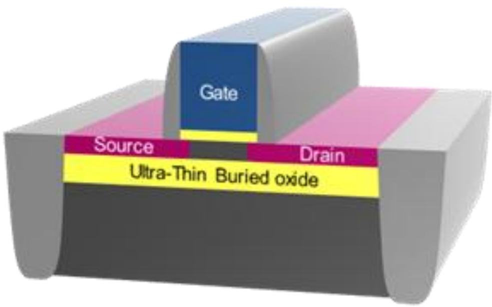
ST Radiation-Hardening Flow at a glance

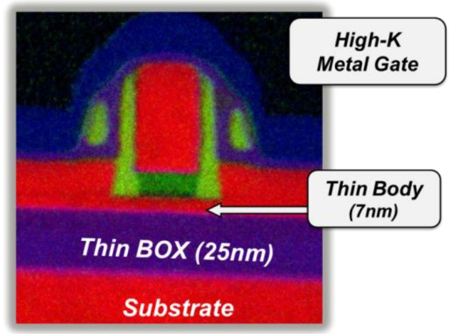
- **Radiation tolerance of IPs ensured with extensive simulations and irradiations**
  - radiation qualification part of TP certification
- **Highest robustness with ST patented rad-hard IPs**
  - rad-hard SRAMs, logic, PLL, IOs, triplication, dual clocks, ECC, space platform, …



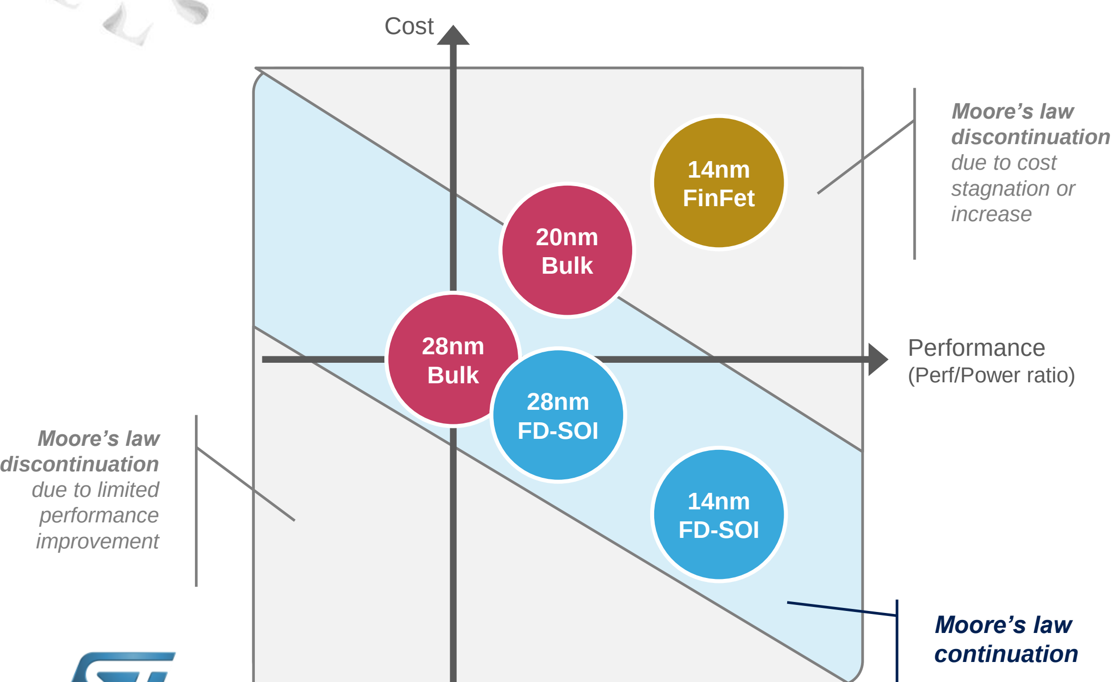
ST Central CAD and Design Solutions, SER FDSOI28, P.Roche et al.

Key Features of 28nm UTBB FD-SOI





Ultra Thin Body & BOX Fully Depleted SOI transistor



- **Shorter channel length**
  - 24nm technology
- **Better electrostatics**
  - faster operation
  - low voltage
  - reduced variability
- **Total dielectric isolation**
  - latch up immunity
- **Lower leakage current**
  - less sensitive to temperature
- **Moore's law continuation**

ST, Central CAD and Design Solutions, SER FDSOI28, P.Roche et al.

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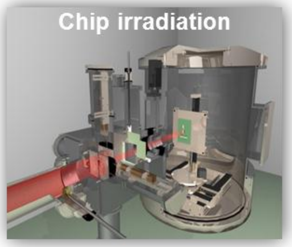
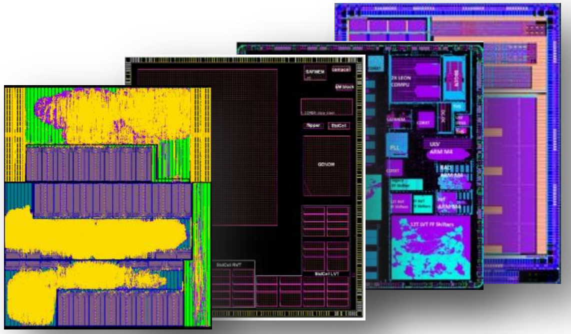
Radiation Test Results in FDSOI 28nm

FDSOI28 Radiation Test Plan

- **Three qualification circuits tested**
  - SRAMs, Flip-flops, SPARCV8, ARM cores, …
  - more to come in 2015





Radiation		Radiation test facility
Atmospheric neutrons (<800MeV)	Sea-level	TRIUMF, Canada
Alpha particles (@0.001cph/cm2)	Sea-level	STCrolles, France
Thermal neutrons (<25meV)	Sea-level	CEA, France
Muons	Sea-level	TRIUMF, Canada
Heavy ions (≤80MeV/(mg/cm²))	space	RADEF, Finland
Low energy protons (<10MeV)	space	RADEF, Finland
Gamma rays (10KeV)	space	UCL, Belgium

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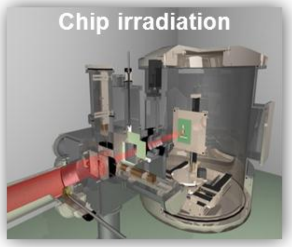

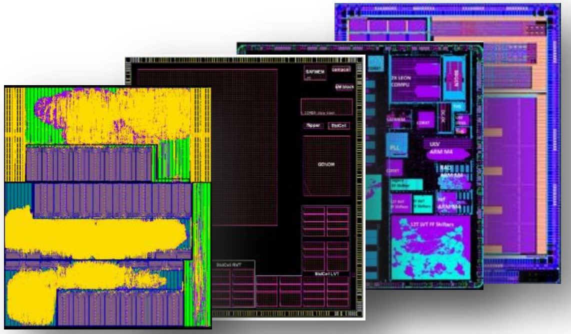

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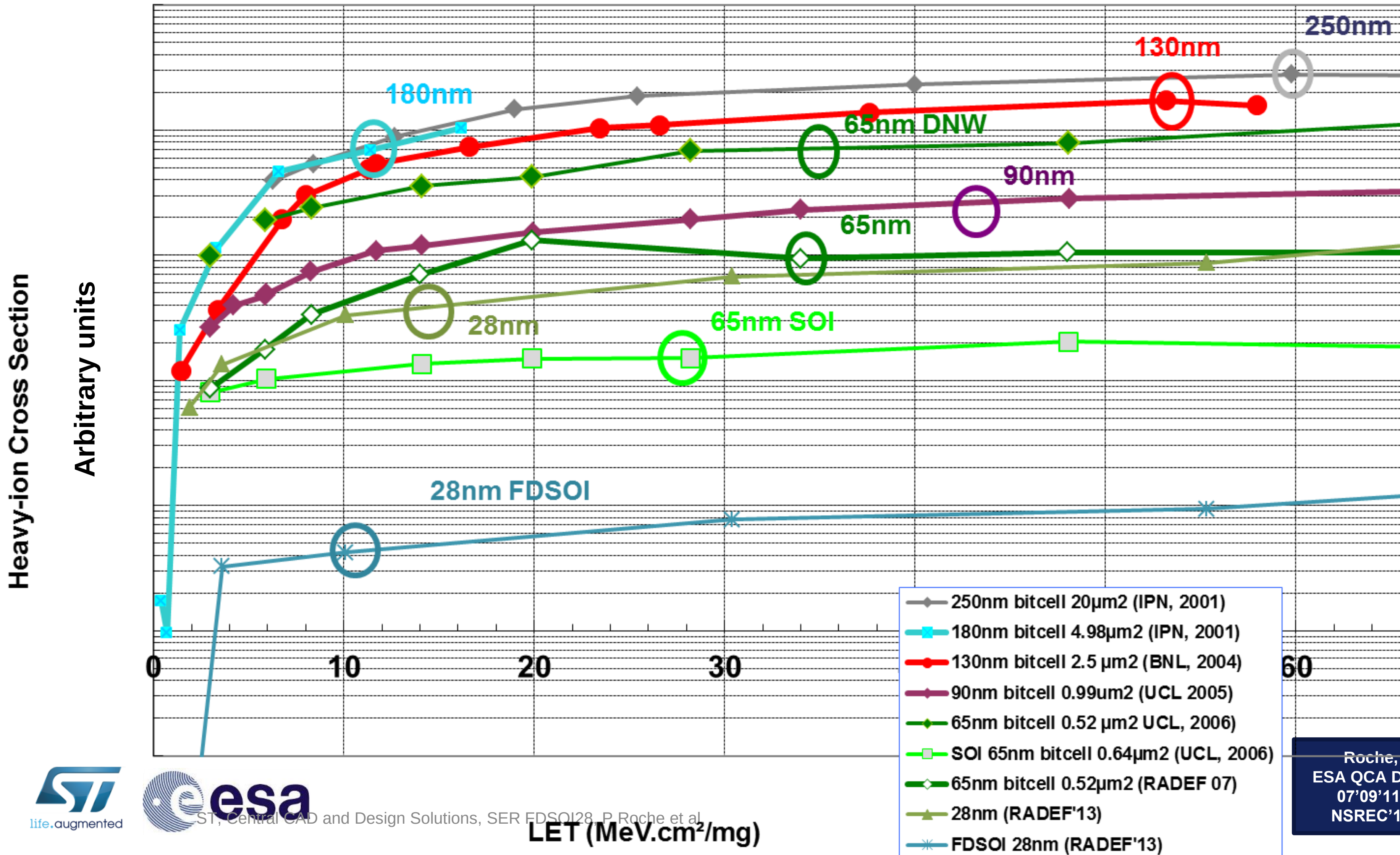
SRAM Heavy Ion Cross-Sections

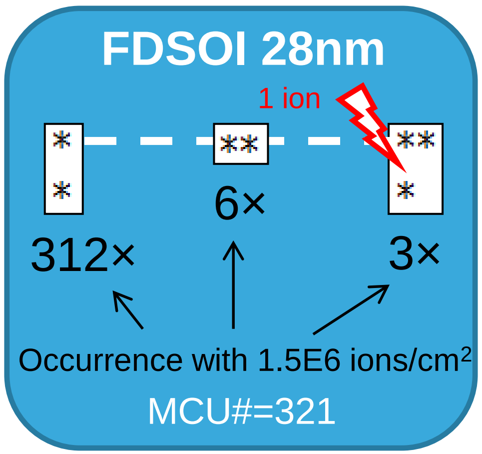
- **Lowest heavy ion SEU cross-sections in FDSOI 28nm**
  - 3 and 2 decades lower respectively than CMOS 65nmn and 28nm (no SEGR/SEL)

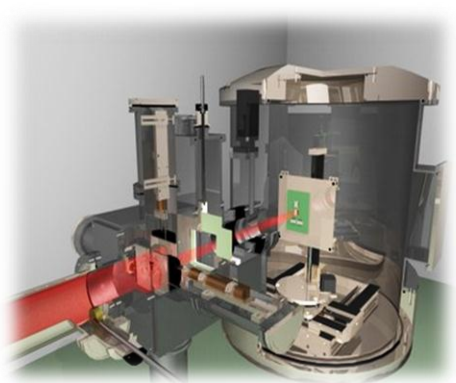


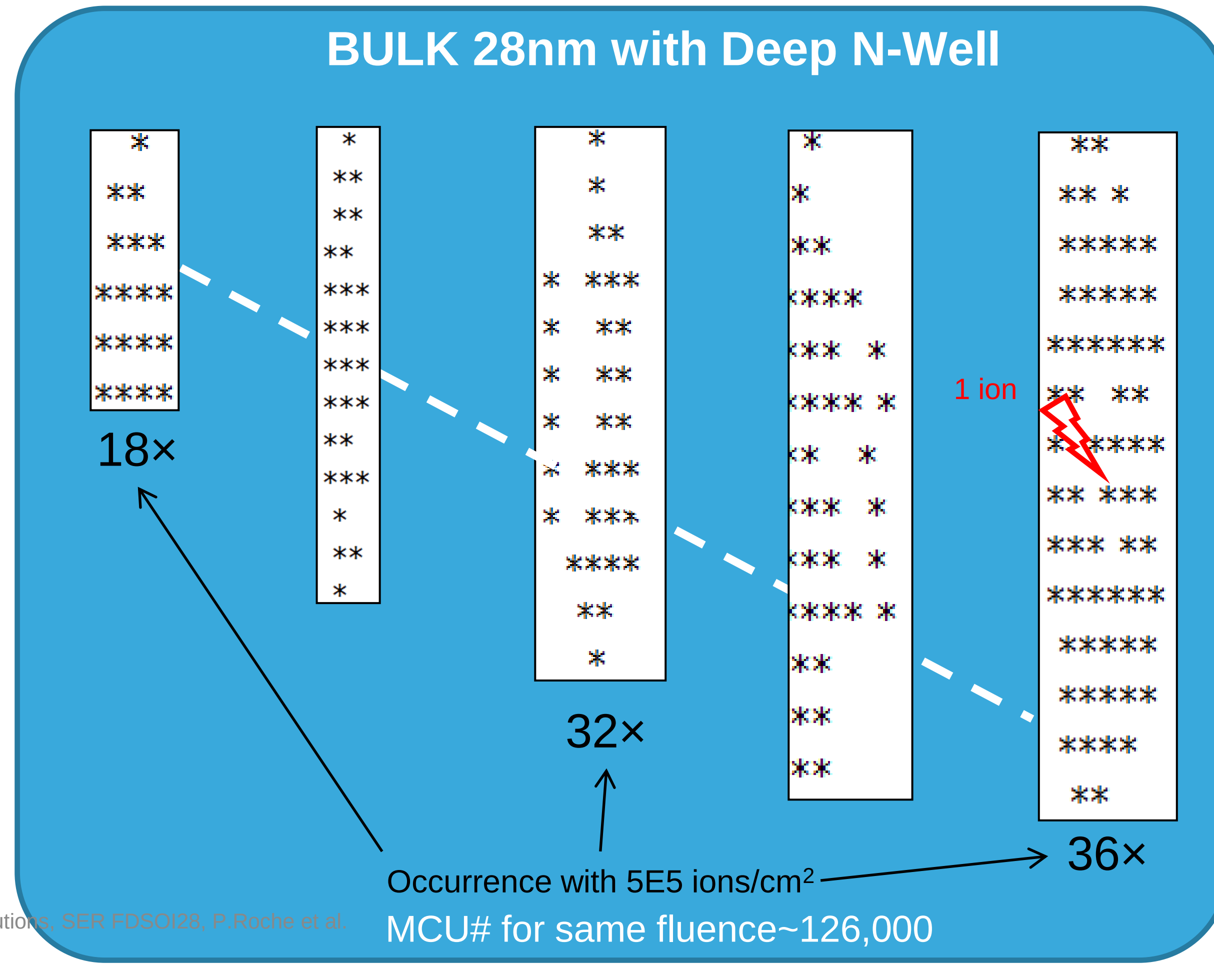
Roche,
ESA QCA Days
07'09'11'
NSREC'14

Heavy-Ion Multiple Cell Upsets in SRAMs: Bulk vs FDSOI

- **Same SRAM design 0.12µ2 at the 28nm node**
  - Bulk with Deep N-Well against SEL
- **Heavy Ion testing with ESA: <1% MCU^{3} with FDSOI28** versus **MCU^{59} in BULK28**
  - RADEF test facility, Finland, ESA SCC 25100, Xenon, high-LET, fluences: 1.5e6 ions/cm² (SOI), 5e5 ions/cm² (BULK)

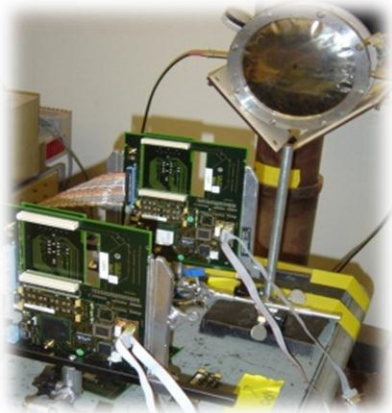


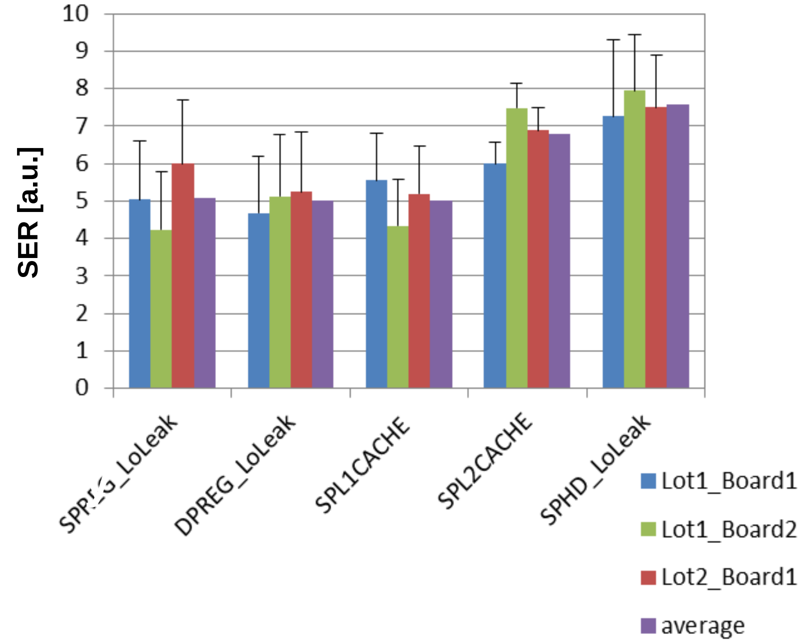




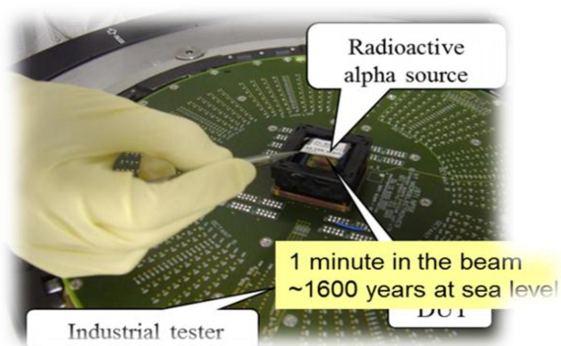
Alpha and Neutron Test Results on SRAMs in FDSOI28

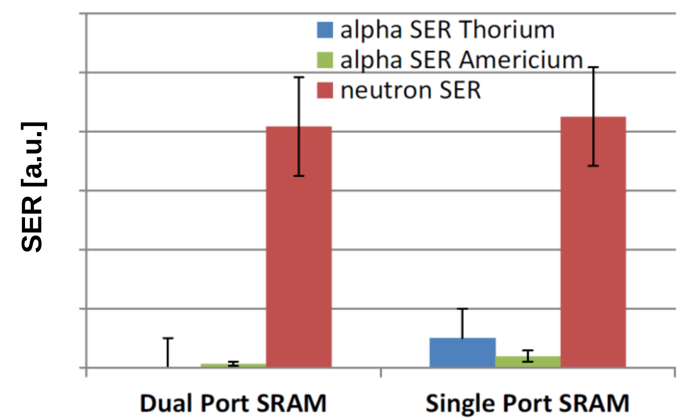
- **Unmitigated n-SER < 10 FIT/Mb**
  - dynamic test algorithms
  - 3 test patterns
  - RT and 125°C
  - 0.8V - 1.3V
  - TRIUMF, Canada





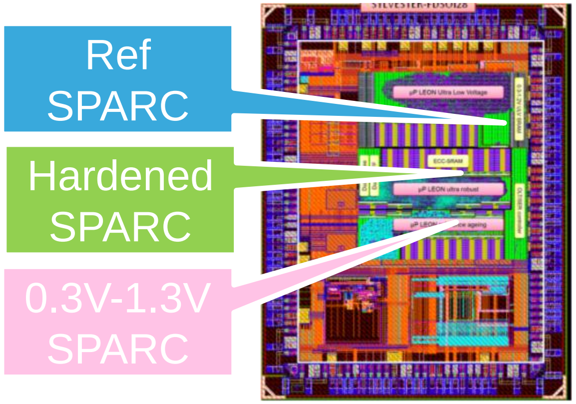
- **Unmitigated α-SER << 1 FIT/Mb**
  - Typically ~0.1 FIT/Mb
  - Am^{241} and Th^{232}



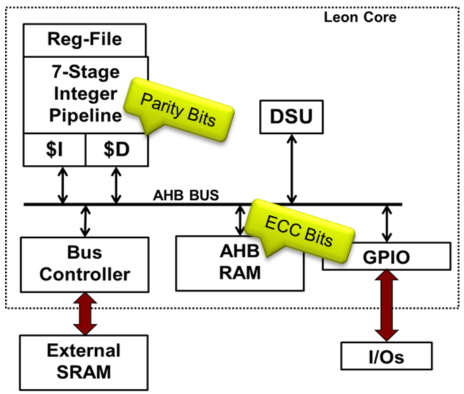


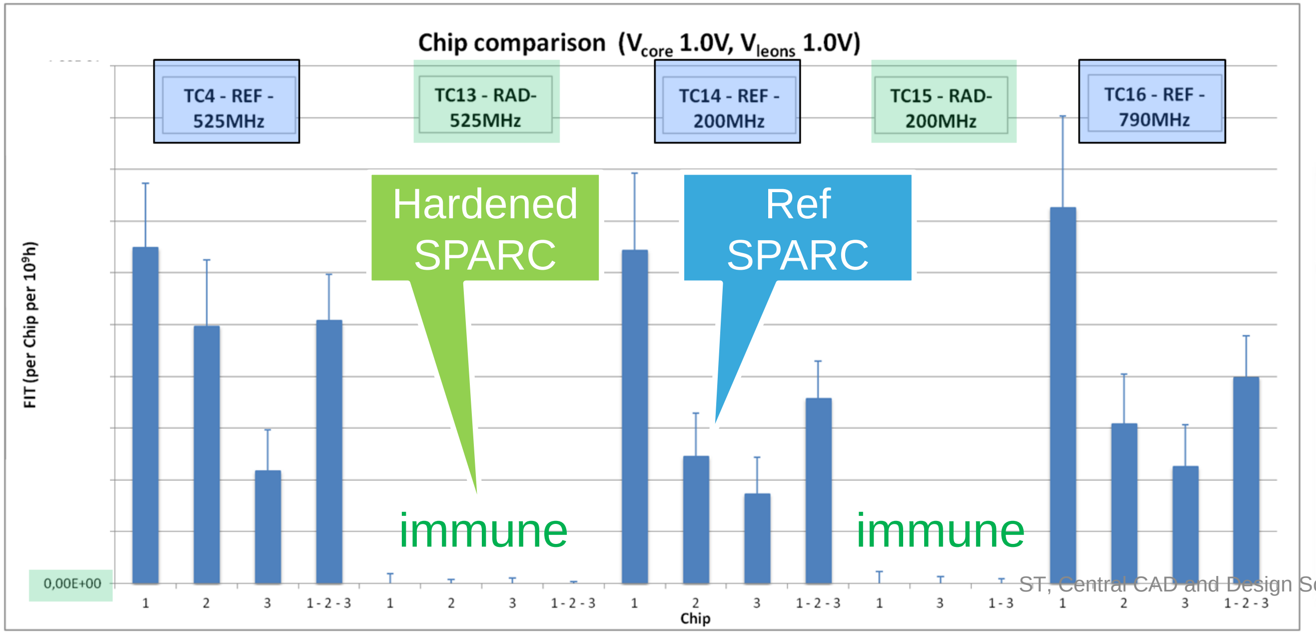
Radiation Test Results on SPARCV8 in FDSOI28

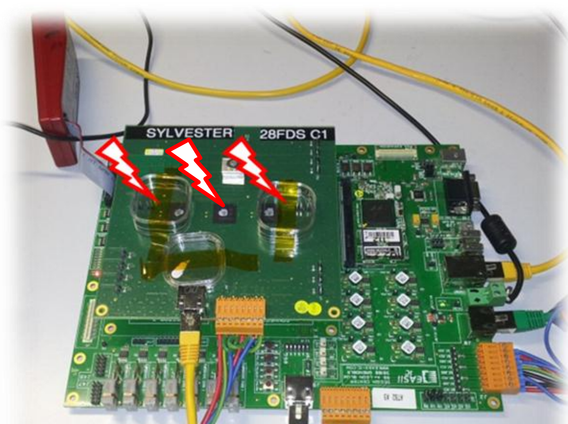
- **Radiation test setup for 32b SPARC**
  - 3 SPARCV8 processors
  - 1 FPGA controls DUTs: boot, reset, collect execution reports
  - CPU computes FFTs
  - Test SW handles errors, scrubbing, timing, bad computation, crashes



- **CPUs tested with alphas @ Crolles and neutrons @ Vancouver**
  - Ref CPU with alphas < 0.01 FIT/chip
  - Ref CPU with neutrons < 1FIT/chip
  - Hardened CPU (ECC, rad-hard FFs…): fully immune

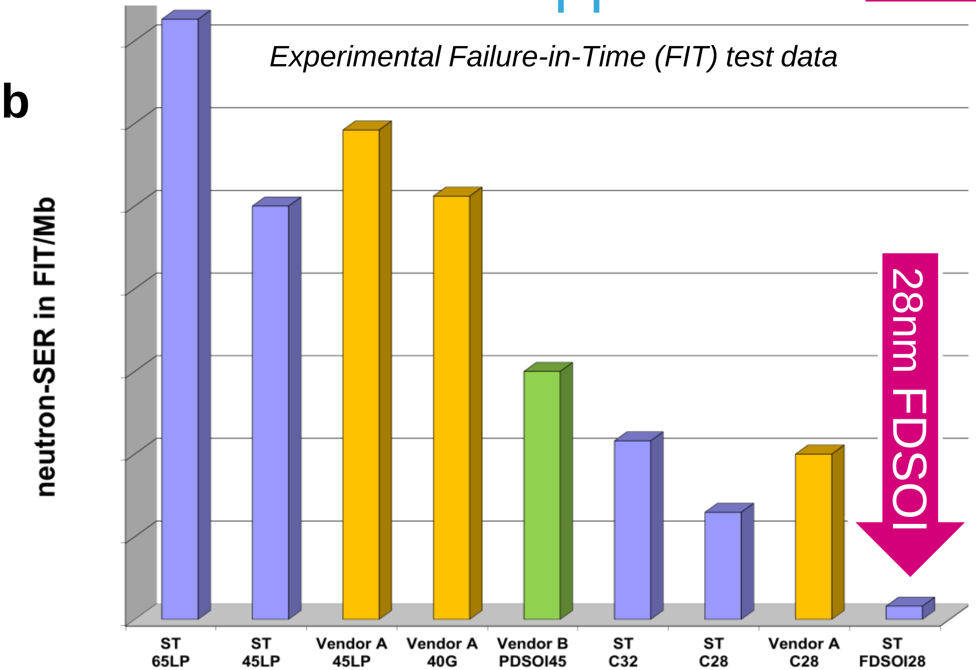


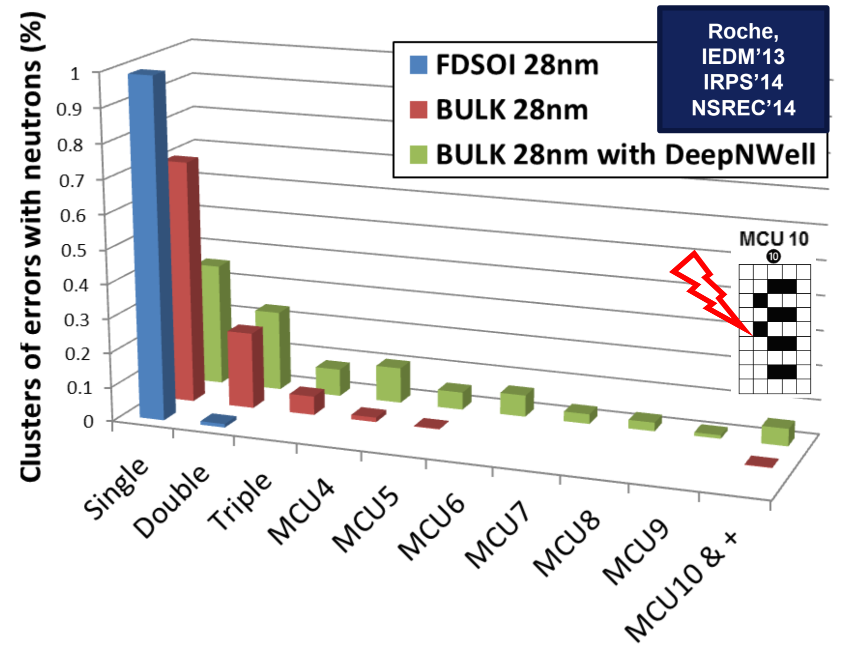




SER/SEL Performances in FDSOI28 for Terrestrial Applications

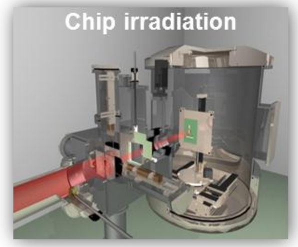
- **Very low neutron-SER SRAM <10 FIT/Mb**
  - 100× better than BULK counterpart
  - ECC/EDAC not systematically required
- **Single Event Latchup immunity**
  - tested with neutrons 125°C/1.3V
- **Alpha quasi-immunity <1 FIT/Mb**
  - no need for ultra-pure alpha packaging
- **Very small error clusters: 99% single bits**
  - Single Error Correction efficient
  - no need for bit scrambling as for BULK

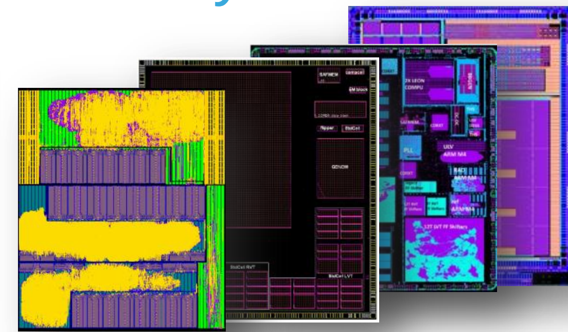




FDSOI28 Radiation Test Synthesis

- **Three qualification circuits already tested**
  - SRAMs, Flip-flops, SPARCV8, ARM cores, …



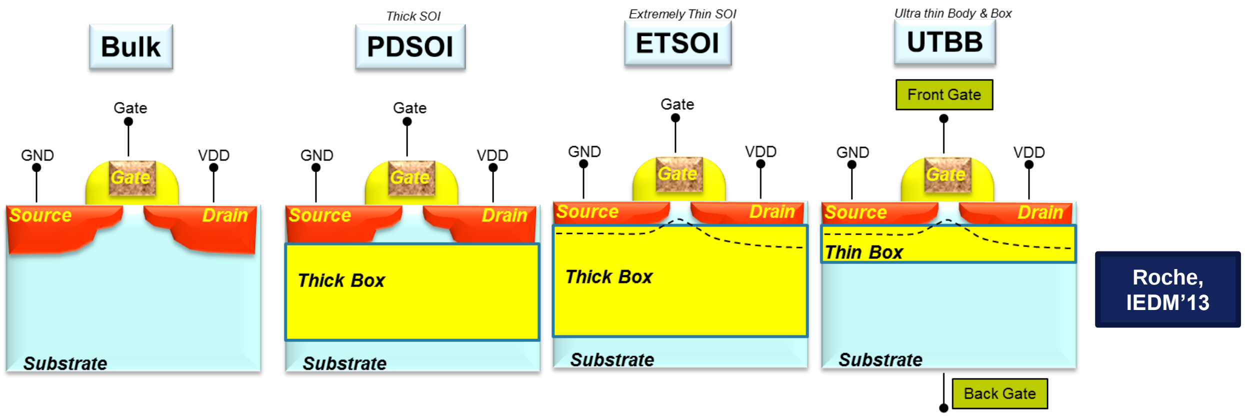


Radiation		Experimental radiation test data	FDSOI28 SER gain w.r.t. BULK 28nm
Atmospheric neutrons (<800MeV)	Sea-level	Neutron-SER < 10FIT/Mb	100×
Alpha particles (@0.001cph/cm2)	Sea-level	Alpha-SER < 1 FIT/Mb	1000×
	Sea-level	RHBD microprocessor immunity	100×
	Sea-level	Ultra low alpha wafer counting	~
Thermal neutron (<25meV)	Sea-level	Thermal-SER < 2 FIT/Mb	20×
Muons	Sea-level	Peak error rate 10x lower than Bulk	>10×
Heavy ions (≤60MeV/(mg/cm²))	space	Asymptotic error X-section=10^{-10} cm²/bit	100×
Low energy protons (<10MeV)	space	Error cross-section < 10^{-14} cm²/bit	1000×
Gamma rays (10KeV)	space	VTH shift <1mV/krad (till 100krad)	~

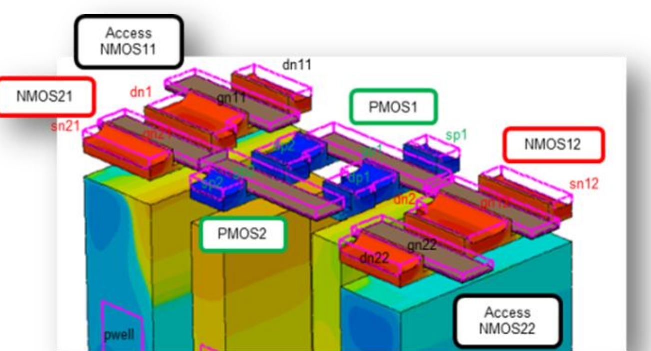
Key SEU Parameters
3D TCAD Simulations in FDSOI 28nm

FDSOI28 Key SEE Parameters

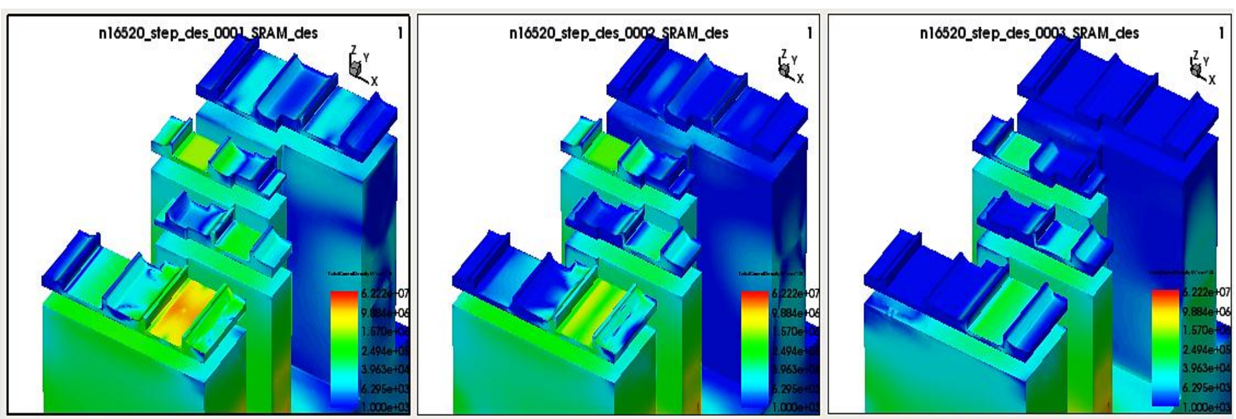
- **Very small volume for charge collection**
  - 160×/70× smaller Si film than PDSOI 130nm/65nm



- **Very low parasitic bipolar gain**
  - minimize the charge amplification inherent to every SOI technology
  - thanks to full depletion

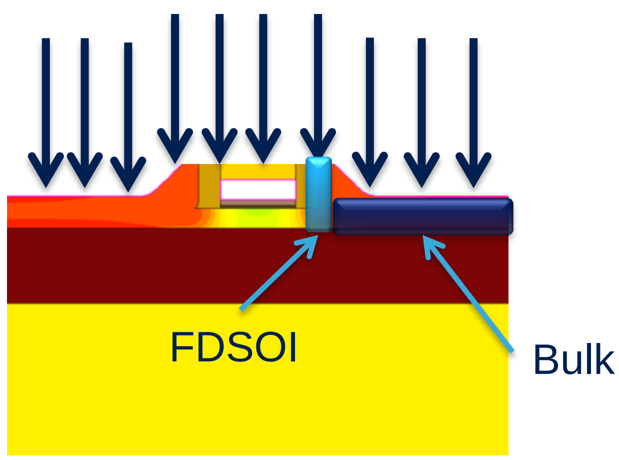


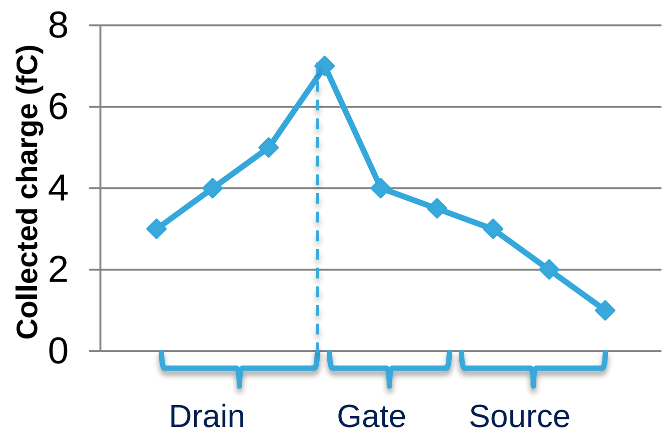
0.120µm² FD28 bitcell 3D TCAD structure



Ion strike on 0.120µm² cell – Current density at various instants

- **Sensitive volume: limited to Si film, high field region**

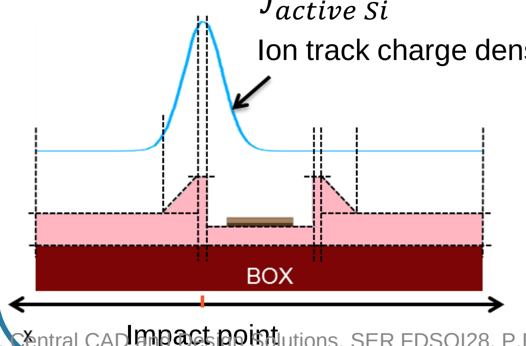




- **Parasitic bipolar gain:** $\beta = Q_{coll}/Q_{dep}$

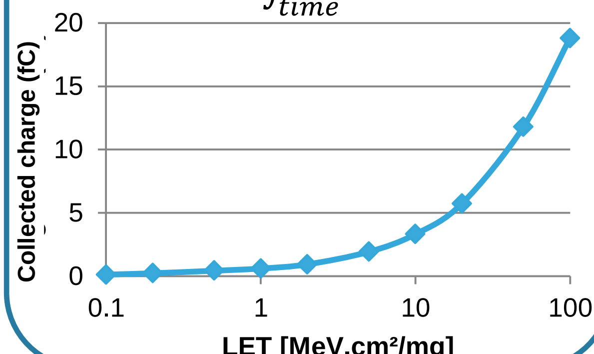
Deposited charge

$$Q_{dep} = \int_{active\ Si} ion\ track$$



Collected charge

$$Q_{coll} = \int_{time} drain\ current$$



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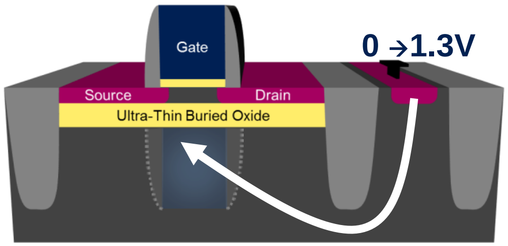
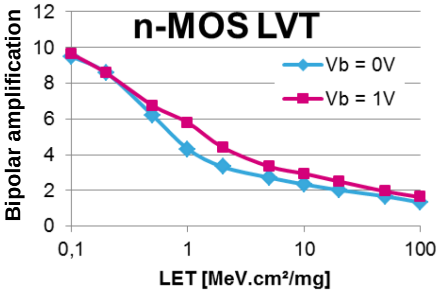
FDSOI28 Bipolar Gain for Back Biasing Schemes

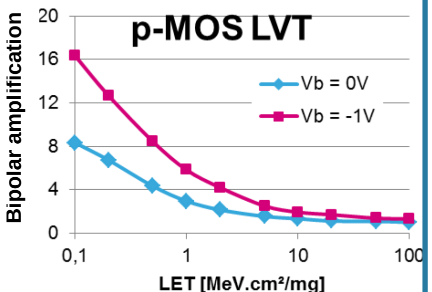
- **Body Biasing: voltage applied to the substrate/body**
  - when voltage is positive, called Forward Body Biasing
  - much wider range of biasing in FDSOI compared to Bulk



FBB: Forward Back Biasing

- Reduces V_t



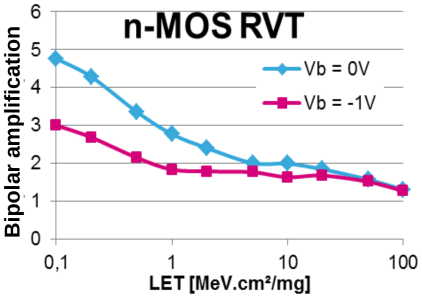


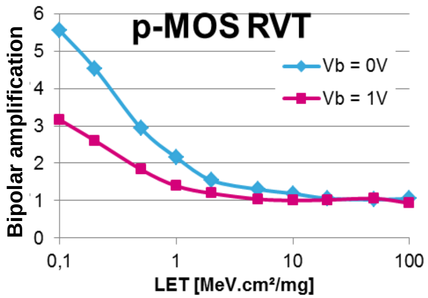
↗ Charge amplification slightly

↗ Speed

RBB: Reverse Back Biasing

- Increases V_t





↘ Charge amplification

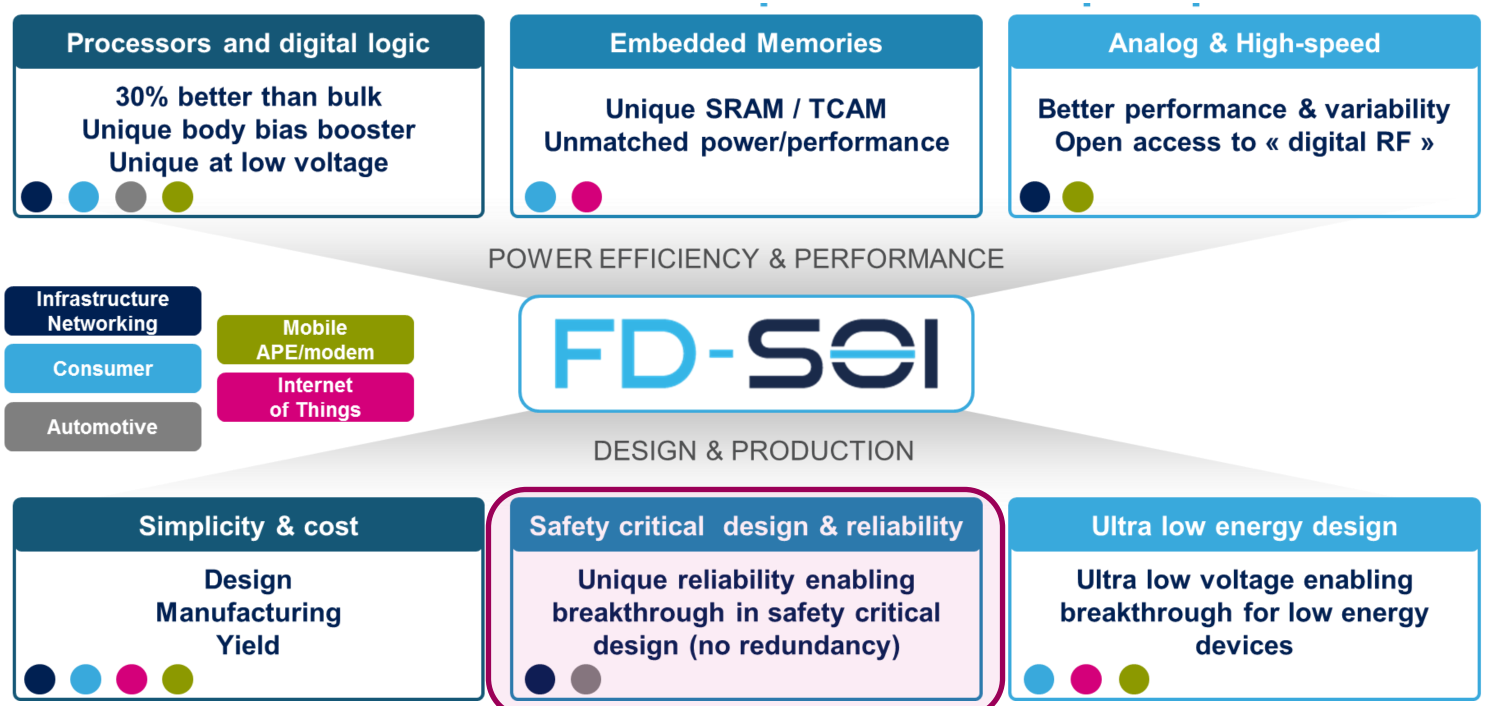
↘ Power consumption

- **FDSOI enables optimum trade-off b/w rad tolerance, performances and power**

- **FDSOI has changed the radiation paradigm**

- **Upset rates improved by 100× to 1000×**
  - against neutrons, alphas, heavy ions, protons, muons, thermals, low energy protons …
  - due to both very small sensitive volume and very low bipolar gain

- **Enabling new classes of products: networking, automotive, IoT, medical…**



Thanks for your attention!

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