Heavy Ion Energy and Tilting Effects in FLASH Memories

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Reliability and Radiation Effects on Advanced CMOS Components
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- Introduction
  - FG memories
  - Previous results
- Effect of ion energy on radiation response
  - Motivation
  - Some results
  - Model
- Effect of tilt angle on radiation response
  - Some results
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- Conclusions

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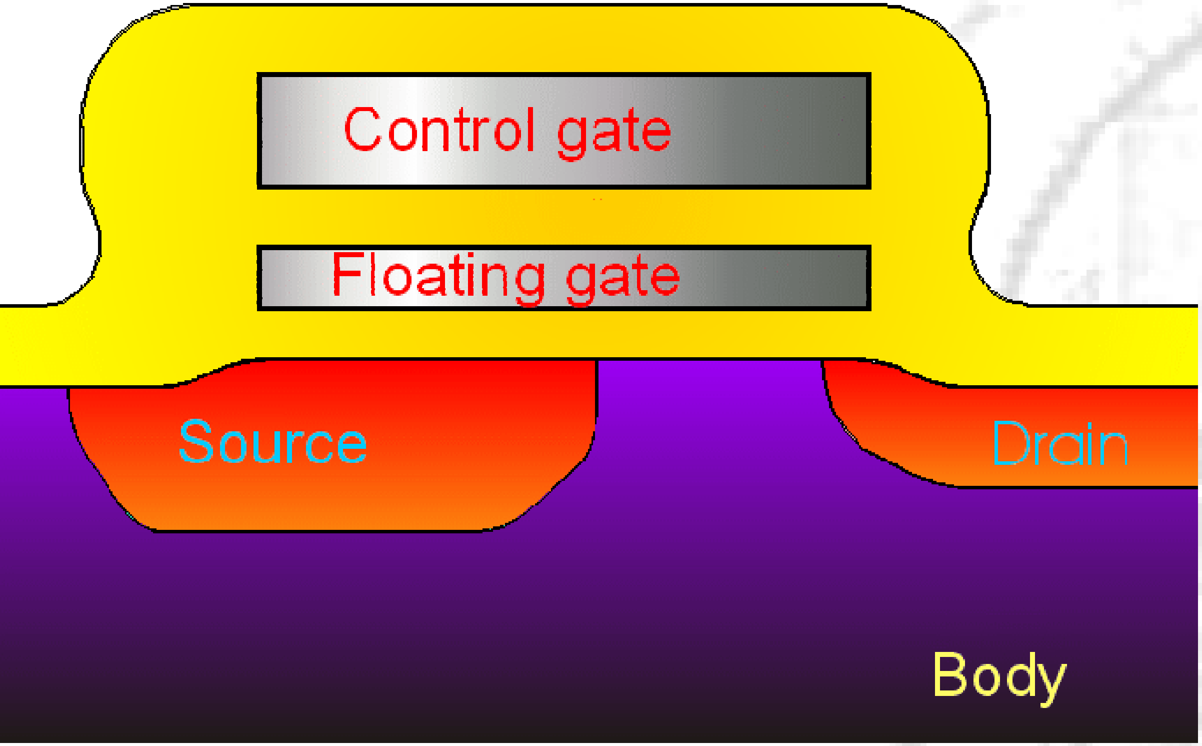
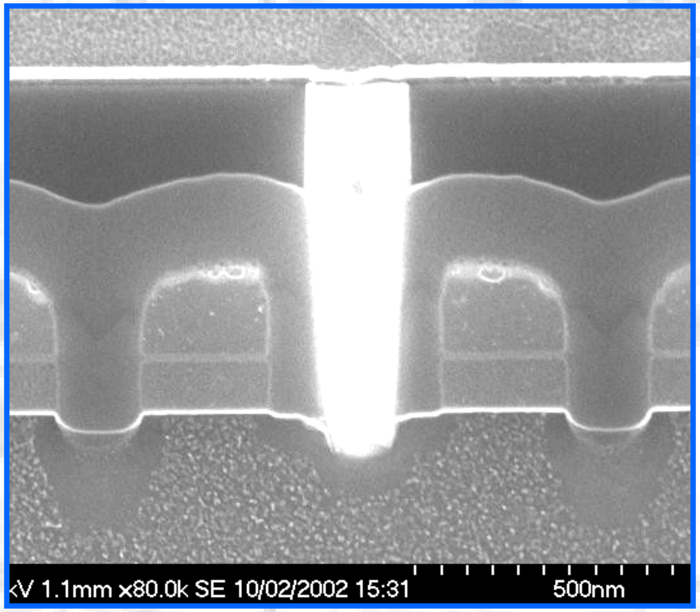


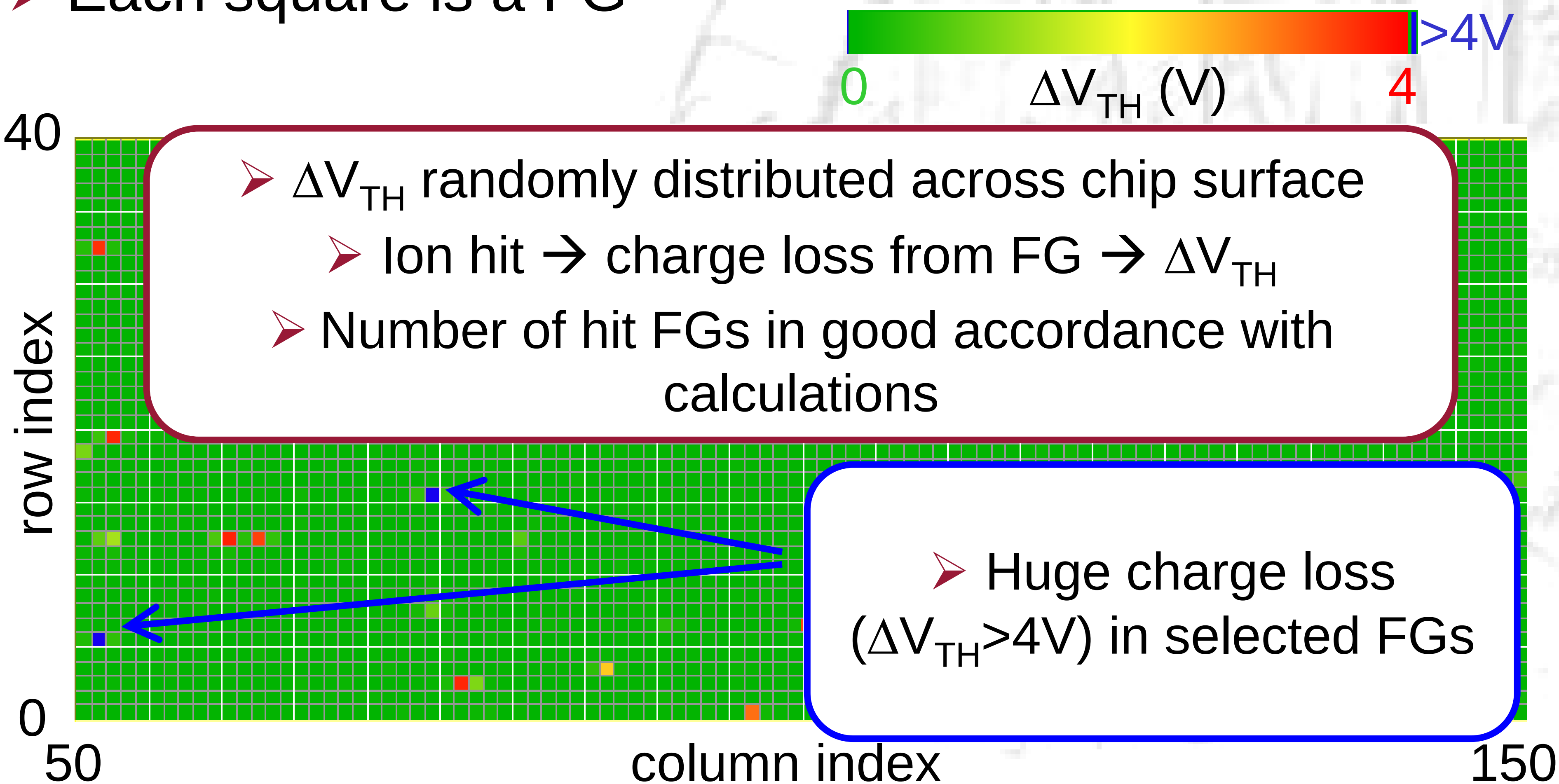


- V_{TH} of the device is controlled by controlling the number of electrons/holes stored in the FG

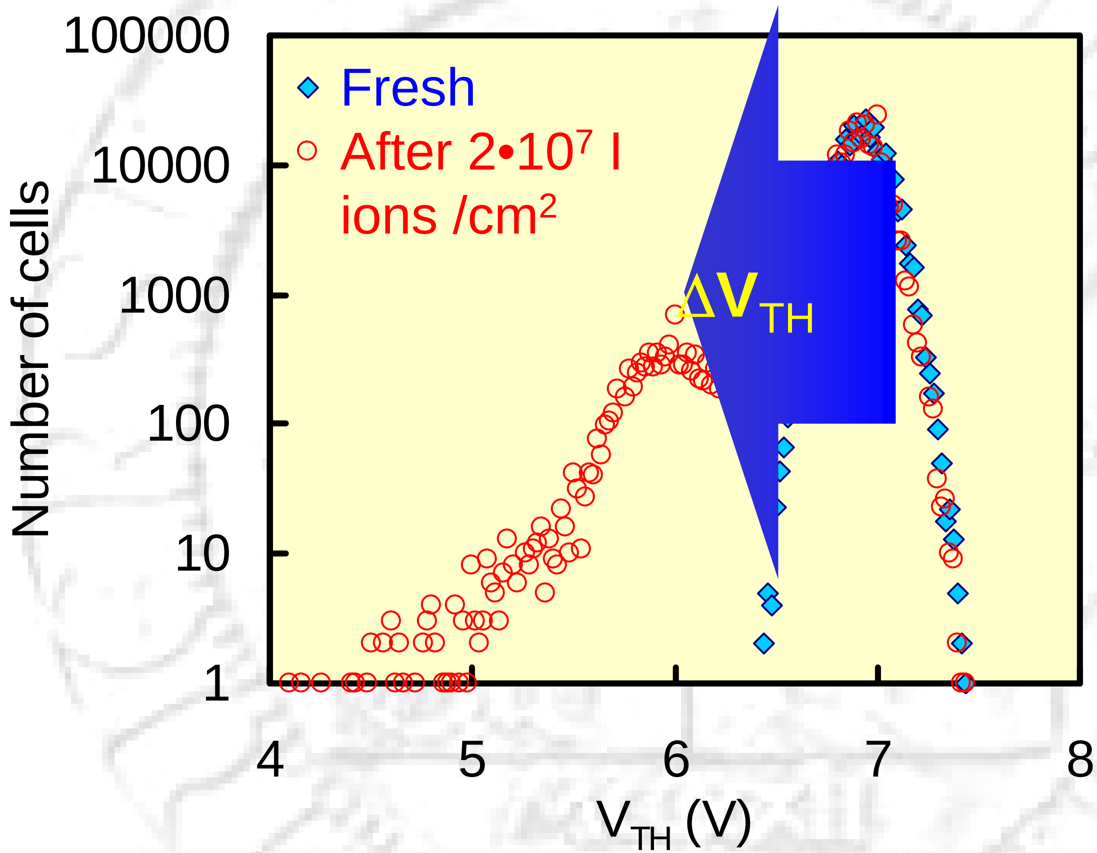
- Effects on the control circuitry
  - Traditionally the most radiation sensitive part [1]
- Effects on the array
  - Prompt charge loss (~10fs) [2]
  - Long time effect (due to RILC) [3]
- As long as ΔV_{TH} is "small enough" no error can be seen in user mode
  - Large charge loss from smaller devices
  - User mode errors are appearing in last years [4]

[1] Nguyen, et al, T-NS, 1998; Schwartz, et al, T-NS, 1997; Roth, et al, REDW, 2000.
[2] Cellere et al, JAP, 2006, and T-NS, 2005
[3] Cellere et al, AP-L, 2005, and T-NS, 2004, 2005, 2006
[4] Oldham, et al, T-NS, 2006; Guertin, et al, T-NS, 2006; Irom, et al, NSREC 2007

- 10^7 iodine ions/cm^2 (LET~64MeVcm^2/mg)
- Each square is a FG



- 0.18μm technology
- FG cells being hit by a single ion form a secondary peak at ~6V
- Distance between the peaks = average ΔV_{TH}



FGs in the secondary peak ←→ hit

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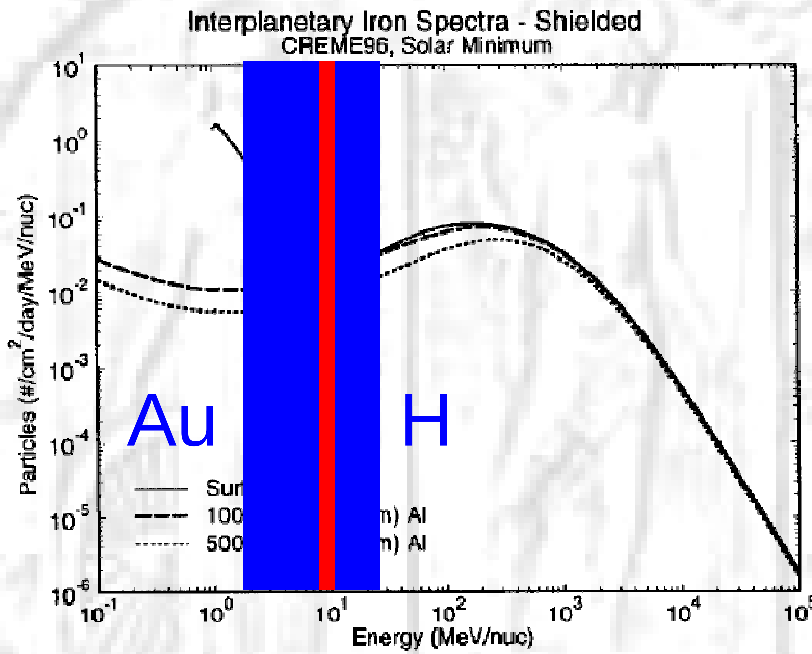
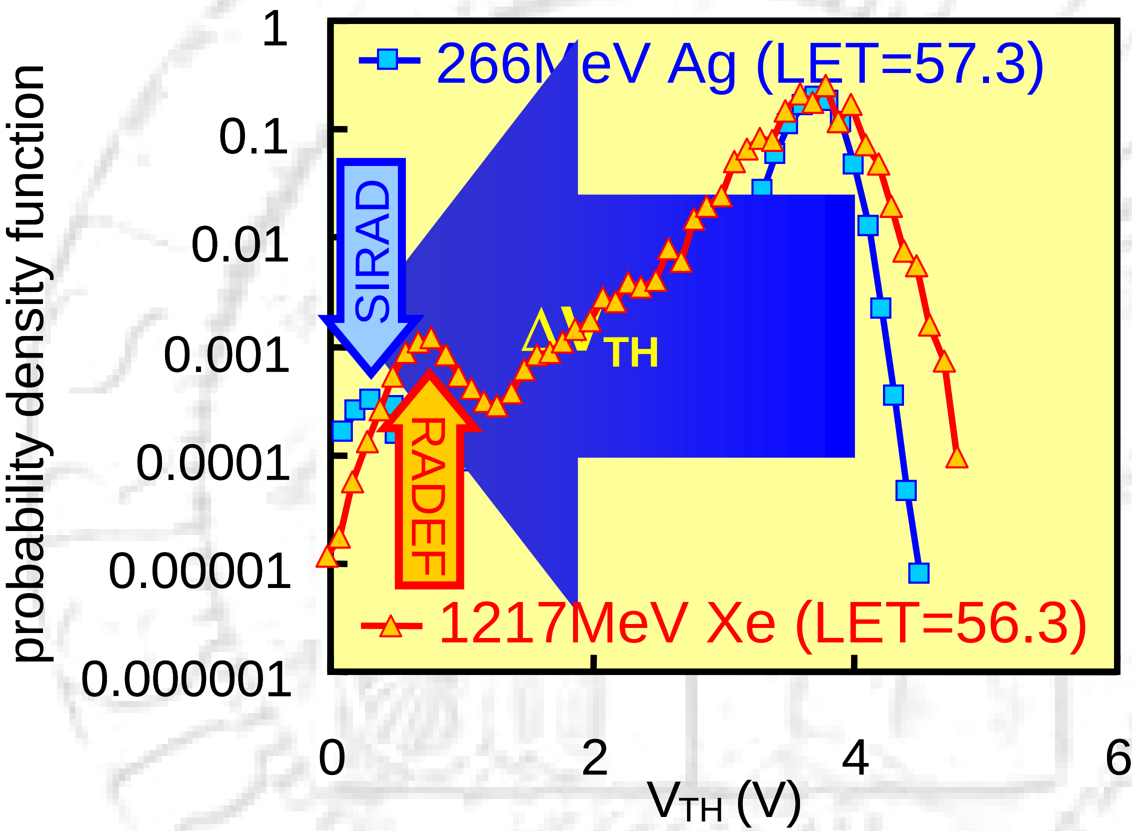
- Typical energies delivered by accelerators are small compared to space
- Space
  - Energies up to 10^5 MeV/amu
- SIRAD
  - LNL-INFN (Italy)
  - Tandem van De Graaff
  - 30MeV/amu (H) → 1.5MeV/amu (Au)
- RADEF
  - Jyväskylä (Finland)
  - Cyclotron
  - 9.3MeV/amu (all ions)



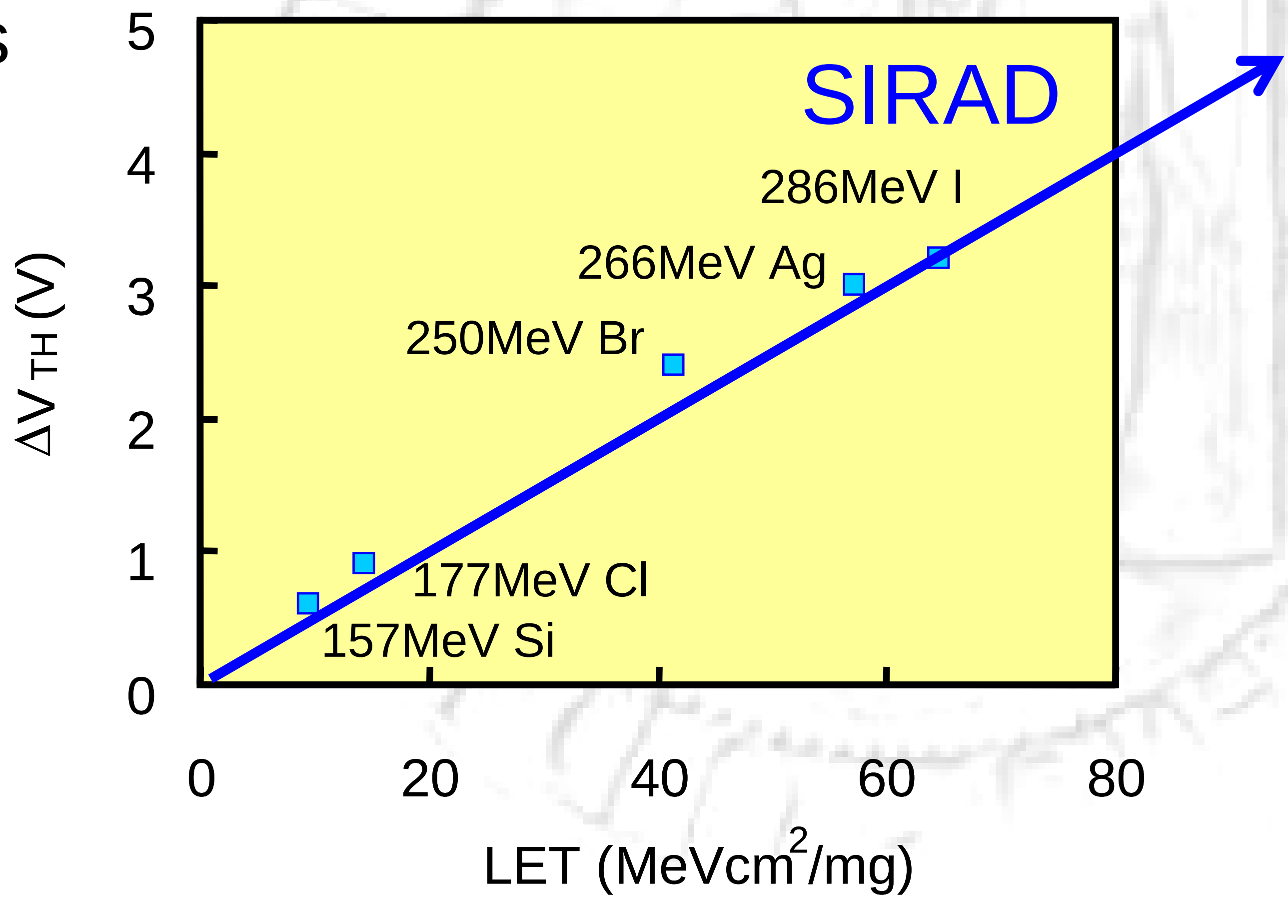
J. Barth, NSREC Short Course, 1997

- The secondary peak corresponds to cells being hit by an ion
- Distance between the peaks = average ΔV_{TH}
- What happens with ions of the same LET but different energy?

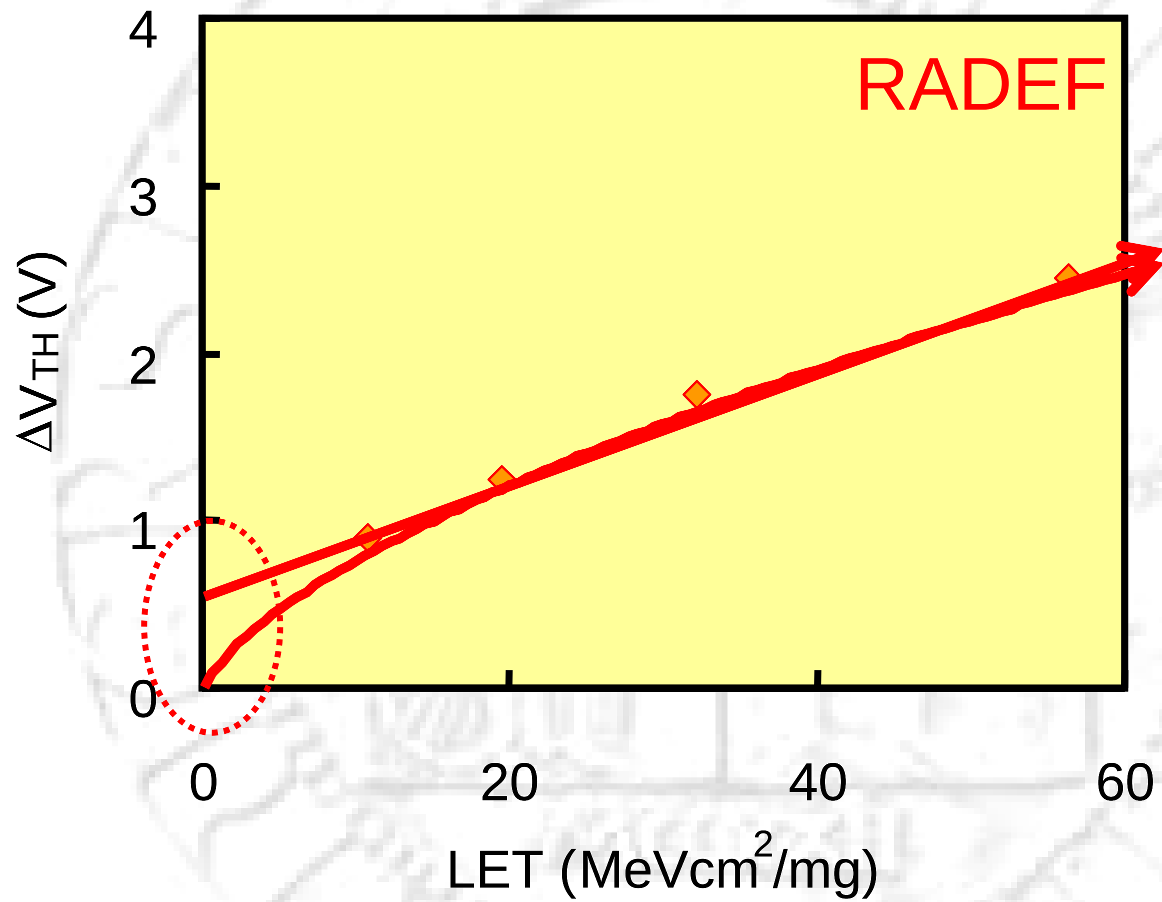


Higher energy
→ smaller charge loss?

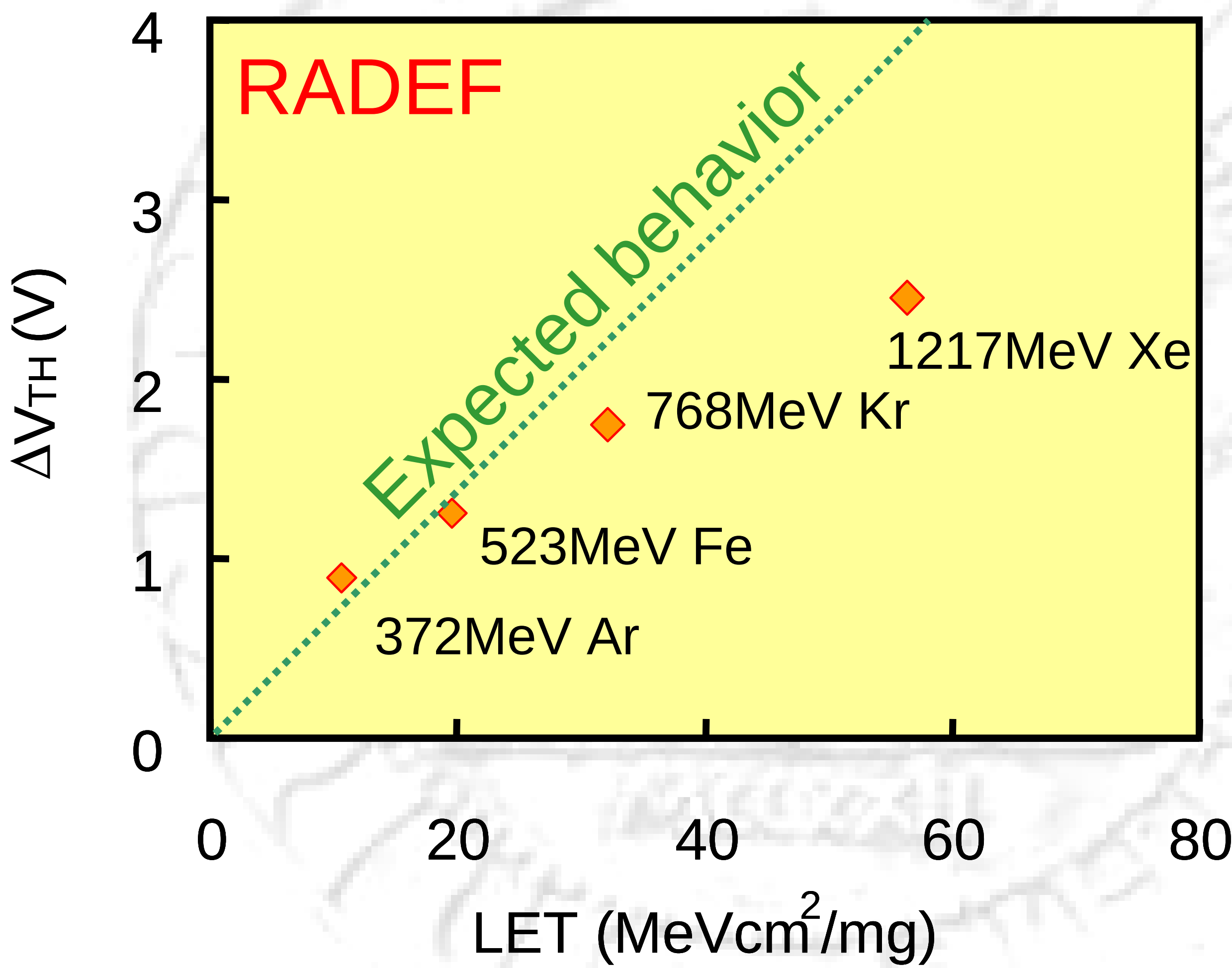
- SIRAD: average charge loss linearly depends on impinging ion LET
- All ion beams have very similar energy



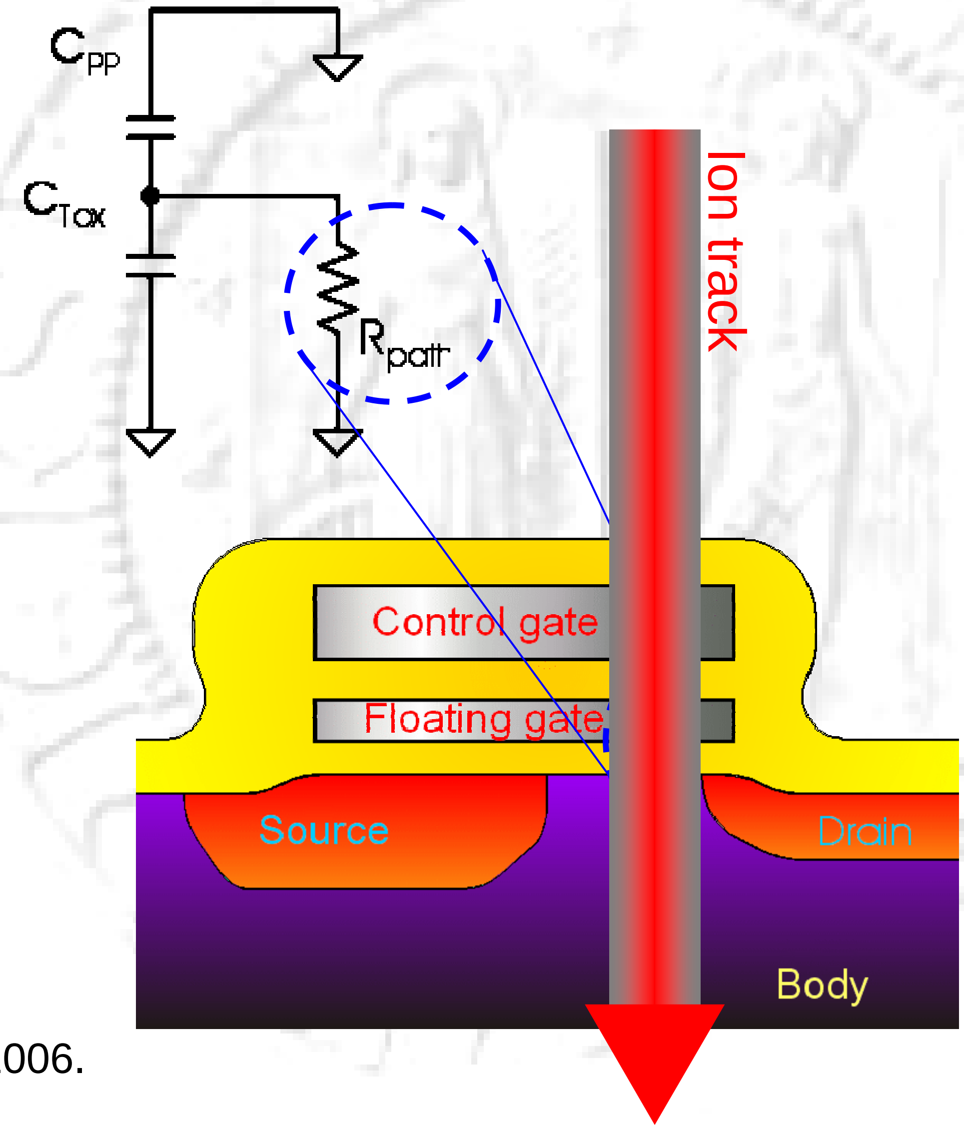
- RADEF
- Linear fit
  - ΔV_{TH} even for LET=0
  - Doesn't make sense!
- Power law fit
  - Works even better
  - What's going on?



- Deviations from the linear behavior at high LET/high energy
- Energy plays a key role
  - Energy strongly increases with LET (unlike at SIRAD!)

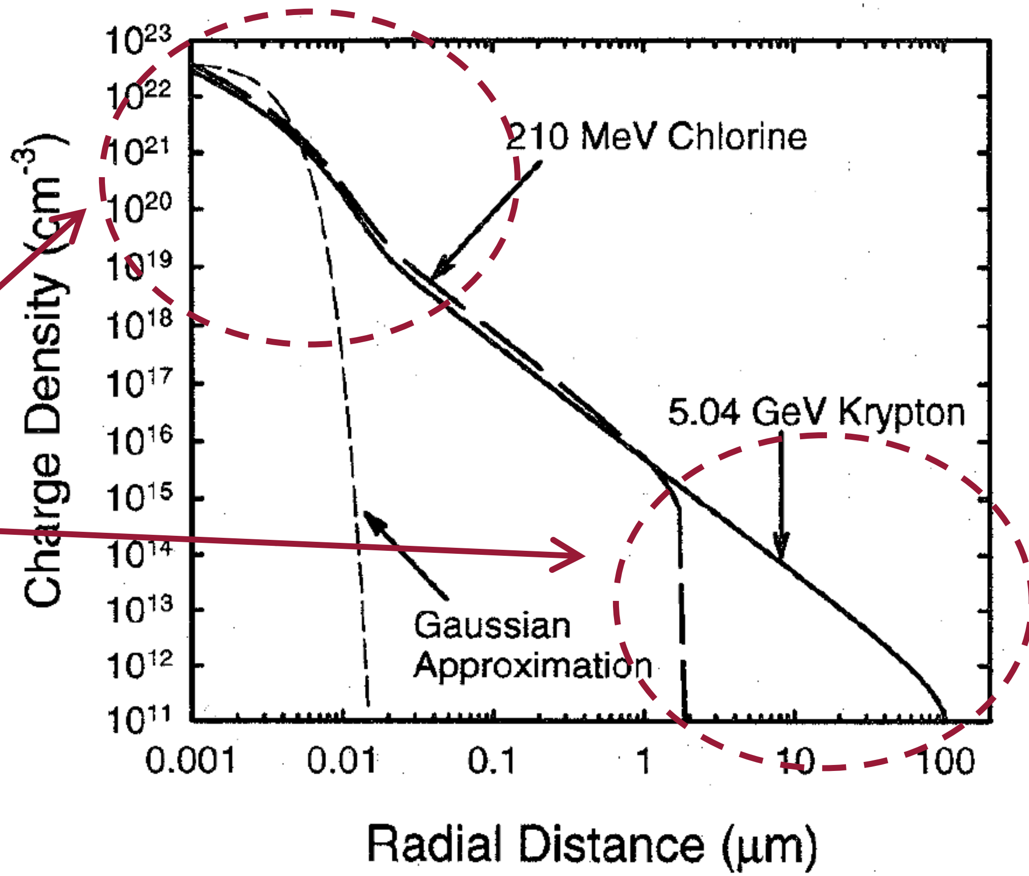


- The e⁻/h⁺ plasma acts as a resistance through the tunnel oxide, discharging the FG
- The discharge duration is linked to electron permanence in the oxide: about 10^{-14} seconds (!)



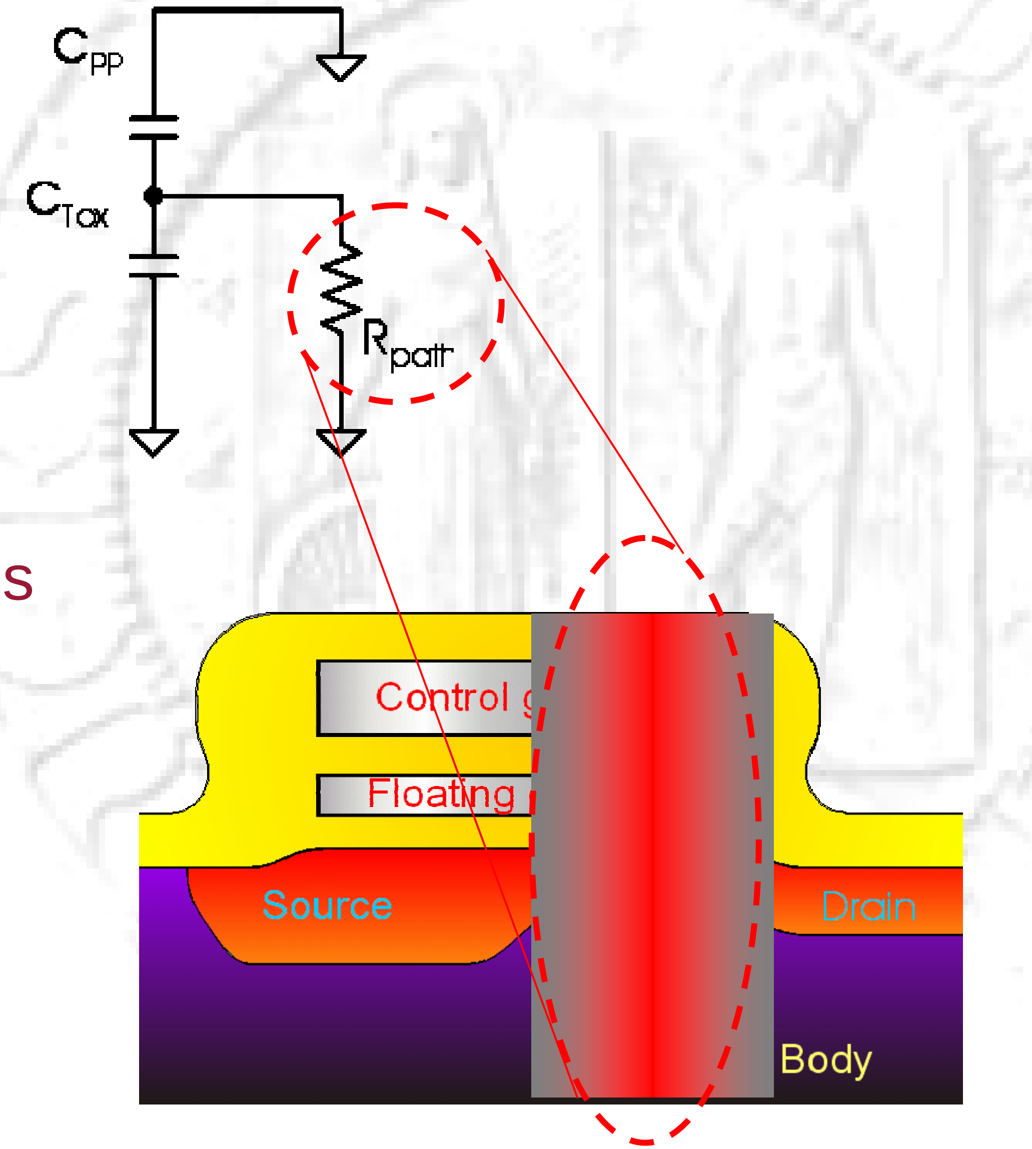
Cellere, et al, IEEE T-NS, 2004, and JAP, 2006.

- Higher ion energy
  - delta electrons have higher energy
  - ion track is less dense in the central region and broader



Dodd et al, T-NS, 1998

- Higher ion energy
  - delta electrons have higher energy
  - ion track is less dense in the central region and broader
  - path resistance increases
    - ➔ ΔQ_{FG} decreases
    - ➔ ΔV_{TH} decreases



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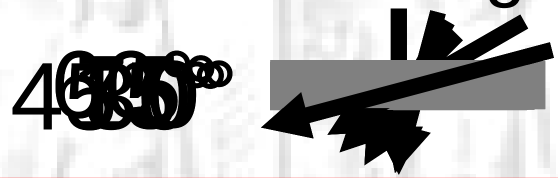
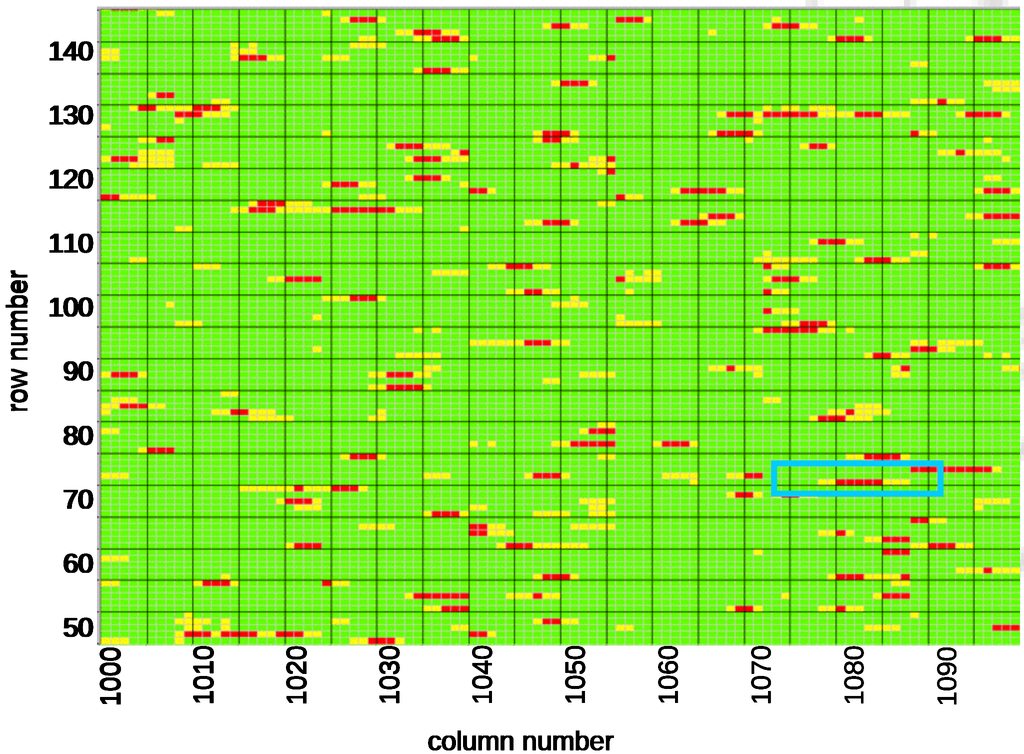
- In real world the ion flux is ~isotropic
- What happens when changing the irradiation angle?
- After 1217MeV Xe irradiation

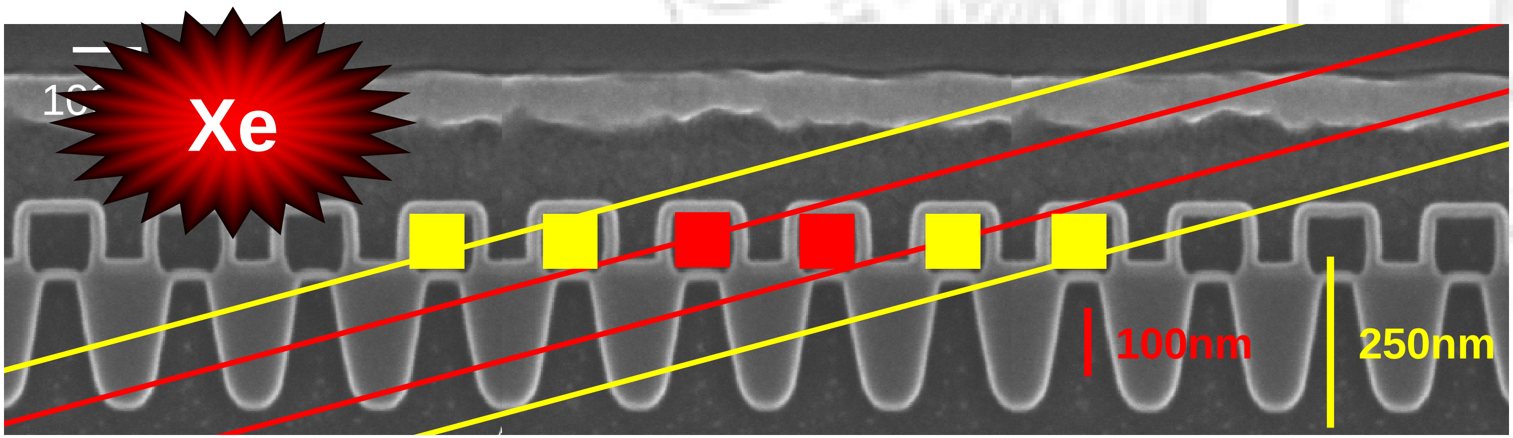




More than 20 FGs corrupted by a single ion!

"Red" and "Yellow" are two distinct populations

- Track size and device geometry can give an estimation of the track diameter
- Inner region (red):
  - Degradation of the stored information
  - Permanent damage
- Outer region (yellow):
  - Degradation of the stored information
  - No permanent damage



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- FG memories
  - Leader nonvolatile technology
  - Very complex devices
  - Aggressively scaled → at the forefront of
    - Technology
    - Physics of ion-matter interaction
- Two case studies (of general interest)
  - Ion energy impacts radiation hardness → energy (not just LET) must be considered
  - At grazing angles, long traces of errors → cosine law is not (always) valid in the deep-submicron regime