8th ESA-ESTEC D/TEC-QCA
Final presentation day
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Louvain-la-Neuve

STUDY OF HEAVY ION RADIATION EFFECTS IN FLASH MEMORIES

TEC-QCA Support Activity

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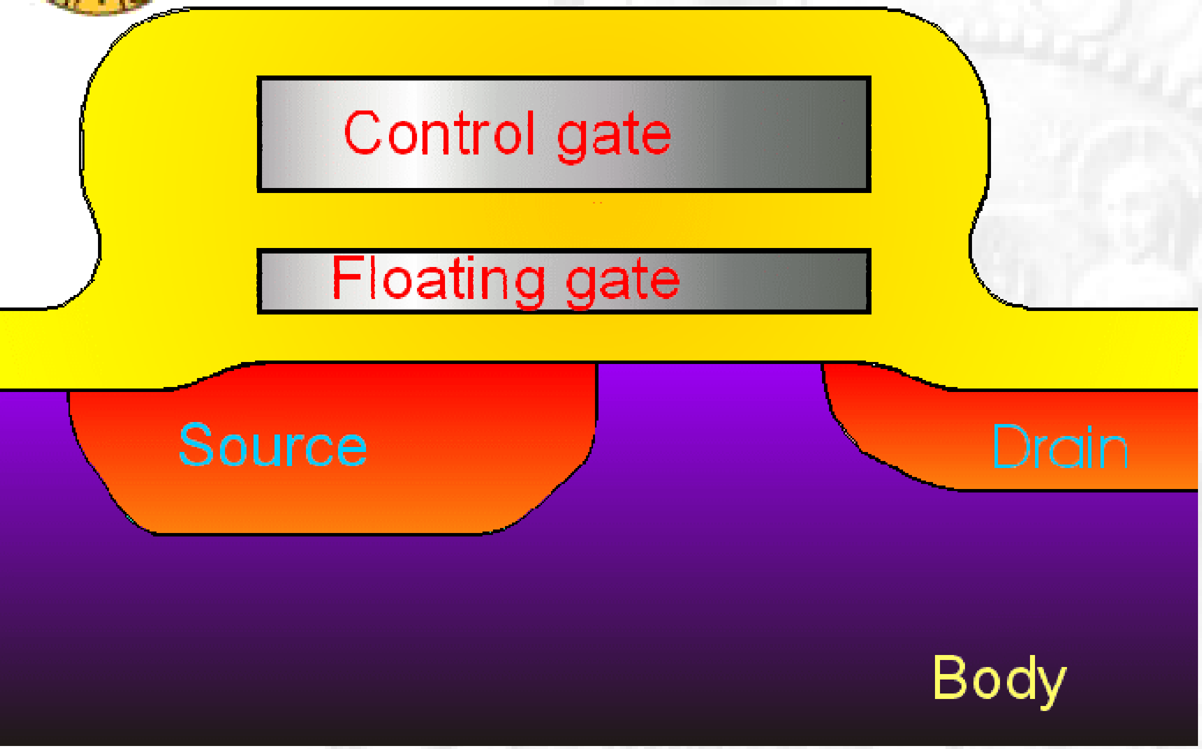

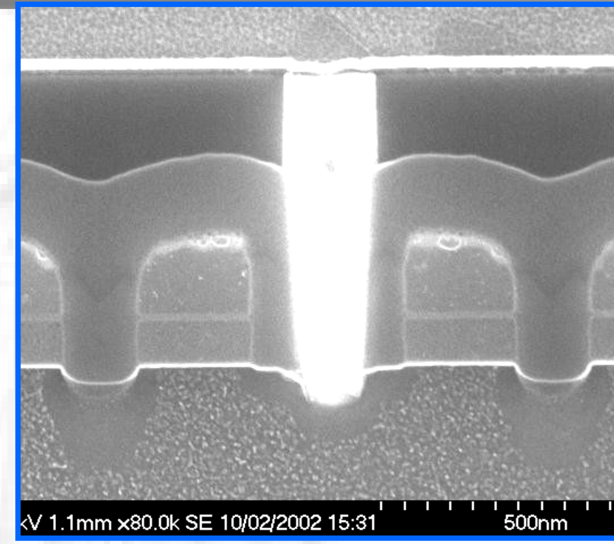

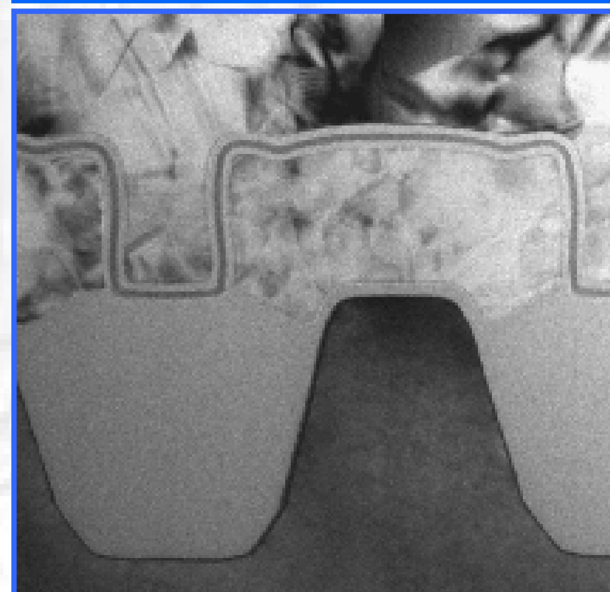

- V_{TH} of the device is controlled by controlling the number of electrons/holes stored in the FG

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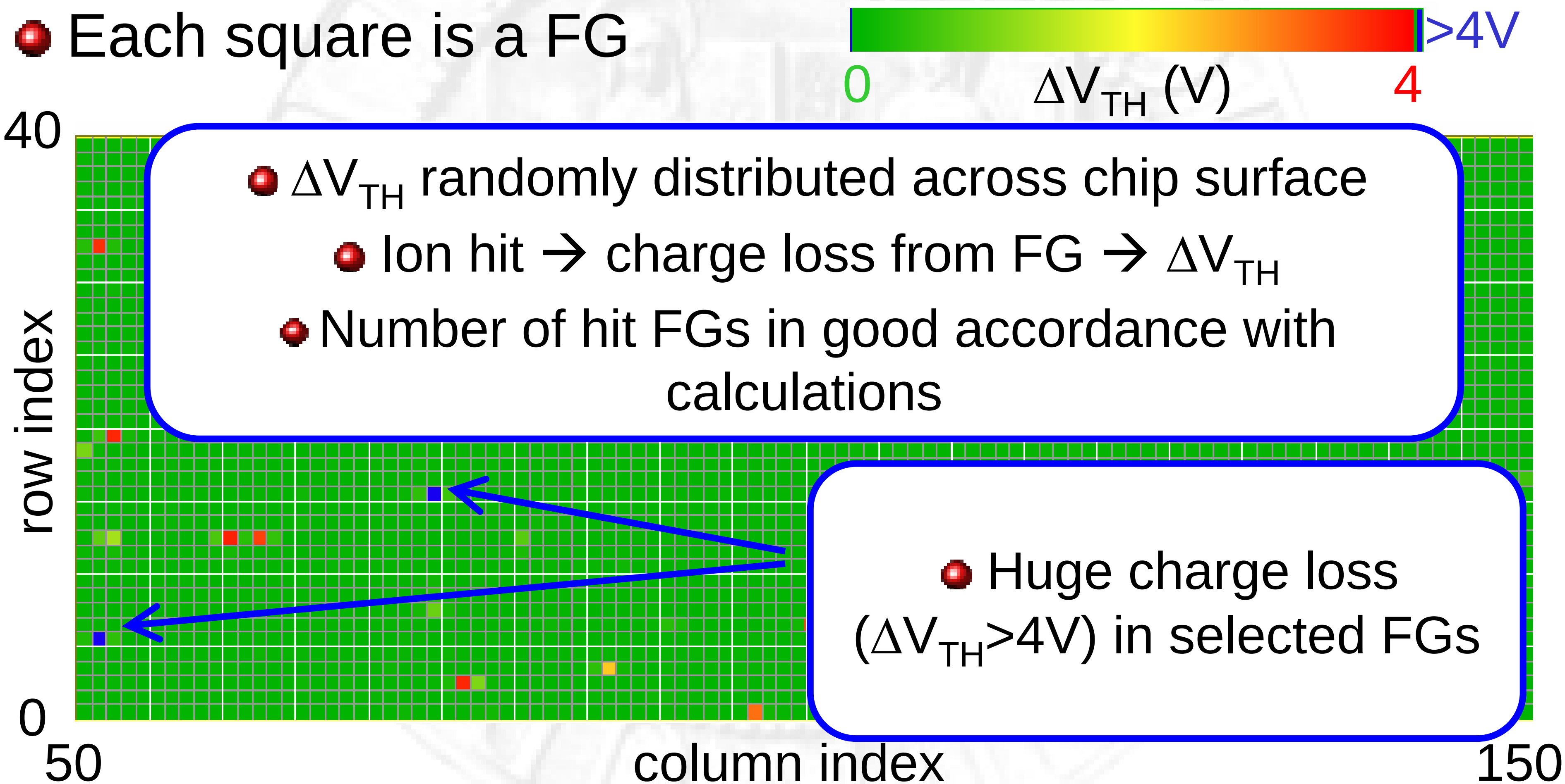
- Introduction
- Single event effect: prompt charge loss from a Floating Gate cell
- RILC and FG retention issues
- Space distribution of hit FG cells
- Recent results at RADEF (Jyvaskyla)

- Technology nodes
  - 0.25μm
  - 0.18μm
  - 0.15μm
  - 0.13μm
  - 90nm
  - 65nm
- Architectures
  - NOR
  - NAND
- Test chips and/or reserved algorithms

Charge loss following ion hit

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



- ΔV_{TH} randomly distributed across chip surface
- Ion hit → charge loss from FG → ΔV_{TH}
- Number of hit FGs in good accordance with calculations

- Huge charge loss (ΔV_{TH}>4V) in selected FGs

SINGLE EVENT EFFECT:
PROMPT CHARGE LOSS
FROM A FLOATING GATE CELL

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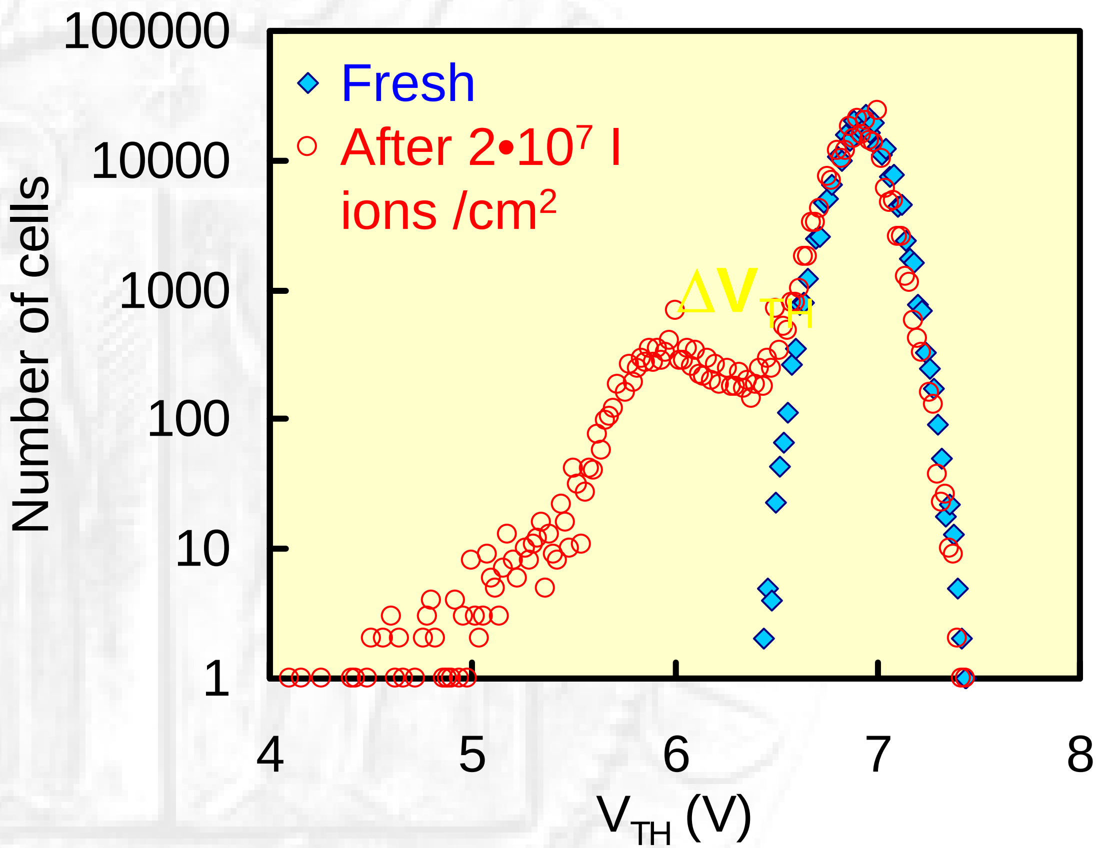
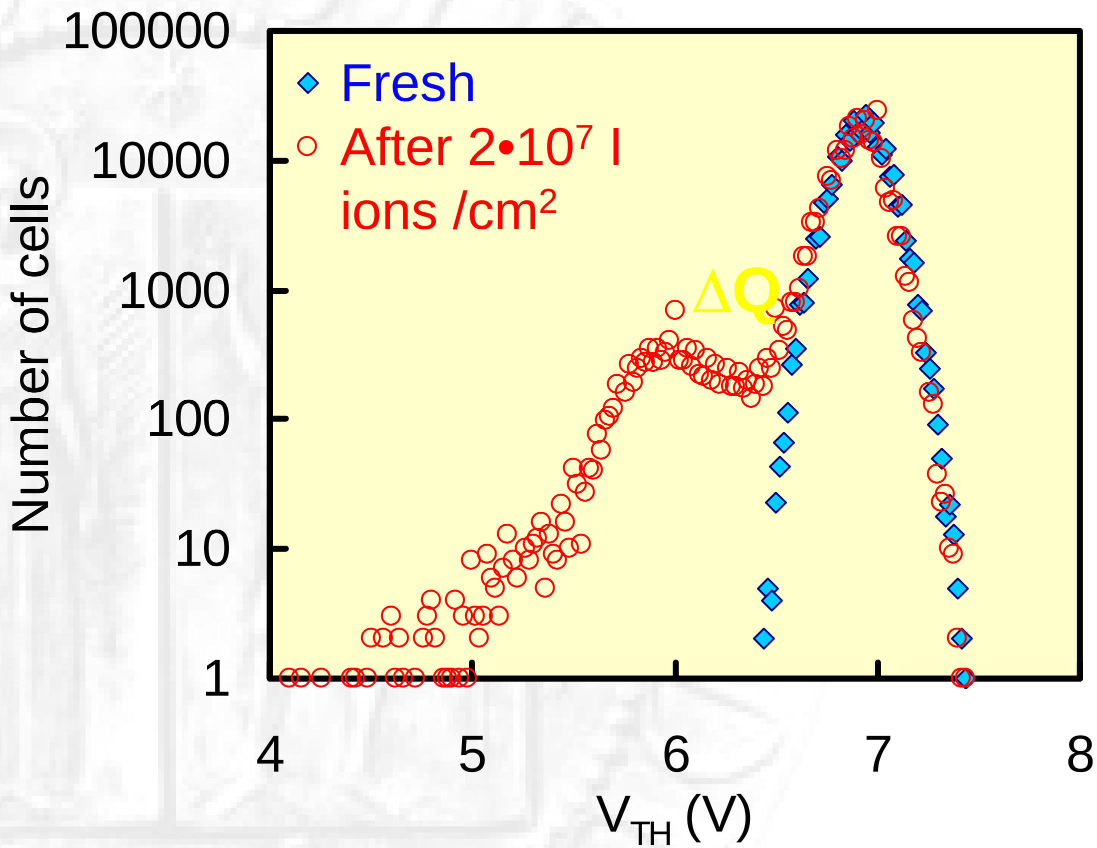
Distribution of hit FGs

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



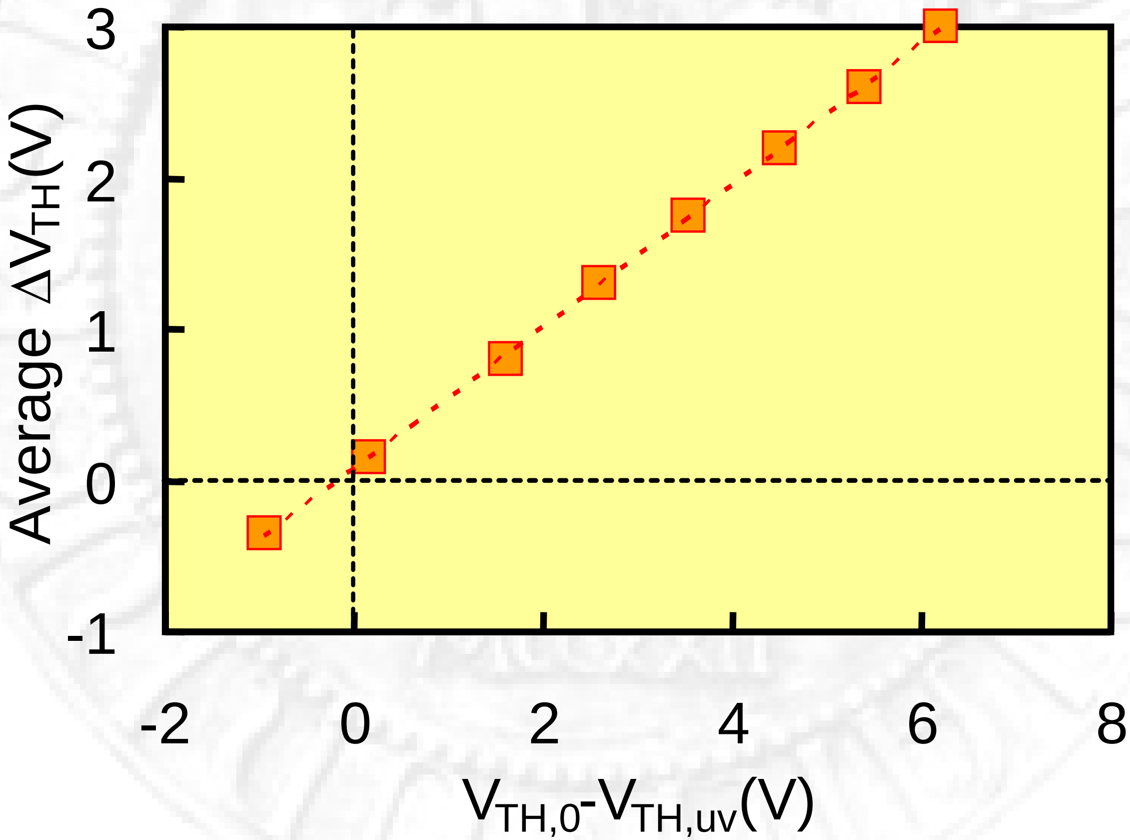
FGs in the secondary peak ←→ ion hit

- How much charge is lost from FG?
- About 7,000 electron/hole pairs are generated
- Less than 1% survive recombination according to the classical models→ 70 electrons injected in the FG

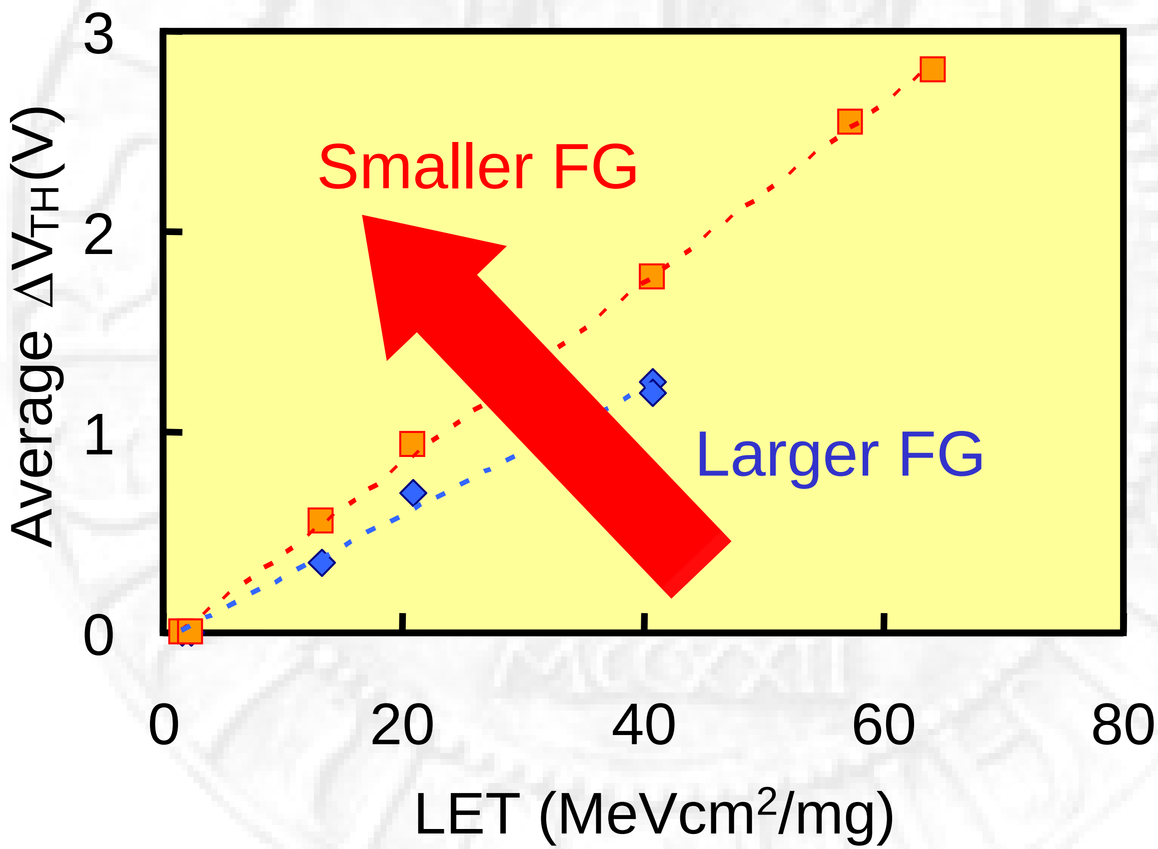


ΔQ=3,500 electrons

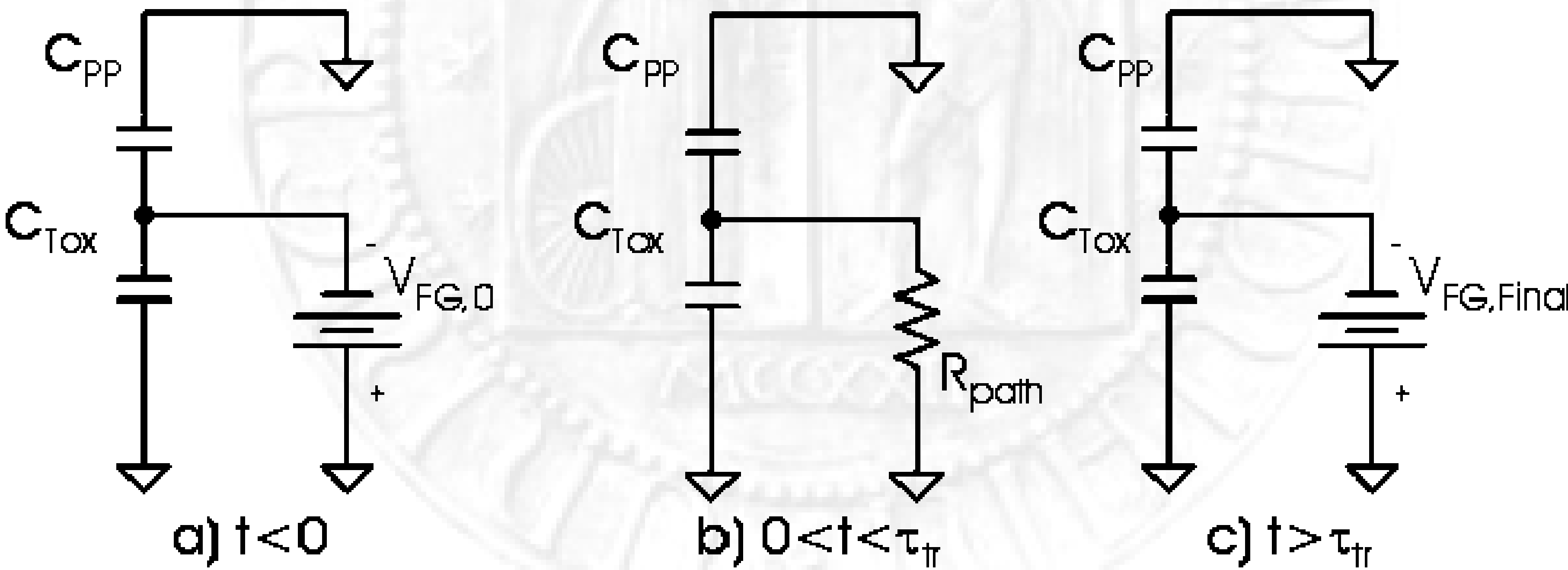
- Average charge loss linearly depends on electric field across the tunnel oxide before irradiation…



- …it also linearly depends on ion LET!



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



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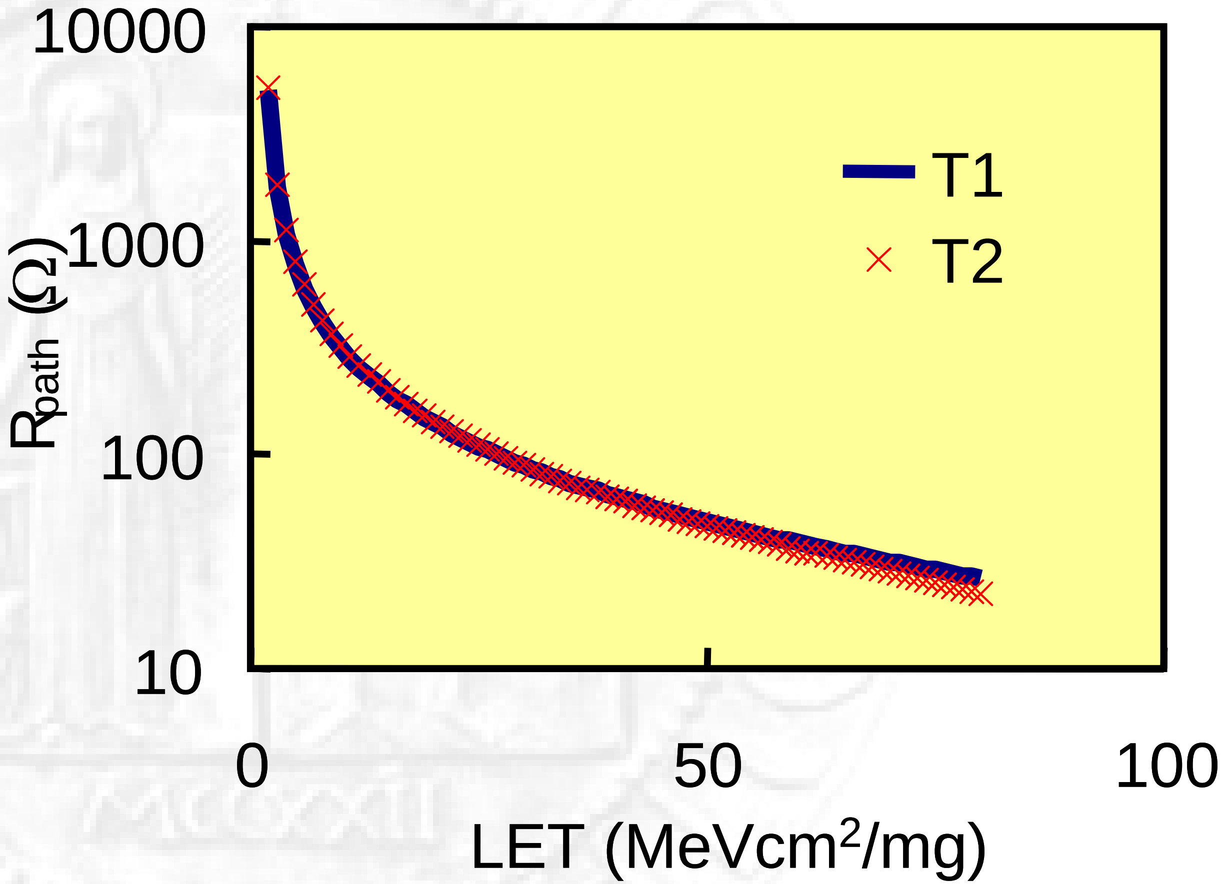
- Values of path resistance obtained for different technologies
  - Same resistance → path characteristics should not depend on the technology
  - In agreement with the high carrier density



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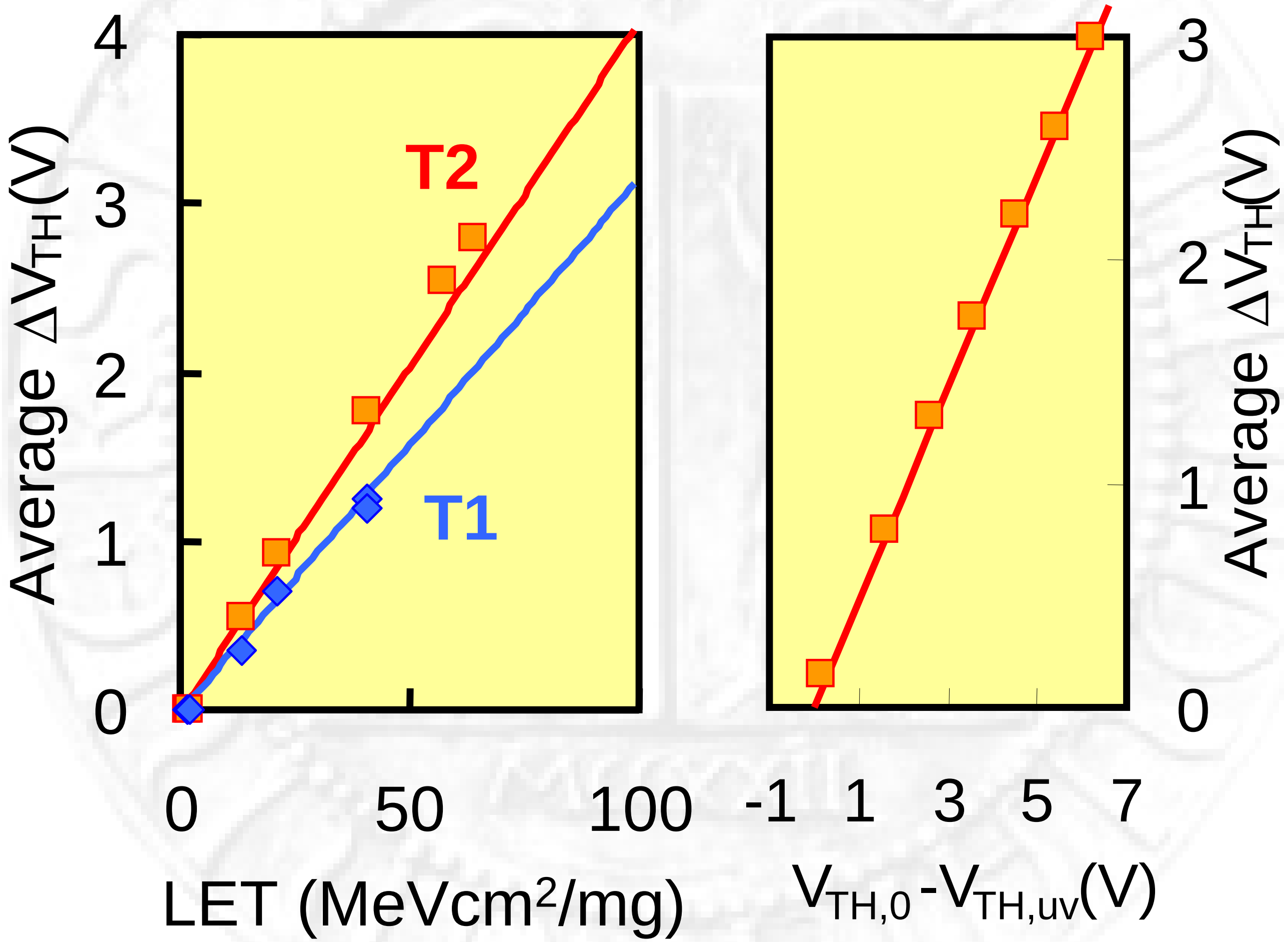
How can we explain charge loss? - 5

- Excellent fitting capabilities!



RILC AND FG RETENTION ISSUES

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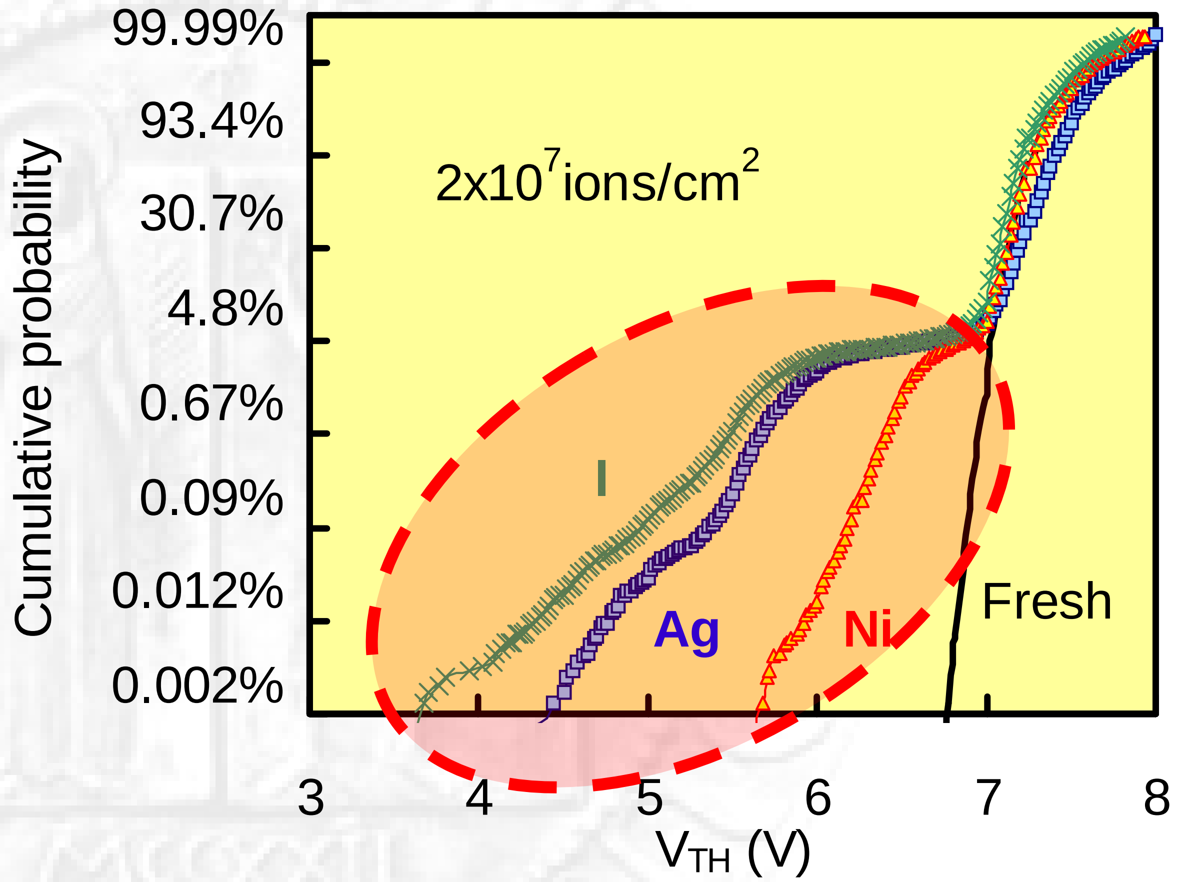
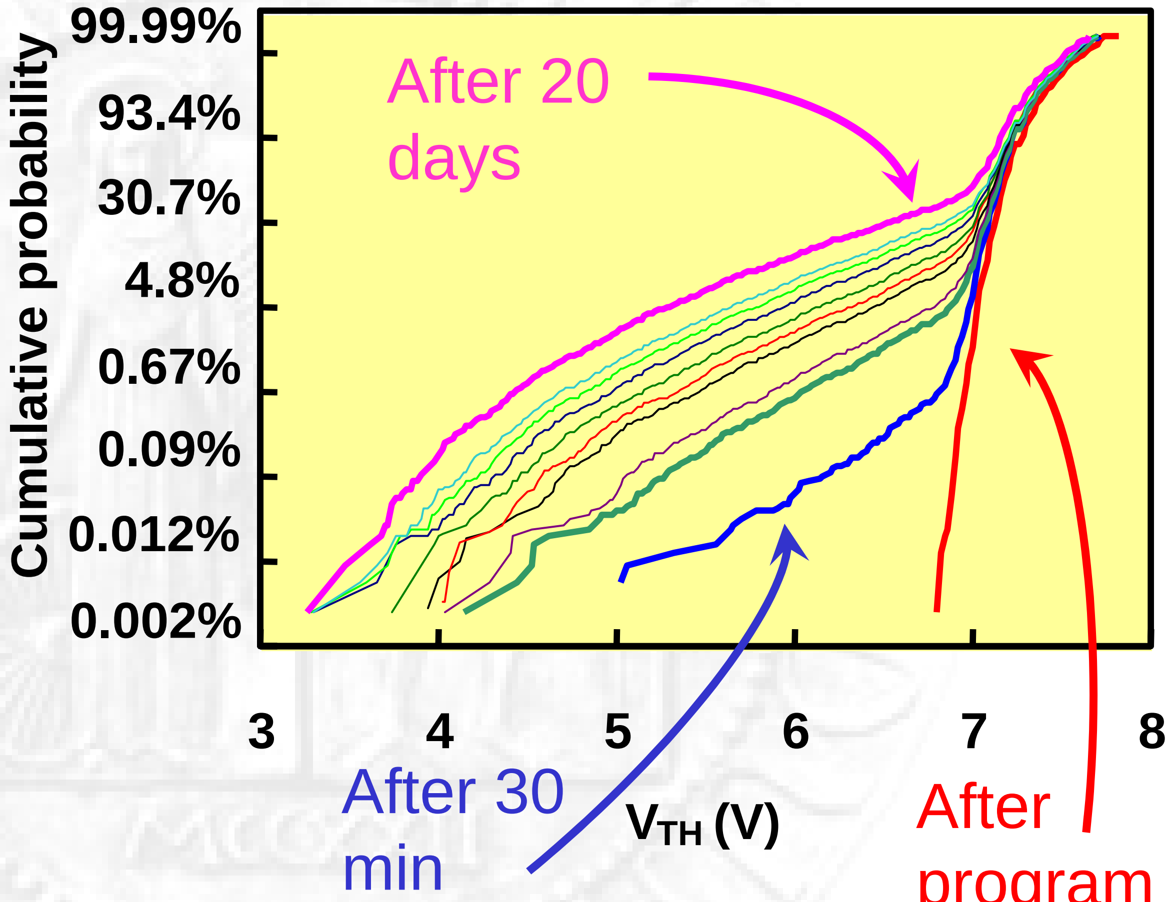
- Large tails after heavy ions irradiation
- Number of bits in tail does not depend on ion LET (it depends on fluence)
- ΔV_{TH} strongly depends on ion LET



- Only hit cells are considered in next experiments

Data retention in hit FG cells

- Only hit FGs were programmed
- After only 30min a clear tail appears…
- …which increases more and more with time



After 20 days, ΔV_{TH}~4V!!!

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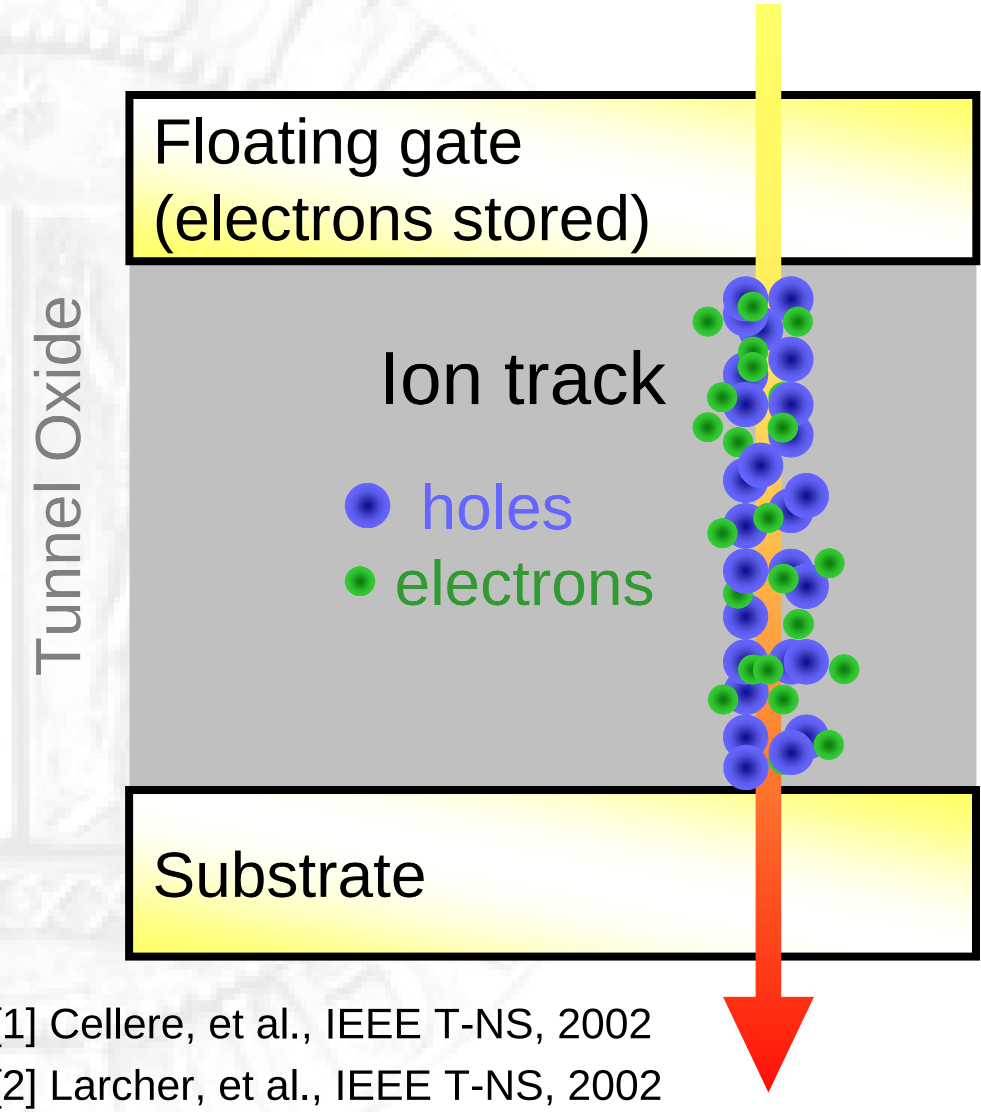
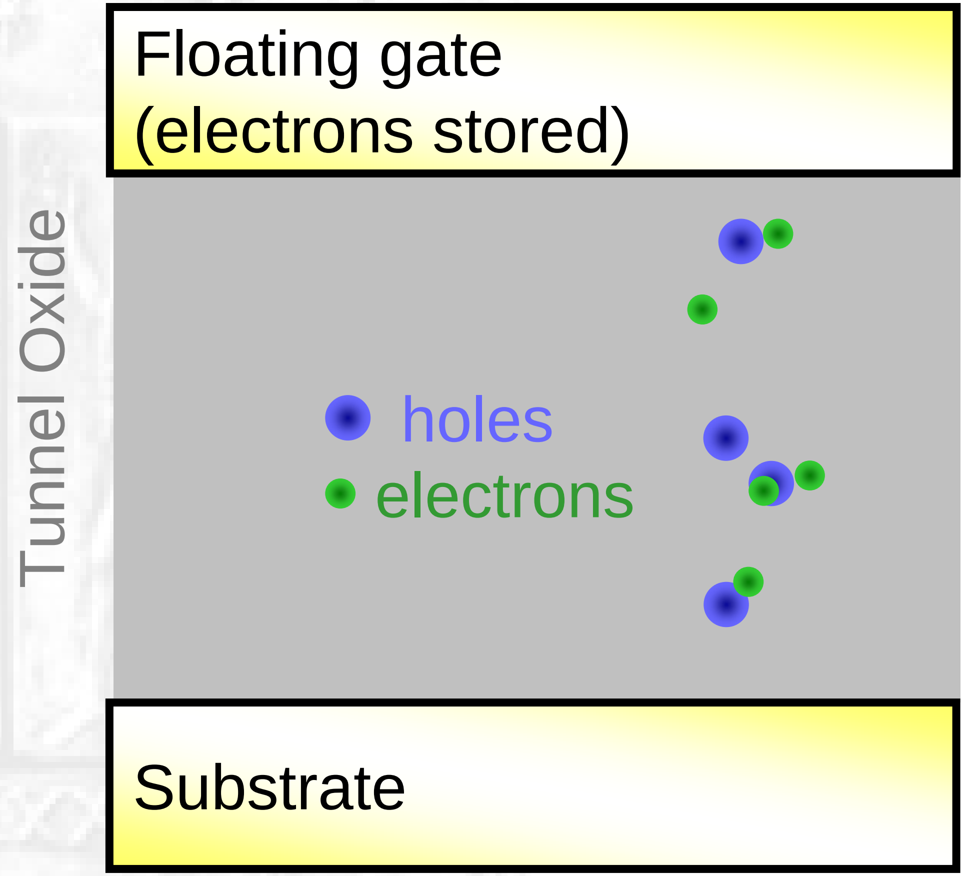
- What's going on?
  - Ion generates a plasma of electrons and holes



[1] Cellere, et al., IEEE T-NS, 2002

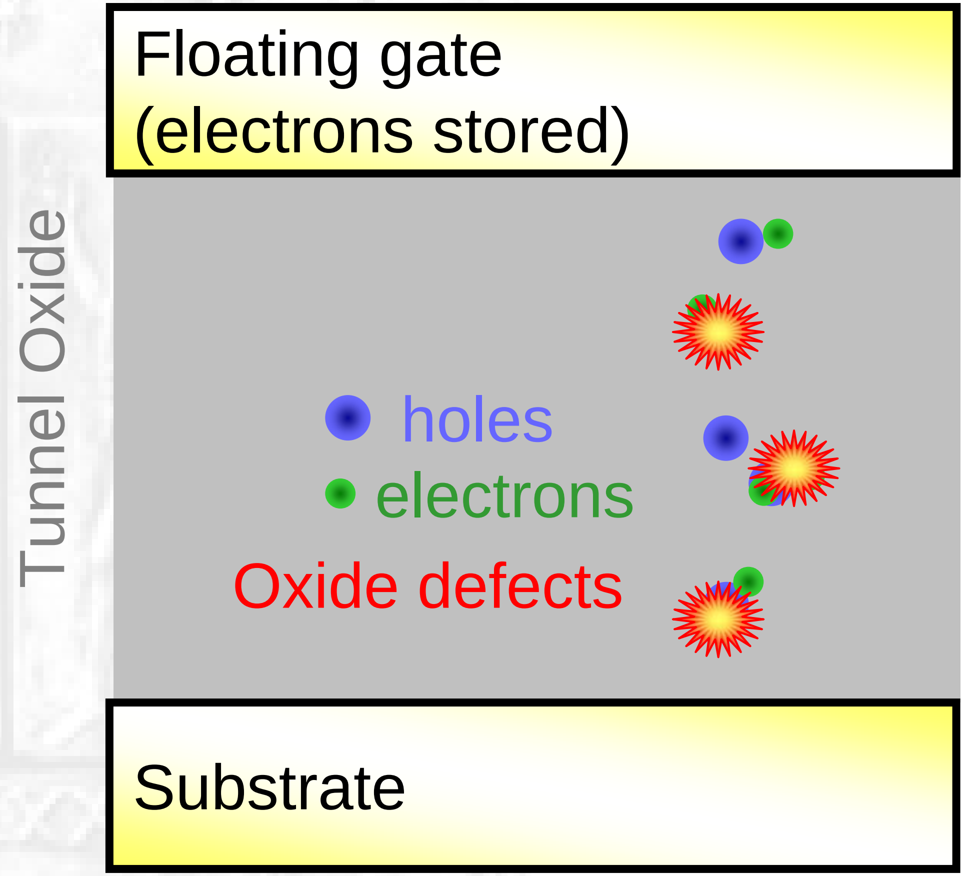
[2] Larcher, et al., IEEE T-NS, 2002

- What's going on?
  - Ion generates a plasma of electrons and holes
  - Prompt columnar recombination



[1] Cellere, et al., IEEE T-NS, 2002
[2] Larcher, et al., IEEE T-NS, 2002

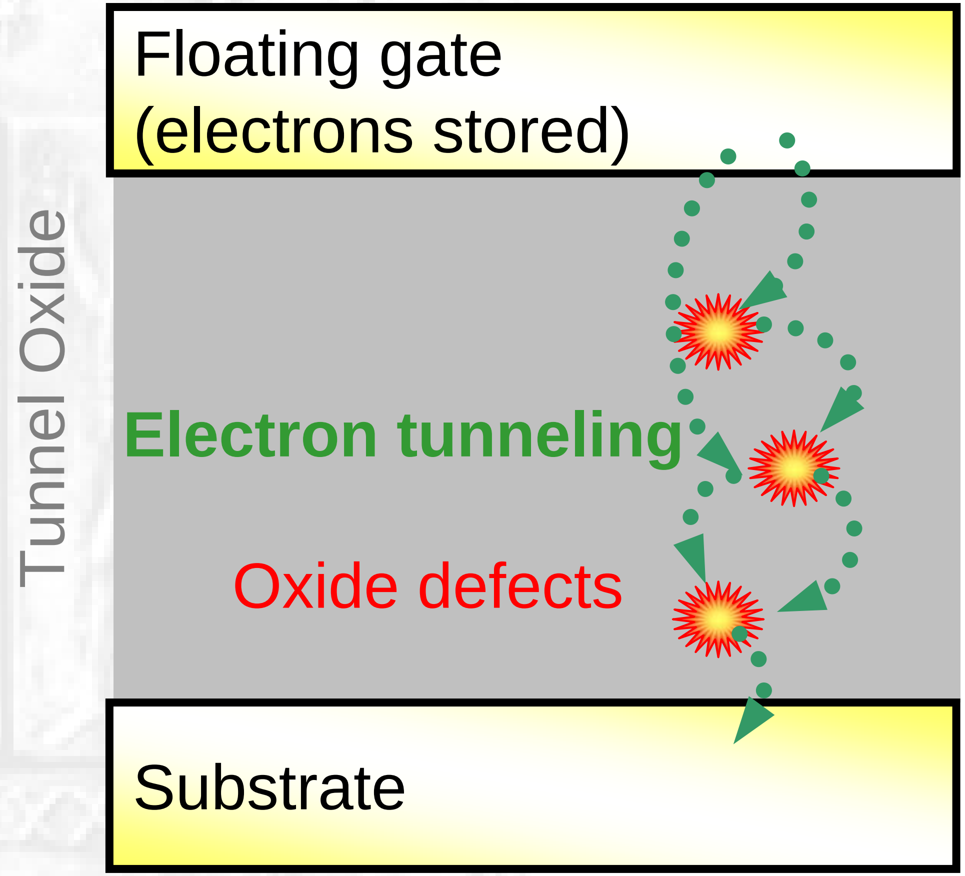
- What's going on?
  - Ion generates a plasma of electrons and holes
  - Prompt columnar recombination
  - Followed/accompanied by generation of oxide defects



[1] Cellere, et al., IEEE T-NS, 2002
[2] Larcher, et al., IEEE T-NS, 2002

Oxide damage model

- What's going on?
  - Ion generates a plasma of electrons and holes
  - Prompt columnar recombination
  - Followed/accompanied by generation of oxide defects
- Oxide defects are used by electrons to escape the FG
  - multi-Trap Assisted Tunneling (m-TAT)

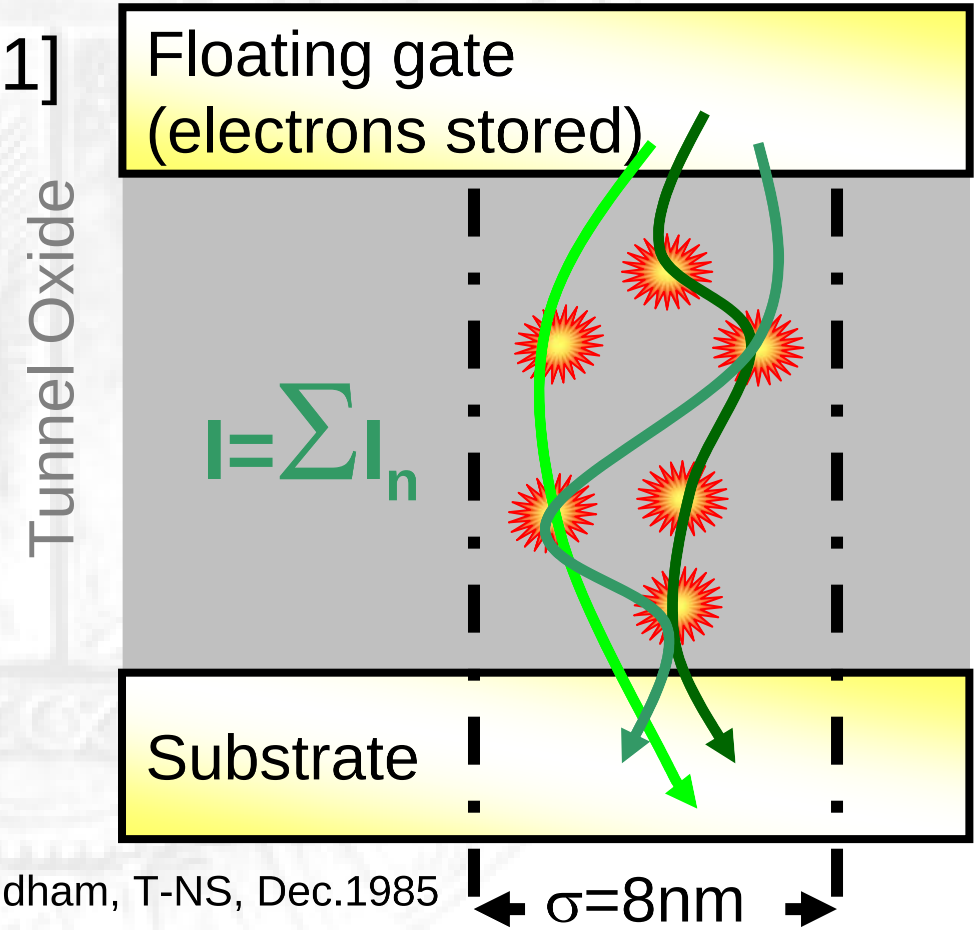


[1] Cellere, et al., IEEE T-NS, 2002

[2] Larcher, et al., IEEE T-NS, 2002

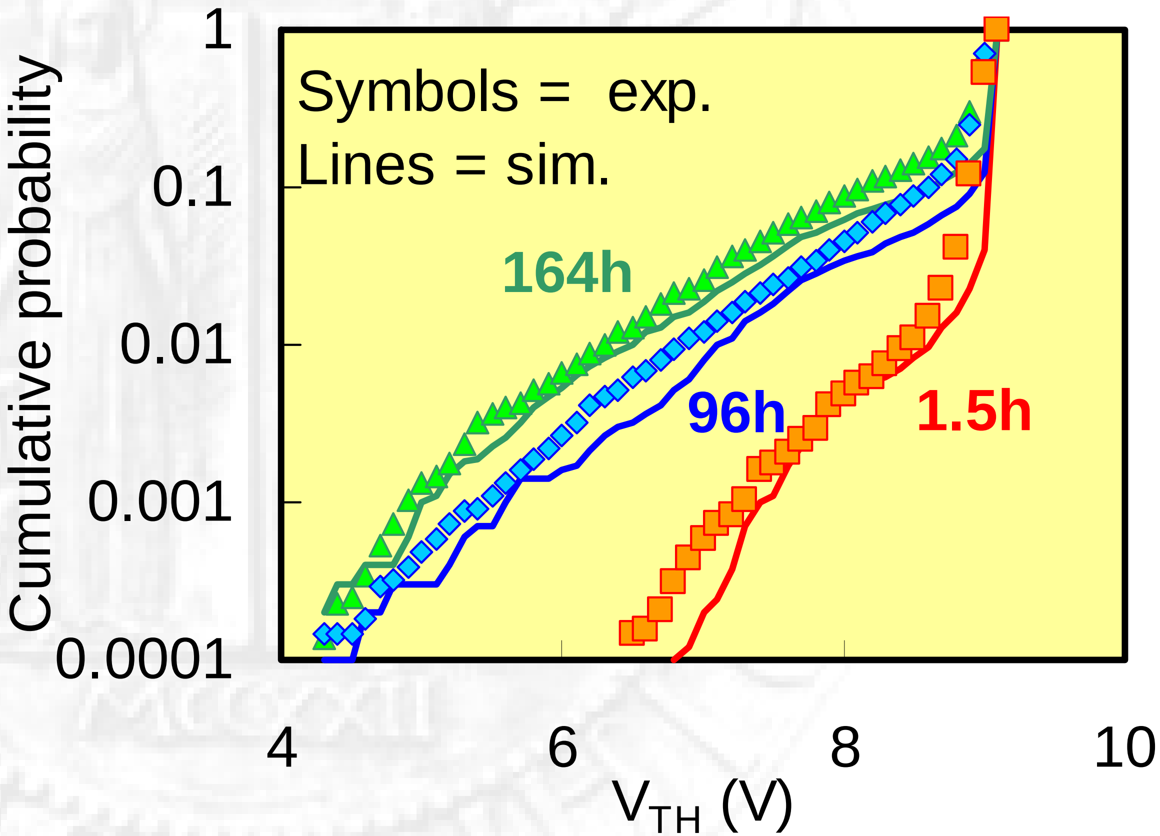
Oxide damage model

- How can we evaluate the current along this path?
- Consider the ion track [1]
- Randomly generate a Gaussian distribution of defects
- Evaluate the current through each possible path
- Then sum all the currents

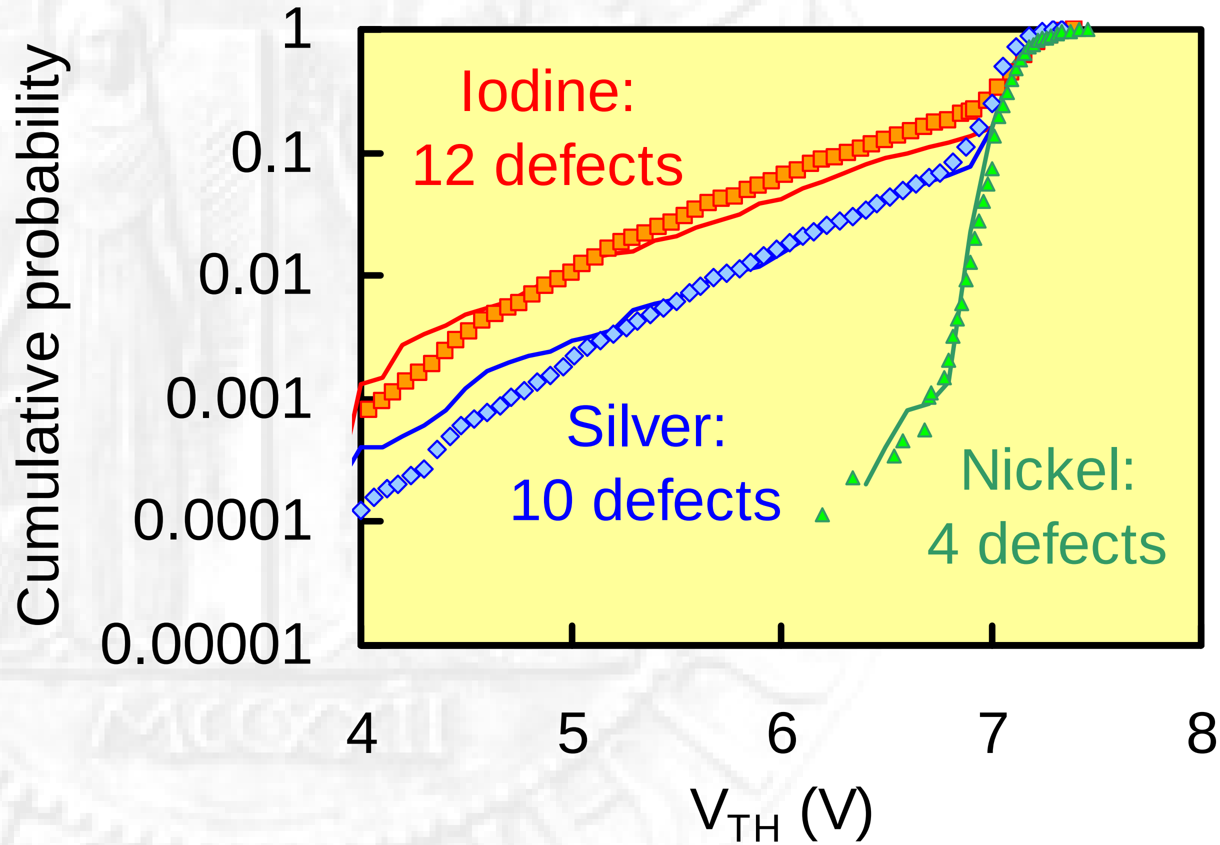


[1] Oldham, T-NS, Dec.1985

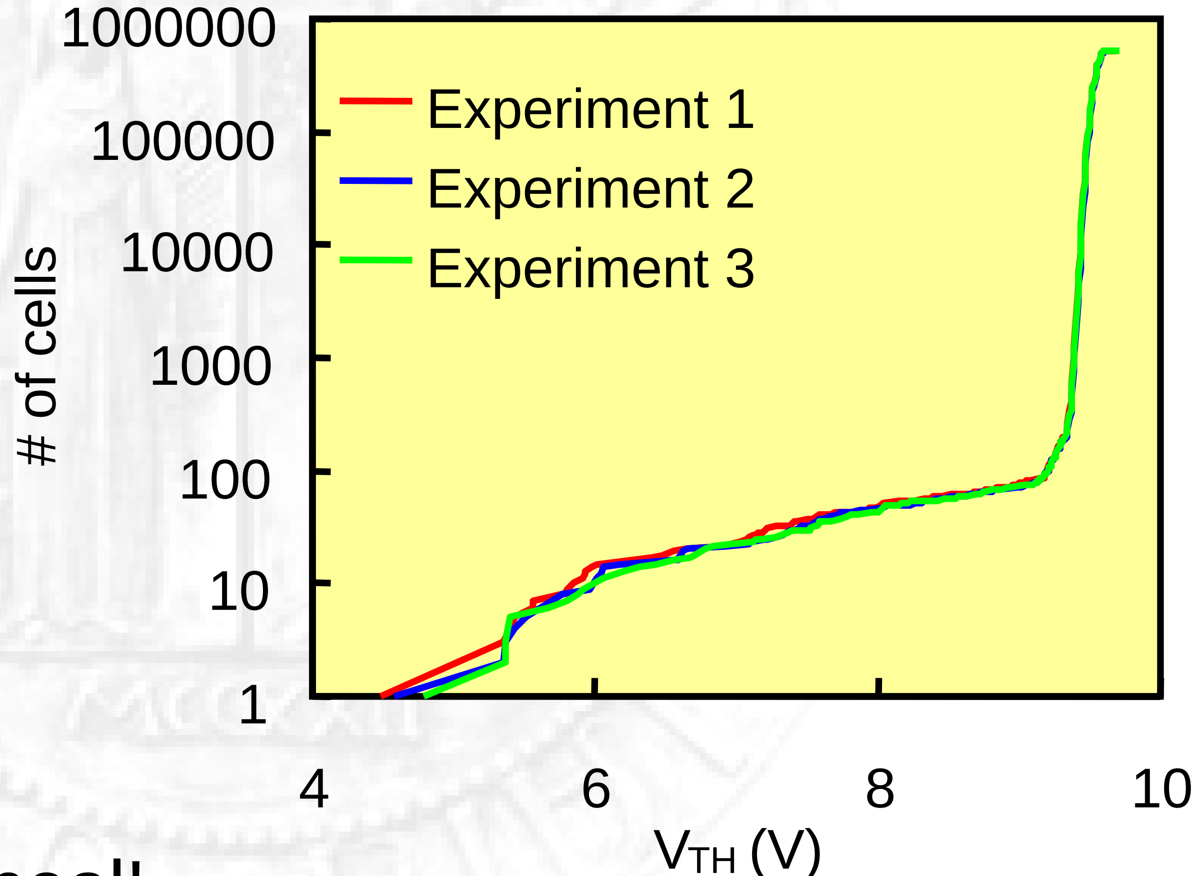
- 0.15μm technology
- After Iodine (LET=64 $MeVcm^2/mg$) irradiation
- 12 oxide defects



- 0.13μm technology
- After 529hours
- Different ions → change only the number of oxide defects
- Smaller FG → larger ΔV_{TH}



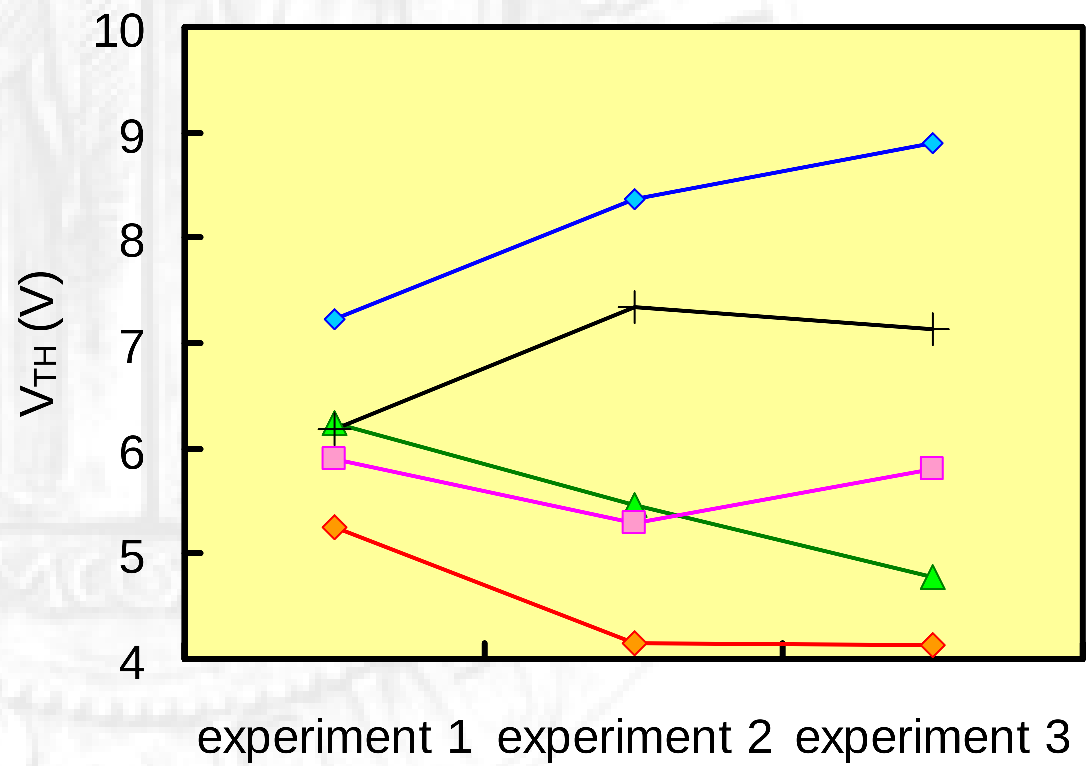
- Three retention experiments:
  - Programming + irradiation
    - Reading
  - Experiment 1:
    - Program
    - Reading
  - Experiment 2:
    - Program
    - Reading
  - Experiment 3:
    - Program
    - Reading



- RILC does not anneal!

Erratic behavior of RILC-2

- However, in some FG cells the V_{TH} changes a lot during the three experiments!
- Due to changes of occupancy state of any “critical” defect in the RILC path
- Similar erratic behavior is well known for SILC



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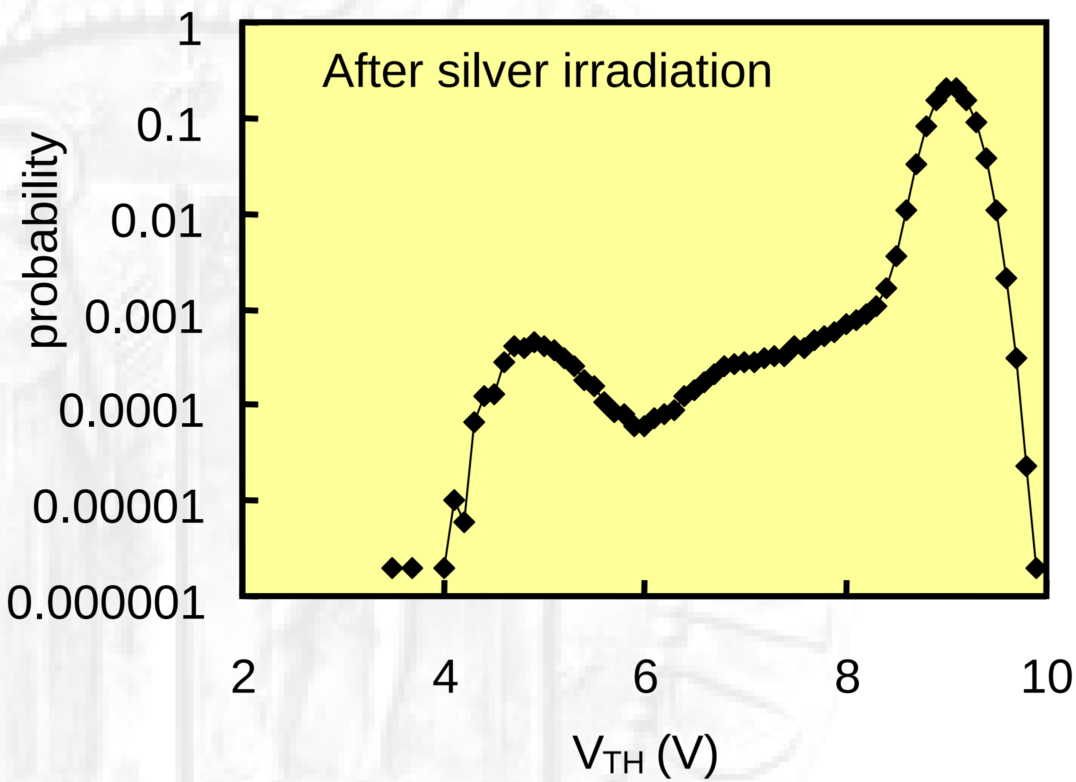
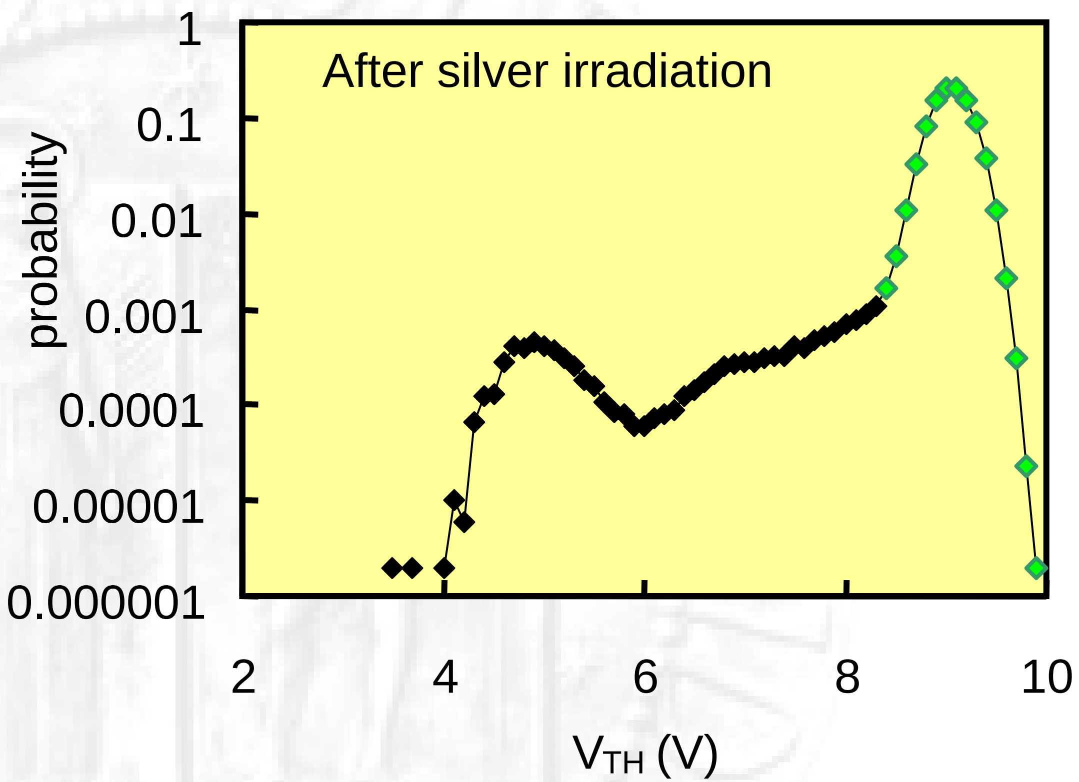
SPACE DISTRIBUTION OF HIT FG CELLS

- 90 nm technology
- Three families



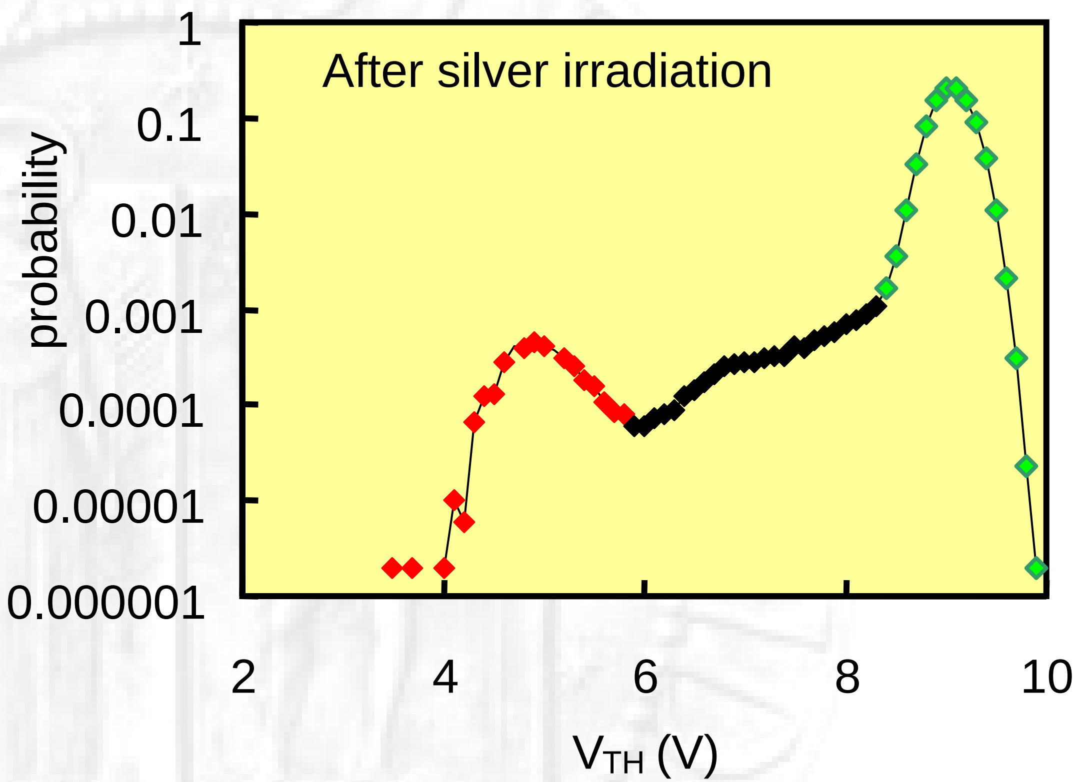
Distribution of hit FGs

- 90 nm technology
- Three families
- "Green" FGs
  - Main distribution
  - Not hit



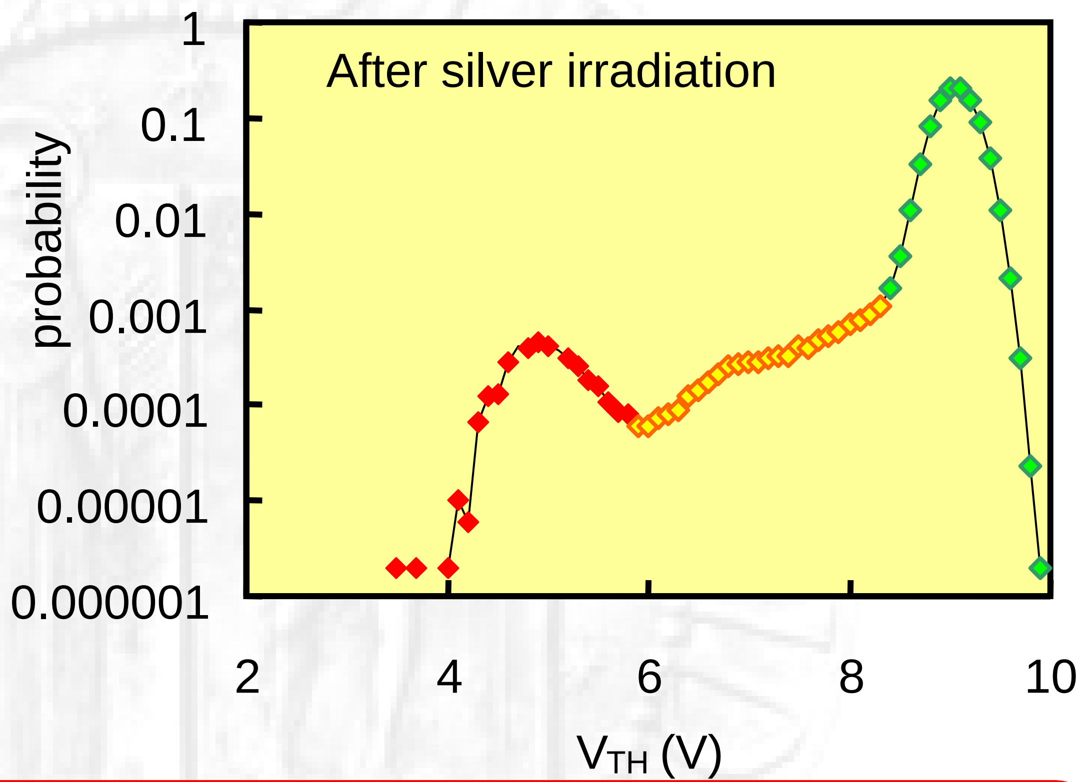
Distribution of hit FGs

- 90 nm technology
- Three families
- “Green” FGs
  - Main distribution
  - Not hit
- “Red” FGs
  - Hit by ions
  - Large charge loss



Distribution of hit FGs

- 90 nm technology
- Three families
- "Green" FGs
  - Main distribution
  - Not hit
- "Red" FGs
  - Hit by ions
  - Large charge loss
- "Yellow" FGs
  - Not hit
  - $\Delta V_{TH}>0$



Corruption of the stored information can happen even in FGs not directly hit by ions!

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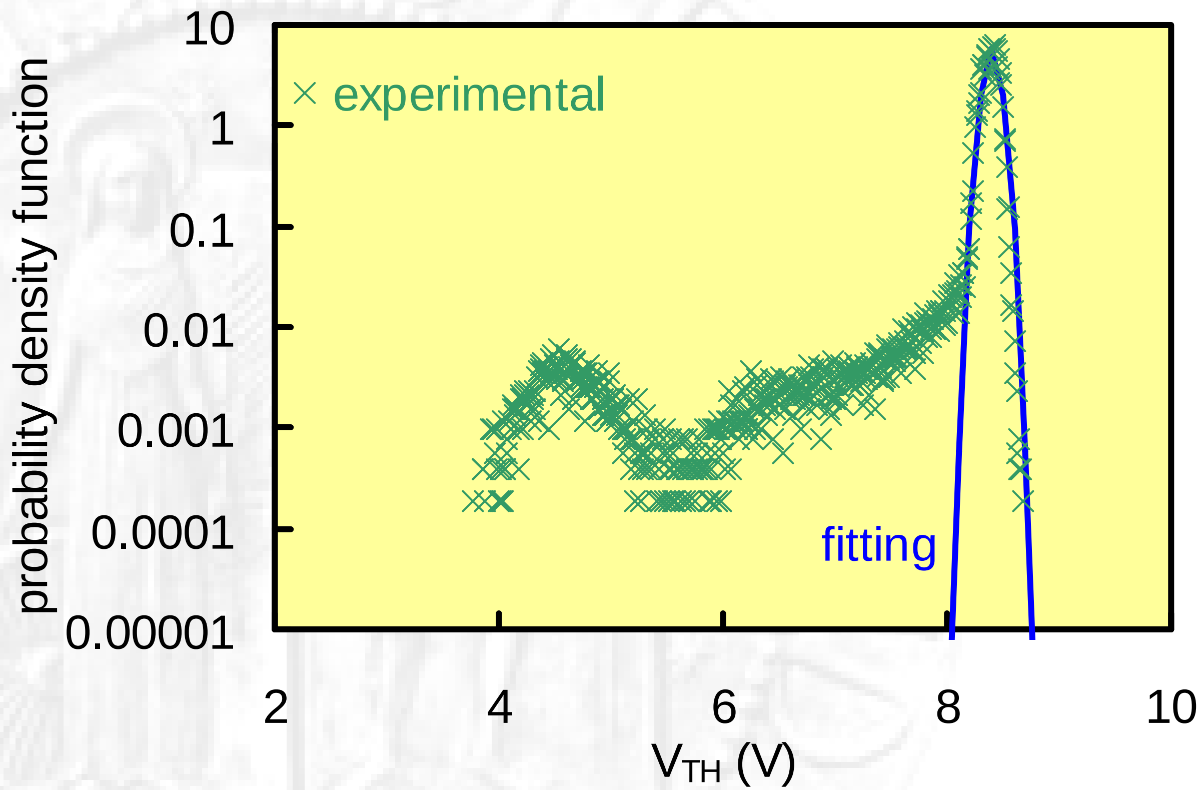
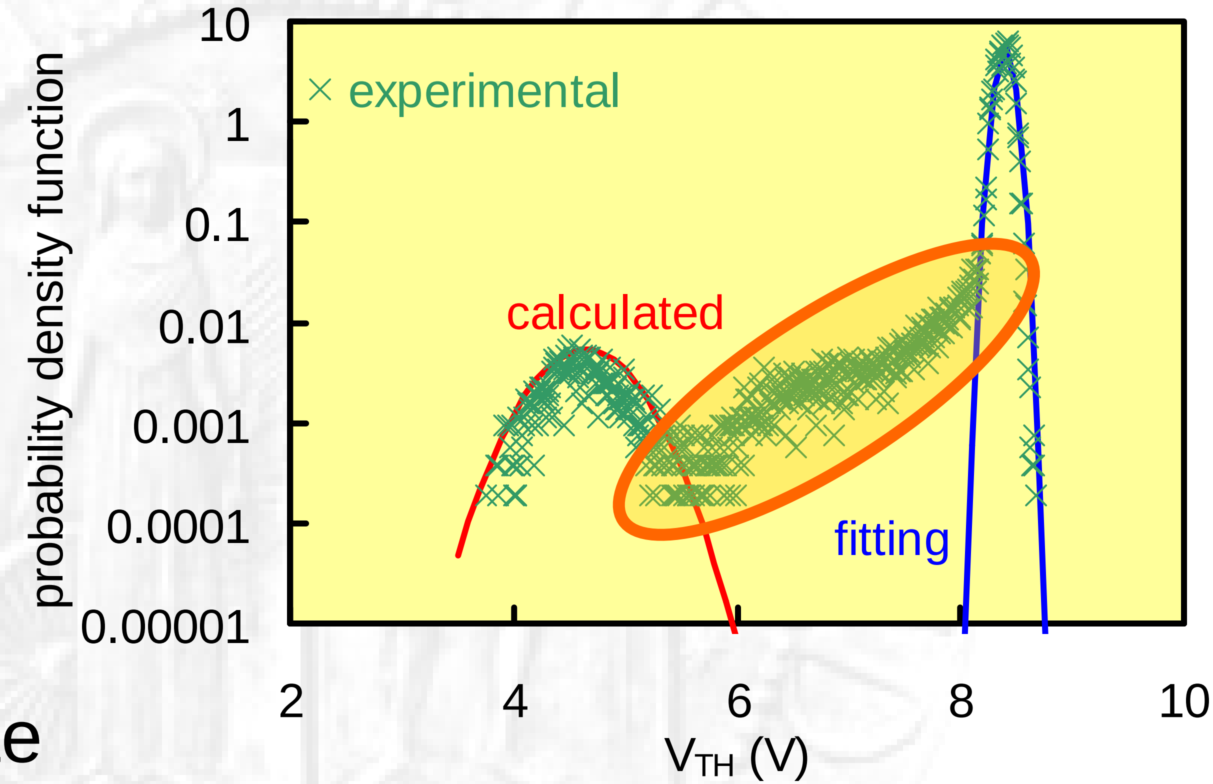
- The main peak can be approximated by a Gaussian

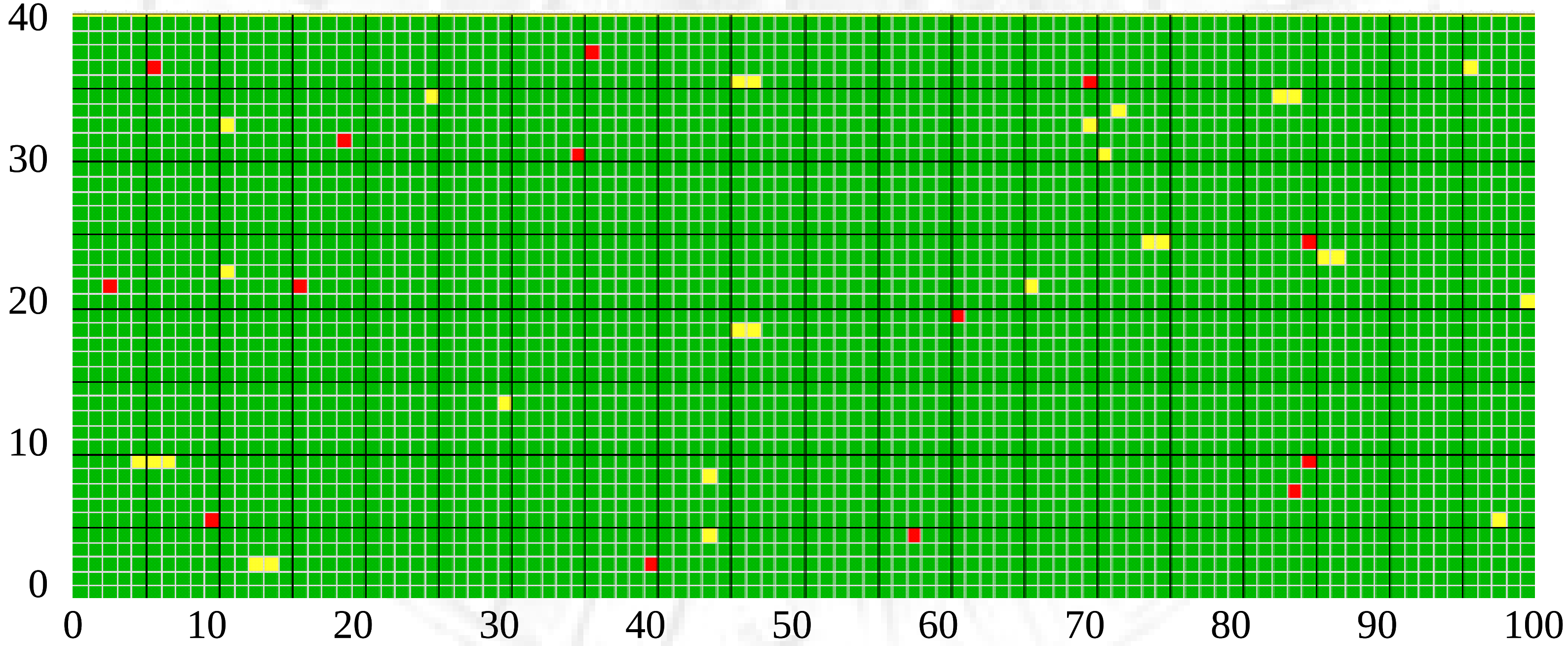


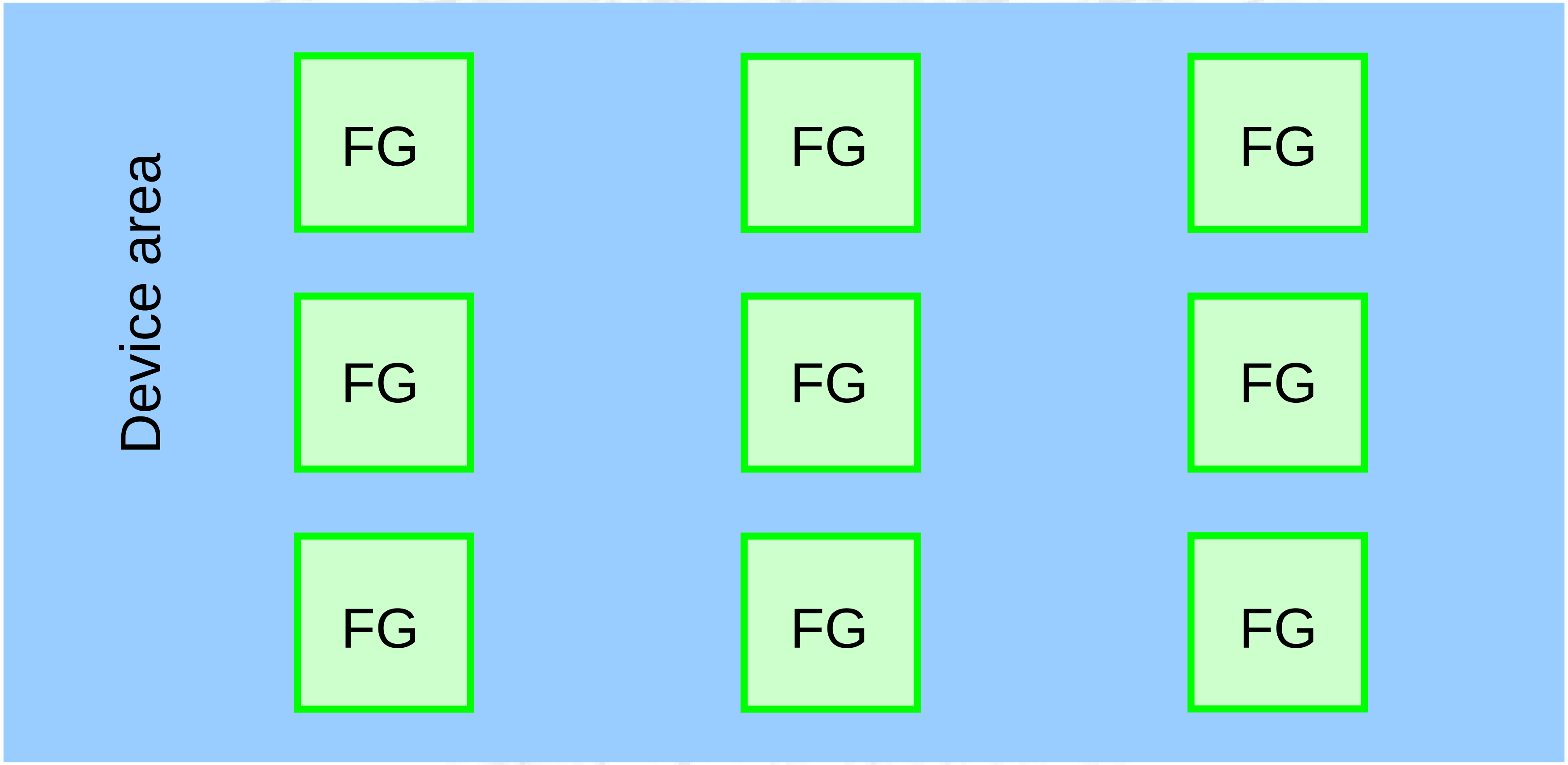
- The main peak can be approximated by a Gaussian
- Based on
  - $V_{TH,pre-rad}$
  - ΔV_{TH}
- One can calculate the distribution of the secondary peak



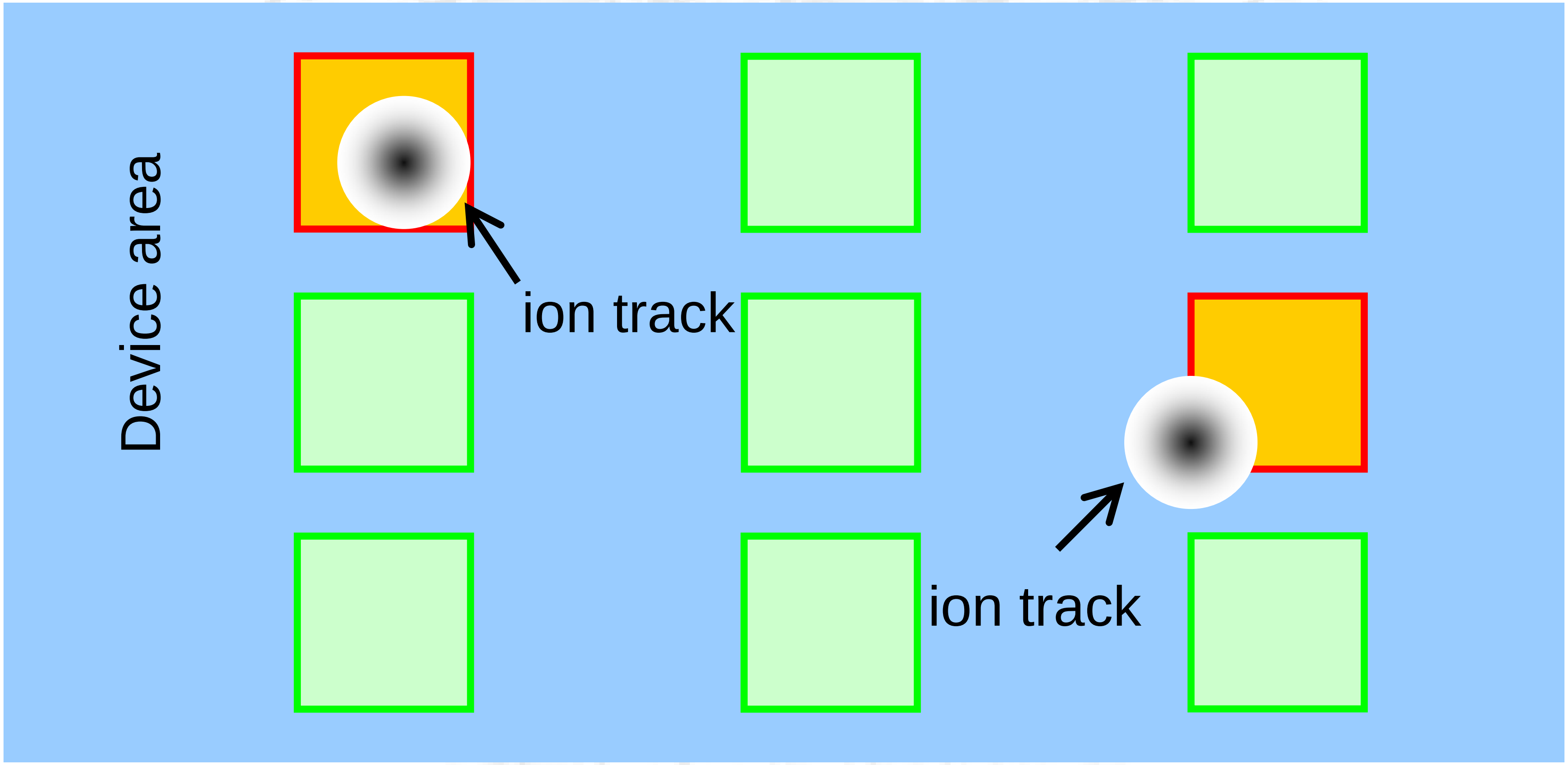
- “Red” FGs: very good fitting
- What about “yellow” cells?

- Yellow and red FGs are randomly distributed on chip surface, but:
  - Almost all red FGs are isolated
  - 30% of yellow FGs are clustered




Device area
FG
FG
FG
FG
FG
FG
FG
FG
FG

Ion crossing the FG → RED



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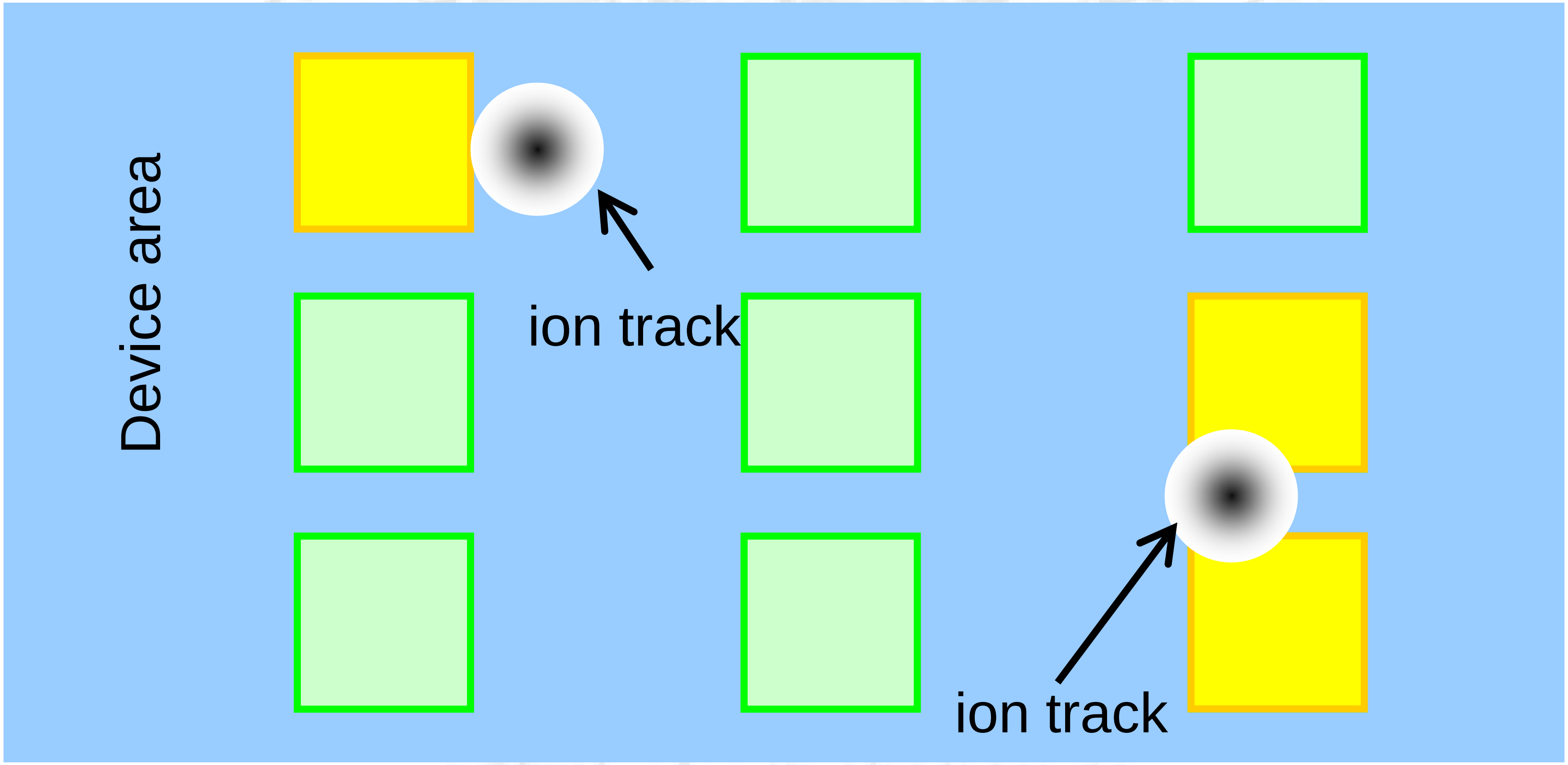
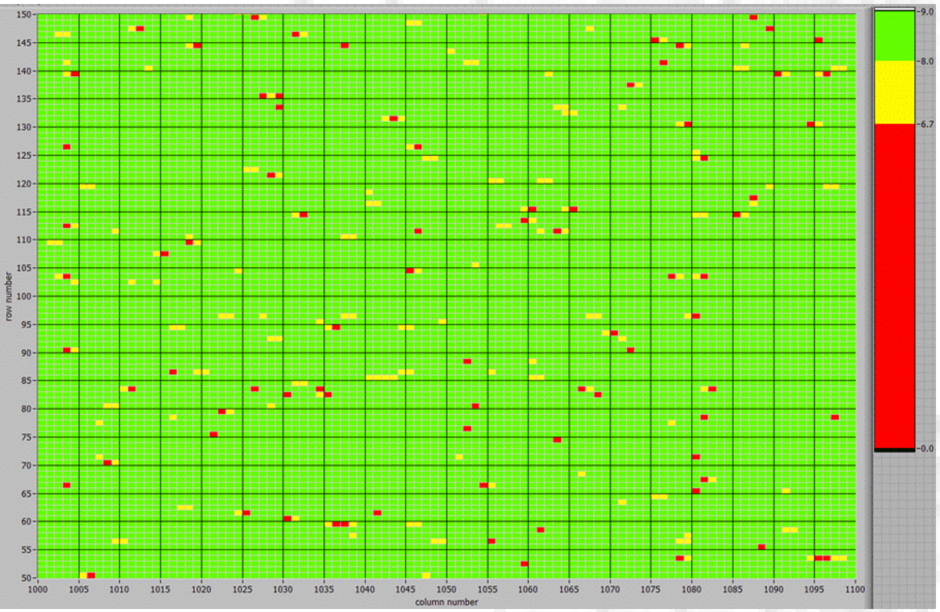
Ion crossing “close” to the FG → YELLOW

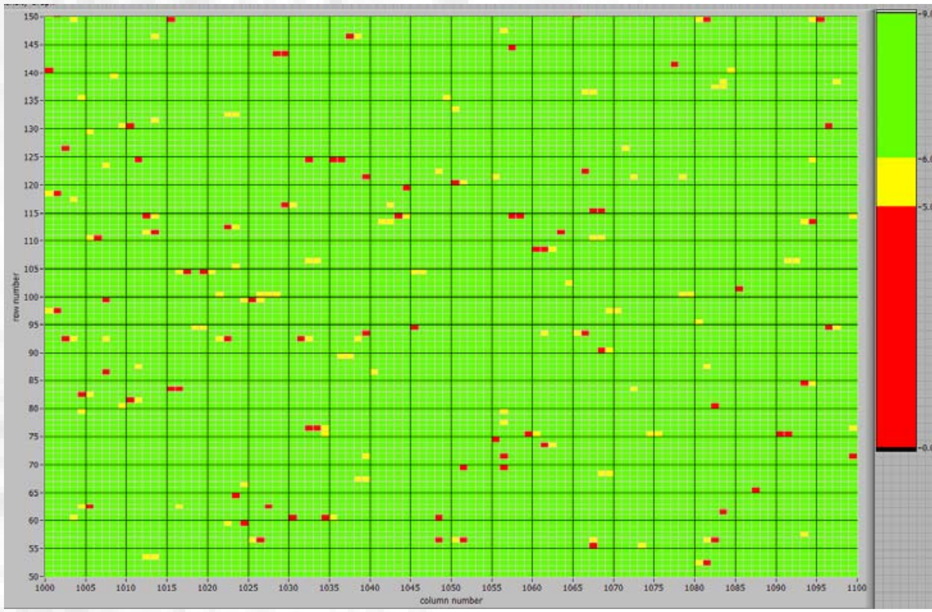


RECENT RESULTS AT RADEF (JYVASKYLA)

- First experiments have been conducted at RADEF-Jyvaskyla in Dec 2006 thanks to ESA-ESTEC support (RHS) to study this phenomenon vs.:
  - Incidence angle
  - Ion energy



1217MeV Xe



768MeV Kr

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