Power MOSFET study :

Fluence effect on SEE response of power MOSFET.

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Objectives of the study (1)

- Work done under CNES financial support.
- Study the heavy ions fluence effect on the power MOSFET gate integrity.
- Check for H.I fluence (Φ) effect on the gate breakdown voltage Vbd(Φ) during Post-irradiation Gate Stress Test (PGST).
- Backside and front side irradiations comparison:

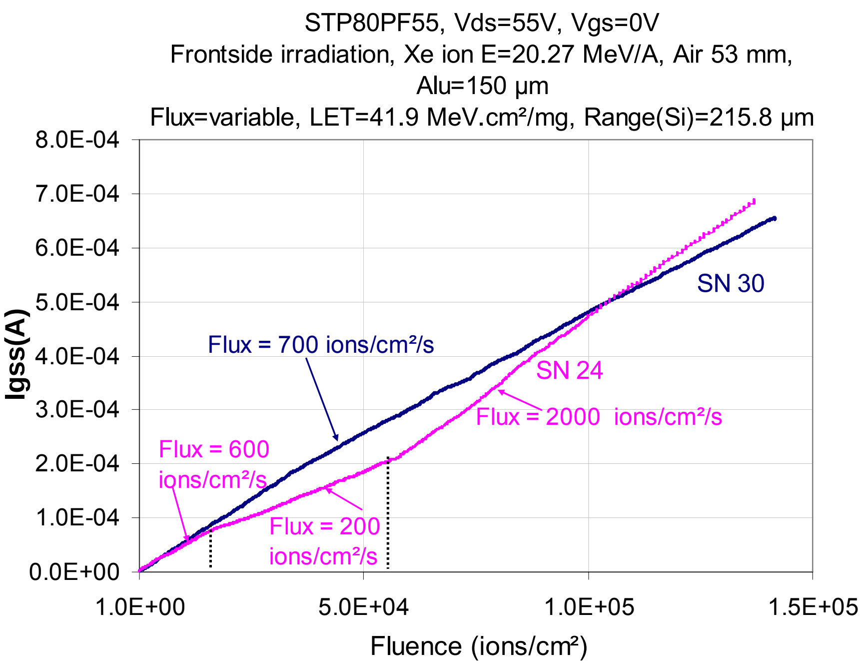
  Try to separate substrate contribution from the gate one about the PGST results.

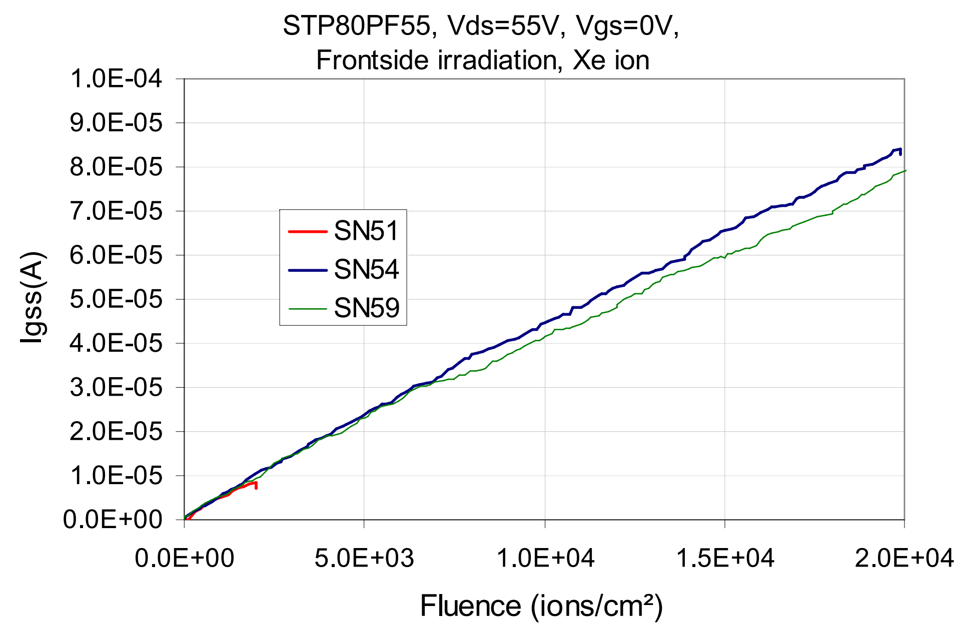
Objectives of the study (2)

- Check for multiple impacts phenomena as being to the origin of gate breakdown voltage during PGST.
- Highlight range effect on the gate degradation.
- Highlight range effect on the SEB triggering.

Gate degradation effect studied in P-channel part: STP80PF55 (55V)

- Frontside irradiation : Flux effect





Flux effect on Igss(Φ) → Same flux (~250 p/cm²/s) and 3 ≠ fluences before PGST (2.10^3, 2.10^4, and 3.10^5 p/cm²)

Heavy ions are from GANIL

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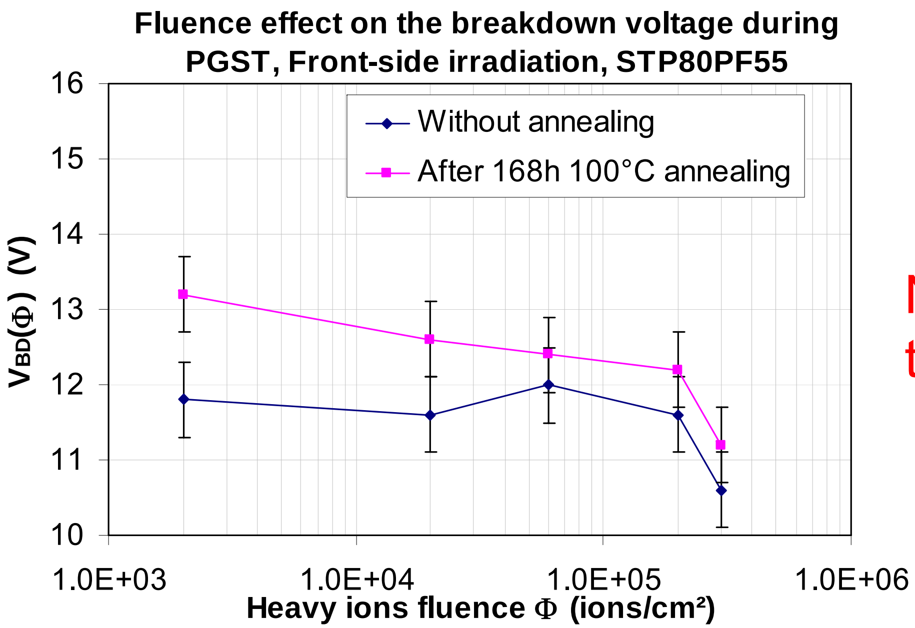
Gate degradation effect studied in P-channel part: STP80PF55 (55V)

- Frontside irradiation : PGST results versus fluence (Φ)



Negative slopes support the model of multiple impacts [1]

- 10 parts used
- Annealed parts after irradiation exhibited higher Vbd

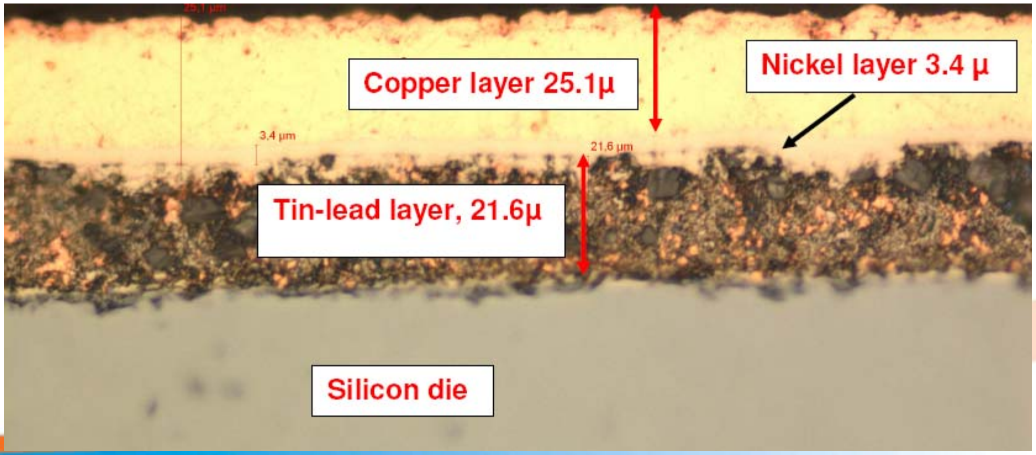
=> Trapped charges in SiO_2 play a role in the earlier gate breakdown.

[1] D.Peyre & al., “SEGR study in power MOSFETs: multiple impacts assumption”, IEEE Tr. on Nuclear Science, vol.55, no.4, August 2008.

Gate degradation effect studied in P-channel part: STP80PF55 (55V)

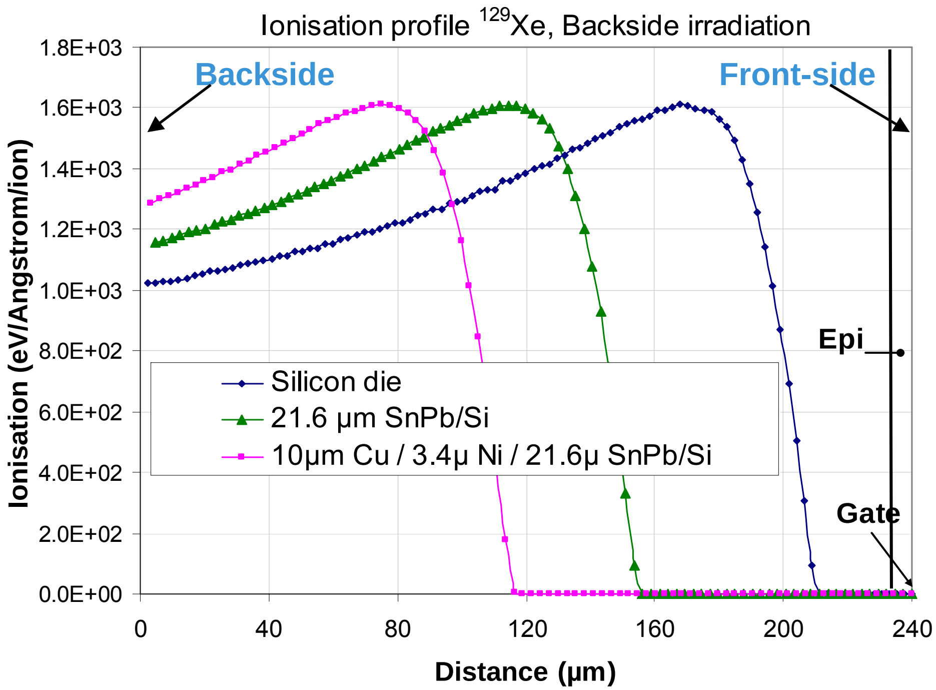
- Backside irradiation

  - Die 240 µm thick, Epi layer 7 µm
  - Backside irradiation possible after mechanical grinding of drain contact : the remaining copper layer thickness is within [10-50 µm] range.



Gate degradation effect studied in P-channel part: STP80PF55 (55V)

- Backside irradiation

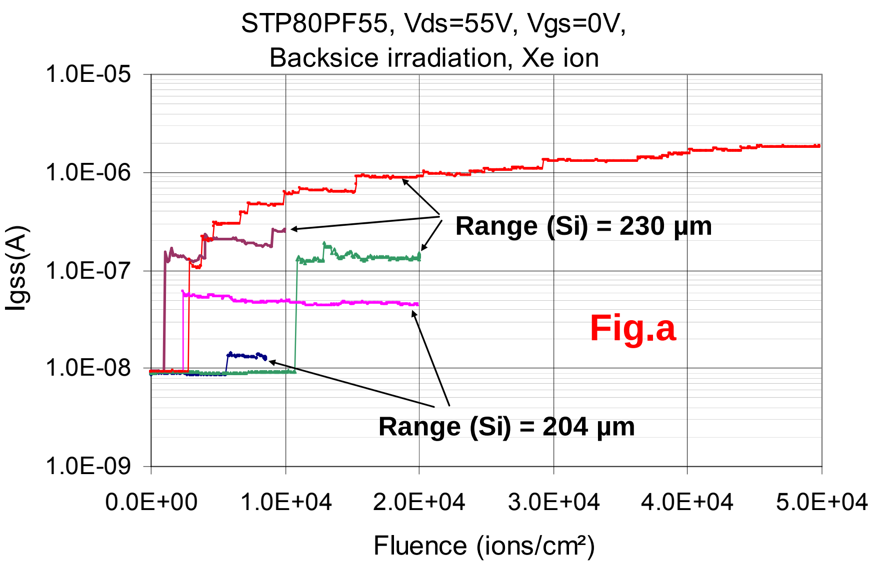


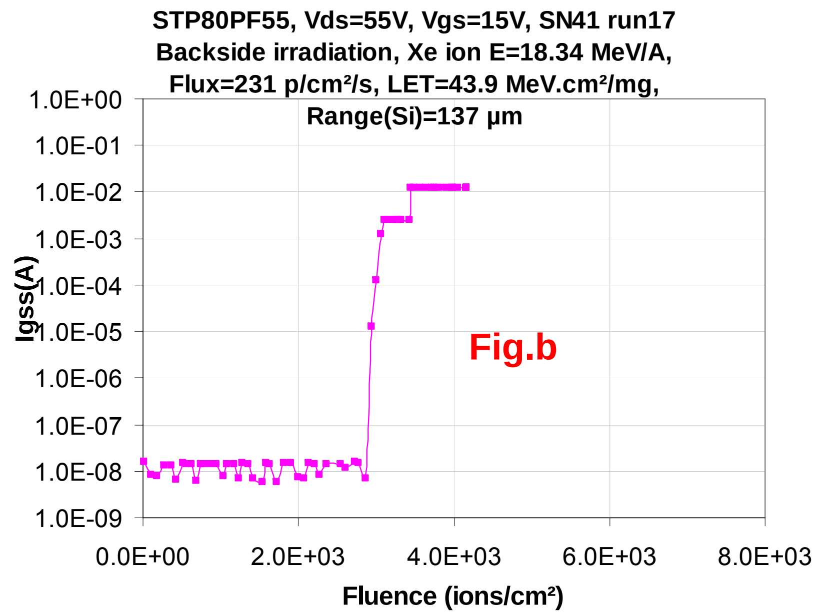
SRIM2006 calculations

- Effect of drain contact material thickness on range in 3 cases:
  - Without drain contact ("Silicon die")
  - With 21.6µm Sn/Pb layer only
  - With (10µm Cu)/3.4µm Ni/21.6µm SnPb <u>which will be our hypothesis in the following</u>, and corresponds to the worst case regarding range (residual copper layer measured within [10-50 µm])

Gate degradation effect studied in P-channel part: STP80PF55 (55V)

▪ Backside irradiation





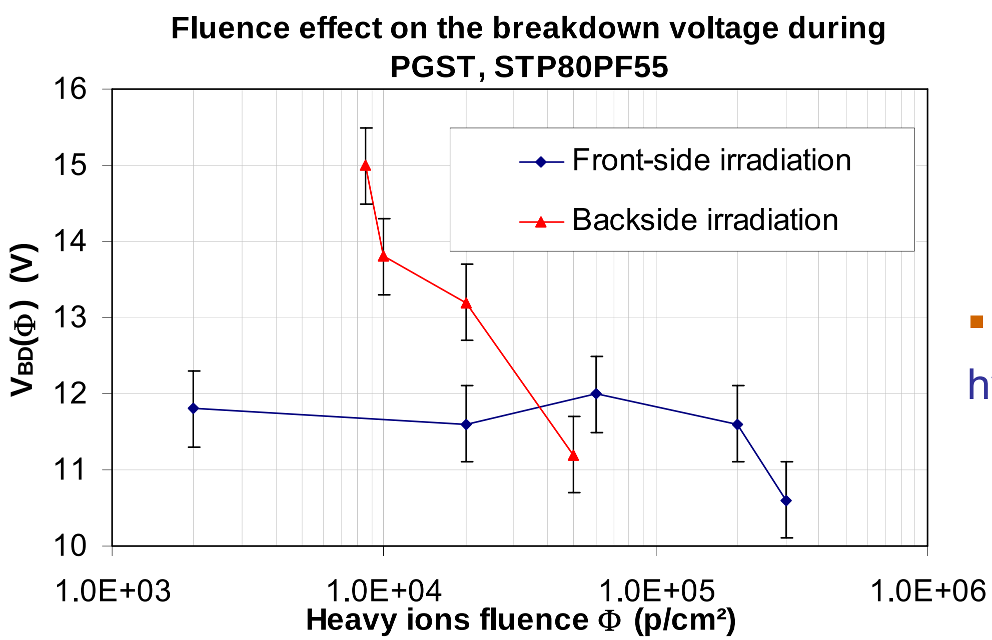
- A distance of [10-35 µm] [Fig.a] between end of ionization profile and gate is able to induce gate degradation at Vds=55V / Vgs=0V. (die thickness is 240 µm).

- Inducing gate degradation within ~100 µm distance from the gate [Fig. b], is possible with Vgs=15V.

➡ **Far below the epi layer, an irradiation is able to trigger gate degradation.**

Gate degradation effect studied in P-channel part: STP80PF55 (55V)

Backside irradiation : PGST results

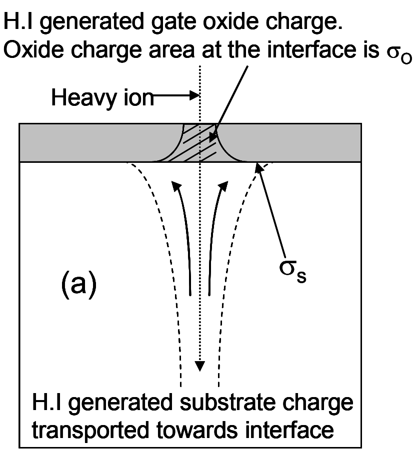


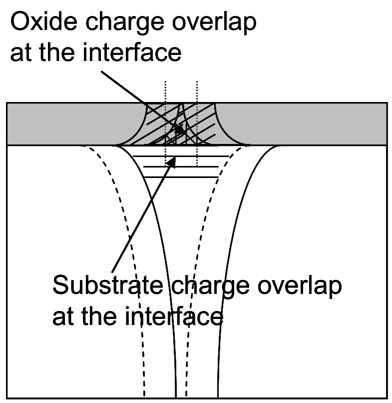
- Negative slope support the hypothesis of multiple impacts

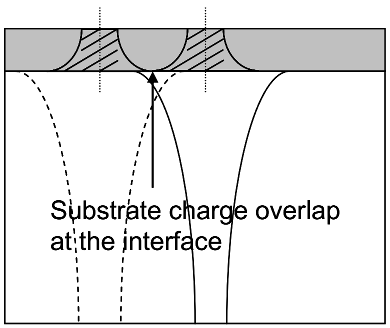
- **Backside irradiation is able to create latent defects, even with ions far from the epi.**

Some possible interpretations..

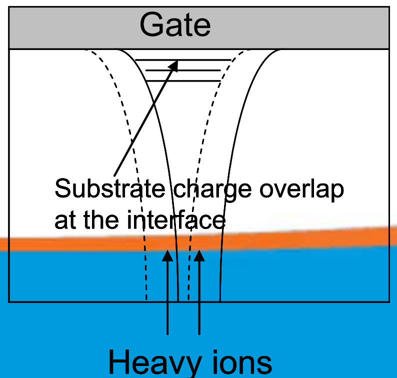
- **H.I. traces overlap.. Traces cross section is σ_s or σ_0**







Front-side irradiations



Backside irradiations

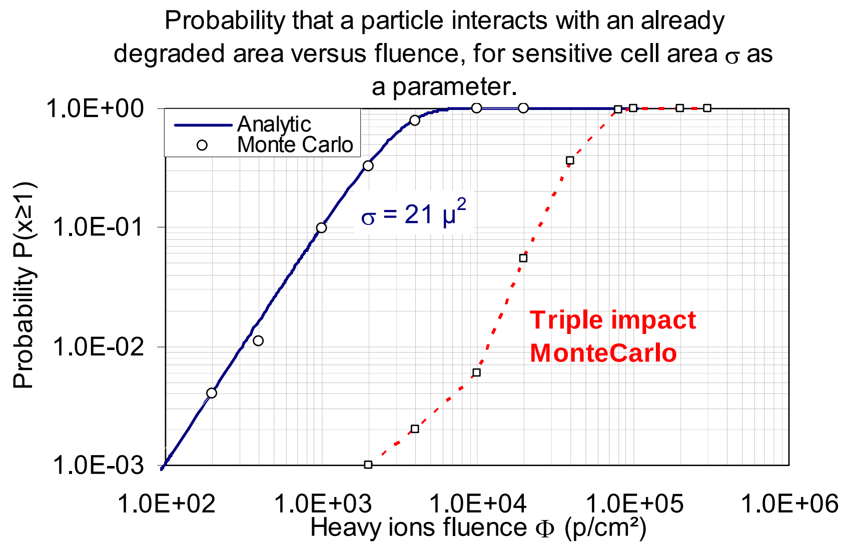
Some possible interpretations..

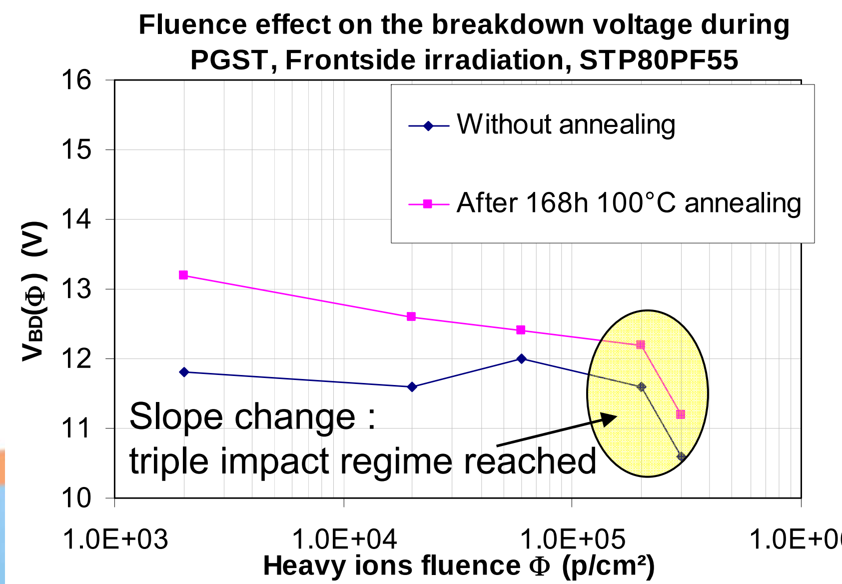
- **The probability of multiple impacts is depending on trace "cross section" σ, that can be defined vs. charge density..**

$$\text{Prob}(x \geq 1) = 1 - \prod_{i=1}^{n} [1 - (i-1)\cdot\sigma]$$

With n being particles fluence

x being the random variable associated to multiple impacts with at least 2 ions.





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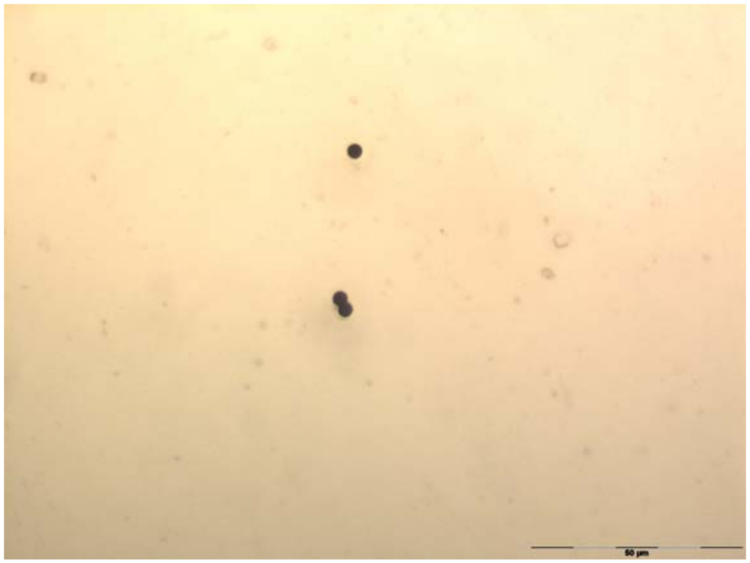
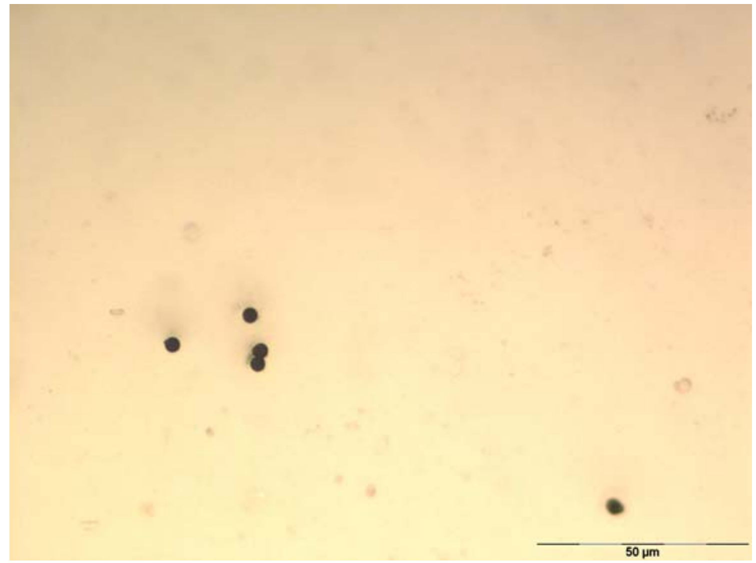
Multiple impact verification..

- H.I. traces observed on films
- Several films irradiated at several H.I. fluences
- Multiple impact probability checked for H.I. trace's diameter = 3.5µ (σ =9.62 μ^2)
- Such "high" diameter is chosen for practical purpose.

Multiple impact verification..

- **Some pictures..**



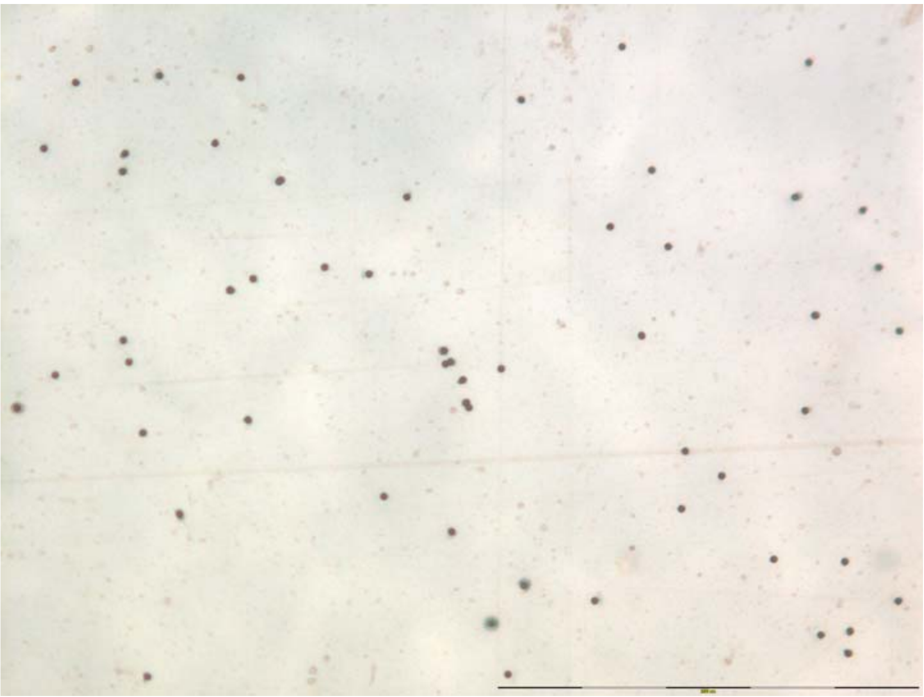


Fluence Φ~4000 p/cm²

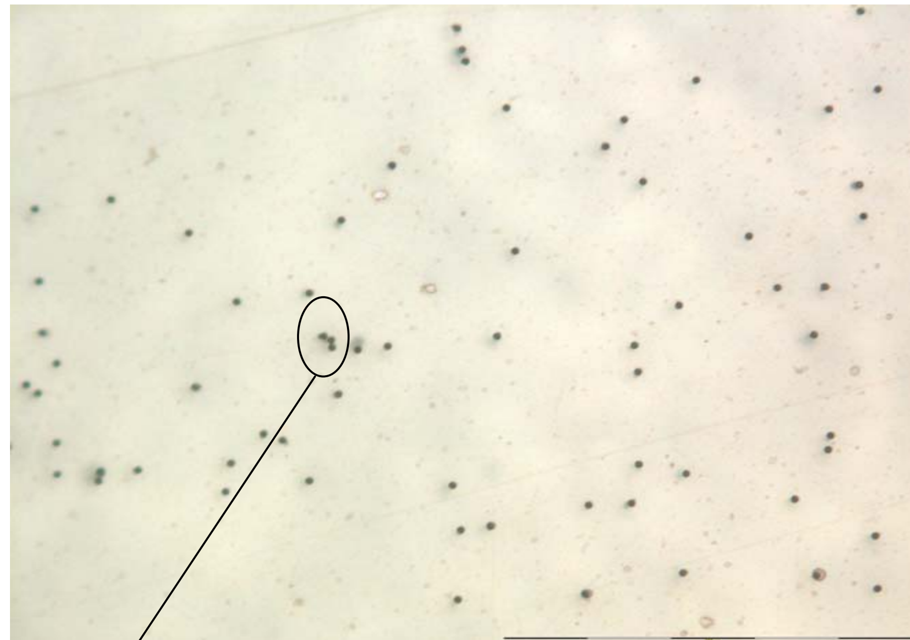
Fluence Φ~8000 p/cm²

Multiple impact verification..

- **Some pictures..**



Fluence Φ~30.000 p/cm²

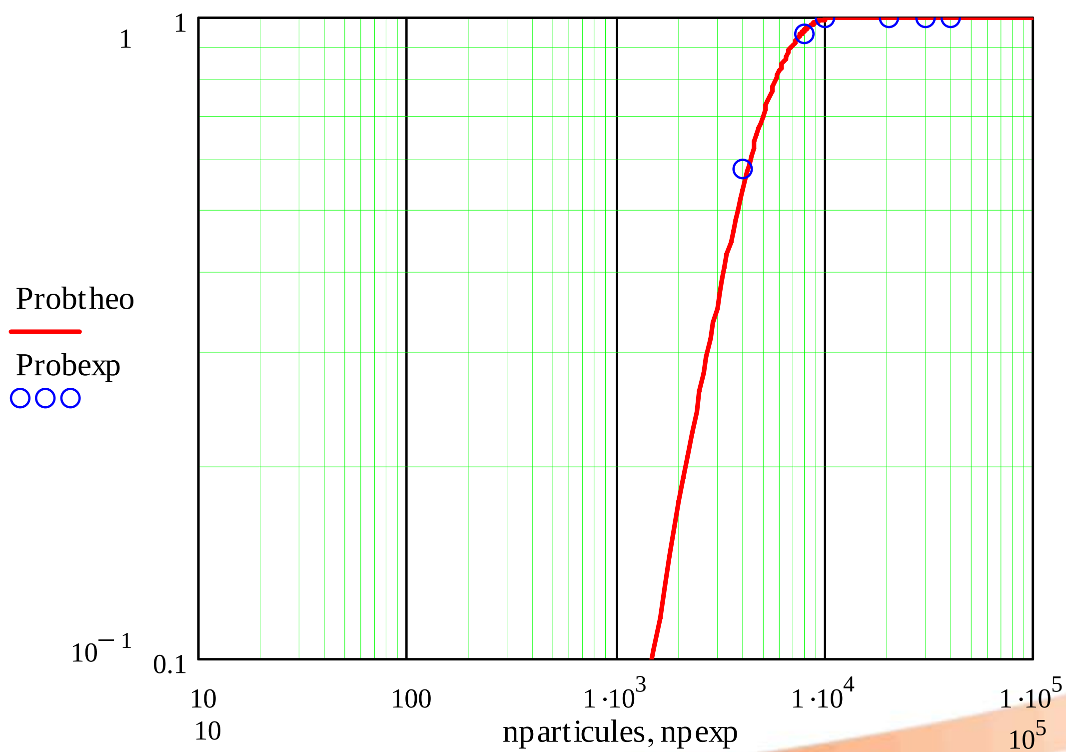


Fluence Φ~40.000 p/cm²

Towards triple impacts regime

Multiple impact verification..

- **Probability Prob(x>=1) verification from set of irradiated films**

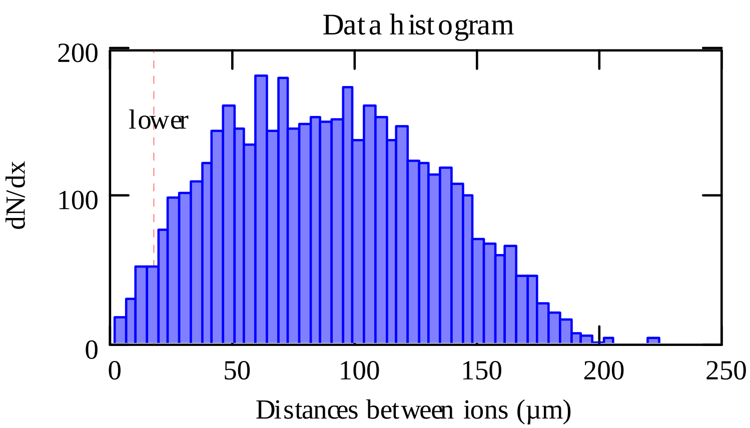


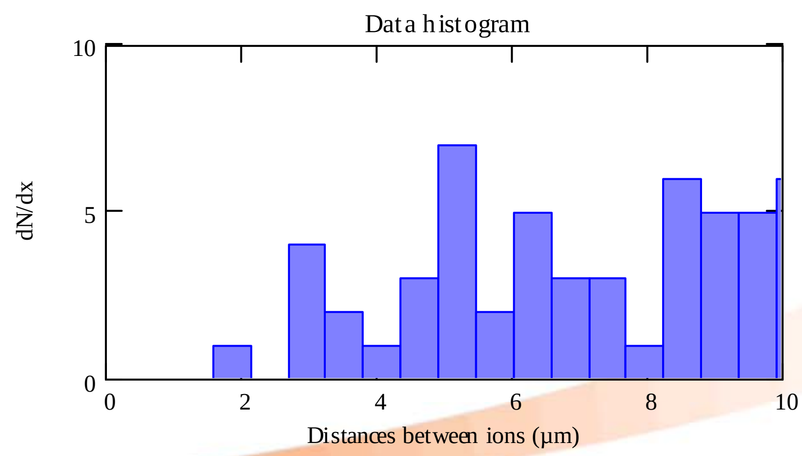
Multiple impact verification..

- **Histogram of distances between ions vs H.I. fluence**

- **Can only be calculated on reduced field of observation for high fluences (the number of distances to be calculated varies as n(n-1)/2).**

- **Example for Φ=3^E5 p/cm², observed on 1e-3 cm²**

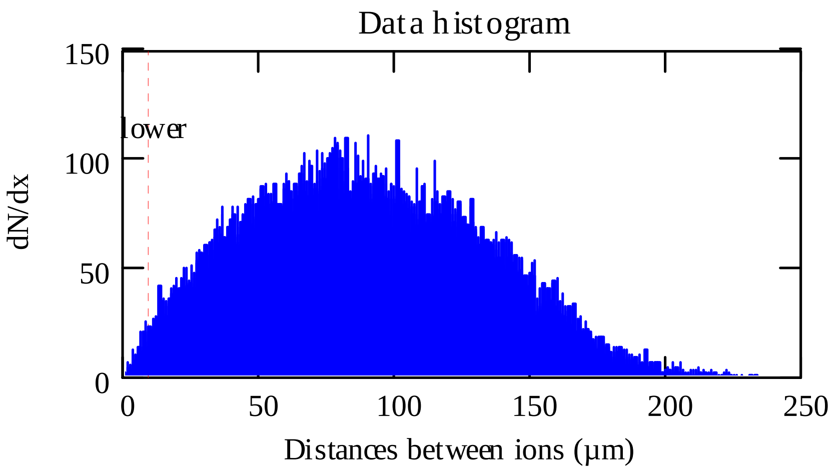


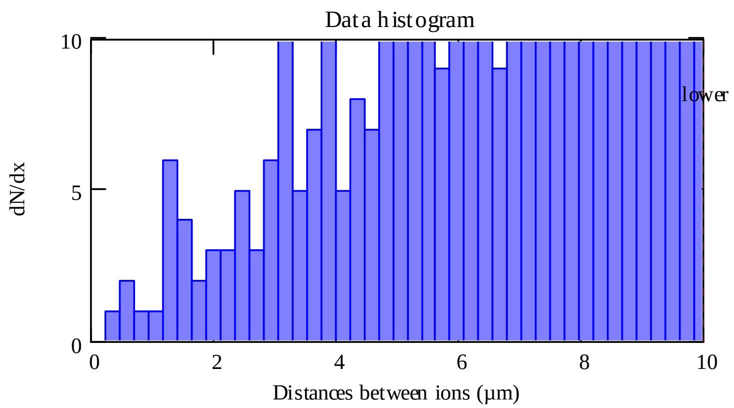


The number of impacts at distances < 1.8µ is <u>at least</u> 1000 on 1 cm²

Multiple impact verification..

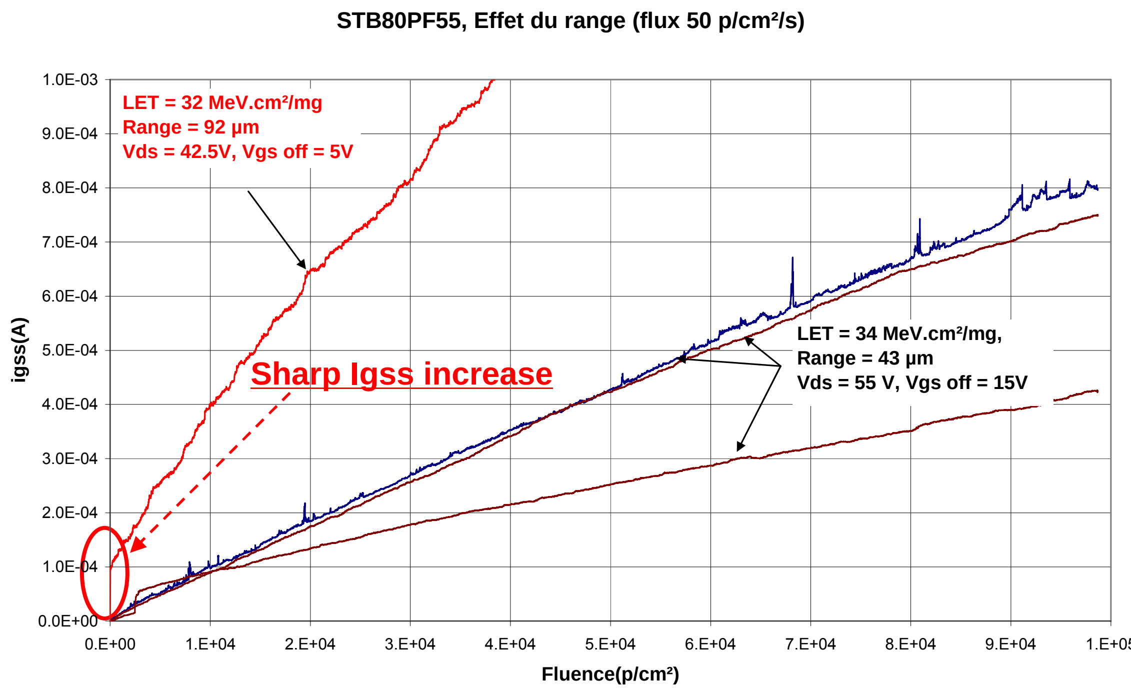
- **Histogram of distances between ions vs H.I. fluence**
- **Example for Φ=1ᴱ6 p/cm², observed on 1e-3 cm²**





The number of impacts at distances < 0.7 µ is <u>at least</u> 4000 on 1cm²

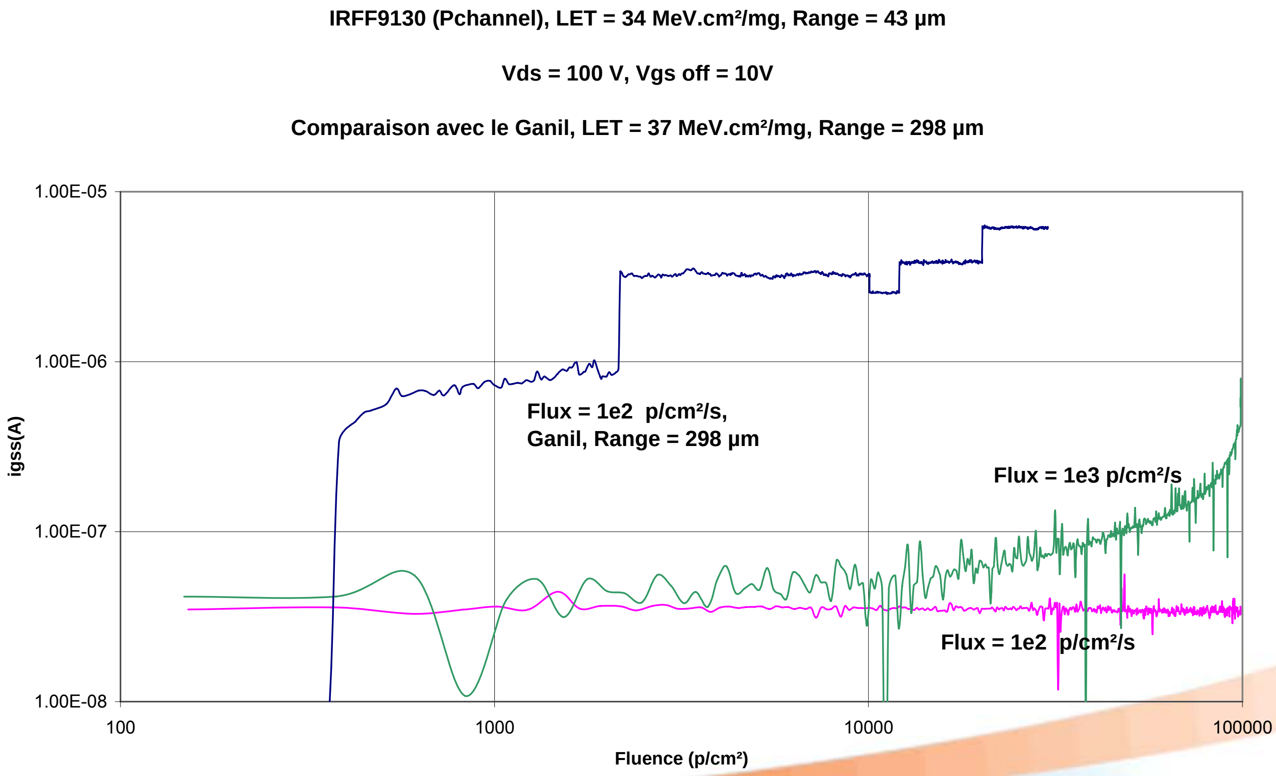
Range effect : Frontside irradiation.



- **Range (43 µm) or (92 µm) >> epi layer 7 µm**
- **Degradation (R=92µm, Vds=42V, Vgsoff=5V) >> Degradation (R=43 µm, Vds=55V, Vgsoff=15V)**
- **Range effect can dominate the (electrical bias + LET) conditions.**

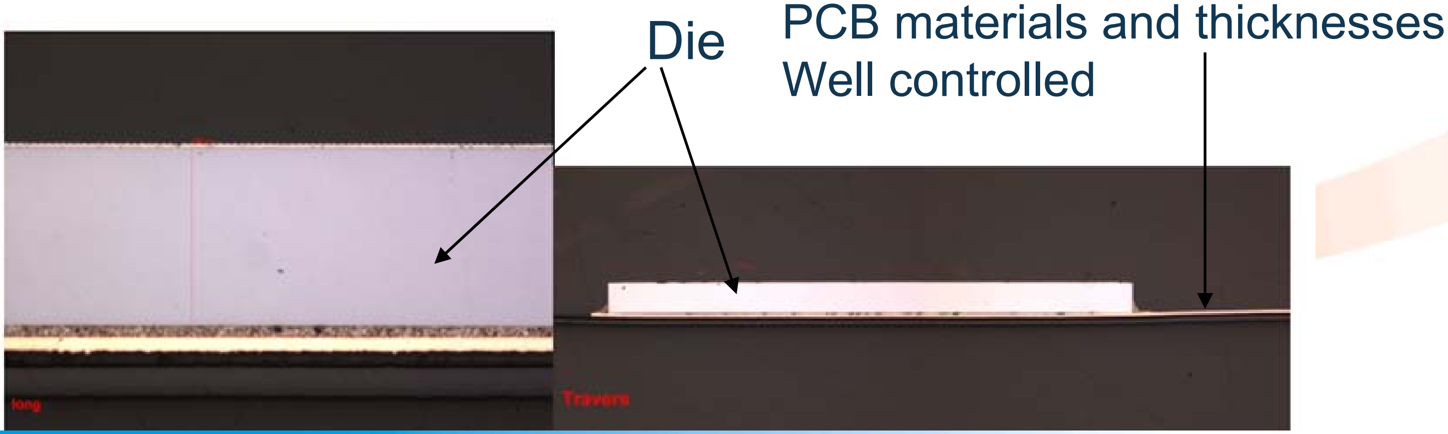
Range effect : Frontside irradiation.

- **Same type of results in other P channel parts: Range effect dominates the LET one.**



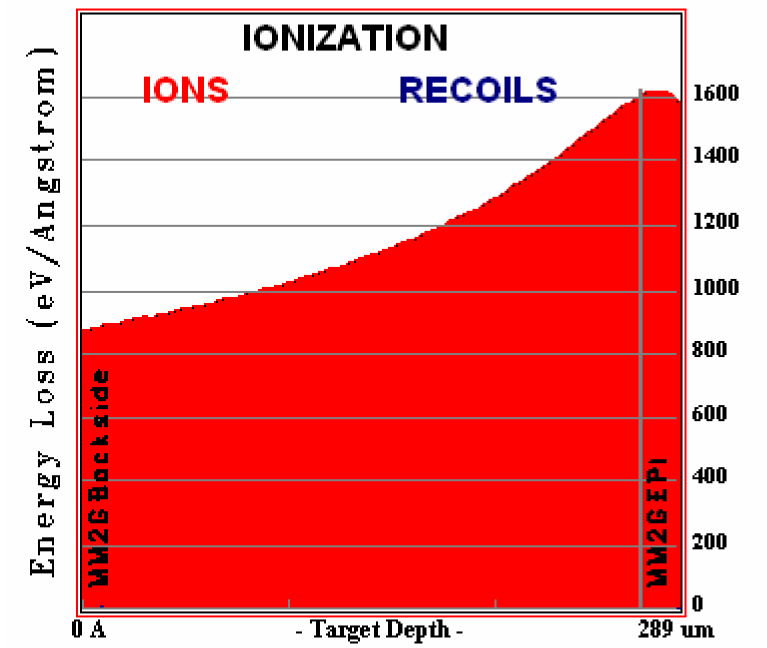
Range effect : Front-side / backside irradiations for SEB.

- SEE testing performed at GANIL facility in W46 2008
- Device type
  - MM2G 200V N-channel power MOSFET from STM
    - Commercial device
- Specific board designed for testing
  - Back side and front side irradiations



Range effect : Front-side / backside irradiations for SEB.

- Back side irradiation
  - Epitaxial layer of 17 µm (measured by CNES)
  - Total die thickness is 289 µm

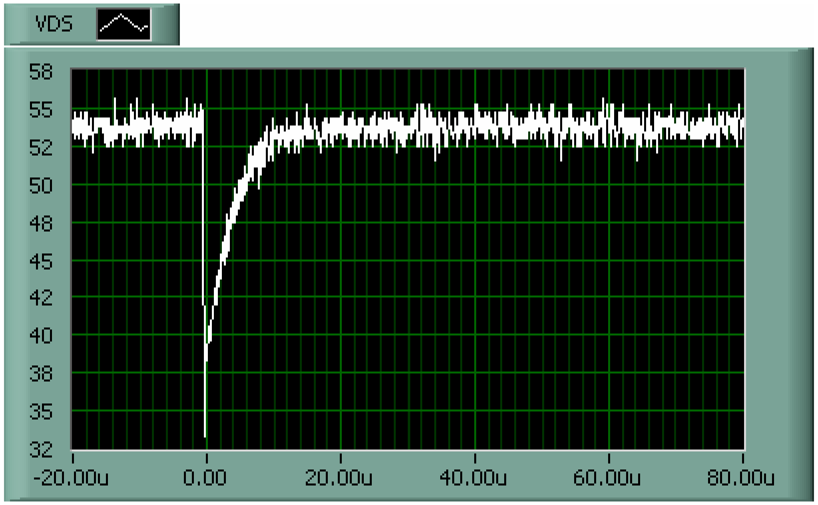


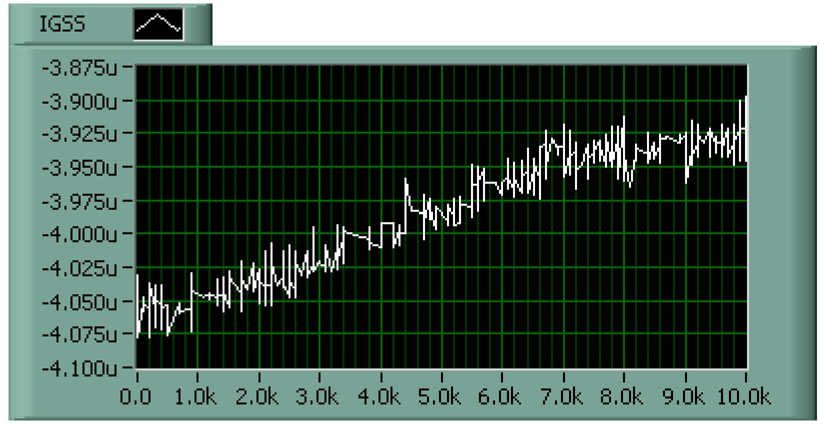
- LET value: rear surface of the MOSFET

LET MeV.cm²/mg	Range (µm)
37.29	319.91

Range effect : Front-side / backside irradiations for SEB.

- SEB triggered, Igss drift recorded





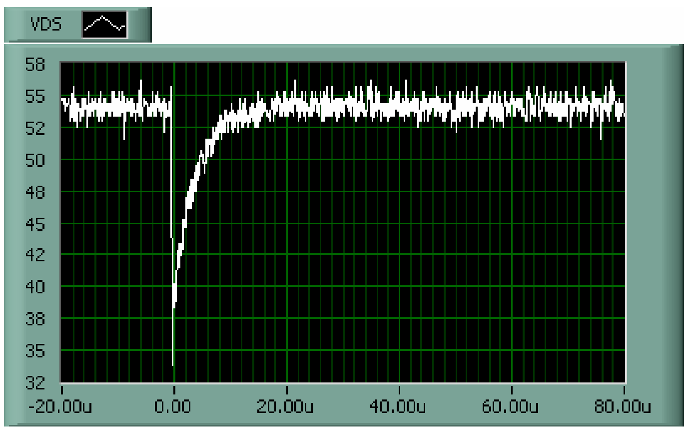
Vgs (V)	Vds	σ_{SEB} (cm²)
0	50	$< 10^{-4}$
0	55	$6.5\ 10^{-3}$

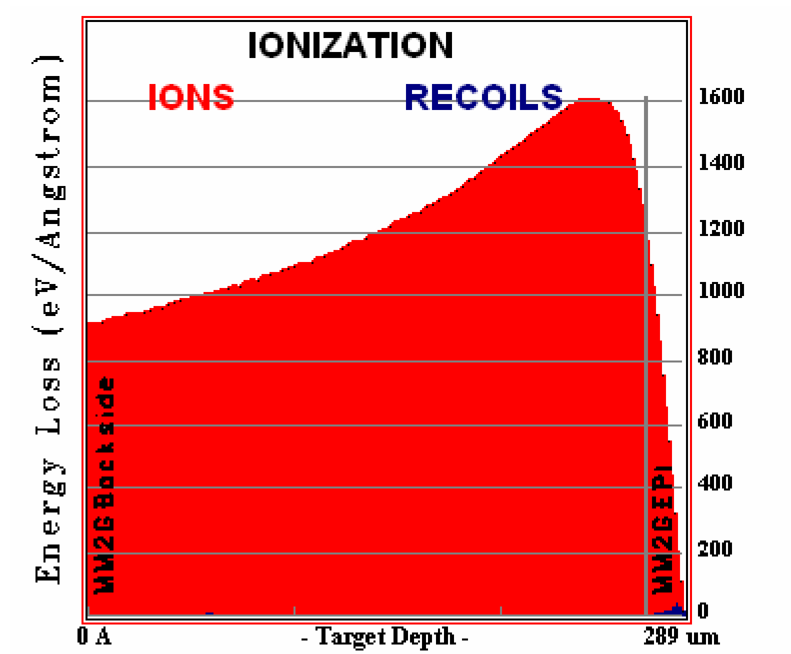
Device sensitivity to SEB expressed vs. Vds

Range effect : Front-side / backside irradiations for SEB.

- Experiment repeated with varying Ion range (LET profile)

LET MeV.cm²/mg	Range (µm)
39.14	285.91





Vgs (V)	Vds	σ_{SEB} (cm²)
0	50	$<10^{-4}$
0	55	$1.5\ 10^{-3}$

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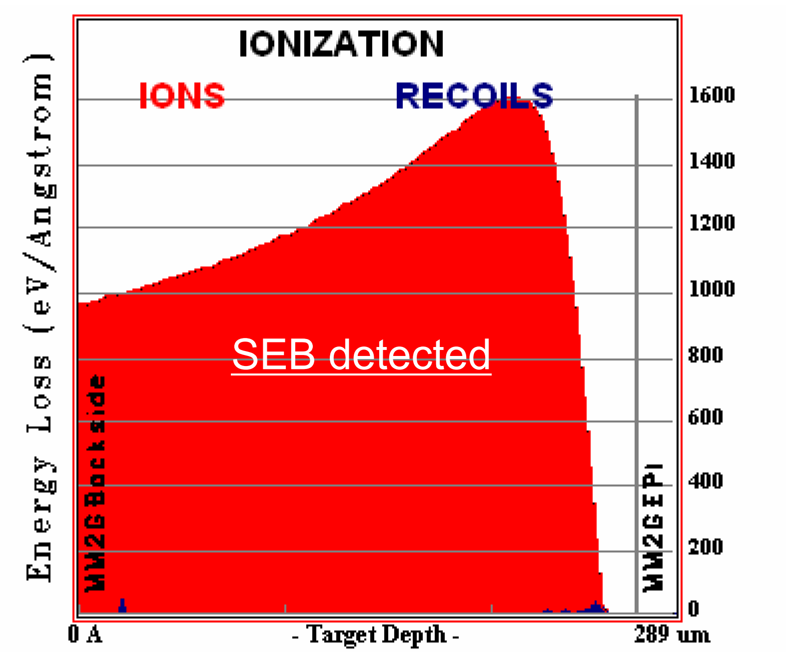
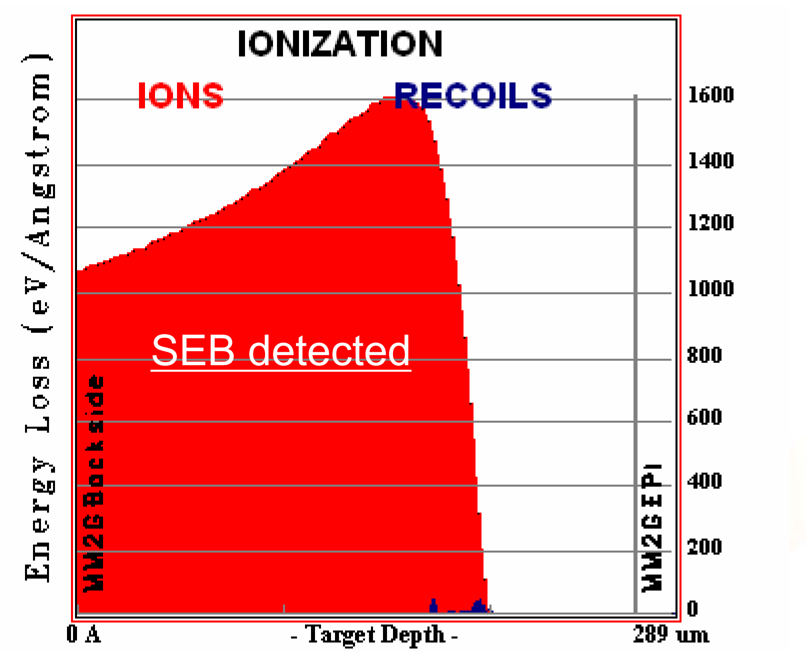
Range effect : Front-side / backside irradiations for SEB.

LET MeV.cm²/mg	Range (µm)
41.3	251.8

LET MeV.cm²/mg	Range (µm)
45.7	196.6





Vgs (V)	Vds	σ_{SEB} (cm²)
0	55	10^{-4}
0	80	$1.5. 10^{-3}$

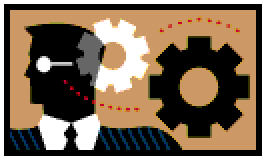
Vgs (V)	Vds	σ_{SEB} (cm²)
0	150	10^{-4}

Range effect : Front-side / backside irradiations for SEB.

Such SEB triggering far from the epi is still not understood.

Some hypothesis : secondaries from the thin PCB?

Some Geant4 calculations have shown few recoils but with very low range, not exceeding the substrate thickness



???

Conclusion : Fluence specification

- **Fluence Specification at 3^{E}5 p/cm^2 is too high to avoid multiple impacts effects during PGST assessment.**
- **Parts assessment should require to use higher number of parts to be irradiated to fluences Φ_I sufficiently low to avoid multiple impacts effects.**
- **Such fluence Φ_I could be determined in order to "ensure" a minimum distance between ions much greater than elementary transistor size ? or H.I. trace size.?. TBD..**
- **Cost impact expected. To be balanced to the drawback related to ITAR stamp on hardened parts procurement.**

Conclusion : SEB/SEGR and latent defect

- SEB / SEGR triggered even though ion trajectory does not reach the epi layer
  - Sensitivity not negligible: sensitive volume depth looks like greater than epi layer
  - Refined technological analysis would be needed (doping profile)
- SEB sensitivity decreases with the distance from epi layer
- SEB sensitivity remains to be precisely quantified according to LET profile, Vds and Vgs values (very recent experiments)
  - Full set of data to be analysed, (including front side experiments)

Conclusion : SEB/SEGR and latent defect

- **Range effect can dominate (electrical bias + LET) conditions**
- **The SEB / SEGR triggering far from the epi is still not understood.**
- **We recommend to test power MOSFETs at high range (>70 µm)**
- ***JPL has raised the following recommendation regarding range to be used vs. drain voltage.***

Device Rating [V]	Device Thickness [um]	Epi Thickness [um]	Needed ion range [um]
100	100	20	70
200	200	40	130
500	500	60	310
1000	1000	150	610

- ***Recent tests from IR are performed at TAMU***