Optocoupler study :

Preliminary Analysis & Results following protons testing.

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Acknowledgments

- This work has been done under ESA contract n° 19623/05/NL/PA; we address a very warm thanks to Reno Harboe Sorensen for his continuous support and exciting discussions.
- We would also like to particularly acknowledge Marcus H. MendenHall and Robert A. Weller from Vanderbilt University, to have provided the GEANT4 module of the modified coulombic scattering model taking into account the screening effects (ZBL) described in references below:

[Weller-2004] Robert A. Weller, Marcus H. MendenHall, Daniel M. Fleetwood, "A Screened Coulomb scattering Module for Displacement Damage computations in GEANT4", IEEE Trans. Nucl. Sci, 51, n°6, pp 3669-3677, (2004).

[Mend-2006] Marcus H. MendenHall, Robert A. Weller, "An algorithm for computing Screened Coulomb scattering in GEANT4", Nuclear Instruments and Methods B, 2006.

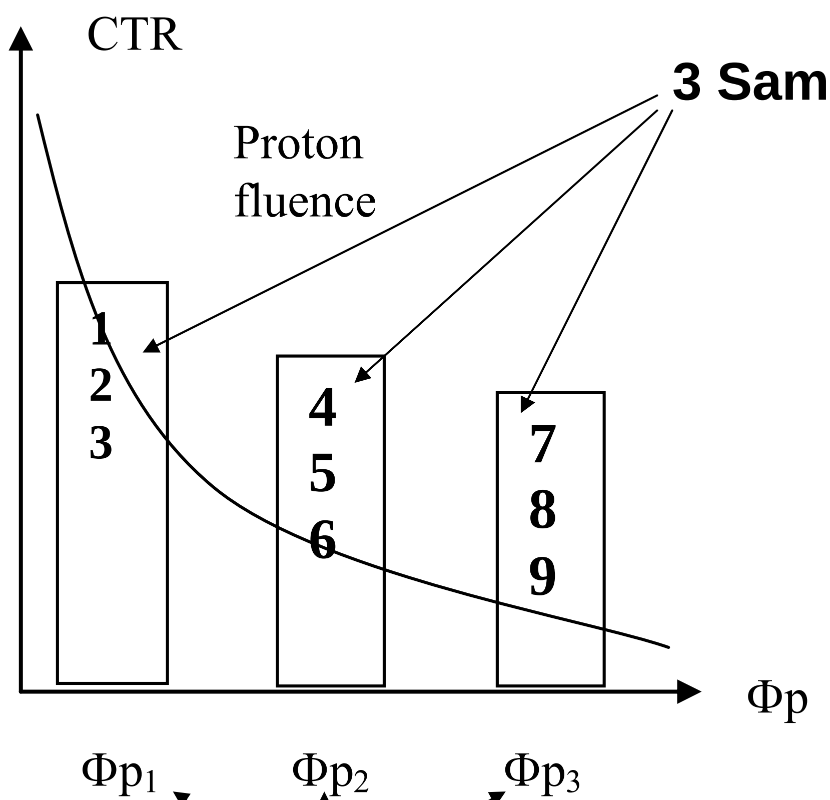
Study description

- The objective is to define a procedure for part selection and assessment regard TID and TNID cumulative constraints.
- Three part types were procured : diodes and transistors can be irradiated separately.

Part name	$Al_xGa_{1-x}As$ diode Stoechiometry
4N49 (880 nm) / ISOLINK	x=0.02
OLH249 (830 nm) / ISOLINK	x=0.11
66099 (660 nm) / MICROPAC	x=0.35

3 different technologies

Study description



3 Samples per irradiation group Φpi

End Irradiation Fluences

- 3 different proton energies:

60 MeV

100 MeV

200 MeV

Study description

- Measured parameters:
  - CTR_{opto}
  - CTR_{diode}
  - $CTR_{transistor}$
  - Diode's τ_{RR0}
- Measurements versus:
  - Fluence
  - NIEL from tables or calculated with GEANT4

Several NIEL tables exist on pure AsGa

Study description

- NIEL was calculated with GEANT4 on $Al_xGa_{(1-x)}As$ material with the modified module for coulombic scattering => within 10% shift between x=0 and x=0.35

Ep (MeV)	NIEDR ($MeV.cm^2/g$)	Si (ρ = 2,33)	AsGa (ρ = 5,32)	$Al_xGa_{1-x}As$ x=2% (ρ = 5,31)	$Al_xGa_{1-x}As$ x=11 % (ρ = 5,26)	$Al_xGa_{1-x}As$ x=35% (ρ = 5,13)
60	Elastic (Coulombic)	$1,744.10^{-3}$	$1,204.10^{-3}$	$1,213.10^{-3}$	$1,213.10^{-3}$	$1,201.10^{-3}$
	Inelastic (Nuclear)	$5,88.10^{-4}$	$7,39.10^{-4}$	$8,25.10^{-4}$	$7,99.10^{-4}$	$6,61.10^{-4}$
100	Elastic (Coulombic)	$1,104.10^{-3}$	$7,76.10^{-4}$	$7,64.10^{-4}$	$8,17.10^{-4}$	$7,57.10^{-4}$
	Inelastic (Nuclear)	$5,83.10^{-4}$	$8,48.10^{-4}$	$7,24.10^{-4}$	$7,54.10^{-4}$	$6,10.10^{-4}$
200	Elastic (Coulombic)	$5,70.10^{-4}$	$4,32.10^{-4}$	$4,19.10^{-4}$	$4,00.10^{-4}$	$3,93.10^{-4}$
	Inelastic (Nuclear)	$4,99.10^{-4}$	$7,76.10^{-4}$	$6,51.10^{-4}$	$6,06.10^{-4}$	$6,97.10^{-4}$

Study description

- Comparison between Barry's value and Calculation with GEANT4, using modified module (Mend-2006)

		Silicon		AsGa	
Ep (MeV)	NIEDR ($MeV.cm^2/g$)	GEANT4	Barry	GEANT4	Barry
60	Elastic (Coulombic)	$1{,}744.10^{-3}$	$3{,}36.10^{-3}$	$1{,}204.10^{-3}$	$1{,}60.10^{-3}$
	Inelastic (Nuclear)	$5{,}88.10^{-4}$	-	$7{,}39.10^{-4}$	-
100	Elastic (Coulombic)	$1{,}104.10^{-3}$	$2{,}60.10^{-3}$	$7{,}76.10^{-4}$	$1{,}25.10^{-3}$
	Inelastic (Nuclear)	$5{,}83.10^{-4}$	-	$8{,}48.10^{-4}$	-
200	Elastic (Coulombic)	$5{,}70.10^{-4}$	$2{,}02.10^{-3}$	$4{,}32.10^{-4}$	$8{,}5.10^{-4}$
	Inelastic (Nuclear)	$4{,}99.10^{-4}$	-	$7{,}76.10^{-4}$	-

- Hypothesis of 10µm target thickness

- Some discrepancy between Barry's table and GEANT4 results

Experimental set-up presentation

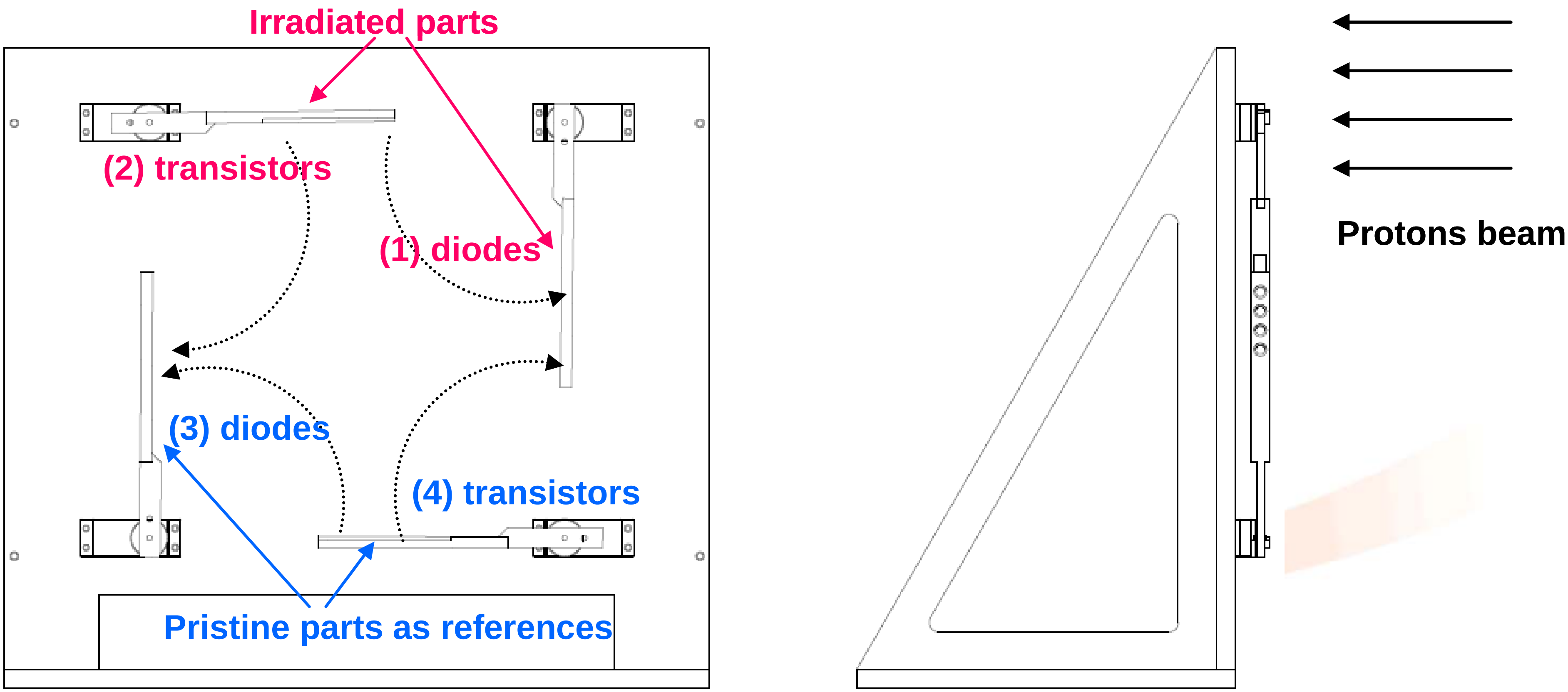
- Parts were procured with diodes and transistors as separate elements.

- The experimental set-up allows to separate the contribution of the irradiated diodes and transistors in the overall degradation, thanks to the measurements done with un-irradiated reference parts.

- All the measurements are remote controlled for higher efficiency.

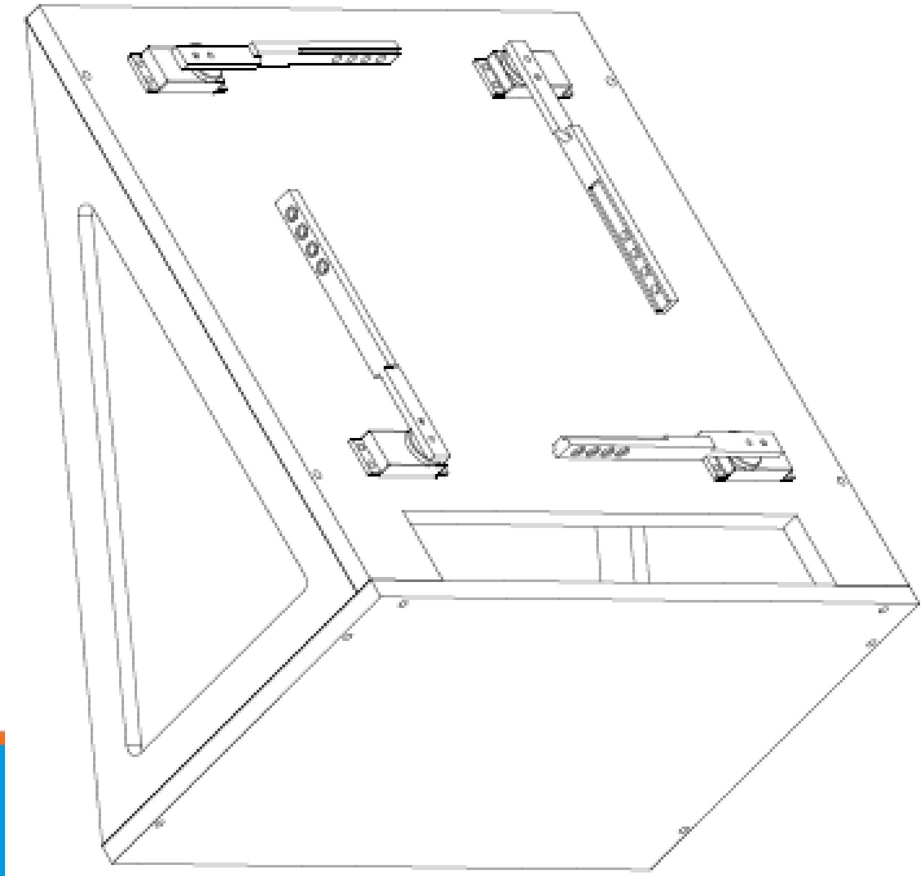
Experimental set-up presentation

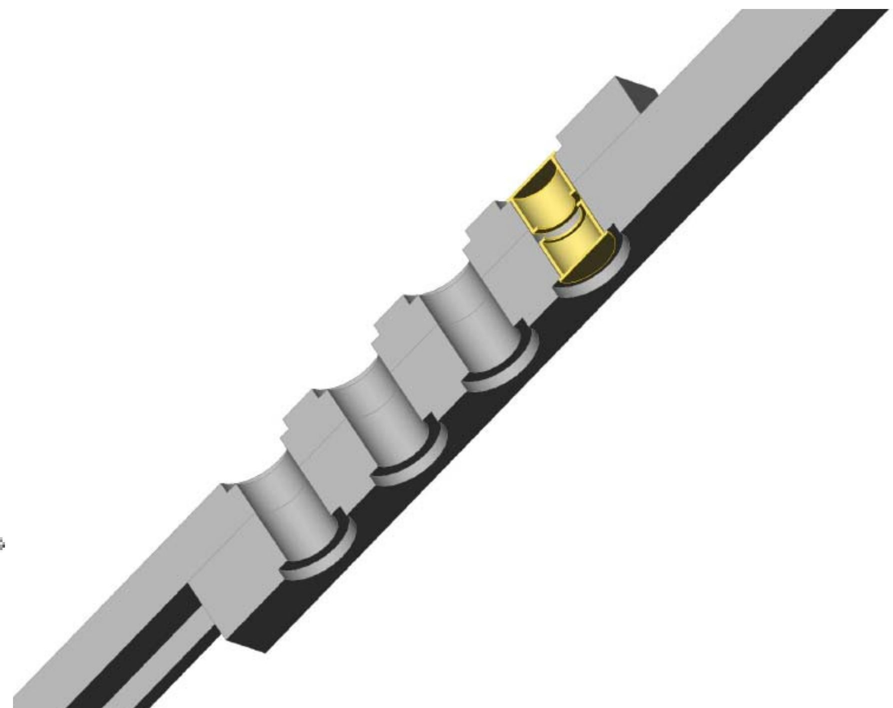
- During the irradiation, diode and transistors are coupled



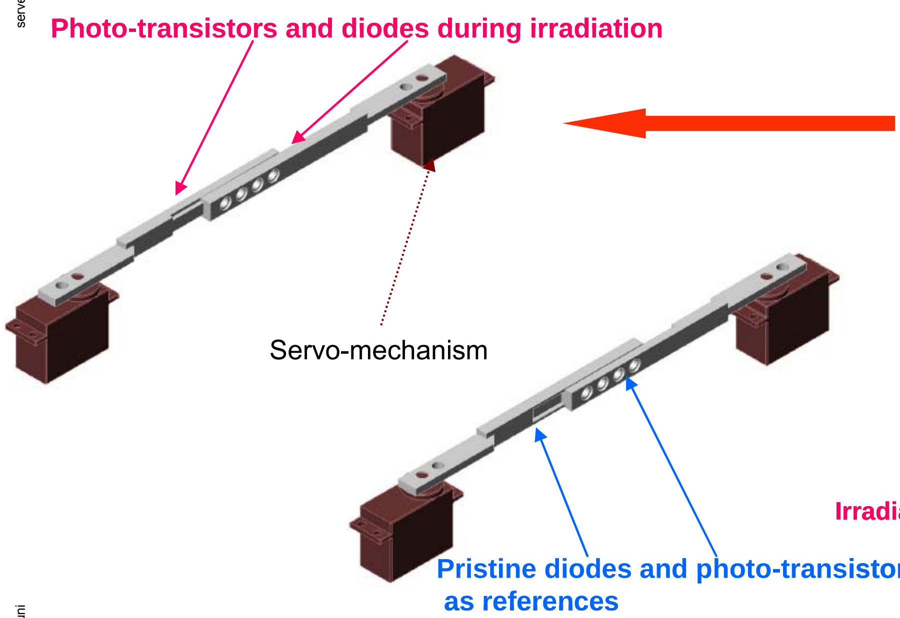
Experimental set-up presentation

- Set-up with detailed view of two coupled branches



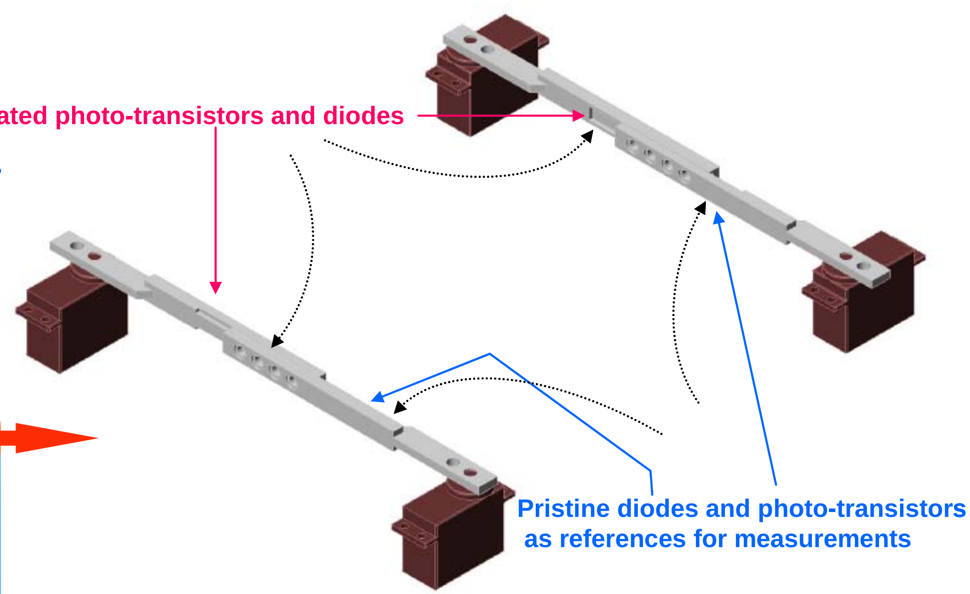


Experimental set-up presentation



- During and after irradiation

- After irradiation :



Experimental set-up presentation (VIDEO)

Experimental results

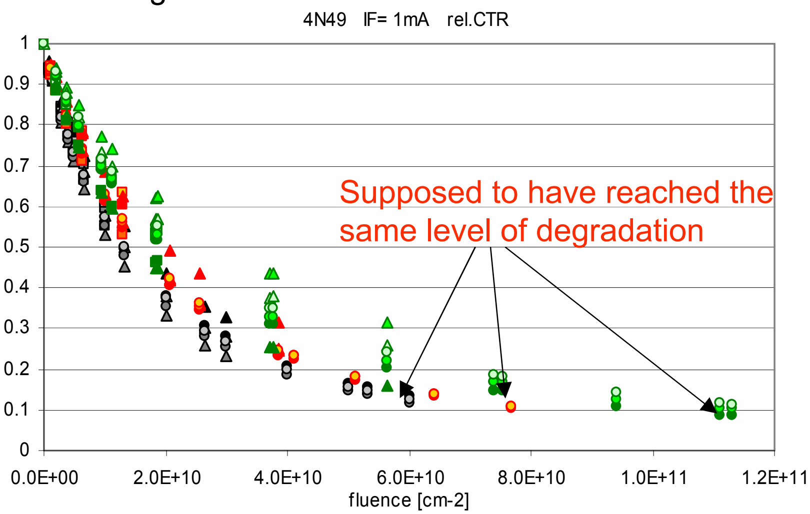
- CTR versus fluence : 4N49

60 MeV

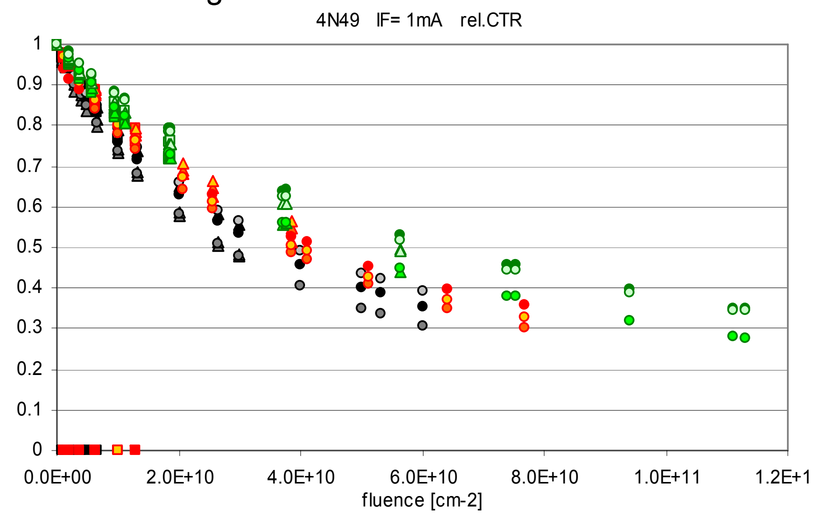
100 MeV

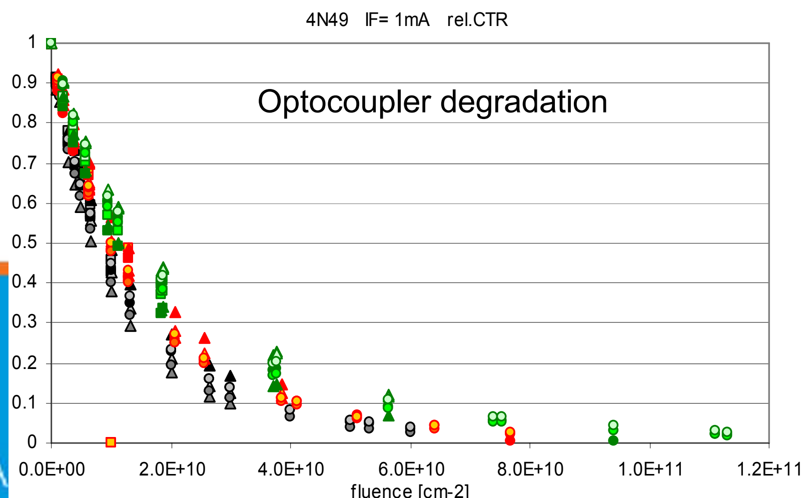
200 MeV

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode





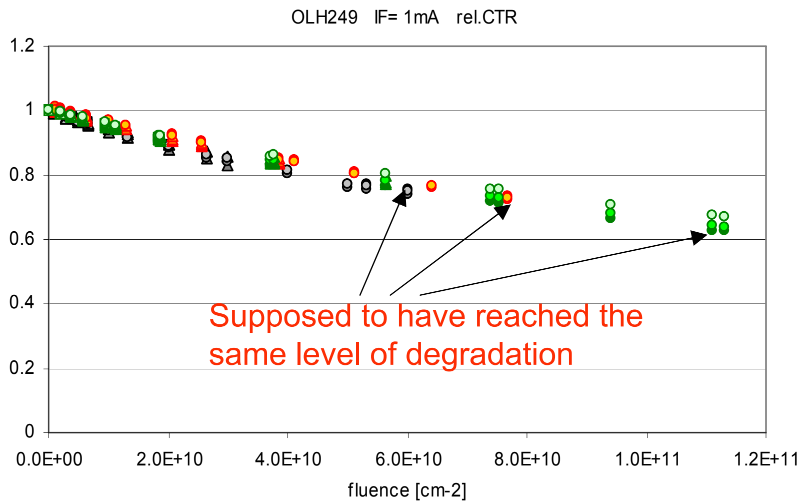
- The diode is the main contributor to the overall degradation
- The degradation at **200 MeV** <u>seems</u> > at **100 MeV** > **60 MeV**

Experimental results

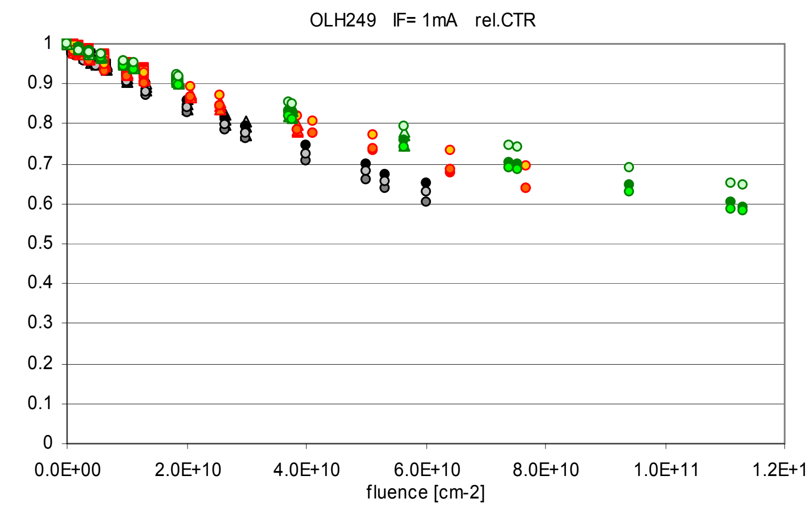
- CTR versus fluence : OLH249

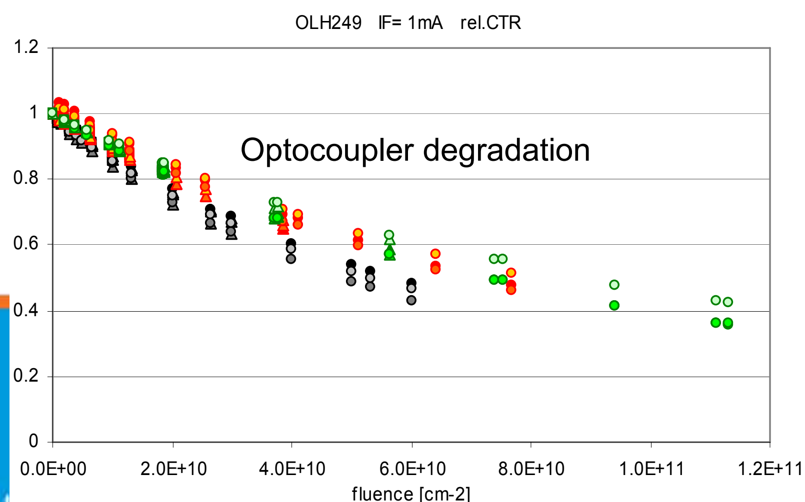
● ■ ▲	60 MeV
○ □ △	100 MeV
○ □ △	200 MeV

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode





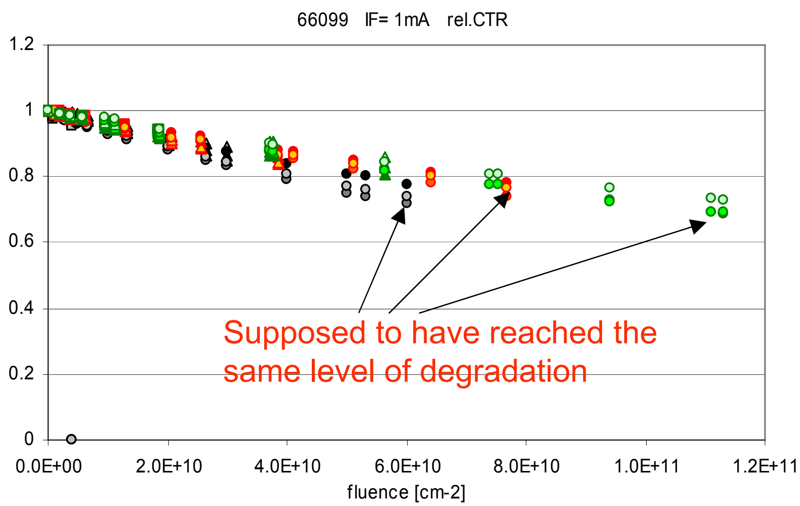
- The transistor is the main contributor to the overall degradation
- The degradation at **200 MeV** seems > at **100 MeV** > **60 MeV**

Experimental results

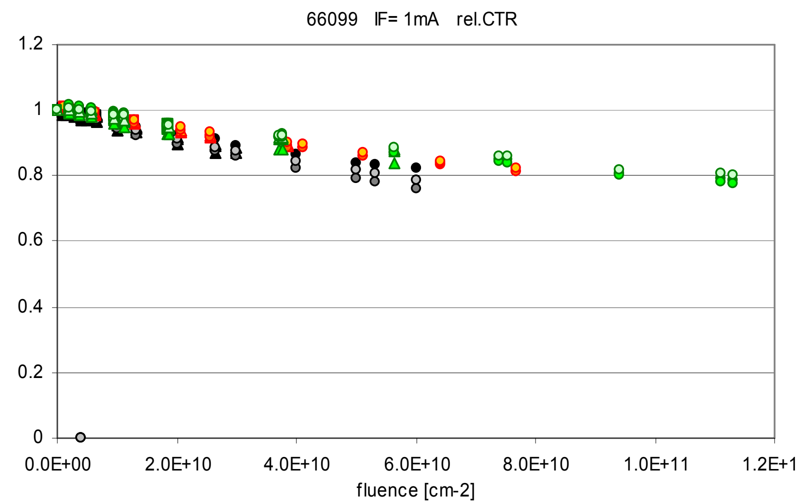
- CTR versus fluence : 66099

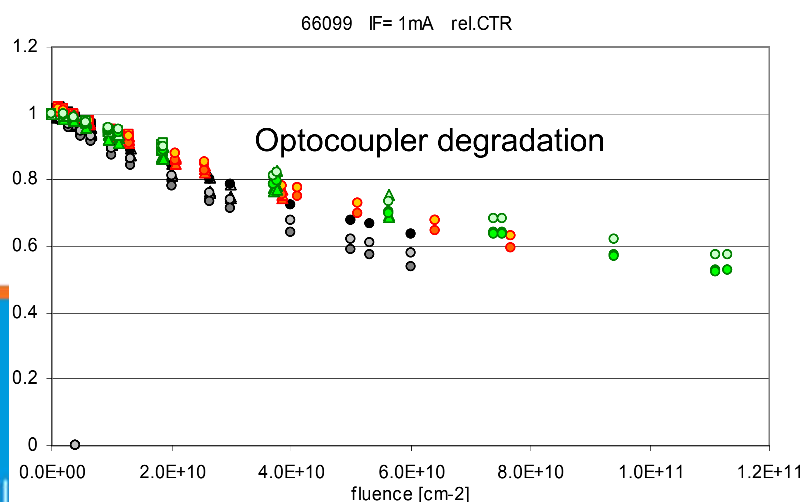
60 MeV
100 MeV
200 MeV

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode

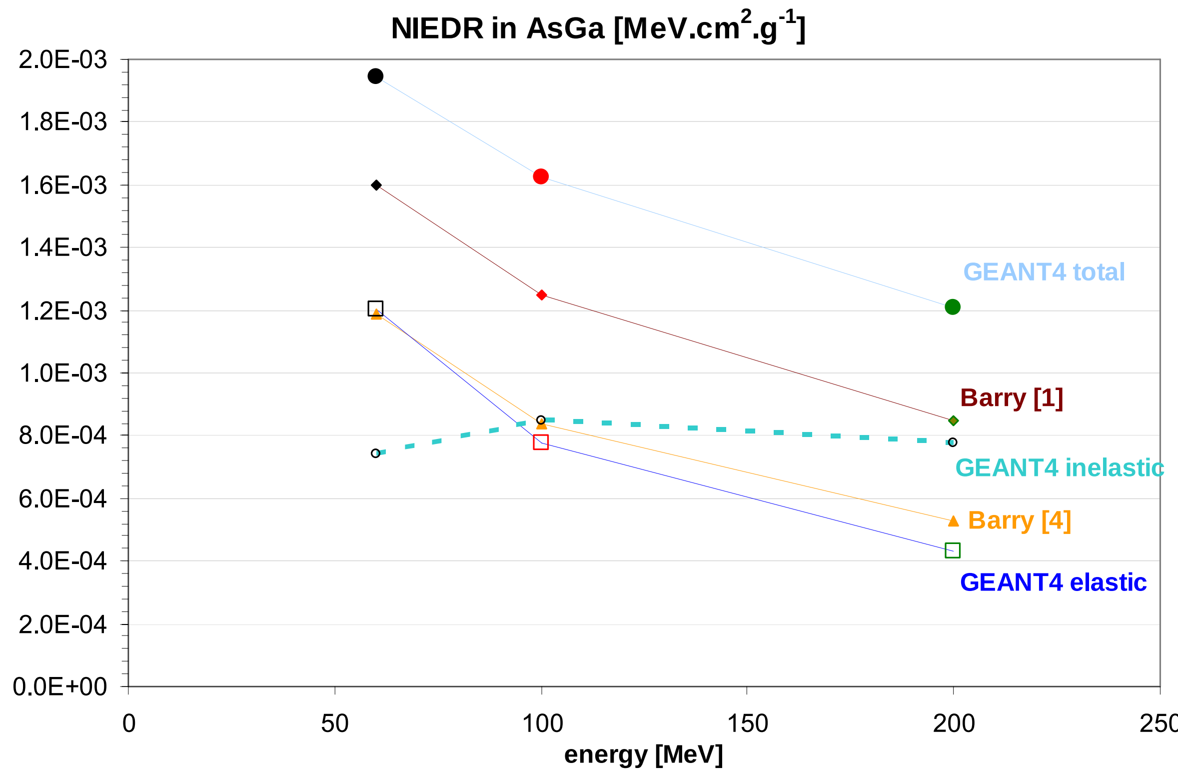




- The diode is the main contributor to the overall degradation
- The degradation at **200 MeV** <u>seems</u> ~ at **100 MeV** ~ **60 MeV**

Experimental results

- CTR versus NIEL: which NIEL to use?



- As in [4], a target thickness of 10 µm was considered for the elastic NIEL calculation with GEANT4

- In GEANT4, the MultiScattering module was skipped and replaced by the module given by M.H.MendenHall et R.A. Weller [4].

[4] R.A. Weller et al., "A screened scattering Coulomb module for displacement damage computations in GEANT4", IEEE Tr. on Nuclear Science, vol.51, no.6, December 2004

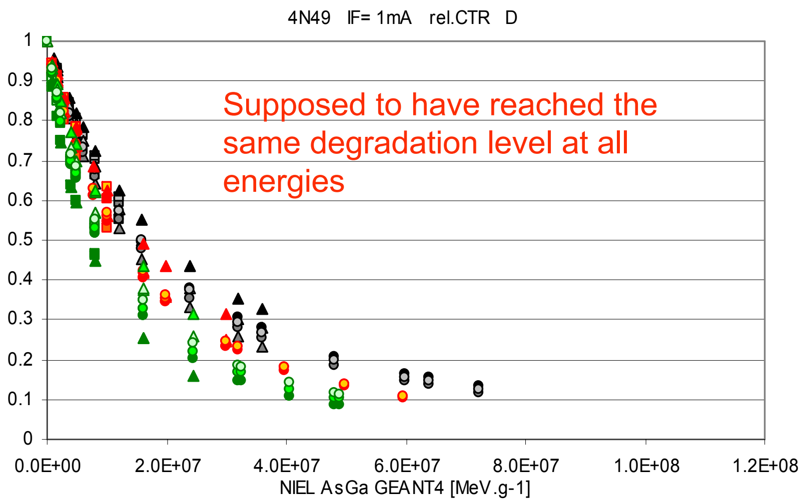
[1] L. Barry, A. J. Houdayer, P. F. Hinrichsen, W. G., Letourneau and J. Vincent, "The Energy Dependence of Lifetime Damage Constants in GaAs LEDs for 1-500 MeV Protons, " IEEE Trans. Nucl. Sci., 42, 2104 (1995)

Experimental results vs Elastic NIEL

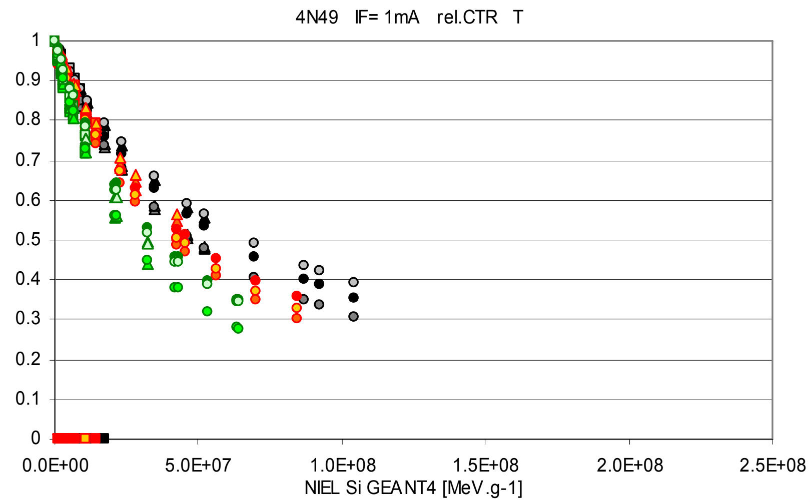
60 MeV
100 MeV
200 MeV

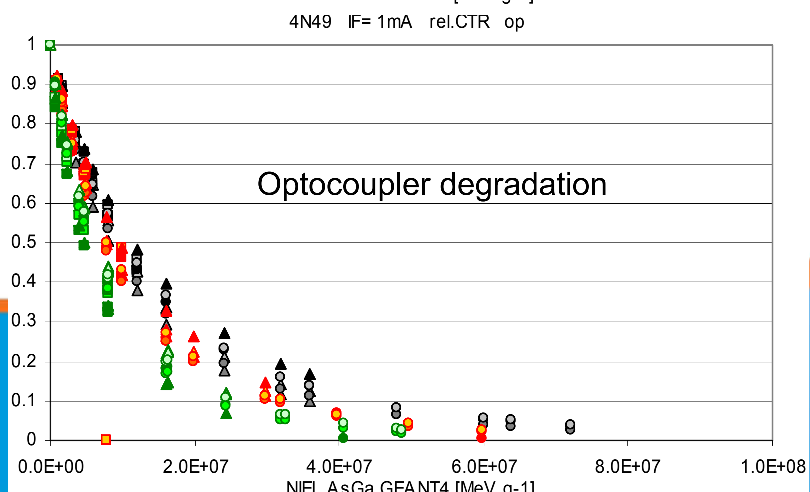
- CTR versus NIEL (GEANT4): 4N49

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode





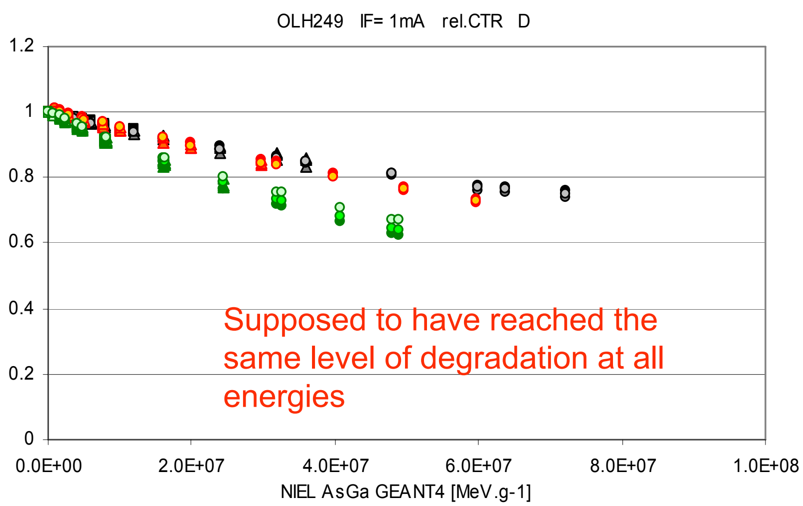
- The diode is the main contributor to the overall degradation
- The degradation at **200 MeV** is > at **100 MeV** > **60 MeV**

Experimental results vs. Elastic NIEL

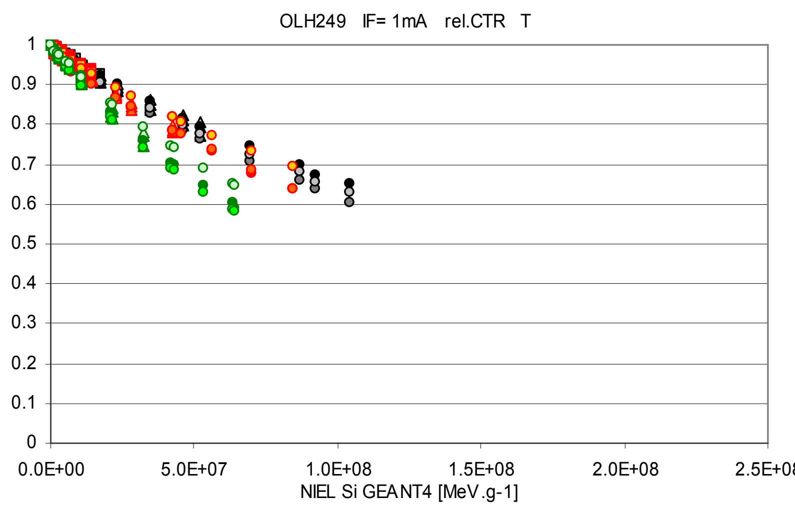
● ■ ▲ 60 MeV
● ■ ▲ 100 MeV
● ■ ▲ 200 MeV

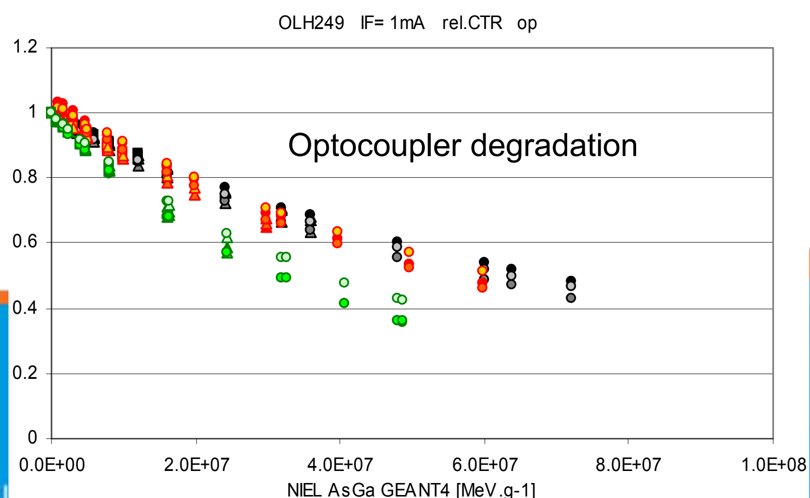
▪ CTR versus NIEL (GEANT4): OLH249

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode



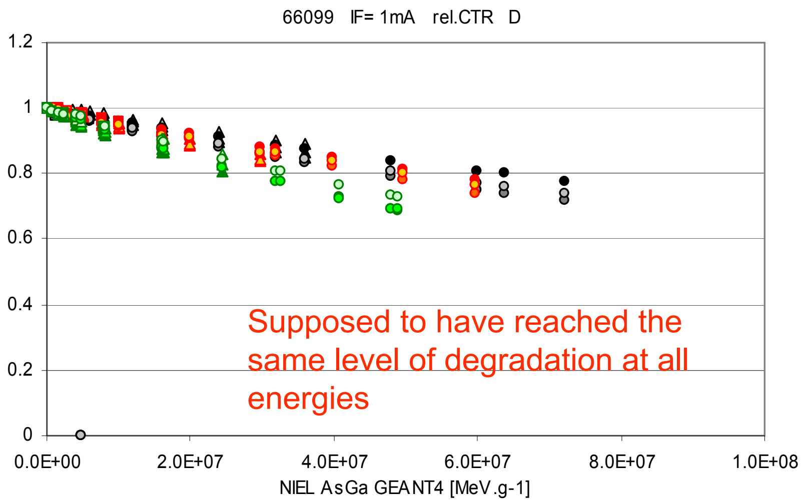


- The transistor is the main contributor to the overall degradation
- The degradation at **200 MeV** is > at **100 MeV** >~ **60 MeV**

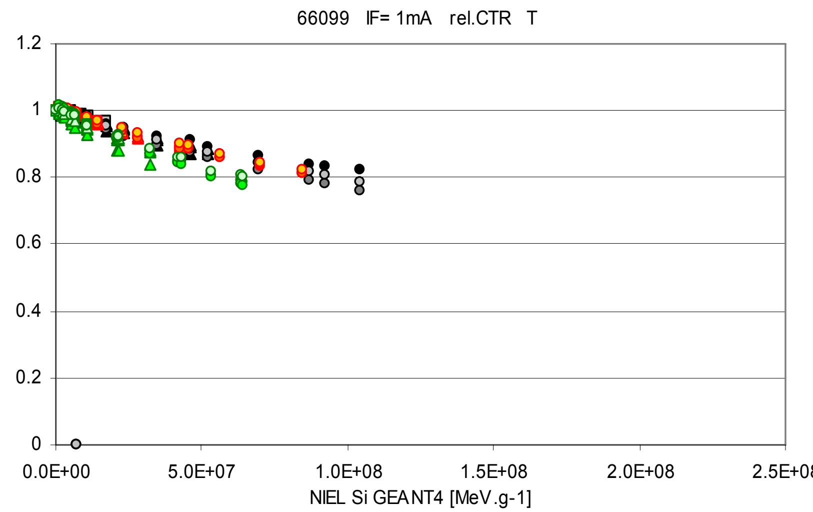
Experimental results vs. Elastic NIEL

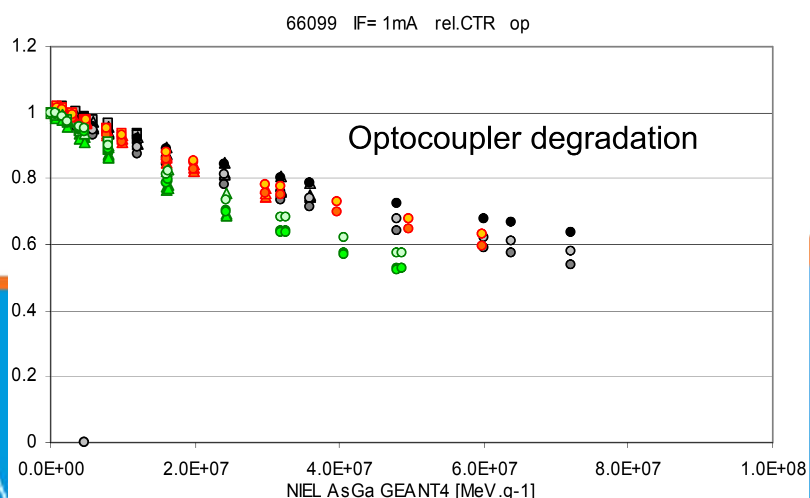
- CTR versus NIEL (GEANT4): 66099

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode





- The diode is the main contributor to the overall degradation
- The degradation at 200 MeV is > ~ at 100 MeV ~ 60 MeV

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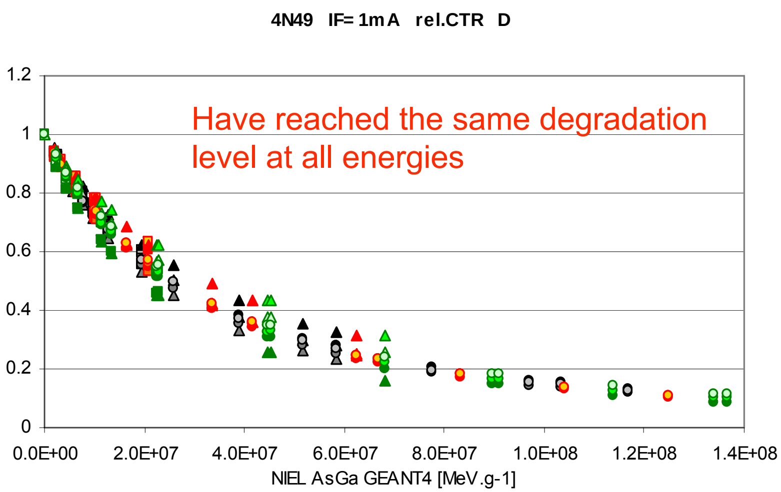
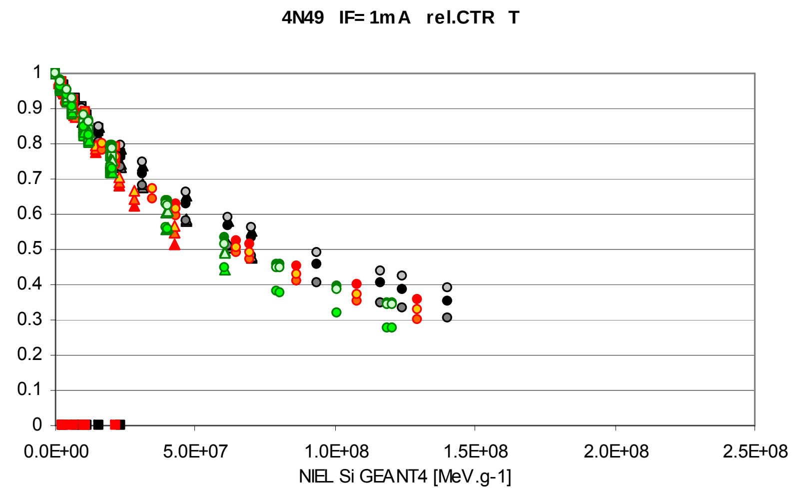
Experimental results vs. (Elastic+Inelastic) NIEL

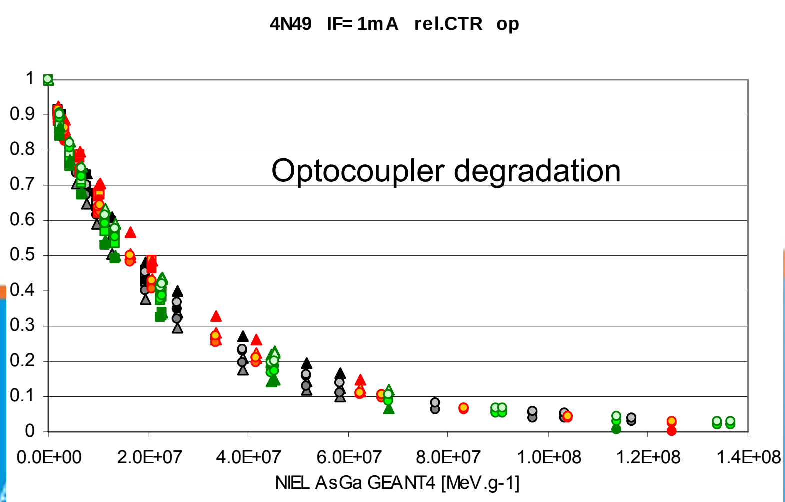
- CTR versus NIEL (GEANT4): 4N49

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode



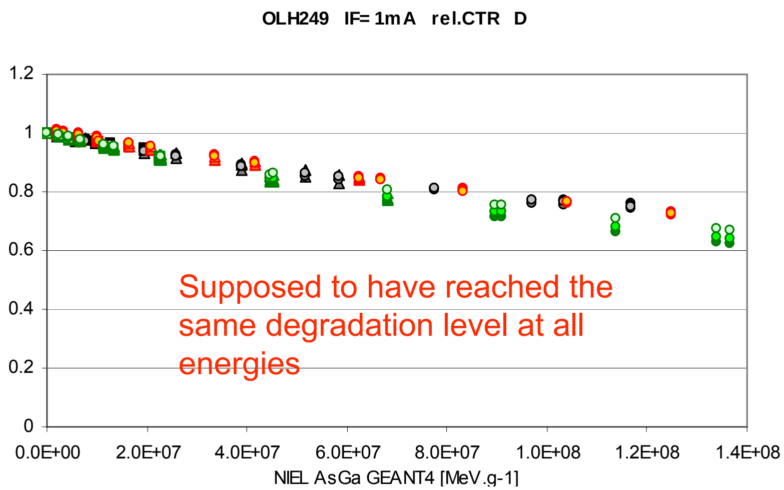


- The diode is the main contributor to the overall degradation
- The degradations are comparable at all energies

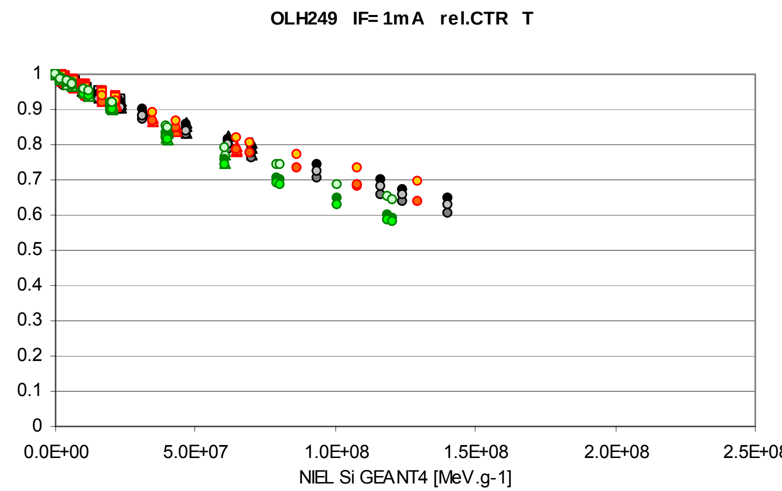
Experimental results vs. (Elastic+Inelastic) NIEL

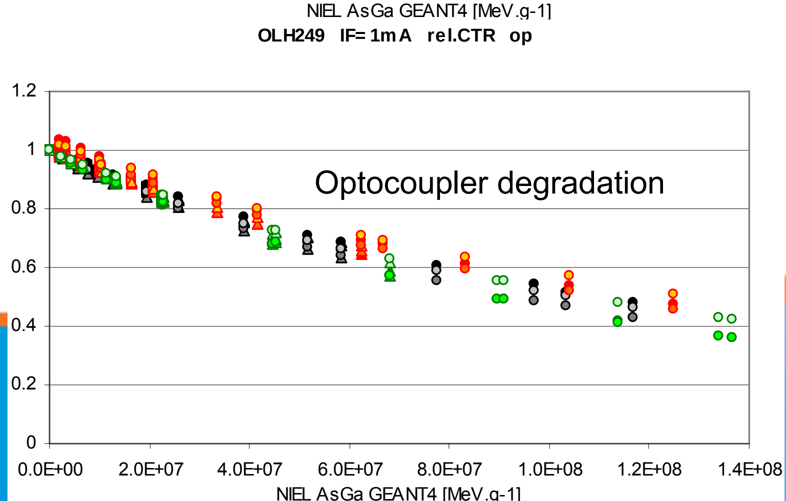
▪ CTR versus NIEL (GEANT4): OLH249

Diode degradation measured with reference transistor



Transistor degradation measured with reference diode



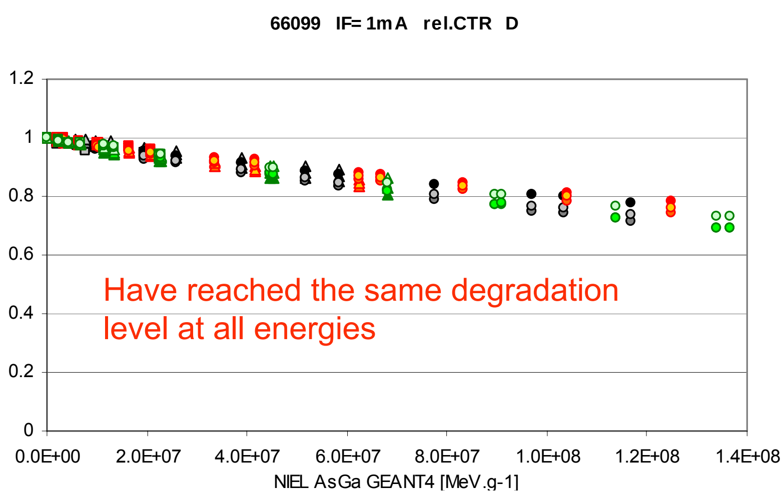


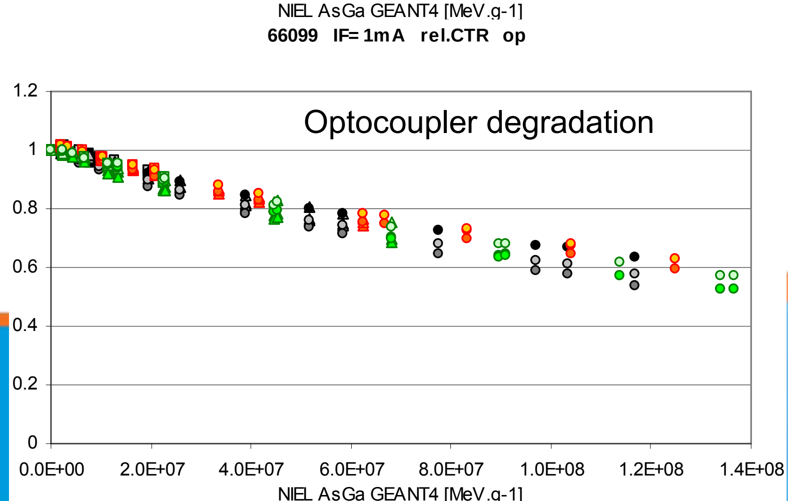
- The transistor is the main contributor to the overall degradation
- The degradations are ~greater at 200 MeV than the other energies

Experimental results vs (Elastic+Inelastic) NIEL

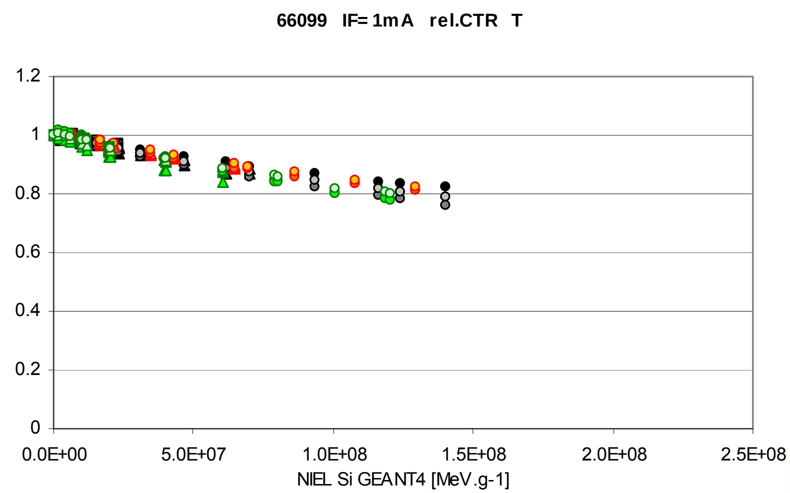
- CTR versus NIEL (GEANT4): 66099

Diode degradation measured with reference transistor





Transistor degradation measured with reference diode



- The diode is the main contributor to the overall degradation
- The degradations are comparable at all energies

All the space you need

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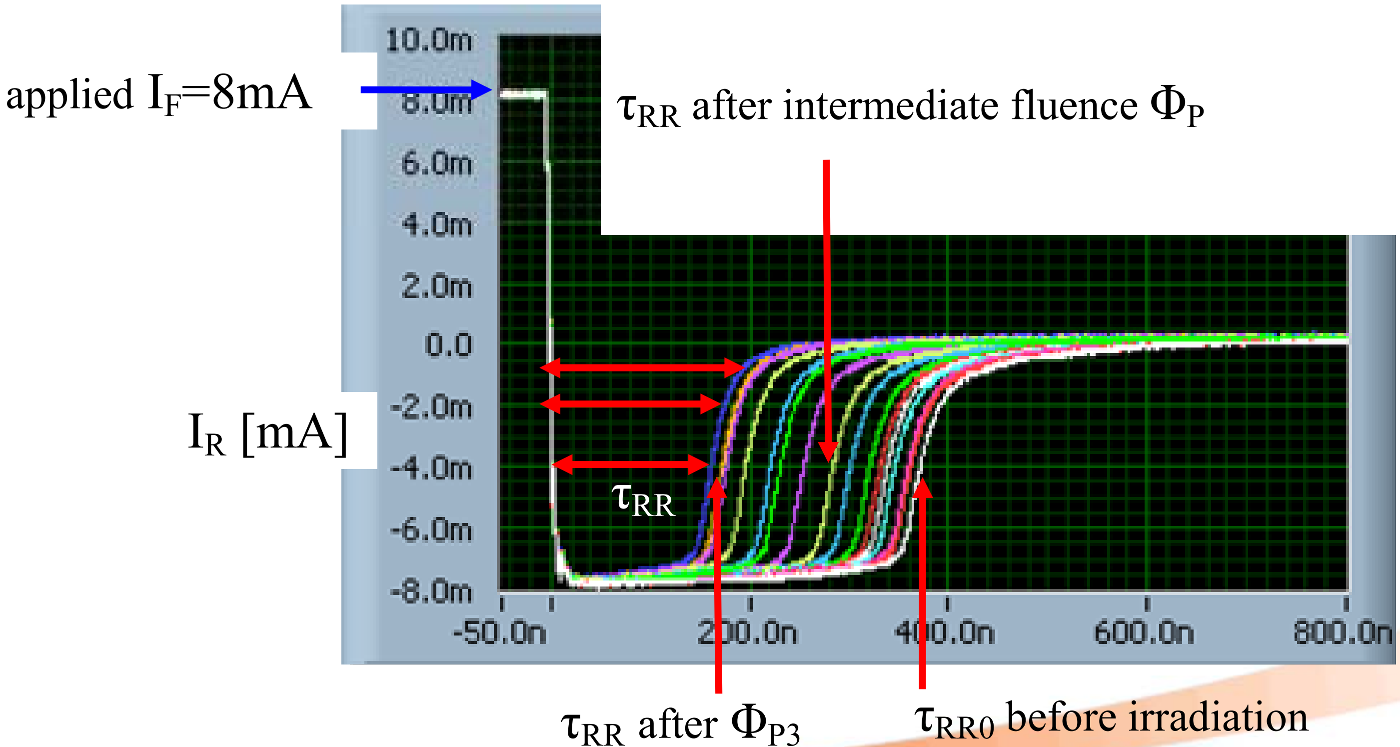
Experimental results Preliminary conclusion

- Relative CTR degradations are :
  - Greater at 200 MeV than at the other energies if the considered NIEL is based on Barry's table (results not shown here) or elastic contribution
  - Comparable within [60MeV-200 MeV] range if the (elastic + inelastic) contributions are considered.

Experimental results

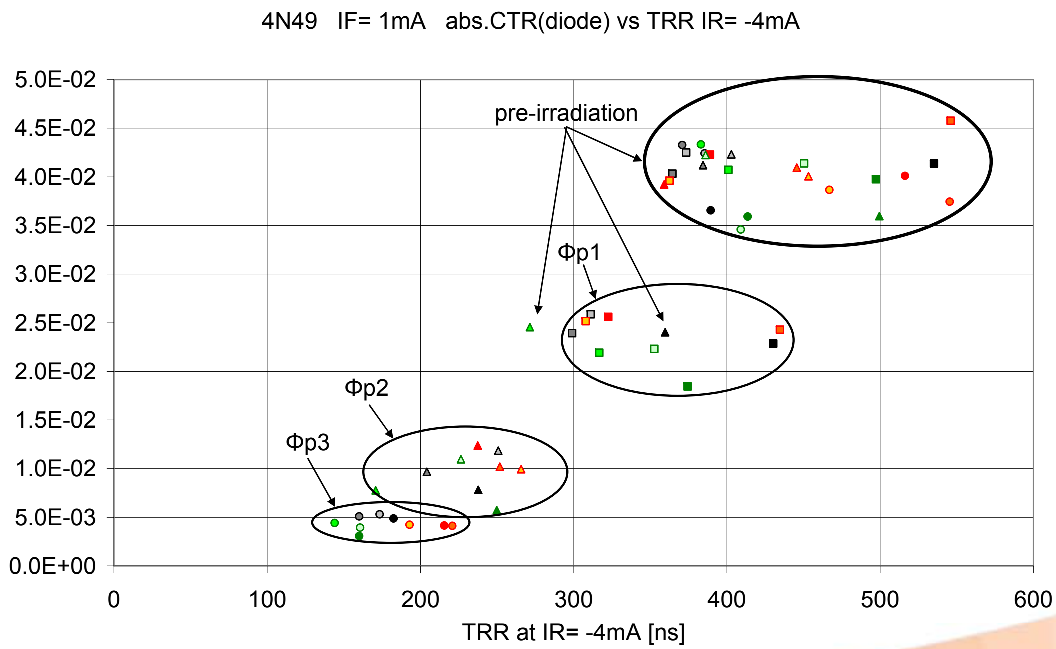
- Effect of NIEL on τ_{RR}:



In the following, τ_{RR} is measured at IR=-4 mA

Experimental results

- Effect of NIEL on τ_{RR} : Correlation between diode's absolute CTR degradation and its τ_{RR} degradation

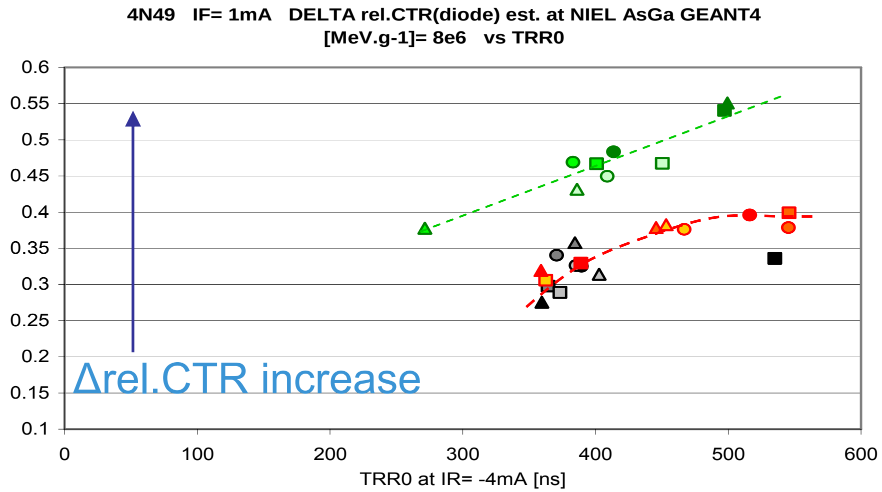


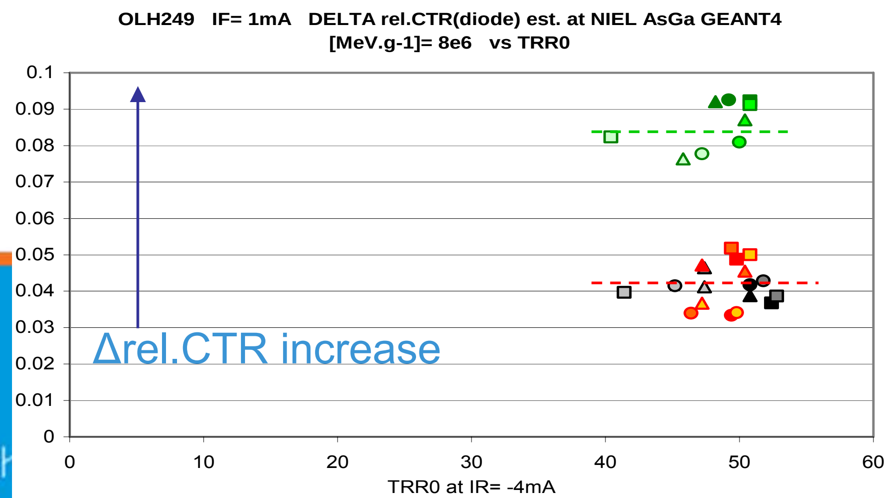
- Considering the pre and post irradiation values, the absolute diode's CTR is not depending on the τ_{RR} .

Experimental results

- Effect of τ_{RR0} on the relative diode's CTR degradation

Let's define Δrel.CTR = $(CTR_0 - CTR)/CTR_0 = (1 - CTR/CTR_0)$ at one NIEL value



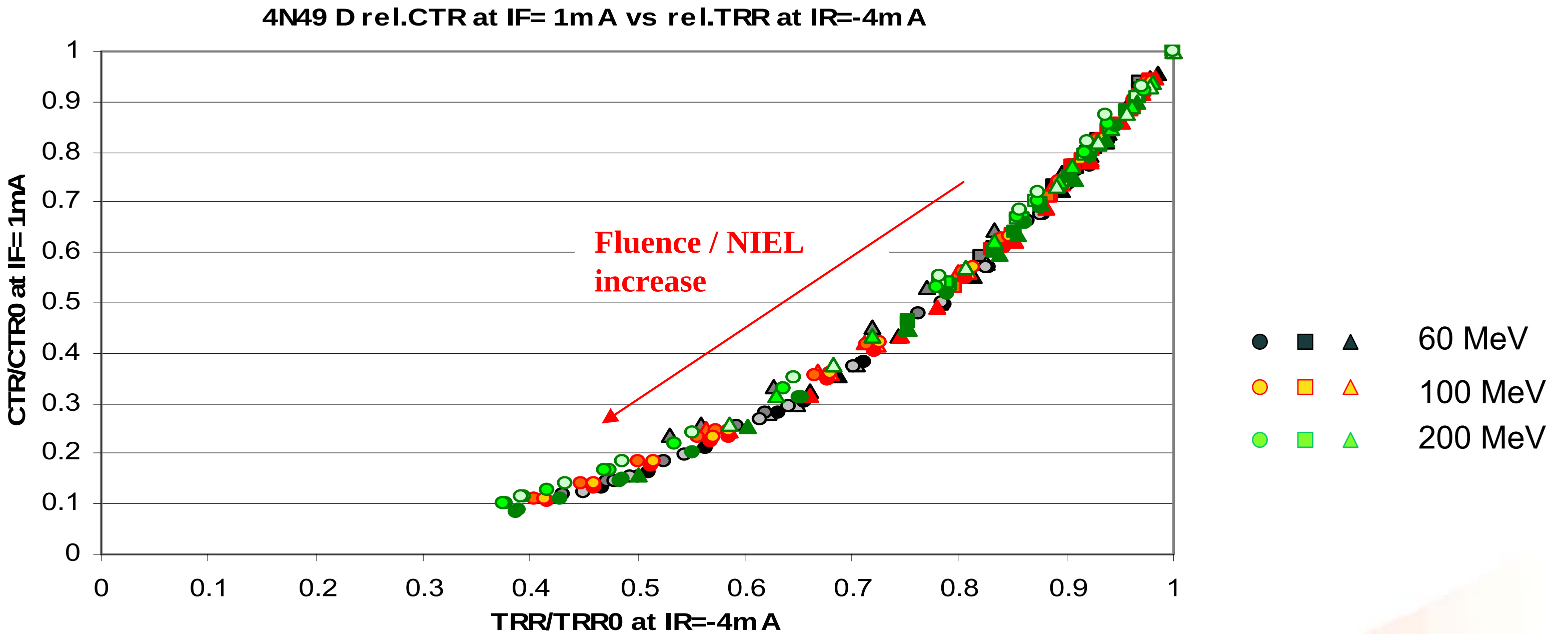


60 MeV
100 MeV
200 MeV

- One salient feature : the lowest the τ_{RR0}, the lowest the degradation.

Experimental results

- Effect of τ_{RR0} on the relative diode's CTR degradation



- This function can be fitted according to $CTR/CTR_0=(\tau_{RR}/\tau_{RR0})^N$, and N integer greater than 1 [2], [3]

[2] A. L. Barry, A. J. Houdayer, P. F. Hinrichsen, W. G., Letourneau and J. Vincent, “The Energy Dependence of Lifetime Damage Constants in GaAs LEDs for 1-500 MeV Protons,” IEEE Trans. Nucl. Sci., 42, 2104 (1995)
[3] A.J. Houdayer et al., GaAs LED based NIEL spectrometer fort he space radiation environment, IEEE Tr. on Nuclear Science, vol.47, no.3, June 2000.

Experimental results

- Effect of τ_{RR0} on the relative diode's CTR degradation

- $CTR/CTR_0 = (\tau_{RR}/\tau_{RR0})^{N}$. [1] Since $\Delta(1/\tau_{RR}) = K_{\phi}.\Phi = K_{NIEL}.\ NIEL$, [2]

=> $\Delta rel.CTR = (1 - CTR/CTR_0)$

$= 1 - (\tau_{RR0}/\tau_{RR})^{-N}$

$= 1 - (1+\tau_{RR0}.\ K_{\phi}.\Phi)^{-N}$ [3]

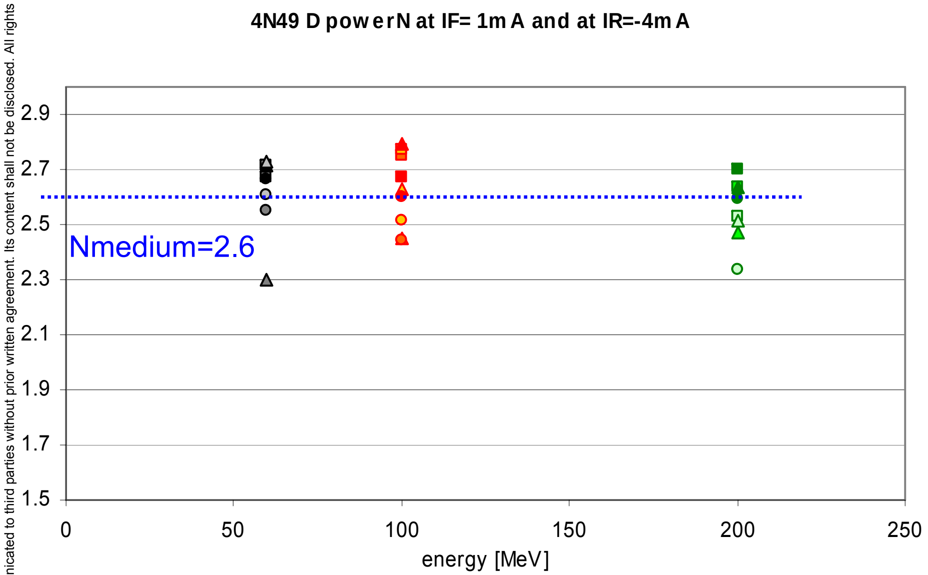
$= 1 - (1+\tau_{RR0}.\ K_{NIEL}.\ NIEL)^{-N}$ [4]

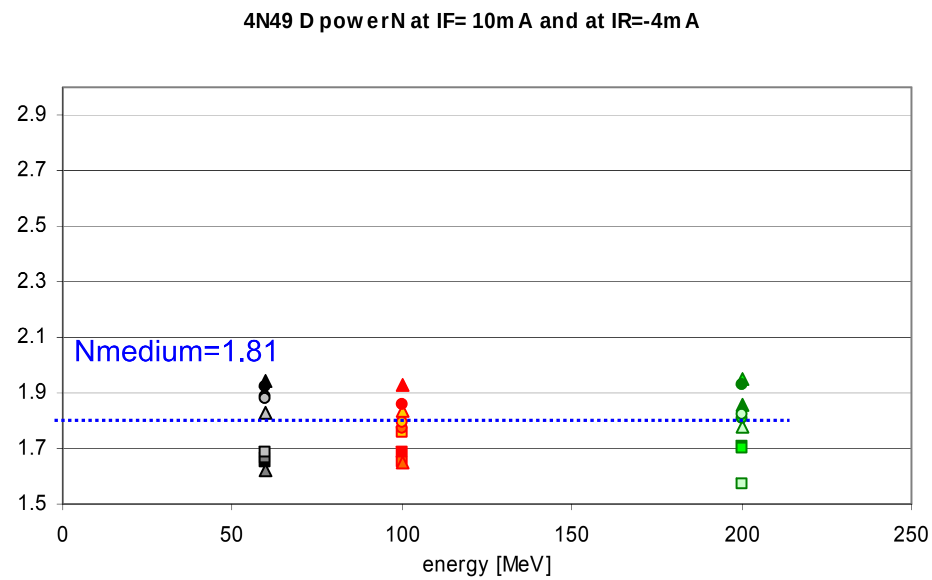
=> According to this expression, one can expect $\Delta rel.CTR$ increase with τ_{RR0} increase.

Calculation can be performed to obtain K_{ϕ} or K_{NIEL} and N.

Experimental results

- calculation of N on 4N49:

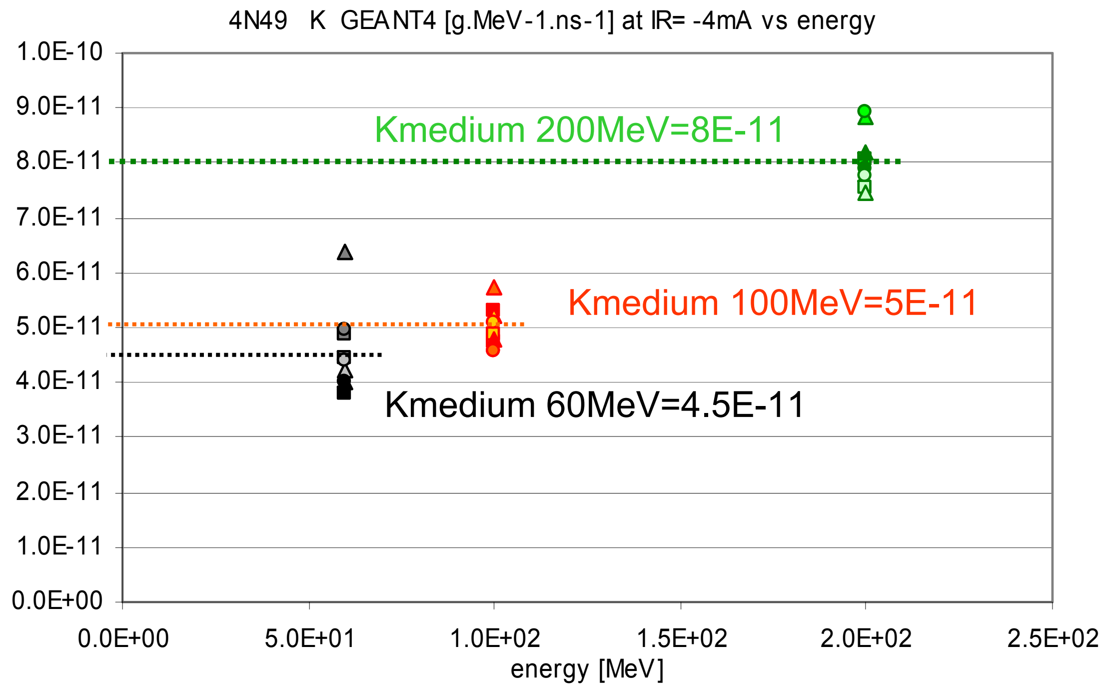




- For a given IF, N does not depend upon the proton energy.

Experimental results

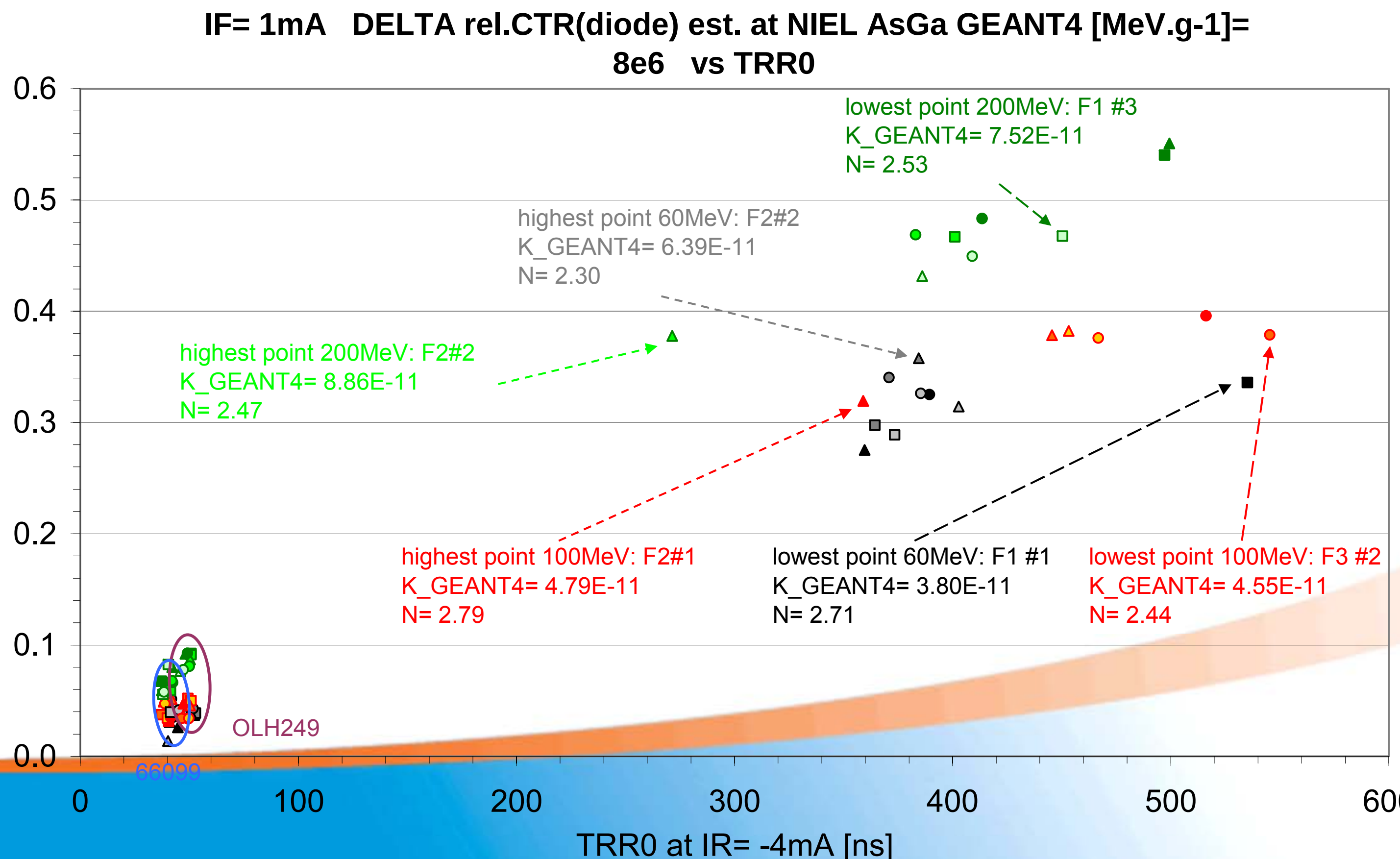
- Calculation of K_{NIEL} (**GEANT 4 Elastic**) on 4N49:



- For a given IF, K_{NIEL} is depending upon the proton energy.
- K_{NIEL} (200 MeV) > K_{NIEL} (60MeV)

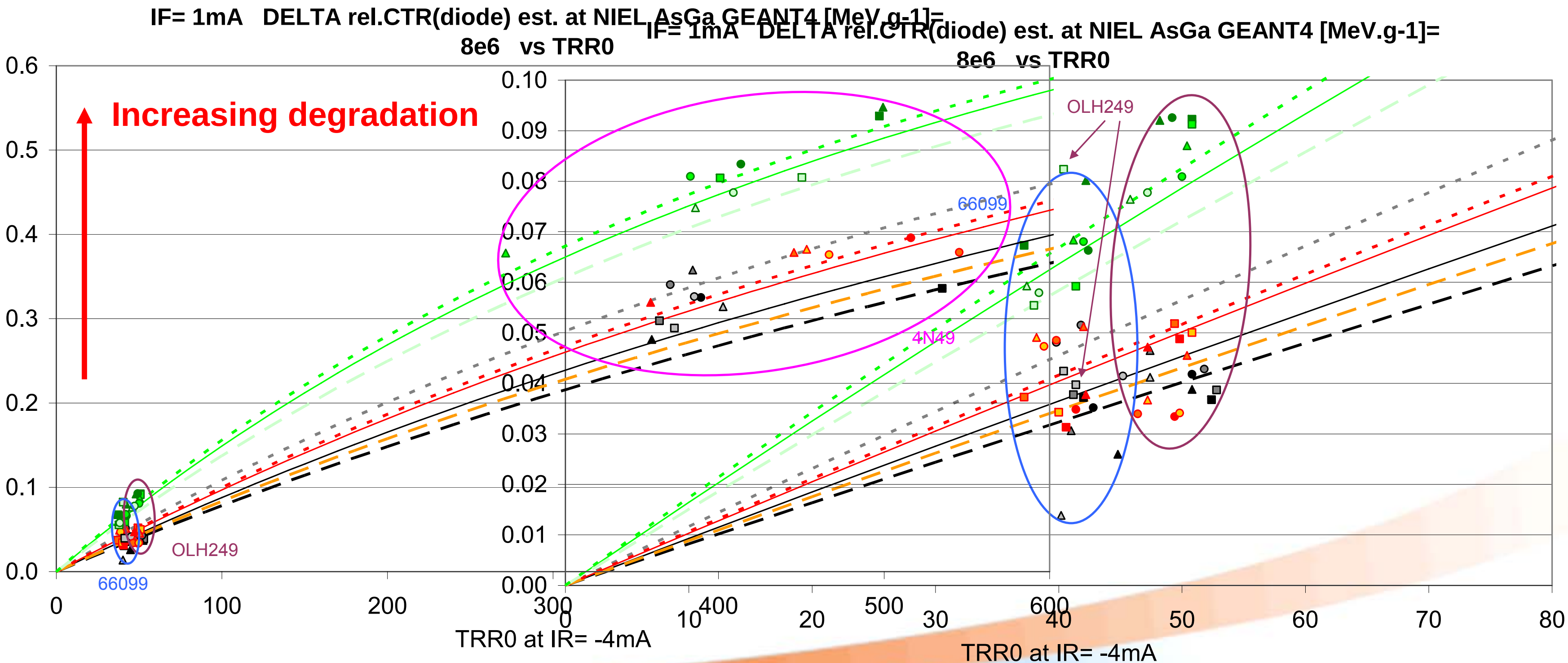
Experimental results

- (1 - CTR/CTR_0) at a NIEL of 8.10^6 MeV.g-1 (GEANT4 ELASTIC) with respect to $\tau_{RR\mathbf{0}}$ (4N49 points)



Experimental results : relative diode degradation

- Δrel.CTR (diode) = (1 - CTR/CTR$_0$) , NIEL = 8.10^6 MeV/g @ If = 1mA



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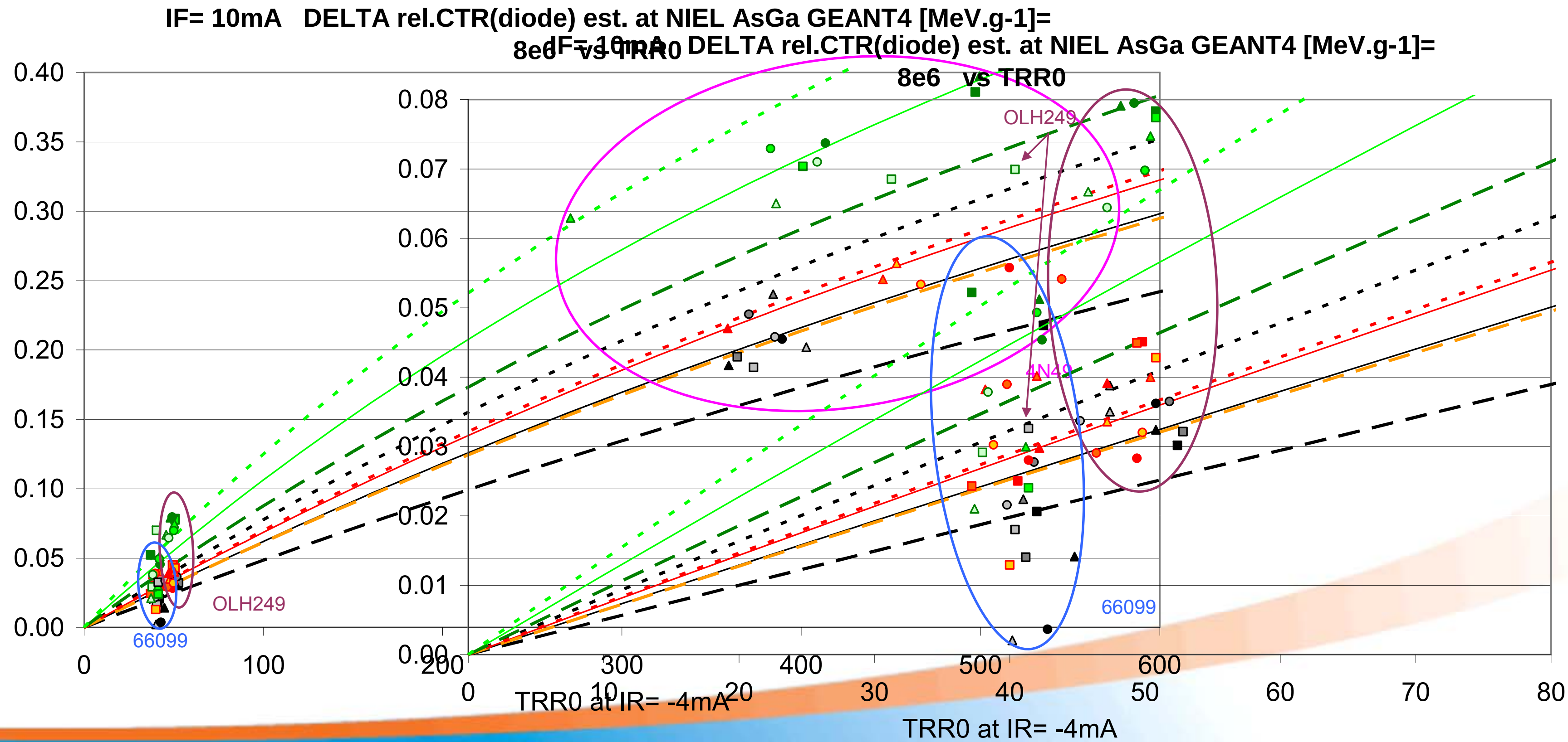
Experimental results : relative diode degradation

- Δrel.CTR (diode) = (1 - CTR/CTR$_0$) , NIEL = 8.10^6 MeV/g @ If = 10 mA



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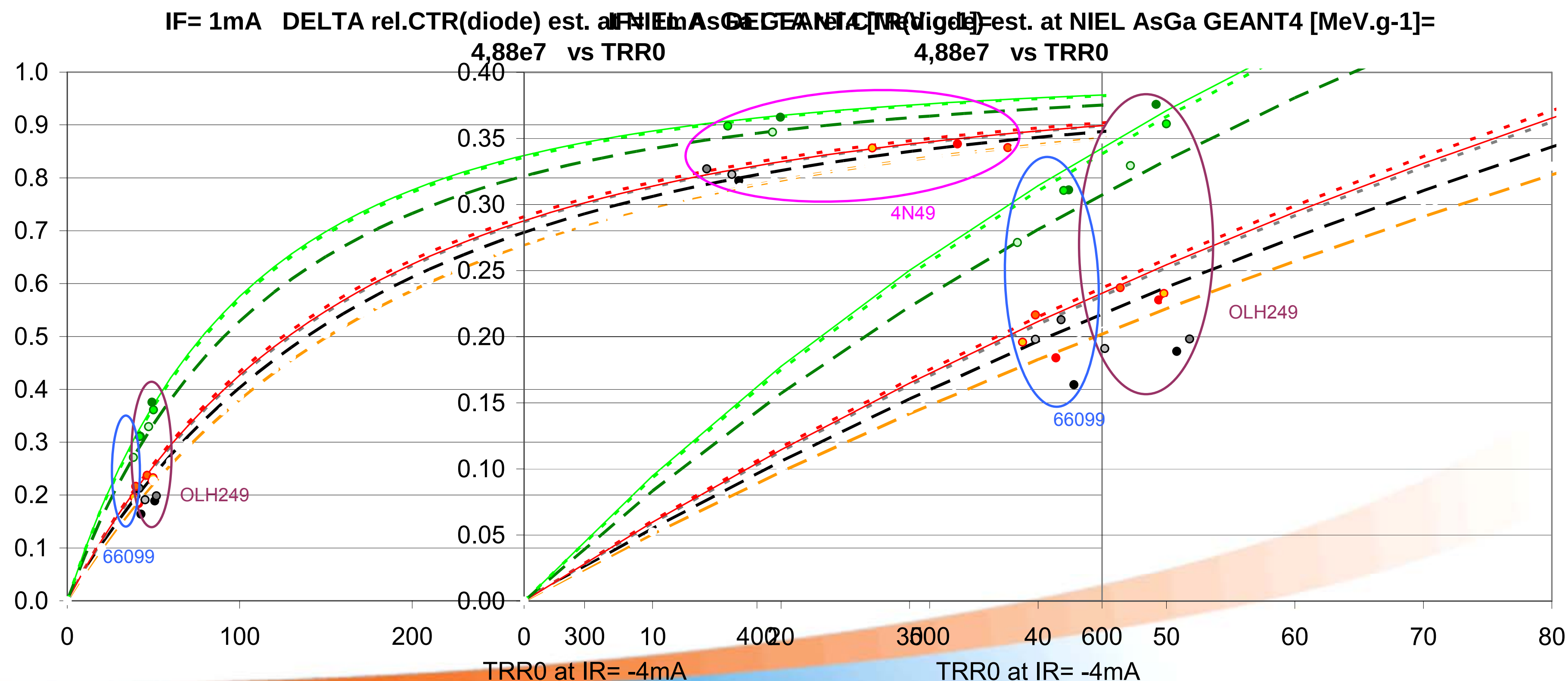
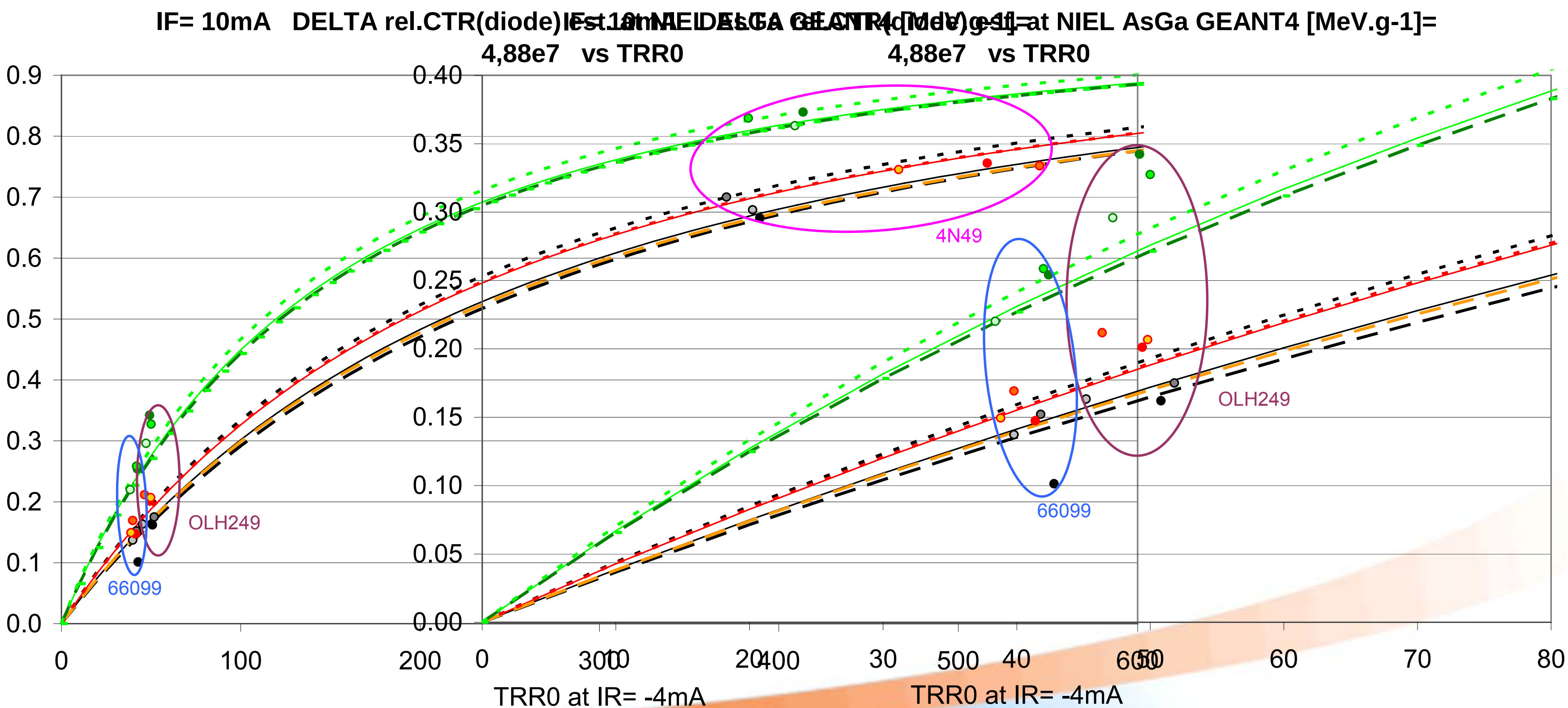
Experimental results : relative diode degradation

- Δrel.CTR (diode) = (1 - CTR/CTR$_0$) , NIEL = 4,9.10^7 MeV/g @ If = 1mA

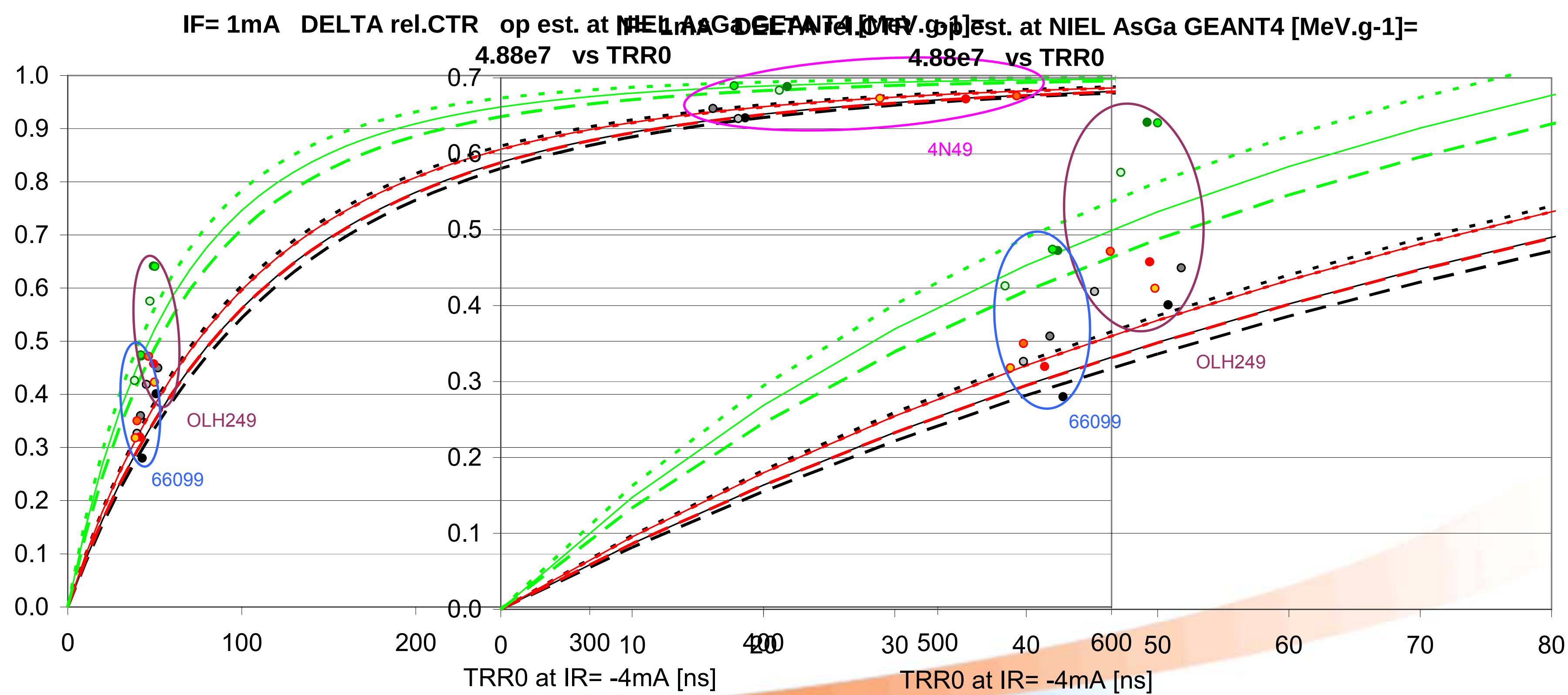


Experimental results : relative diode degradation

- Δrel.CTR (diode) = (1 - CTR/CTR$_0$) , NIEL = 4,9.10^7 MeV/g @ If = 10 mA



Experimental results : relative optocoupler degradation @ If= 1 mA & NIEL= 4,9.10^7 MeV/g



- Discrepancy for OLH249 : remember, the main contribution to degradation is coming from transistor

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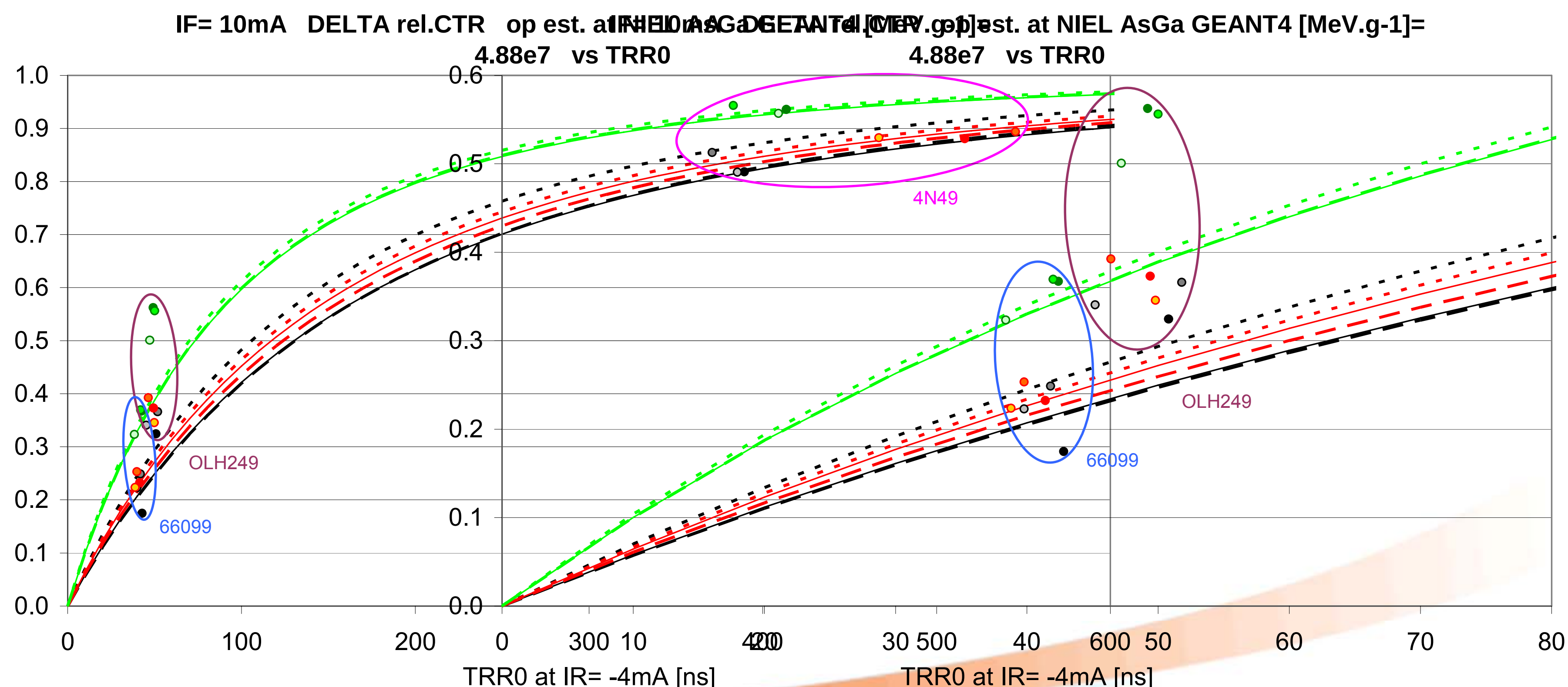
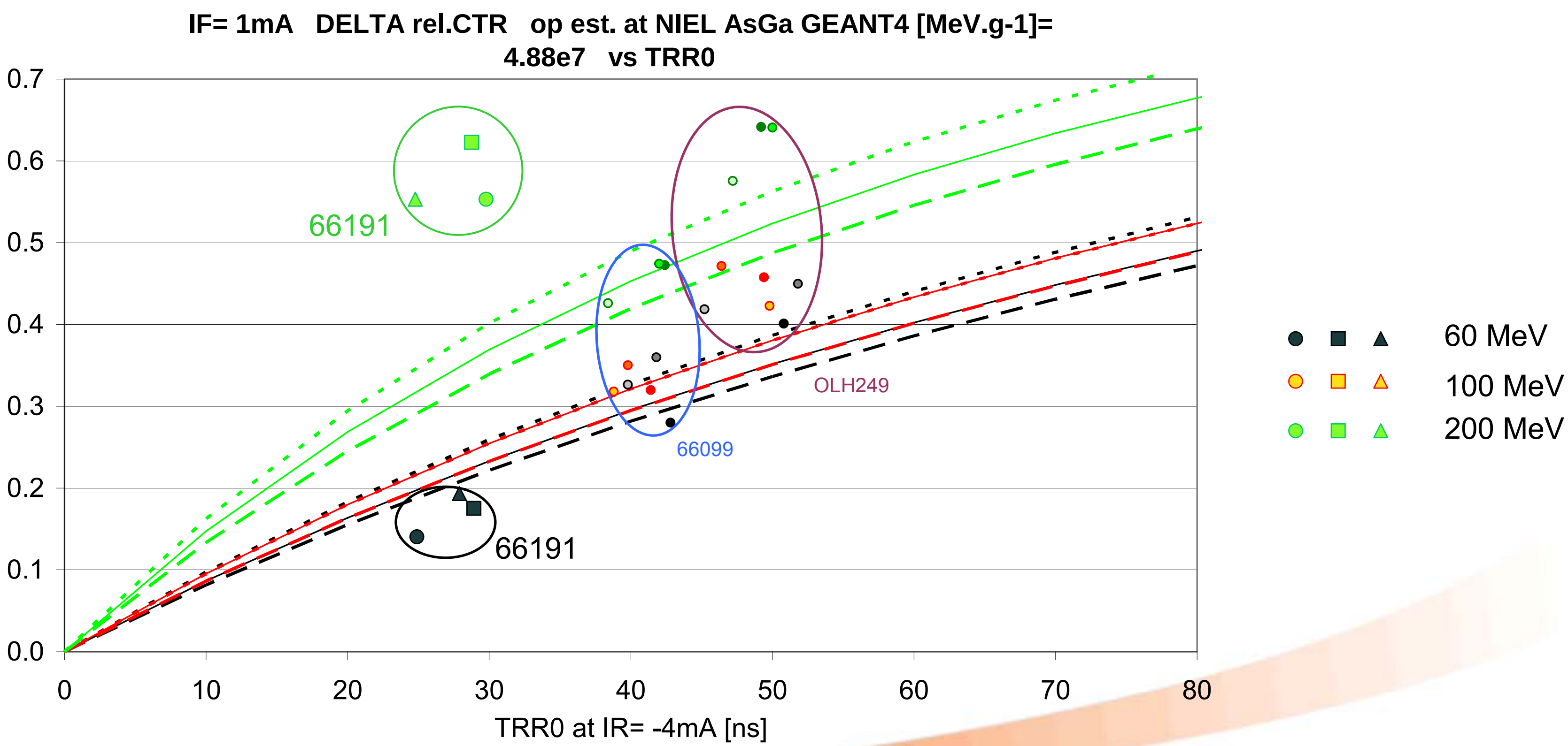
Experimental results : relative optocoupler degradation @ If= 10 mA & NIEL= 4,9.10^{7} MeV/g

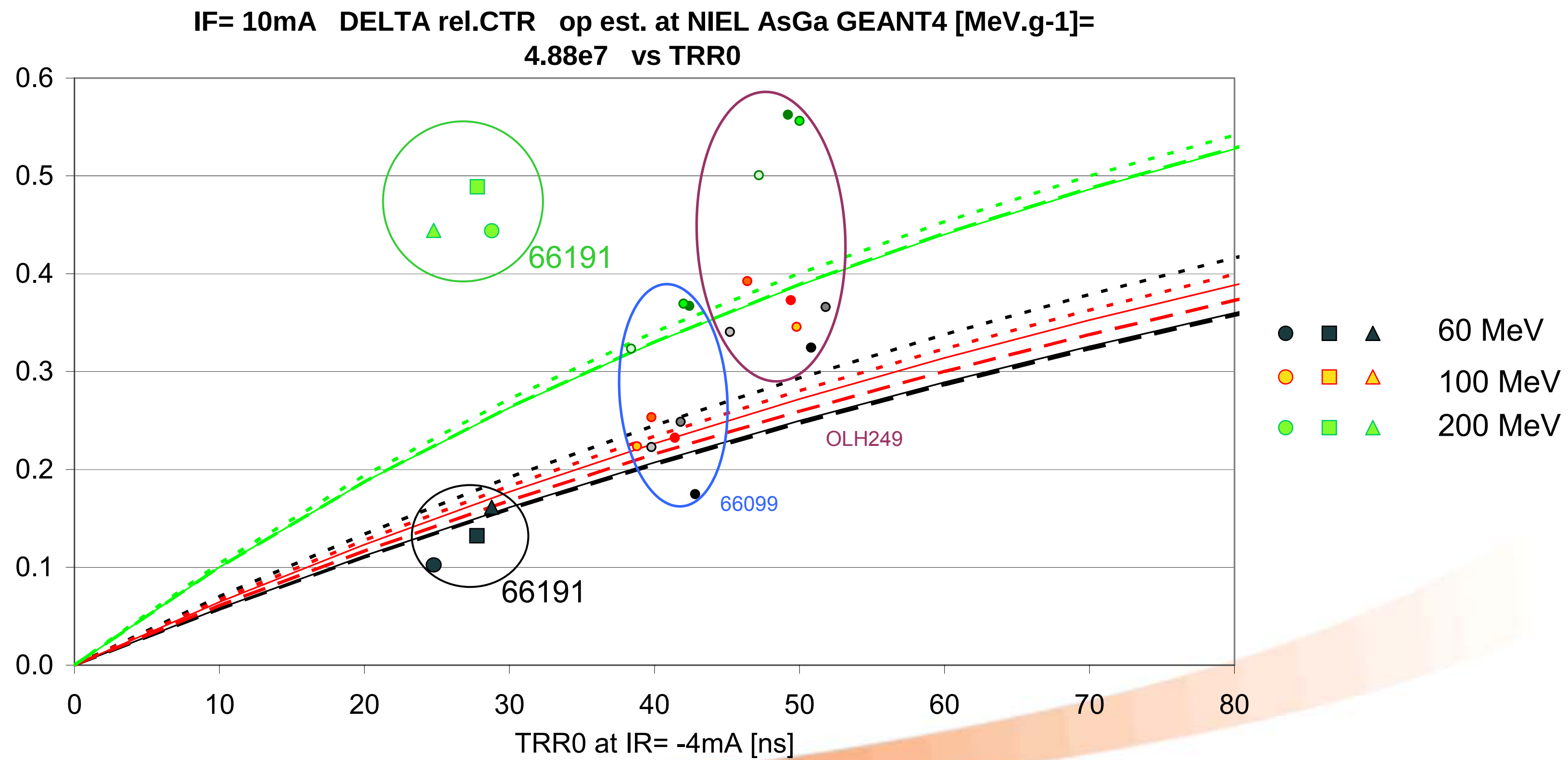


- Discrepancy for OLH249 : remember, the main contribution to degradation is coming from transistor

Experimental results : relative optocoupler degradation @ If= 1 mA & NIEL= 4,9.10^{7} MeV/g



Experimental results : relative optocoupler degradation @ If= 10 mA & NIEL= 4,9.10^{7} MeV/g



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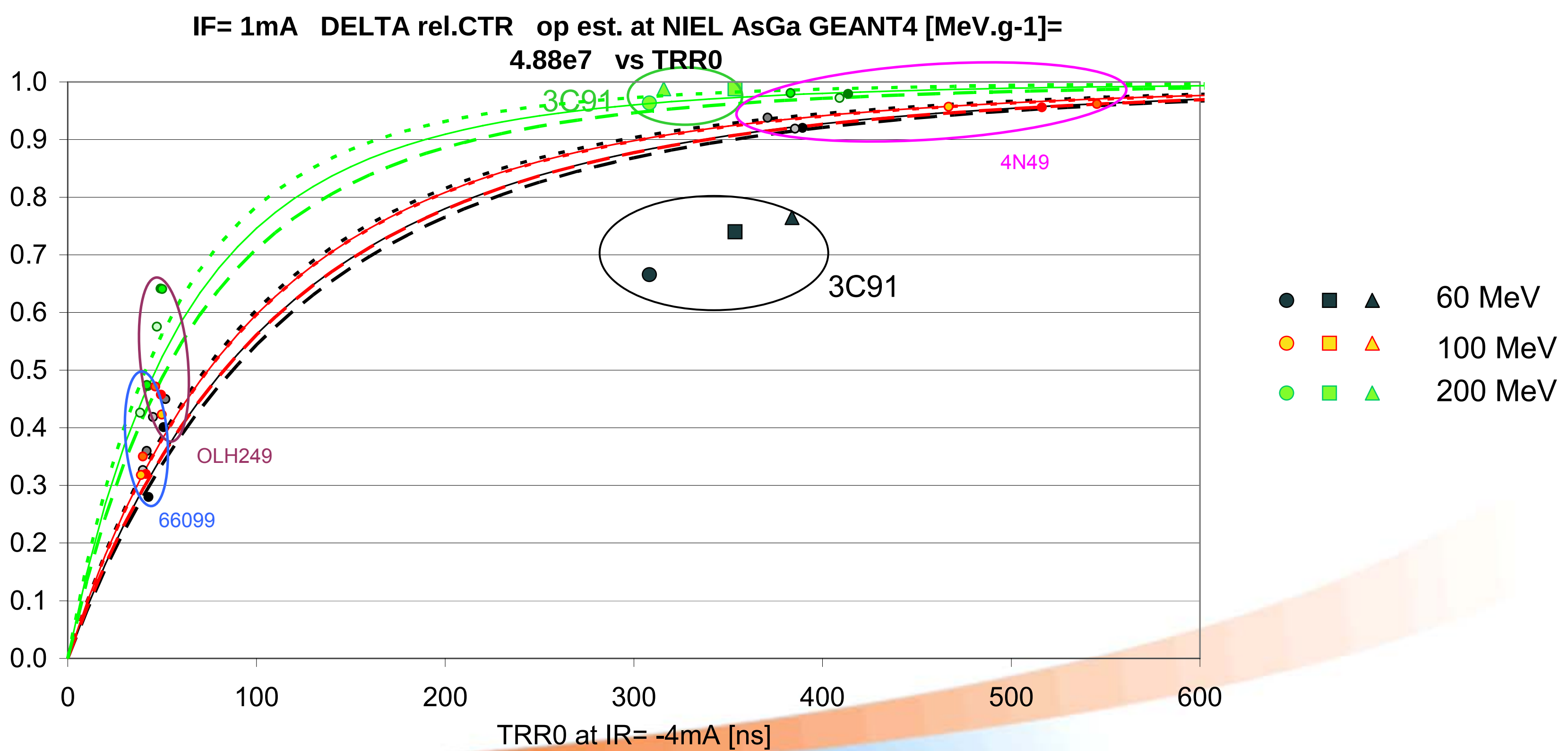
Experimental results : relative optocoupler degradation @ If= 1 mA & NIEL= 4,9.10^{7} MeV/g



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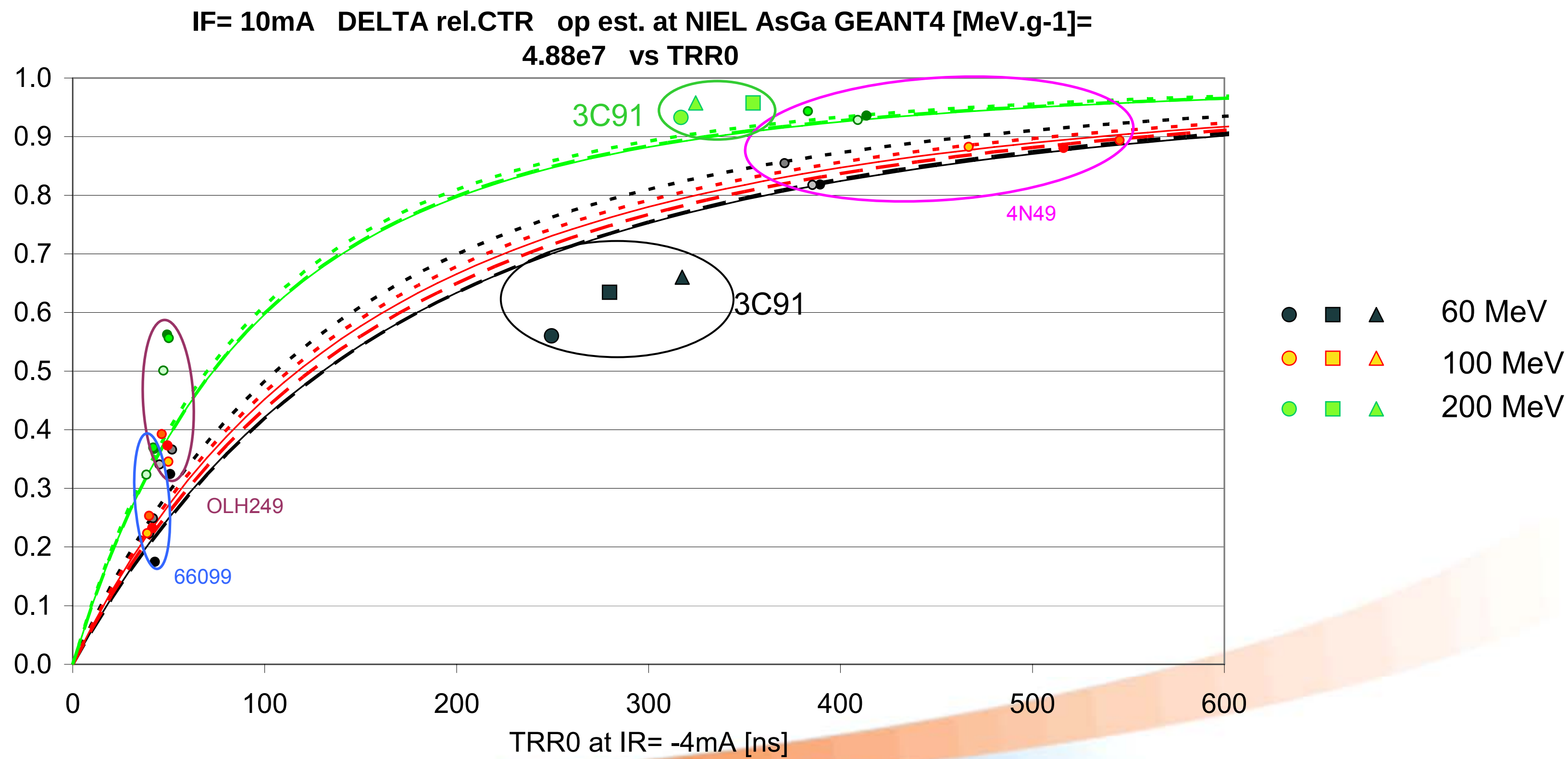
Experimental results : relative optocoupler degradation @ If= 10 mA & NIEL= 4,9.10^7 MeV/g



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Conclusion

- NIEL calculation performed with GEANT4 (elastic) and (elastic + inelastic) on AsGa thickness of 10µm
- Degradation vs. NIEL curves fit **very well** within [60-200 MeV] range under the assumption of total NIEL.
    - Optocoupler testing can be performed with a single energy with confidence in results representativeness
        - To investigate the possibility to extend it to other optoelectronic devices
- If only elastic contribution is considered, then the curve at 200 MeV show some higher degradation as compared with the 60 and 100 MeV. Some contribution coming from material surrounding the active layer is suspected.
- The lower the $\tau_{RR\mathbf{0}}$ the lower the degradation

Conclusion

- Equations [1] to [4] used for 4N49, allowed to predict the degradation of other diodes corresponding to other technologies vs. NIEL, after K_{NIEL}(4N49) and N(4N49) parameters obtained by non-linear regression.
- The diode degradation is only depending on $\tau_{RR\mathbf{0}}$ not on its technology.
- Part selection based on diode $\tau_{RR\mathbf{0}}$ and transistor $\tau_{RR\mathbf{0}}$ measurement seems a relevant criteria for optocoupler assessment regarding TNID : the lower $\tau_{RR\mathbf{0}}$ would lead to the lower degradation for both transistor and diode.

Conclusion

- Work on going:

  - Verify that lower transistor τ_{RR0} would lead to lower optocoupler degradation
  - Verify that equations [1] to [4] applied to TID with K_{TID}(4N49) and N(4N49) regression allow to predict diode / optocouplers TID degradation.

Conclusion

- This study could be performed after:
  - More than 21000 measurements,
  - 15 pizzas great size,
  - 5 kg cakes,
  - 1kg peanuts…
  - 12 L Beers (not for me)
  - 20 L banana juices (for me) also…
  - …