Velo & Velo Upgrade Parallel Session

107th LHCb Week

End of Life Radiation damage estimation for Velo

Evangelos –Leonidas Gkougkousis[1]

[1]University of Zurich

CERN, February 27th, 2023

•Current condition & Scenarios

Replacement w/wo cooling

2022 **Current Status**

Luminosity (Nathan)
- 0.793 fb^{-1} VELO open (31 mm)
- 0.264 fb^{-1} VELO closed (1 mm)

Annealing budget (TIBER Data)
- -20°C for irradiation
- 3h at -10°C (17th and 22nd of November)

2023

Luminosity
- 0 fb^{-1} VELO open (31 mm)

Annealing budget (TIBER Data)
- 21°C since the foil incident (28 days, since 10/2)

Foil Replacement with cooling
(120 days at -20°C)

2023
- 1 fb^{-1} VELO @ 11 mm → -20°C (April to November)
- 120 days (November to April 2024) @ -20°C
- 4 days @ 21°C (maintenance)

2024 – 2025 (per year)
- 5.5 fb^{-1} VELO @ 0 mm → -20°C
- 4 days @ 21°C (maintenance)

2026 – 2028 (per year)
- 0 fb^{-1} VELO @ 0 mm → -20°C
- 4 days @ 21°C (maintenance)

2029 – 2032 (per year)
- 7 fb^{-1} VELO @ 0 mm → -20°C
- 4 days @ 21°C (maintenance)

Foil Replacement with cooling, high 2023 luminosity
(120 days at -20°C)

Same but…..
- 4 fb^{-1} VELO @ 11 mm → -20°C (April to November)

Foil Replacement without cooling
(120 days at 21°C)

Same but…..
- 120 days (November to April 2024) @ 21°C

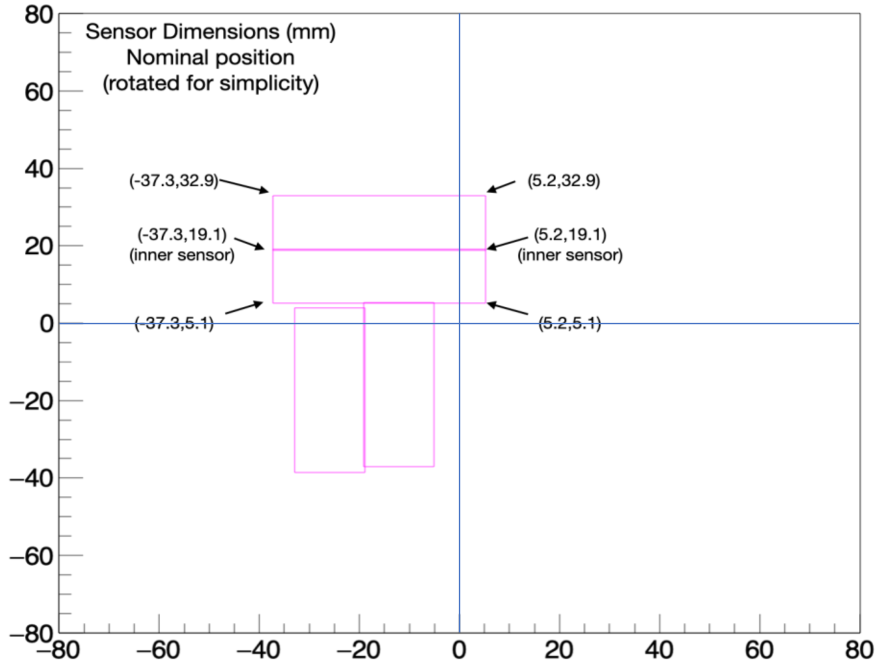
Foil Replacement without cooling, high 2023 luminosity
(120 days at 21°C)

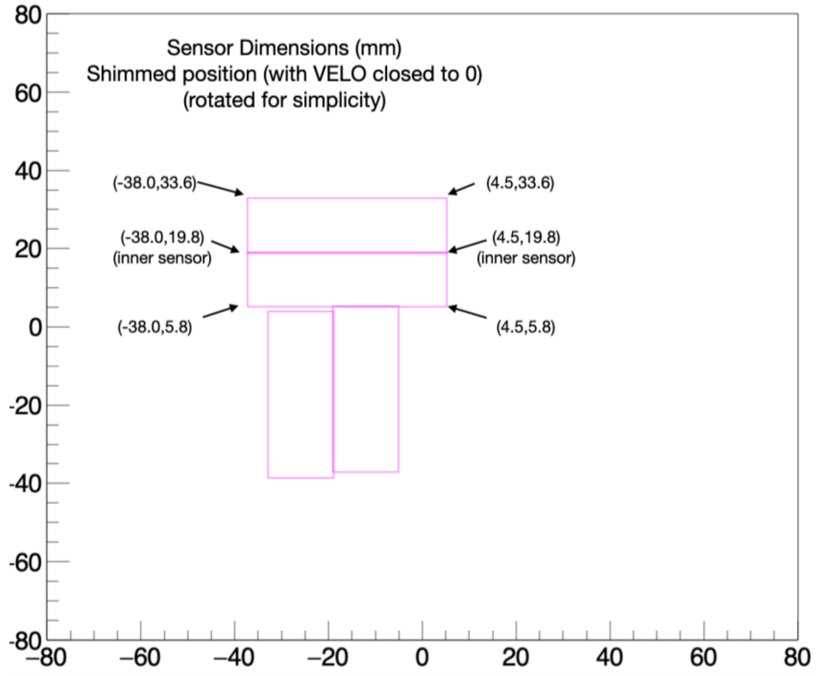
Same but…..
- 4 fb^{-1} VELO @ 11 mm → -20°C (April to November)
- 120 days (November to April 2024) @ 21°C

Baseline Scenario: **No incident, Shims for 2023, 4fb^{-1} @ 2023, same afterwards**

•Velo Coordinate System

Module positions and radial distances





- Rotated cartesian coordinate system
- Assume only lateral movement with respect to the bam axis
- $\Phi_{mv.}$= 45°
- Distances converted to coordinates for fluence estimation
- Mean per ladder fluence estimation using numerical integration assuming uniform per pixel fluence
- Number of steps equal to number of per module pixels

$$\Phi_{\mathrm{mv.}} = \tan^{-1}\frac{|y_0 - y_n|}{|x_0 - x_n|} \xLeftrightarrow{\Phi_{\mathrm{mv.}}=45^0}$$

$$|y_0 - y_n| = |x_0 - x_n| \xLeftrightarrow{y\uparrow,\ x\downarrow}$$

$$y_n = x_0 + y_0 - x_n$$

$$R = \sqrt{|x_0 - x_n|^2 + |y_0 - y_n|^2} \xLeftrightarrow{y\uparrow,\ x\downarrow}$$

$$R = \sqrt{(x_0 - x_n)^2 + (y_n - y_0)^2} \xLeftrightarrow{y_n = x_0 + y_0 - x_n}$$

$$R = \sqrt{2}(x_0 - x_n) \Leftrightarrow$$

$$x_n = x_0 - \frac{R}{\sqrt{2}}$$

•Fluence Estimation

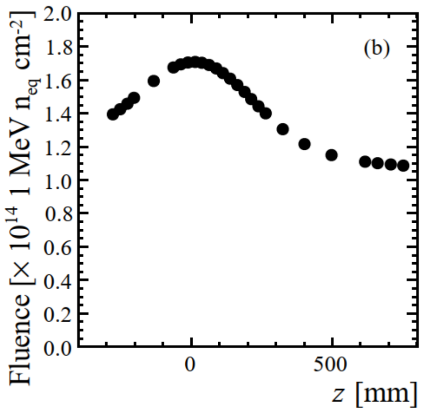
Velo Upgrade 1 TDR: CERN-LHCC-2013-021 ; LHCB-TDR-013 (page 10)

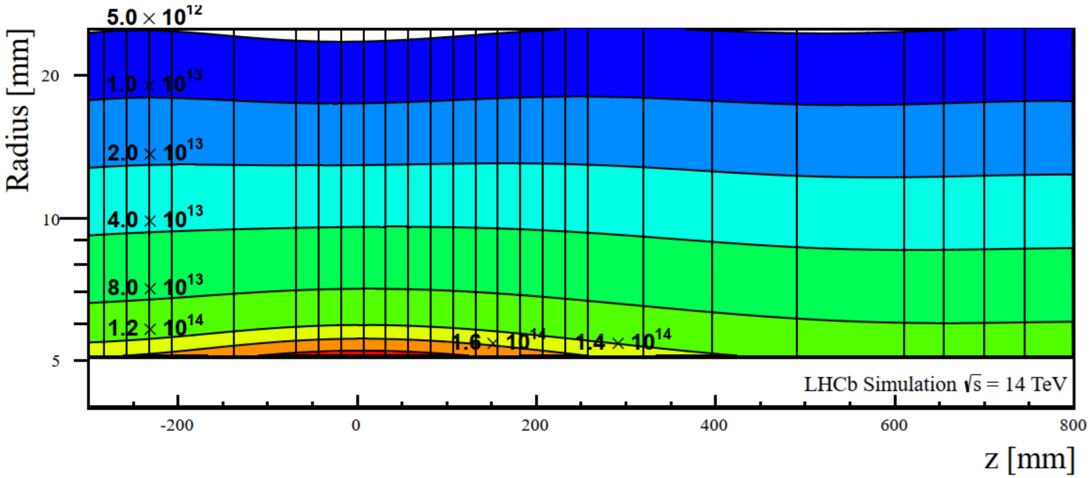
7^{th} order polynomial fit

$$\Phi(\mathrm{R},\mathrm{z}) = \underbrace{(a_0 + a_1 \times z + a_2 \times z^2 + a_3 \times z^3 + a_4 \times z^4 + a_5 \times z^5 + a_6 \times z^6)}_{A(z)} \times L \times R^{-\overbrace{(k_0+k_1 \times z+k_2 \times z^2+k_3 \times z^3 + k_4 \times z^4 + k_5 \times z^5 + k_6 \times z^6)}^{k(z)}}$$

- Exponential dependence with radius from beam axis on a dedicated z position ($A \times R^{-k}$
- 7^{th} order approximation through polynomial fit from Fluka simulations
- R in centimeters, luminosity in fb^{-1}
- Fit factors estimated for fluence units of $10^{13}\ n_{eq}/cm^2$

Alpha Factors		Kappa Factors	
α_0	3.63	k_0	2.3
α_1	2.72×10^{-4}	K_1	-1.22×10^{-4}
α_2	-3.30×10^{-6}	K_2	-5.11×10^{-6}
α_3	-3.43×10^{-9}	K_3	6.22×10^{-9}
α_4	6.36×10^{-12}	K_4	2.79×10^{-11}
α_5	1.94×10^{-15}	K_5	-6.87×10^{-14}
α_6	1.63×10^{-18}	k_6	4.18×10^{-17}





Single Pixel

$$\begin{cases} \Phi(z)_{pixel} = A(z) \times L \times \left(\sqrt{x^2_{<pix.>} + y^2_{<pix.>}}\right)^{-k(z)} \\ x_{<pix.>}, y_{<pix.>} = x_i, y_i + \sqrt{N_{pixels} / S_{ladder}} \\ \delta\Phi(z)_{pixel} = \sqrt{\frac{1}{2} \times \left(\left|\Phi(z)_{pixel} - \Phi(z)_i\right|^2 + \left|\Phi(z)_{pixel} - \Phi(z)_{i+1}\right|^2\right)} \end{cases}$$

•Fluence Estimation

2D Trapezoidal model for Ladders

D. Kaffer, Numerical Techniques for the Evaluation of Multi-Dimensional Integral Equations

$$\langle\Phi(z)\rangle = \frac{1}{S_{ladder}} \times \underbrace{\iint_{ladder} A(z) \times L \times \sqrt{x^2 + y^2}^{\,-k(z)}\, \partial x \partial y}$$

$$\boxed{\frac{h_x h_y}{4} \times \left(\Phi(x_0, y_0) + \Phi(x_f, y_0) + \Phi(x_f, y_f) + 4 \times \sum_{i=2}^{n_y} \sum_{j=2}^{n_x} \Phi(x_j, y_i) + 2 \times \sum_{i=2}^{n_y} [\Phi(x_0, y_i) + \Phi(x_f, y_i)] + 2 \times \sum_{j=2}^{n_x} [\Phi(x_j, y_0) + \Phi(x_j, y_f)] \right)}$$

2D trapezoidal integration rule (uniform pixel fluence approximation)

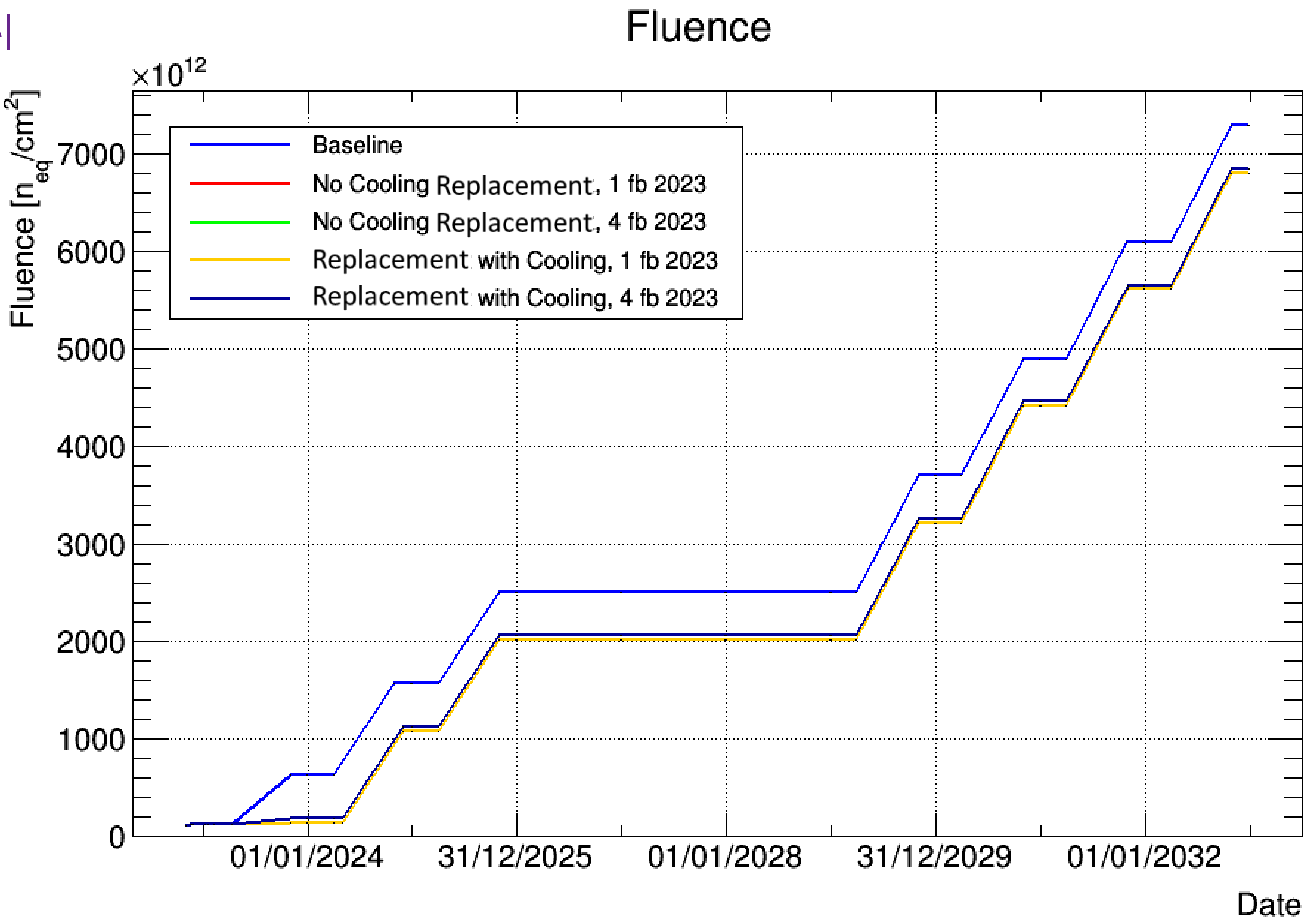
(x_0, y_0)	Coordinates of closer pixel to beam
(x_f, y_f)	Coordinates of furthest pixel from beam
(x_0, y_f)	Verticality furthers pixel from beam
(x_f, y_0)	Horizontally furthest pixel from beam
n_y	Number of pixel rows
n_x	Number of pixel columns
h_x	Pixel width
h_y	Pixel height

Fluence uncertainty approximation

$$\delta\langle\Phi(z)\rangle\ \frac{1}{N_{pix.}} \times \sqrt{\underbrace{\sum \left(\delta\Phi(z)_{pixel}\right)_i^2}_{\text{Single Pixel fluence uncertainty}}}$$

•Fluence Estimation

Hottest Pixel



•Leakage Current modeling

Hamburg Model

$$I_n(T_{\mathrm{ref}}) \equiv I_n^{\exp} + I_n^{\log} = \sum_{i=1}^{n} \delta\Phi_i^{\mathrm{eq}} \cdot \alpha_{\mathrm{I}} \cdot \exp\left(-\frac{t_{n,i}^{\mathrm{I}}}{\tau_{\mathrm{I}}(T_{\mathrm{ref}})}\right) + \sum_{i=1}^{n} \delta\Phi_i^{\mathrm{eq}}(\alpha_0^* - \beta\ \ln(t_{n,i}^{\log}/t_0)) \qquad (A.1)$$

$$t_{n,i}^{\mathrm{I}} = \sum_{j=i}^{n} \delta t_j \frac{\tau_{\mathrm{I}}(T_{\mathrm{ref}})}{\tau_{\mathrm{I}}(T_j)}, \qquad t_{n,i}^{\log} = \sum_{j=i}^{n} \delta t_j \Theta_{\mathrm{A}}(T_j) \qquad (A.2)$$

$$\frac{1}{\tau_{\mathrm{I}}(T)} = k_{0\mathrm{I}} \cdot \exp(-\frac{E_{\mathrm{I}}}{k_{\mathrm{B}}T}), \qquad \Theta_{\mathrm{A}}(T) = \exp\left(-\frac{E_{\mathrm{I}}^*}{k_{\mathrm{B}}}\left[\frac{1}{T} - \frac{1}{T_{\mathrm{ref}}}\right]\right) \qquad (A.3)$$

$$A = \pi r^2$$

M. Moll, Thesis, Universität Hamburg (1999), O. Krasel, Thesis, Universität Dortmund (2004)

$\alpha_I = (1.23 \pm 0.06) \times 10^{-17}$ A/cm
$k_{0I} = 1.2_{-1.0}^{+5.3} \times 10^{13}$ s^{-1}
$E_I = 1.11 \pm 0.05$ eV
$\alpha_0^* = 7.07 \times 10^{-17}$ A/cm
$\beta = 3.29 \times 10^{-18}$ A/cm
$E_I^* = 1.30 \pm 0.14$ eV
$t_0 = 1$ min
$T_{ref} = 21°$C

Leakage Current scaling
($E_{eff.} = 1.214 \pm 0.014\ eV$)

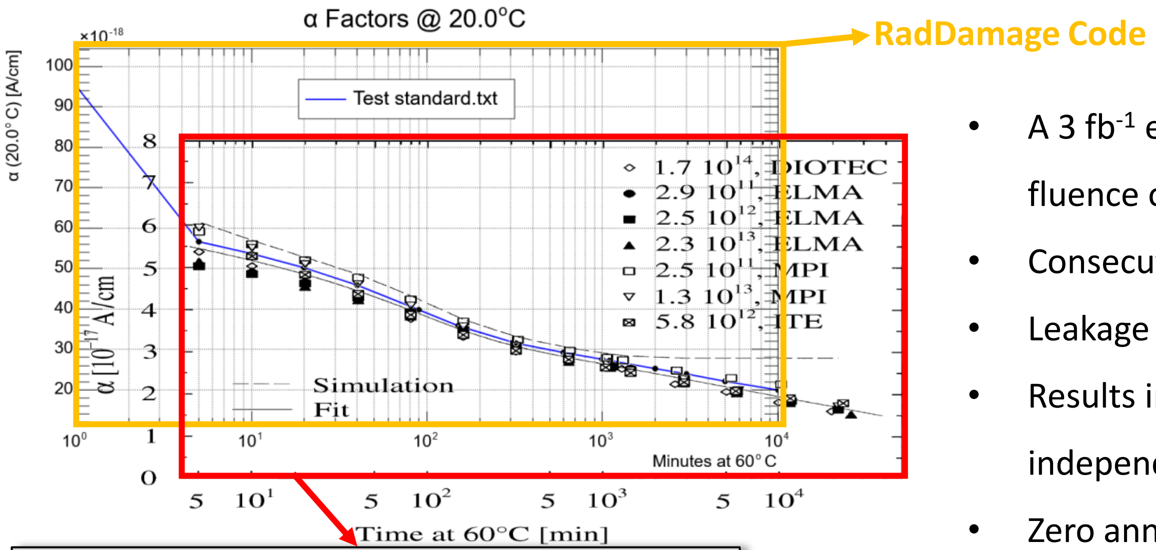
$$\left\{\begin{array}{l} I(T) \propto T^2 e^{-\frac{E_{eff.}}{2k_B T}} \\ I(T_R) \propto T_R^2 e^{-\frac{E_{eff.}}{2k_B T_R}} \end{array}\right. \rightarrow I(T) = I(T_R) \times \left(\frac{T}{T_R}\right)^2 \times e^{-\frac{E_{eff.}}{2k_B}\left(\frac{1}{T} - \frac{1}{T_R}\right)}$$

Depletion Voltage estimation

$$\left\{\begin{array}{l} Depletion\ Voltage:\ V_{FD} = \frac{D^2}{2\varepsilon_{Si}\mu\rho} \\ Bulk\ Resistivity:\ \rho = \frac{1}{e\mu N_{eff}} \end{array}\right. \rightarrow V_{FD} = \frac{e|N_{eff}|D^2}{2\varepsilon_0 \varepsilon_{r,Si}}$$

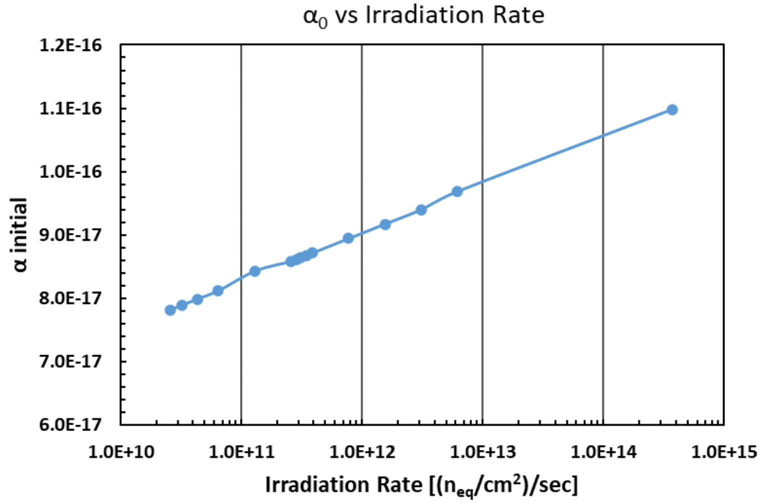
•Leakage Current modeling

Validation Tests I – Standard Annealing Experiment



M. Moll, E. Fretwurst, G. Lindstrom, "Leakage Current of Hadron Irradiated Silicon Sensors – Material Dependence"

- A 3 fb^{-1} exposure in a 60-minute interval at -20°C was simulated, corresponding to an equivalent fluence of 3.74 x 10^{14} n_{eq}/cm^2 for the hottest pixel
- Consecutive annealing steps at 60°C are performed and leakage current is evaluated at 21°C (T_{ref})
- Leakage current scaled to 20°C and corresponding α factors estimated
- Results in perfect agreement with ROSE collaboration measurements (material and fluence independent)
- Zero annealing time predictions are non-defined by the model as the original parametrization assumes adiabatic irradiation only valid at an infinitely low-rate irradiation

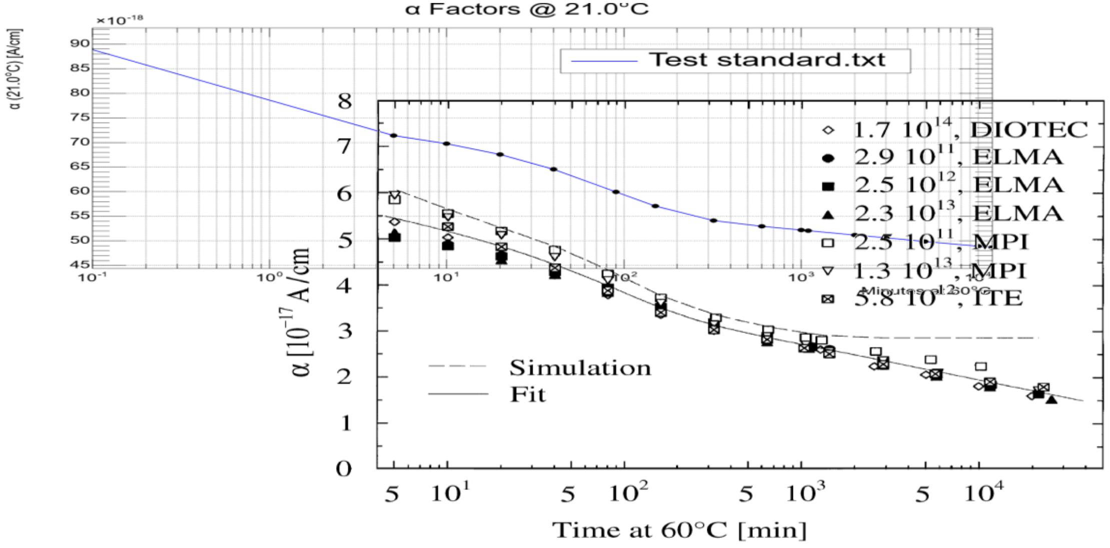


Rate (n_{eq}/cm^2 x min^{-1})	α_0
3.74E+14	1.10E-16
6.23E+12	9.69E-17
3.11E+12	9.40E-17
1.56E+12	9.17E-17
7.79E+11	8.95E-17
3.89E+11	8.72E-17
3.46E+11	8.68E-17
3.11E+11	8.64E-17
2.87E+11	8.62E-17
2.60E+11	8.58E-17
1.30E+11	8.43E-17
6.49E+10	8.13E-17
4.33E+10	7.992E-17
3.24E+10	7.90E-17
2.60E+10	7.82E-17

- Standard fluence of 3.74 x 10^{14} n_{eq}/cm^2 at -20°C was administered in varied time intervals, ranging from 1 to 14400 minutes
- α_0 estimated for each case, with values converging to model predictions at $t_{irad} >> t_{anneal}$
- Behavior justified by the differential nature of annealing estimation performed by the code, both annealing and irradiation are performed simultaneously

•Leakage Current modeling

Validation Tests II – ln vs log base terme



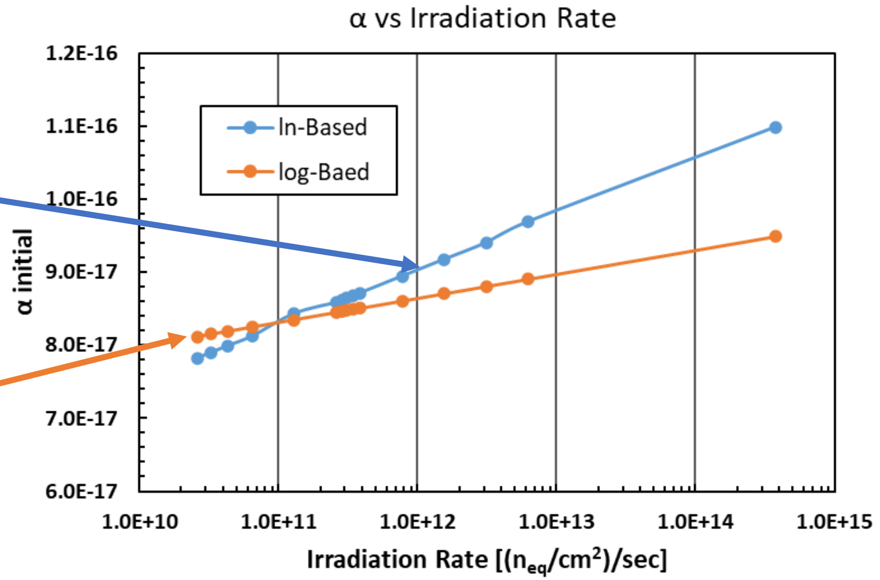
- In several papiers, the logarithmic term of the leakage current model is incorrectly represented with a base-10 logarithm instead of a natural-based logarithm
  e.g.: JINST 14 (2019) P06012 - page 5,
  arXiv:2203.06216v4 [physics.ins-det] 29 Dec 2022 - page 11
- Repeating simulation for the standard experiment and comparing with bibliographic data demonstrates the magnitude of the disagreement
- Same exercise can be repeated for the α_0 estimation, where in this case the irradiation rate dependence becomes less pronounced and can even some times be completely neglected

Correct

$$\frac{I_n}{V} = \sum_{i=1}^{n} \delta\Phi_i^{eq} \times \left[a_0^* + a_I \times e^{-\left(\sum_{j=i}^{n} \frac{\delta t_j}{\tau_I(T_j)}\right)} - \beta \times \ln \sum_{j=i}^{n} \frac{\delta t_j}{60} \times \Theta_A(T_j) \right]$$

Wrong

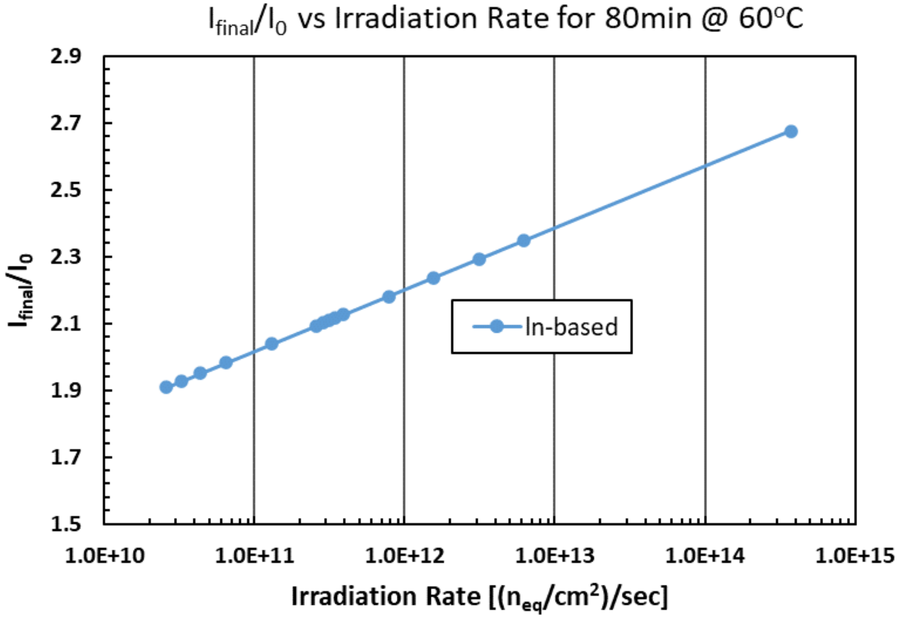
$$\frac{I_n}{V} = \sum_{i=1}^{n} \delta\Phi_i^{eq} \times \left[a_0^* + a_I \times e^{-\left(\sum_{j=i}^{n} \frac{\delta t_j}{\tau_I(T_j)}\right)} - \beta \times \log \sum_{j=i}^{n} \frac{\delta t_j}{60} \times \Theta_A(T_j) \right]$$

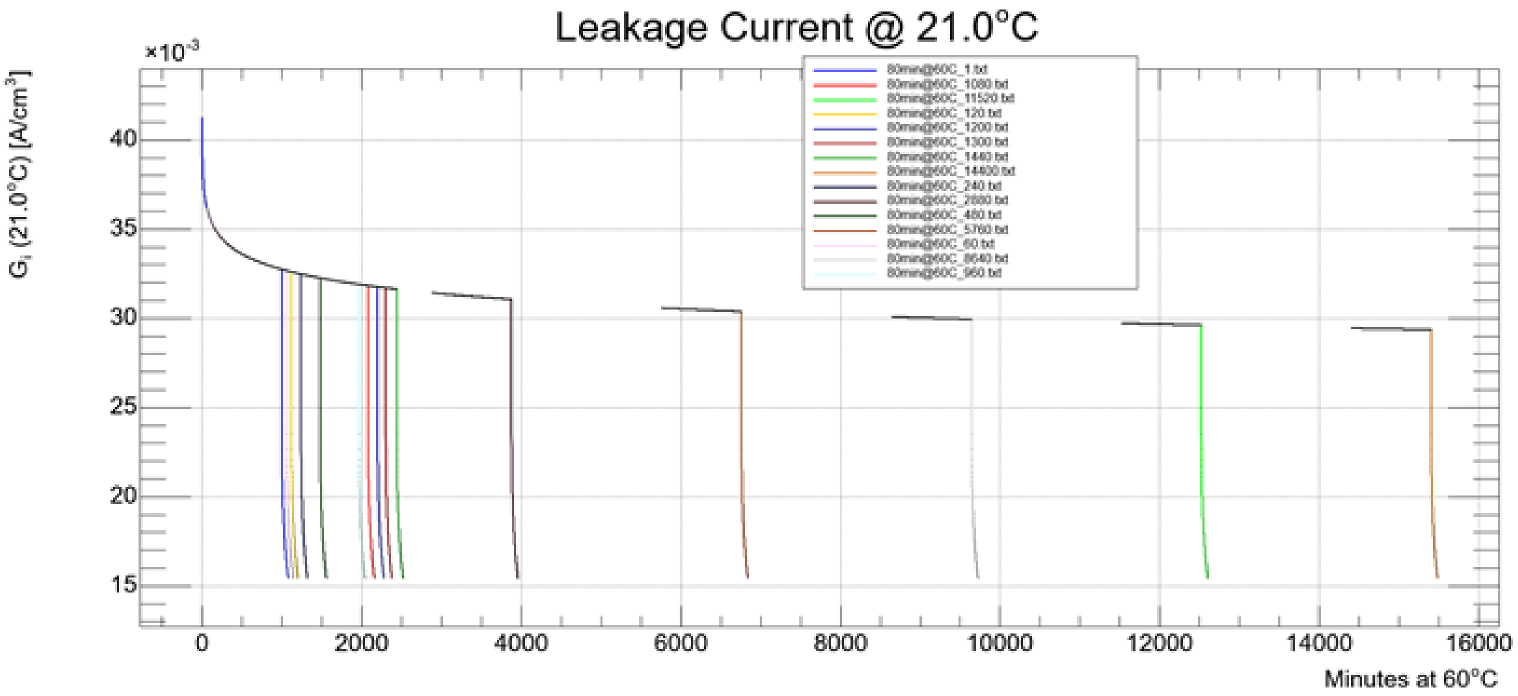


•Leakage Current modeling

Validation Tests III – Long term annealing

- Since initial α is irradiation rate dependent, so will I_{final}/I_0
- In the standard experiment (3.74 x 10^{14} n_{eq}/cm^2 @ -20°C), the I_{final}/I_0 is represented for various irradiation rates after an annealing of 80 min at 60 °C
- Although factors seem to change with respect to the initial time of irradiation, this is of low consequence.

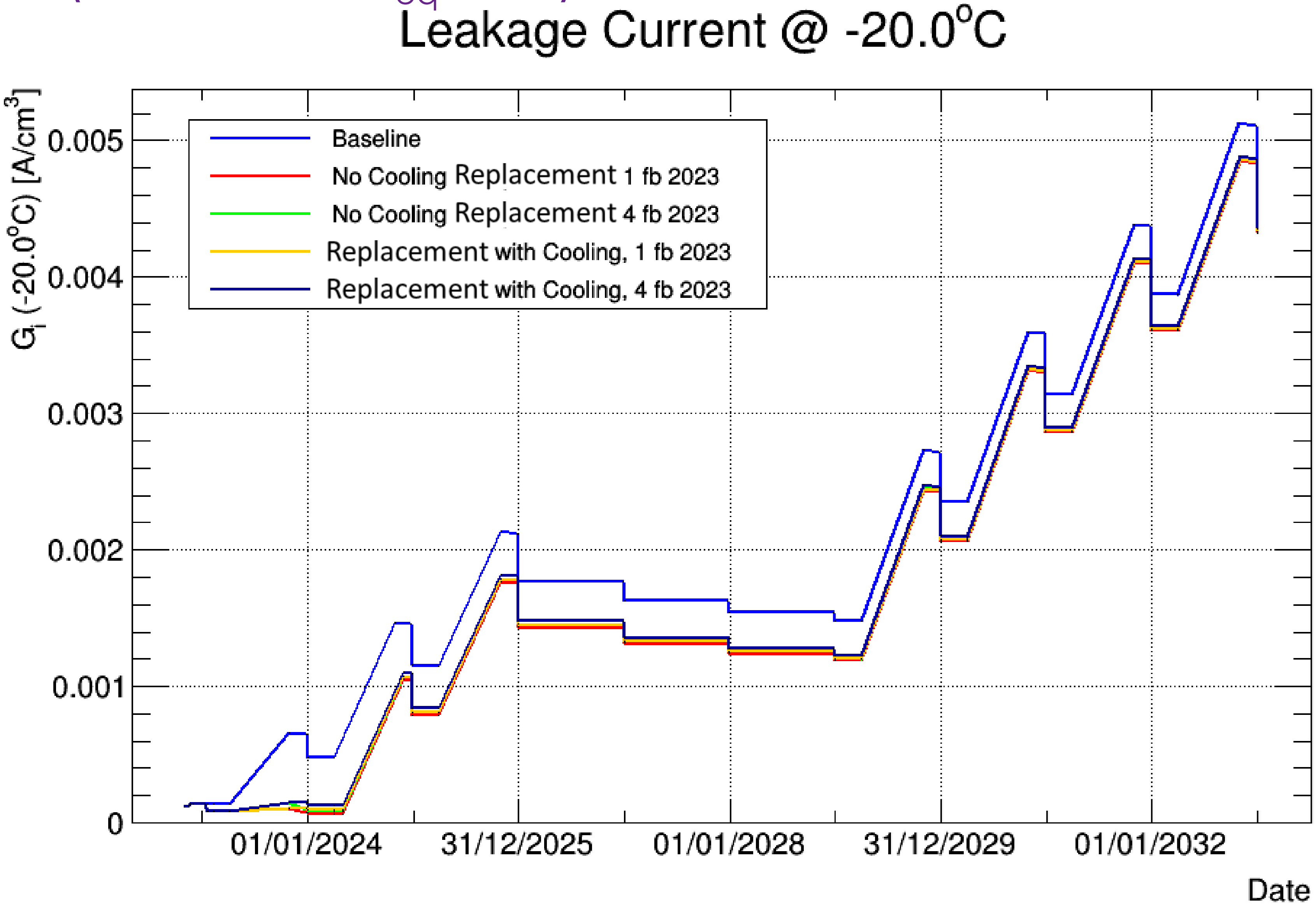




- Final leakage current for all cases is the same, no matter of the irradiation rate
- For all scenarios, independent of the irradiation rate, after 80 min at 60°C we end up at the same value of leakage current. The current just after the irradiation though - the starting point - is not the same and may vary up to 25%.

•Leakage Current modeling

Hottest pixel (~ $7.4 \times 10^{15}\ n_{eq}/cm^2$)



•N_{eff} – Dynamic Model

Differential equations on Effective dopant

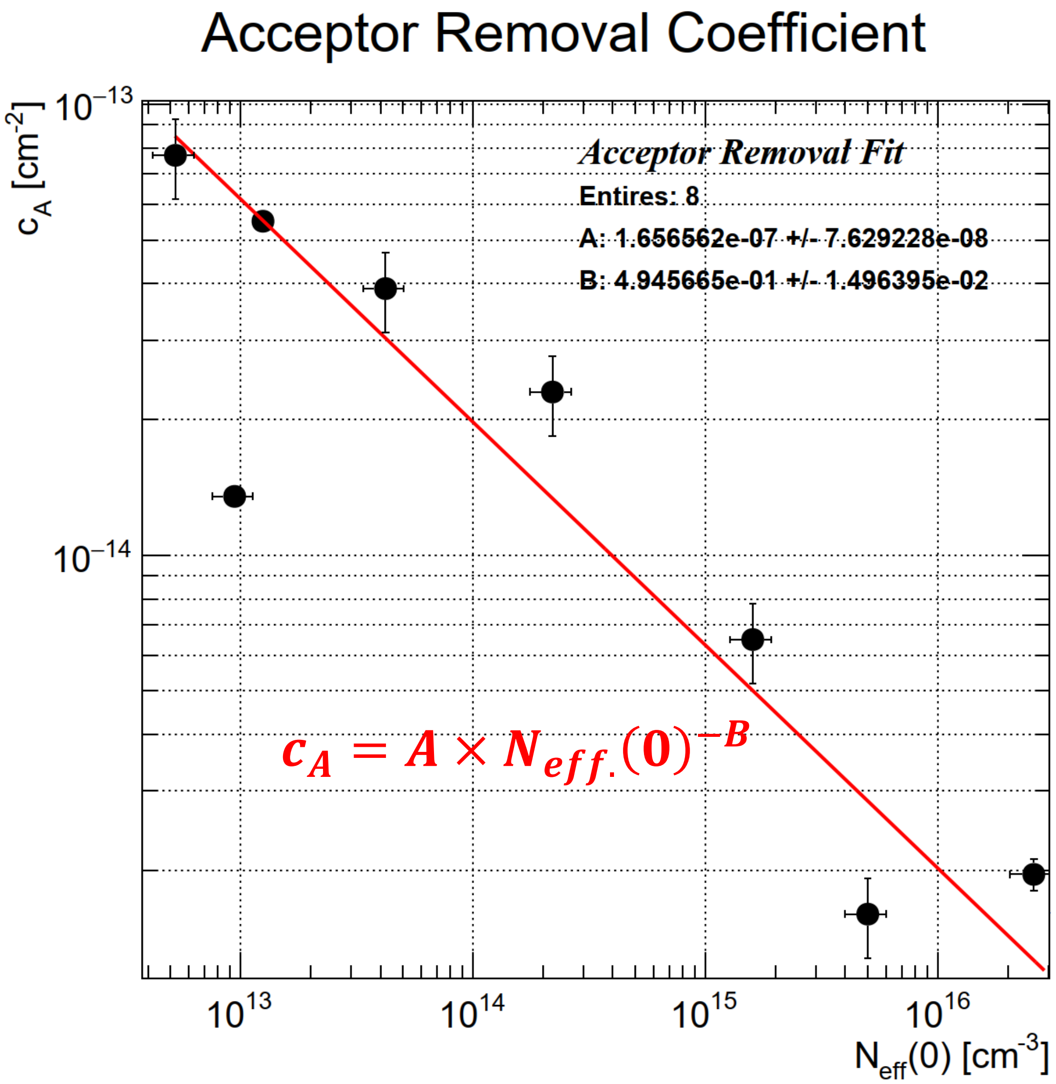
G. Lindstrom et al., NIM A 466(2001) 308-326
"Radiation damage in silicon detectors"

		Radiation damage modeling	
Irradiation Related part	Constant Damage Terms	**Acceptor Introduction**	$\frac{dN^{con.}_{acc.}(t)}{dt} = g_{C_A} \times \Phi_{eq}(\mathrm{t})$
		Donor Introduction	$\frac{dN^{con.}_{don.}(t)}{dt} = g_{C_D} \times \Phi_{eq}(\mathrm{t})$
		Acceptor Removal	$\frac{dN^{rem.}_{acc.}(t)}{dt} = -c_{C_A} \times \Phi_{eq}(\mathrm{t}) \times N^{rem.}_{acc.}(t)$
		Donor Removal	$\frac{dN^{rem.}_{don.}(t)}{dt} = -c_{C_D} \times \Phi_{eq}(\mathrm{t}) \times N^{rem.}_{acc.}(t)$
Annealing Related part	Short term annealing	Acceptor Reduction	$\frac{dN^{short.}_{acc.}(t)}{dt} = g_A \times \Phi_{eq}(\mathrm{t}) - k_A(T) \times N^{short.}_{acc.}(t)$
	Long term annealing	Max Introducible Acceptors	$\frac{dN^{Max.long.}_{acc.}(t)}{dt} = g_y \times \Phi_{eq}(\mathrm{t}) - k_Y(T) \times N^{Max.long.}_{acc.}(t)$
		Acceptor Introduction	$\frac{dN^{long.}_{acc.}(t)}{dt} = k_Y(T) \times N^{Max.long.}_{acc.}(t)$

•N_{eff} – Dynamic Model

<table>
<tr><th colspan="3">Radiation damage modeling</th></tr>
<tr><td rowspan="4">Constant Damage Terms</td><td>Acceptor Introduction</td><td>$N_{acc.}^{con.}(t) = g_{C_A} \times \int_0^t \Phi_{eq.}(\tau)\partial\tau$</td></tr>
<tr><td>Donor Introduction</td><td>$N_{don.}^{con.}(t) = g_{C_D} \times \int_0^t \Phi_{eq.}(\tau)\partial\tau$</td></tr>
<tr><td>Acceptor Removal</td><td>$N_{acc.}^{rem.}(t) = f_{C_A} \times N_{eff.}(0)\left(1 - e^{-c_{C_A}\int_0^t \Phi_{eq.}(\tau)\partial\tau}\right)$</td></tr>
<tr><td>Donor Removal</td><td>$N_{don.}^{rem.}(t) = f_{C_D} \times N_{eff.}(0)\left(1 - e^{-c_{C_D}\int_0^t \Phi_{eq.}(\tau)\partial\tau}\right)$</td></tr>
<tr><td>Short term annealing</td><td>Acceptor Reduction</td><td>$N_{acc.}^{short.}(t_i) = g_A \times \int_{t_{i-1}}^{t_i} \Phi_{eq.}(\tau)\partial\tau \Big/ \delta t \times \frac{\left(1 - e^{-k_a(T_i)\times\delta t}\right)}{k_a(T_i)} + N_{acc.}^{short.}(t_{i-1}) \times e^{-k_a(T_i)\times\delta t}$</td></tr>
<tr><td rowspan="2">Long term annealing</td><td>Max Introducible Acceptors</td><td>$N_{acc.}^{Max.\,long.}(t_i) = g_Y \times \int_{t_{i-1}}^{t_i} \Phi_{eq.}(\tau)\partial\tau \Big/ \delta t \times \frac{\left(1 - e^{-k_Y(T_i)\times\delta t}\right)}{k_Y(T_i)} + N_{acc.}^{Max.\,long.}(t_{i-1}) \times e^{-k_Y(T_i)\times\delta t}$</td></tr>
<tr><td>Acceptor Introduction</td><td>$N_{acc.}^{long.}(t_i) = N_{acc.}^{long.}(t_{i-1}) +$
$g_Y(T) \times \frac{\int_{t_{i-1}}^{t_i} \Phi_{eq.}(\tau)\partial\tau \Big/ \delta t}{k_Y(T)} \times \left(k_Y(T) \times t + e^{-k_Y(T)t} - 1\right) +$
$N_{acc.}^{Max.\,long.}(t_i) \times \left(1 - e^{-k_Y(T)t}\right)$</td></tr>
</table>

•Acceptor Removal Fit



Current Velo

200 μm thick, non-oxygenated, n-in-p, FZ, 3 – 8 kΩ × cm

Acceptor removal part

$$N_{C.}(\Phi_{eq.}) = -\boxed{f_C \times \underbrace{N_{eff.}(0)}_{\text{Original doping concentration}}\left(1 - e^{-c_A \Phi_{eq.}}\right)}$$

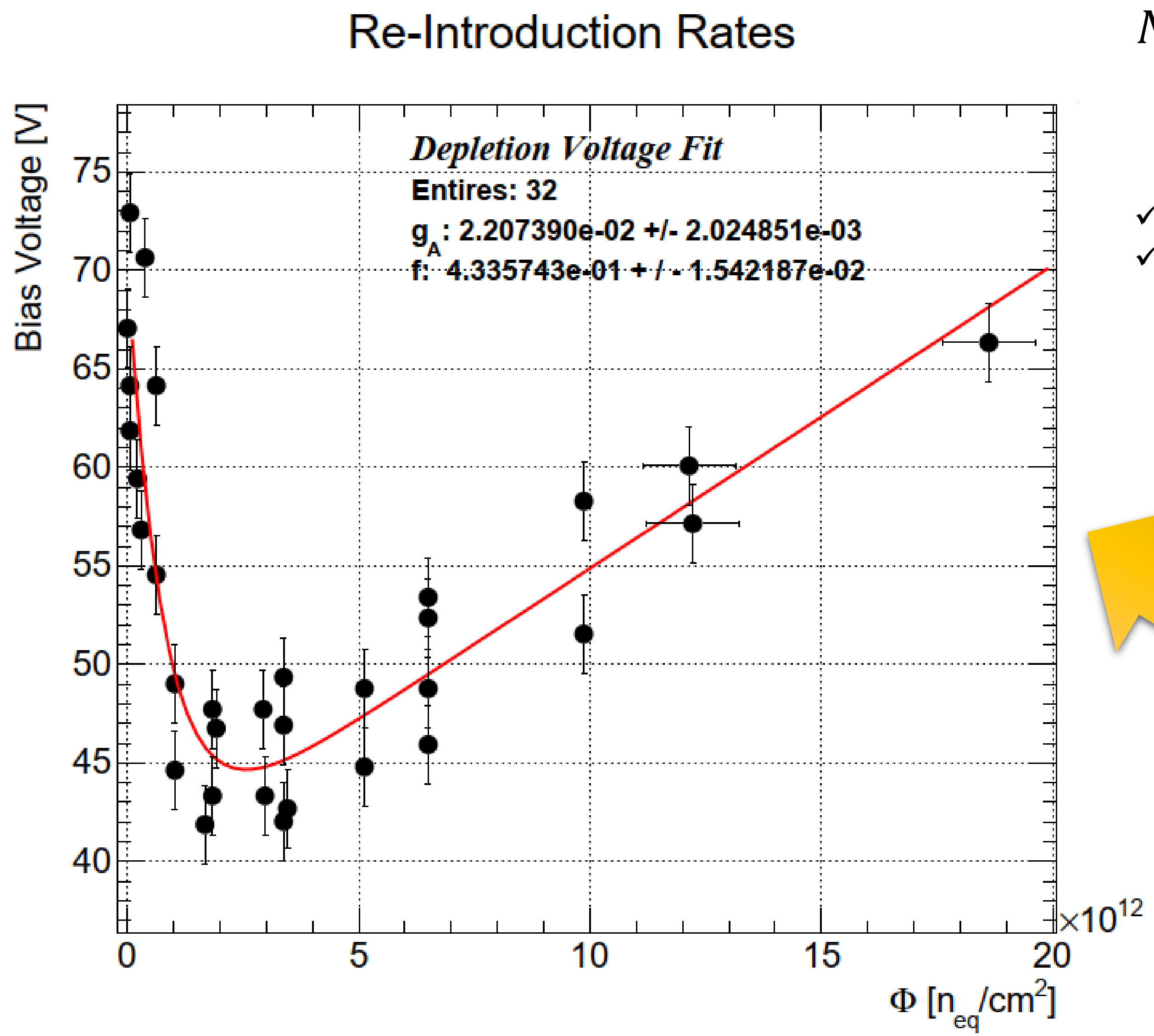
Original doping concentration

Acceptor Removal Coefficient

Removable Fraction

Neff(0) [cm-3]		c_A [cm^{-2}]	Sensor Type	Reference
Method	*Value*			
SiMS	*5×10^{15} (± 20%)*	16×10^{-16} (± 20%)	LGAD	G. Kramberger et al., JINST Vol. 10 (2015) P07006.
	$(2.59 \pm 0.54) \times 10^{16}$	$(19.6 \pm 1.6) \times 10^{-16}$		E. – L. Gkougkousis et al. J. Phys.: Conf. Ser. 2374 012175
CV Meas.	*$(9.44 \pm 0.07) \times 10^{12}$*	**$(1.35 \pm 0.03) \times 10^{-14}$**	Pad Diodes - MCz	K. Kaska, PhD Thesis, Technical University Vienna, 2014
	$(12.49 \pm 0.74) \times 10^{12}$	$(5.5 \pm 0.04) \times 10^{-14}$	Epi 150 μm pad diodes	
Resistivity	*1.6×10^{15} (± 20%)*	6.5×10^{-15} (± 20%)	Epi 50 μm pad diodes	P. D. de Almeida, "Measurement of the acceptor removal rate in silicon pad diodes," 30th RD50 Workshop, https://indico.cern.ch/event/637212/contributions/2608666/
	2.2×10^{14} (± 20%)	2.3×10^{-14} (± 20%)		
	4.21×10^{13} (± 20%)	3.9×10^{-14} (± 20%)		
	5.25×10^{12} (± 20%)	7.7×10^{-14} (± 20%)		

•Re-introduction coefficient



Acceptor removal part

$$N_{C.}(\Phi_{eq.}) = \underbrace{g_c \times \Phi_{eq.}}_{\text{Re-Introduction rate } g_c} - \boxed{f_c \times \underbrace{N_{eff.}(0)}_{\text{Original doping concentration}}\left(1 - e^{-c_A \Phi_{eq.}}\right)}$$

Re-Introduction rate g_c

✓ > 0 primarily acceptor introduction

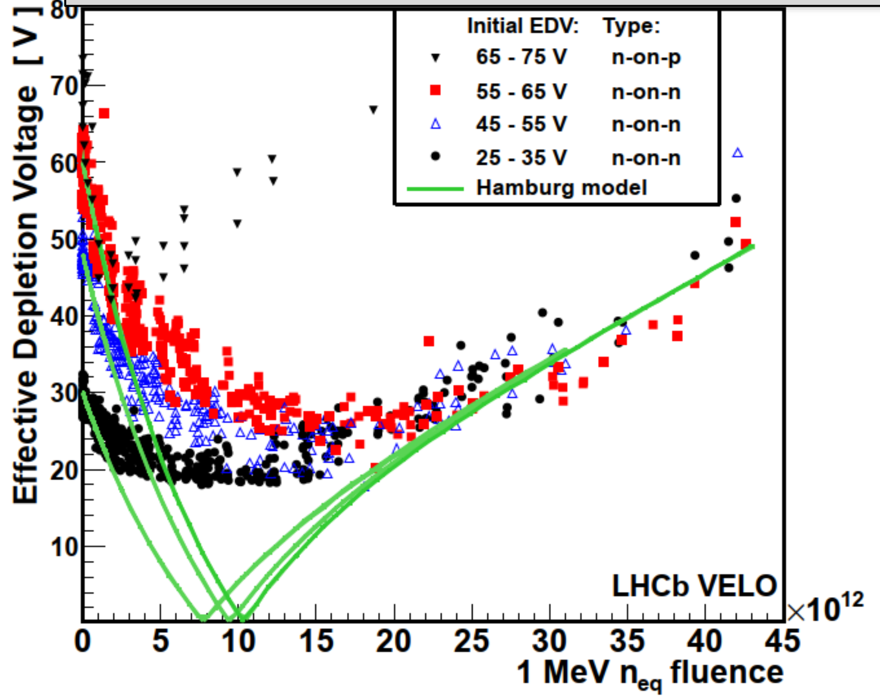
✓ < 0 primarily donor introduction

Original doping concentration

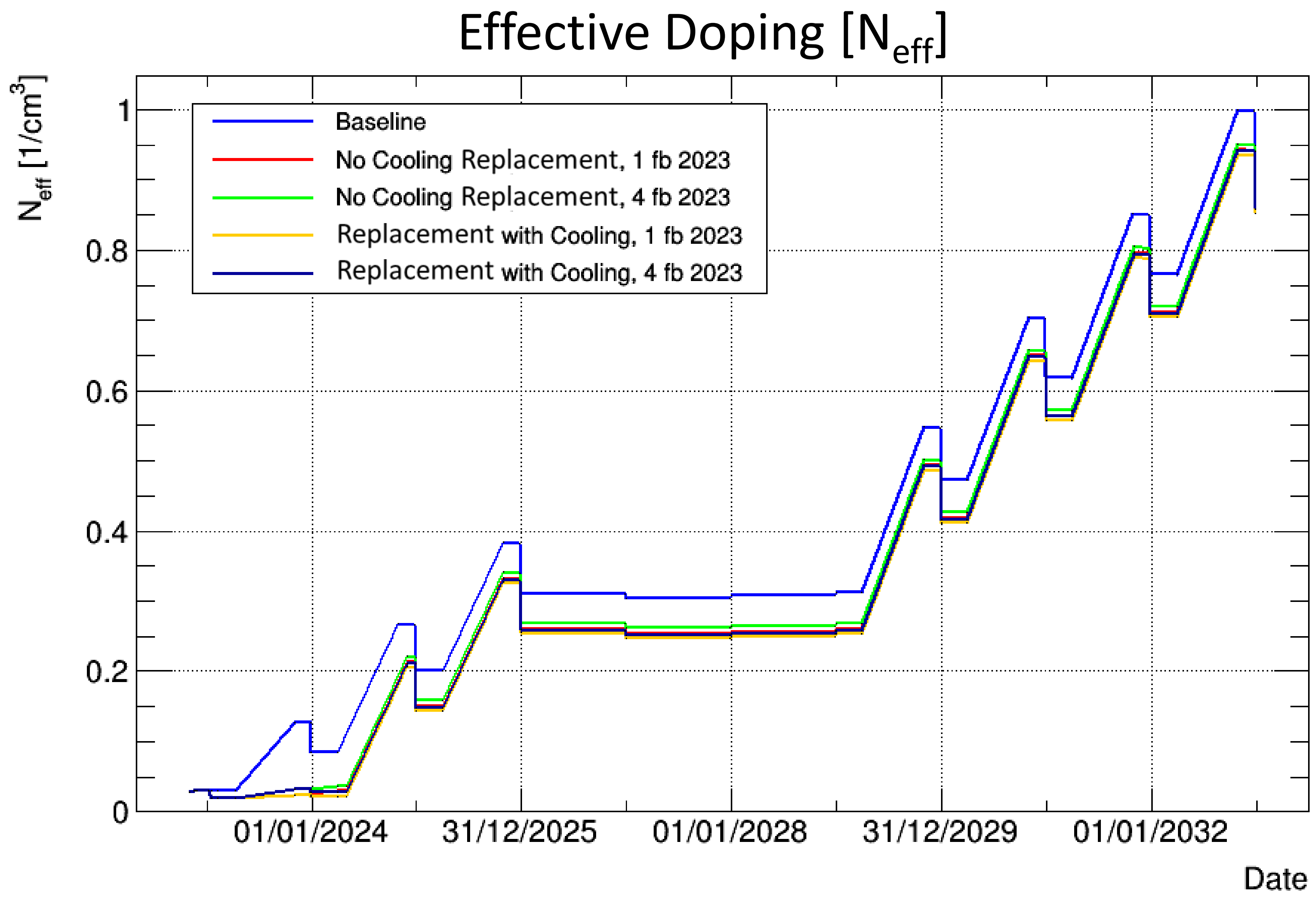
Acceptor Removal Coefficient

Removable Fraction

"Radiation Damage in the LHCb vertex locator", JINST 8, P08002, 2013



•N_{eff} – Dynamic Model



•Code Structure

Run Time Interaction

Acceptor removal Fit from bibliography (data in Share\AcceptorRemoval.txt) to establish the equation for calculation he removal coefficient with respect to $N_{eff}(0)$

Fit using data in Share\VDepVelo1.txt to determine the re-introduction rates to be used for the calculations of the N_{eff}

Folder where scenario files will be searched, all present files will be treated as different scenarios

Processed scenario

Printing final values of the final scenario for control and debug purposes. Not really needed, can be expanded to every included scenario

```
(RadDamage *) 0x234a172f150
 FCN=89.5311 FROM MINOS     STATUS=SUCCESSFUL     44 CALLS          384 TOTAL
                     EDM=1.10201e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Factor       1.65656e-07   7.61792e-08  -8.54537e-06   4.37059e-02
   2  Exponent     4.94566e-01   1.49418e-02   1.49418e-02  -5.01063e-02
 FCN=89.5311 FROM MINOS     STATUS=SUCCESSFUL     44 CALLS          384 TOTAL
                     EDM=1.10201e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Factor       1.65656e-07   7.61792e-08  -8.54537e-06   4.37059e-02
   2  Exponent     4.94566e-01   1.49418e-02   1.49418e-02  -5.01063e-02
 FCN=95.3134 FROM MINOS     STATUS=SUCCESSFUL     52 CALLS          399 TOTAL
                     EDM=1.29973e-08    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  g_{A}        2.20738e-02   2.02334e-03  -7.98061e-04  -2.29641e-03
   2  f            4.33574e-01   1.54399e-02  -1.73868e-03  -1.82045e-02
   3  c_{A}        1.25261e-12   1.33921e-13   1.33921e-13  -8.72214e-04
1: C:/Users/Vagelis/Desktop/VELOU1Radiation/RadDamage/Backup/Scenarios/*.*
RadDamage::Calculate INFO: Profile succesfully read from file: "Test standard.txt". Profile legnth: 16
<====================> :100%, Processed entries: 16 / 16
0.000421523 8.65308e-05 4.87136
RadDamage::Calculate INFO: Processing finished, writing data...
Final Effective Doping [N_{eff}] is: 2.18777e+13
Final Donors [N_{don.}] is: 0
Final Acceptors [N_{acc.}] is: 2.18777e+13
Final Depletion Voltage is: 677.876
Final #alpha Factors @ 21.0^{o}C is: 1.98917e-17
Final Leakage Current per module @ 21.0^{o}C is: 0.000884688
Final Leakage Current per module @ -20.0^{o}C is: 1.02972e-05
Final Leakage Current @ 21.0^{o}C is: 0.00743435
Final Leakage Current @ -20.0^{o}C is: 8.65308e-05
Final Power Consumption @ 21.0^{o}C is: 5.03957
Final Power Consumption @ -20.0^{o}C is: 0.0586571
Final Temperature is: 333.15
Final Fluence is: 3.73742e+14
```

•Conclusions

Outlook and next steps

- Introduction of asymmetric band uncertainties (currently underway)
- Validation against data (mainly α factors and N_{eff})
- Re-optimization of fitting parametrization from data
- Direct link to TIMBER and to luminosity monitor for automatization
- Expand to n-in-p type sensors (intrinsically supported, treated indifferently in re-introduction rate fit level)