

JOURNEY THROUGH THE THESIS WRITING

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R&D

LHCb UK student seminar
29.6.2023

- I am **not** a professional writer, just sharing my experience and what worked for me
- Your mileage may (**and will**) vary!!
- Will summarize:
 - Planning of the durations
 - What (I think) makes difference
- My thesis for reference (apparently people liked it):
 - <https://cds.cern.ch/record/2806219>



PLANNING



THE PLAN

CP: chapters and lengths look reasonable

CP: send chapters when you are done, will correct within 2 weeks

PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	ESTIMATE	weeks
abstract, table of contents,...				XX		x	0
introduction				3	3	x	0
upgrade 1	theory	LHCb in general		5	38	end of may	4
		semiconductor detectors	general	15			
			rad damage	7			
		VELO	vacuum	3			
			cooling	3			
		readout	5				
	VELO modules	construction		7	49	end of april	2
		metrology		7			
		testing		10			
		database		15			
analysis		10					
VELO commissioning	CCE	toy studies	15	15	end of july	2	
conclusions				2	2	x	0
upgrade 2	theory	LHCb plan in general		3	10	late june	3
		detectors	fast timing	7			
	sensor development	TCAD simulations		15	15	mid august	2
		device testing		5	5	end of june	1
conclusions				2	2	x	0
bibliography, acronyms, ...				XX		x	0
HEV				XX		x	1
TOTAL COUNT					139		17

CP: 139 pages is a little short, might aim for 150-200 but do not worry now

- Plan produced at the beginning of April 2021, deadline end of September 2021
- Verify the feasibility with your supervisor and agree on the process of corrections!
- All good! Will be done mid August, still a month to spare before the end of funding!

.... right



THE REALITY



Plan

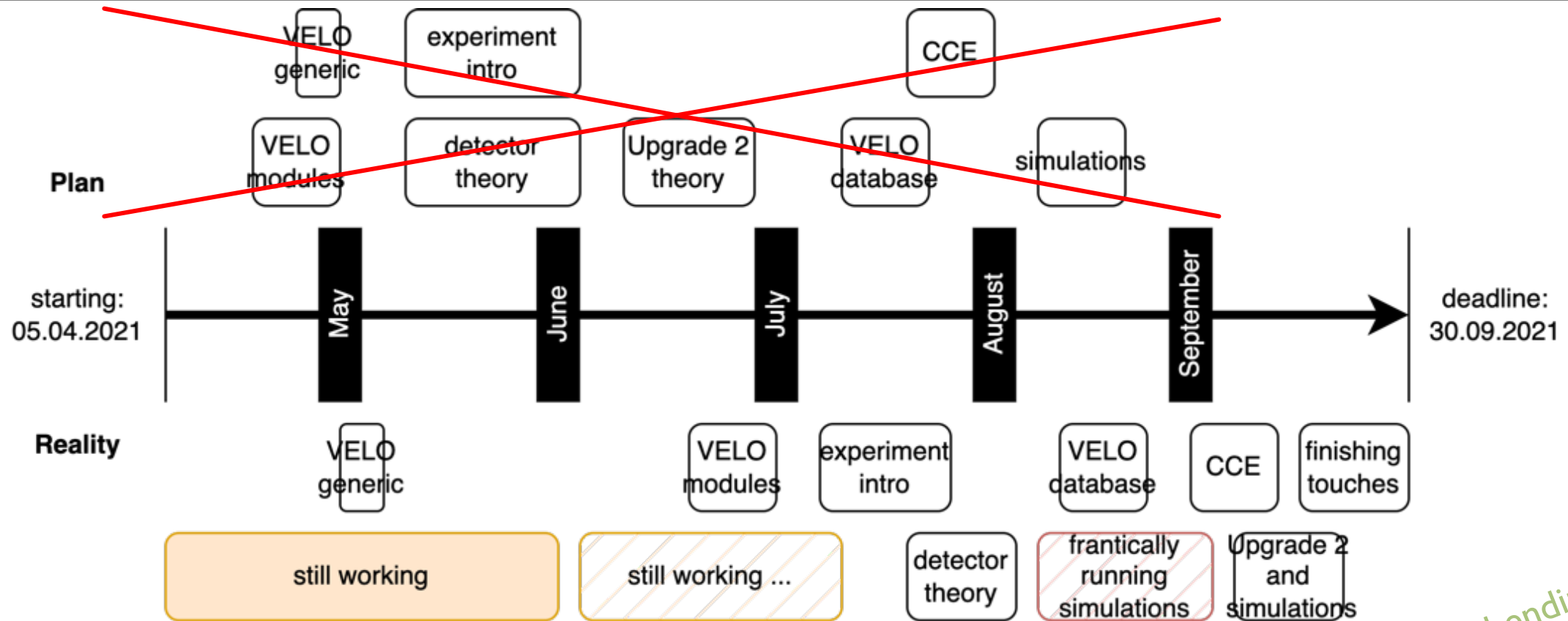
PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	ESTIMATE	weeks
abstract, table of contents,...				XX		x	0
introduction				3	3	x	0
upgrade 1	theory	LHCb in general		5	38	end of may	4
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	VELO modules	construction		7	49	end of april	2
		metrology		7			
		testing		10			
		database analysis		15			
VELO commissioning	CCE	toy studies	15	15	end of july	2	
upgrade 2	theory	LHCb plan in general		3	10	late june	3
		detectors	fast timing	7			
	sensor development	TCAD simulations		15	15	mid august	2
		device testing		5	5	end of june	1
				2	2	x	0
bibliography, acronyms, ...				XX		x	0
HEV				XX		x	1
TOTAL COUNT					139		17

Reality

PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	REALITY	weeks
abstract, table of contents,...				35	35		
preface				3	3		
upgrade 1	LHCb experiment and its Upgrade	CERN and LHC		3	25	end of july	3
		LHCb and LHCb Upgrade		11			
		VELO Upgrade	mechanics	2			
			cooling	2			
			electronics	6			
			Summary		1		
	Semiconductor detectors	Interaction of radiation		4	24	early august	2
		Semiconductors		13			
		Radiation damage		6			
		Summary		1			
VELO Upgrade modules	Assembly		7	24	end of june	2	
	Metrology		4				
	Module installation		5				
	Module performance testing		7				
		Summary		1			
Database and quality assurance	Database		6	35	mid august	2	
	Assembly		1				
	Metrology		11				
	Electrical testing		13				
	Evaluation		3				
	Summary		1				
Charge collection efficiency scans	CCE		12	13	early september	2	
	Summary		1				
upgrade 2	Future upgrades	LHCb Upgrade II		3	21	mid september	3
		Ultra fast silicon detectors		5			
		Sensor simulations		2			
		iLGAD simulation		10			
		Summary		1			
Summary and Conclusions					3		
bibliography, acronyms, ...					10		
HEV					30		
TOTAL COUNT					223		14

- Outline changed a bit
- Page estimate ballpark OK (142 without extras)
- Got **very** delayed (about 2 months)

COMPARISON



- It takes **months** to actually stop working and start writing
 - Be sure to set a deadline after which you stop joining meetings
 - Plan for time needed for corrections!

*Story with a good ending:
Submitted night 28-29.09.2021*

WHAT (I THINK) MAKES A DIFFERENCE



- Leave the abstract, preface and conclusions as the **last** thing (before that you do not fully know what you write about)

- Start with the acronyms from the **beginning**, it would be a pain to add them later

- Try to use them for everything and to get used to it

Acronyms

Notation	Description	Page List
AC-LGAD	AC coupled LGAD	169, 170
ADC	Analog-Digital Converter	41, 76, 148
ALICE	A Large Ion Collider Experiment	37, 38
APD	Avalanche Photodiodes	166
API	Application Programming Interface	47, 48
ASIC	Application Specific Integrated Circuit	29, 30, 40, 53, 55–60, 66, 76, 77, 85, 89, 90, 93, 97, 98, 103–107, 111, 116, 121–124, 126, 129–131, 133–137, 148, 154, 156, 158, 159, 165, 179, 188
ATLAS	A Toroidal LHC Apparatus	37, 38, 102

- Make sure your tables of contents/figures/tables populate well

- Use shortened descriptions, make sure it plays well with citations and acronyms!

6.10 Meshing map of the simulated diode..... 175

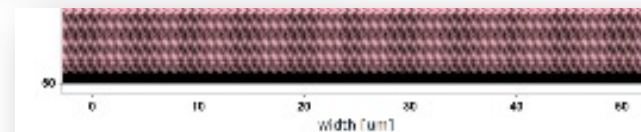


Figure 6.10: Meshing map of the simulated diode with thickness 50 μm . The meshing is more refined in the implant regions in order to better simulate the avalanche process in the multiplication layer.

- Leave the abstract, preface and conclusions as the **last** thing (before that you do not fully know what you write about)

- Start with the acronyms from the **beginning** to add them later

Start with the template and populate text with Lorem Ipsum
- it is a nice excuse of "I already started writing"
- you have quick turnaround of changes
- eases you into changing your work pattern

- Make sure acronyms, figures, tables populate well
 - Use short descriptions, make sure it plays well with citations and acronyms!

ATLAS	A Toroidal LHC ApparatuS
37, 38, 102	
158, 159, 165, 179, 188	
131, 133-137, 148, 154, 156,	
111, 116, 121-124, 126, 129	
85, 89, 90, 93, 97, 98, 103-107,	
49, 53, 55-60, 66, 76, 77,	



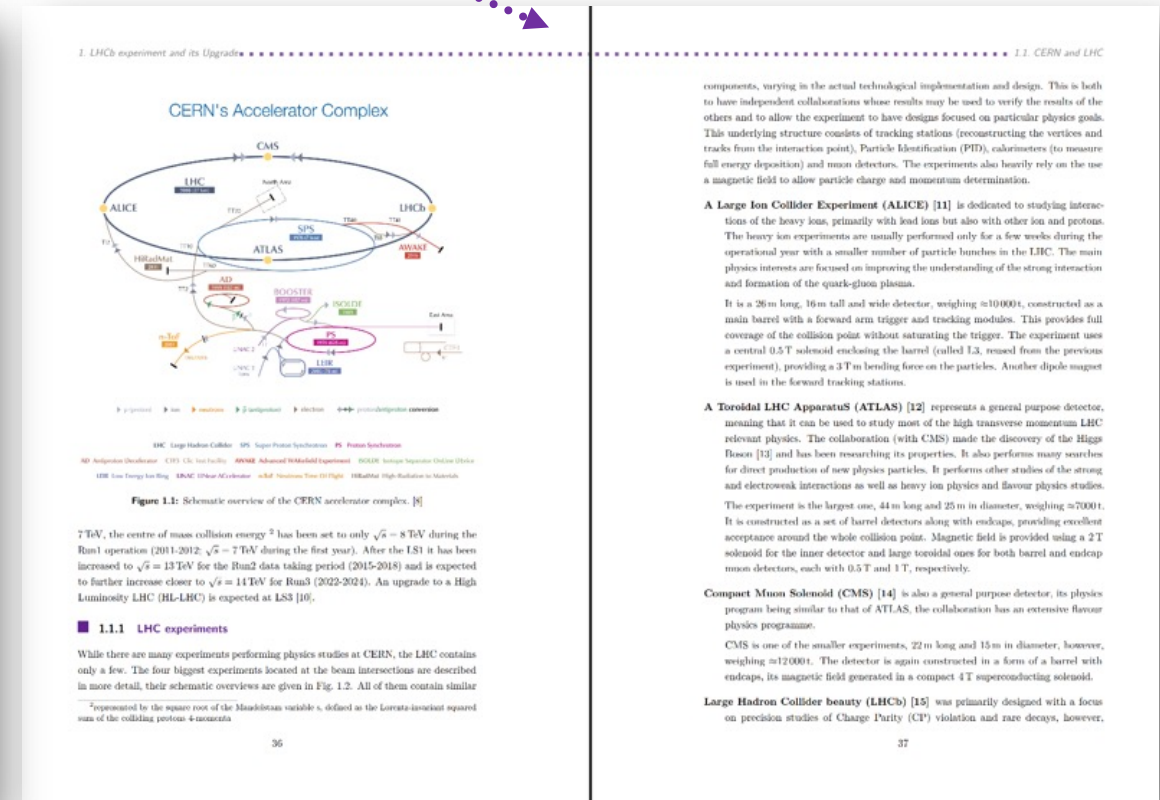
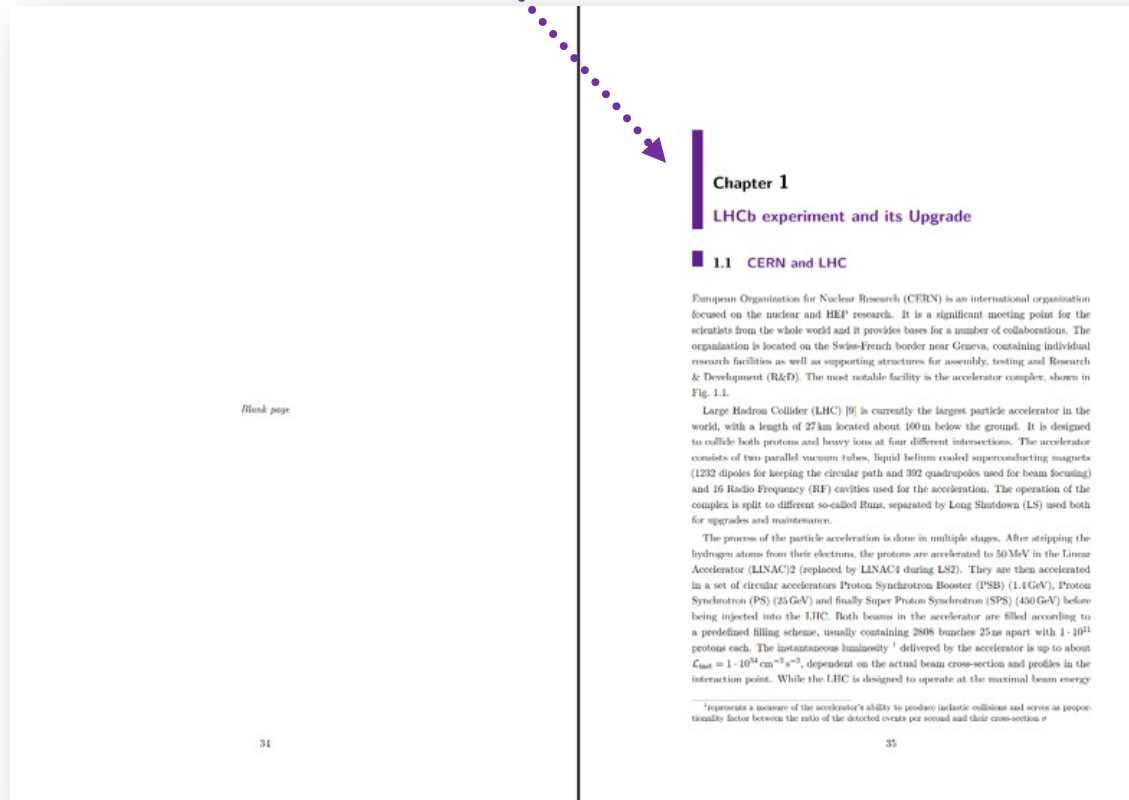
6.10 Meshing map of the simulated diode..... 175



Figure 6.10: Meshing map of the simulated diode with thickness 50 μm . The meshing is more refined in the implant regions in order to better simulate the avalanche process in the multiplication layer.

CONSISTENT DESIGN THAT YOU LIKE

- I colour matched the university theme, use the double sided layout to your advantage



CONSISTENT DESIGN THAT YOU LIKE

- I colour matched the university theme, use the double sided layout to your advantage
- Make your own graphics (where it makes sense) that match the style (takes time, but worth the effort)

2. Semiconductor detectors • 2.2. Semiconductors

It is clear that at the absolute zero temperature the Fermi level is in the middle of the bandgap, at higher temperatures the deviation is caused due to different effective masses of electrons and holes.

2.2.3.1 Doping

The commonly used dopants have a shallow energy level in the forbidden bandgap region, either close to the conduction (donor impurity) or valence (acceptor impurity) bands. The comparison between intrinsic, n- and p-type semiconductors is visualized in Fig. 2.6. Since the energy difference of impurities is very close to their respective bands (only about 0.05 eV), almost all of the atoms are in an ionized state at the room temperature. Given that the concentration of dopants is much larger than the intrinsic density and the silicon is heavily doped only with one element, the carrier density $n_{\text{ind}} \approx N_{\text{D(A)}}$ is equal to the concentration of the donors (acceptors). For $N_D \gg N_A$ the shift of the Fermi level can be estimated as

$$E_F - E_i + k_B T \ln \left(\frac{N_D}{n_i} \right) \quad (2.24)$$

analogously for $N_A \gg N_D$

$$E_F = E_i - k_B T \ln \left(\frac{N_A}{n_i} \right) \quad (2.25)$$

Using $n_i^2 = \text{const} \approx 1 \cdot 10^{20} \text{ cm}^{-6}$ from the Eq. (2.21) a thermal equilibrium means that in both doping cases the concentration increase of one charge carrier is at the expense of the other. This effectively increases the total amount of charge carriers and thus also the conductivity. As an example, doping with donor impurities $n_n \approx N_D = 1 \cdot 10^{17} \text{ cm}^{-3}$ satisfies the condition for concentrations of holes $n_p = 1 \cdot 10^{17} \text{ cm}^{-3}$. The density of charge carriers $n = n_n + n_p$ is then $n \approx 2 \cdot 10^{17} \text{ cm}^{-3}$ and $n \approx 1 \cdot 10^{17} \text{ cm}^{-3}$ for intrinsic and doped semiconductor, respectively.

In reality, semiconductors are usually doped with both n- and p- types, in some cases even different concentrations of the same type (n+-con- semiconductors). In such case the effective doping concentration is used, defined as an absolute value of the difference of the two.

2.2.4 p-n junction

Probably the most important property of extrinsic semiconductors is the existence of p-n junction, created on the contact border of the n- and p- type devices. [59, 61, 62] They are used in diodes or transistors, controlling the direction and flow of the current.

As a result of different Fermi levels, a gradient of the concentration of the charge carriers occurs in the junction (see Fig. 2.7). Electrons from the donor impurity flow in the direction of the p-type region, the holes experience the exact opposite flow towards the n-type region. The charge carriers in the centre recombine and create a depletion region with an electric field opposing further diffusion. The system eventually reaches an equilibrium, also resulting in the matching of the Fermi levels across the junction.

The equilibrium state of the junction is best described using an abrupt junction (large jump in concentration) in Fig. 2.8. The charge carriers in the depletion region are recombined, its width is written as

$$d = d_n + d_p \quad (2.26)$$

where d_n and d_p correspond to the width of the depletion region in the donor and acceptor parts, respectively. The charge density $Q(x)$ can be written as a function of depth

$$Q(x) = \begin{cases} 0, & x \leq -d_n \\ qN_D, & -d_n < x \leq 0 \\ -qN_A, & 0 < x \leq d_p \\ 0, & d_p < x \end{cases} \quad (2.27)$$

the electric field $E(x)$ and potential $\phi(x)$ can be then derived from the Poisson's equation

$$\frac{d^2\phi}{dx^2} = -\frac{Q(x)}{\epsilon} \quad (2.28)$$

The $\epsilon = \epsilon_0 \epsilon_r$ is a product of permittivity of vacuum ϵ_0 and relative permittivity of the material ϵ_r .

After integrating Eq. (2.28) and applying the boundary conditions $E(x) = 0$ for both d_n and d_p , the electric field is

$$E(x) = -\frac{dq(x)}{dx} = \begin{cases} -\frac{qN_D}{2}(x + d_n), & -d_n < x \leq 0 \\ \frac{qN_A}{2}(x - d_p), & 0 < x \leq d_p \end{cases} \quad (2.29)$$

Since the two values have to match at the contact position $x = 0$, a condition fulfilling charge neutrality in the semiconductor is obtained

$$N_D d_n = N_A d_p \quad (2.30)$$

Depletion depth is therefore proportional to the doping concentration of the two parts. In the case where one side is heavily doped with respect to the other, the region with larger concentration is narrow and vice-versa for the other side. This is frequently used in the particle detectors as one side of the sensor tends to have much larger doping concentration than the other.

The further integration of Eq. (2.29) results in the electric potential

$$\phi(x) = \begin{cases} -\frac{qN_D}{6}(x + d_n)^2 + V_i, & -d_n < x \leq 0 \\ \frac{qN_A}{6}(x - d_p)^2, & 0 < x \leq d_p \end{cases} \quad (2.31)$$

the integration constants were selected based on the boundary conditions $\phi(d_n) = 0$ and $\phi(-d_n) = V_i$, where V_i is a potential difference present between the two sides. Matching the equations at $\phi(0)$, the voltage can be estimated as

$$V = \frac{q}{2\epsilon} (N_D d_n^2 + N_A d_p^2) \quad (2.32)$$

In the case where no external field is applied, the difference represents a built-in voltage $V_{bi} = V$ in the diode. This also corresponds to the difference of the Fermi levels between the two semiconductor types and can be obtained in a different form from Eq. (2.22)

$$V_{bi} = \frac{1}{q} (E_{F_n} - E_{F_p}) = \frac{k_B T}{q} \ln \left(\frac{N_A N_D}{n_i^2} \right) \quad (2.33)$$

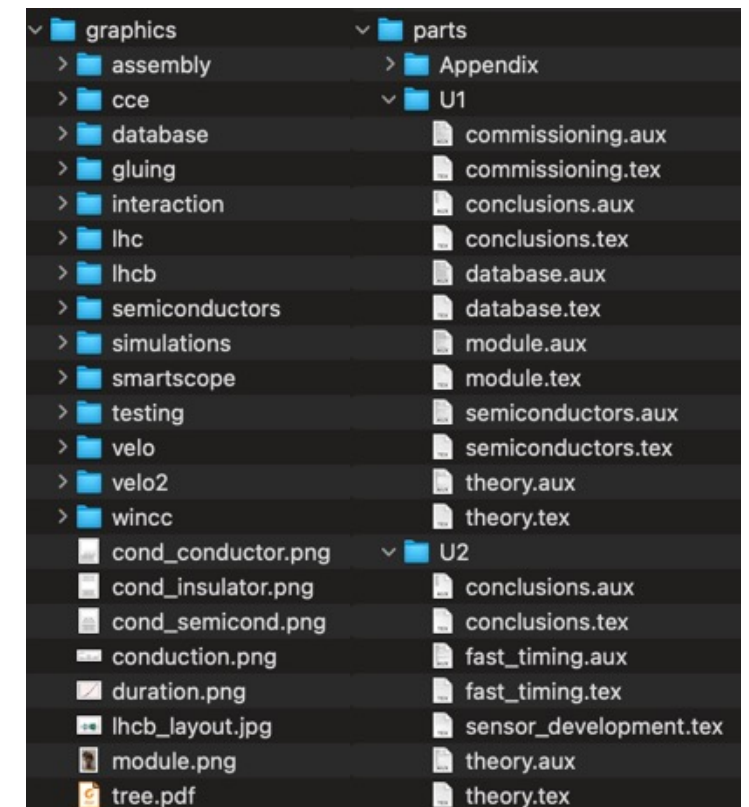
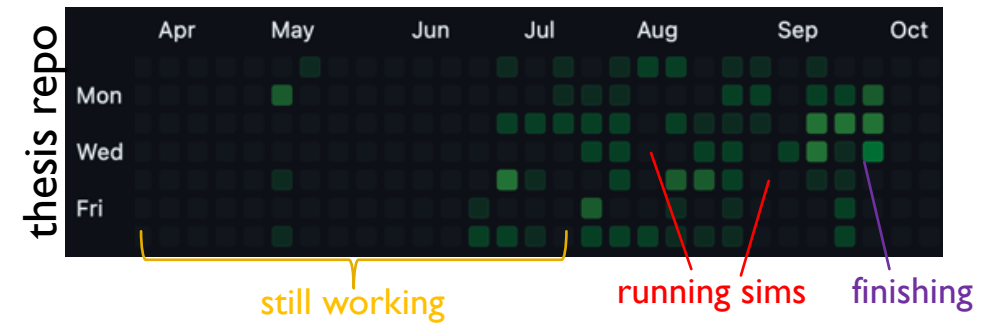
Since the value of the built-in voltage is very small, the particles that interacted in the depleted volume would be missed compared to the large amount of thermally produced e-h pairs.

used draw.io for graphics
free software available online or as an app

GOOD WRITING PRACTICES



- Have `git` (-hub / -lab) repository where you push changes at least once a day
- Do not fully rely on overleaf, always have offline copies available (ideally, be able to compile offline ...)
- Split the document based on chapters/sections (makes simpler navigation and compilation chapters)
- **!!! Have backups of everything !!!** (separate machines, all plots, figures, partially compiled pdfs ...)
- You will most certainly have to remake some of the old plots
 - You will get stuck for days on this alone, don't be afraid of some MS-Paint magic for labels/fonts/...
- Don't forget references to everything!



- Write a summary at the end of each chapter (just a few paragraphs)
 - Good both for you when thinking about what you forgot, but also for someone just skimming through your thesis
- You are not writing a novel, but does not mean it has to be boring – try to make a story out of it where possible
- Make sure you have forward/backward references where needed
 - e.g. My chapter 3 describes module assembly and tools for characterisation, but only Chapter 4 mentions the actual measurement results and overall metrics

■ 3.1.2 Tiles attachment

Placement of the tiles on the modules is one of the tasks requiring the highest accuracy during the module construction, aiming at achieving a precision better than 30 µm. Furthermore, the thickness of the glue layer used for the tile attachment affects the final cooling performance of the whole module. The temperature of the tip of the overhanging tile is the most critical element, the targeted glue layer thickness underneath each tile is 80 µm. While the production steps are described further in the text, the metrology measurements are discussed in detail in Sect. 3.2.2 and 3.2.3 and their results in Sect. 4.3.2 and 4.3.3.

■ 4.3.2 Glue layer thickness and tile flatness

This measurement is done for both UoM (described in Sect. 3.2.2) and Nikhef, once again the data-input from the two sites differ. The differences are bigger than for a simple substrate flatness measurement, therefore the calculation has to be performed differently as well. The results are not only needed to verify the uniformity but also used later in the cooling performance described in Sect. 4.4.5.

HOW TO FINALLY START WRITING



HOW TO FINALLY START WRITING



- But **do not worry** if it takes you months
- Put your thoughts on screen
 - Whatever works for you, bullet-points, short text, ... really just need to start
 - **Do not worry** if it is good or bad, the main point is you started!
- You will get better over time as you get to it, **do not worry** if you constantly rewrite paragraphs
- Find what helps you to sit down and write
 - set goals / go to a library / join writing (zoom) rooms / meet with friends in office / try pomodoro / ...
 - Try to be in a good environment (family, friends, eat good food, sleep properly, have access to loads of chocolate and coffee, ...)
 - **Really do not be afraid saying no to work and no to meetings**

SUMMARY AND LET'S DISCUSS



- It takes time and effort (last minute finishes, unexpected problems)
 - try to plan a bit and estimate how much time you need
... it will **always** take longer !
- Really, just start
 - First with a template (**make it pretty!**)
 - Slowly ease into the full time writing frenzy
... but to not forget to take breaks (even a holiday halfway through!)
- As with everything, ask for help whenever you think you need it

