JOURNEY THROUGH THE THESIS WRITING

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LHCb UK student seminar 29.6.2023

DISCLAIMER



- 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

	MANCHESTER 1824
Tł	ne University of Manchester
DO	OCTORAL THESIS
D	eveloping a Silicon Pixel Detector for the Nex
Ge	eneration LHCb Experiment
	eter Švihra pervisor: Prof. Chris Parkes, PhD.
	hesis submitted to The University of Manchester
for	the degree of Doctor of Philosophy the
	partment of Physics and Astronomy
	ulty of Science and Engineering
	21

PLANNING



THE PLAN



CP: chapters and lengths look reasonable

PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	ESTIMATE	weeks
abstract, table	of contents,			XX		x	0
introduction				3	3	x	0
		LHCb in general		5			
		semiconductor detectors	general	15		end of may	4
	ab en er i	semiconductor detectors	rad damage	7	38		
	theory		vacuum	3	38		
		VELO	cooling	3		end of april	1
			readout	5			
upgrade 1		construction		7			
		metrology		7		end of april	2
	VELO modules	testing		10	49		
		database		15		and all trades	2
		analysis		10		mid july	2
	VELO commissionir	CCE	toy studies	15	15	end of july	2
	conclusions			2	2	x	0
	theony	LHCb plan in general		3	10	lata iuma	3
	theory	detectors	fast timing	7	10	late june	3
upgrade 2	sensor	TCAD simulations		15	15	mid august	2
	development	device testing		5	5	end of june	1
	conclusions			2	2	x	0
ibliography, a	cronyms,			ХХ		x	0
IEV				XX		x	1
	Т	OTAL COUNT			139		17

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

CP: send chapters when you are

done, will correct within 2 weeks

- Plan produced at the beginning of April 2021, <u>deadline end of September 2021</u>
- 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





THE REALITY



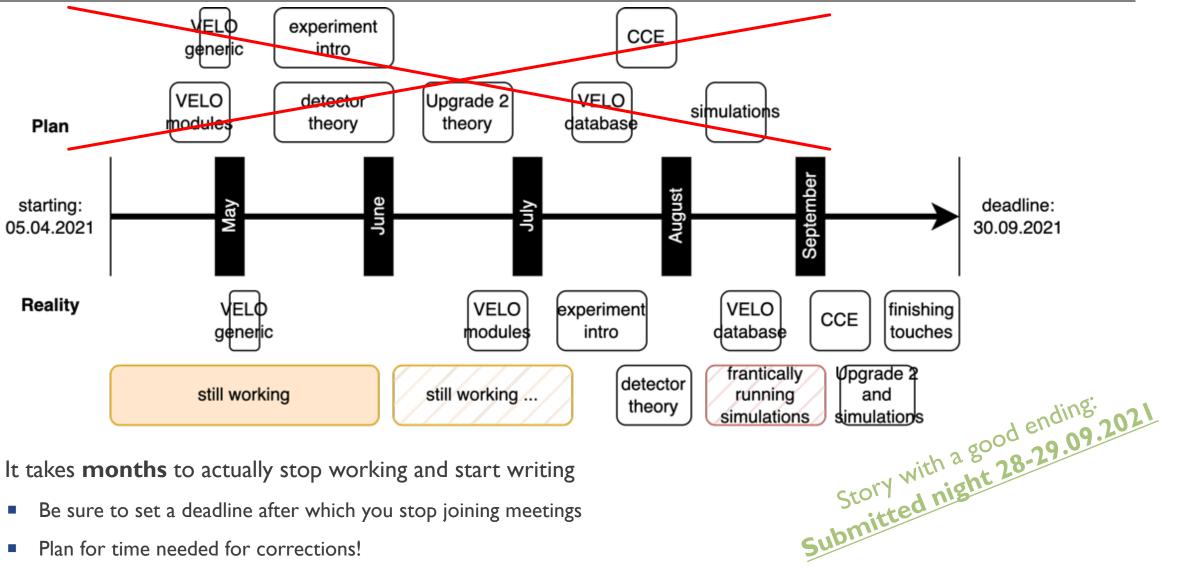
Plan

Reality

PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	ESTIMATE	weeks	PARTS	CHAPTERS	SECTIONS	SUBSECTIONS	PAGES	PAGE SUMMARY	REALITY	weeks
abstract, table	of contents,			XX		x	0	abstract, table	of contents,			35	35		
introduction				3	3	x	0	preface			25	3	3		
		LHCb in general		- 5 -						CERN and LHC		3			
		semiconductor detectors	general	15		end of may	4			LHCh and LHCh Ungrade		11		•	
	theory	semiconductor detectors	rad damage	7	38	-			LHCb experiment		mechanics	2	25	end of july	3
	theory		vacuum		50				and its Upgrade	VELO Upgrade	cooling	2		end of july	3
		VELO	cooling	3		end of april	1				electronics	6			
			readout	5						Summary		1			~
upgrade 1		construction		7		100000000000000000000000000000000000000	† 			Interaction of radiation		4			
		metrology		7		end of april	2	>	Semiconductor	Semiconductors		13	24	early august	2
	VELO modules	testing		10	49				detectors	Radiation damage		6	*	carry august	-
		database		15		mid july	2			Summary		1			
		analysis		10		inia juiy	-			Assembly		7			
	VELO commission	in CCE	toy studies	15	15	end of july	2	upgrade 1	VELO Upgrade	Metrology		4			~~~~
	eenelusiens-			-2-	2	x	U		modules	Module installation		5	24	end of june	2
	theory	CHCb plan in general		3	10	late june	3		modules	Module performance testing		7			
	licory	detectors	fast timing	7	10	June	3.55			Summary		1			
upgrade 2	sensor	TCAD simulations		15	15	mid august				Database		6			
	development	device testing		5	5	end of june	1		Database and	Assembly		1			
	conclusions			2	2	x	0		guality	Metrology		11	35	mid august	2
bibliography, a	cronyms,			XX		x	0		assurance	Electrical testing		13		inia august	-
HEV				XX		x	1		assurance	Evaluation		3			
		TOTAL COUNT		~~	139		17			Summary		1			
									Charge collection	CCE		12	13	early september	2
									efficiency scans	Summary		1			
	utline ch	nanged a bit								LHCb Upgrade II		3			
Ŭ								2.59	57	Ultra fast silicon detectors	_	5			
								upgrade 2	Future upgrades	Sensor simulations		2	21	mid september	3
Pa	ge estim	nate balloark (ЭК (14	2 w	ithout ex	xtras				iLGAD simulation		10			
1 4	80 000m	nate ballpark (- 2			Summary	_	1			
								Summary and				3	3		
	ot verv	delayed (abou	it 2 mc	nth	c)			bibliography,	cronyms,			10	10		
5				- i ci i	<i>.</i> ,			HEV				30	30		<u> </u>
										TOTAL COUNT			223		14

COMPARISON



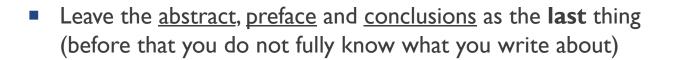


- It takes **months** to actually stop working and start writing
 - Be sure to set a deadline after which you stop joining meetings
 - Plan for time needed for corrections!

WHAT (ITHINK) MAKES A DIFFERENCE



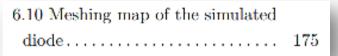
GENERICS

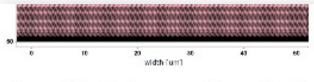


- Start with the <u>acronyms</u> from the **beginning**, it would be a pain to add them later
 - Try to use them for everything and to get used to it

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 Cir-	29, 30, 40, 53, 55-60, 66, 76, 77,
ASIC	cuit	85, 89, 90, 93, 97, 98, 103-107,
1310	cuit	
ASIC	cut	111, 116, 121-124, 126, 129-
ASIC	cuit	111, 116, 121–124, 126, 129
ASIC	cuit	

- Make sure your <u>tables of contents</u>/<u>figures</u>/<u>tables</u> populate well
 - Use shortened descriptions, make sure it plays well with citations and acronyms!





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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.

GENERICS



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



CONSISTENT DESIGN THAT YOU LIKE

LHCb experiment and its Upgrade

1.1 CERN and LHC

Chapter 1

European Organization for Nuclear Research (CERN) is an international organization focused on the nuclear and HEP research. It is a significant meeting point for the scientific from the viole world and it provides bases for a number of collaborations. The organization is located on the Swise-French berefer near Geneva, containing individual research facilities as well as supporting attractures for assembly, testing and Research & Development (R&D). The most notable facility is the accelerator complex, shown in Fig. 1.1.

Large Hadron Cellifer (LHC) [9] is currently the largest particle accelerator in the world, with a length of 27 km located about 100m below the ground. It is designed to collide holds protons and heavy ions at four different intersections. The accelerator consists of two parallel wavaums tables, liquid helium cooled superconducting magnets (122 dipols for keeping the circuitage path and 320 guadrupoles used for beam focusing) and 16 Radio Frequency (RF) cavities used for the acceleration. The operation of the complex is split to different so-called Runa, separated by Long Shutdown (LS) used both for upprades and maintenance.

The process of the particle acceleration is done in multiple stages. After stripping the hydrogen atoms from their decisions, the protons are accelerated to 50 MeV in the Linux Accelerator (LINAC)2 (replaced by LINAC4 during LS2). They are then accelerated in a set of circular accelerators Proton Synchrotron (PSB) (1.4.GeV), Proton Synchrotron (PS) (20 GeV) and fully Super Proton Synchrotron (PSB) (4.00 GeV) below being injected into the LTC. Both beass in the accelerator are filled according to a percedimed filling schemes, usually containing 2008 bunches 22m apart with 1.10²¹ protons each. The instrumences huminosity ¹ delivered by the accelerator is up to about $\mathcal{L}_{\rm BM}=1.10^{14}\,{\rm cm}^{-3}\,{\rm s}^{-3}$, dependent on (PS).

 3 represents a measure of the accelerator's ability to produce inelastic collisions and serves as proportionality factor between the ratio of the detocted ovents per second and their cross-section σ



I. LHCb experiment and its Upgrade



b pripetter | bin | b mattern | b particular | b electron | 0+0- president prates conversion

EHC Large Hadron Callider. 195. Super Proton Synchrotrom. 15. Proton Synchrotrom. Antigeroton Uncollin ator: C113. Circ. Inc. Tro. Tro. 2010. Advanced WARsfield Egyptiment. ISSUE: Entropy: Separator: OnLine Univ.

IBE Los Dorge las Bing - IBAC IPhear ACcelerator - and at Visations Time Di Flight - Hillad Mail High-Radiation to Materials

Figure 1.1: Schematic overview of the CERN accelerator complex. [8]

7 TeV, the centre of mass collision energy ⁵ has been set to only $\sqrt{s} = 8$ TeV during the Run1 operation (2011-2012; $\sqrt{s} = 7$ TeV during the first year). After the 1S1 it has been increased to $\sqrt{s} = 13$ TeV for the Run2 data taking period (2015-2013) and is expected to further increase closer to $\sqrt{s} = 11$ TeV for Run3 (2022-2024). An upgrade to a High Luminoity LEC RUL-LHC) is expected at LS3 H0.

1.1.1 LHC experiments

While three are many experiments performing physics studies at CERN, the LHC contains only a few. The four biggest experiments located at the beam intersections are described in more detail, their schematic overviews are given in Fig. 1.2. All of them contain similar ⁻¹represented by the space row of the Mandeltans variable s, defined as the Lorentz-invariant separed us of the colling periods - incoments.

-

1.1. CERN and LHC

EP R&D

components, varying in the actual technological implementation and design. This is both to have independent collaborations whose results may be used to verify the results of pole. This underlying structure consists of tracking stations (reconstructing physics goals. This underlying structure consists of tracking stations (reconstructing the vertices and tracks from the interaction goals). Particle Meentiframion (PDD), advantaces (no means full energy deposition) and man detectors. The experiments also heavily rely on the use a magnetic field to ablow particle denges and monorum determination.

A Large Ion Collider Experiment (ALICE) [11] is dedicated to studying interactions of the heavy loss, primarily with lead loss but also with other ion and protons. The heavy ion experiments are usually performed only for a few weeks during the operational year with a smaller number of particle bunches in the LHC. The main physics interests are focused on improving the understanding of the strong interaction and formation of the quirt-gloop plasma.

It is a 36 m long, 16 m tall and wirke detector, weighing ≈ 100001 , constructed as a main barred with a forward arm trigger and tracking modules. This provides full coverage of the collision point without saturating the trigger. The experiment uses a central 0.57 solessid enclosing the barred (culled 1.3, reased from the previous experiment), providing a 3 T m berling force on the particles. Another dipole suggest is used in the forward tracking stations.

A Torokial LHC Apparatus' (ATLAS) [12] represents a general purpose detector, meaning that it can be used to study most of the high transverse momentum LHC relevant physics. The collaboration (with CAS) made the discovery of the Higgs Boson [13] and has been researching its properties. It also performs many searches for direct production of new physics particles. It performs other studies of the strong and electroweak interactions are will as heavy ion physics and flavour physics its studies.

The experiment is the largest one, 44 m long and 25 m in diameter, weighing =7000 t. It is constructed as a set of hard disctences along with endoques providing excellent acceptance around the whole collision point. Magnetic field is provided using a 2 T solenoid for the inner detector and large toroidal ones for both barrel and endopmono detectors, and with 0.5 T and 1.7, respectively.

Compact Muon Solenoid (CMS) [14] is also a general purpose detector, its physics program being similar to that of ATLAS, the collaboration has an extensive flavour physics programme.

CMS is one of the smaller experiments, $22 \,\mathrm{m}$ long and $15 \,\mathrm{m}$ in diameter, however, weighing $\approx 12000 \,\mathrm{t}$. The detector is again constructed in a form of a barrel with endcaps, its magnetic field generated in a compact $4 \,\mathrm{T}$ superconducting solenoid.

Large Hadron Collider beauty (LHCb) [15] was primarily designed with a focus on precision studies of Charge Parity (CP) violation and rare decays, however,

Blank near

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CONSISTENT DESIGN THAT YOU LIKE



Make your own graphics (where it makes sense) that match the style (takes time, but worth the effort)

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. Semiconductor detectors

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 imperity) or valence (accentor imperity) hands. The comparison between intrinsic, n- and p-type semiconductors is visualised 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 $n_{n(p)} \approx N_{D(\Lambda)}$ 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

$$F_F - F_1 + k_N T \ln \left(\frac{N_D}{n_1}\right)$$
, (2.24)
analogically for $N_A \gg N_D$
 $E_F = E_1 - k_D T \ln \left(\frac{N_A}{n_1}\right)$. (2.25)

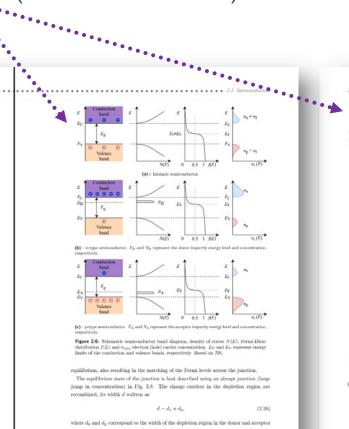
Using $n_1^2 - \text{const} \approx 1 \cdot 10^{20} \, \mathrm{cm}^{-6}$ from the Eq. (2.21) in a thermal equilibrium means that in both doping cases the concentration increase of one charge carrier is at the expense of the other. This effectively increases the total amount of charge carriers and thus also the conductivity. As an example, doping with donor impurities $n_{\rm B}\approx N_{\rm D}=1\cdot 10^{17}\,{\rm cm}^{-3}$ satisfies the condition for concentration of holes $n_p = 1 \cdot 10^3 \,\mathrm{cm}^{-3}$. The density of charge carries $n = n_{\rm e} \pm n_{\rm e}$ is then $n \approx 2 \cdot 10^{10} \, {\rm cm}^{-3}$ and $n \approx 1 \cdot 10^{12} \, {\rm cm}^{-3}$ for intrinsic and doped semiconductor, respectively

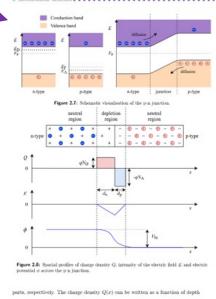
In reality, semiconductors are usually doped with both n- and p- types, in some cases even different concentrations of the same type (n⁺-on-n semiconductors). In such case the effective doping concentration is used, defined as an absolute value of the difference of the two.

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 depiction

region with an electric field opposing further diffusion. The system eventually reaches an





 $x \leq -d_x$

(2.27)

 $qN_{\rm D}, -d_{\rm u} < x \le 0$

 $-qN_A$, $0 < x \leq d_0$

 $0, d_p < x$

O(x) :

the electric field E(x) and potential $\phi(x)$ can be then derived from the Poisson's equation $\frac{d^2 \phi}{dx^2} = -\frac{Q(x)}{\varepsilon}.$ (2.28)The $z = z_0 z_0$ is a product of permittivity of vacuum z_0 and relative permittivity of the material cr After integrating Eq. (2.28) and applying the boundary conditions E(x) = 0 for both d_a, and d_a, the electric field is $E(x) = \frac{d\phi(x)}{d\phi(x)}$ $-2N_{D}(x+d_{n}), -d_{n} < x < 0$ (2.29) $\frac{qN_h}{x}(x - d_p), \quad 0 < x \le d_p$ Since the two values have to match at the contact position x = 0, a condition fulfilling charge neutrality in the semiconductor is obtained $N_D d_B = N_A d_B$ (2.30) Depletion depth is therefore proportional to the doping concentration of the two parts. In

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the case where one side is heavily doped with respect to the other, the region with larger concentrations 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

$$\phi(x) = \begin{cases} -\frac{g M_{D}}{2 L} (x + d_n)^2 + V, & -d_n < x \le 0 \\ \frac{g M_{D}}{2 L} (x - d_n)^2, & 0 < x \le d_\mu \end{cases}, \quad (2.31)$$

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

$$V = \frac{q}{q_p}(N_D d_p^2 + N_A d_p^2).$$
 (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)

$$V_{bl} = \frac{1}{q} (E_{F_b} - E_{F_b}) = \frac{k_B T}{q} \ln \left(\frac{N_A N_B}{n_l^2} \right).$$
 (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 c-h pairs. 73

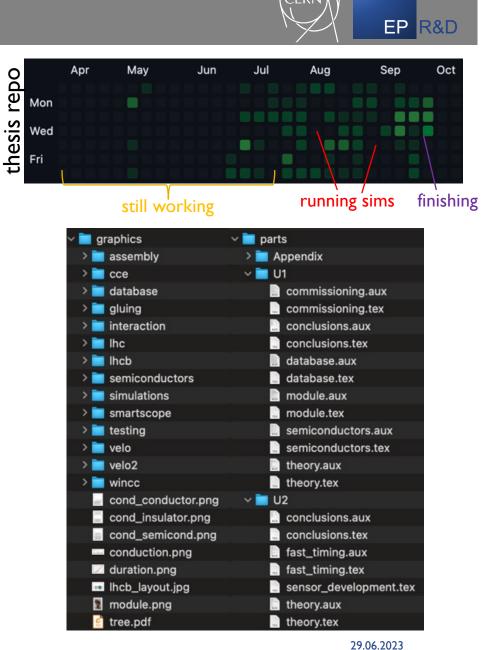
used draw.io for graphics free software available online or as an app

PETER.SVIHRA@CERN.CH **JOURNEY THROUGH THE THESIS WRITING**

29.06.2023

GOOD WRITING PRACTICES

- Have <u>git</u> (-hub / -lab) <u>repository</u> 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 ...)
- <u>Split the document</u> based on chapters/sections (makes simpler navigation and compilation chapters)
- <u>III Have backups of everything III</u> (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!



GOOD WRITING PRACTICES



- 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 <u>forward/backward references</u> 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





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 <u>no</u> to <u>work</u> and <u>no</u> to <u>meetings</u>

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SUMMARY AND LET'S DISCUSS



CONCLUSIONS



- 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





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