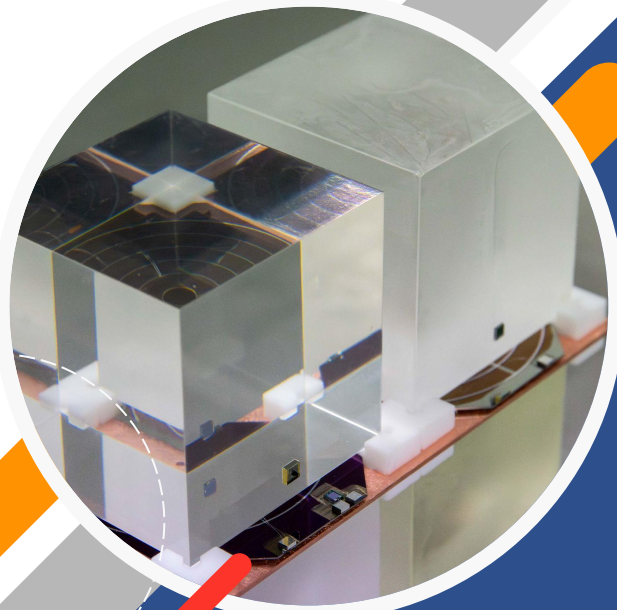
# CUPID

## The next generation $0\nu\beta\beta$ bolometric experiment

Mathieu Pageot
on behalf of JUST ME
NOT CUPID collaboration
they are not related to ... that



# Questions I'm going to answer

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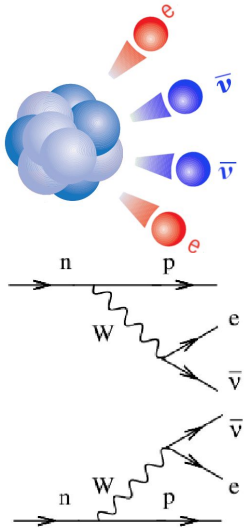
- Why are we still not in week end ?

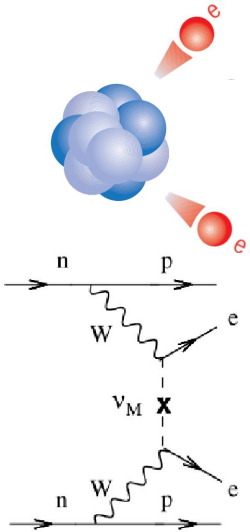
# What is the $0\nu\beta\beta$ decay ?

$2\nu2\beta$




Allowed By Standard Model

$0\nu2\beta$




Needs Beyond Standard Model Physics !

$$\Delta L = 2$$

Lepton Number Violation

$$\nu = \bar{\nu}$$

Majorana Particle

# Why is it important ?


## CP violation

This discovery could help us understand why the Universe is matter-dominated by finding a matter-creating process.


## See-Saw mechanism

Heavy right-handed Majorana neutrinos can provide a natural explanation of the smallness of neutrino masses via the See-Saw mechanism.

# How do we observe it ?

**Extremely rare process : $t_{1/2} > 10^{27}$ years**

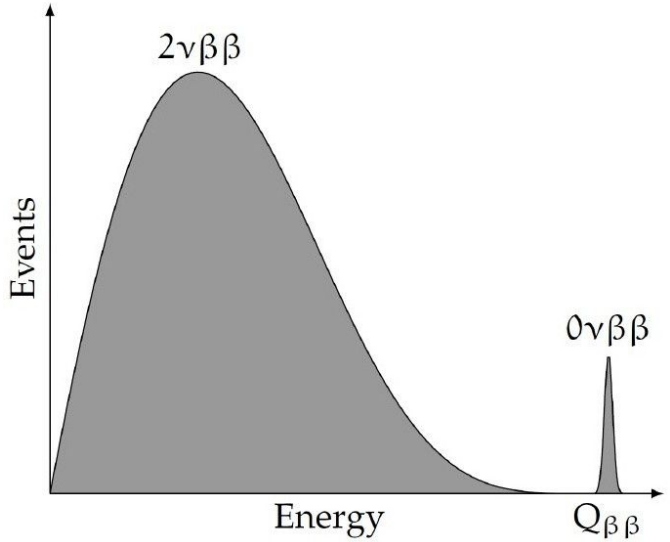
If :

- 10 people start a PhD
- each looking at 1 ton of atoms $^{100}$Mo
- during all 3 years of their PhD
- estimating the attention rate of a 1%
- (very high proportion of ADHD in the profession)

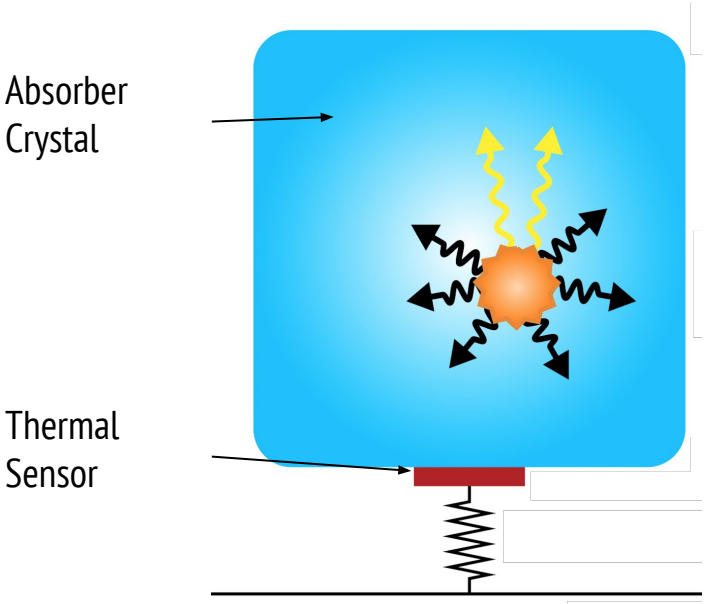
⟶ 50% chance of seeing it **once**.

**Me and the boyz looking for $0\nu\beta\beta$**

# How do we (really) observe it ?




Main signature of the 0$\nu\beta\beta$: peak at the Q-value of the reaction




## Cryogenic calorimeters

- High detection efficiency : $\beta\beta$ emitter embedded in the detector
- Flexible in isotope choice
- Excellent energy resolution ⟶ narrow 0$\nu\beta\beta$ peak
- Cost efficient
- Scalable as array of O(1000) crystals (100g - 1kg each)

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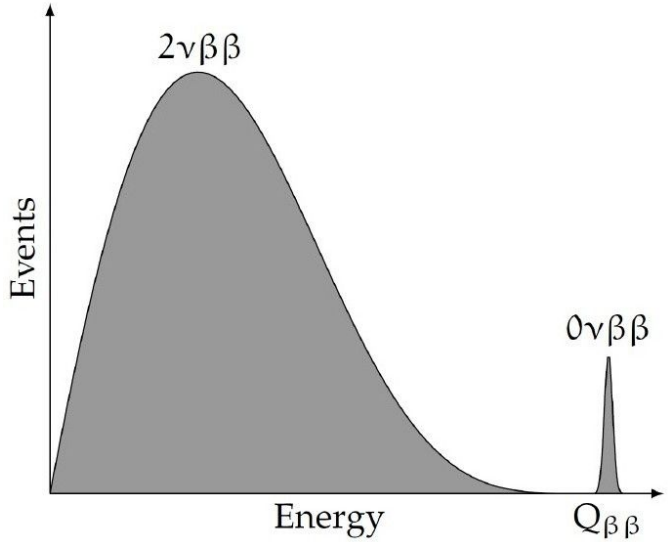


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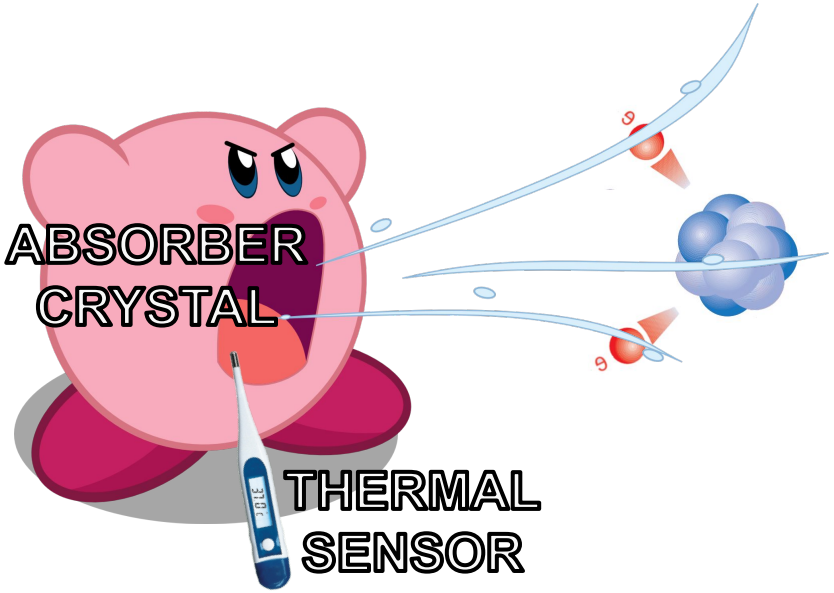


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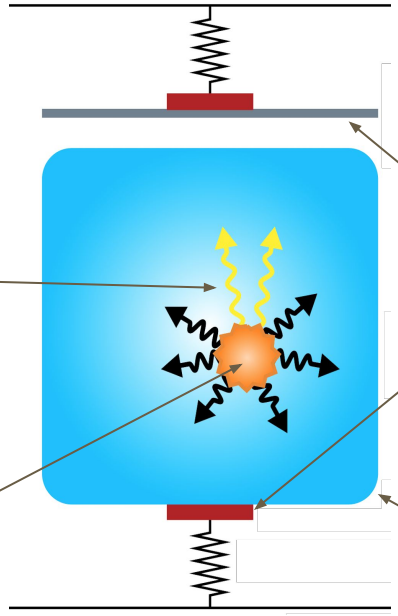
# How do we (really) observe it ?

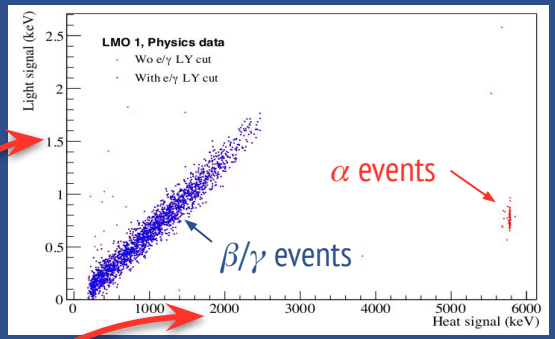
CUORE

Continuous & efficient operation of ton-scale cryogenic calorimeter over >7 years!

The $\alpha$ background is now the limiting factor.

# Just one more detector plea




*CUPID Mo: EPJ C* arXiv:1909.02994

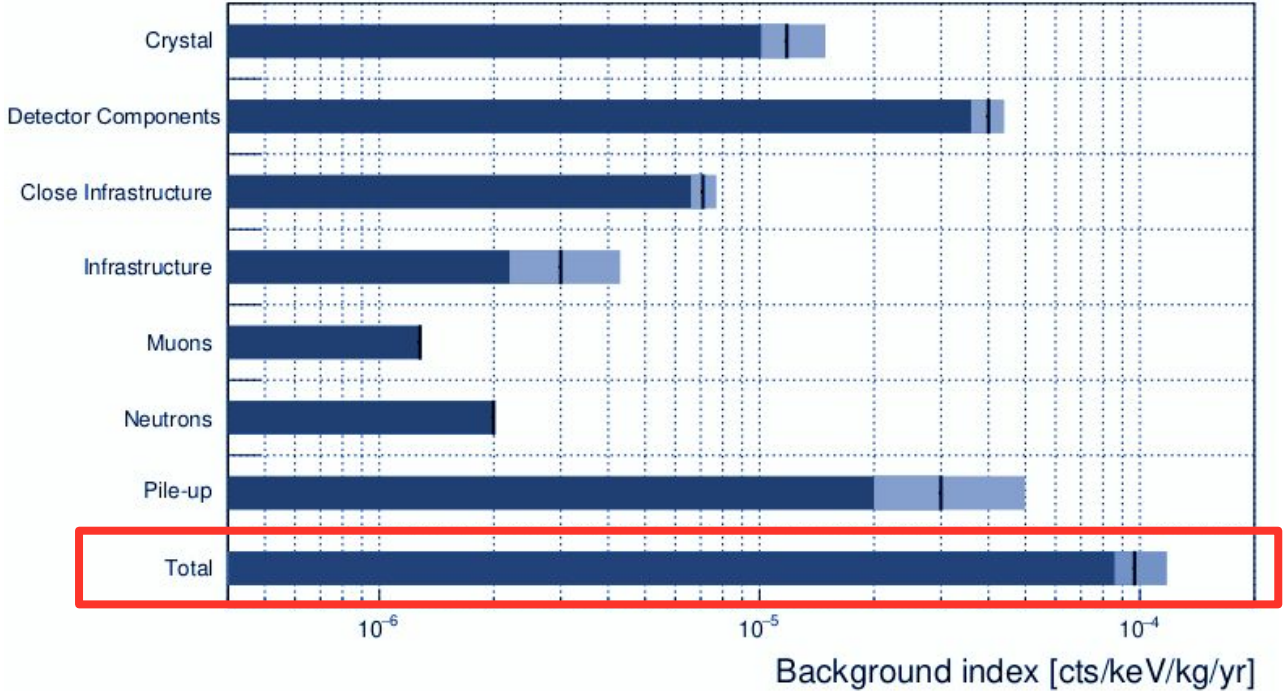
Particle Identification with light detector to discriminate between $\alpha$ from $\beta/\gamma$


# What we really see (Spoil : Noise)

Mainly due to surface contamination:
mitigated by a clean assembly

Coming from outside the detector structure :
mitigate by shielding and vetos

Two $2\nu\beta\beta$ events occurring simultaneously which sum of energy ends up in the ROI:
mitigate by using the fast light channel



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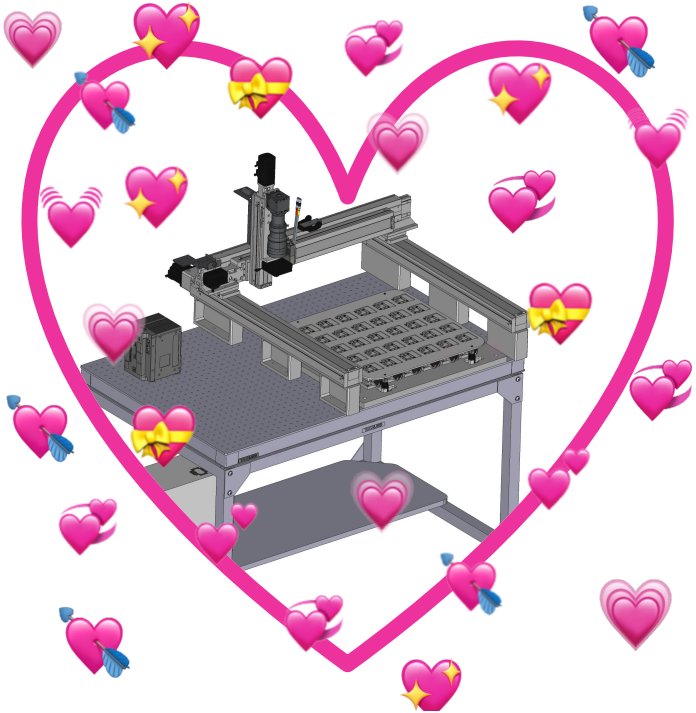
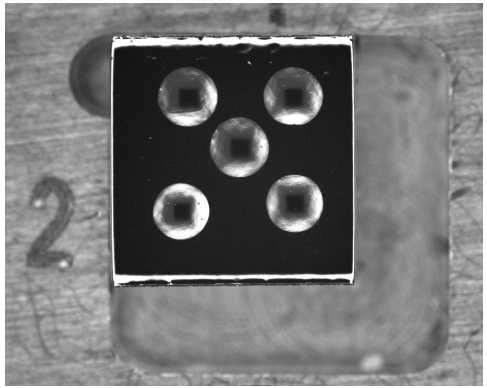
# What do I do ?
# Gluing Robot

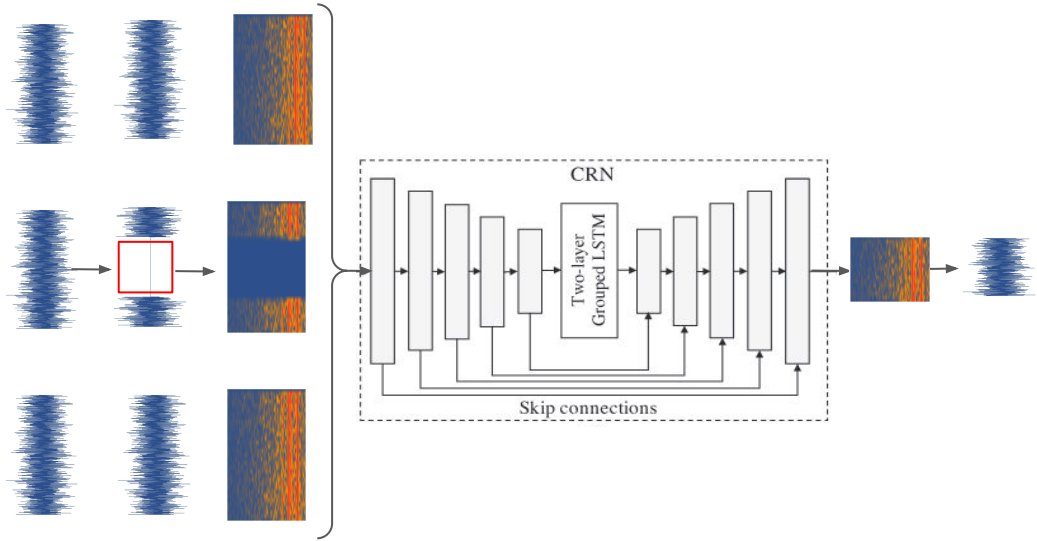





PDSDs

# Denoising

A Neural Network designed to predict and subtract noise from signal pulses by using data from surrounding time windows and neighboring channels.



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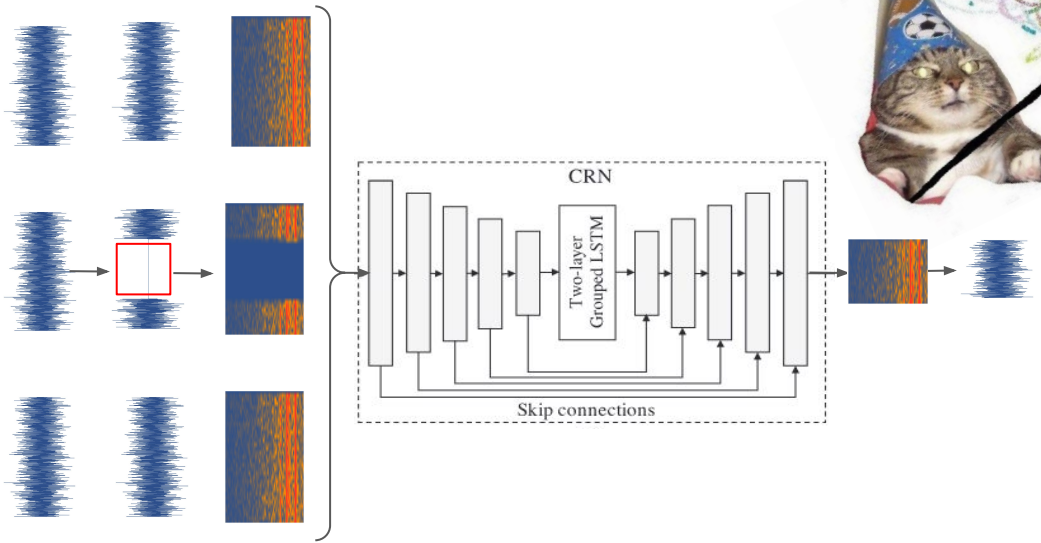
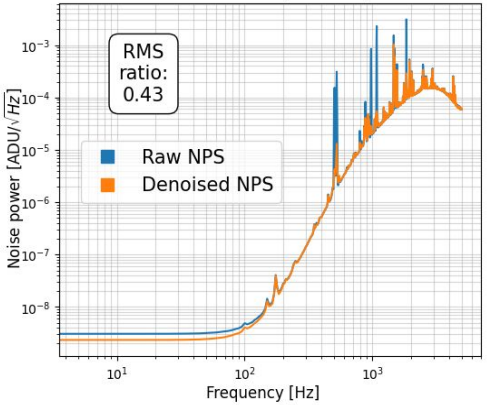
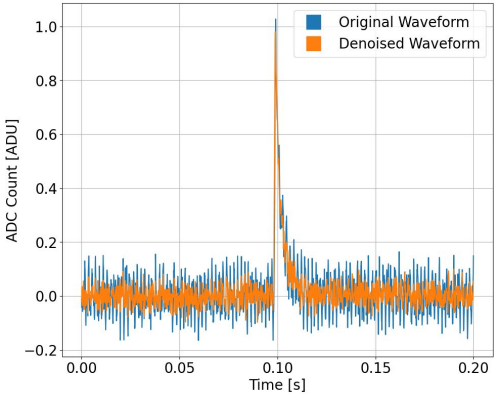






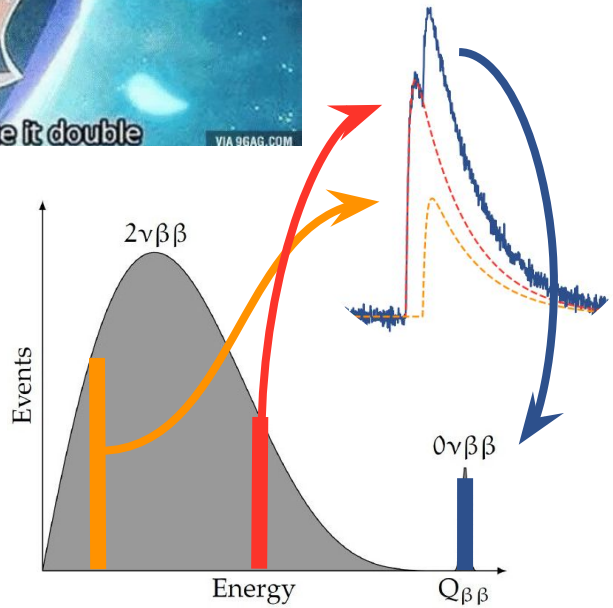



# $2\nu\beta\beta$ pile-up

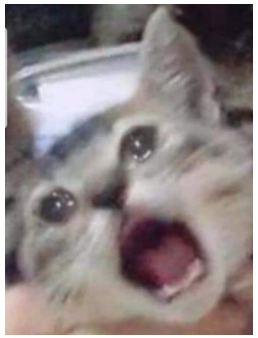

- $^{100}$Mo has a higher rate of $2\nu\beta\beta$ than $^{130}$Te.
- Two $2\nu\beta\beta$ events close enough in time that are not resolved, but reconstructed as a single event

→ **background at the Q-value**

- Parameters that determine the ability to identify pile-up events: rise time and signal-to-noise ratio



# Pile-up : a bit of analytic computation



$$\hat{A}_1 = Re(\sum_f X(f)H(f)) = A + Re(\sum_f N(f)H(f)) \quad (1)$$

$$\hat{A}_2 = \frac{\sum_t x_H(t)s_H(t)}{\sum_t s_H(t)^2}$$

$$\sigma^2 = Var(R) = \mathbb{E}[Re(A^2_{noise})] = \mathbb{E}[A_{noise}A^*_{noise}] - \mathbb{E}[A^2_{noise}] = \frac{1}{2}\sum_f \Phi(f)^2|H(f)|^2 P_N(f) = \frac{1}{2}\sum_f \Phi(f)^2 W(f)$$

$$R_{pileup} = \frac{\hat{A}_{1,pileup}}{\hat{A}_{2,pileup}} = \frac{(1-r)A + rA\sum_f W(f)e^{-j2\pi f\Delta t} + Re(\sum_f N(f)H(f))}{(1-r)A + rA\frac{\sum_f W(f)^2 e^{-j2\pi f\Delta t}}{\sum_f W(f)^2} + \frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2}} = \frac{(1-r) + r\sum_f W(f)e^{-j2\pi f\Delta t} + \frac{1}{A}Re(\sum_f N(f)H(f))}{(1-r+r\frac{\sum_f W(f)^2 e^{-j2\pi f\Delta t}}{\sum_f W(f)^2} + \frac{1}{A}\frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2}} \quad (6)$$

Using Parseval's Theorem:

$$\hat{A}_2 = \frac{Re(\sum_f X(f)H(f)S^*(f)H^*(f))}{\sum_f |S(f)H(f)|^2)} = \frac{\sum_f X(f)H(f)W(f)}{\sum_f W(f)^2} = A + \frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \quad (3)$$

Now considering the Pileup we get :

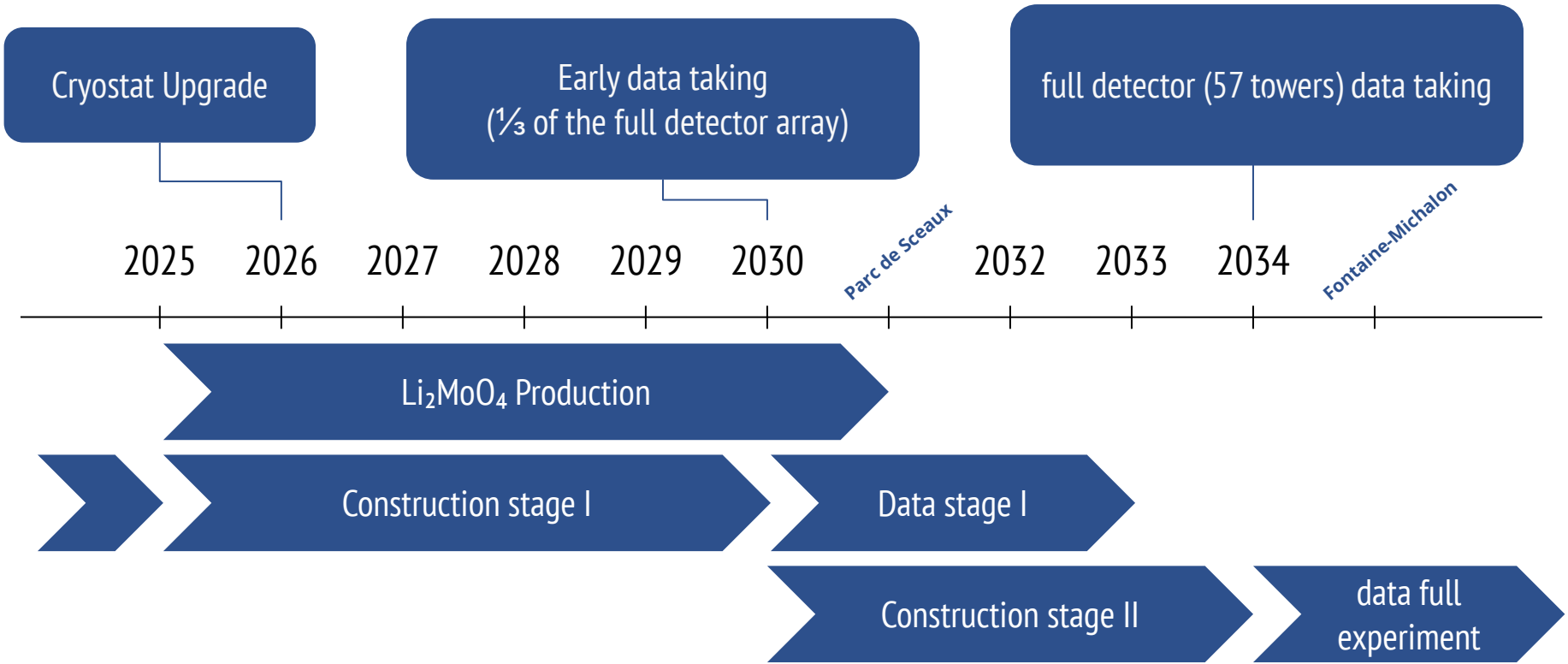
$$\hat{A}_{1,pileup} = \sum_f X_{pileup}(f)H(f) = (1-r)A + rA\sum_f W(f)e^{-j2\pi f\Delta t} + Re(\sum_f N(f)H(f)) \quad (4)$$

$$\hat{A}_{2,pileup} = \frac{\sum_f X_{pileup}(f)H(f)W(f)}{\sum_f W(f)^2} = (1-r)A + rA\frac{\sum_f W(f)^2 e^{-j2\pi f\Delta t}}{\sum_f W(f)^2} + \frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \quad (5)$$

Taylor expending R considering $\frac{\sum_f W(f)^2 e^{-j2\pi f\Delta t}}{\sum_f W(f)^2} \sim 1$ since $\Delta t \sim 0$ and $\frac{1}{A}\frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \sim 0$ (rather good signal to noise ratio (SNR))

$$\begin{aligned} R_{pileup} &= (1-r) + r\sum_f W(f)e^{-j2\pi f\Delta t} + \frac{1}{A}Re(\sum_f N(f)H(f)) \\ &\quad + r - r\frac{\sum_f W(f)^2 e^{-j2\pi f\Delta t}}{\sum_f W(f)^2} - \frac{1}{A}\frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \\ &= 1 + rRe(\sum_f (1 - \frac{W}{\sum_{f'} W(f')^2})W(f)e^{-j2\pi f\Delta t}) + \frac{1}{A}\sum_f (1 - \frac{W}{\sum_{f'} W(f')^2})N(f)H(f) \\ &= 1 + rRe(\Phi(f)W(f)e^{-j2\pi f\Delta t})) + \frac{1}{A}Re(\sum_f \Phi(f)N(f)H(f)) \\ &= 1 + B(r,\Delta t) + \frac{A_{noise}}{A} \end{aligned} \quad (7)$$

# CUPID Timeline



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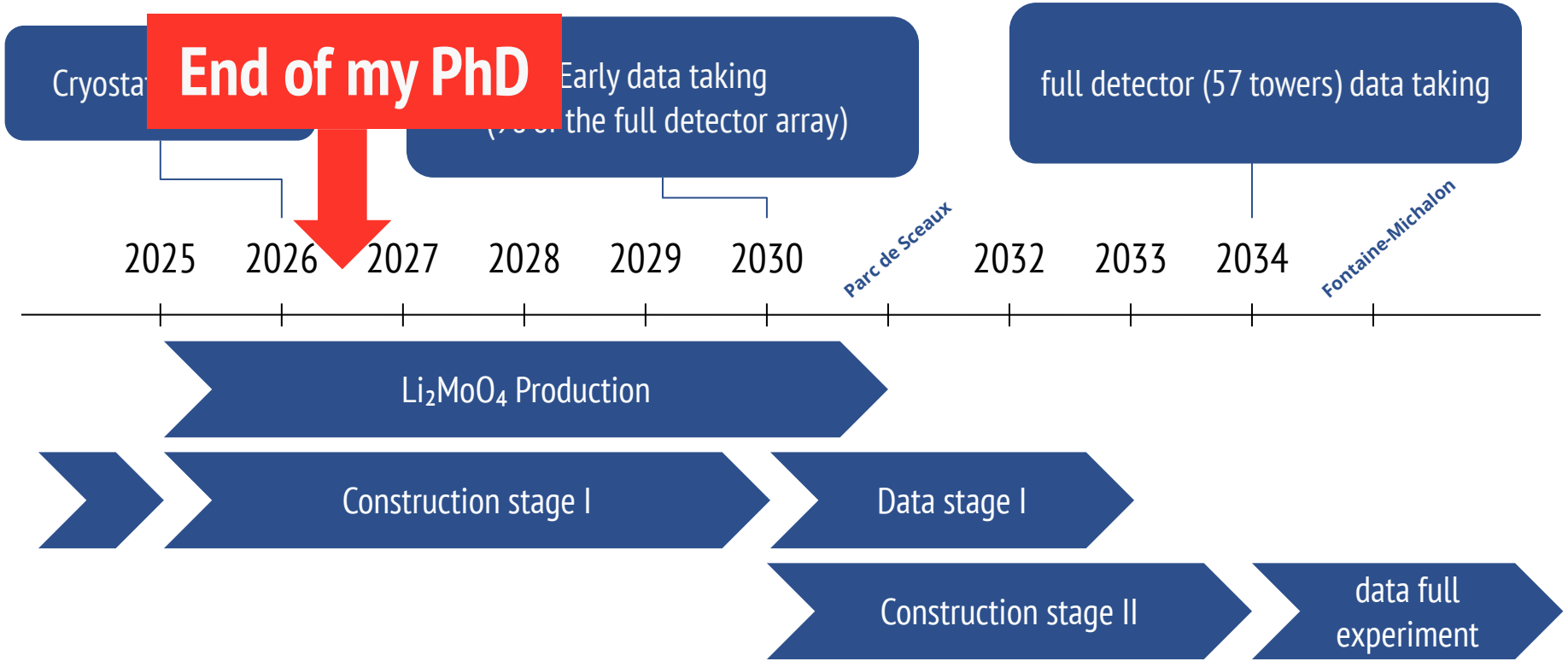

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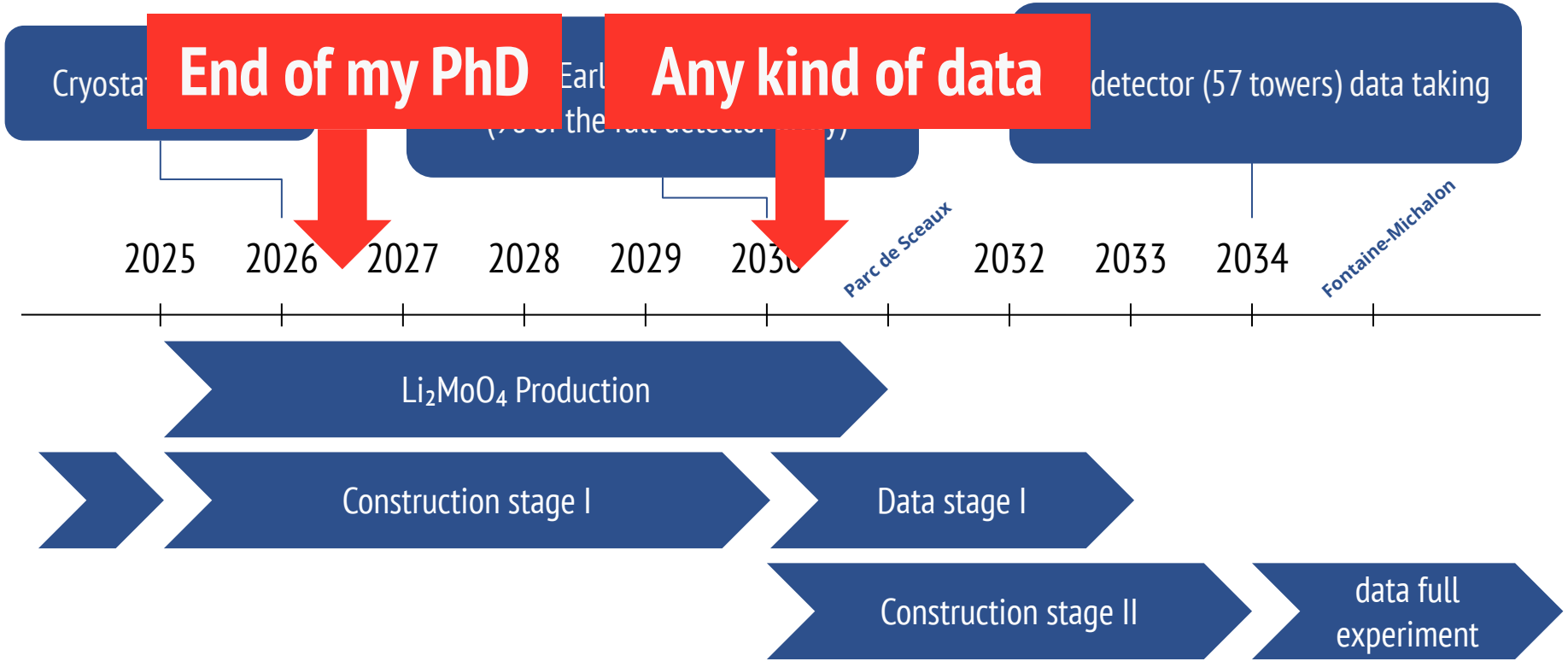
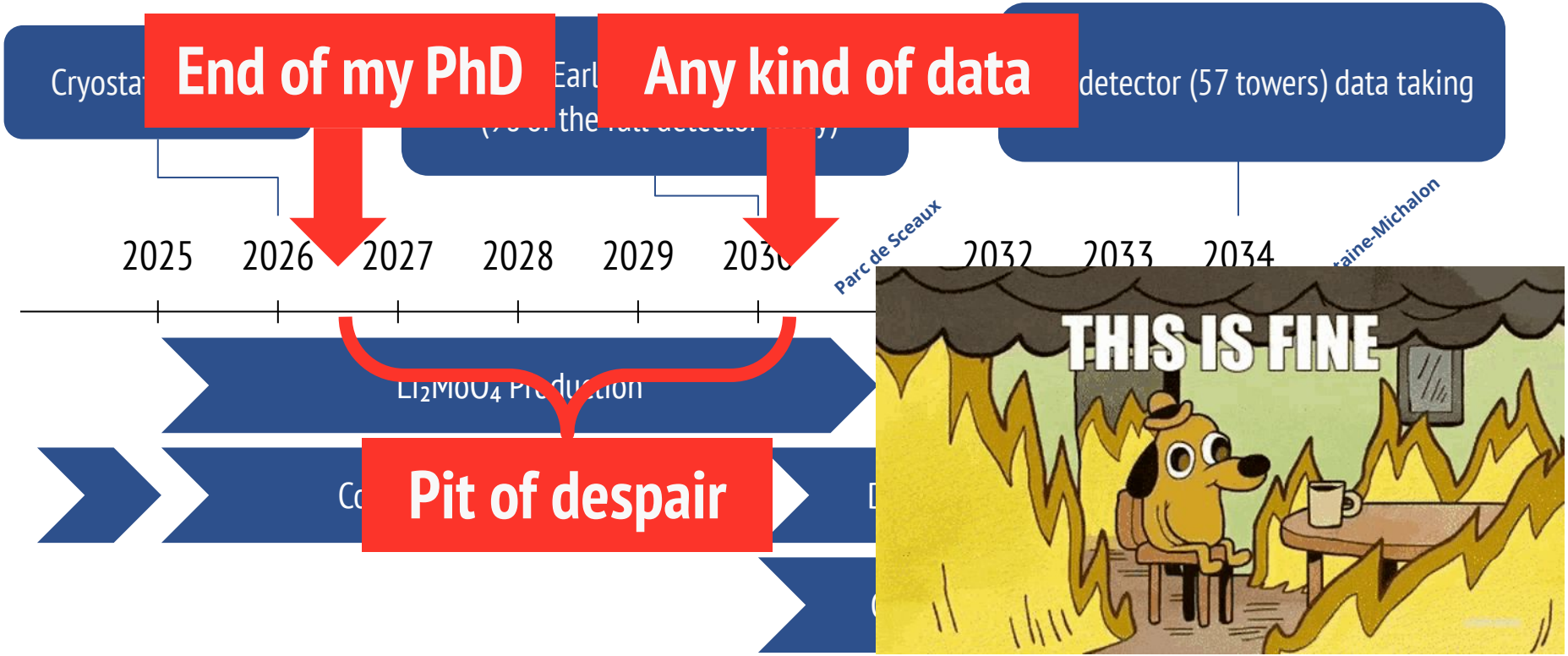
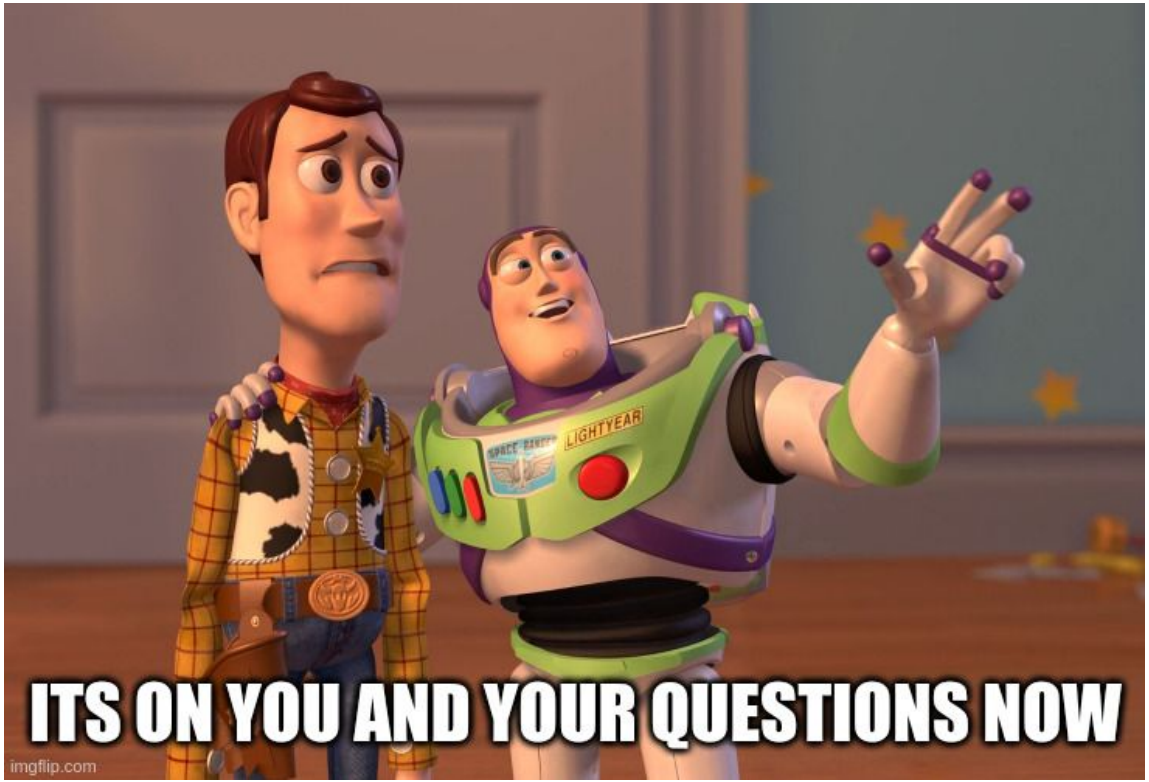
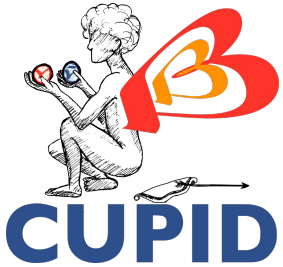


# CUPID Timeline

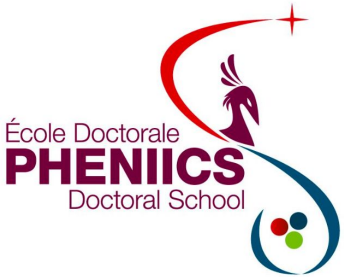


# Why are we still not in week end ?





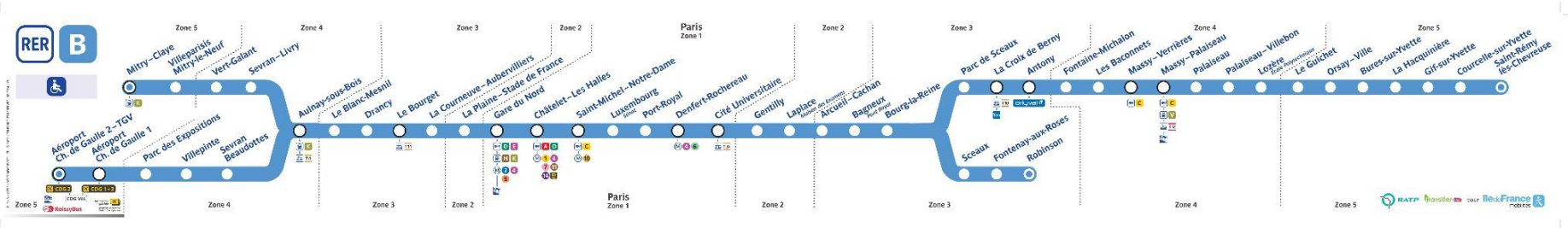





# Thank you !

(No cats have been harmed during this presentation)
(my feelings during the PhD have been tho)

CUPID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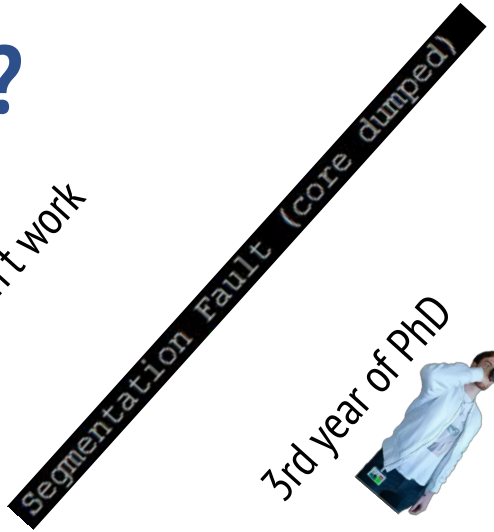
Zone 4
Zone 3
Zone 2
Paris
Zone 1
Mitry–Claye
Villeparisis
Mitry-le-Neuf
Vert-Galant
Sevran–Livry
Aéroport Ch.-de Gaulle 2–TGV
Aéroport Ch.-de Gaulle 1
Parc des Expositions
Villepinte
Sevran Beaudottes
Aulnay-sous-Bois
Le Blanc-Mesnil
Drancy
Le Bourget
La Courneuve–Aubervilliers
La Plaine–Stade de France
Gare du Nord
Châtelet–Les Halles
Saint-Michel–Notre-Dame
Luxembourg
Port-Royal
Denfert-Rochereau
Cité Universitaire
Gentilly
Laplace
Arcueil–Cachan
Bagneux
Bourg-la-Reine
Parc de Sceaux
La Croix de Berny
Antony
Fontaine-Michalon
Les Baconnets
Massy–Verrières
Massy–Palaiseau
Palaiseau
Palaiseau–Villebon
Lozère
Le Guichet
Orsay–Ville
Bures-sur-Yvette
La Hacquinière
Gif-sur-Yvette
Courcelle-sur-Yvette
Saint-Rémy lès-Chevreuse
Sceaux
Fontenay-aux-Roses
Robinson
RATP
Transilien
IledeFrance mobilités

# How am I doing ?

2nd year of PhD

1st year of PhD

Experiment doesn't work



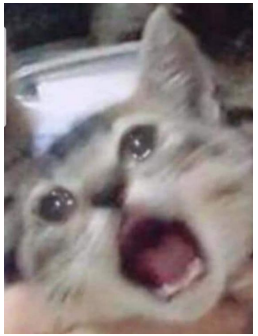

3rd year of PhD



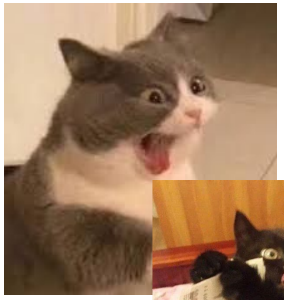
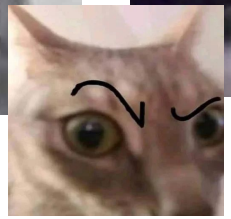
Fontaine-Michalon

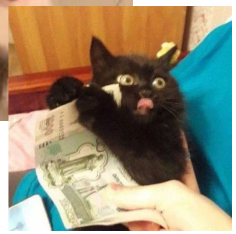
meeting at 8:30

CUPID





# 28 cats in the main presentation
# + 7 extras