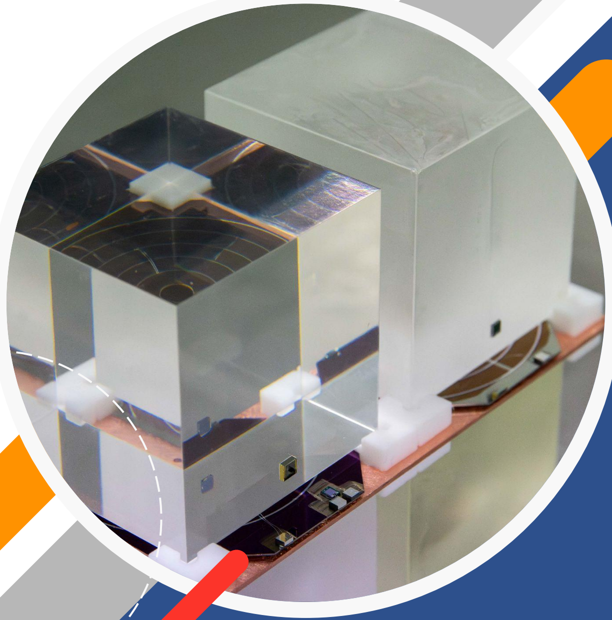
CUPID

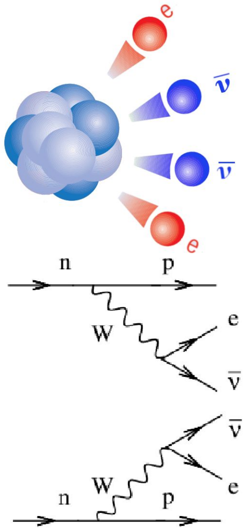
The next generation $0\nu\beta\beta$ bolometric experiment

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



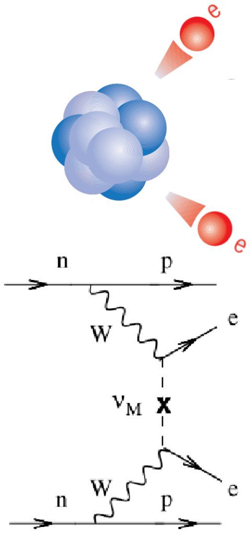
What is the $0\nu\beta\beta$ decay ?

$2\nu 2\beta$



Allowed By Standard Model

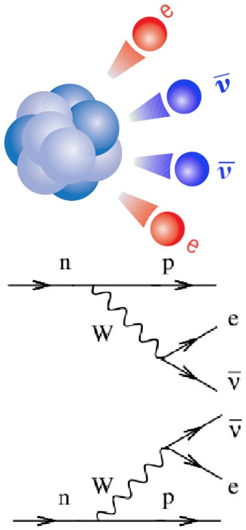
$0\nu 2\beta$



Needs Beyond Standard Model Physics !

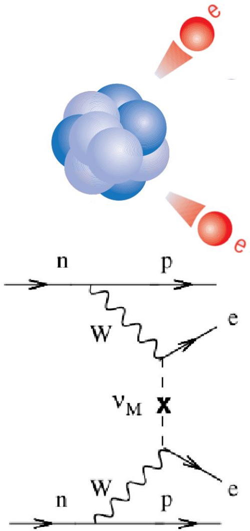
What is the $0\nu\beta\beta$ decay ?

$2\nu2\beta$



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 ?

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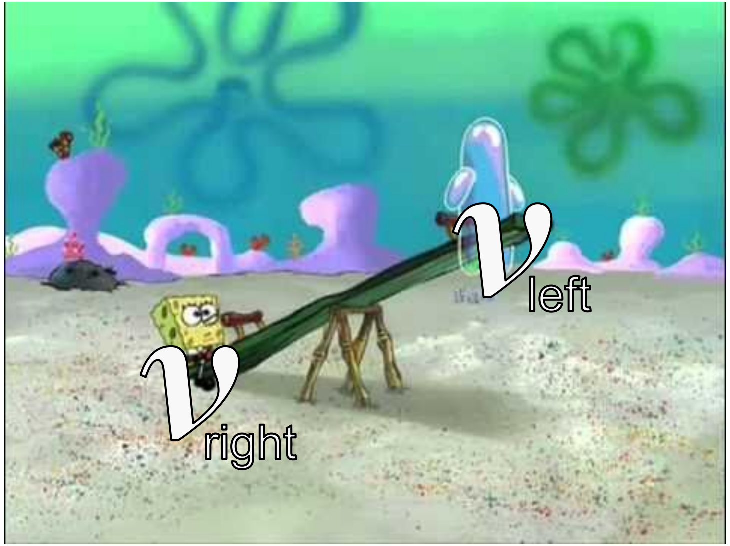
Matter - Antimatter asymmetry



See-Saw mechanism

How do we observe it ?

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Extremely rare process : $t_{½}$ > 10^{27} years

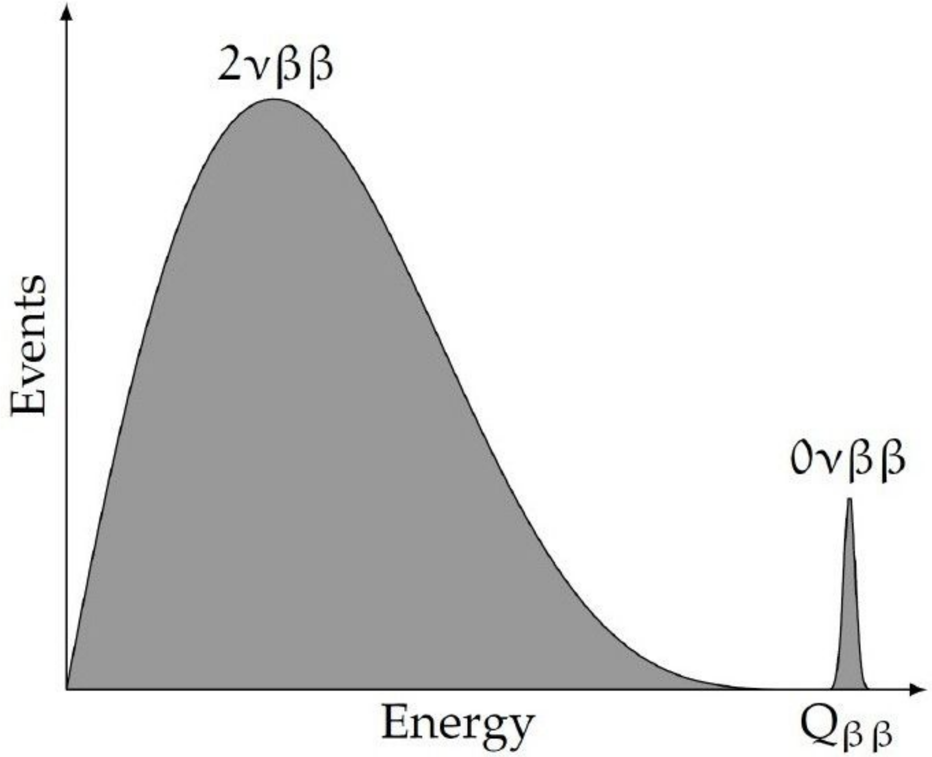
If :

- 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)

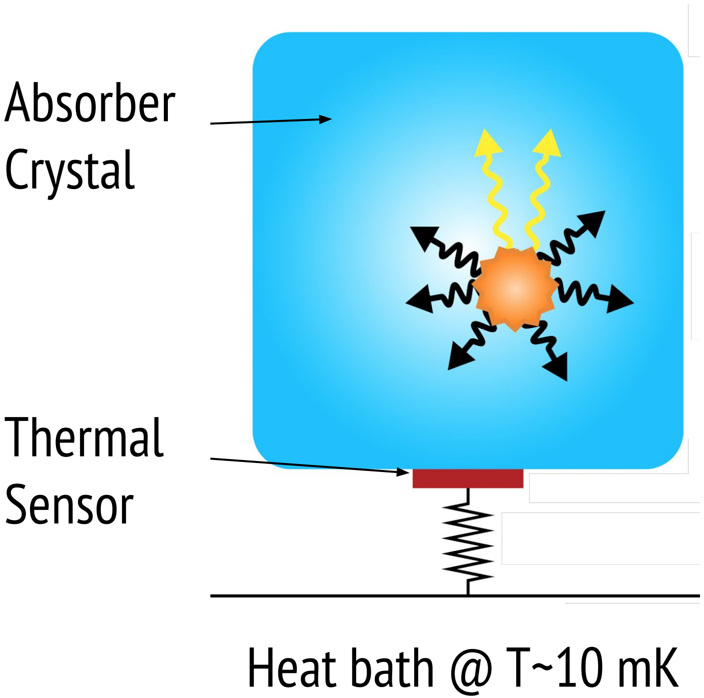
→ 50% chance of seeing it **once**.

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

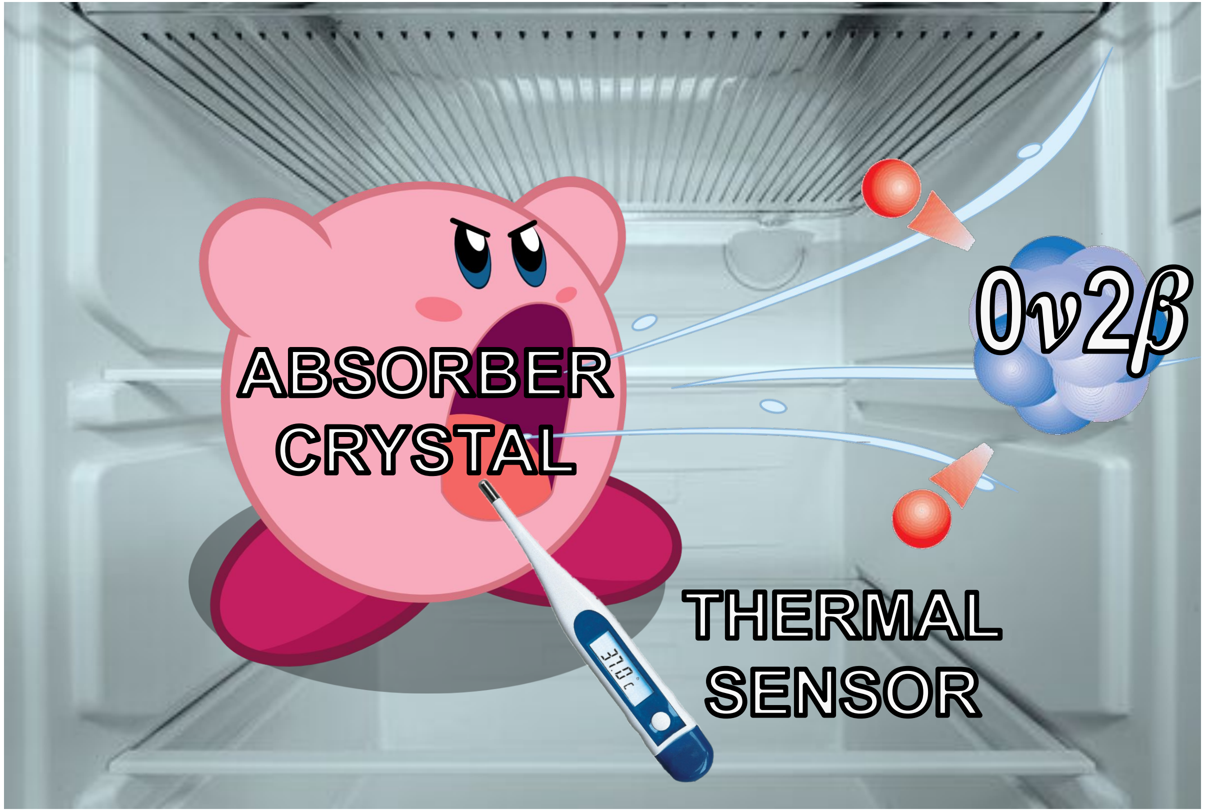
How do we (really) observe it ?
Signature



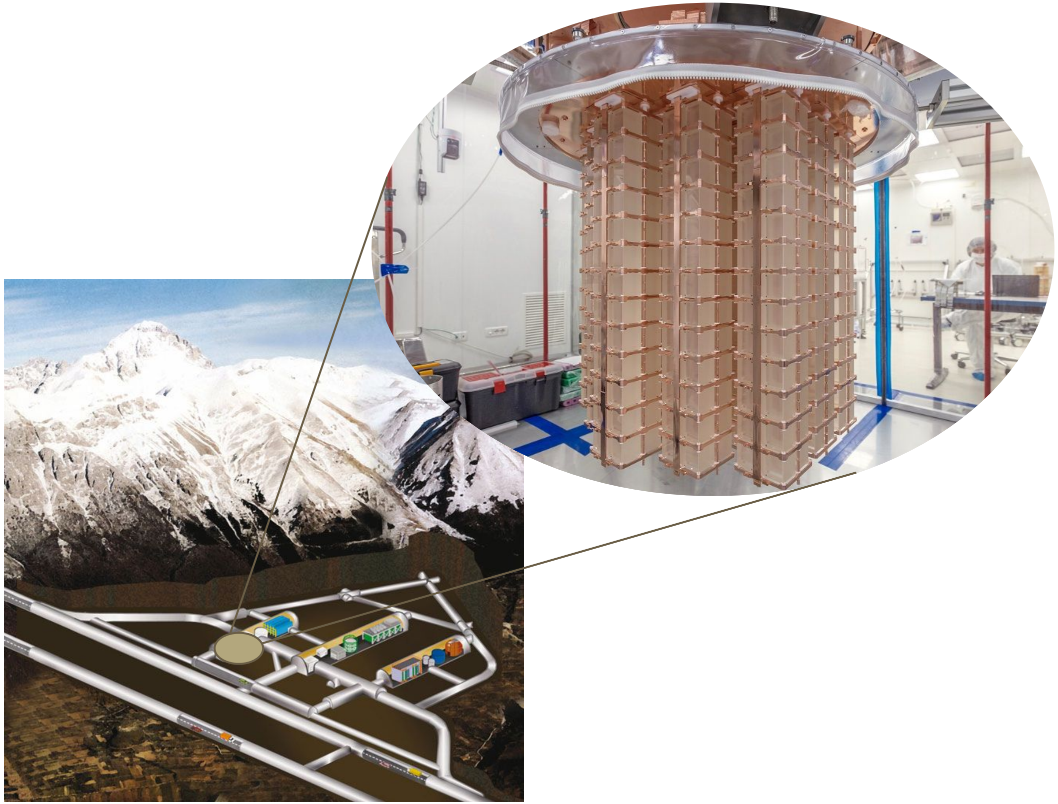
How do we (really) observe it ?
Cryogenic calorimeters



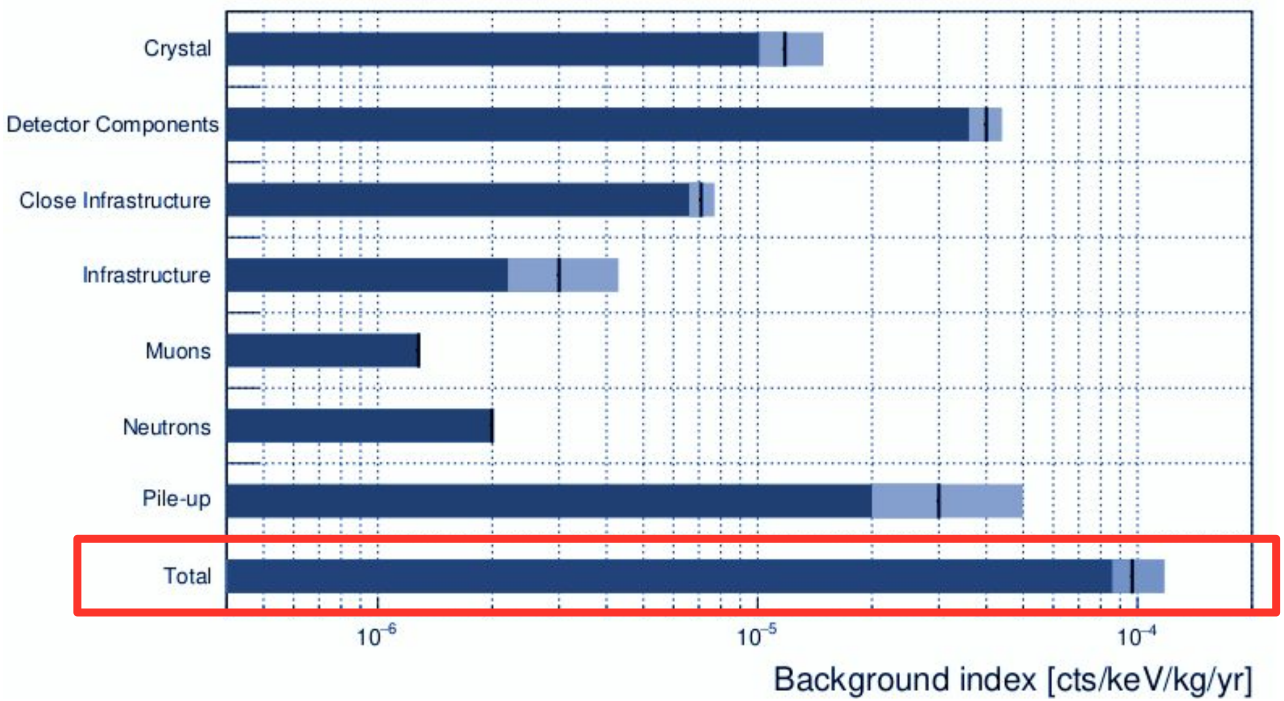
How do we (really) observe it ?



How do we (really) observe it ?

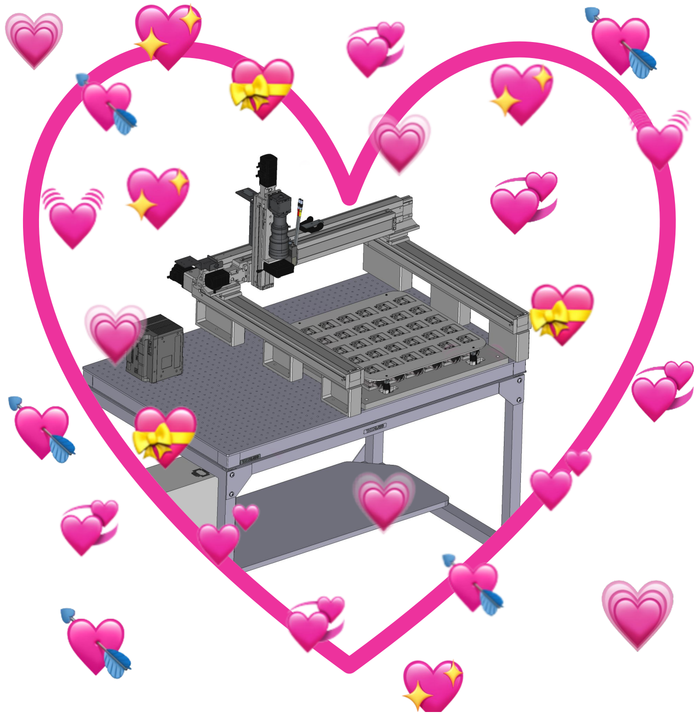


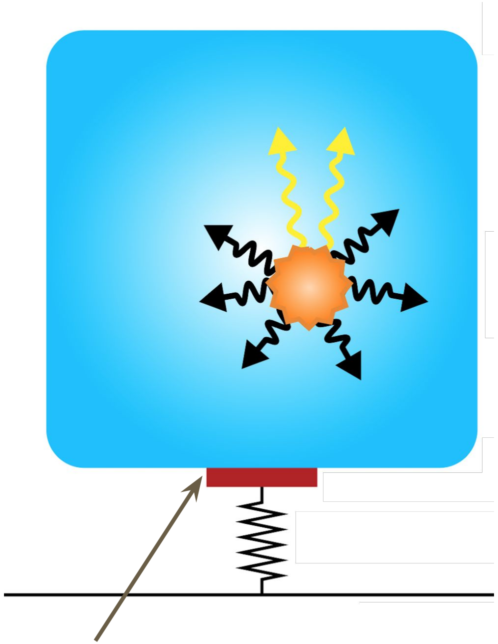
What we really see (Spoil : Noise)



What we really see (Spoil : Noise)

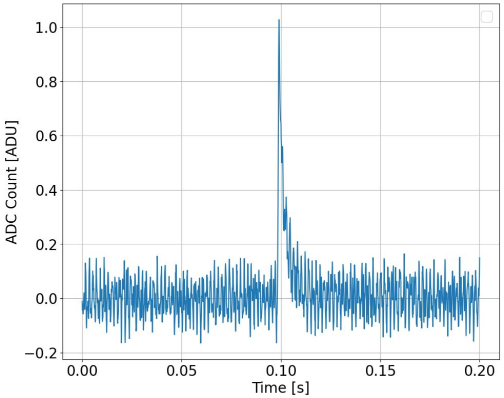
What do I do ?
Gluing Robot



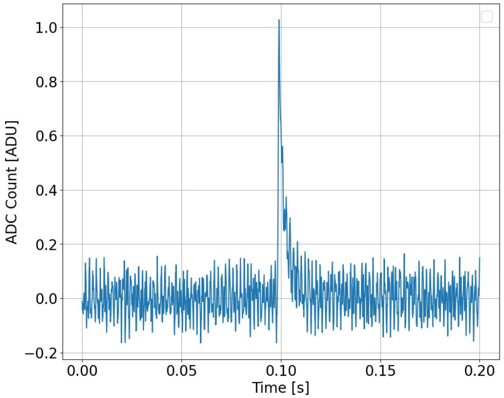


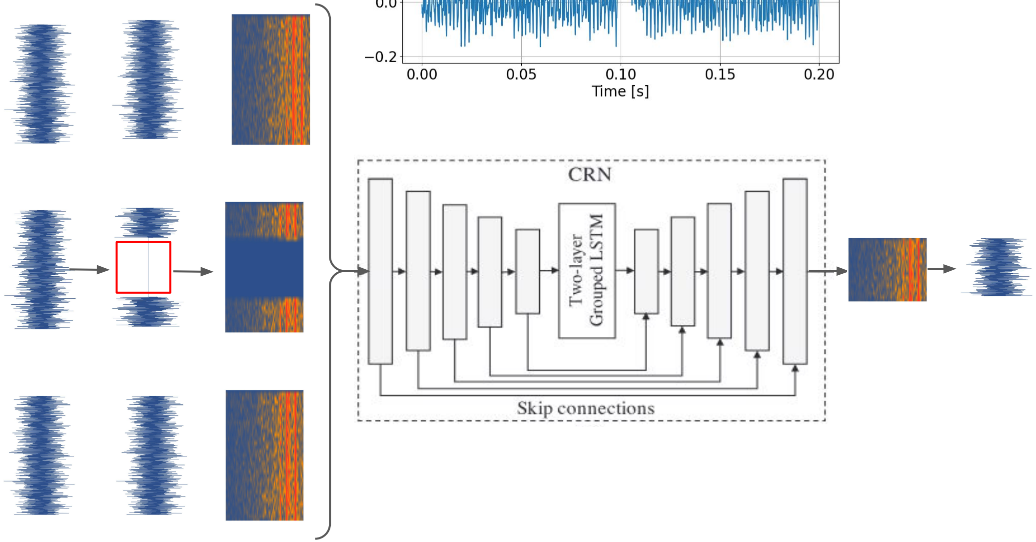
Glue this

Denoising

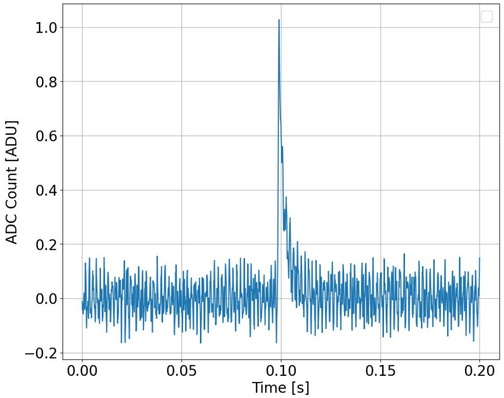


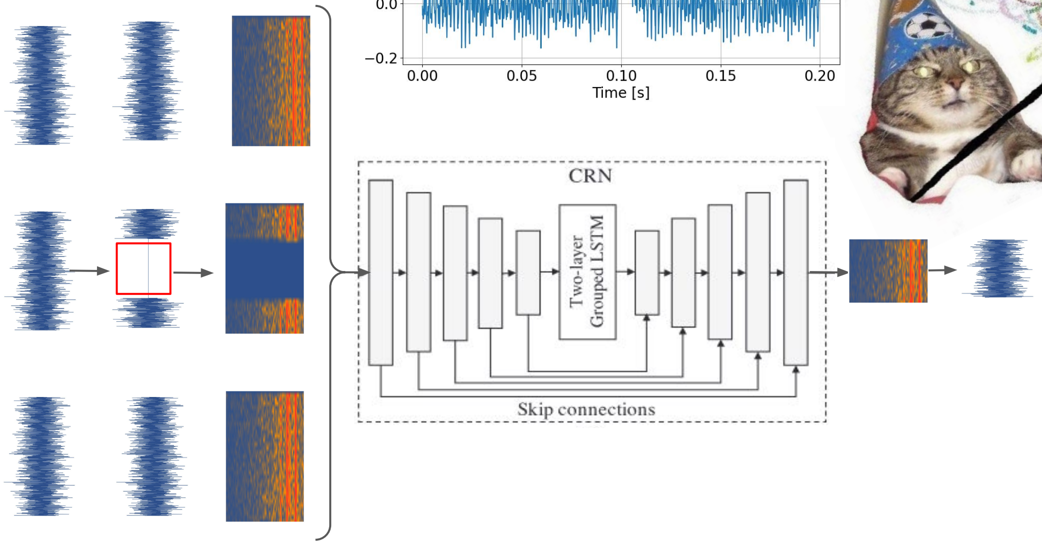
Denoising


ADC Count [ADU]
Time [s]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.00
0.05
0.10
0.15
0.20

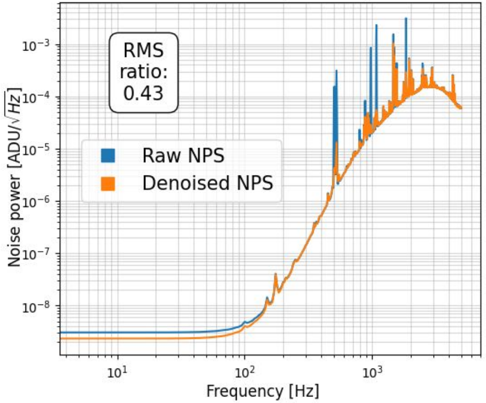

CRN
Two-layer Grouped LSTM
Skip connections

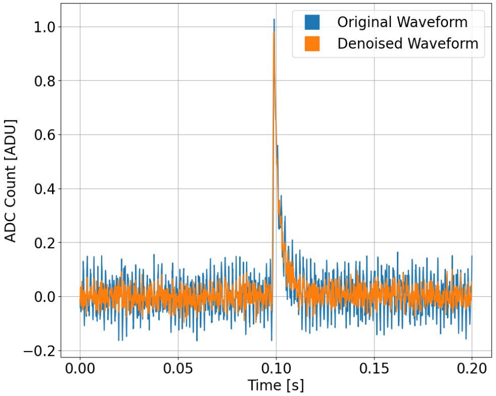
Denoising


ADC Count [ADU]
Time [s]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.00
0.05
0.10
0.15
0.20


CRN
Two-layer Grouped LSTM
Skip connections


Whoosh

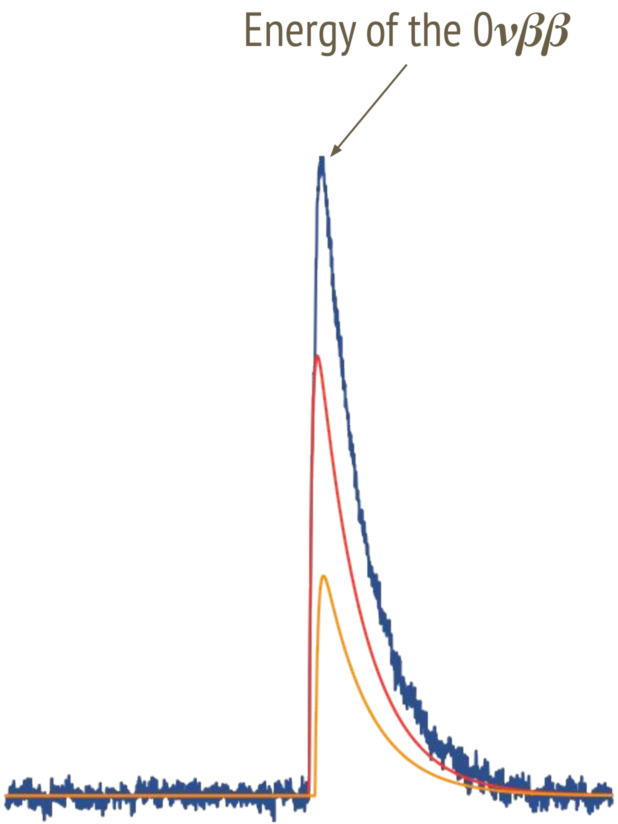

RMS ratio: 0.43
Raw NPS
Denoised NPS
Noise power [ADU/√Hz]
Frequency [Hz]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{1}
10^{2}
10^{3}


Original Waveform
Denoised Waveform
ADC Count [ADU]
Time [s]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.00
0.05
0.10
0.15
0.20

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

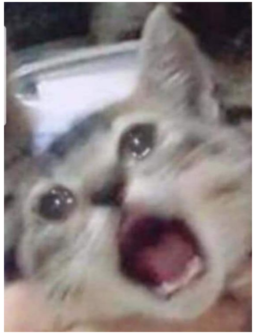
$2\nu\beta\beta$ pile-up

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



Pile-up : a bit of analytic computation

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



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

Using Parseval's Theorem:

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

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

Now considering the Pileup we get :

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

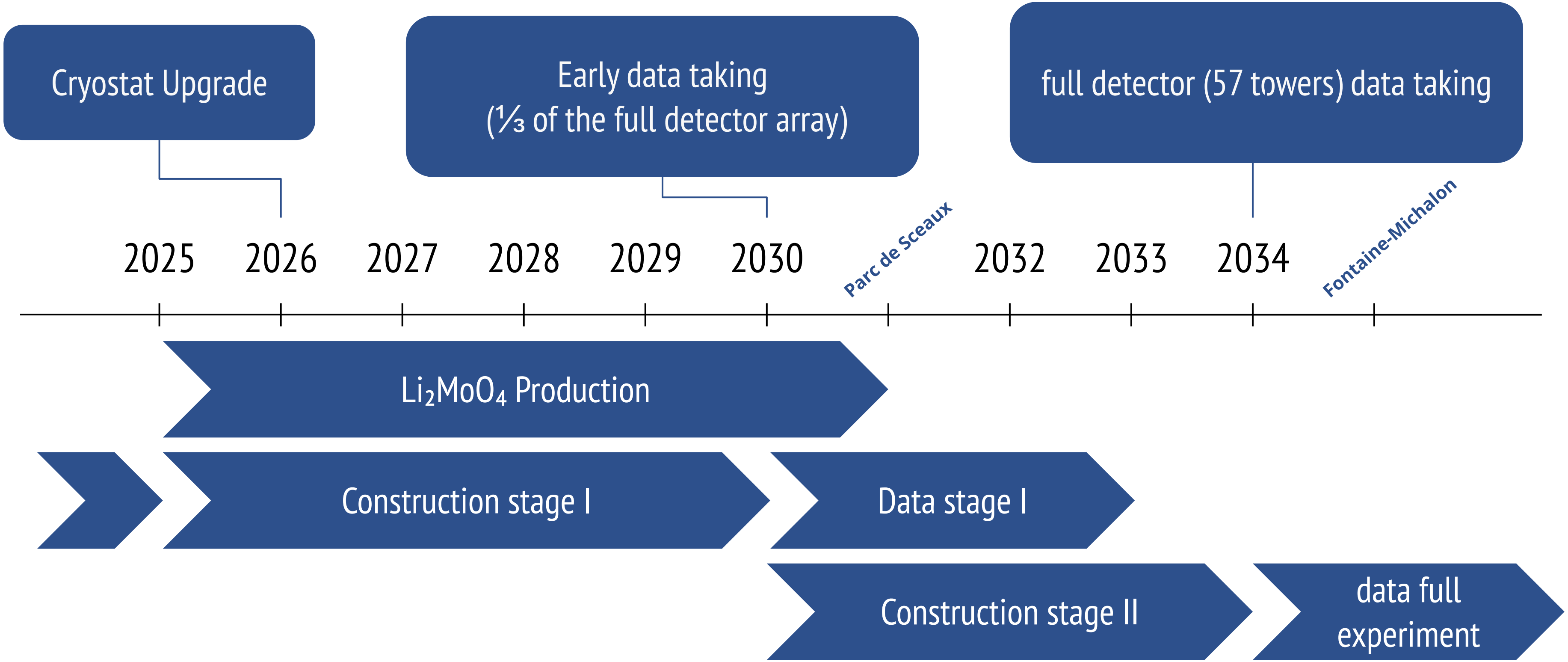
$$\hat{A}_{2,pileup} = \frac{\sum_f X_{pileup}(f)H(f)W(f)}{\sum_f W(f)^2} = (1-r)A + rA \frac{\sum_f W(f)^2 e^{-j2\pi f \Delta t}}{\sum_f W(f)^2} + \frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \qquad (5)$$

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

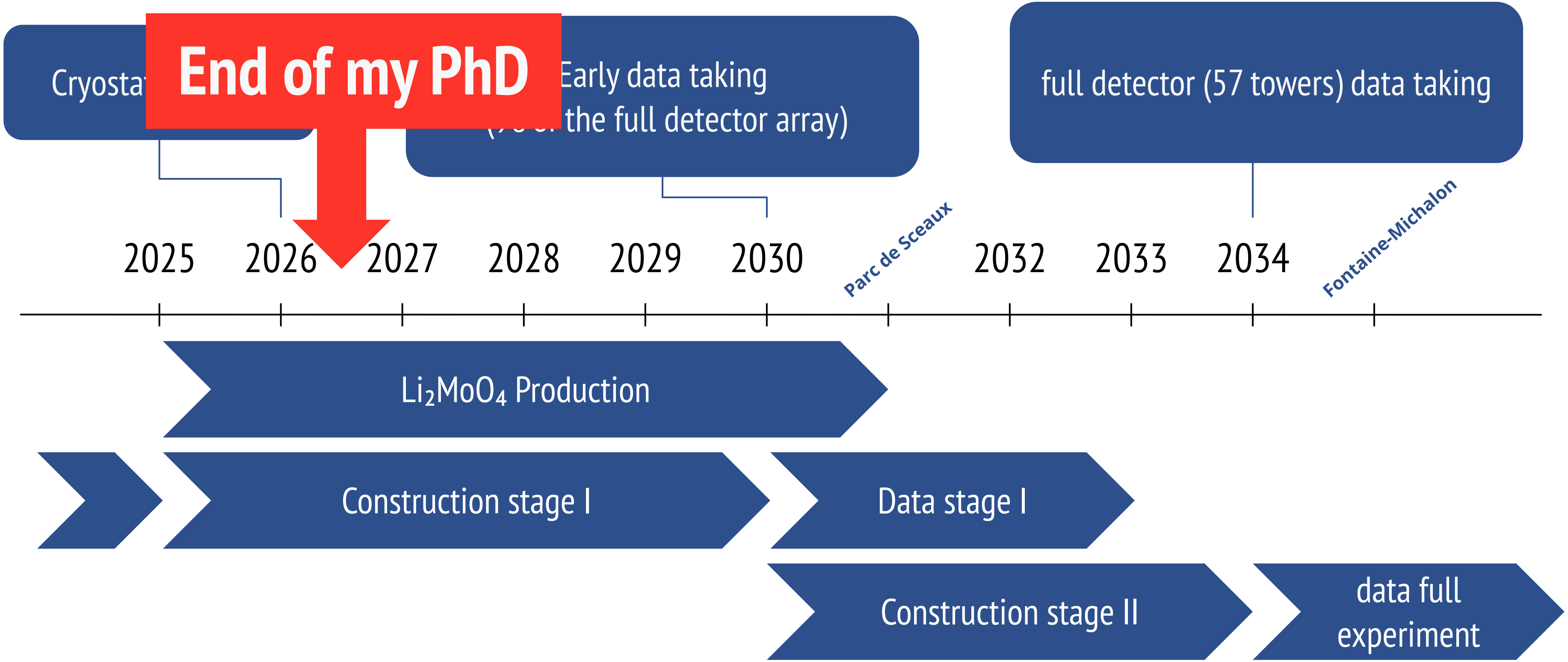
Taylor expending R considering $\frac{\sum_f W(f)^2 e^{-j2\pi f \Delta t}}{\sum_f W(f)^2} \sim 1$ since $\Delta t \sim 0$ and $\frac{1}{A}\frac{\sum_f N(f)H(f)W(f)}{\sum_f W(f)^2} \sim 0$ (rather good signal to noise ratio (SNR))

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

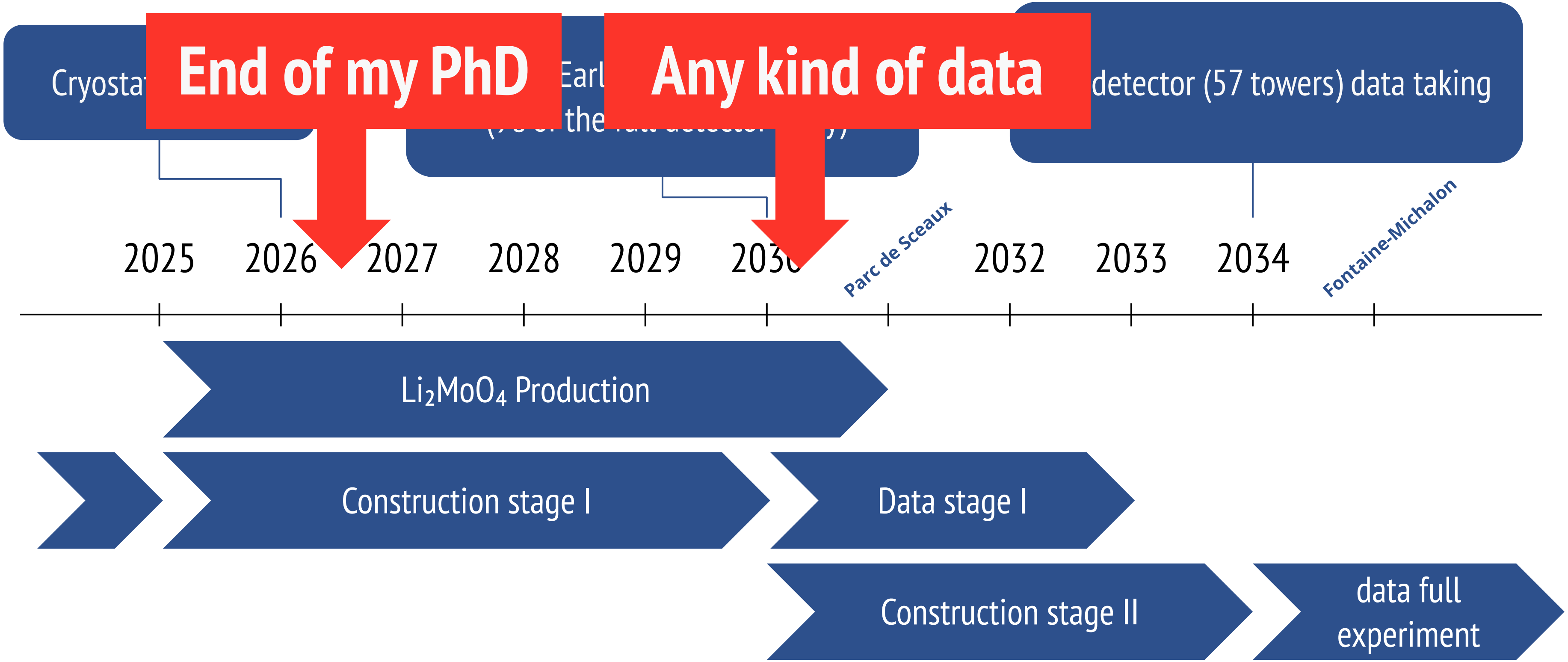
CUPID Timeline



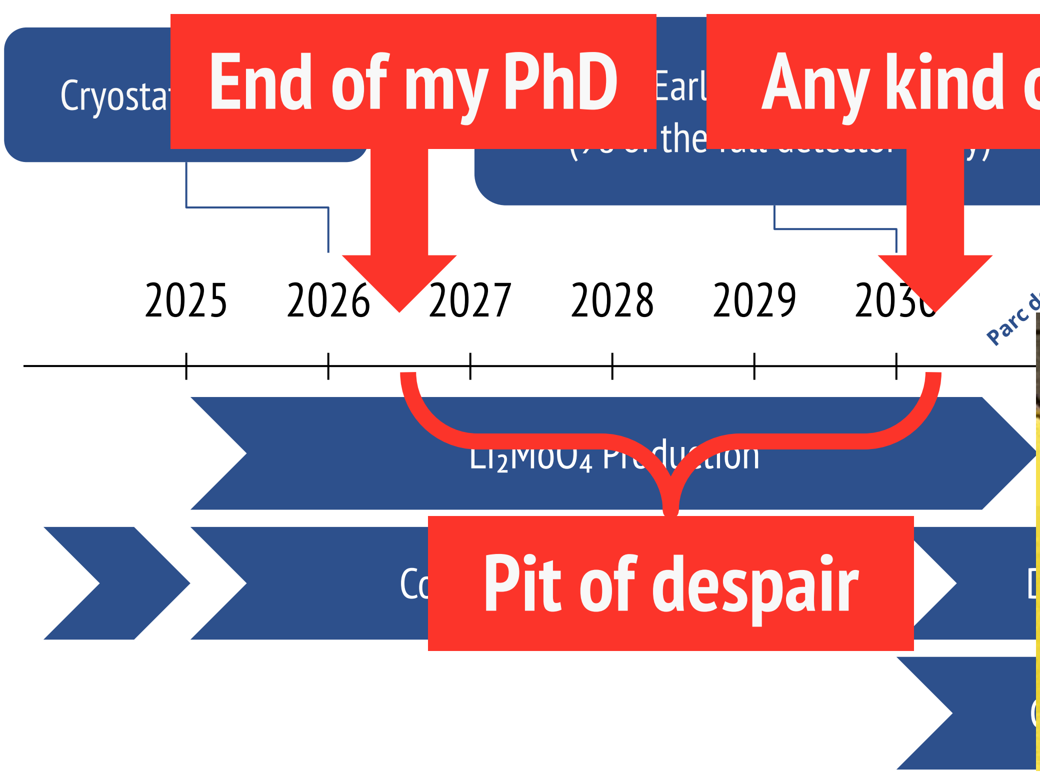
CUPID Timeline

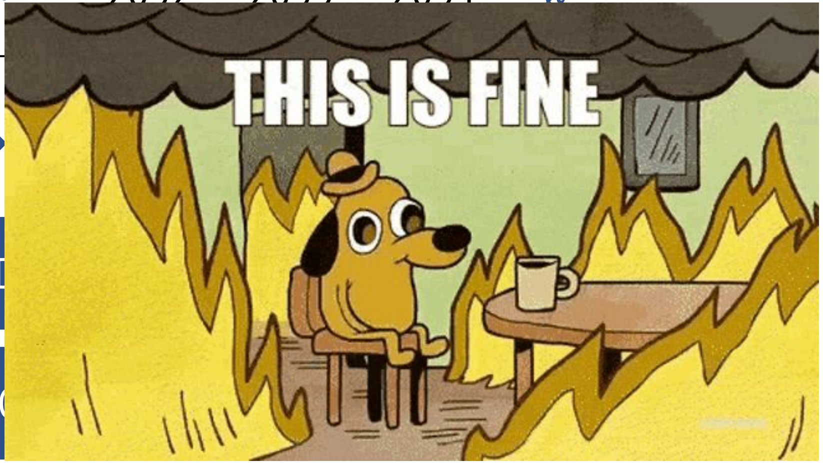


CUPID Timeline



CUPID Timeline





Thank you !

(No cats have been harmed during this presentation)

(my feelings during the PhD have been tho)