

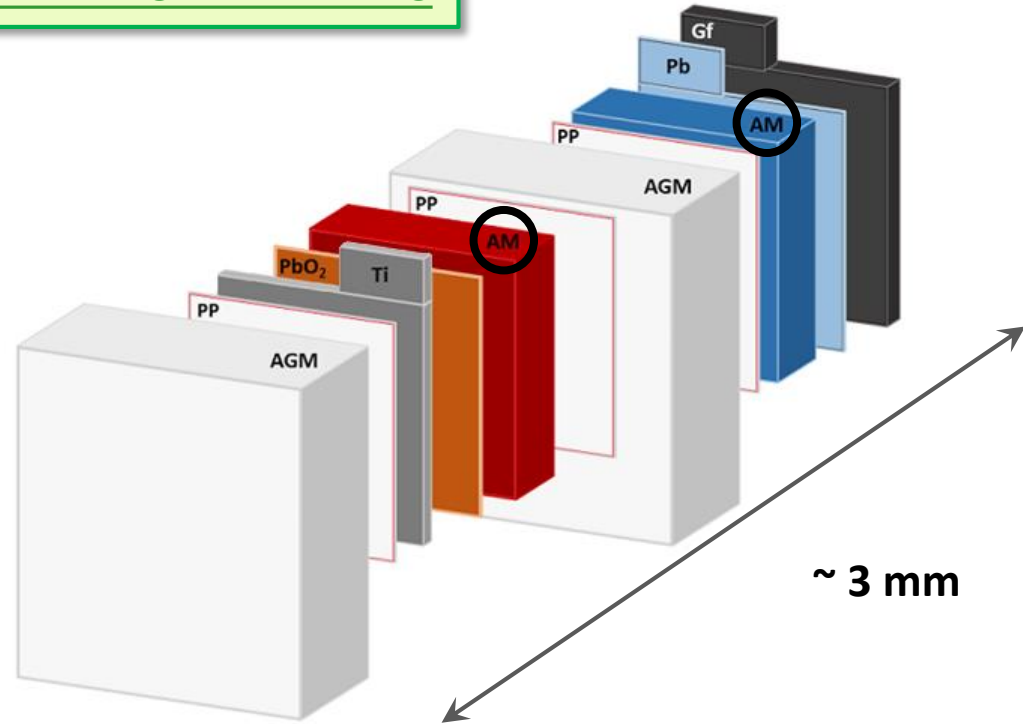
# THREE-DIMENSIONAL MODEL OF A NEW THIN-PLATE LEAD-ACID BATTERY

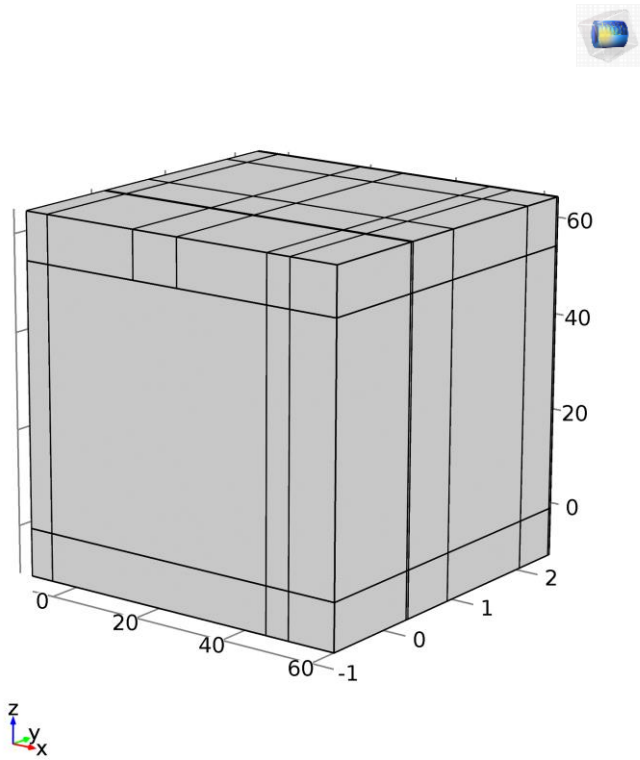
Jérémy Lannelongue

PhD Student  
(with M. Cugnet & A. Kirchev)

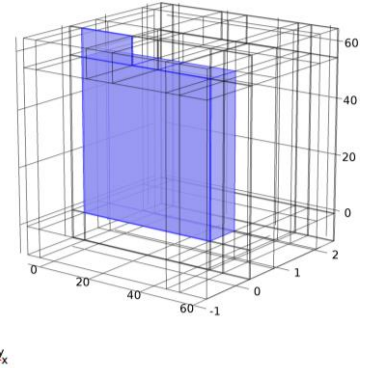


## THIN-PLATE TECHNOLOGY FOR LEAD-ACID BATTERIES

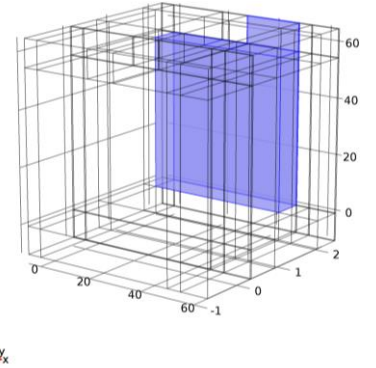




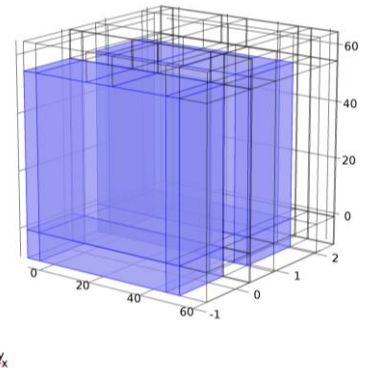
**Positive**



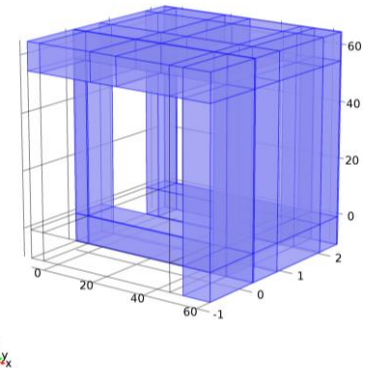
**Negative**



**Separators**

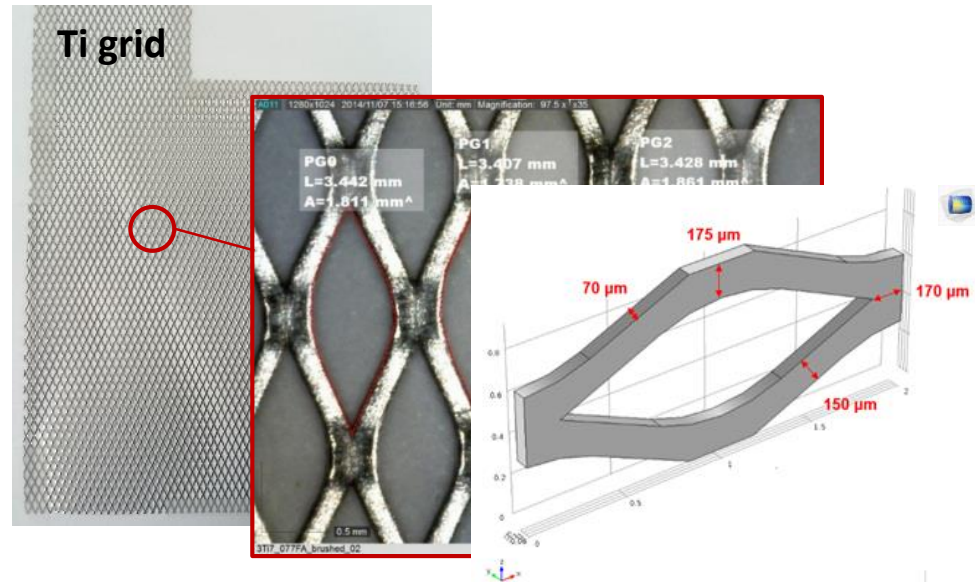
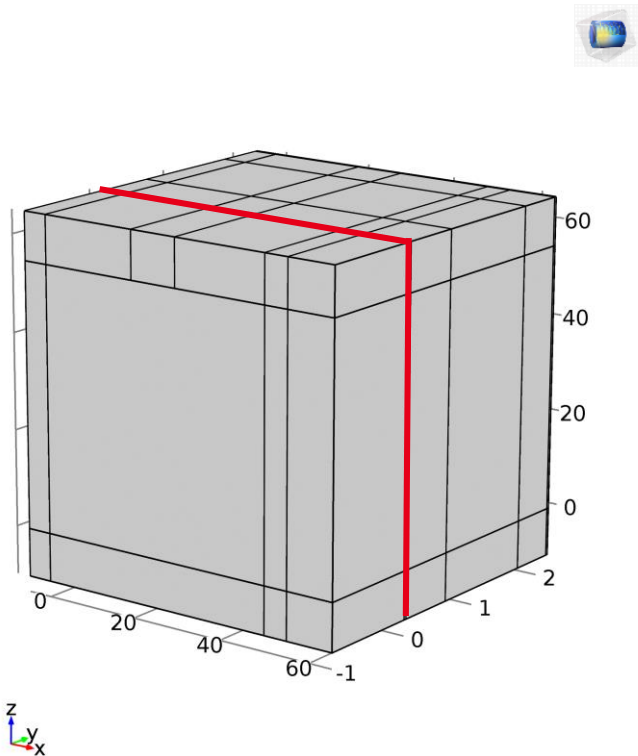


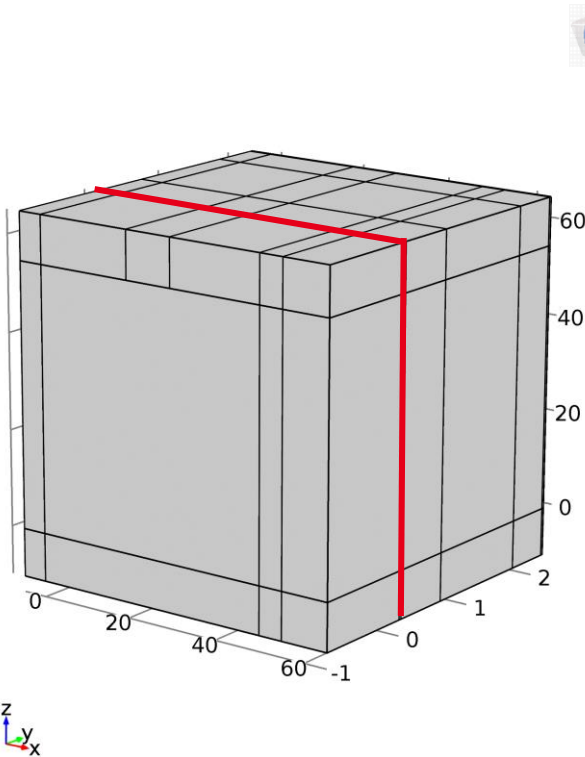
**Electrolyte**



## 84 domains

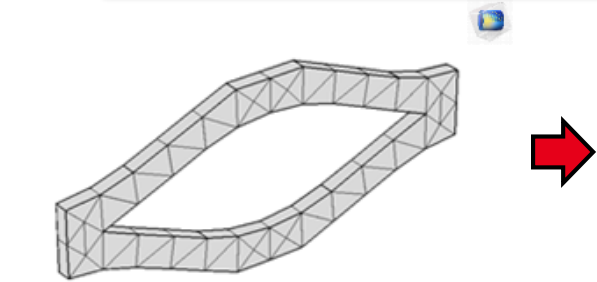
- Hypothesis : remove collectors (ex : positive)
  - High mesh cost
  - Low influence (at low rate)






## 84 domains

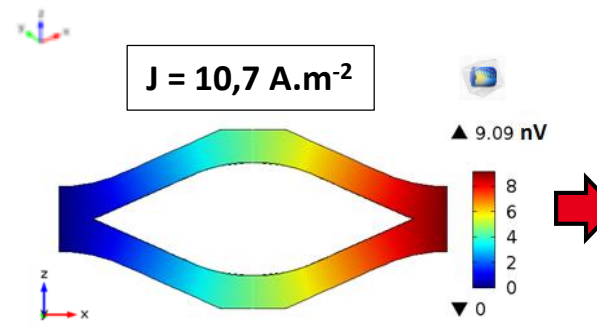
- Hypothesis : remove collectors (ex : positive)
  - High mesh cost
  - Low influence (at low rate)



64 elements/ 

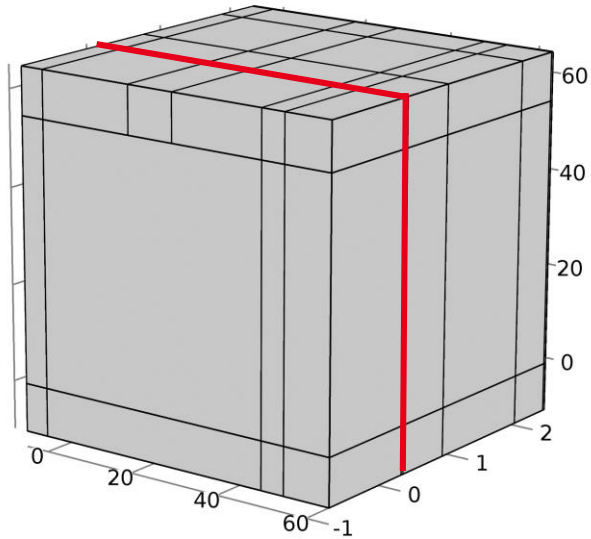
↓ x 1 495

**95680 elements**



**Collector :**

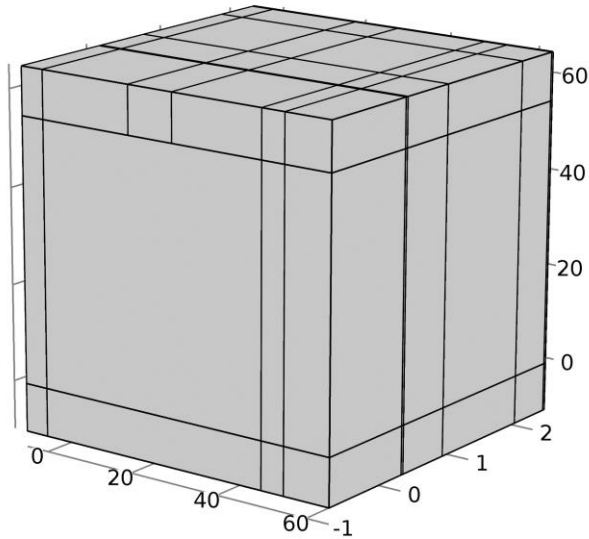
Ohmic Loss  $\cong$  mV



## 84 domains

- Hypothesis : remove collectors (ex : positive)
  - High mesh cost
  - Low influence (at low rate)





## 84 domains

- Hypothesis : remove collectors (ex : positive)
- Physics implementing
  - Ohm's law (solid (1)/liquid)
  - Porosity (2)
  - Material balance

$$(1) i_{soln} - \epsilon_a^{exm} \sigma \frac{\delta \varphi_{solid}}{\delta x} - I = 0$$

$$(2) \frac{\partial \epsilon}{\partial t} - \frac{\delta i_{soln}}{\delta x} \frac{1}{nF} (\bar{V}_a S_{a,e} + \bar{V}_b S_{b,e}) + \frac{R_{b,e}}{S_{b,s}} (\bar{V}_a S_{a,s} + \bar{V}_b S_{b,s}) = 0$$



Model Builder

- mdl3D\_B03\_DCH3\_C20\_cell\_sep2.mph (r)
- Global Definitions
  - Parameters
    - Interpolation 1 (Ucellexp)
    - Interpolation 2 (Uposexp)
    - Interpolation 3 (Unegexp)
    - Interpolation 4 (lcellexp)
  - Materials
- Component 1 (comp1)
  - Definitions
    - a= Variables Entire model
    - a= Variables Electrolyte
    - a= Variables Positive electrode
    - a= Variables PAM
    - a= Variables Separator
    - a= Variables NAM
    - a= Variables Negative electrode
    - a= Variables Void
    - AV Average 1 (aveops1)
    - AV Average 2 (aveops2)
    - AV Average 4 (aveopv4)
    - AV Average 5 (aveopv5)
    - AV Average 6 (aveopv6)
    - AV Average 7 (aveopv7)
    - AV Average 8 (aveopp8)
    - Electrodes
    - AM
    - Positive Electrode
    - Ti tab
    - PAM
    - Separator
    - NAM

Settings Properties

Variables

Label: Variables NAM

Geometric Entity Selection

Geometric entity level: Domain

Selection: NAM

32

Active

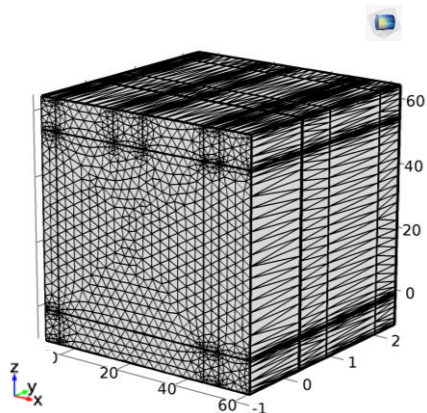
Variables

Name	Expression	Unit	Description
S_electron	$-Aa\_neg \cdot i0\_neg \cdot \exp((1-a\_neg) \cdot n \cdot F\_const \cdot \eta / (R\_const \cdot T)) - \exp(-a\_neg \cdot n \cdot F\_const \cdot \dots)$	A/m <sup>2</sup>	Electron current source
S_ion	$-S\_electron$	A/m <sup>2</sup>	Ion current source
eta	$\phi i1 - \phi i2 - U\_neg$	V	Overpotential
U_neg	$-0.294606[V] - 0.073595[V] \cdot \log_{10}(m[kg/mol]) - 0.030432[V] \cdot \log_{10}(m[kg/mol])^2 - 0.000\dots$	V	Negative equilibrium volt...
S_por	$-(PMV\_PbSO4 - PMV\_Pb) / (2 \cdot F\_const) \cdot S\_ion$	1/s	Source term of the porosi...
e_0	$e\_neg\_0$		Initial porosity
e_neg	$e$		Negative electrode poros...
s_NAM	$s\_Pb \cdot e^{0.5}$	S/m	Effective NAM electronic...
Aa_neg	$Aa\_neg\_0 \cdot (1 - \exp(-0.5 \cdot (e - 0.448) / (e - 0.448))) / (1 - \exp(-0.5))$	1/m	Effective active area
S_tds	$(1 - 2 \cdot tp0) / (2 \cdot F\_const) \cdot S\_ion - c \cdot S\_por$	mol/(m...	Source term of material b...
i0_neg	$i0\_neg\_0 \cdot (c/c\_ref)^1$	A/m <sup>2</sup>	Exchange current density
n_Pb	$\rho_{Pb} \cdot V\_nam \cdot e\_Pb / MW\_Pb$	mol	Moles of Pb

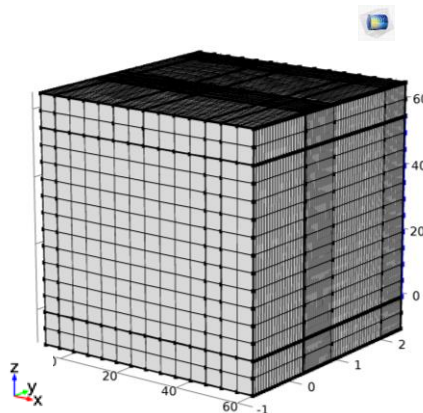
**84 domains**

- Hypothesis : remove collectors
- Physics implementing
  - ↳ Parameters, Variables & Selections

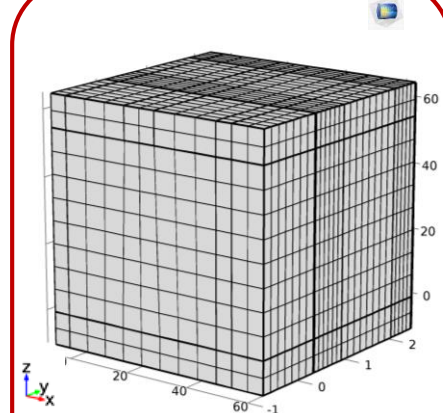




Physics-controlled mesh  
Coarser size  
**57 107** elements



User-controlled mesh  
Mapped 1 & Distribution 1  
**13 860** elements  
*1h10min*

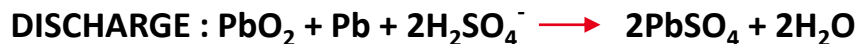
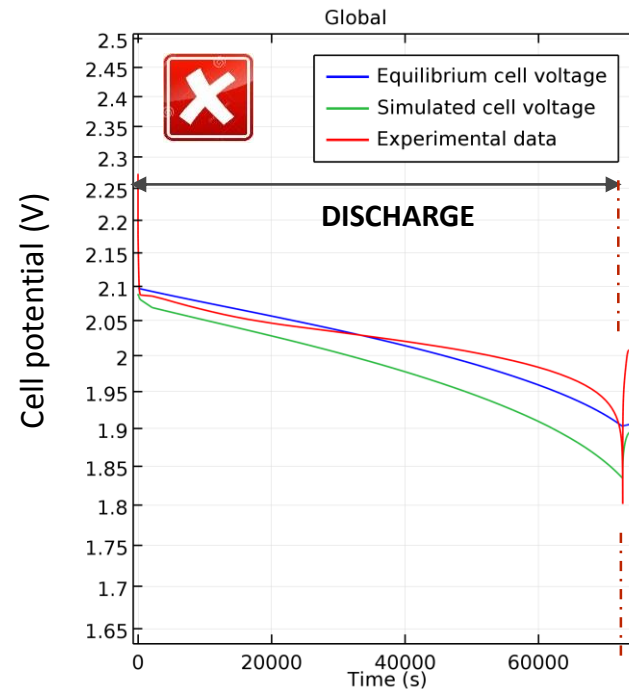
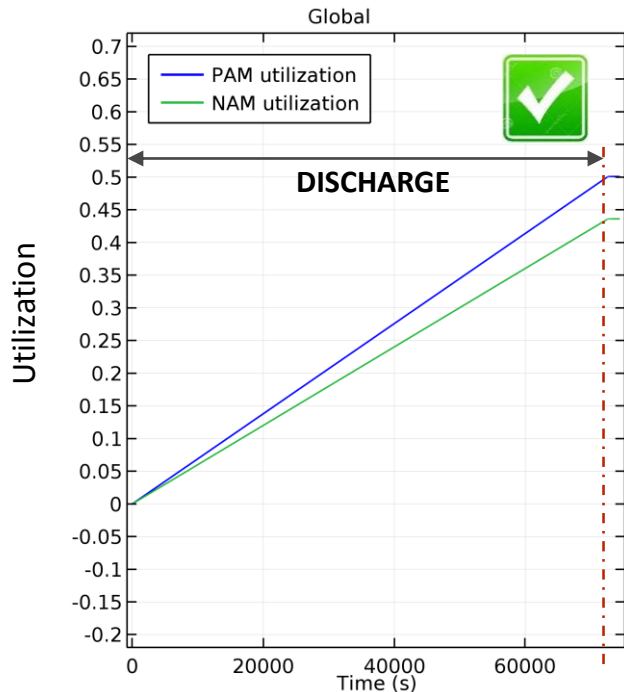


User-controlled mesh  
Mapped 2 & Distribution 2  
**4 032** elements  
*15min*

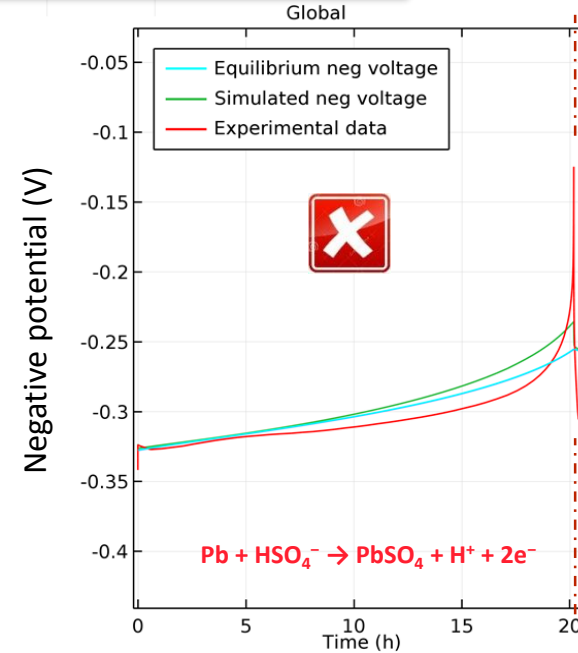
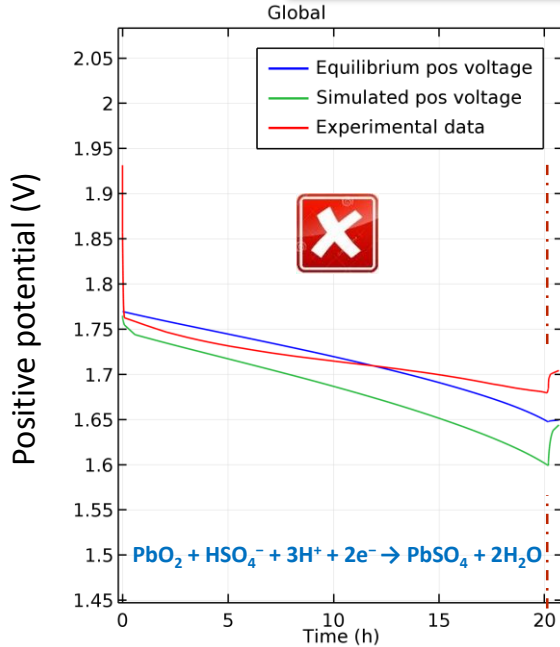
## EFFICIENT MESH = TIME GAIN

- User-controlled mesh
- Mapped & Swept
- Distribution

## Discharge + rest : first results



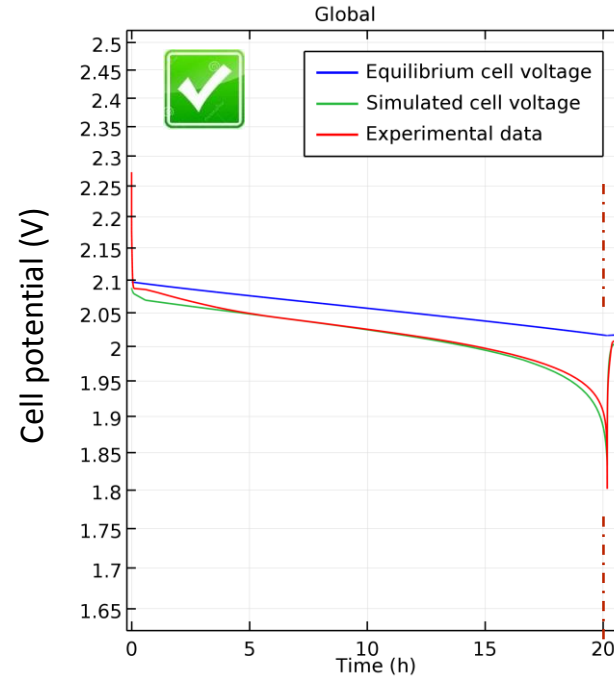
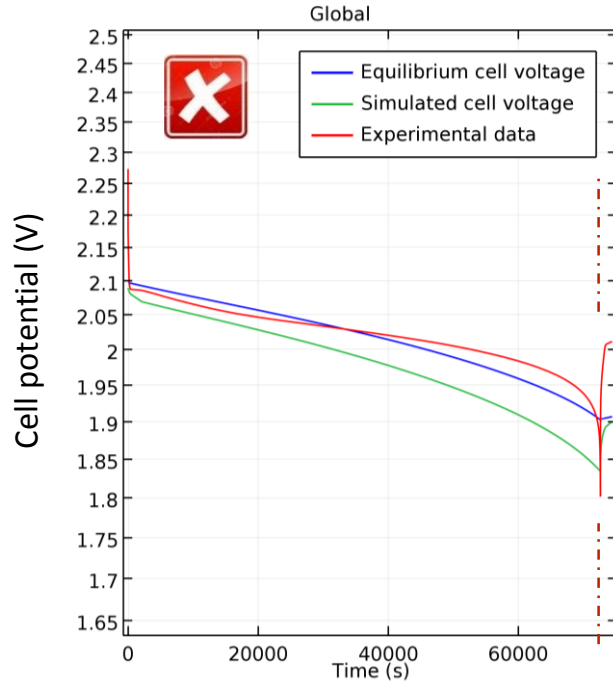
## Discharge + rest : first results



- Lack of acid (+ & -)
- Inappropriate surface coverage (-)

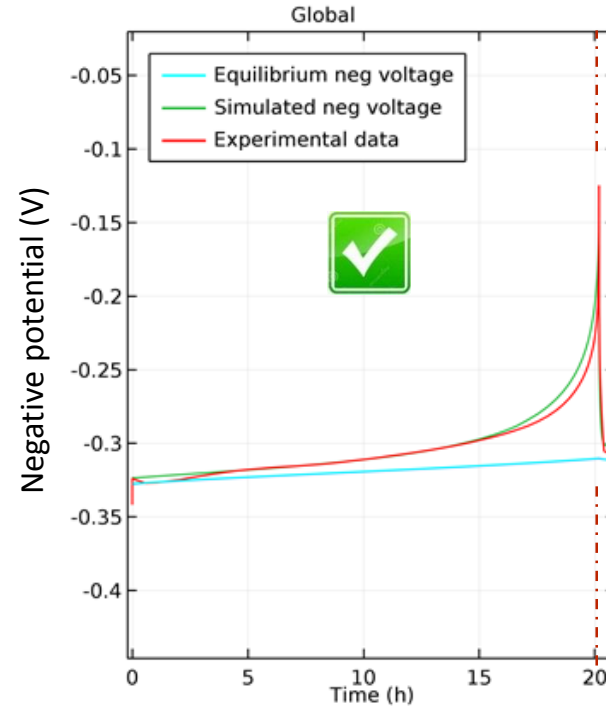
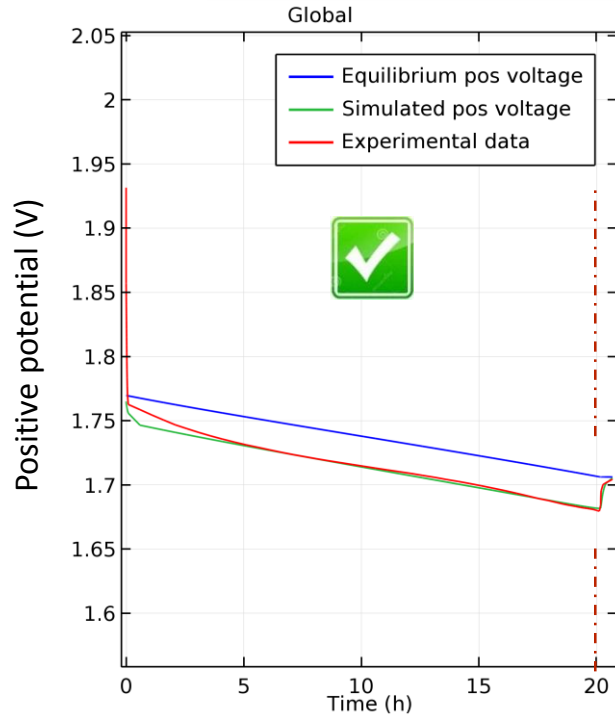
## Adjustments

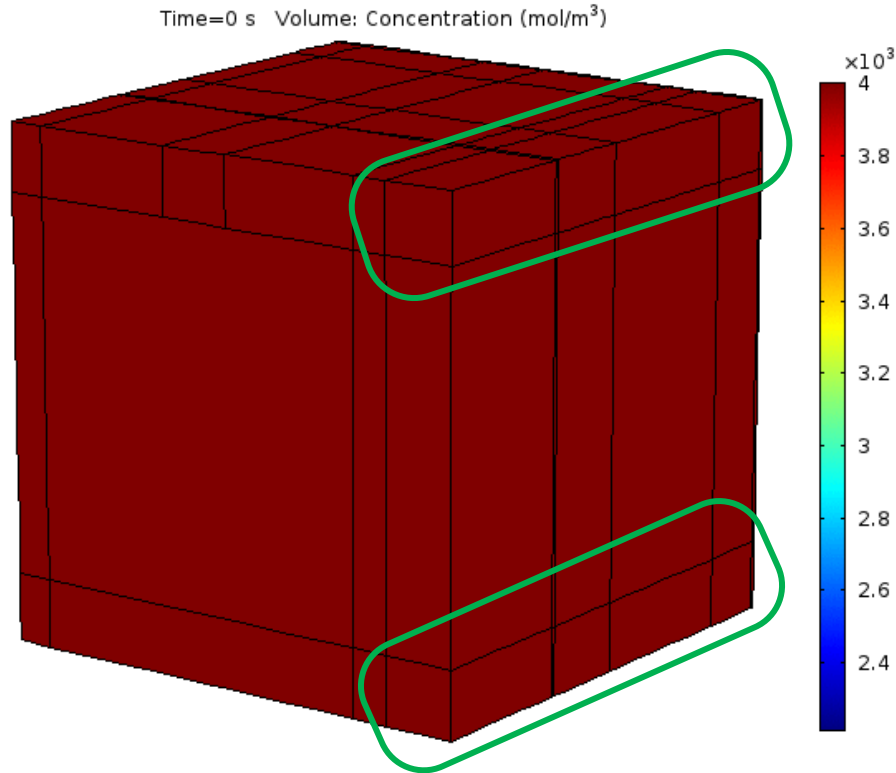
- PAM & NAM thicknesses / Porosity
- Electrolyte volume
- Coverage factor



## Adjustments

- PAM & NAM thicknesses / Porosity
- Electrolyte volume
- Coverage factor





## *Acid concentration*

- Heterogeneous consumption
- Critical volume

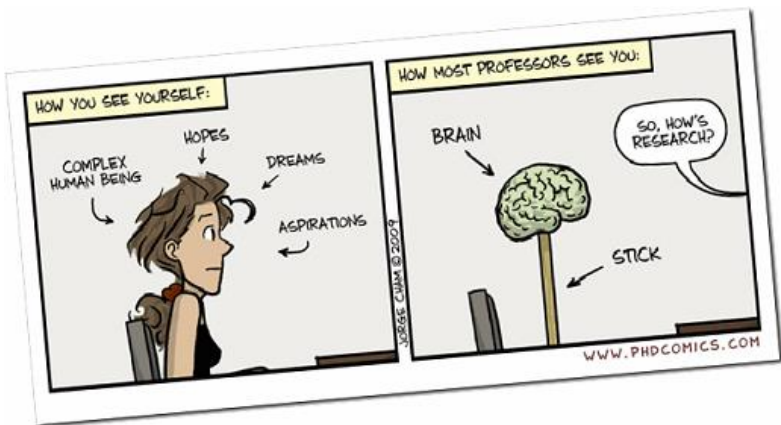
## *Conclusions*

- Importance of Hypothesis / Mesh / Parameters
- Determine precisely the key parameters :
  - AM thicknesses
  - Porosity
  - Exchange current etc
- Better understanding of the reaction (Acid consumption)

## *Perspectives*

- Add Physics (heat transfer, nucleation and growth)
- Modelisation of Discharge at high rate
- Move to 2D ?





# Thank you for your attention

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Laboratoire de Stockage Electrochimique