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Shape Influence on Electropolishing

(Single-Cell Cavities)

COMSOL modeling

TESLA, RE-ILC and LL-ILC shapes

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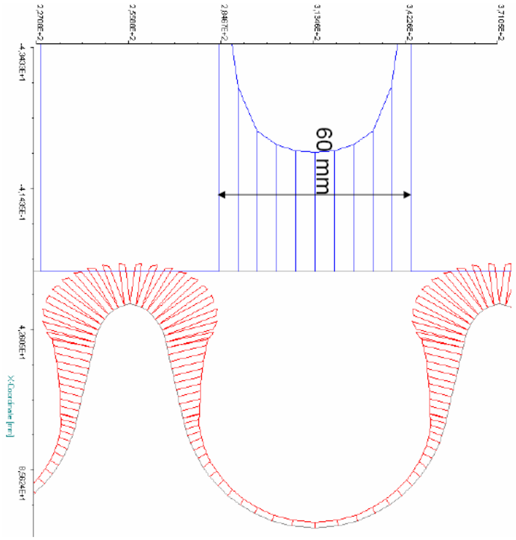
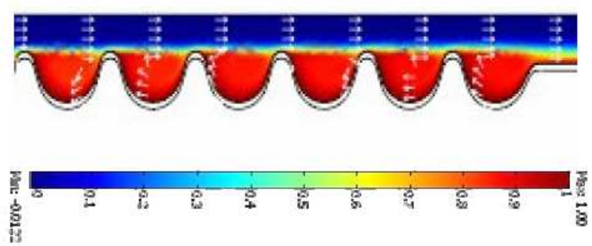
Outline

- Chemical Modeling
- Modeling Hypothesis
- Equations - Diffusion Coefficient
- Better electropolishing understanding on 1-cell cavity
  - 2D Horizontal EP
  - Difference between beam tubes and equator
  - Comparison between different shapes (TESLA, RE and LL)
  - How to obtain an uniform EP ?

Chemical Modeling





- FermiLab (*COMSOL*)
  - BCP on Multicell
  - Fluid dynamics
  - Temperature and Nb^{5+} concentration

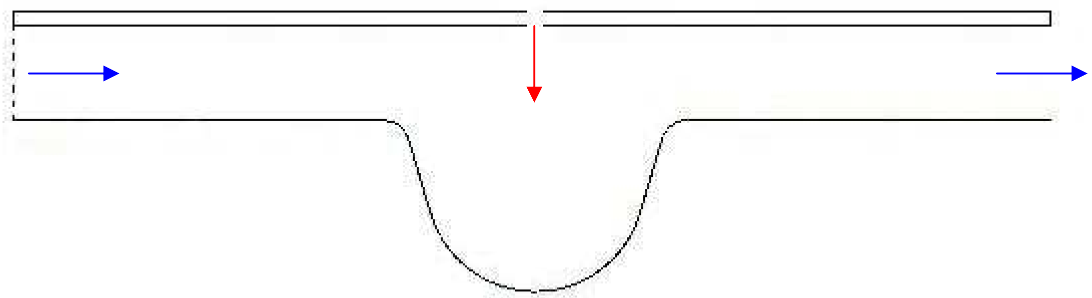
- DESY (*ELSYCA*)
  - EP on Multicell
  - No fluid dynamics, No Acid properties
  - Only Current density
  - Cathode: mask and profile effects

- Saclay (*COMSOL*)
  - EP on single cell
  - Fluid dynamics + Convection-Diffusion
  - + Chemical reaction + Kinetics Equation
  - F^{1-} / Nb^{5+} / NbF_5 concentration

Modeling Hypothesis

- Flow acid incoming (central cathode hole) non ideal

Dead end in beam pipe – non symmetric flow



- More intuitive solution
- Easier to model

Laminar flow through cavity from left to right

General Equations

- Phenomenon transport (inspired from work of Lee et al.):

$$N_i = -D_i \nabla c_i - z_i \cancel{\omega_i F} c_i \nabla \phi + u c_i$$

Diffusion Migration Convection

- Navier Stockes equation (incompressible fluid)
- Electroneutrality
- Gravity effect

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Additional Equations

- Reminder of Nb electropolishing:

$$2\,Nb + 5\,H_2O \rightarrow 5\,H_2 + Nb_2O_5$$

$$\boxed{Nb_2O_5 + 10\,HF \rightarrow 2\,NbF_5 + 5\,H_2O}$$

$$Nb_2O_5 \xrightarrow{F^-\ (HF \rightarrow H^+ + F^-)} NbF_5$$

- Kinetic equation: $\boxed{v = \frac{1}{2}\frac{d[NbF_5]}{dt} = k[F^-]^\alpha[Nb_2O_5]^\beta}$

$\rightarrow$ Limit concentration in NbF_5

- Study of $[F^-]$

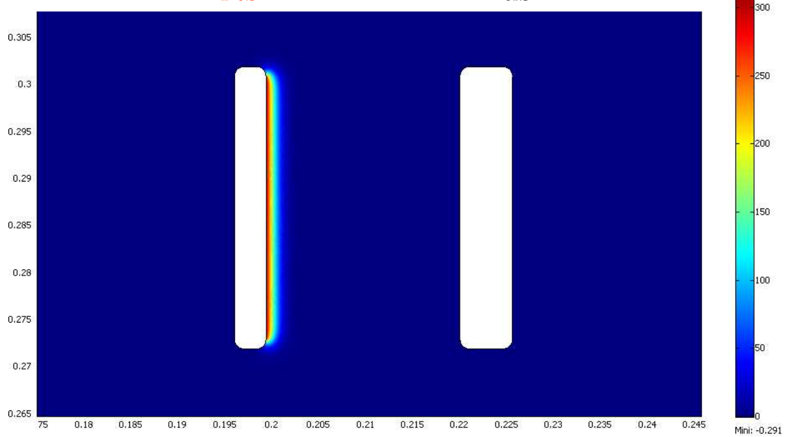
Diffusion Coefficient

Determined from matching sample modeling
to experiments:

Fast forming of the viscous layer

Low density and high fluid viscosity to ensure its stability

t= 500s $D_{Nb}=10^{-8}$ $m^2.s^{-1}$ d_{ab}=2cm



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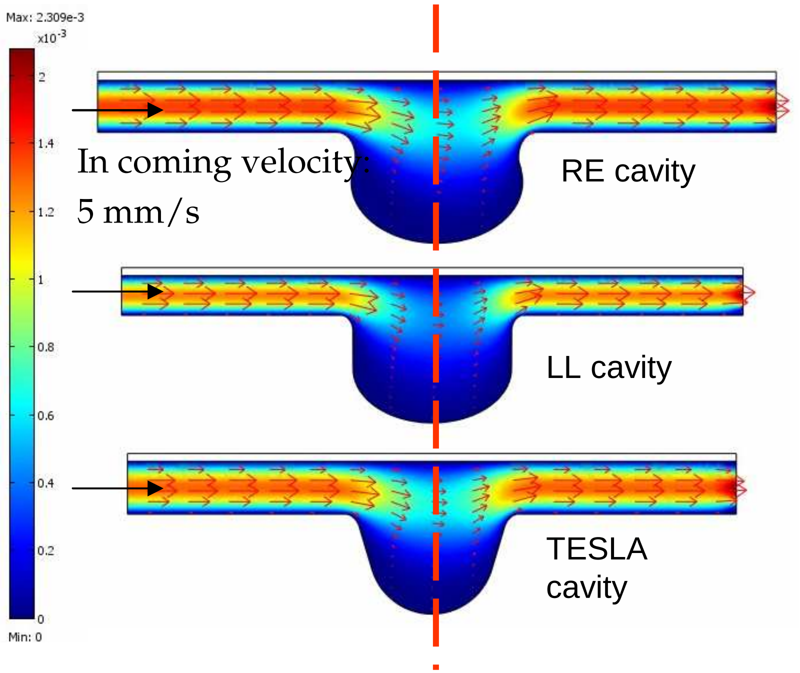
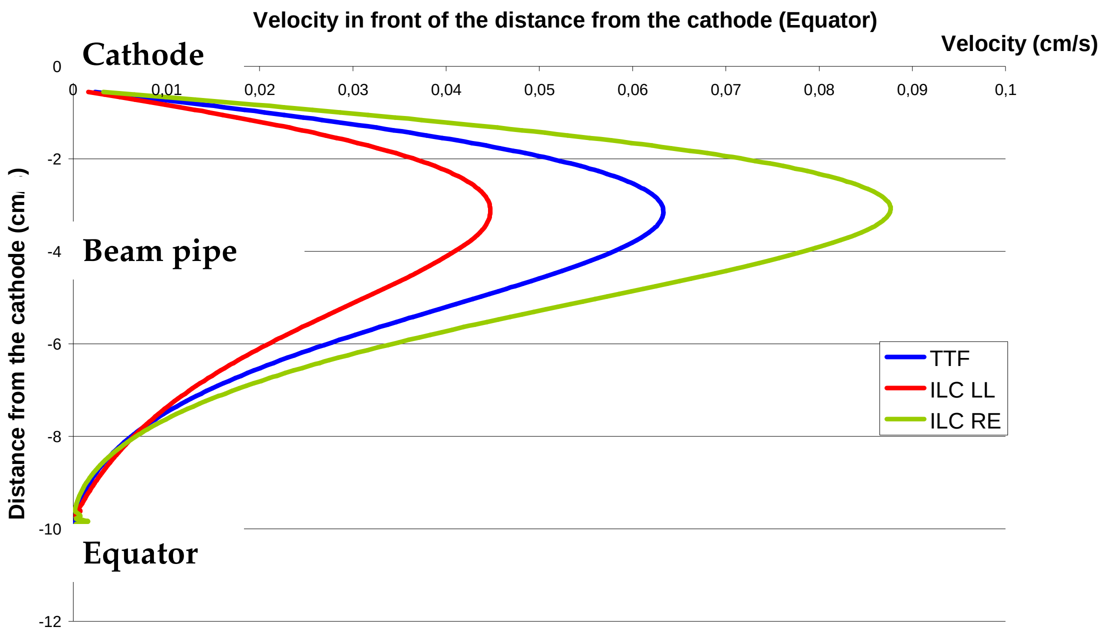
Fluid Velocity in the Cavity





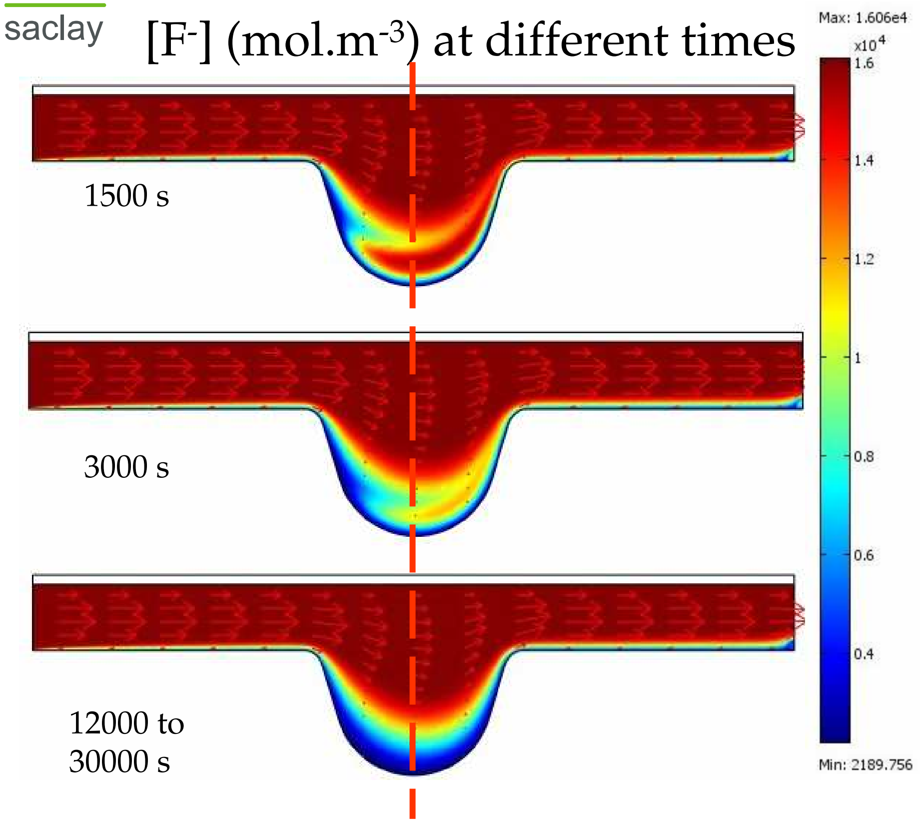
For each cavity profile :

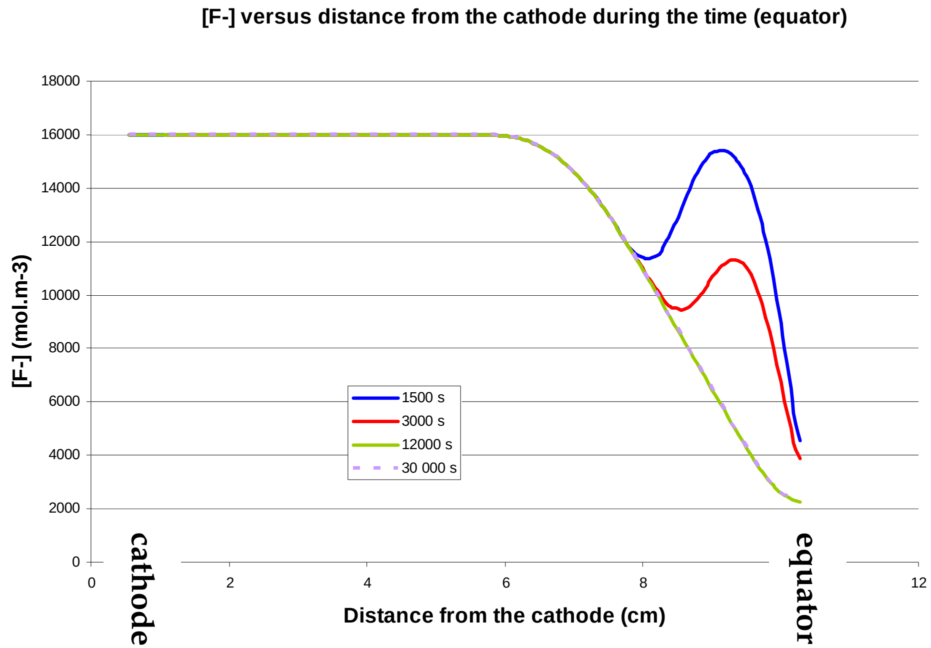
- Fluid velocity quasi null at the equator
- Highest velocity in the beam pipes

Bad Renewal of F^- at the Equator

(TESLA shape)

[F-] (mol.m-3) at different times

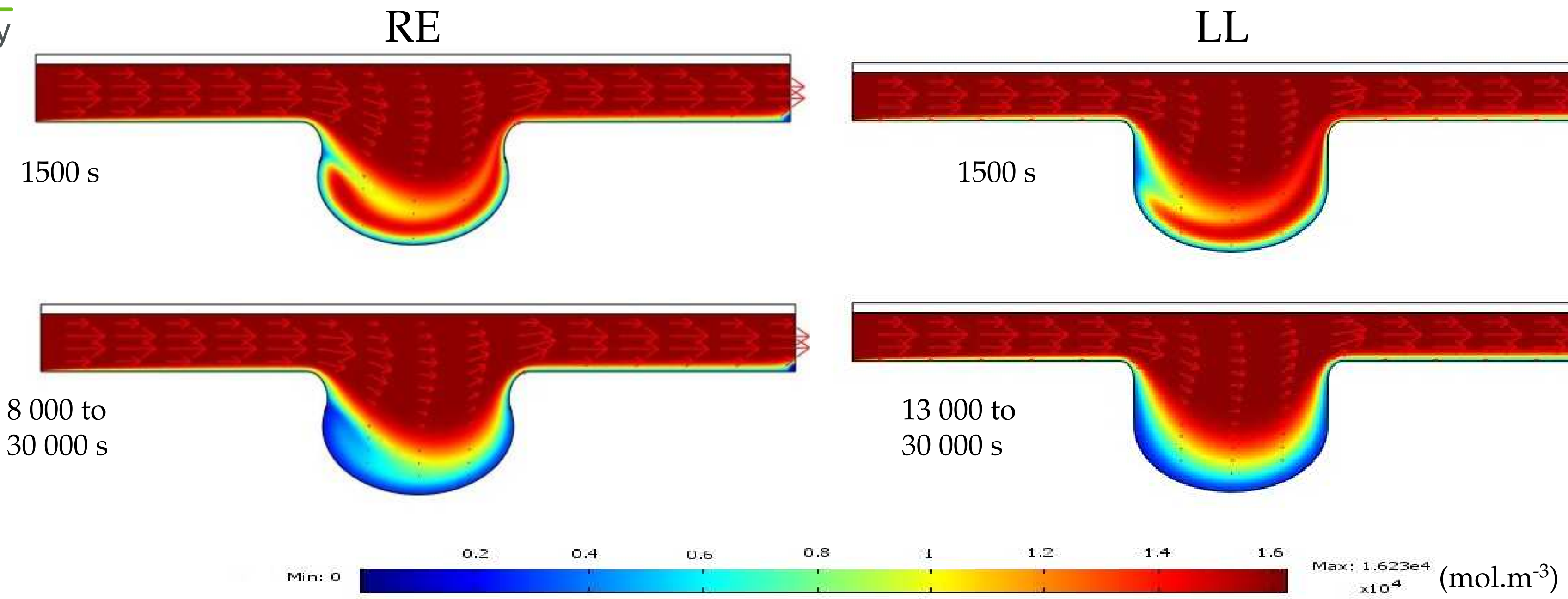




- Before 12 000 s: $[F^-]$ decreases
- After 12 000 s: $[F^-]$ constant = bad regeneration of F^-

→ Aging of the acid at the equator

RE and LL Shapes

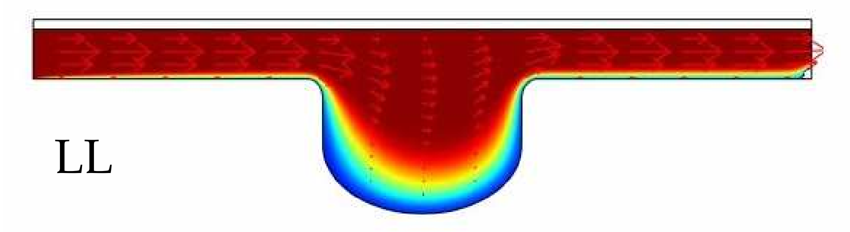


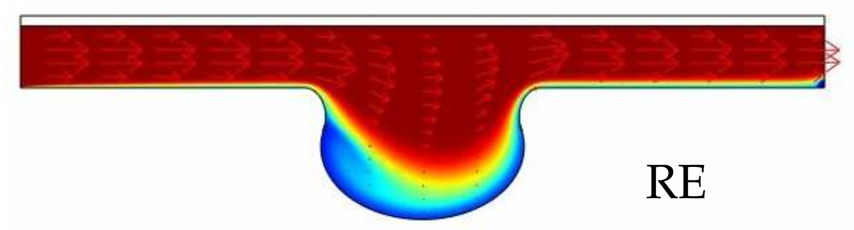
Same conclusions as for TESLA:

- Non uniform EP at the beginning
- Stabilization of the [F-] concentration after a long time (cf. kinetics equation) → aging of the acid
- Not symmetric EP for the RE cavity

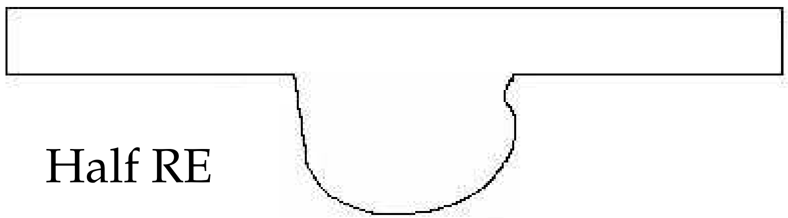
Half RE Shape

Not symmetric EP for the RE cavity



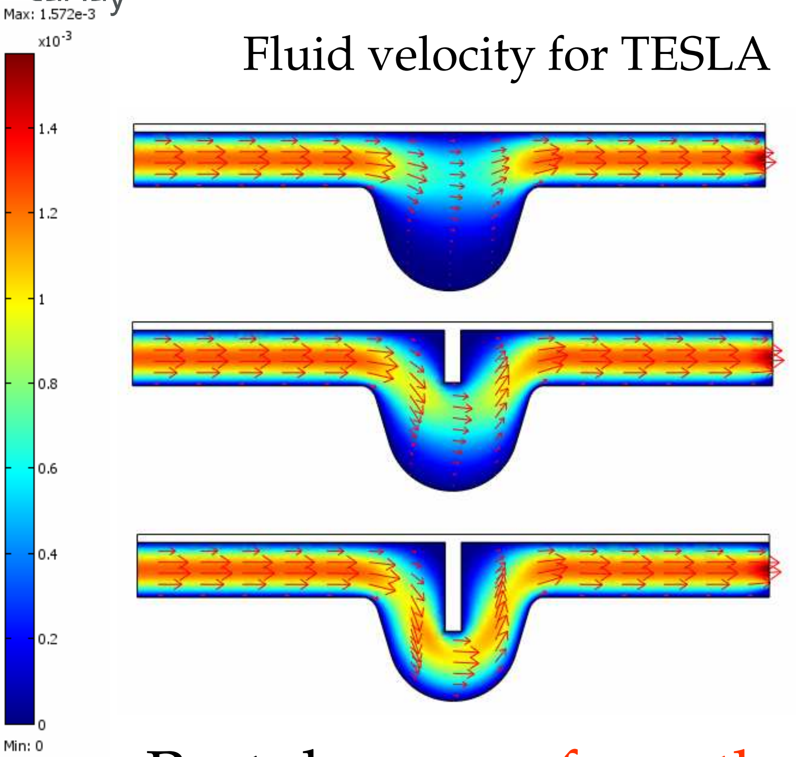


Half RE : interesting shape - outlook for the next modeling

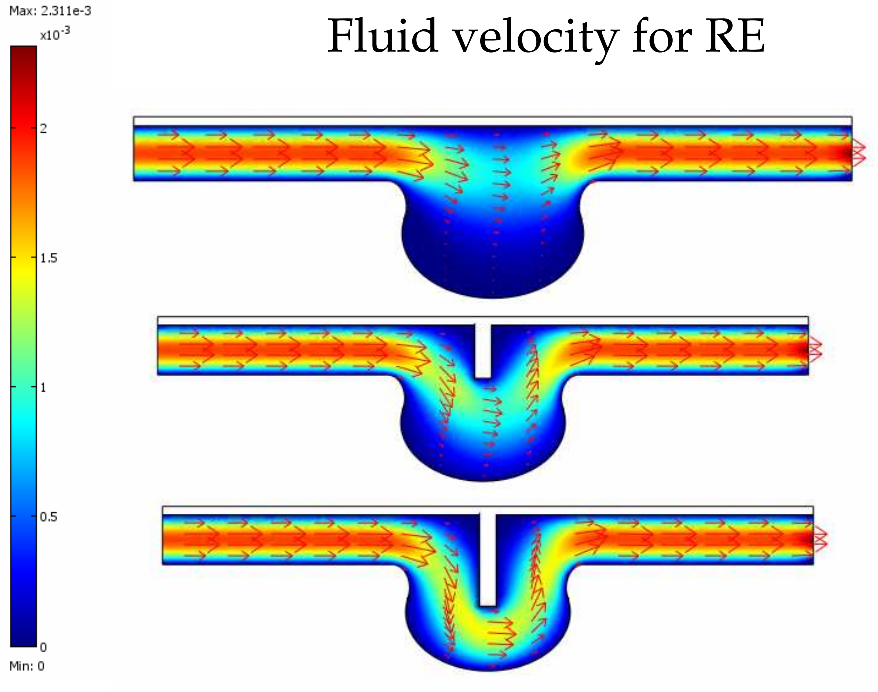


Uniform EP ? Adding a Protuberance

Fluid velocity for TESLA



Fluid velocity for RE



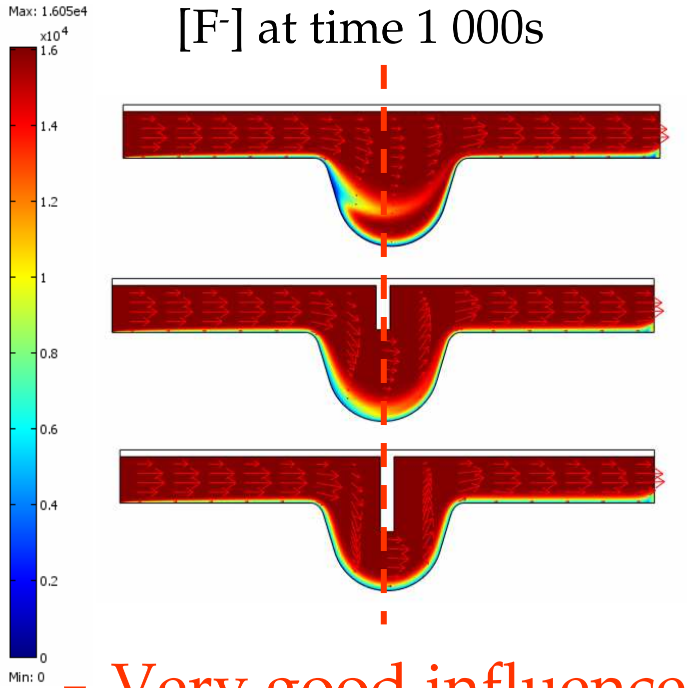
- Protuberance: force the acid to sweep the bottom of the cell for RE and TESLA → can extend this conclusion to LL
- Will it be enough to soften the asymmetric EP on RE ?

→ study the [F$^-$] consumption

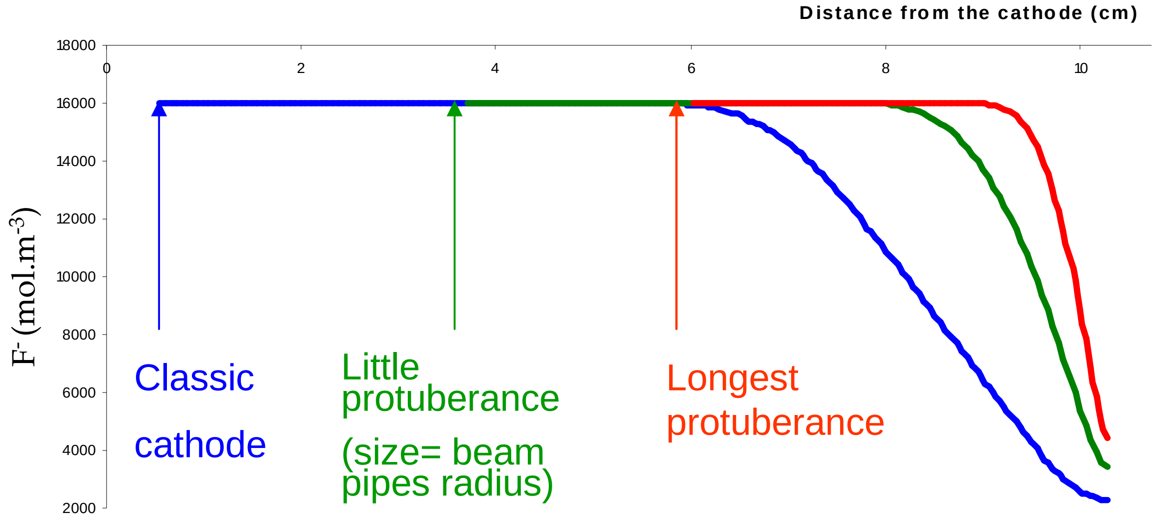
Adding a Protuberance

(TESLA shape)

[F$^-$] at time 1 000s



[F$^-$] at time 20 000s



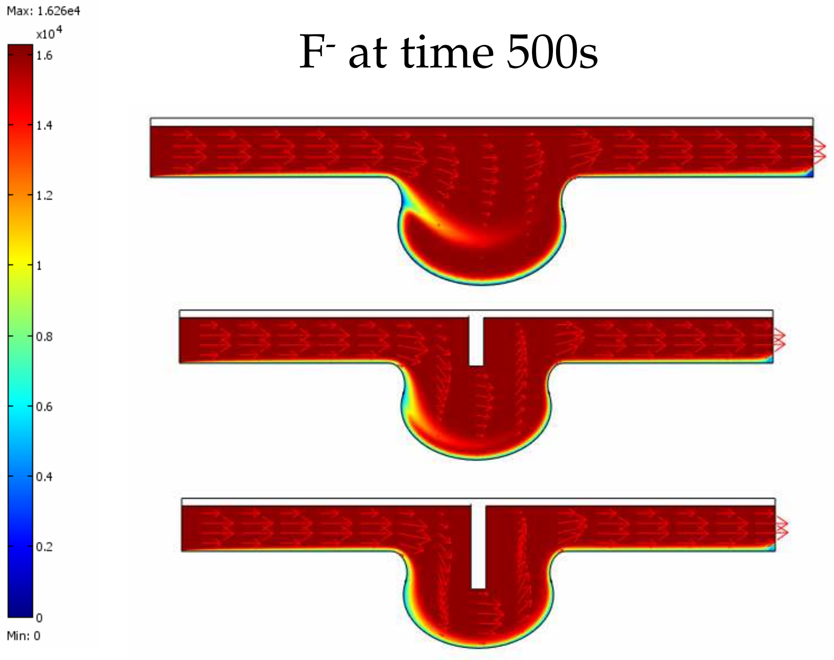
- Very good influence of the protuberance:

- Reduce the perturbation in the cavity, faster stabilization
- Better renewal of F$^-$ at the equator (thinner and more concentrated layer of old acid) = improved EP at the equator

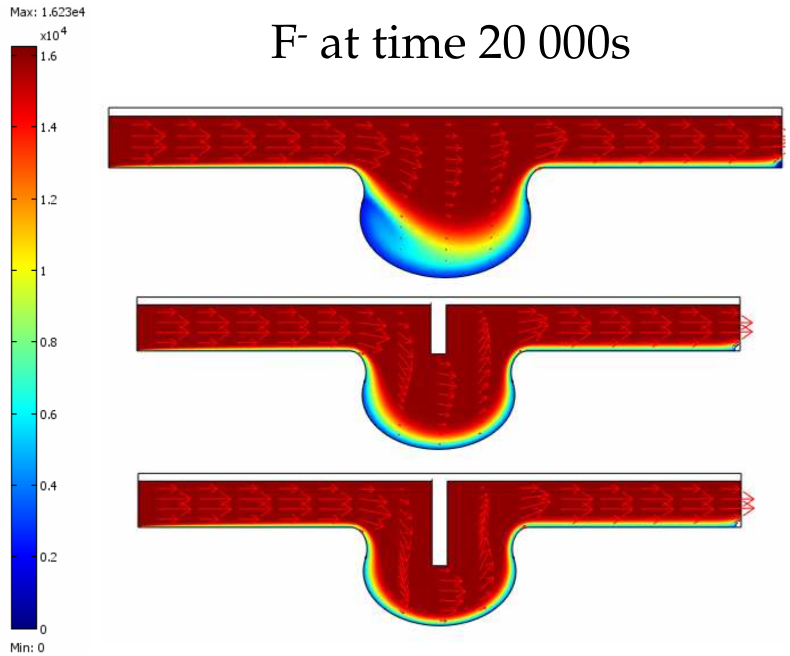
Adding a Protuberance

(RE shape)

F$^-$ at time 500s



F$^-$ at time 20 000s



- Same conclusion as for TESLA:
- Reduce the non uniform EP at the beginning and better renewal of the acid at the equator
- EP is more symmetric

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Summary

- New acid incoming:
  - Can be applied for TESLA and LL shapes
  - Asymmetric EP in the cell for RE
  - Benefit effect of cathodic protuberance

- EP modeling well overcame:
  - Modeling central flow incoming to validate hypothesis
  - Model the more complex reality
    (2D axi-symmetric, cavity rotation …)

Thanks to …

- Jacek Sekutowicz, Hasan Padamsee and Valery Shemelin to provide dimensions of cavity shape

- Bernard Visentin and Fabien Eozénou