# Numerical Prediction of Particles Dynamics Within a Cytometer

## Application to Counting and Sizing by Impedance Measurement

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**Impedance gating and particle sizing principle**:
In hematology analysis, counting and sizing of blood cells are based on electrical gating in an orifice–electrode system [1]. The resulting voltage variation allows to work out particle volume measurement but various phenomenon can produce overestimations.

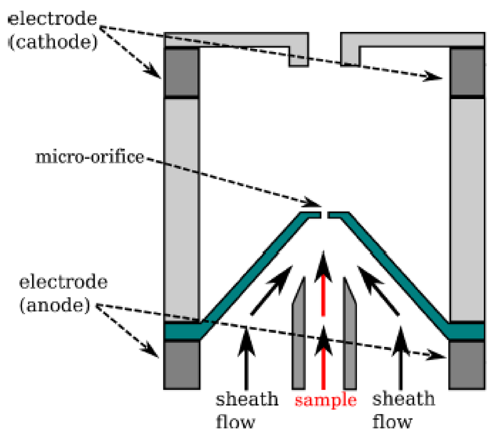


**Figure 1**. The orifice-electrode system

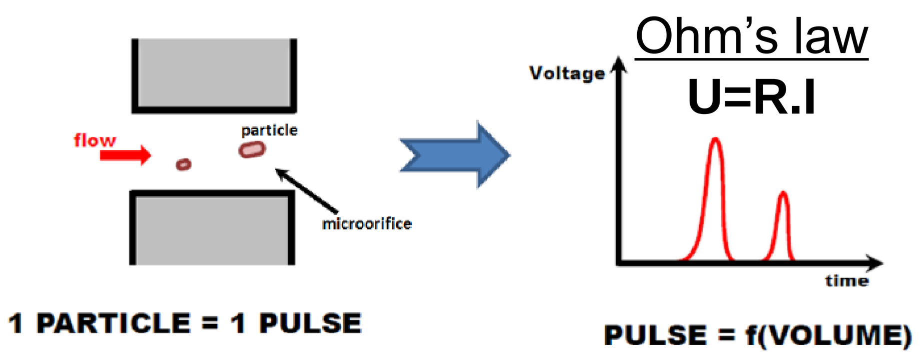


**Figure 2**.Principle of impedance gating

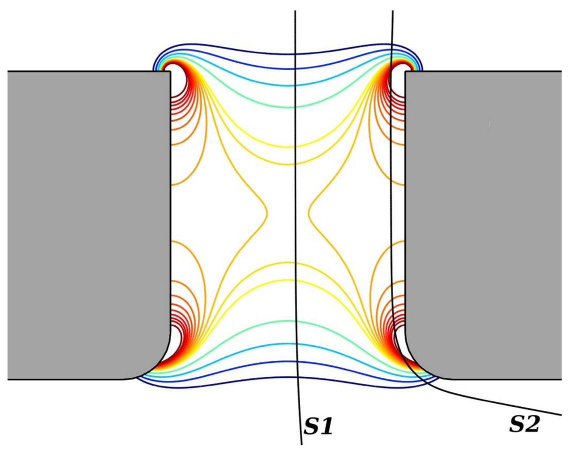


**Figure 3**. Isovalues of the electrical field inside the orifice

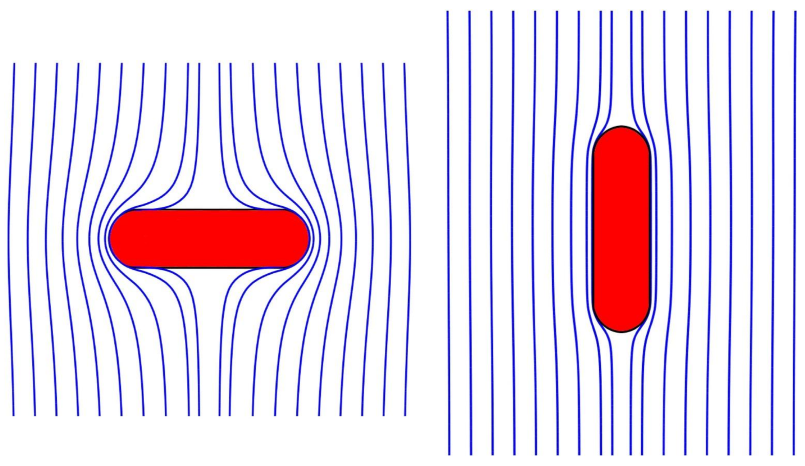

**Figure 4**. Effect of insulation particle on the electrical field

**Numerical model for particle counting & sizing**:

### The flow model

$$\rho\frac{\partial\vec{u}}{\partial t}-\nabla\cdot\mu\left(\nabla\vec{u}+(\nabla\vec{u})\right)+\rho(\vec{u}\cdot\nabla)\vec{u}+\nabla p=0$$

$$\nabla\cdot\vec{u}=0$$

### The particle transport (moving boundary $\Gamma_p$)

$$\vec{v}\left(M_p(t),t\right)=\vec{v}_{tr}\left(M_p(t),t\right)+\vec{v}_{ang}\left(M_p(t),t\right)\times\left(C_p(t)-M_p(t)\right)$$

with

$$m\cdot\frac{d\vec{v}_{tr}}{dt}=\vec{F}_{hyd}\text{ where }\vec{F}_{hyd}=\int_{\Gamma_p}\vec{\sigma}\cdot\vec{n}\,d\Gamma_p$$

and

$$I^*\cdot\frac{d\vec{v}_{ang}}{dt}=\vec{T}\text{ where }\begin{array}{l}I^*=m\cdot\int_{\Gamma_p}\|C_p-M_p\|\,dM_p\\ \vec{T}=\int_{\Gamma_p}(C_p-M_p)\times(\vec{\sigma}\cdot\overrightarrow{n})\,dM_p\end{array}$$

### The electrical field

$$-\nabla\cdot\left[\left(\sigma_e+\frac{\epsilon}{\tau}\right)\nabla V\right]=0$$

### The voltage pulse

$$U_p(t)=\frac{W(t_2)-W(t_1)}{(\Delta t)\cdot\bar{I}}\text{ where }t=\frac{t_1+t_2}{2}\text{ and }W=\frac{\epsilon}{2}\int_{\Omega}\|\vec{E}\|^2$$

**Computational Methods**: Deformed mesh and FSI setting – ALE formulation for the moving mesh.
Automatic remeshing (solver stops when mesh quality is lower than 0.5) – Around 30 remesh/start cycles.

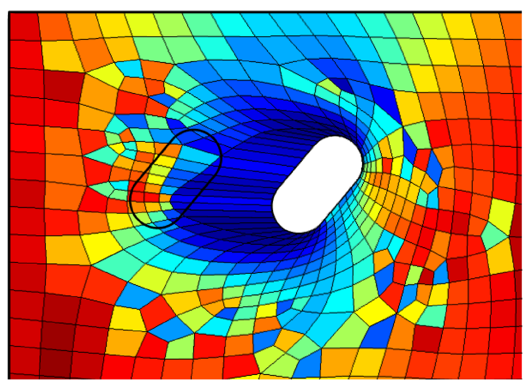

**Figure 5**. Remesh/start cycle to control mesh quality

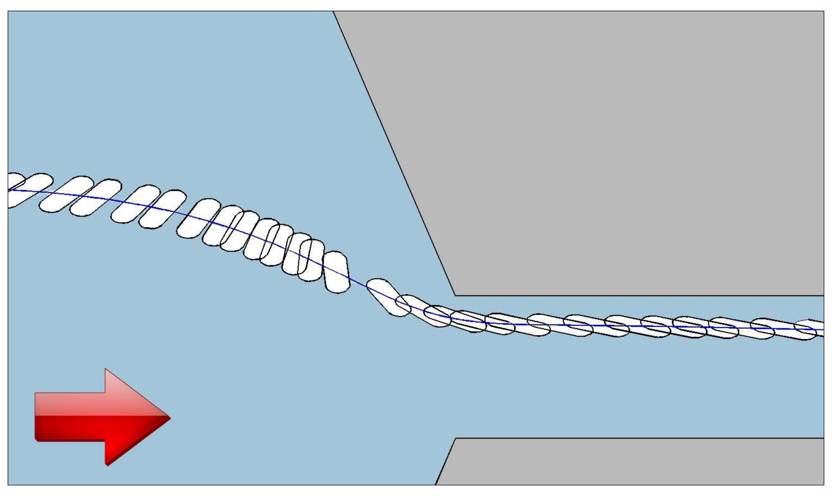

**Figure 6**. The whole displacement of the particle through the orifice

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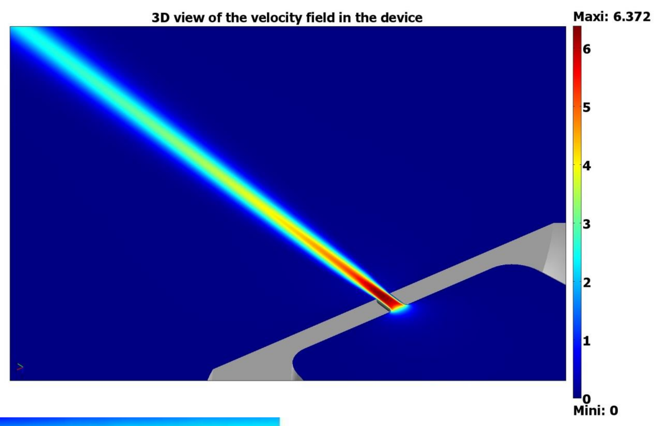
**Results**: Considered particles are shaped like capsules and supposed to be rigid and totally insulating.

*Micro-orifice* : L=65µm ; Ø=50µm
*Particle data* : l=5µm ; L=8µm
*Mean velocity in the orifice* : 4.5m/s
*Voltage* : 7.6V



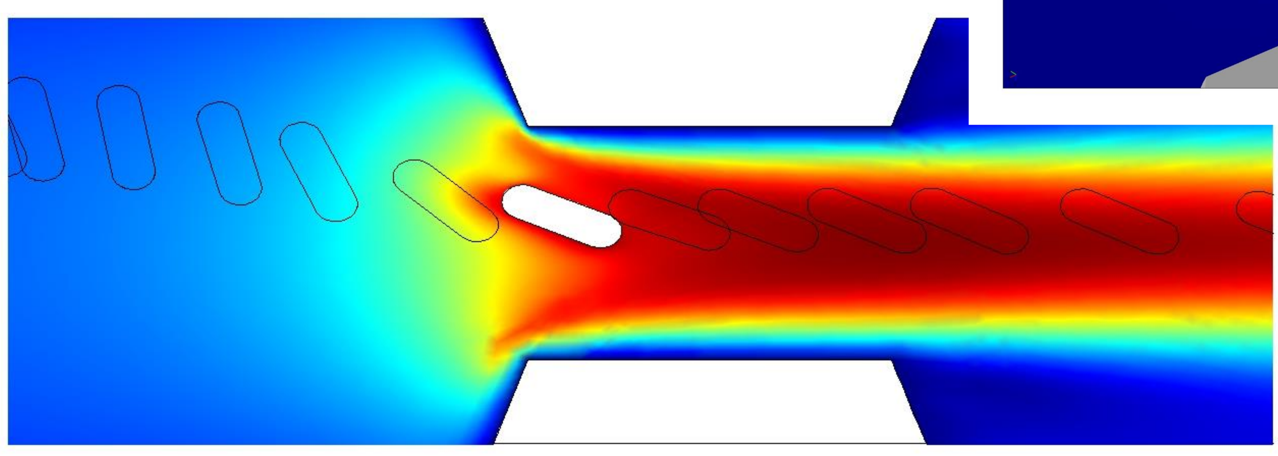



**Figure 8**. Velocity field – Particle through the micro-orifice (FSI)

### Effect of particle size on voltage pulses

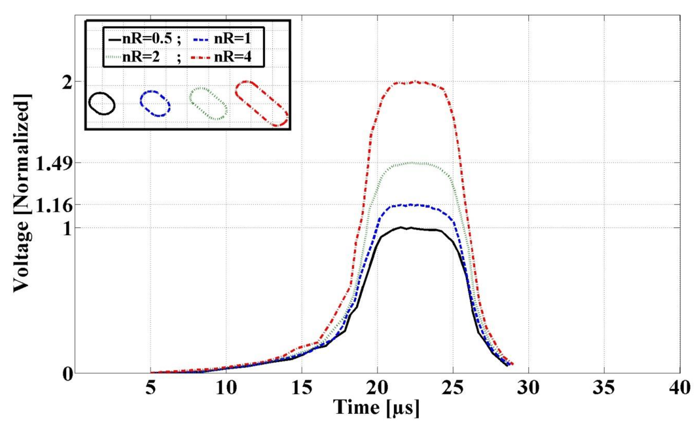



**Figure 9**. Effect of particle size

### Effect of particle orientation on voltage pulses

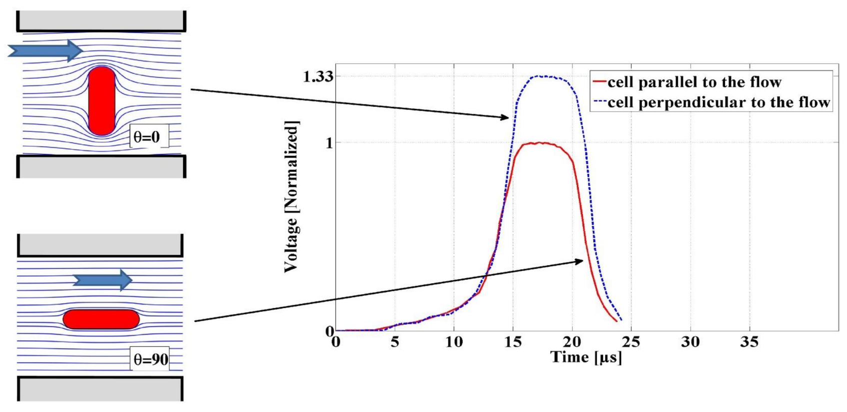



**Figure 10**. Effect of particle orientation

### Effect of particle trajectory on voltage pulses

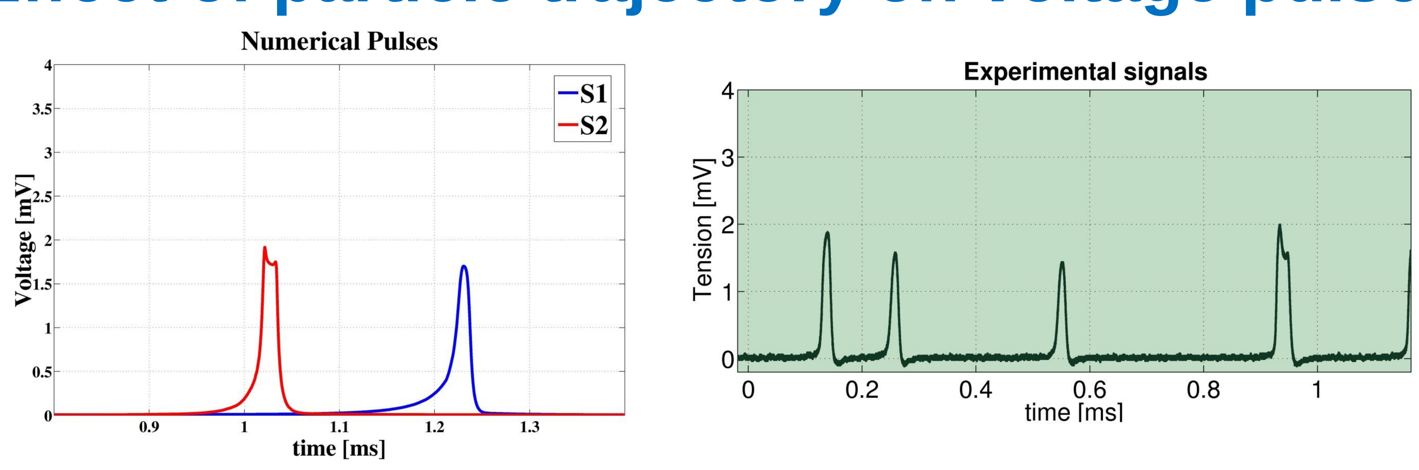



**Figure 11**. Effect of particle trajectory – (left) numerical; (right) experimental

### Role of hydrodynamic focusing in cell sizing

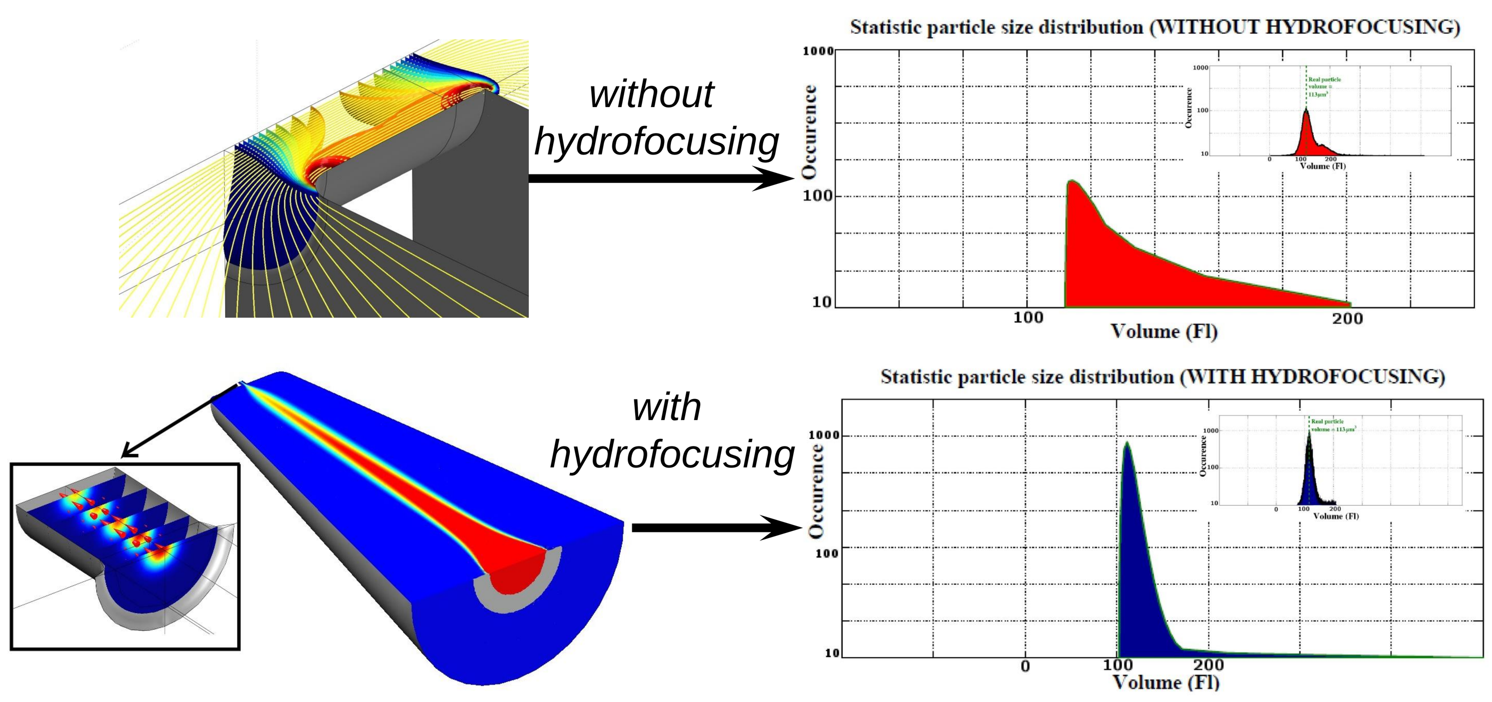
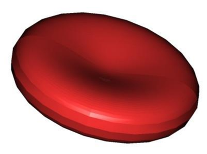



**Figure 12**. Improvement of Particle Size Distribution by Sample Hydrodynamic Focusing

**Conclusions**: A fully innovative numerical approach, in lines with experimental tests, is presented to tackle the problem of counting and sizing particles. Substantial improvements on the transport model, including 3D processing and deformability of particles under strong hydrodynamic stresses, are investigated.



**References**:

1. V. Kachel and al., Elecrical Resistance Pulse Sizing : Coulter Sizing, Flow Cytometry & Sorting, 35p., 1990
2. D. Isèbe and al., Numerical simulation of particle dynamics in an orifice-electrode systeme, IJNMBE, 13p., 2013

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