Joint Industry Research Consortium on Formation Evaluation

# Self-Adaptive Goal-Oriented $hp$-Finite Element Simulations of: (1) Axisymmetric Borehole Acoustics, and (2) 3D Resistivity Logging Instruments

Motivation and Progress Report

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     - Parallel Computations
   - Expected Results

# MOTIVATION

## To Utilize One Code to Invert Multi-Physics 2D and 3D Problems

3 Developers $\longrightarrow$ 1 $hp$-FE Software $\longrightarrow$ 20 Users

### Main Advantages

- Less lines of code,
- More robust code (less bugs),
- More reliable code,
- More stable and compatible code,
- Less expensive software.

**Better Code**

### Feasibility

It is feasible, because:

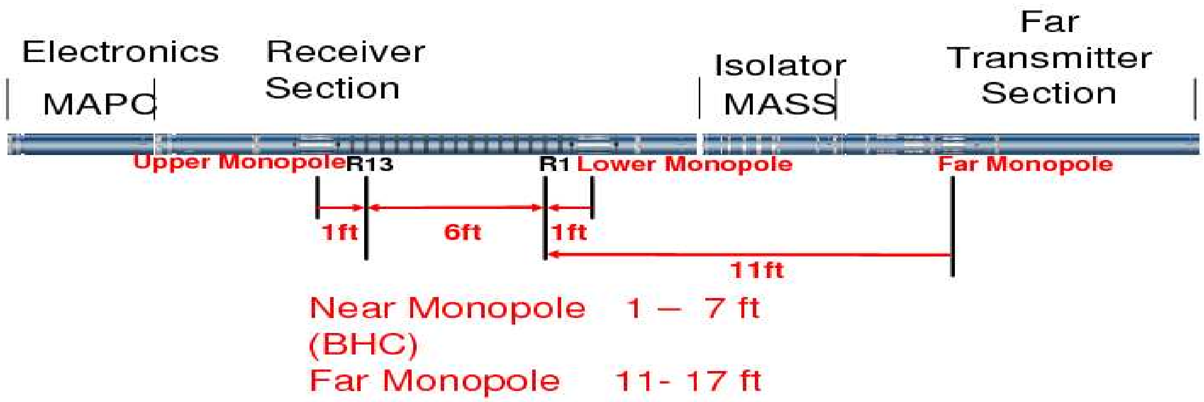
- No analytical approximation is used,
- No asymptotic approximation is used,
- The Green's function is approximated numerically,
- The algorithms are general,
- The algorithms are robust.

**Pure Numerical Method**

# MOTIVATION

## To Utilize One Code to Invert Multi-Physics 2D and 3D Problems

**New Schlumberger Sonic Tool**




**Modelling of Mandrel for Acoustics-Elasticity**

# 2D BOREHOLE ACOUSTICS

## 2D Variational Formulation for Acoustics/Elasticity Frequency Domain

**We solve for the acoustic pressure $p$ and the elastic displacement $\mathrm{u}$**

$$\left\{\begin{array}{l}
\text{Find } (p,\mathrm{u}) \in (p_0,\mathrm{u}_0) + H^1_D(\Omega_1) \times \mathrm{H}^1_\mathrm{D}(\Omega_2) \text{ such that:} \\
\int_{\Omega_1} \nabla p \cdot \nabla q dV - \int_{\Omega_1} \frac{\omega^2}{C^2} pq dV + i\omega\gamma \int_{\Gamma_3^1} pq dS \\
\qquad -\rho_f \omega^2 \int_{\Gamma_{12}} \mathrm{u_n} q dS = \int_{\Gamma_2^1 \cup \Gamma_3^1} gq dS \quad \forall q \in H^1_D(\Omega_1) \\
\int_{\Omega_2} \sigma_{ij}(\mathrm{u})\epsilon_{ij}(\mathrm{w}) dV - \int_{\Omega_2} \rho_s \omega^2 \mathrm{u} \cdot \mathrm{w} dV + i\omega \int_{\Gamma_3^2} \beta_{ij} u_j w_i dS \\
\qquad - \int_{\Gamma_{12}} p \mathrm{w_n} dS = \int_{\Omega_2} \mathrm{f} \cdot \mathrm{w} dV + \int_{\Gamma_2^2 \cup \Gamma_3^2} \mathrm{h} \cdot \mathrm{w} dS \quad \forall \mathrm{w} \in \mathrm{H}^1_\mathrm{D}(\Omega_2) \,.
\end{array}\right.$$

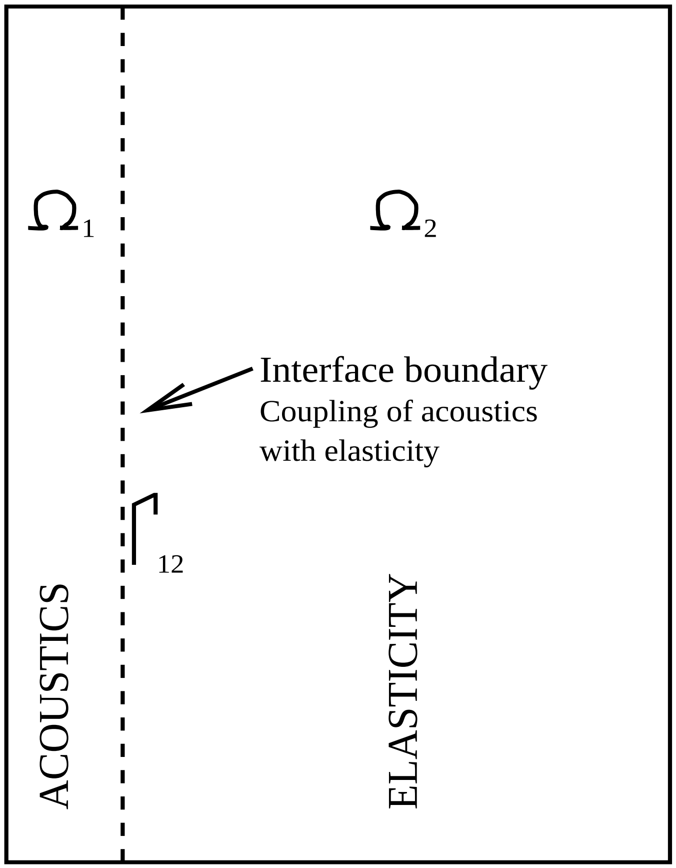
$\mathrm{H}^1_\mathrm{D}(\Omega)$ **FUNCTIONS WITH $L^2$-INTEGRABLE FIRST ORDER DERIVATIVES**

**It can be solved using a system of 3 equations with standard (continuous) finite elements**

# 2D BOREHOLE ACOUSTICS

## Preliminary Results

### A Coupled Acoustics-Elasticity Problem.




**DENSITY FLUID = 1 $g/cm^3$.**

**SOUND SPEED = 1483 $m/s$.**

**DENSITY SOLID = 2.3 $g/cm^3$.**

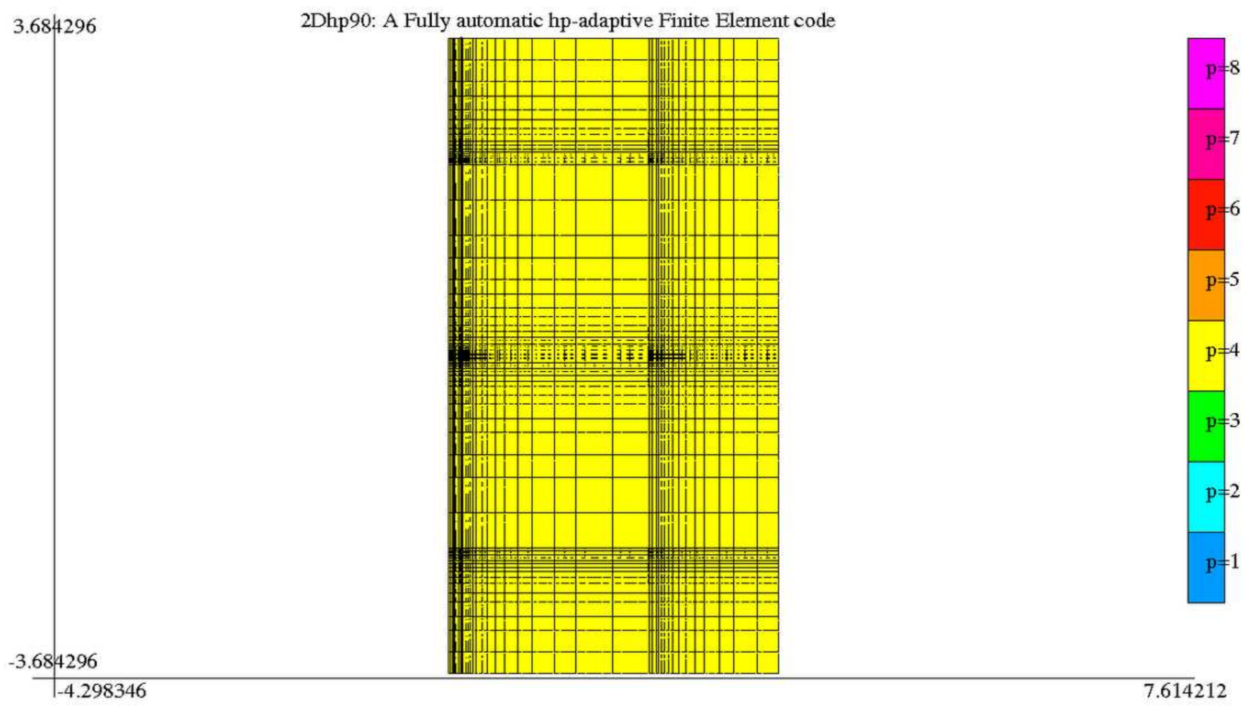
**LAME CONSTANTS (MU = 1 GPA ; LAMBDA = 0.5 GPA).**

**FREQUENCY= 2 kHz.**

**DOMAIN SIZE = 2 m x 4 m (+ 2 m in each direction of PML).**

# 2D BOREHOLE ACOUSTICS

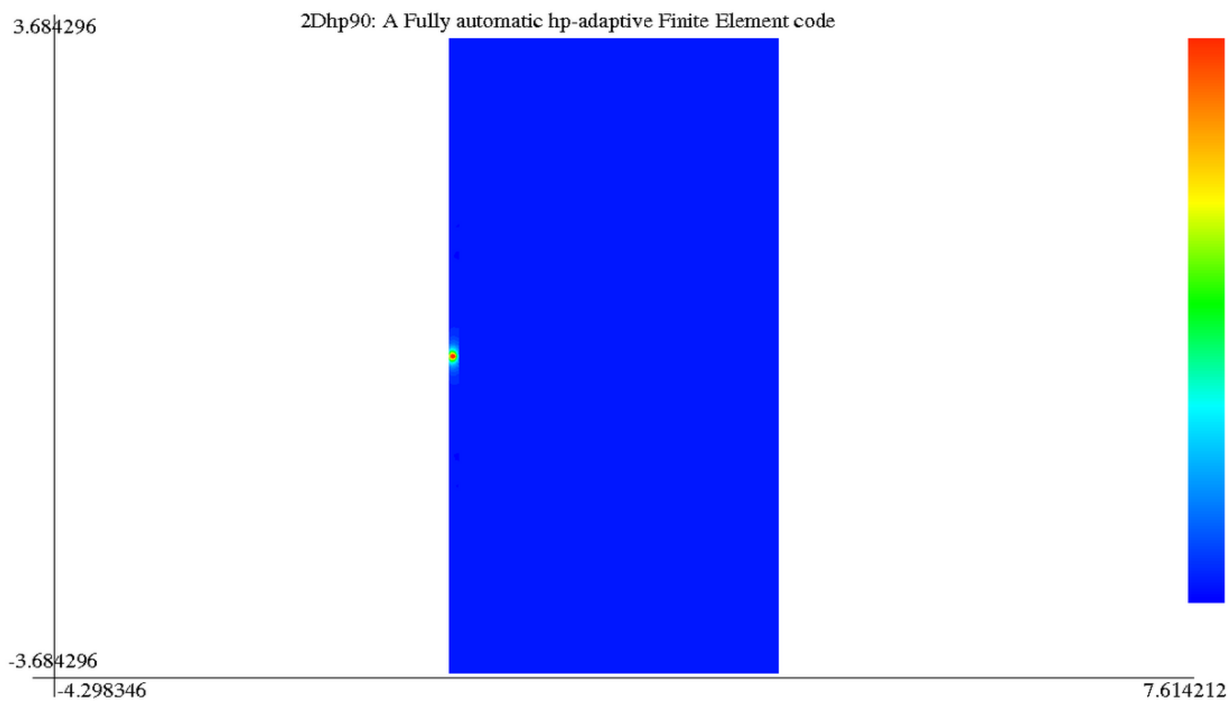
## Preliminary Results




**Final $hp$-grid**

# 2D BOREHOLE ACOUSTICS

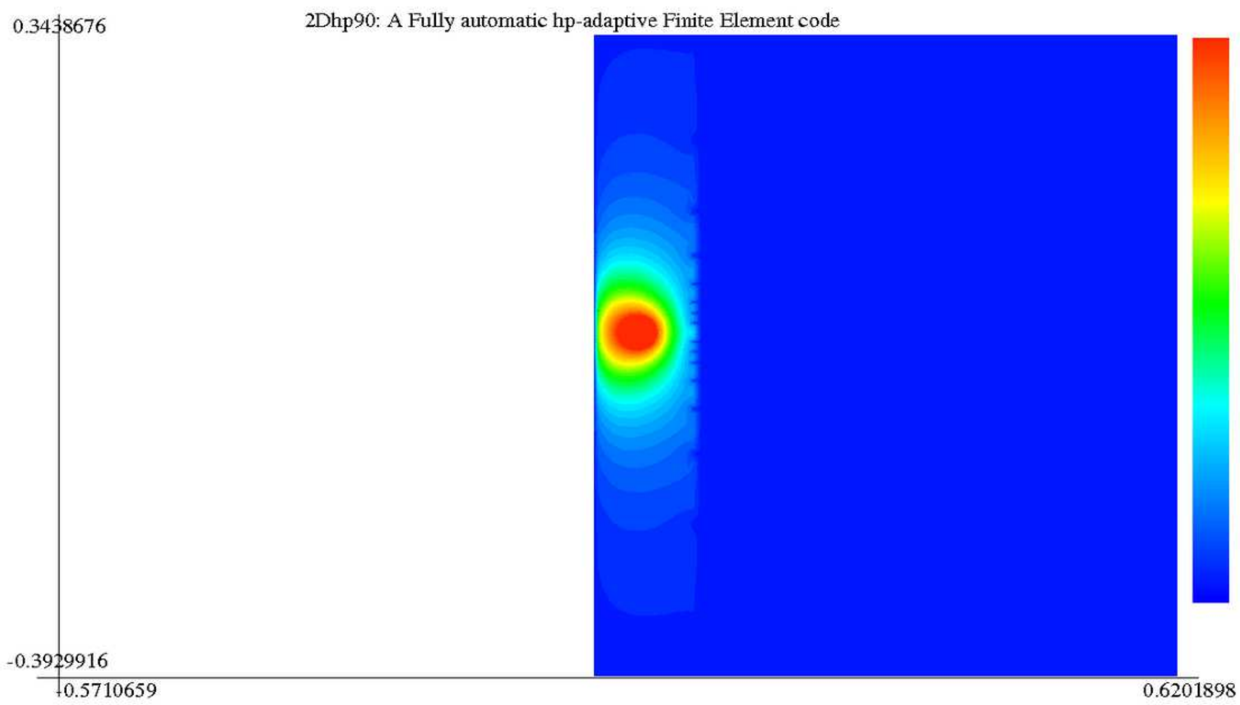
## Preliminary Results




**Acoustic Pressure**

# 2D BOREHOLE ACOUSTICS

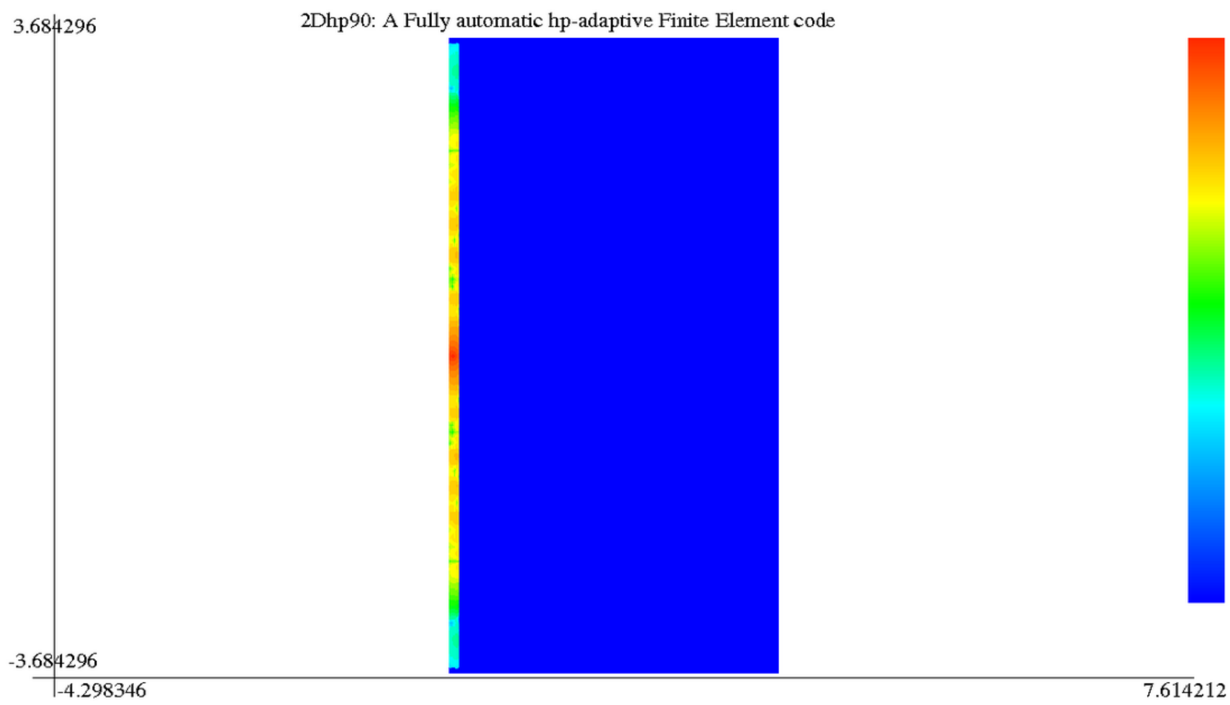
## Preliminary Results




**Acoustic Pressure (amplification by a factor of 10)**

# 2D BOREHOLE ACOUSTICS

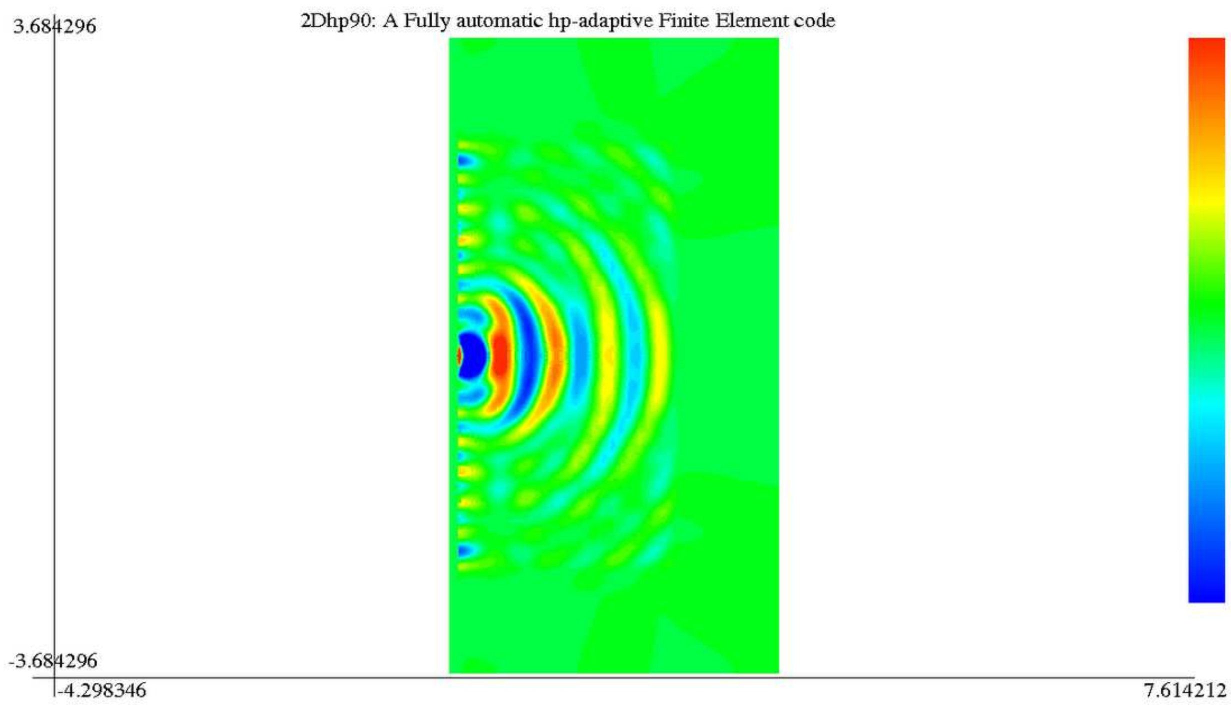
## Preliminary Results




**Acoustic Pressure (logarithmic scale)**

# 2D BOREHOLE ACOUSTICS

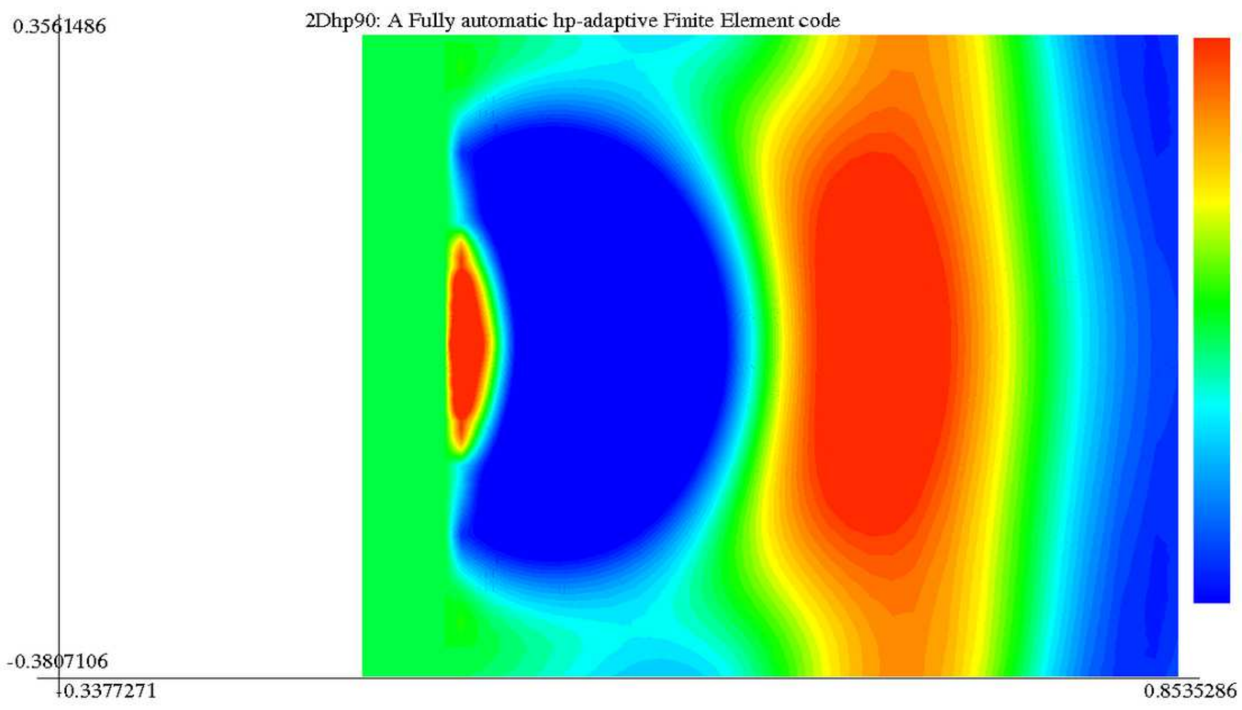
## Preliminary Results




**Horizontal Displacement**

# 2D BOREHOLE ACOUSTICS

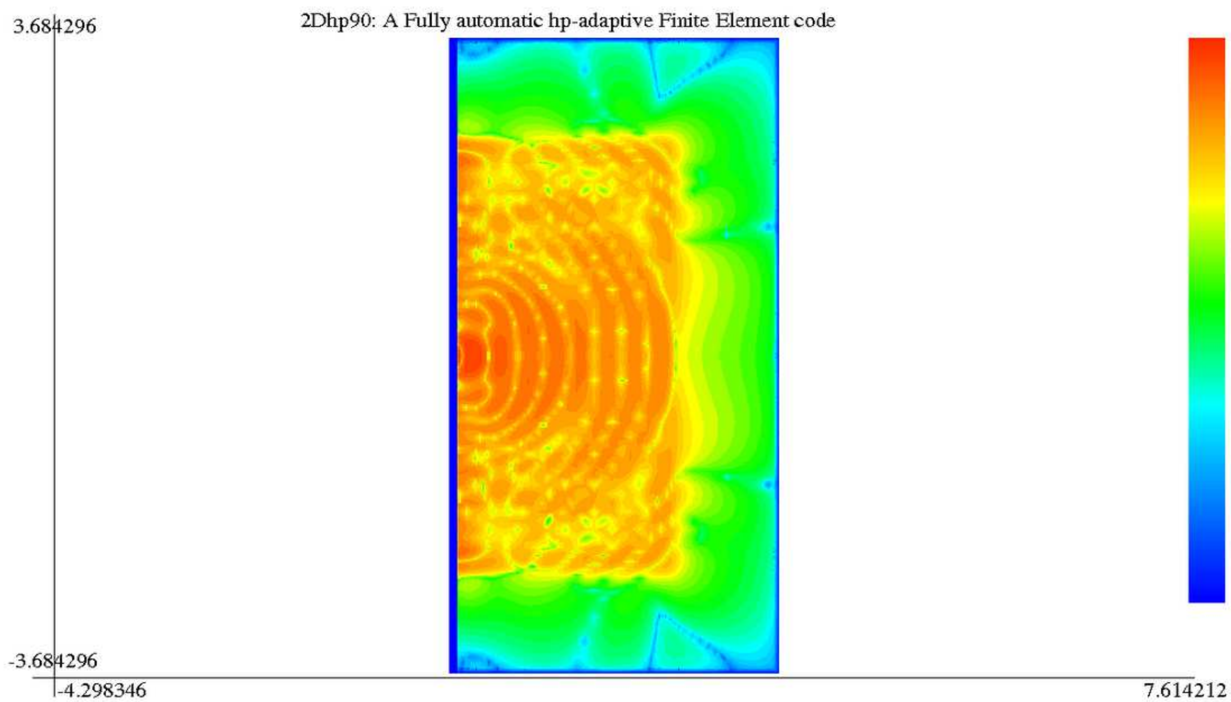
## Preliminary Results




**Horizontal Displacement (amplification by a factor of 10)**

# 2D BOREHOLE ACOUSTICS

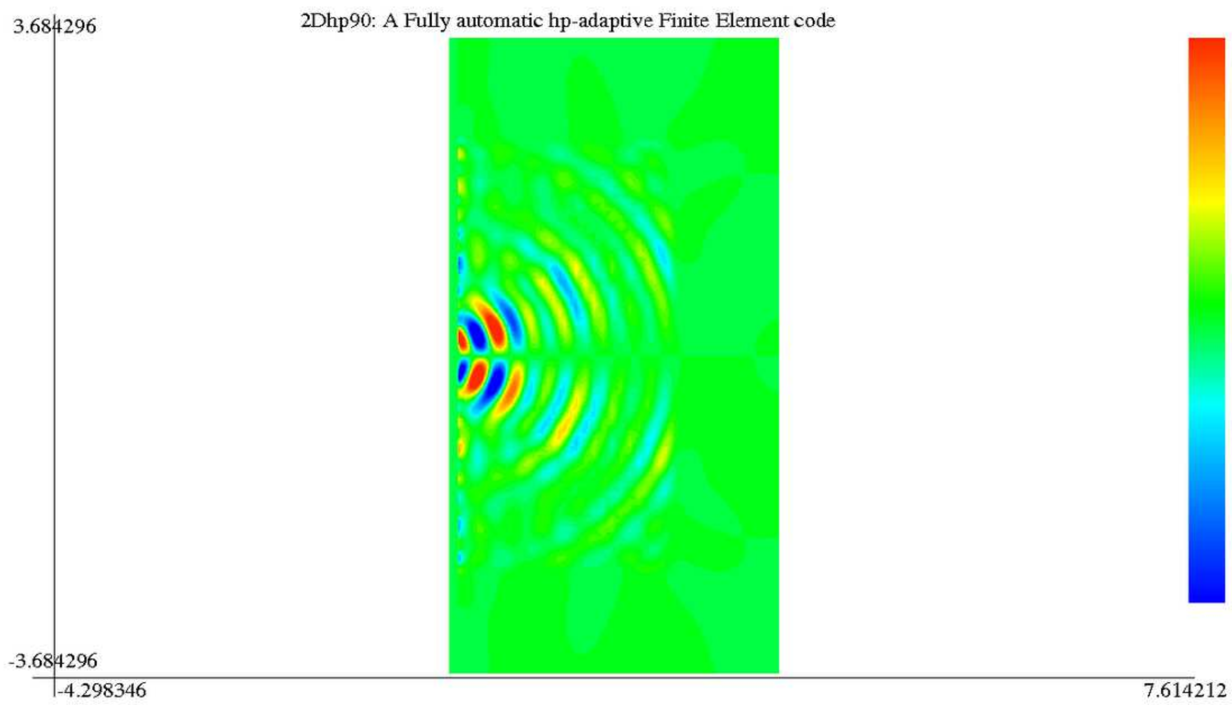
## Preliminary Results




**Horizontal Displacement (logarithmic scale)**

# 2D BOREHOLE ACOUSTICS

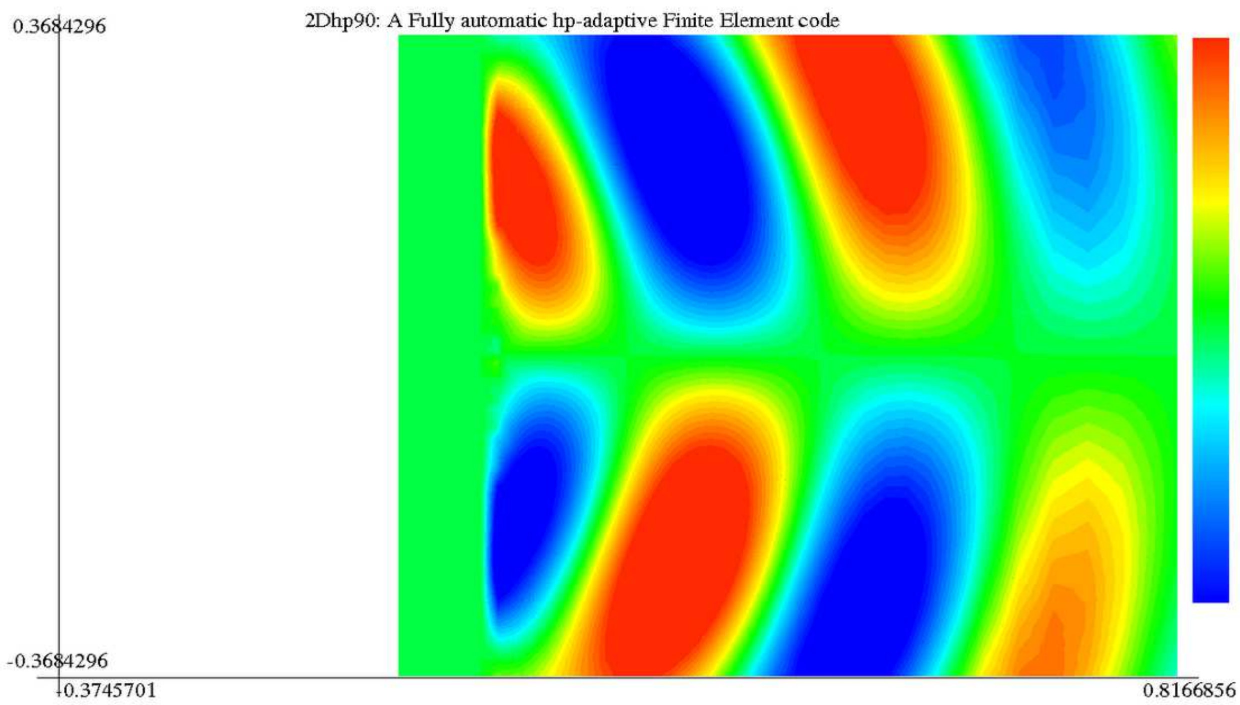
## Preliminary Results




**Vertical Displacement**

# 2D BOREHOLE ACOUSTICS

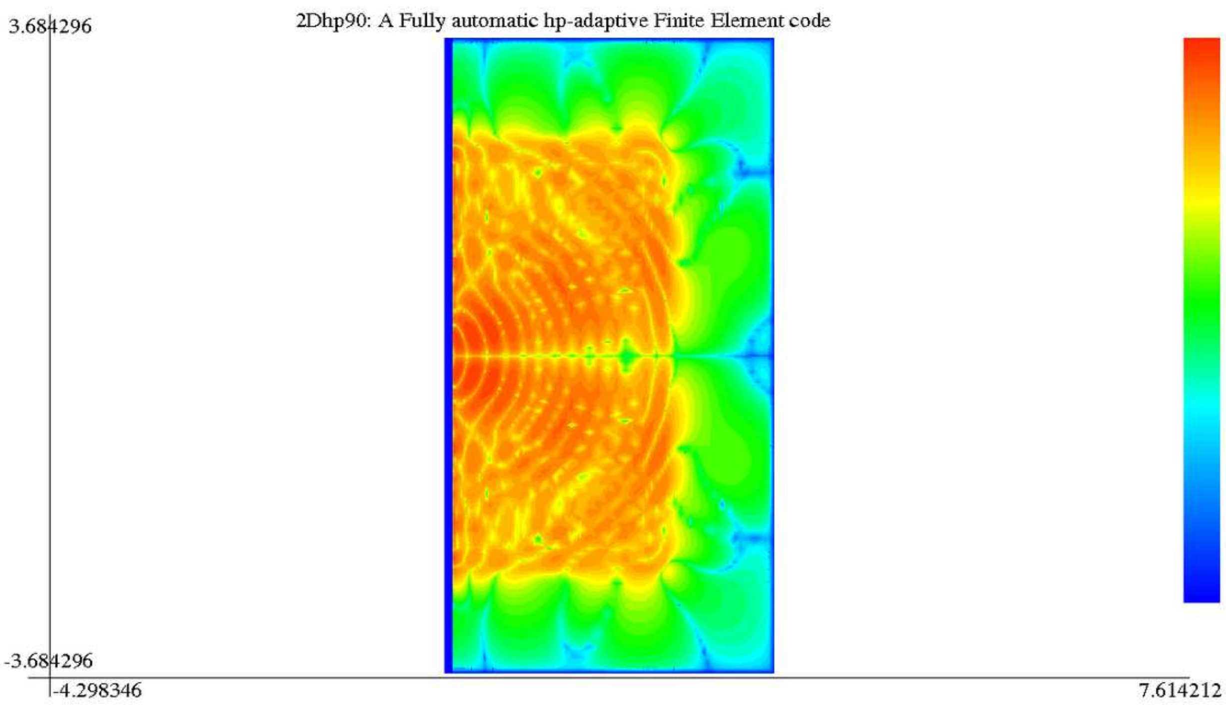
## Preliminary Results




**Vertical Displacement (amplification by a factor of 10)**

# 2D BOREHOLE ACOUSTICS

## Preliminary Results




**Vertical Displacement (logarithmic scale)**

# 2D BOREHOLE ACOUSTICS

## Main Challenges

1. **Boundary Conditions for Truncating the Domain**
    - **Perfect Matched Layers (PML)**
    - **Absorbing Boundary Conditions**
    - **Infinite Elements**

2. **Inverse Fourier Transform (for Time-Domain Results)**
    - **Parallel Computations**
    - **Optimize Number of Frequencies to be Computed**
    - **Iterative (Multi-Frequency) Solvers**

# 2D BOREHOLE ACOUSTICS

## Expected Results

**A Self-Adaptive Goal-Oriented**

**$hp$-Finite Element Method**

**Suitable for Simulation of**

**Axisymmetric Electromagnetic and**

**Borehole Acoustic Problems.**

**Modelling of Mandrel, LWD/Wireline tools for acoustics, etc.**
**This is the first step towards multi-physics problems**

# ACKNOWLEDGMENTS


## THANKS!!!

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