New Approaches for Performance Definition of Composite Materials and Structures
Thursday 11 March 2010
Venue: National Physical Laboratory (NPL), London, UK
BSSM
BRITISH SOCIETY FOR STRAIN MEASUREMENT

Ecole Nationale Supérieure d'Arts et Métiers

High strain rate photomechanics on composites: use of a ultra high speed camera and the virtual fields method

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Objectives

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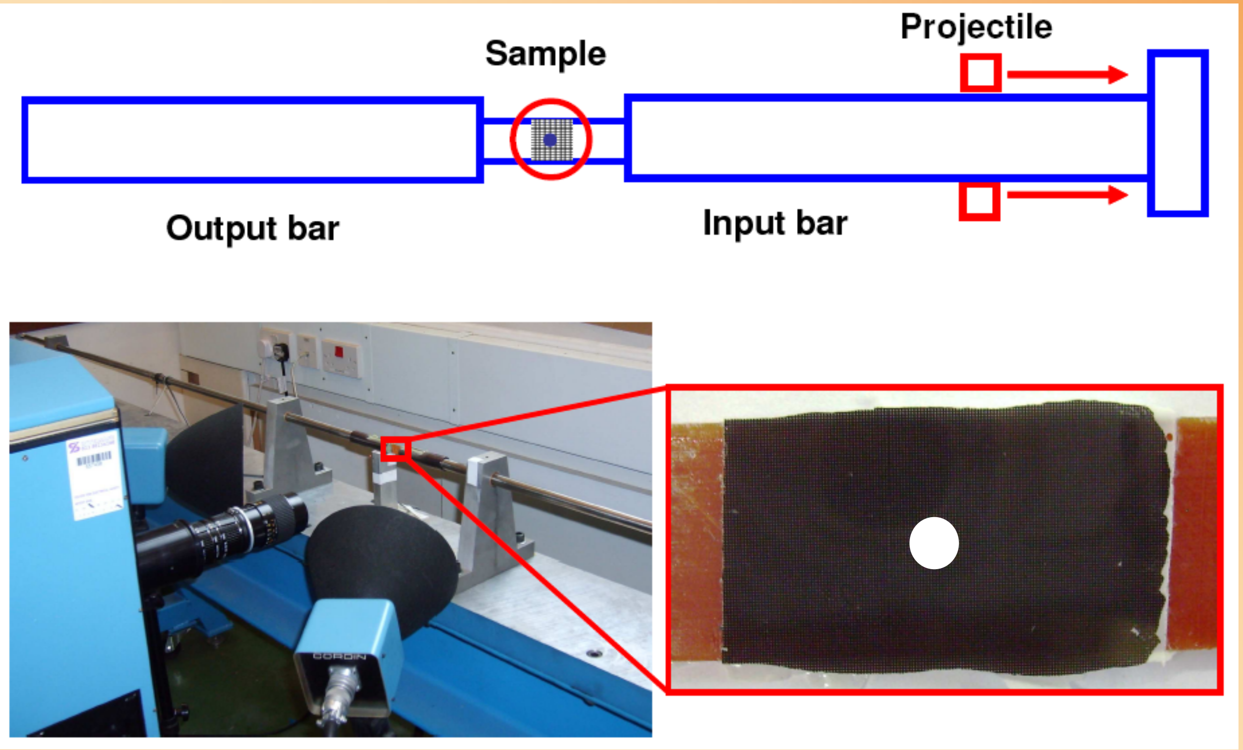
- **Perform full-field deformation measurements with a ultra high speed camera**
  - **Evaluate performances (quantitative measurements)**
- **Process the deformation data to identify stiffnesses**
  - **Use of acceleration maps to make up for the lack of force data**

Test set-up

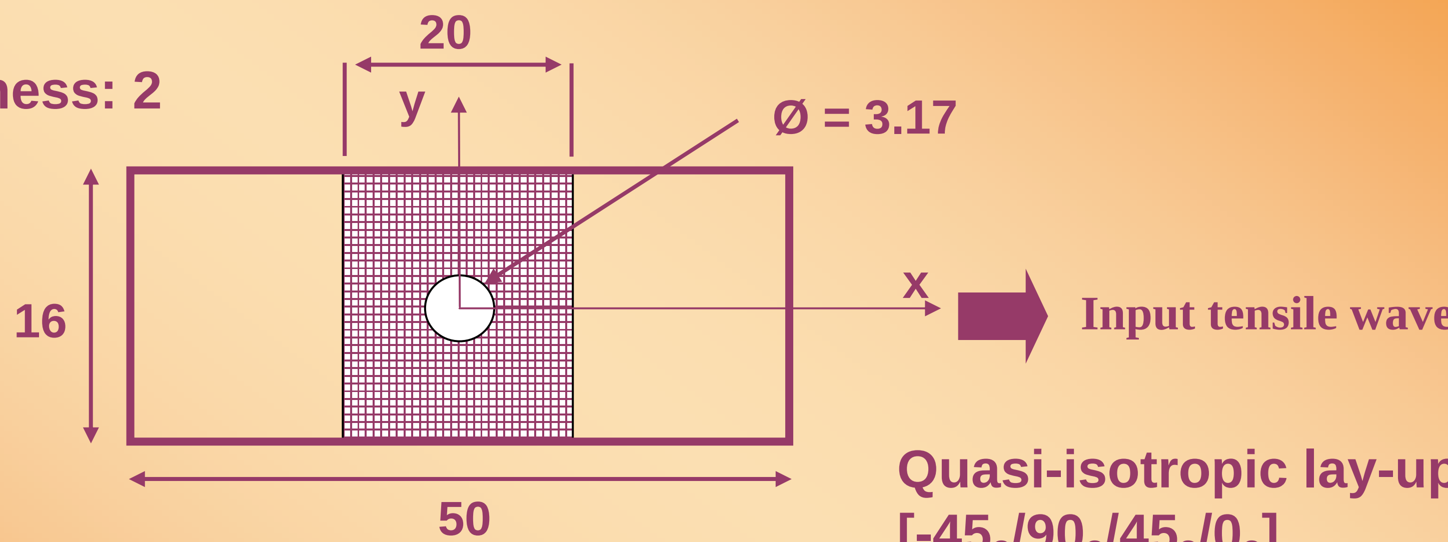

Projectile
Sample
Output bar
Input bar


End-caps are screwed onto the bars
The sample is glued to end-caps

Test set-up

- **Test specimen: glass-epoxy composite**

Thickness: 2

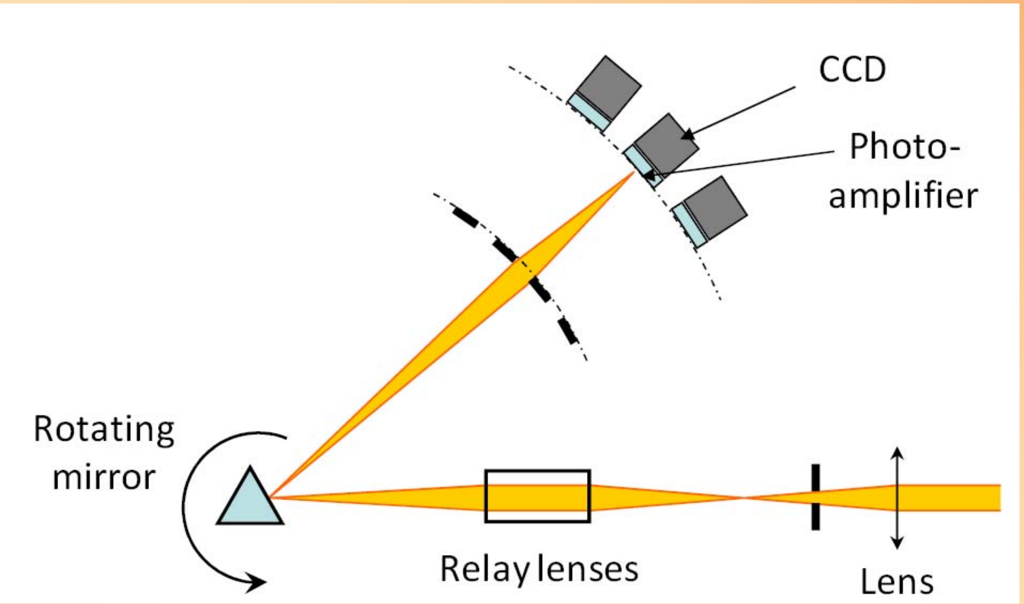


Quasi-isotropic lay-up:
$[-45_2/90_2/45_2/0_2]_s$

- **Cross-line grid: 200 μm pitch**
  - **Transferred onto specimen**
  - **Displacements obtained by spatial phase shifting**

Test set-up

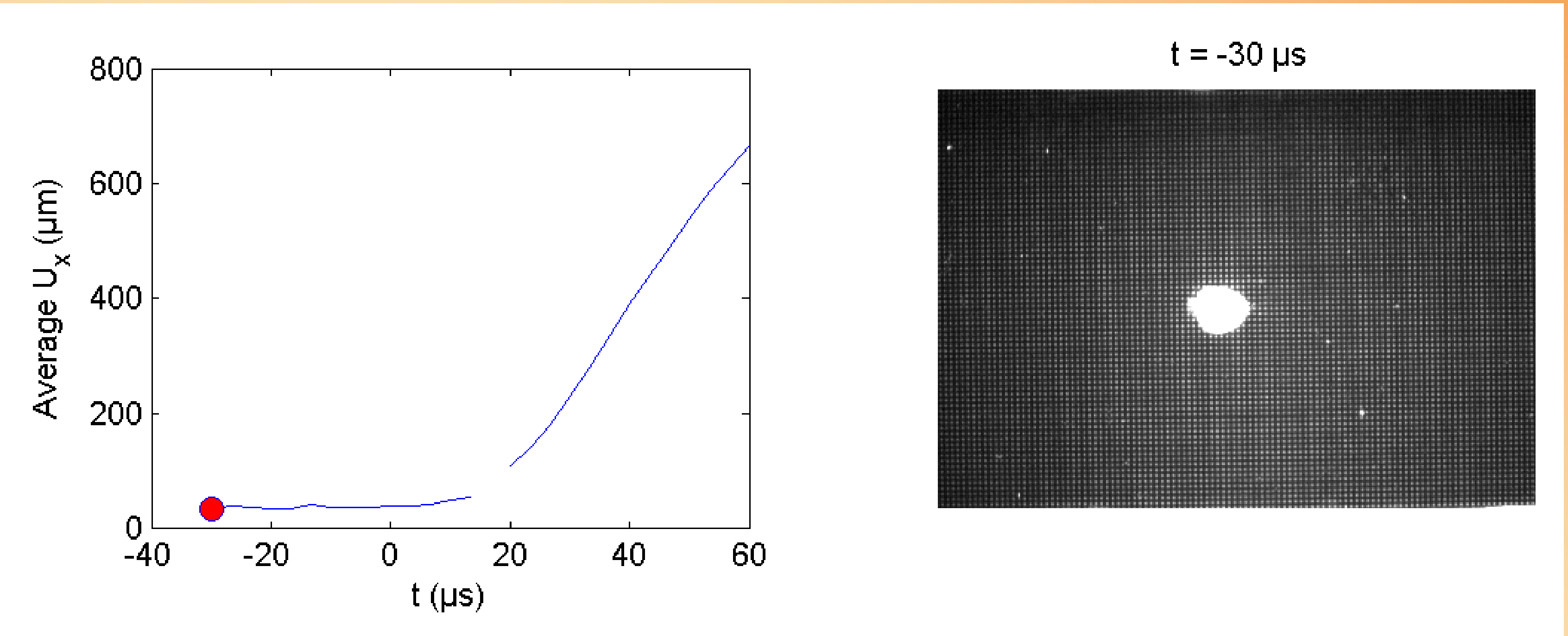
- Ultra high speed camera: Cordin 550-62



- Time resolution: 3.3 µs (300.000 fps) – light issues
  - Maximum frame rate: 4 Mfps!
- Spatial resolution: 1 Mpixel

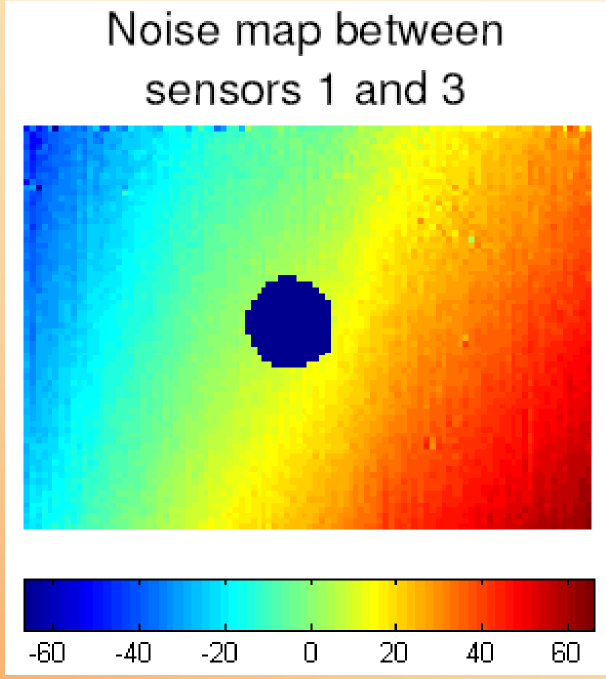
Measurements

- Grey level images

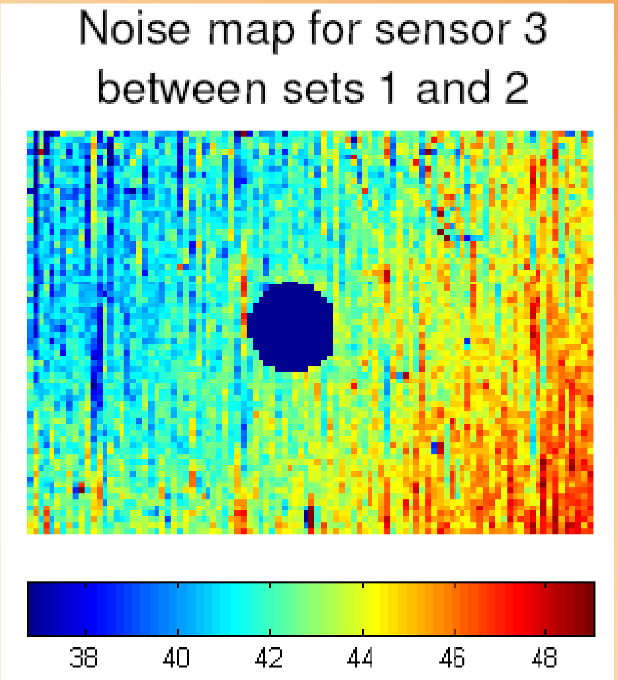


Measurements

- Problem of bias caused by sensor positions



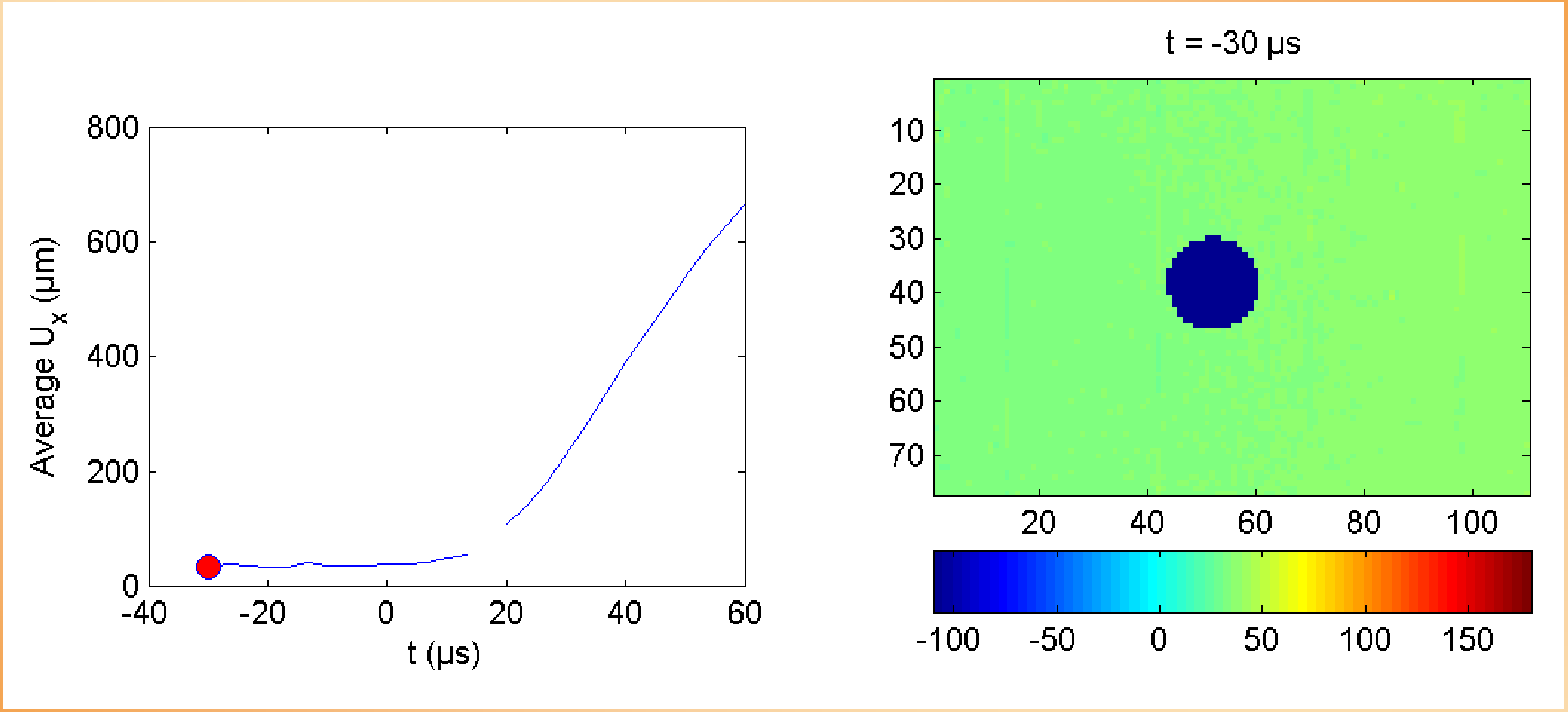
Ux in μm



- Need for a first set of 62 still images
- Phase maps obtained sensor by sensor
- Final resolution: 5 μm (2.5% of grid pitch)

Measurements

- **Longitudinal displacement**



Ux in µm

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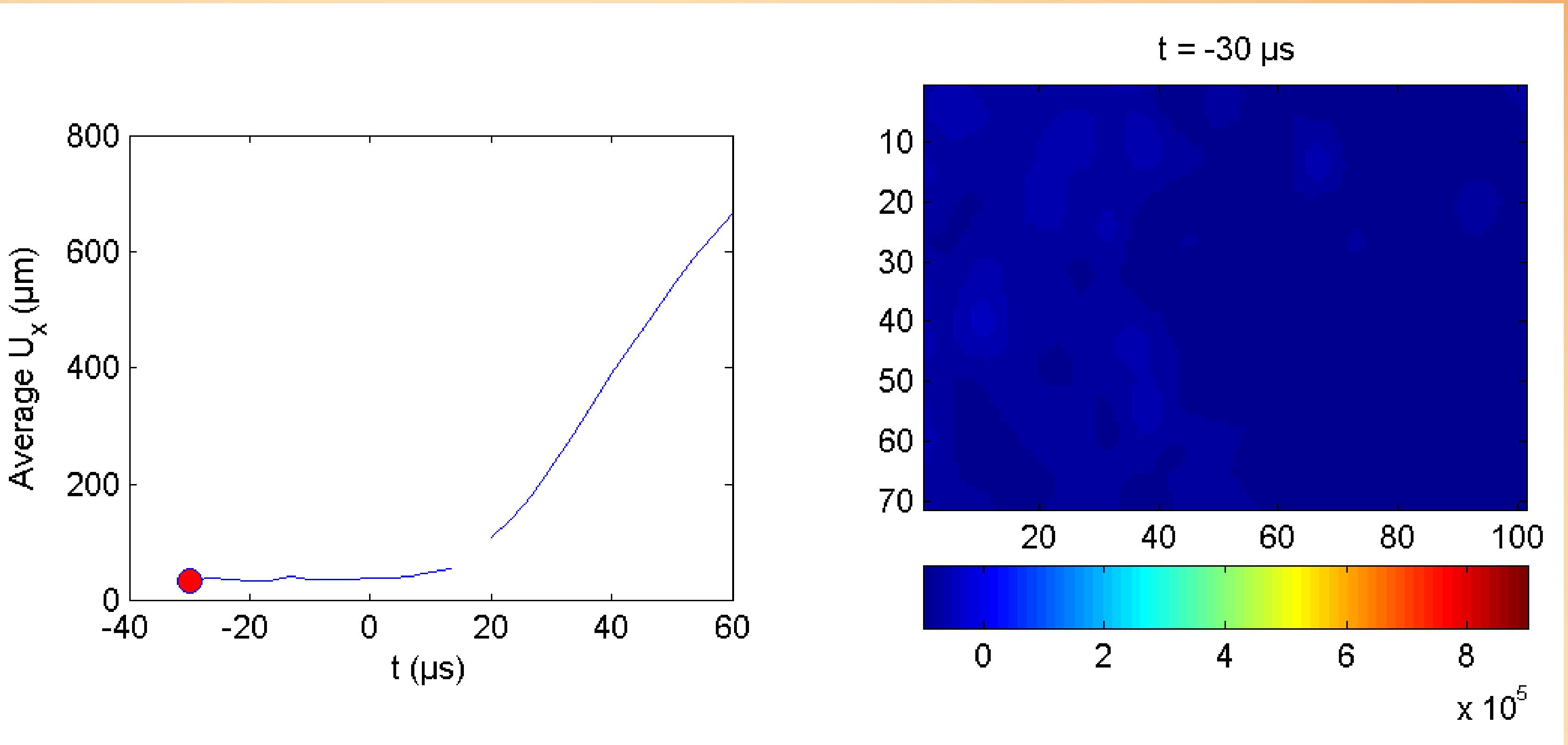
Measurements

- **Acceleration maps: double temporal differentiation**
  - 4th order polynomial fit over time
  - Sliding window of 9 images
  - Resolution: between 1 and 2.10^5 m.s^{-2}



m.s^{-2}

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Measurements

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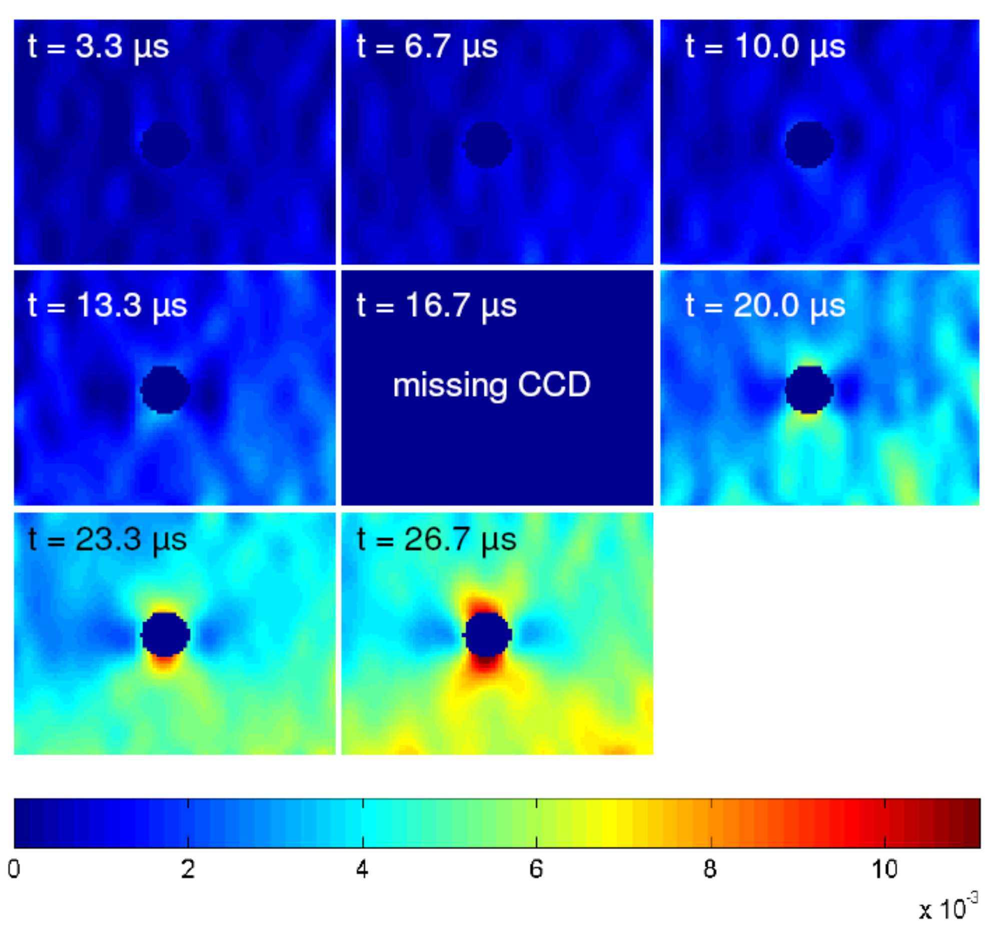
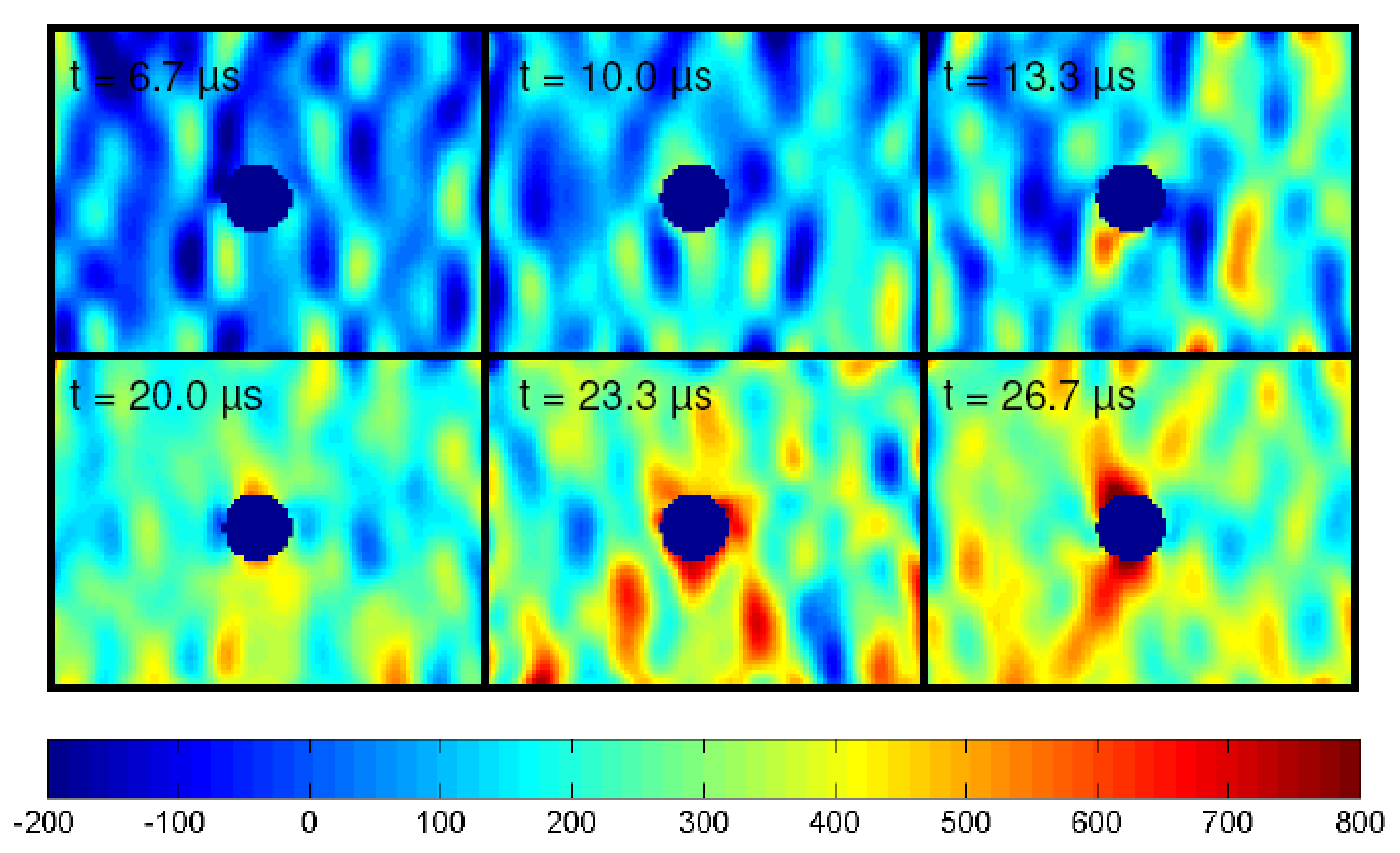
- **Strain maps: spatial differentiation**
  - **Local smoothing (diffuse approximation)**
  - **Resolution: 10^{-3}**



Measurements

- Strain rate maps (s^{-1}): temporal differentiation
  - Calculated through point to point finite difference
  - Resolution: about 400 s^{-1}



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Identification

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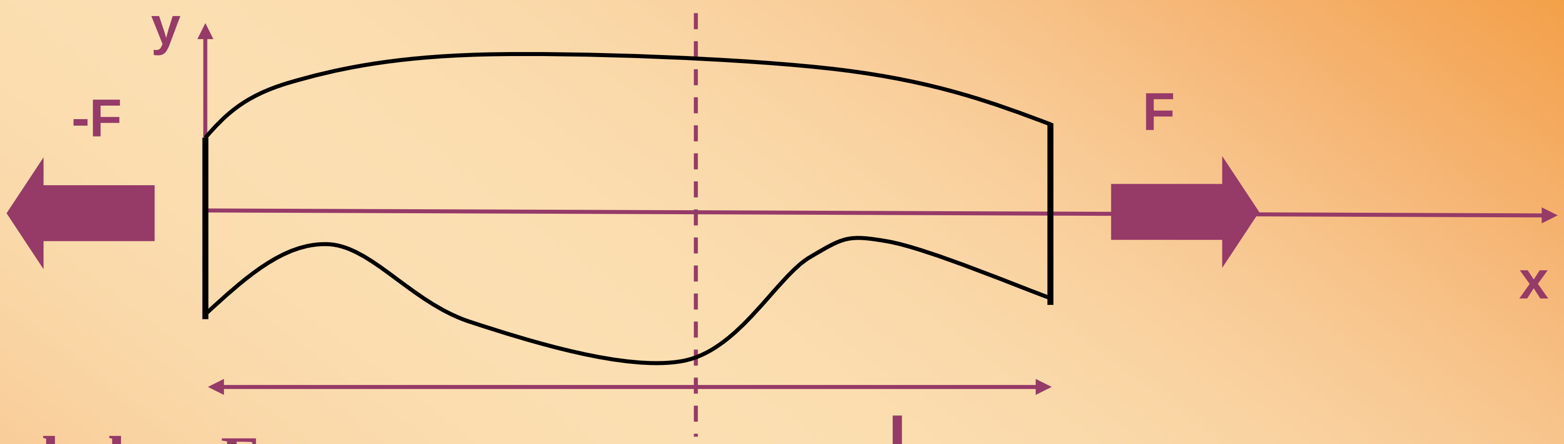
- The virtual fields method



$$\int_S \sigma_x dydz = F$$

Integrate over x

$$\int_V \sigma_x dxdydz = FL$$

Plane stress

$$\int_S \sigma_x dxdy = \frac{FL}{t}$$

Linear elastic isotropy

$$\int_S (Q_{xx}\varepsilon_x + Q_{xy}\varepsilon_y) dxdy = \frac{FL}{t}$$

Homogeneous material

$$Q_{xx}\int_S \varepsilon_x dxdy + Q_{xy}\int_S \varepsilon_y dxdy = \frac{FL}{t}$$

Identification

- Principle of virtual work

$$-\int_V \sigma : \varepsilon^* dV + \int_{\partial V} T.u^* dS = \int_V \rho a.u^* dV$$

1 VF: 1 linear equation

- No force measurement
  - In "static":

$$\int_V \sigma : \varepsilon^* dV = 0 \qquad [A]\{Q\} = \{0\}$$

    - Only stiffness ratios (ν)

- No force measurement
  - In dynamic

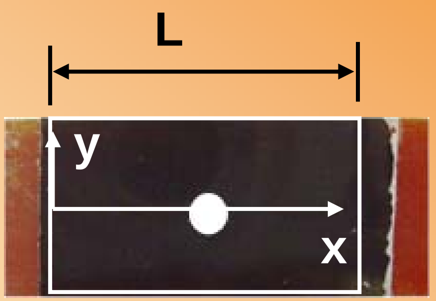
$$-\int_V \sigma : \varepsilon^* dV = \int_V \rho a.u^* dV$$

    - Acceleration forces: distributed volumic load cell!

Identification

- Choice of virtual fields: field 1

$$\begin{cases} u_x^* = x(x-L) \\ u_y^* = 0 \end{cases} \qquad \begin{cases} \varepsilon_x^* = 2x-L \\ \varepsilon_y^* = 0 \\ \varepsilon_s^* = 0 \end{cases}$$



$$\int_{\partial V} T.u^* dS = 0$$

$$Q_{xx}\int_S (2x-L)\varepsilon_x dxdy + Q_{xy}\int_S (2x-L)\varepsilon_y dxdy = -\rho\int_S x(x-L) a_x dS$$

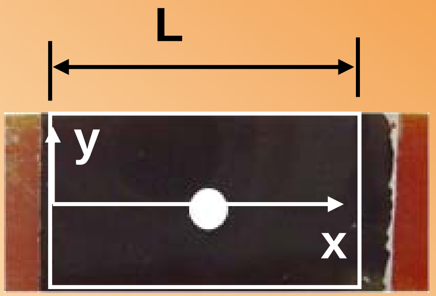
Spatial differentiation of U_x

Spatial differentiation of U_y

Double time differentiation of U_y

Identification

- **Choice of virtual fields: field 2**



$$\begin{cases} u_x^* = 0 \\ u_y^* = x(x-L)y \end{cases} \qquad \begin{cases} \varepsilon_x^* = 0 \\ \varepsilon_y^* = x(x-L) \\ \varepsilon_s^* = (2x-L)y \end{cases}$$

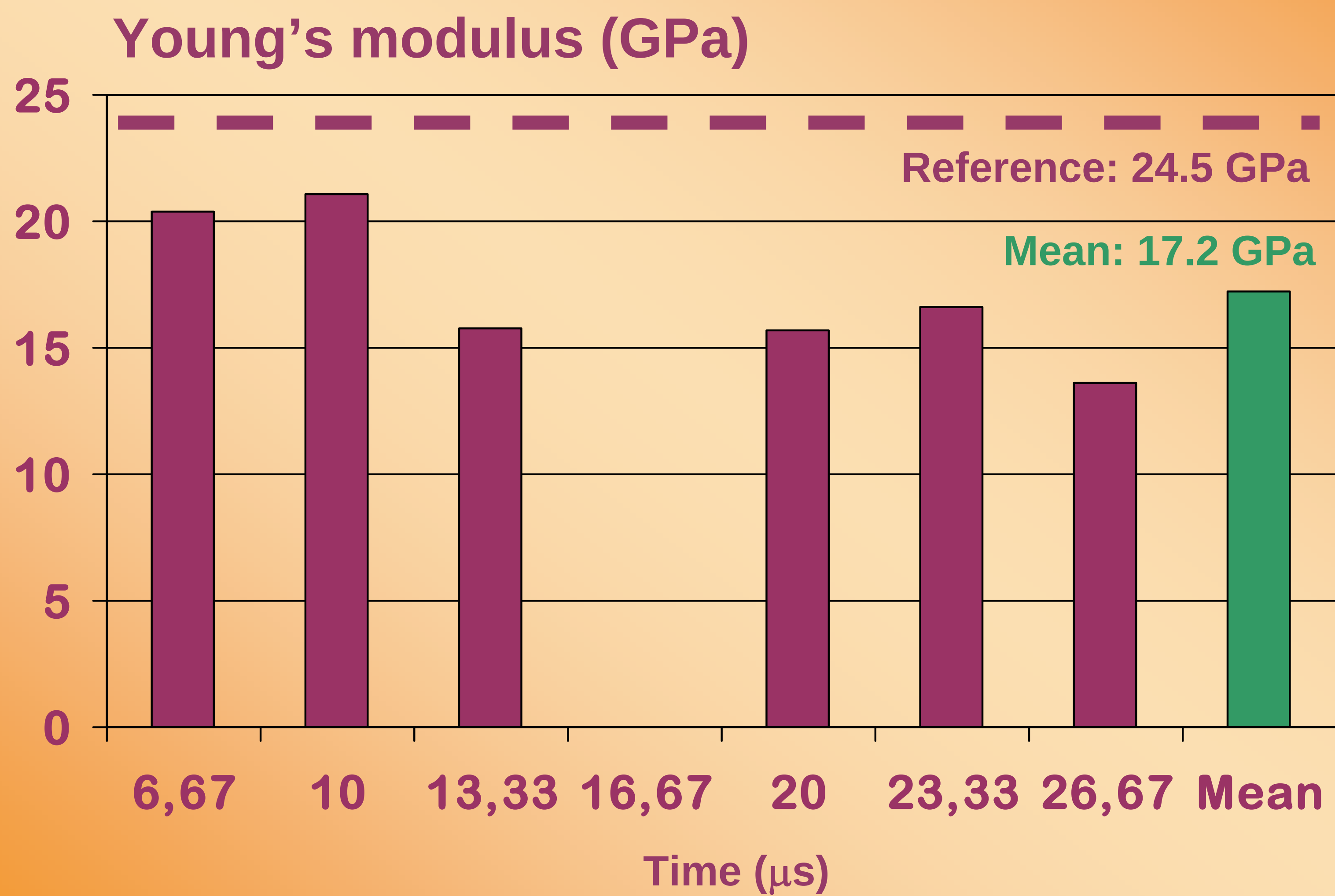
$$Q_{xx}\int_S \left(x(x-L)\varepsilon_y + \tfrac{1}{2}(2x-L)y\varepsilon_s\right)dxdy +$$
$$Q_{xy}\int_S \left(x(x-L)\varepsilon_x - \tfrac{1}{2}(2x-L)y\varepsilon_s\right)dxdy = -\rho\int_S x(x-L)y a_y dS$$

Linear system $[A]\{Q\} = \{B\}$

www.camfit.fr

Identification

- Results



Identification

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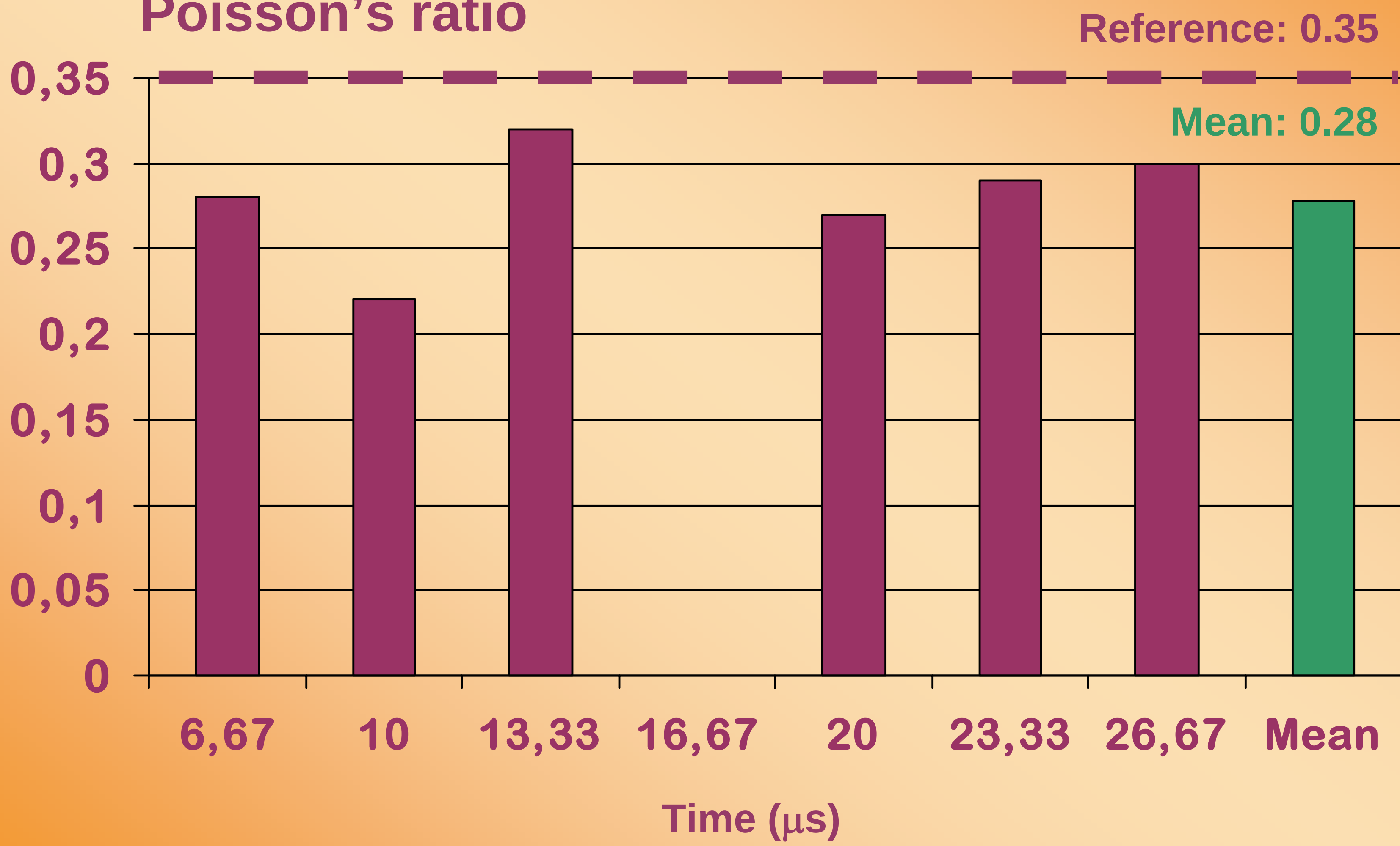
- Results

Poisson's ratio



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Identification

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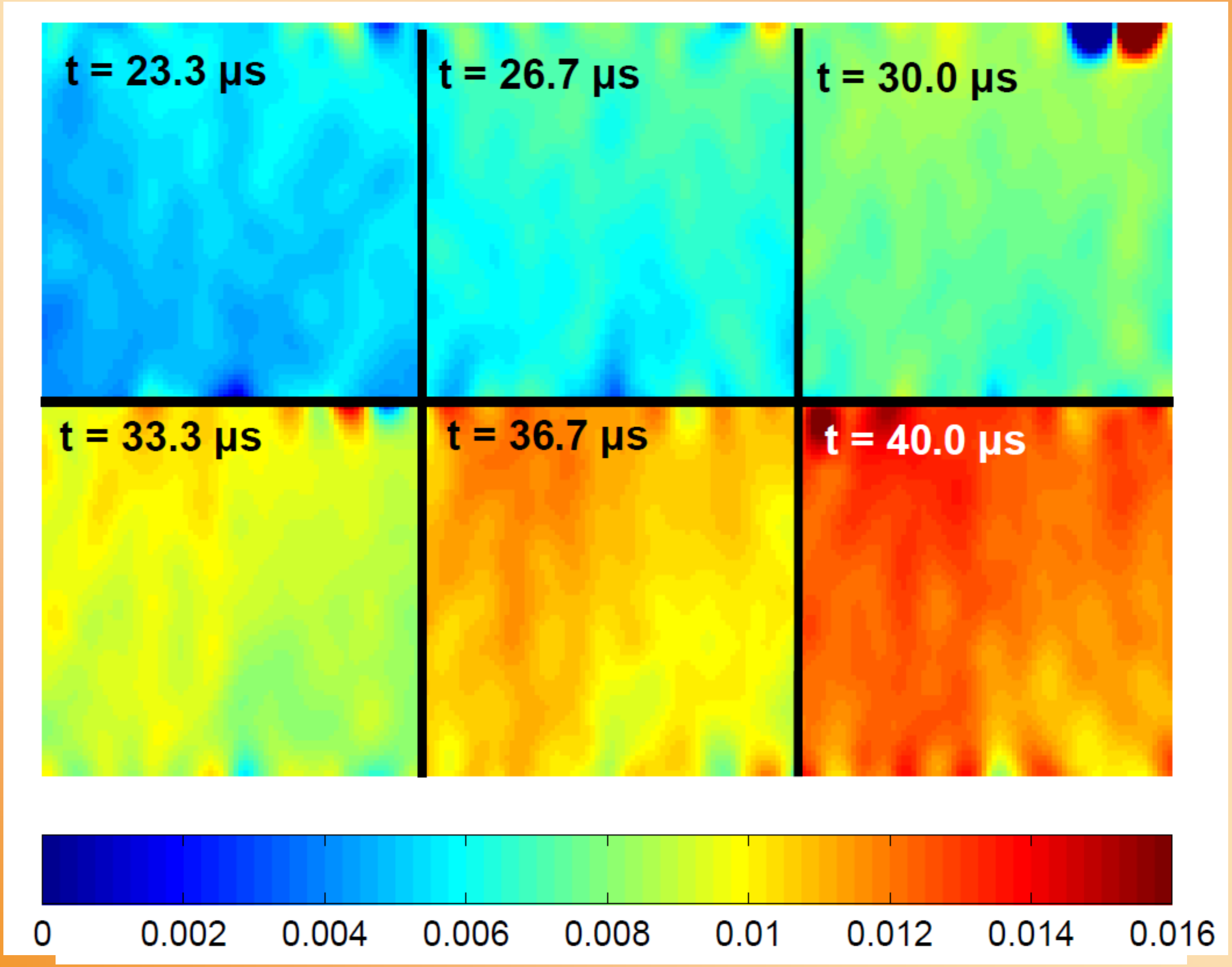
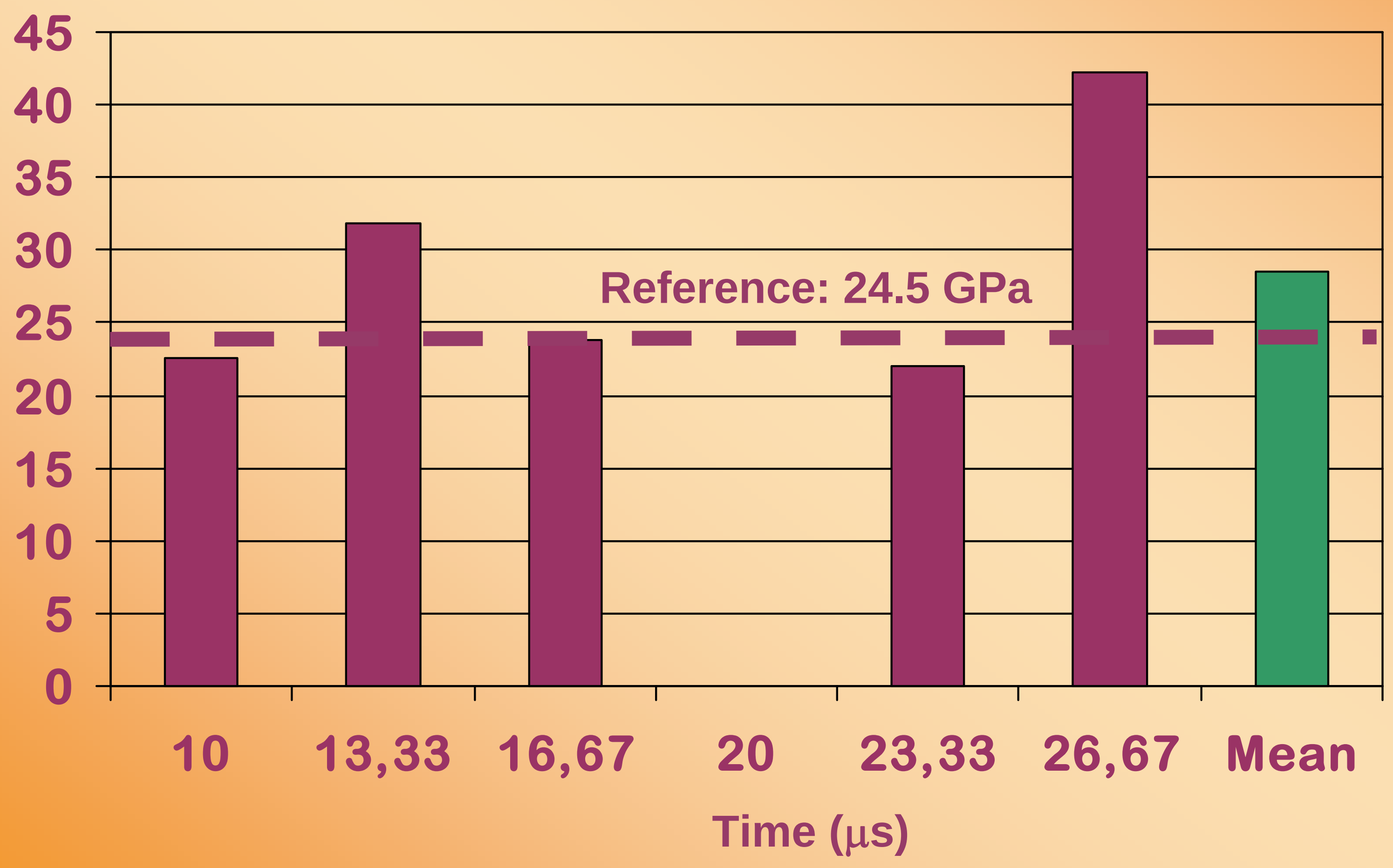
Specimen without a hole



Identification

- Results

Young's modulus (GPa)



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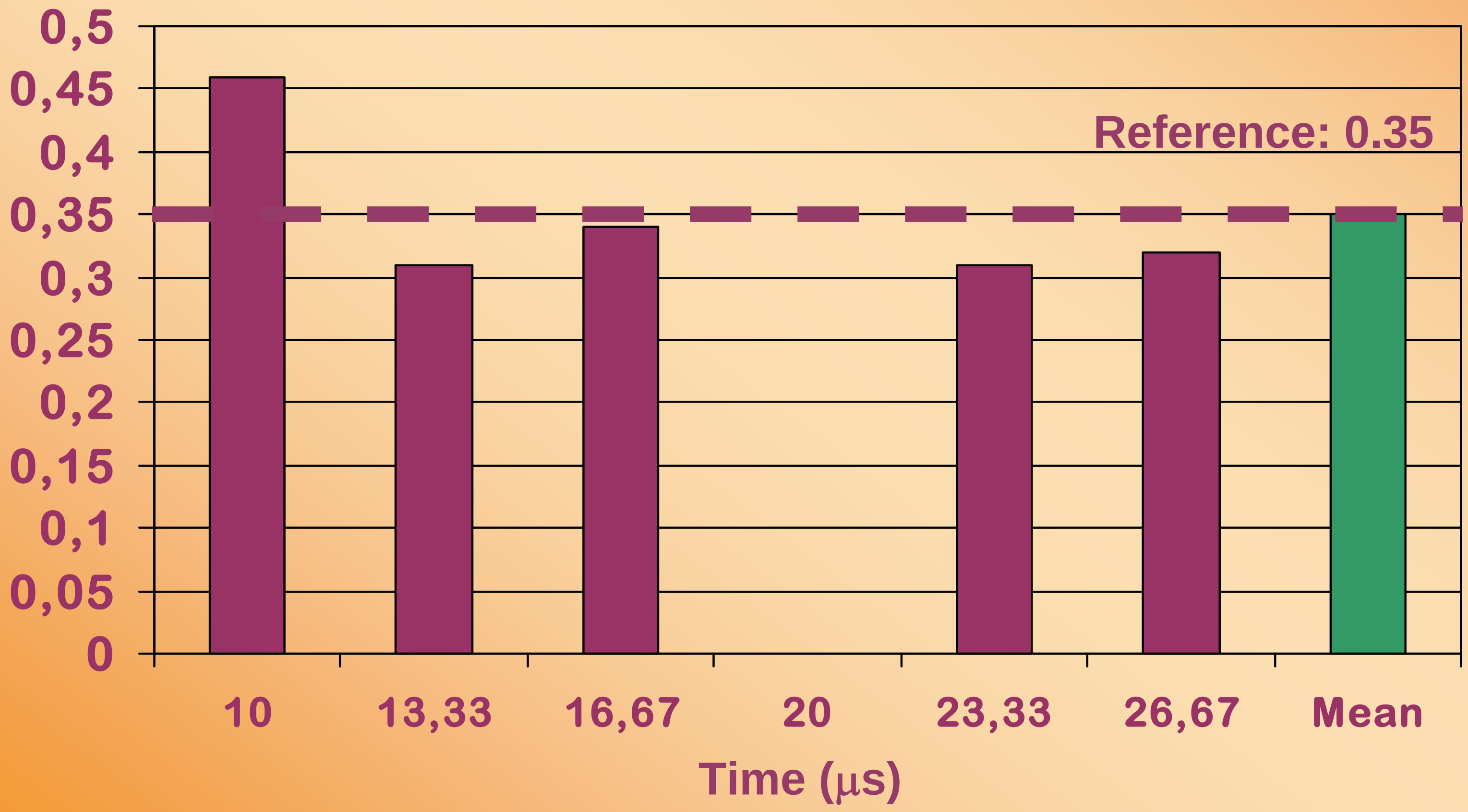
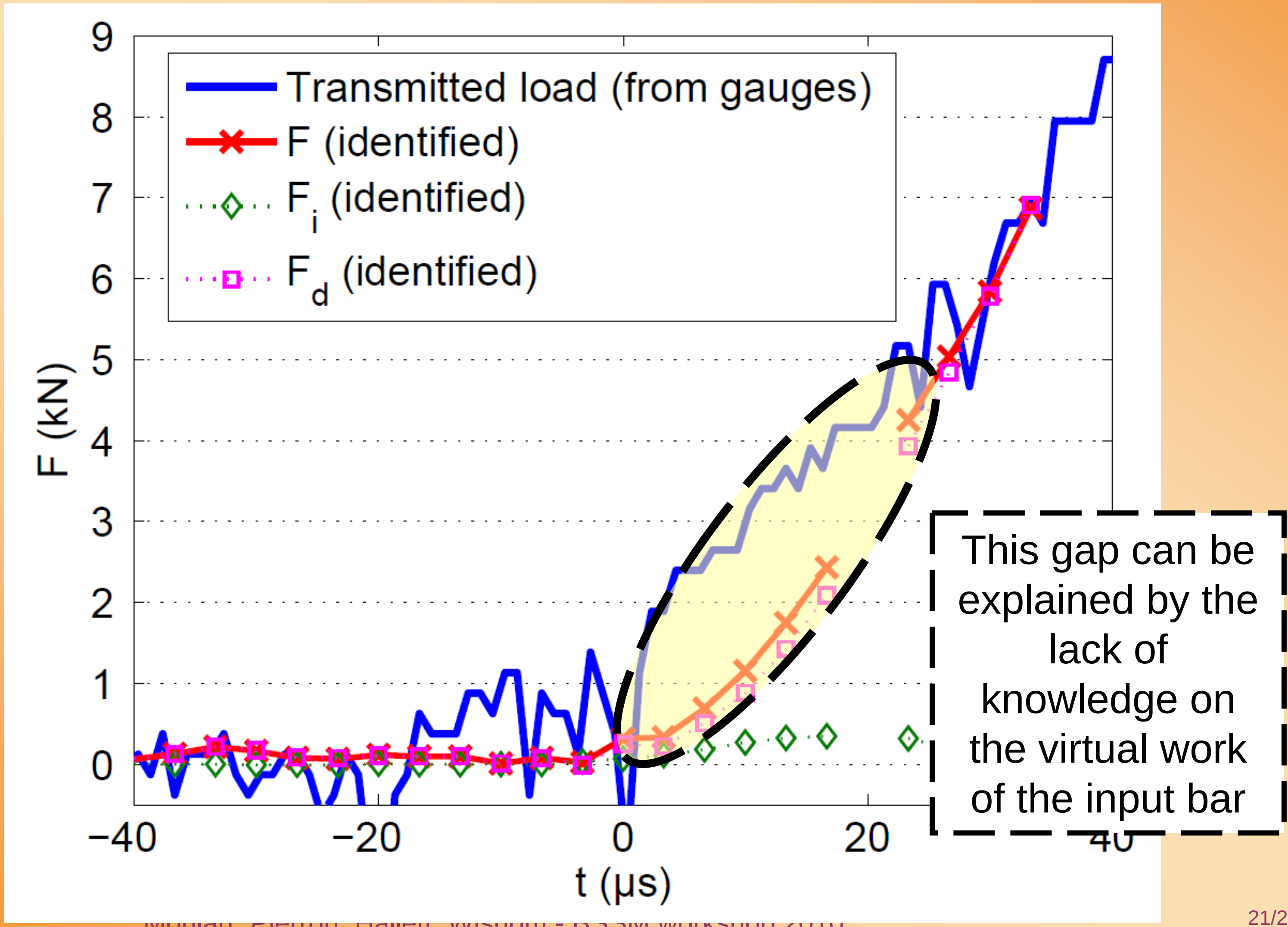
- Results

Poisson's ratio



Identification

Force reconstruction



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CONCLUSION

- **Measurements**
  - Use of a UHS speed camera
  - Quantitative data obtained (novel)
  - Quality can be improved
    - Increase frame rate (limit: 4 Mfps)
    - Improve lighting, improve spatial resolution (grid pitch)
    - Understand origin of bias and noise
- **Identification**
  - Quantitative data obtained
  - Use of acceleration forces (novel)
  - Huge future potential: no need for Hopkinson bar setup
  - Need for better (and cheaper) cameras
  - Need for new test designs

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