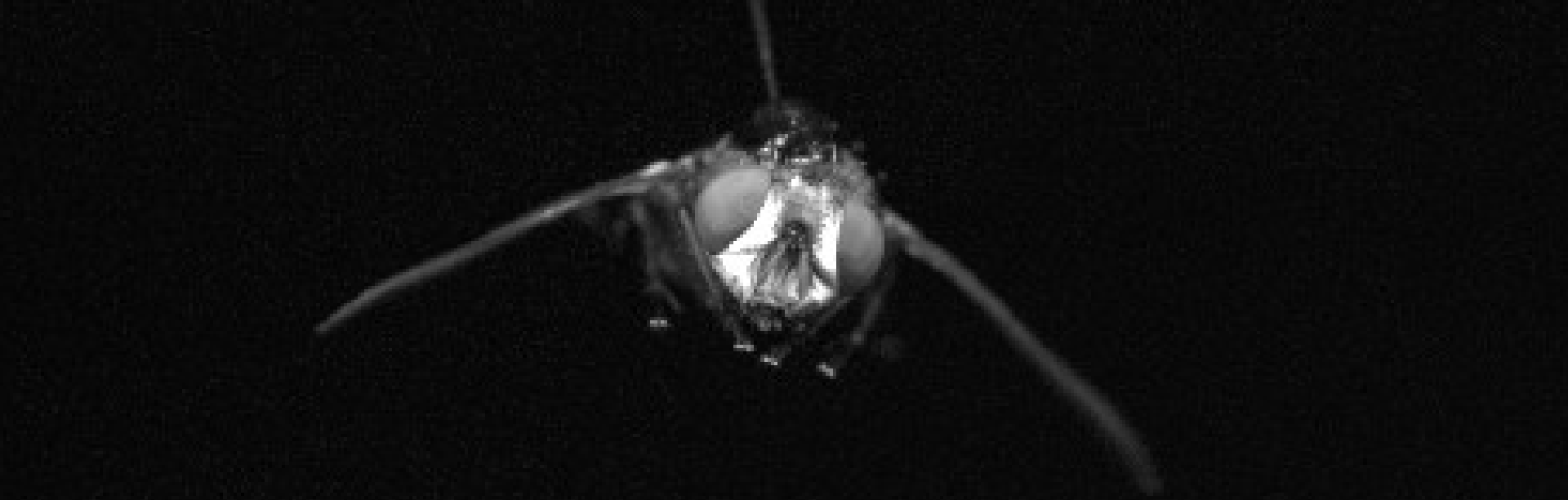
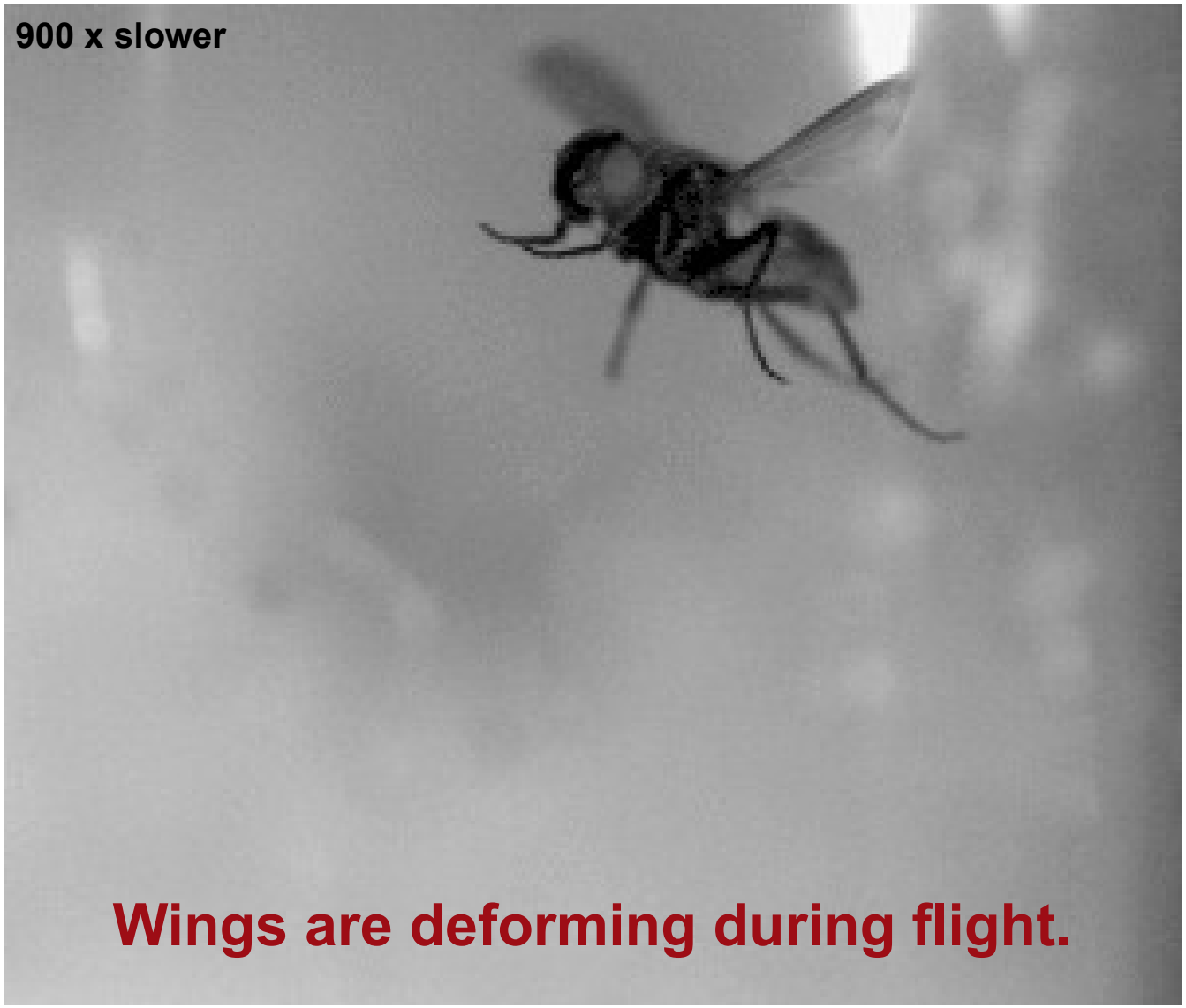


Local deformation and stiffness distribution in fly wings

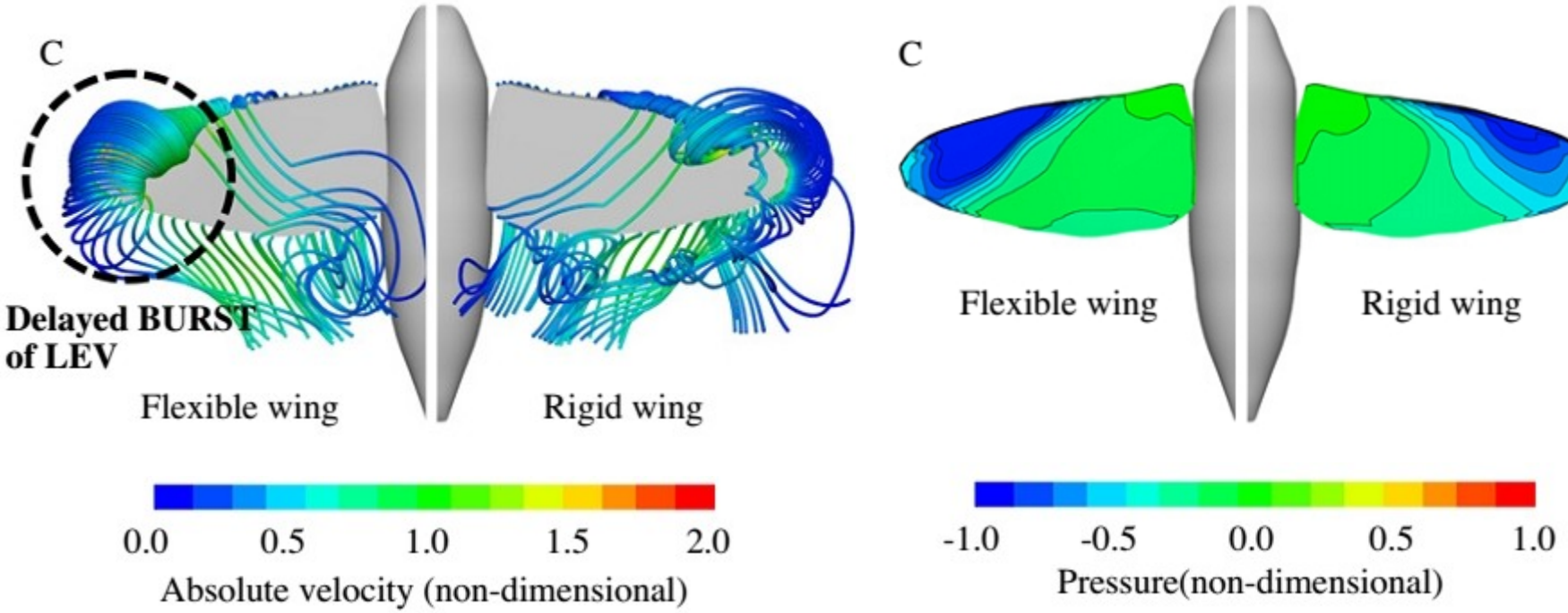
Henja-Niniane Wehmann, Lars Heepe,
Stanislav N. Gorb, Thomas Engels, Fritz-Olaf Lehmann

06.12.2018 **AIFIT Meeting** | Paris

Flight of the house fly, *Musca domestica* L.



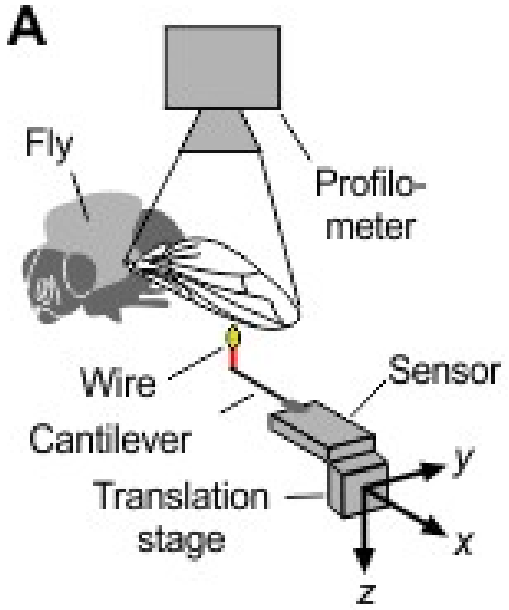
Mechanical properties are important

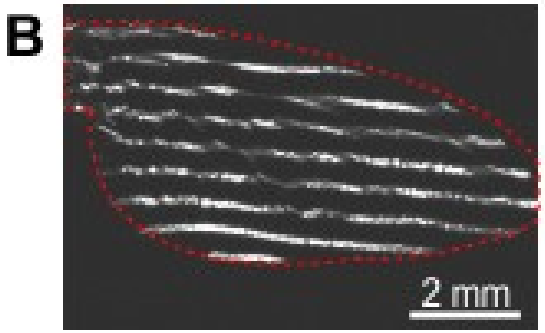


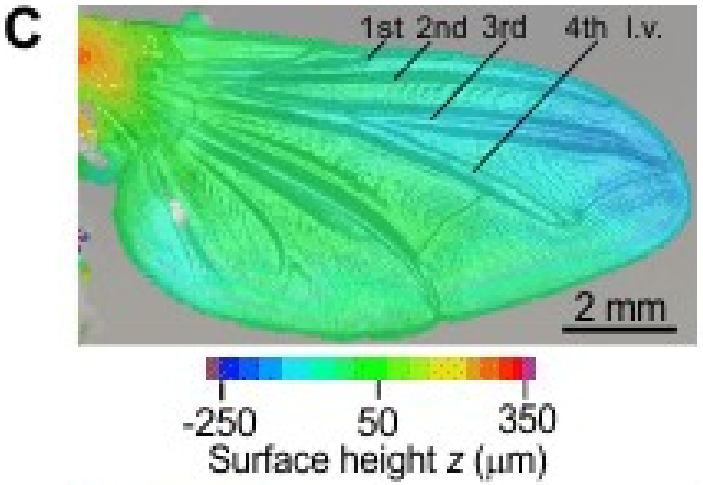
Nakata & Liu 2012, *J. Comput. Physics* 231, 1822-1847, Fig. 17

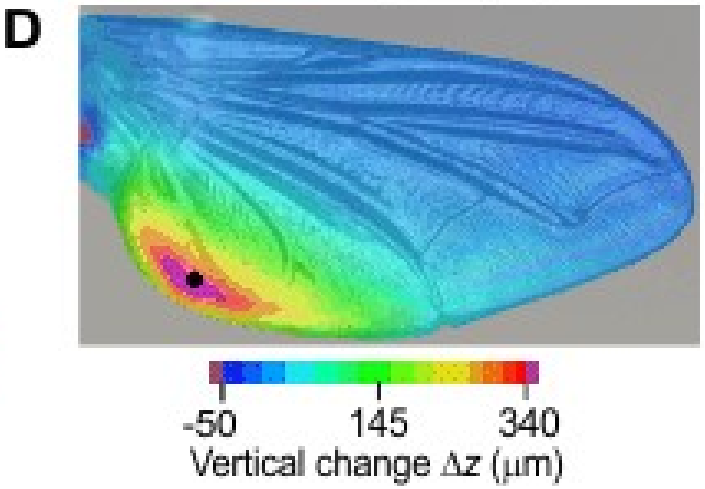
Rigid and flexible wings produce different forces.

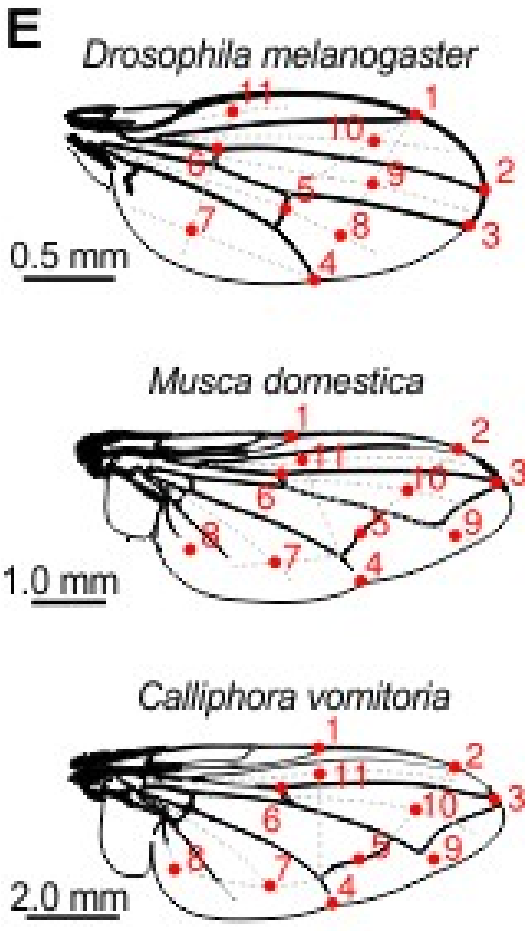
Measuring the mechanical behaviour of fly wings



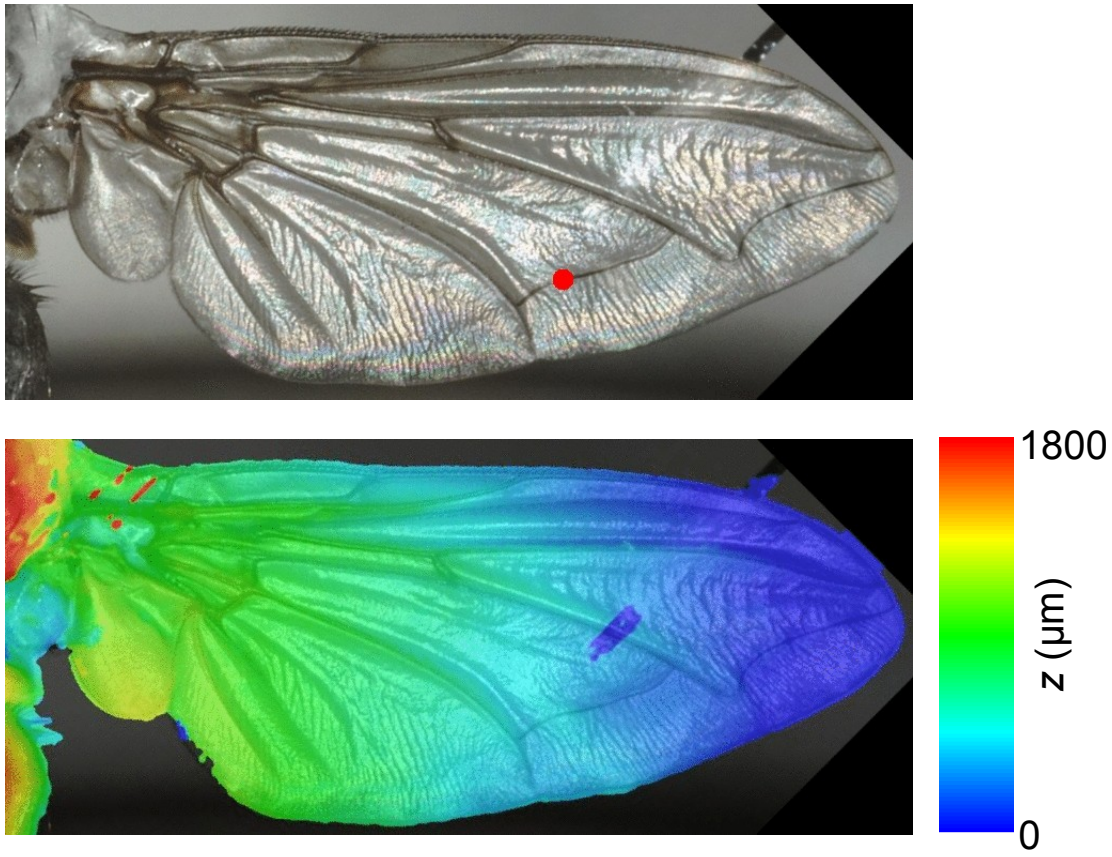






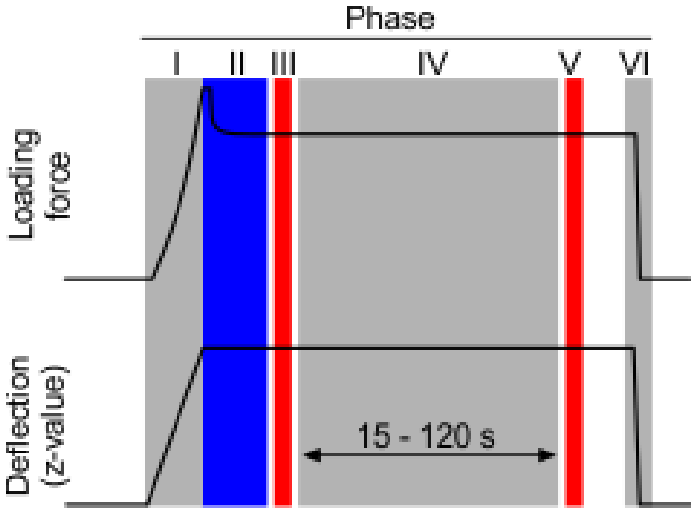


Measuring the mechanical behaviour of fly wings



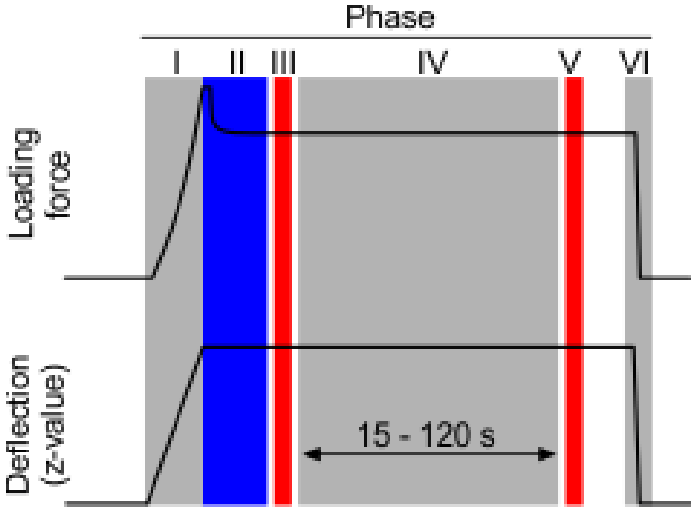
Comparison of shape of deformed and undeformed wings.

Recording the force

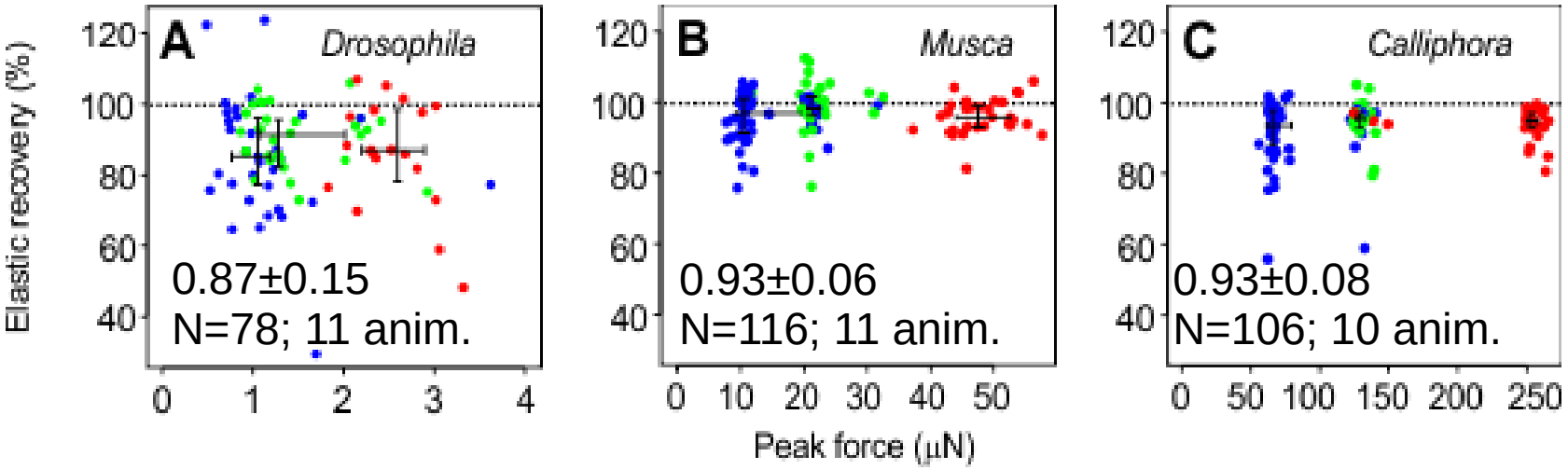


Phases I, VI: Movement of the sensor
Phase II: Sabilisation of force readings
Phases III, V: Force measurement taken
Phase IV: Profile measured optically

Recording the force

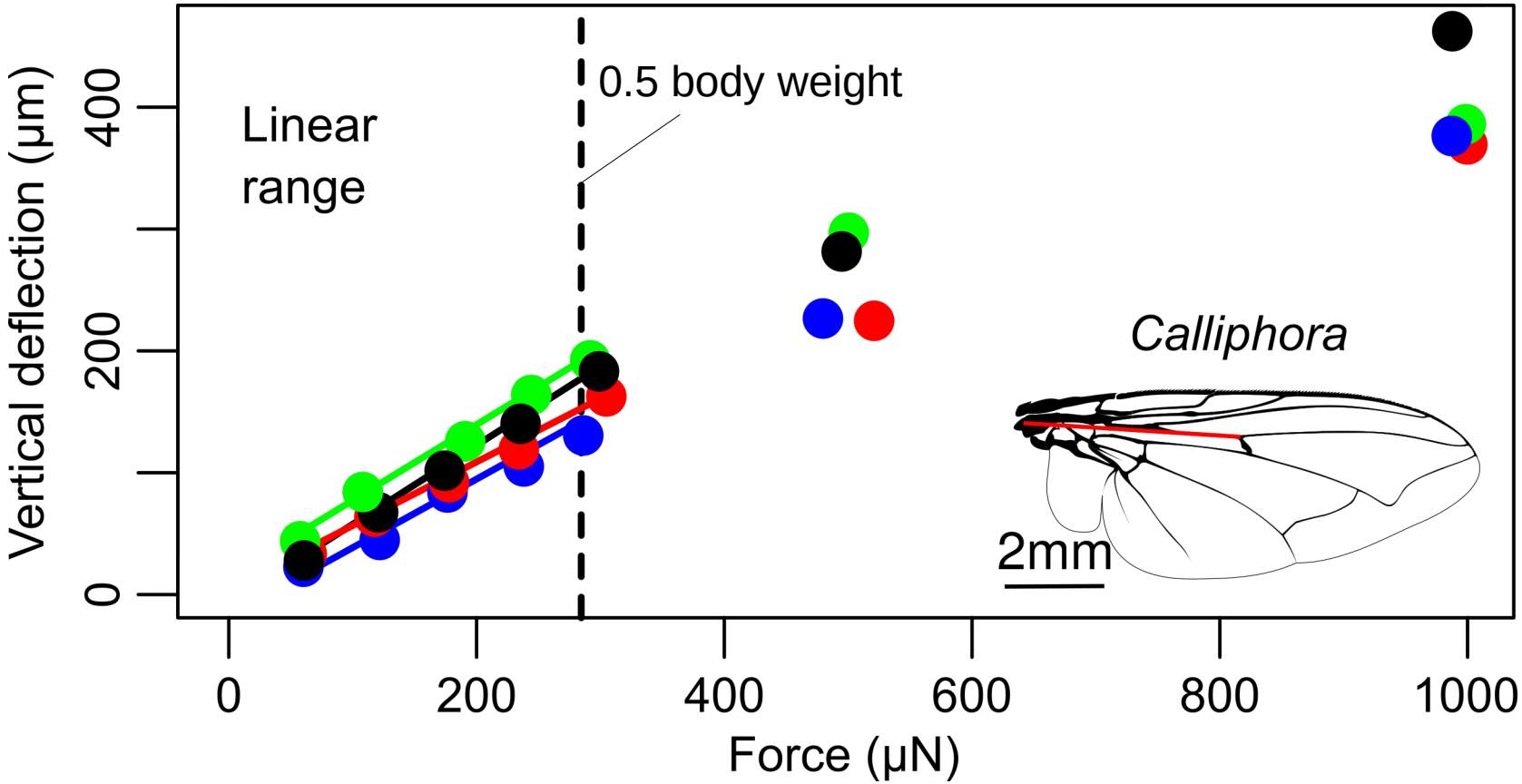


- Sensor tip sliding on cuticle
- Relaxation process or plastic deformation somewhere (wing, joint fixation, fly body, body fixation, fly holder)



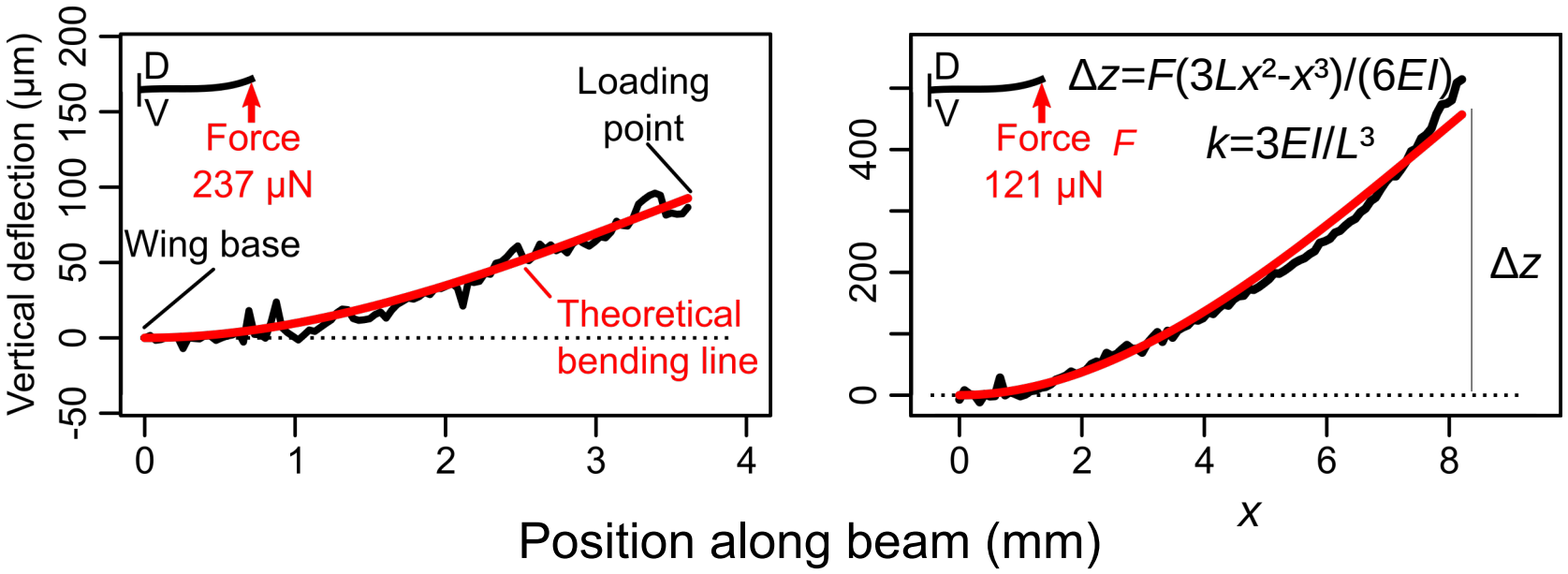
Leading edge Wing tip Trailing Edge

Blow-fly *Calliphora vomitoria* L.: Linear behaviour for small deflections



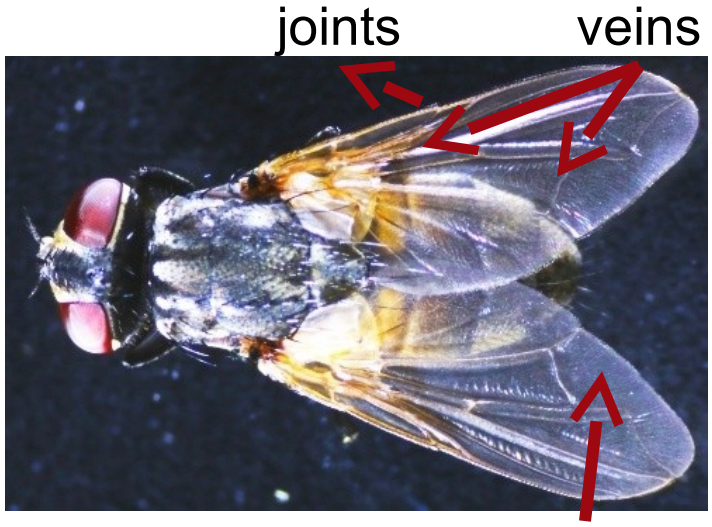
Individual animals colour-coded.
Stiffness 1.54 N/m ≤ k ≤ 2.05 N/m

Calliphora: Behaviour like a cantilevered beam

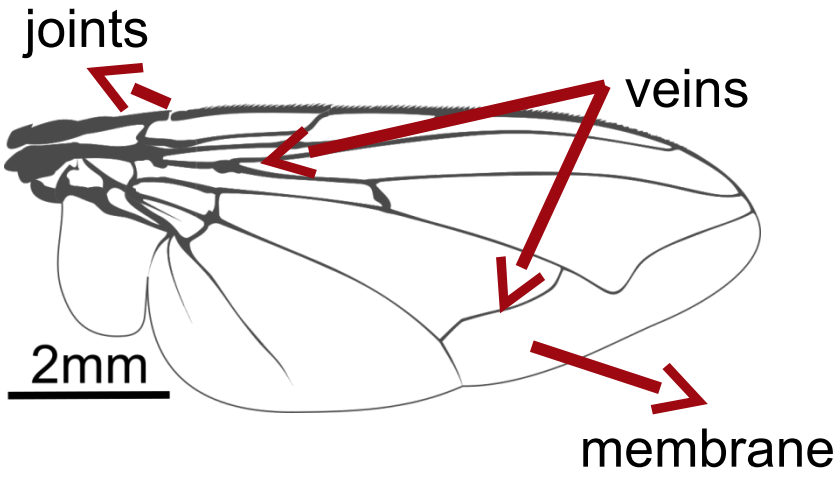


Theoretical bending line → Stiffness along beam

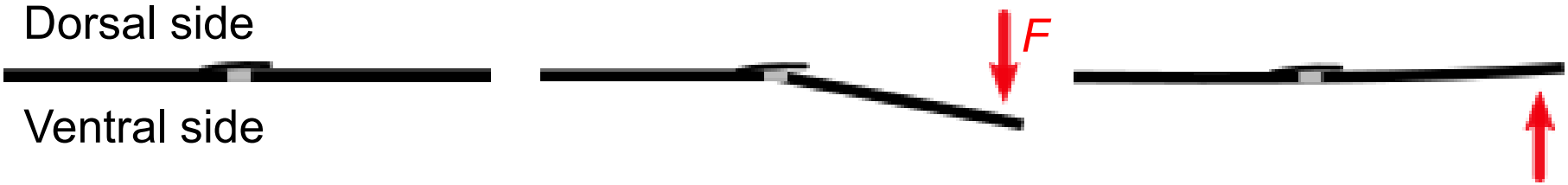
Insect wings are complex mechanical structures



Musca

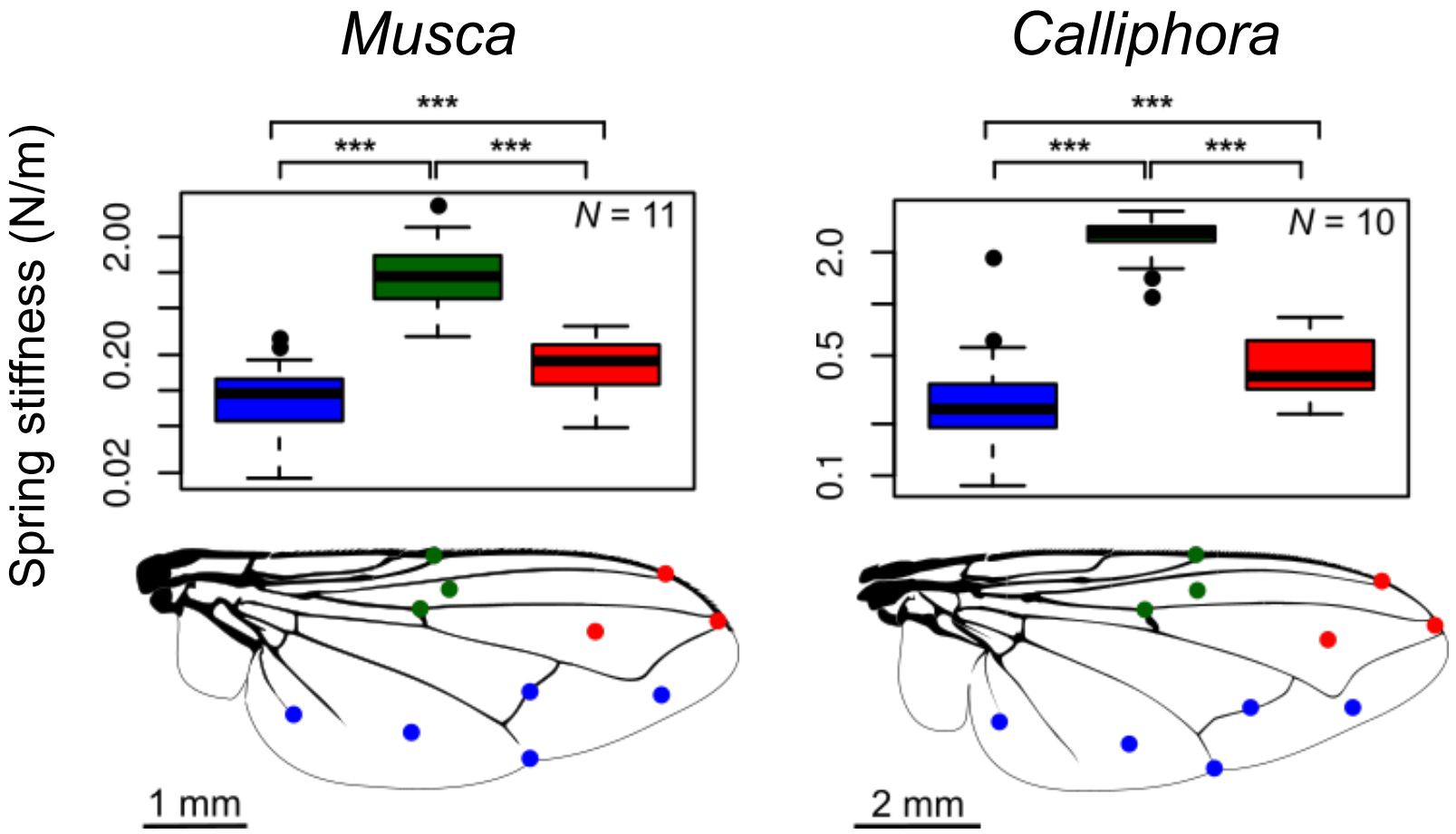


Calliphora



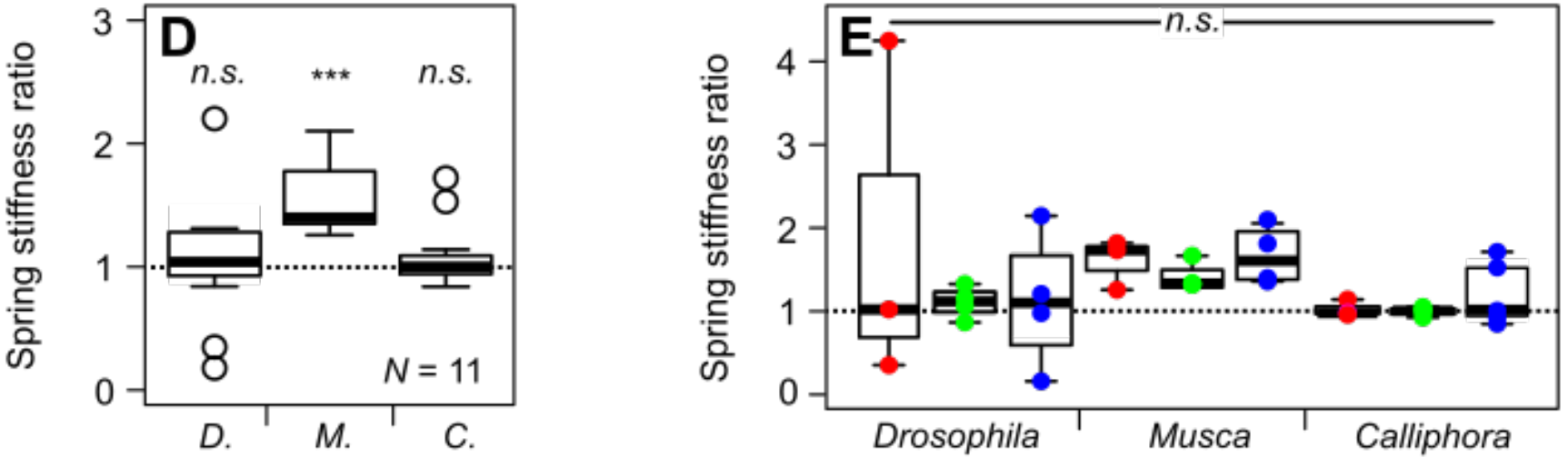
Is there spatial or dorsoventral anisotropy?

Different parts of the wing have different stiffness



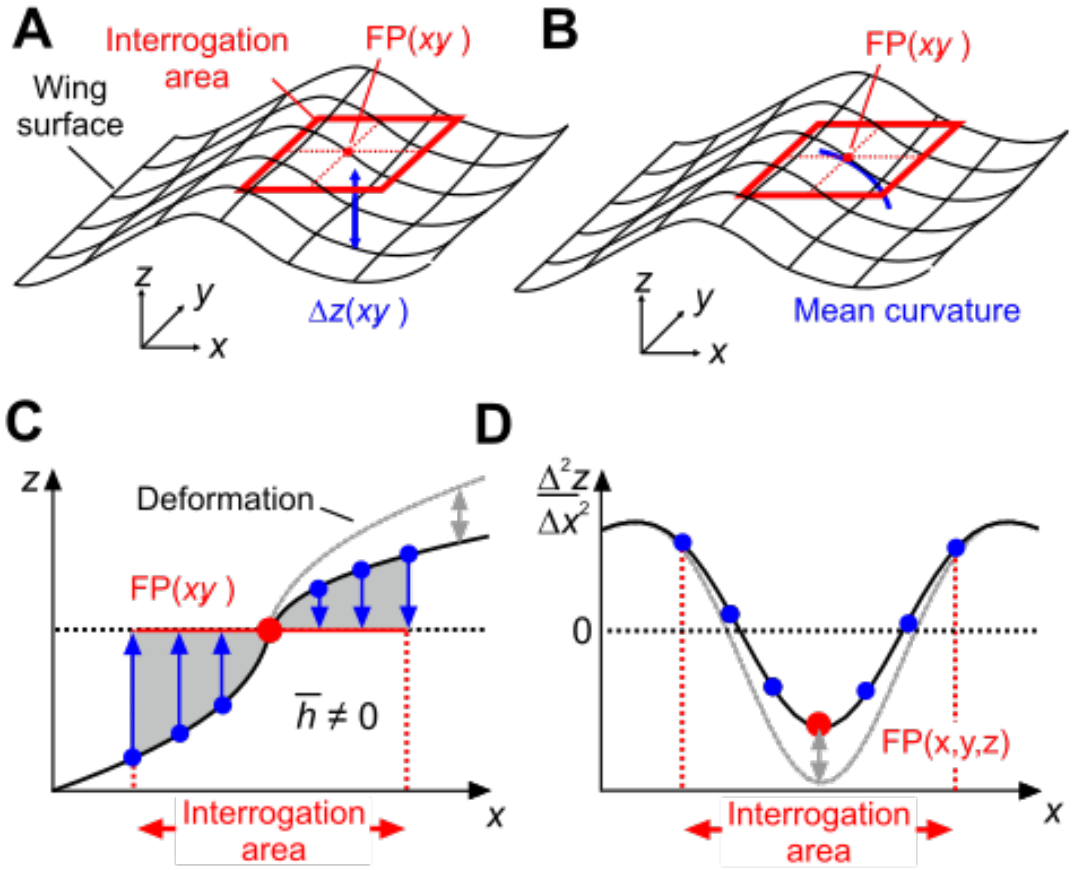
Leading edge Wing tip Trailing Edge

No consistent dorsoventral anisotropy



- Found *Musca* wings to be significantly stiffer when loaded from the ventral side (corresponding to downstroke), but not the other species‘ wings
- Ma et al. (2017), Ning et al. (2017) found similar anisotropy for honeybees, Rajabi et al. (2015) explained potential sources for dorsoventral anisotropy for dragonflies
- Other studies found no dorsoventral anisotropy (e.g. Combes et al., 2003)

Deformation: Shape changes of the entire wing

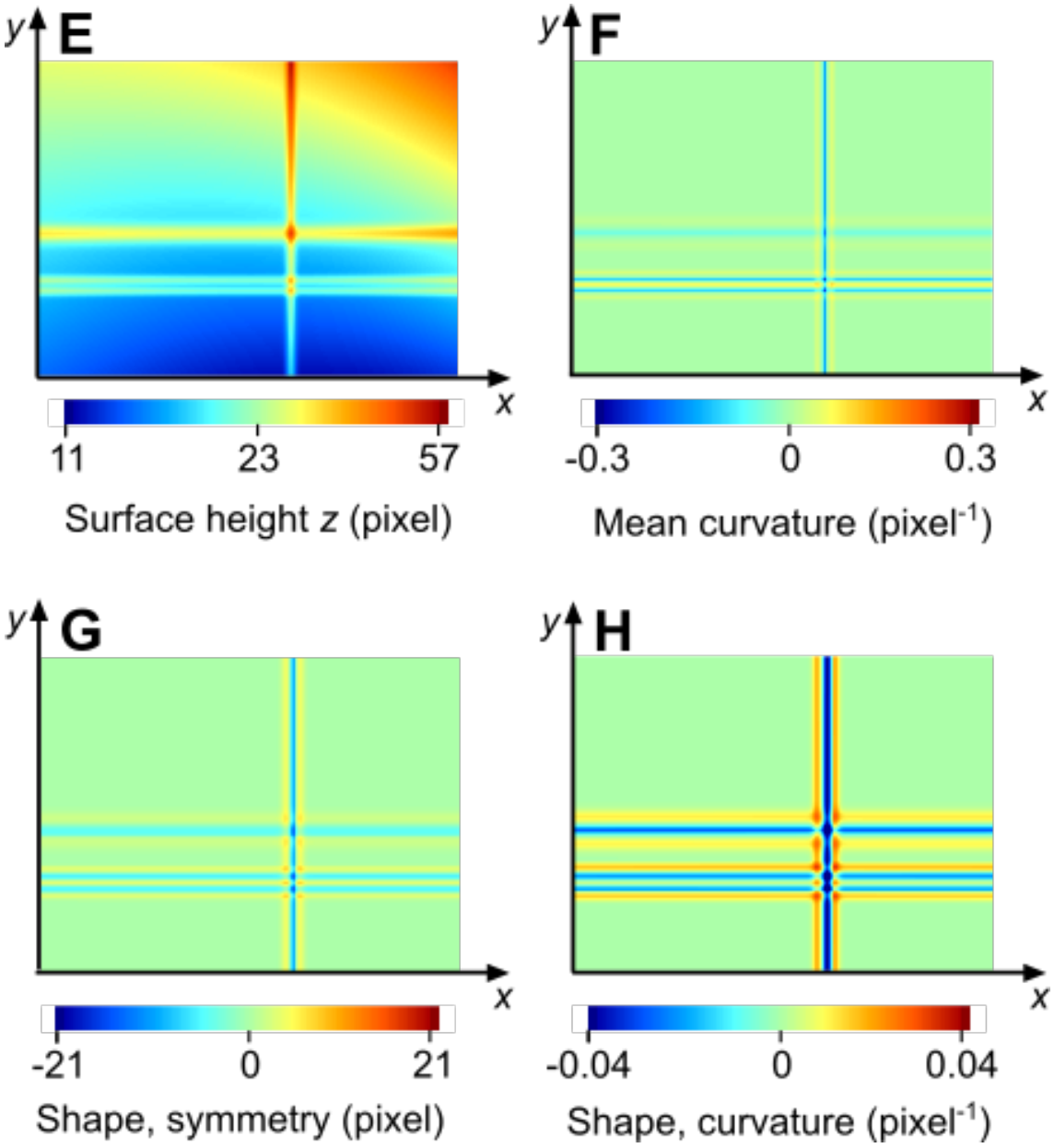


$$f(x,y) = ax^2+by^2+cxy+dx+ey+f$$

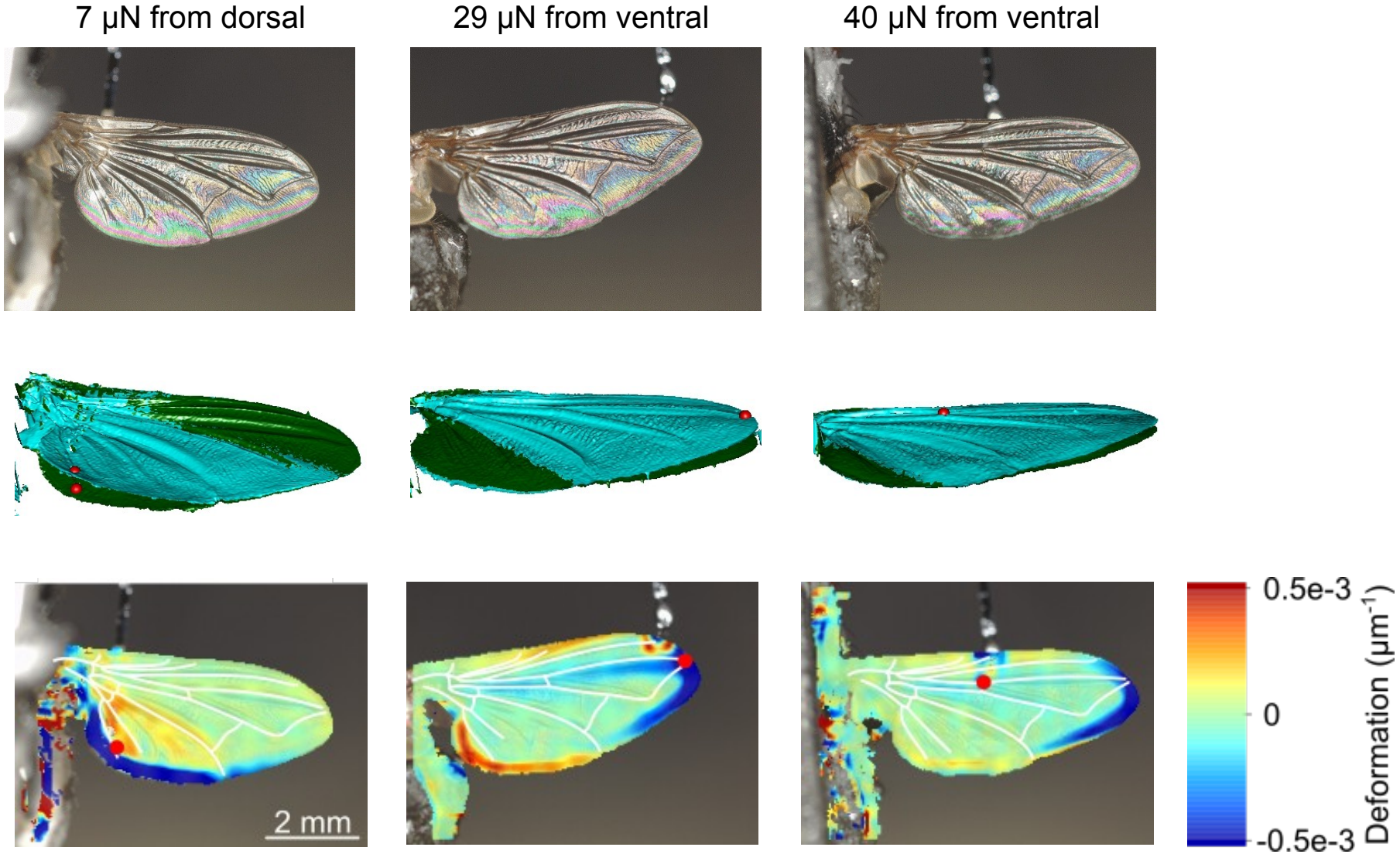
Mean relative *z*
0 when symmetrical around FP

$$C_m(x,y)=0.5\,\frac{(1+f_x^{\,2})f_{yy}-2f_x f_y f_{xy}+(1+f_y^{\,2})f_{xx}}{(1+f_x^{\,2}+f_y^{\,2})^{3/2}}$$

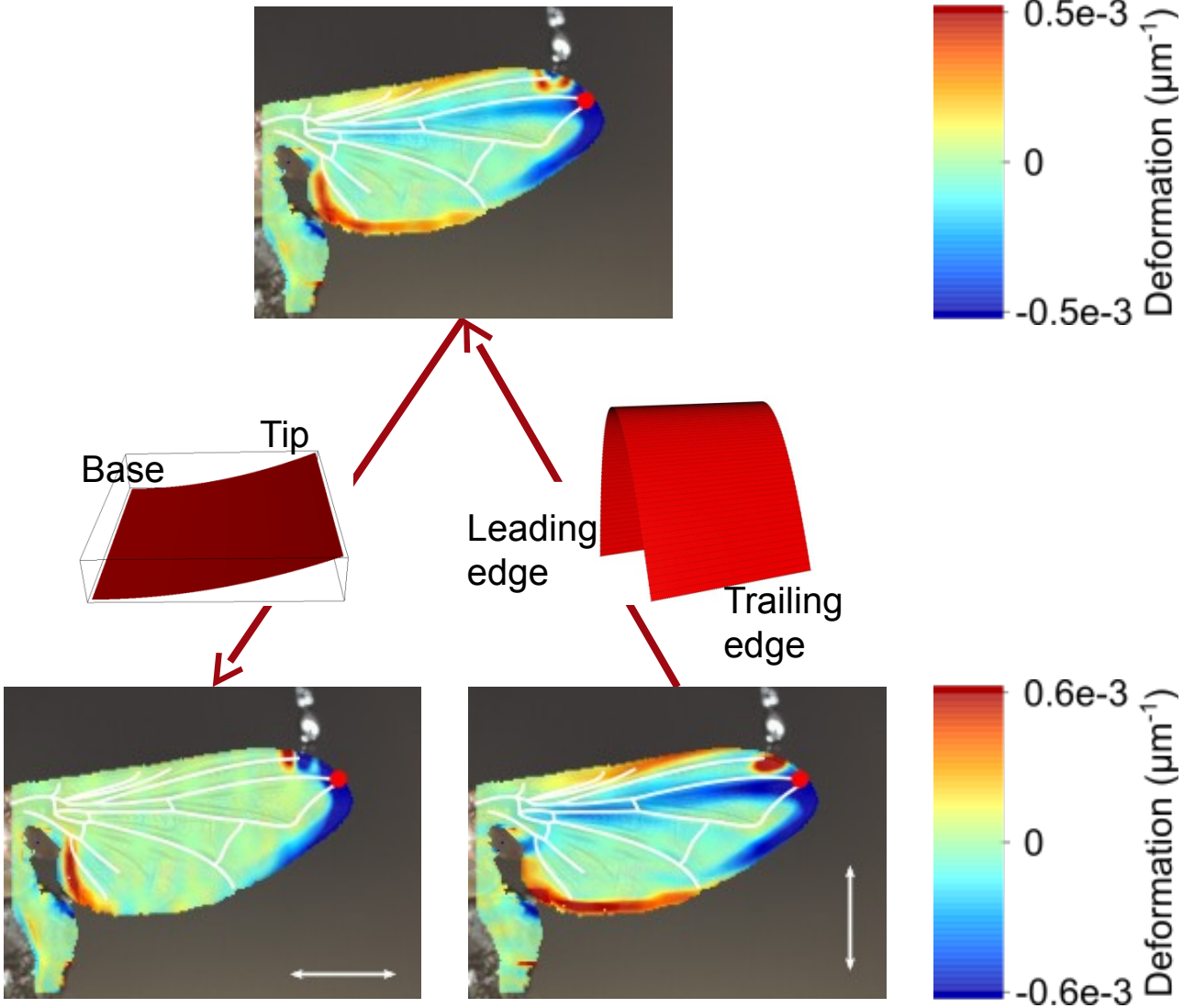
Deformation: Shape changes of the entire wing



Musca: Deformation of entire wing



Musca: Deformation of entire wing



Wing does not only deform along beam.

Summary

- For physiological forces similar to cantilevered beam
- BUT: More complex behaviour of the rest of wing
- Now more data available
  - Wings in nearly natural state
  - Shape changes for entire wing available
- Prerequesite for (computational) wing models which include fluid-structure interactions → profile / force data for Hung‘s model

Acknowledgements

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