Analysis of 3D structures using IGA solids: Current status and future directions

Stefan Hartmann, Lukas Leidinger
DYNAmore GmbH, Germany

Manuel Meßmer
Technical University of Munich, Germany

Liping Li, Marco Pigazzini, Lam Nguyen, Attila Nagy, Dave Benson
Ansys/LST, Livermore, CA, USA

1st eigenmode

M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

Outline

1. Motivation
2. Trimmed B-Spline solids
3. Current workflow
4. Examples
5. Conclusion and Outlook

Outline

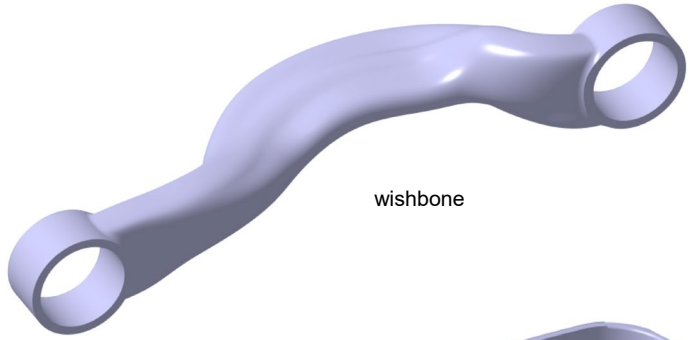
1. **Motivation**
2. Trimmed B-Spline solids
3. Current workflow
4. Examples
5. Conclusion and Outlook

Motivation

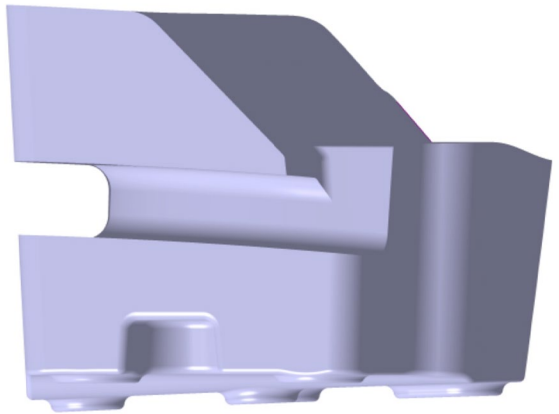
Volume components in engineering

- Cast parts in car
  - Not practically feasible to model them with finite shell elements

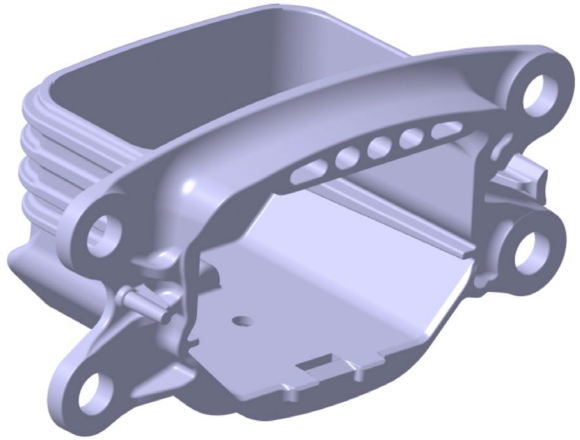
https://www.hulkmetal.com/precision-aluminum-die-casting-parts.html



wishbone



crashpad (foam)

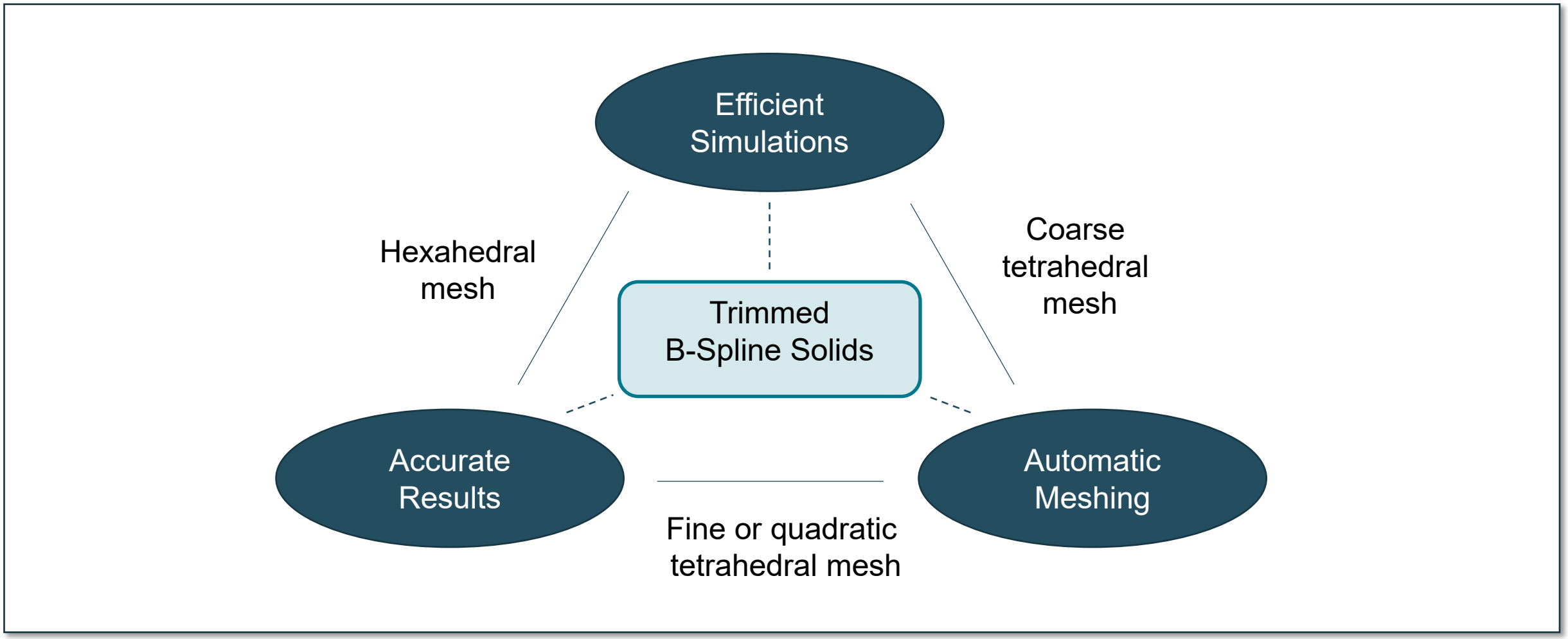


gearbox bearing housing

Courtesy of BMW Group

Motivation

Finite Element solid model for crash: Conflicting goals



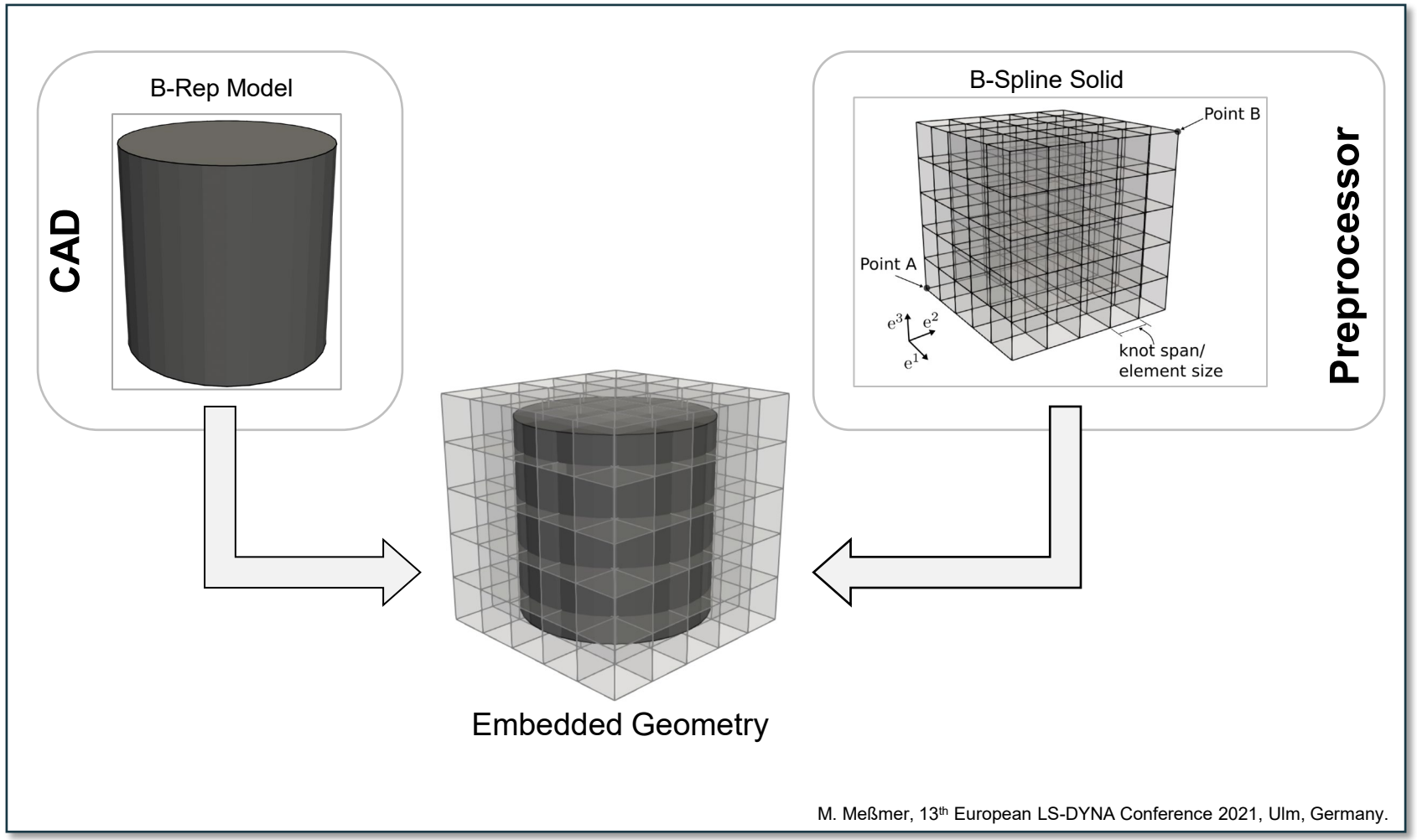
Outline

1. Motivation
2. **Trimmed B-Spline solids**
3. Current workflow
4. Examples
5. Conclusion and Outlook

Trimmed B-Spline solids

Prototypical approach

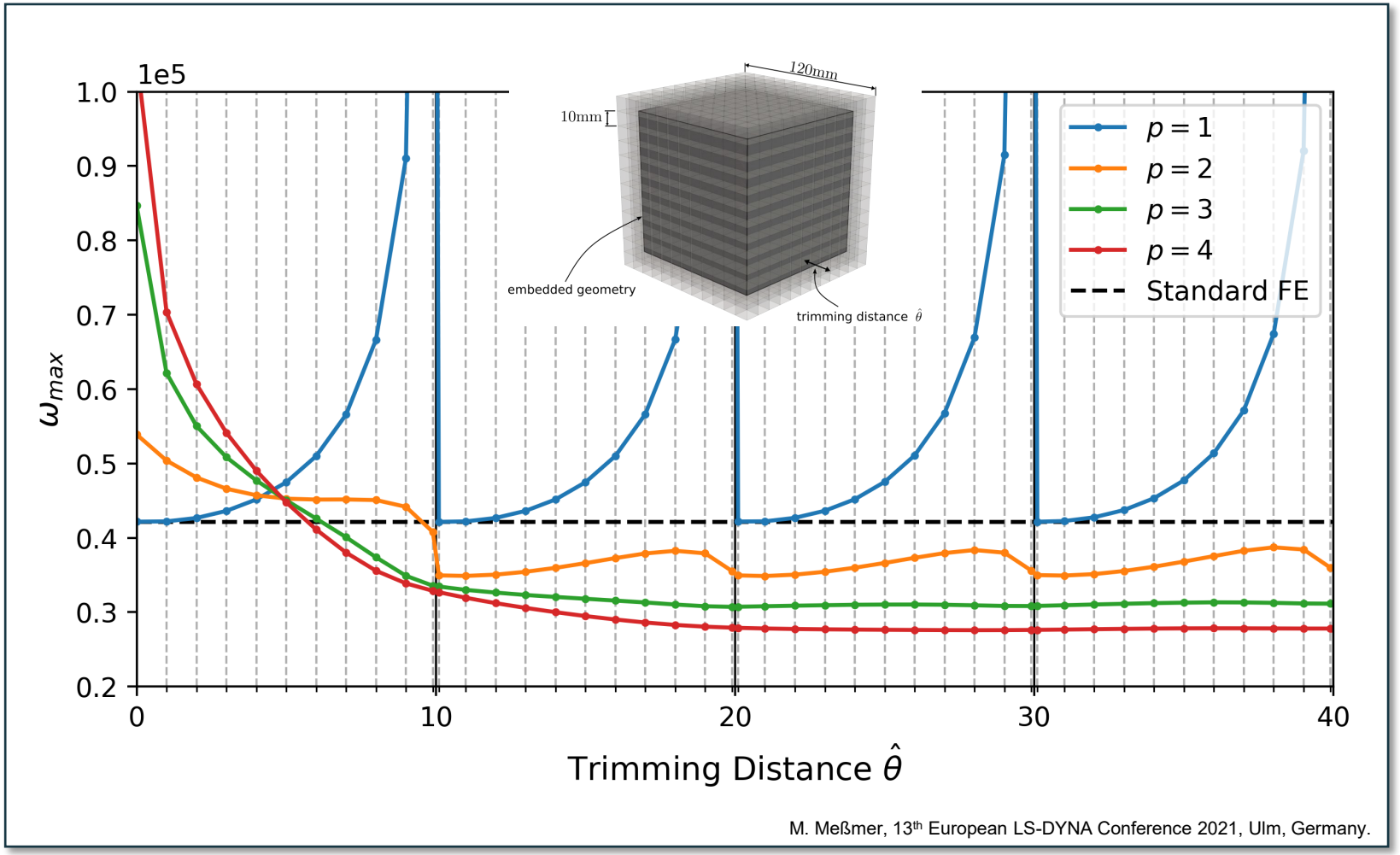
- **General Idea**
  - B-Spline background grid
  - Embed geometry
  - Generate integration rule



Trimmed B-Spline solids

Prototypical approach

- General Idea
- **Accurate time step estimation**
  - Trimming has no negative effect on timestep (p>1)

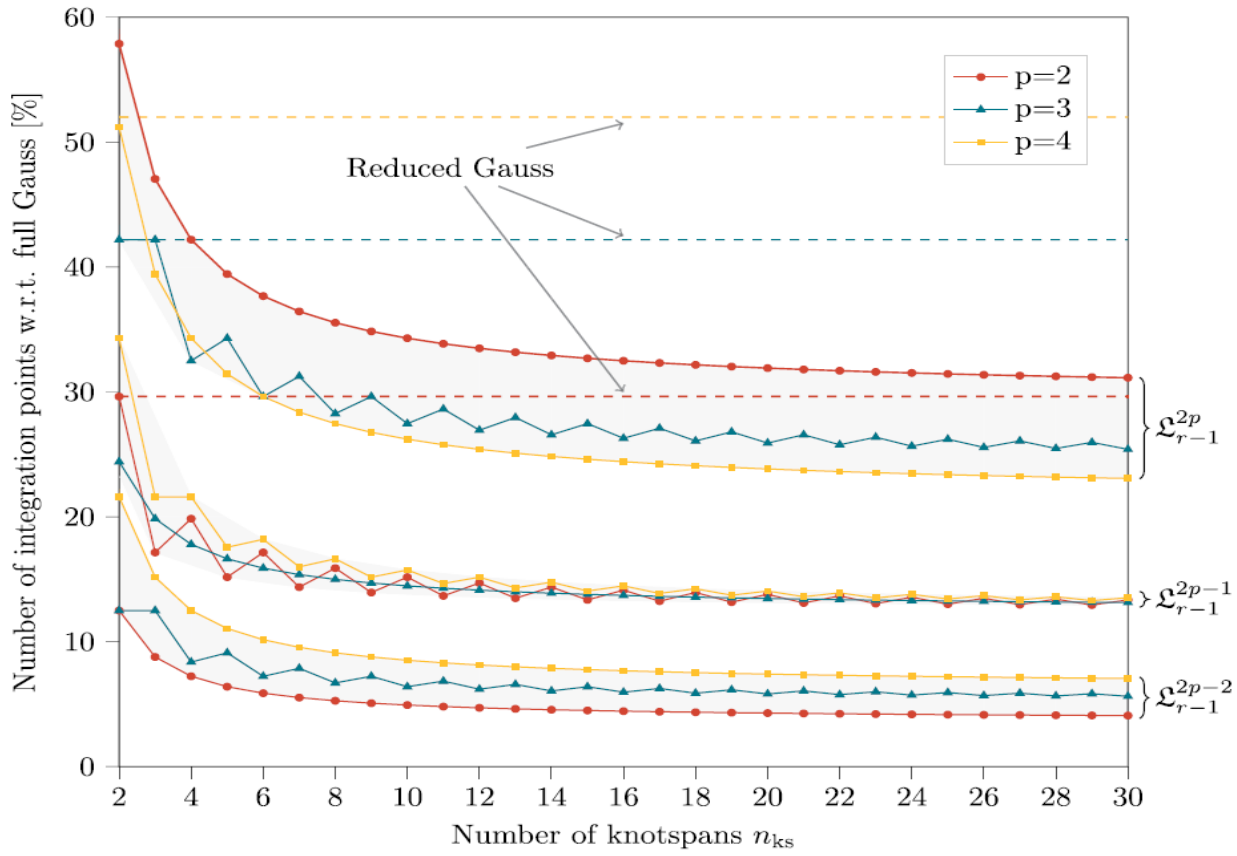


M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

Trimmed B-Spline solids

Prototypical approach

- General Idea
- Accurate Time step estimation
- **Efficient integration rules**
  - Full Gauss
  - Reduced Gauss
  - Generalized Gaussian Quadrature (GGQ)



M. Meßmer et al., Efficient CAD-integrated isogeometric analysis of trimmed solids, Comput. Methods Appl. Mech. Eng. 400 (2022) 115584.

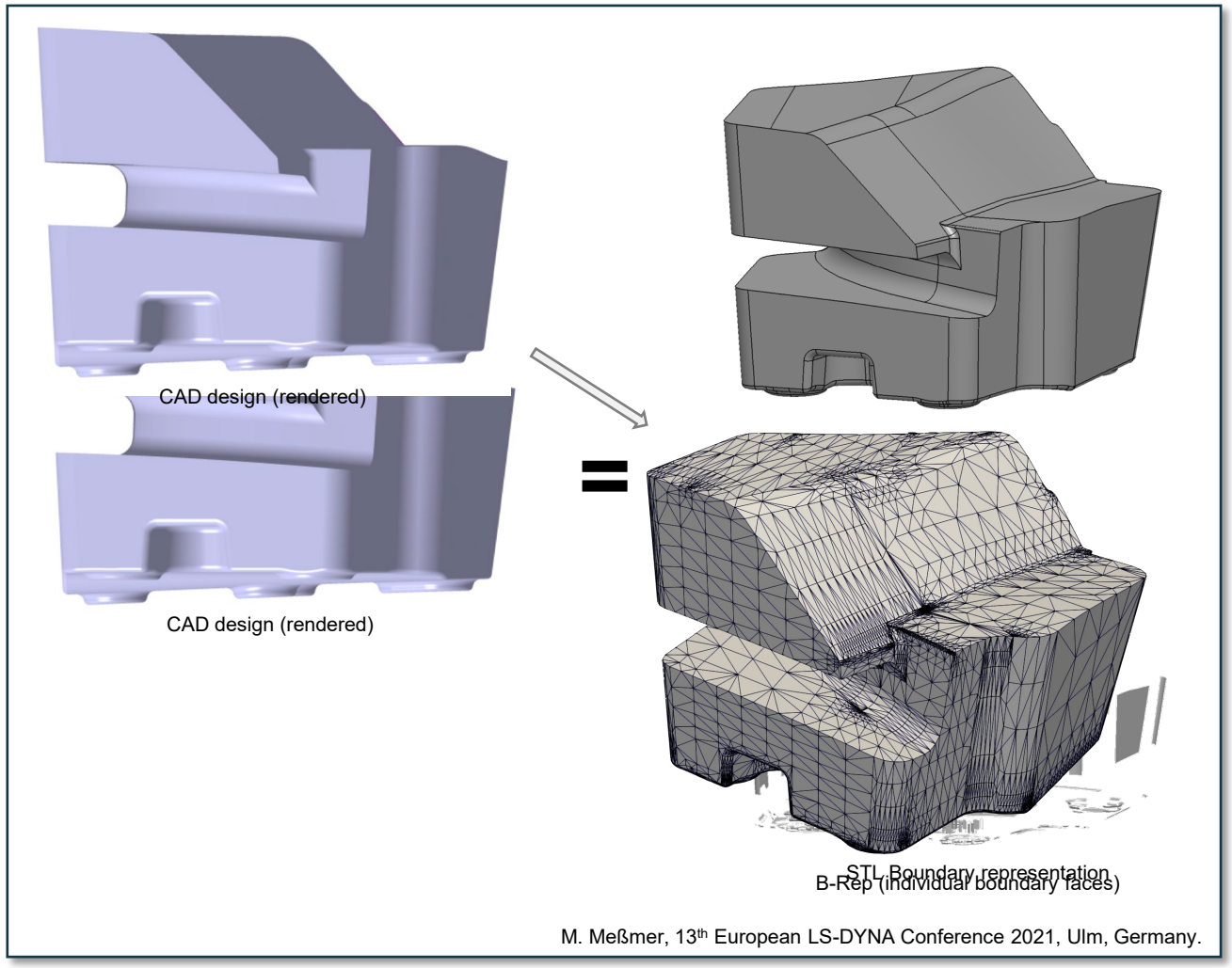
Outline

1. Motivation
2. Trimmed B-Spline solids
3. **Current workflow**
4. Examples
5. Conclusion and Outlook

Current workflow - I

External Preprocessing (M. Meßmer, TUM)

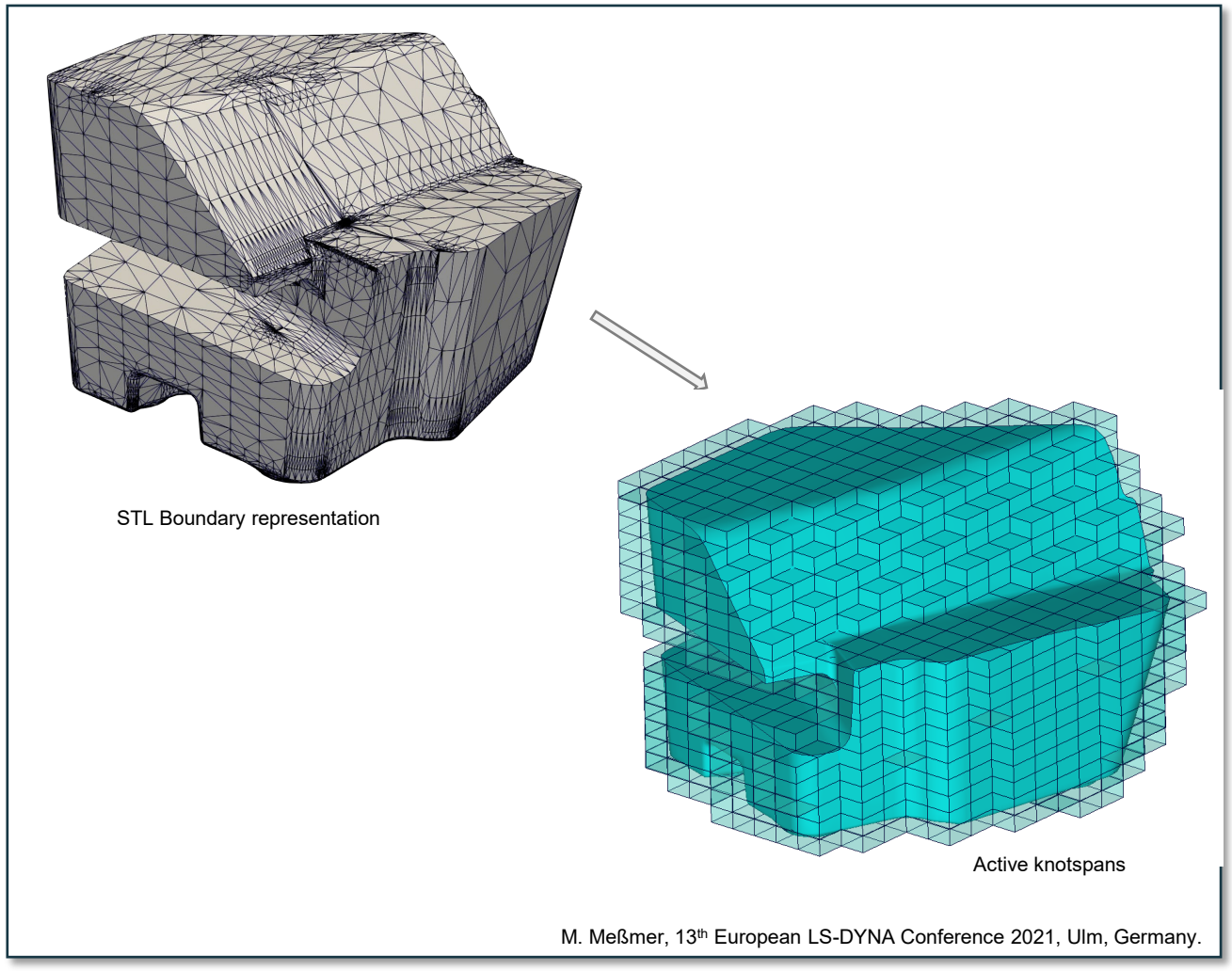
- **Generate STL Boundary Representation**



Current workflow - I

External Preprocessing (M. Meßmer, TUM)

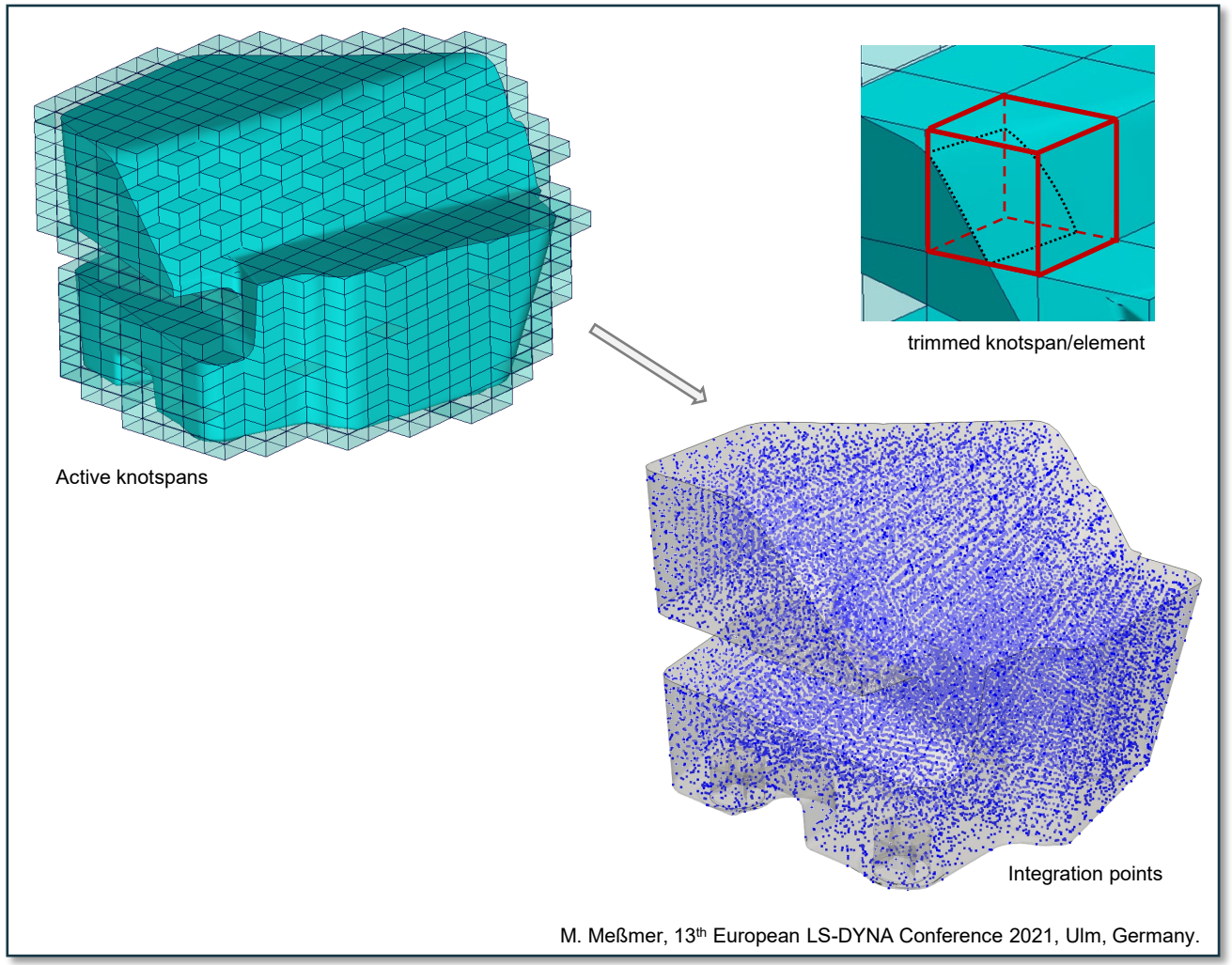
- Generate STL Boundary Representation
- **Identify active knotspans (elements)**
  - Boolean operation
  - Inside/outside test (ray tracing)



Current workflow - I

External Preprocessing (M. Meßmer, TUM)

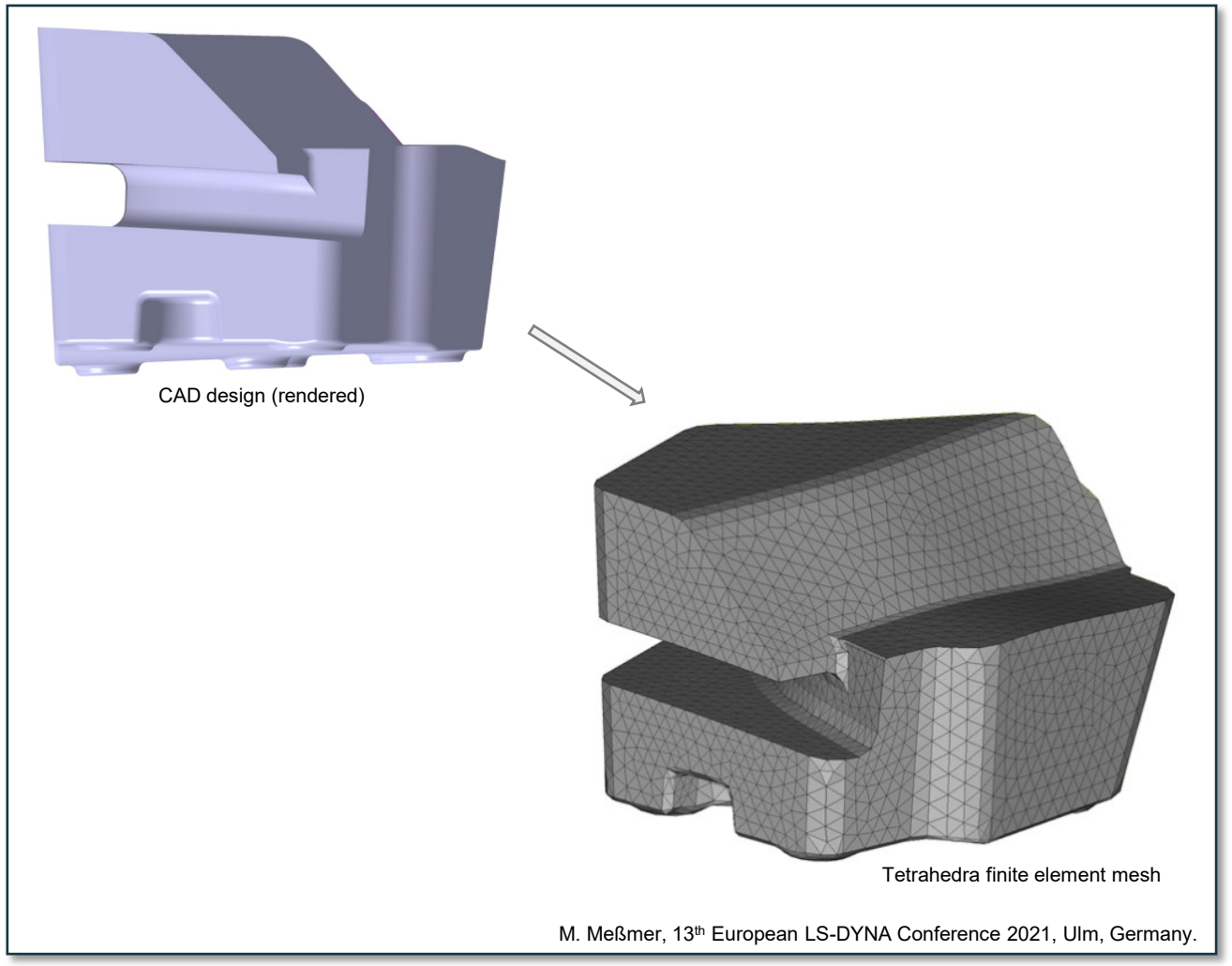
- Generate STL Boundary Representation
- Identify active knotspans (elements)
  - Boolean operation
  - Inside/outside test (ray tracing)
- **Generate integration rule for each knotspan**
  - Untrimmed knotspan/element
    - Full/reduced Gauss
    - GGQ (Generalized Gaussian Quadrature)
  - Trimmed knotspan/element
    - Moment fitting algorithm



Current workflow - I

External Preprocessing (M. Meßmer, TUM)

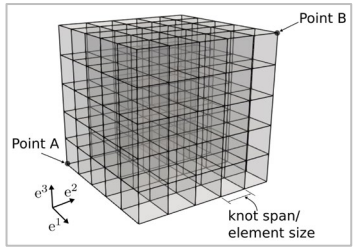
- Generate STL Boundary Representation
- Identify active knotspans (elements)
  - Boolean operation
  - Inside/outside test (ray tracing)
- Generate integration rule for each knotspan
  - Untrimmed knotspan/element
    - Full/reduced Gauss
    - GGQ (Generalized Gaussian Quadrature)
  - Trimmed knotspan/element
    - Moment fitting algorithm
- **Generate volumetric mesh**
  - Fully constrained to B-spline background grid
  - BCs (contact) and post-processing



Current workflow - II

LS-DYNA

- **Read in B-Spline information**



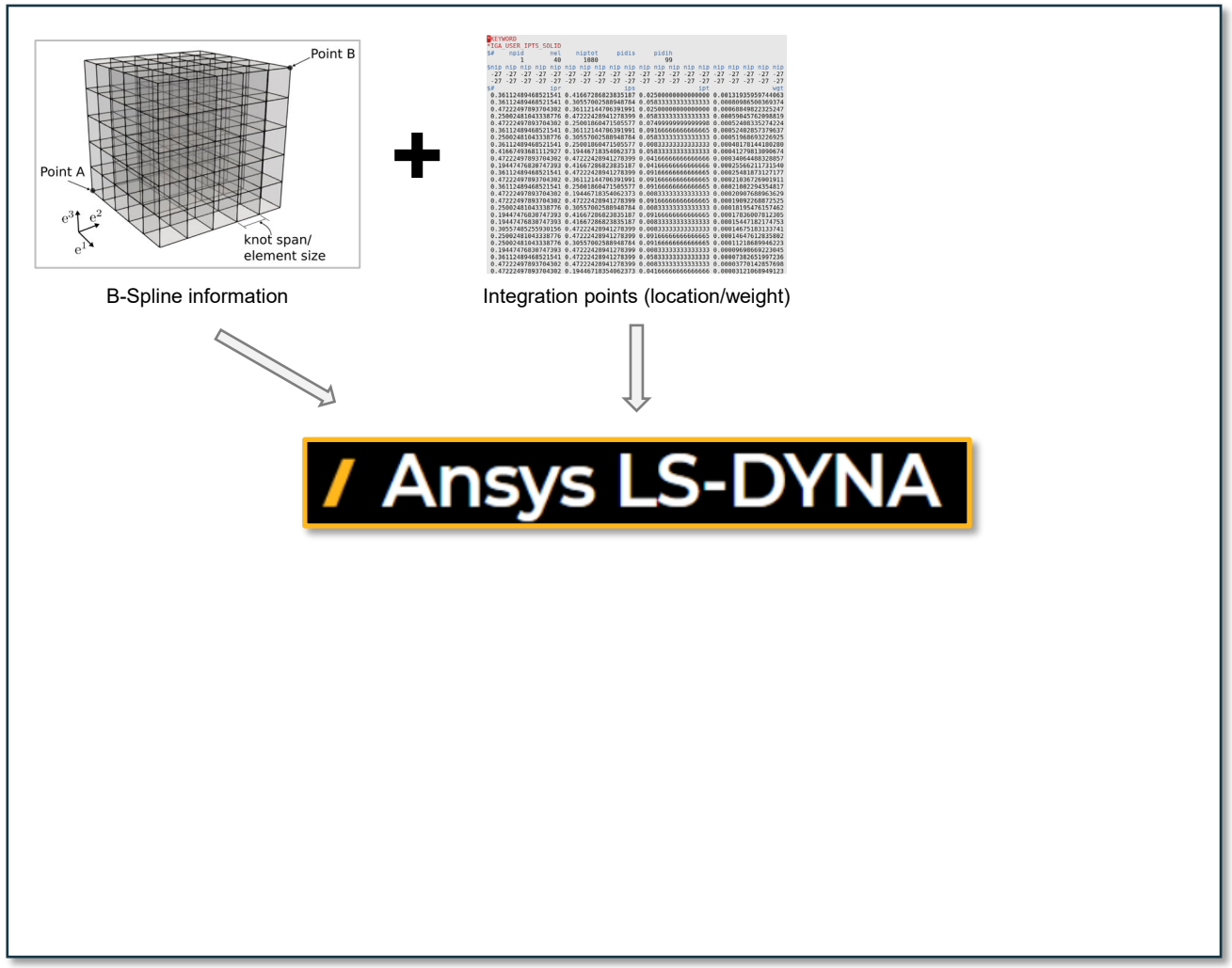
B-Spline information

Ansys LS-DYNA

Current workflow - II

LS-DYNA

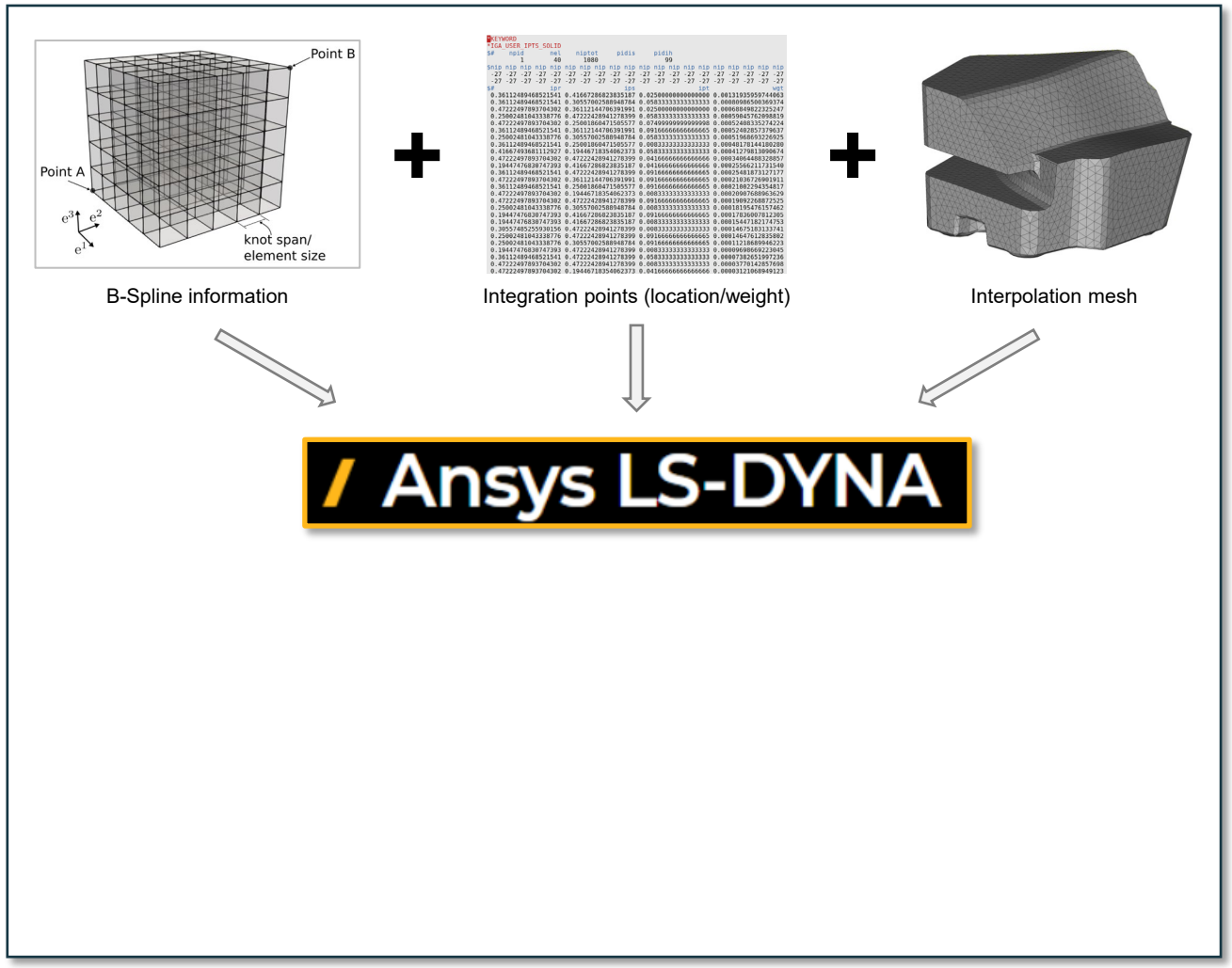
- Read in B-Spline information
- **Read in and use predefined integration rule for B-Spline elements (trimmed/untrimmed)**



Current workflow - II

LS-DYNA

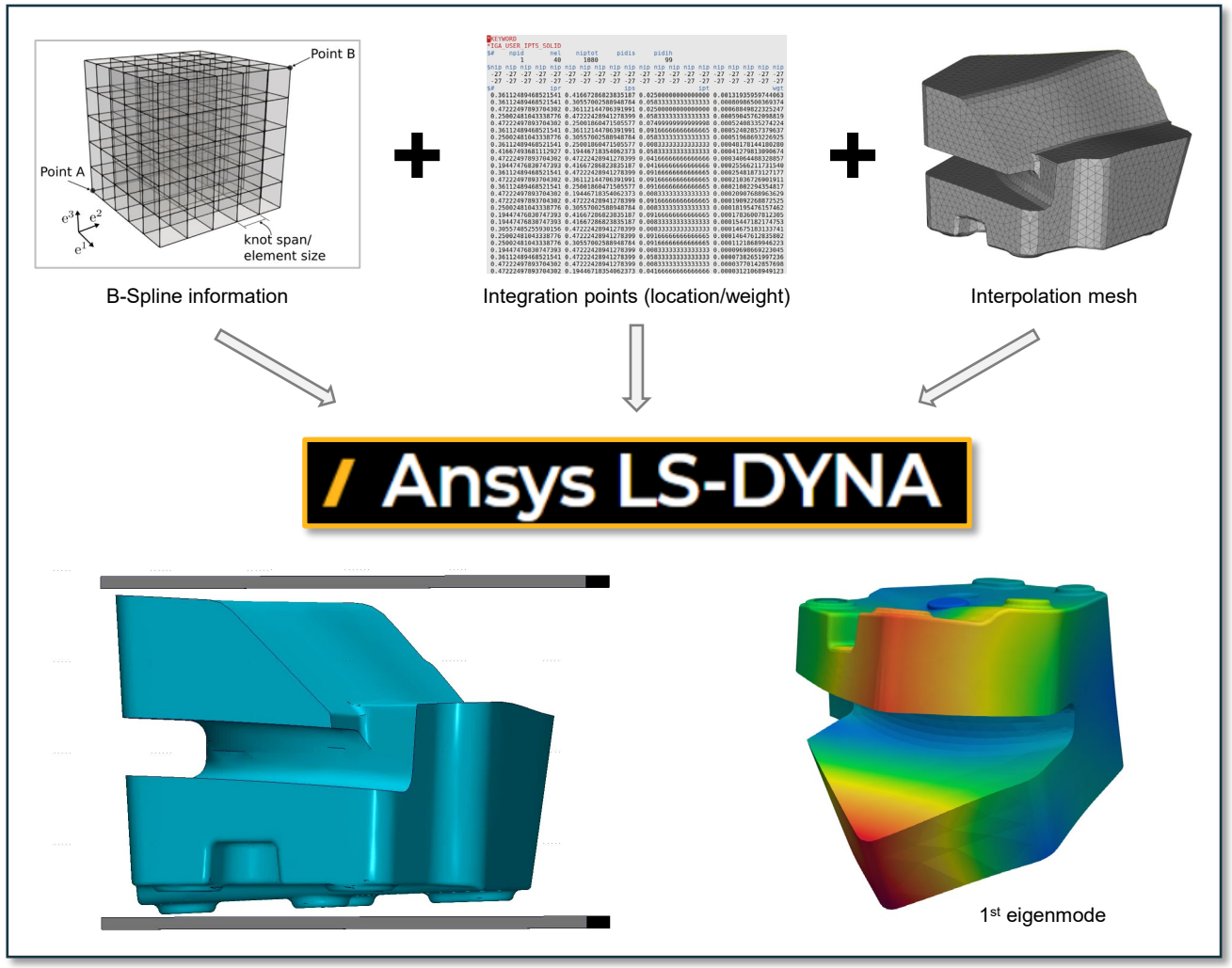
- Read in B-Spline information
- Read in and use predefined integration rule for B-Spline elements (trimmed/untrimmed)
- **Tetrahedra finite element mesh**
  - Constrain each node to background grid
  - Use for contact
    - Map contact forces back to B-Spline DOFs
  - Map results from B-Spline elements for postprocessing
    - Displacements, stresses, …



Current workflow - II

LS-DYNA

- Read in B-Spline information
- Read in and use predefined integration rule for B-Spline elements (trimmed/untrimmed)
- Tetrahedra finite element mesh
  - Constrain each node to background grid
  - Use for contact
    - Map contact forces back to B-Spline DOFs
  - Map results from B-Spline elements for postprocessing
    - Displacements, stresses, …
- **Accurate timestep estimate**
- **Stabilization scheme for light CPs**
- **MPP support**



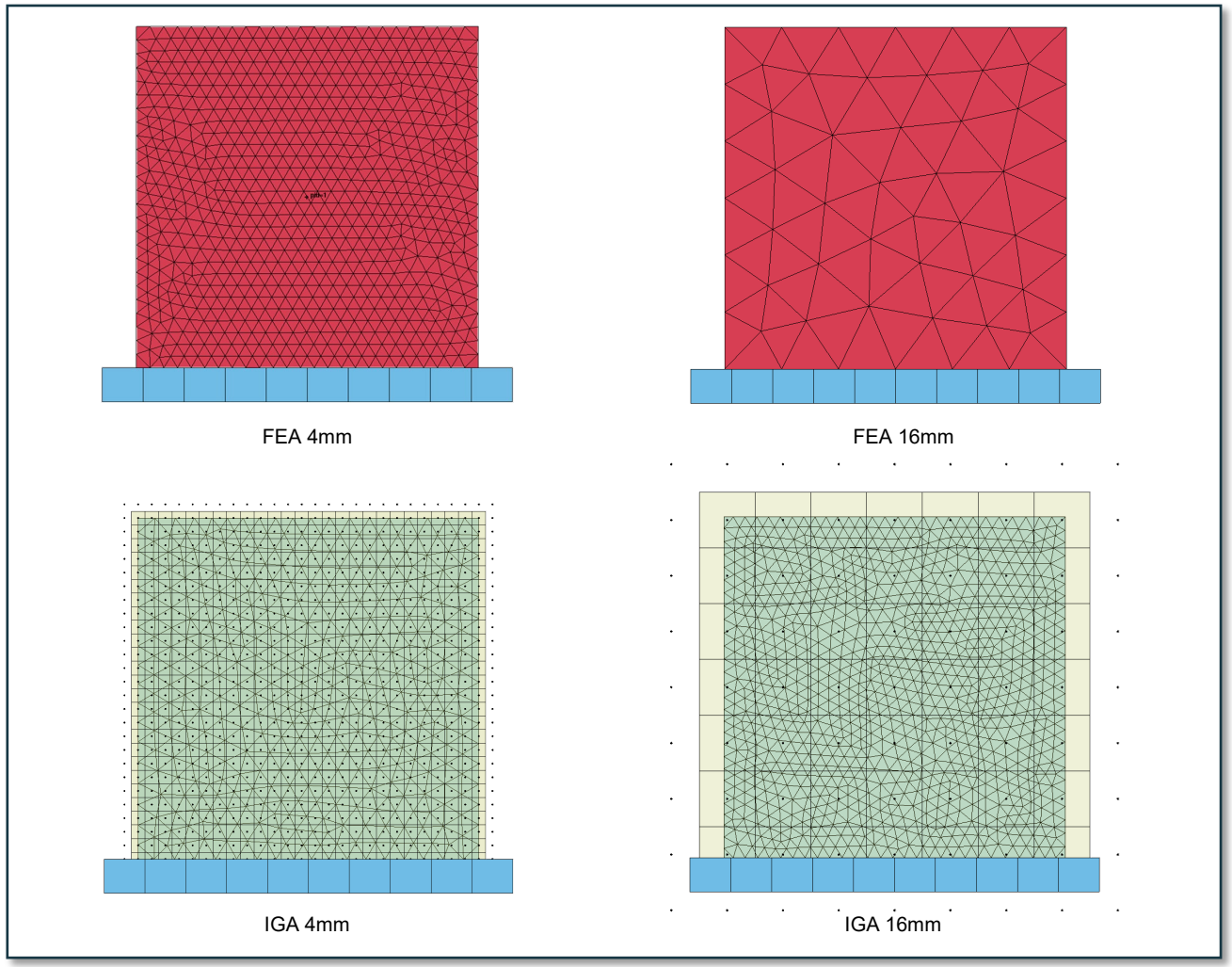
Outline

1. Motivation
2. Trimmed B-Spline solids
3. Current workflow
4. **Examples**
5. Conclusion and Outlook

Examples

Impact on Trimmed Solid Cube: Problem Definition

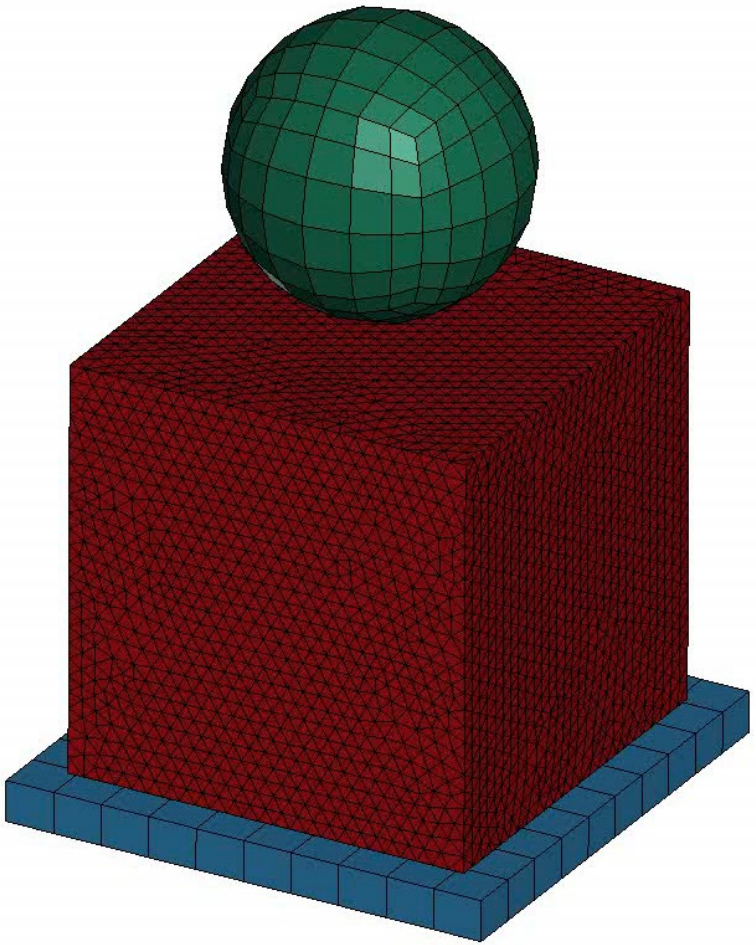
- Foam Cube (**`*MAT_CRUSHABLE_FOAM`**)
  - FE solid: ELFORM=10 (1-point tet)
  - Trimmed tri-quadratic B-spline solid
- Rigid FE solid sphere + plate
- **`*CONTACT_SURFACE_TO_SURFACE`** (SOFT=2)
- Settings FE cube
  - Mesh: 4mm / 16mm
- Settings trimmed IGA cube
  - B-Spline mesh: 4mm / 16mm
  - Interpolation mesh: 4mm tets

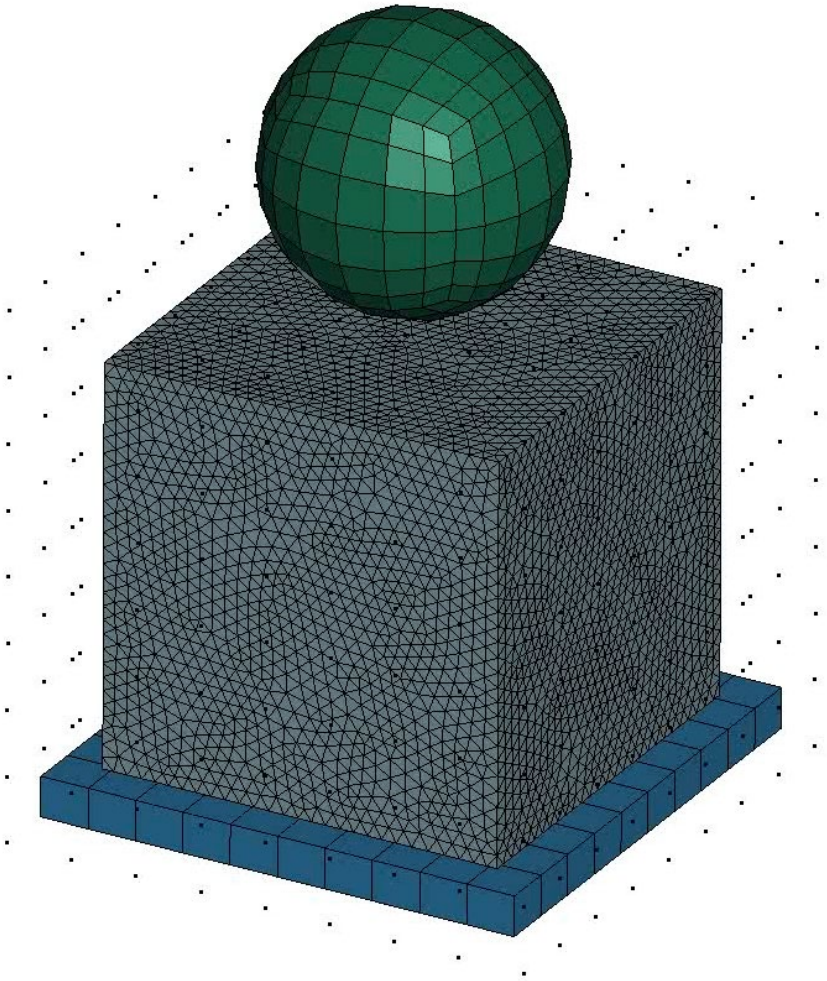


Examples

Impact on Trimmed Solid Cube: FEA vs. IGA

FEA 4mm

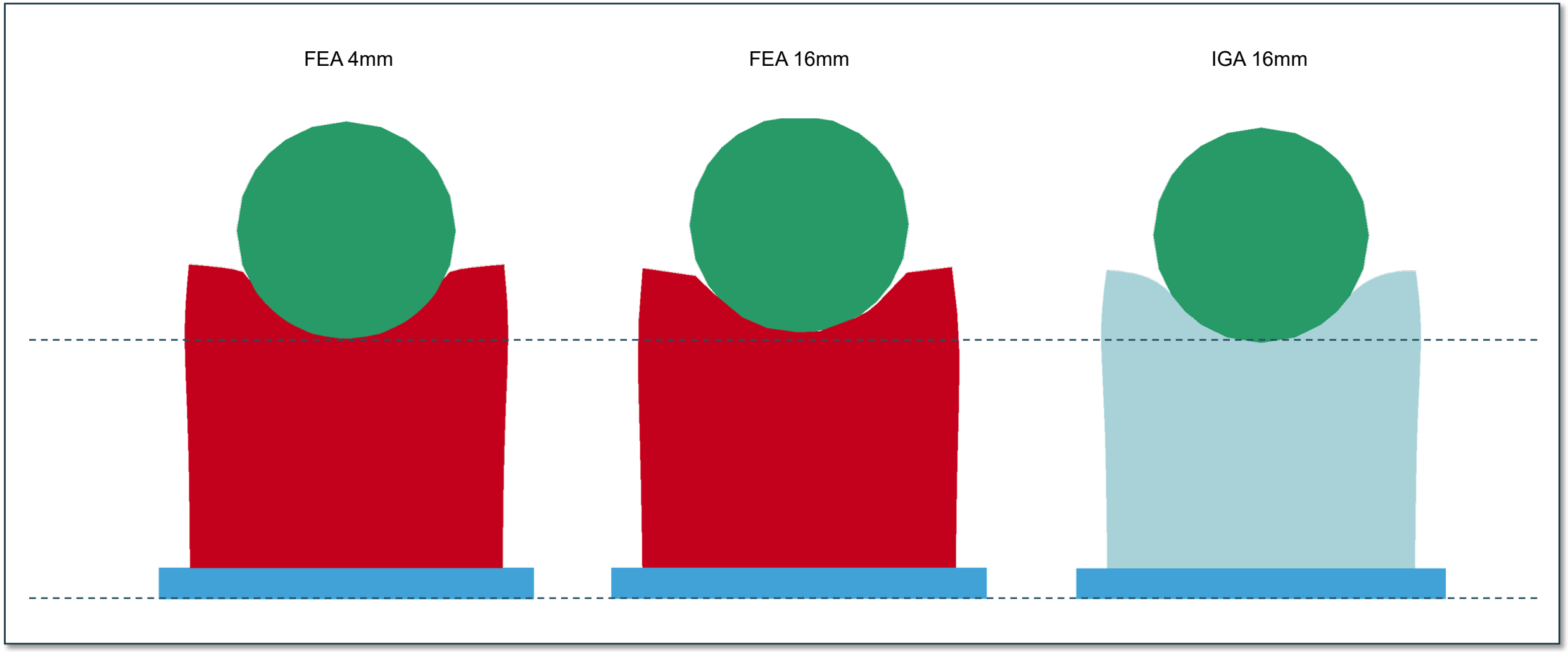




IGA 16mm

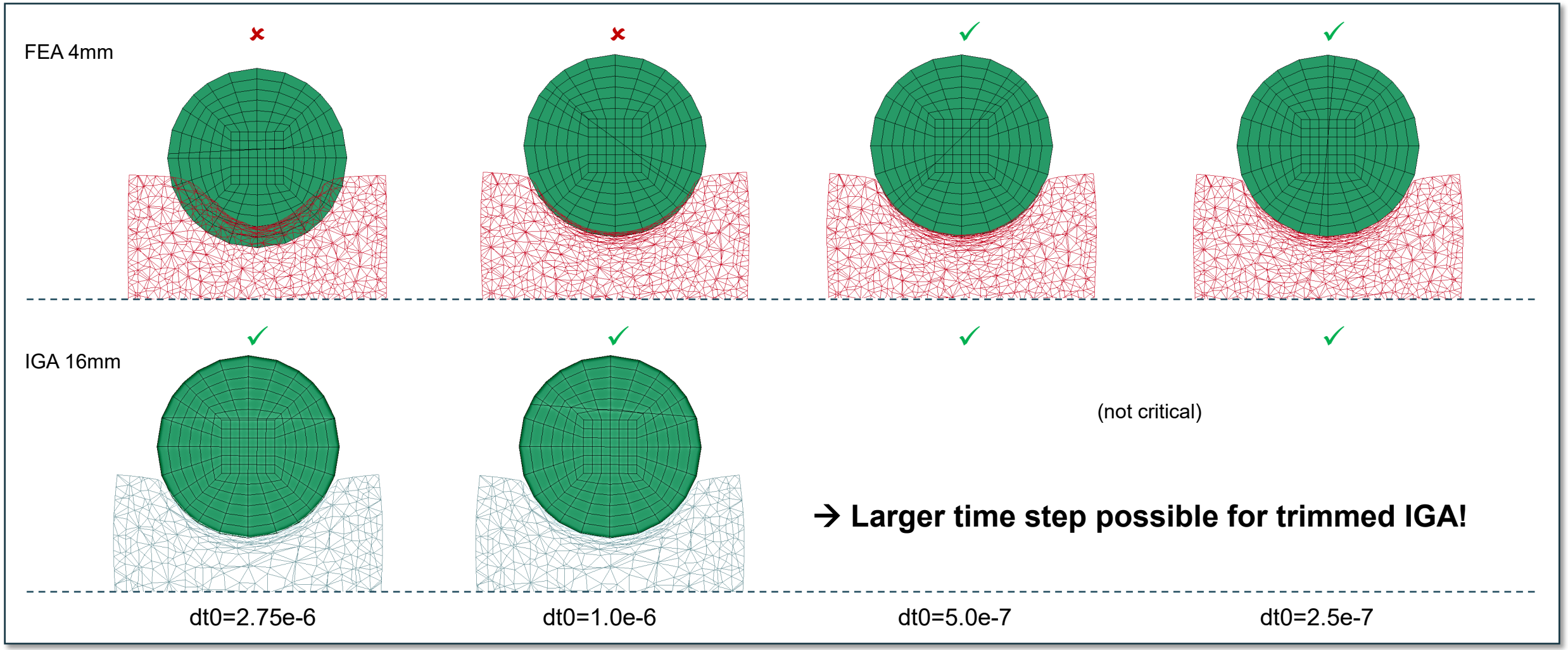
Examples

Impact on Trimmed Solid Cube: FEA vs. IGA – Deformed shape during impact



Examples

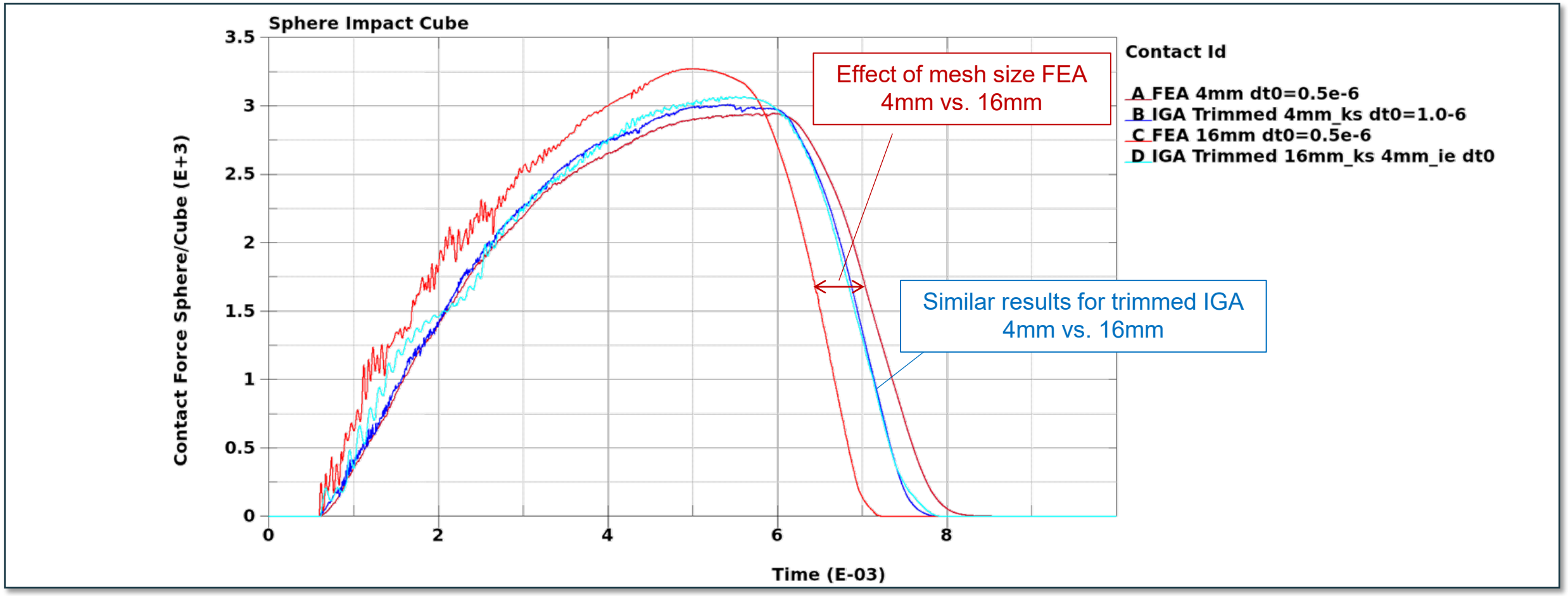
Impact on Trimmed Solid Cube: FEA vs. IGA – Importance of time step size



Examples

Impact on Trimmed Solid Cube: FEA vs. IGA – Importance of time step size

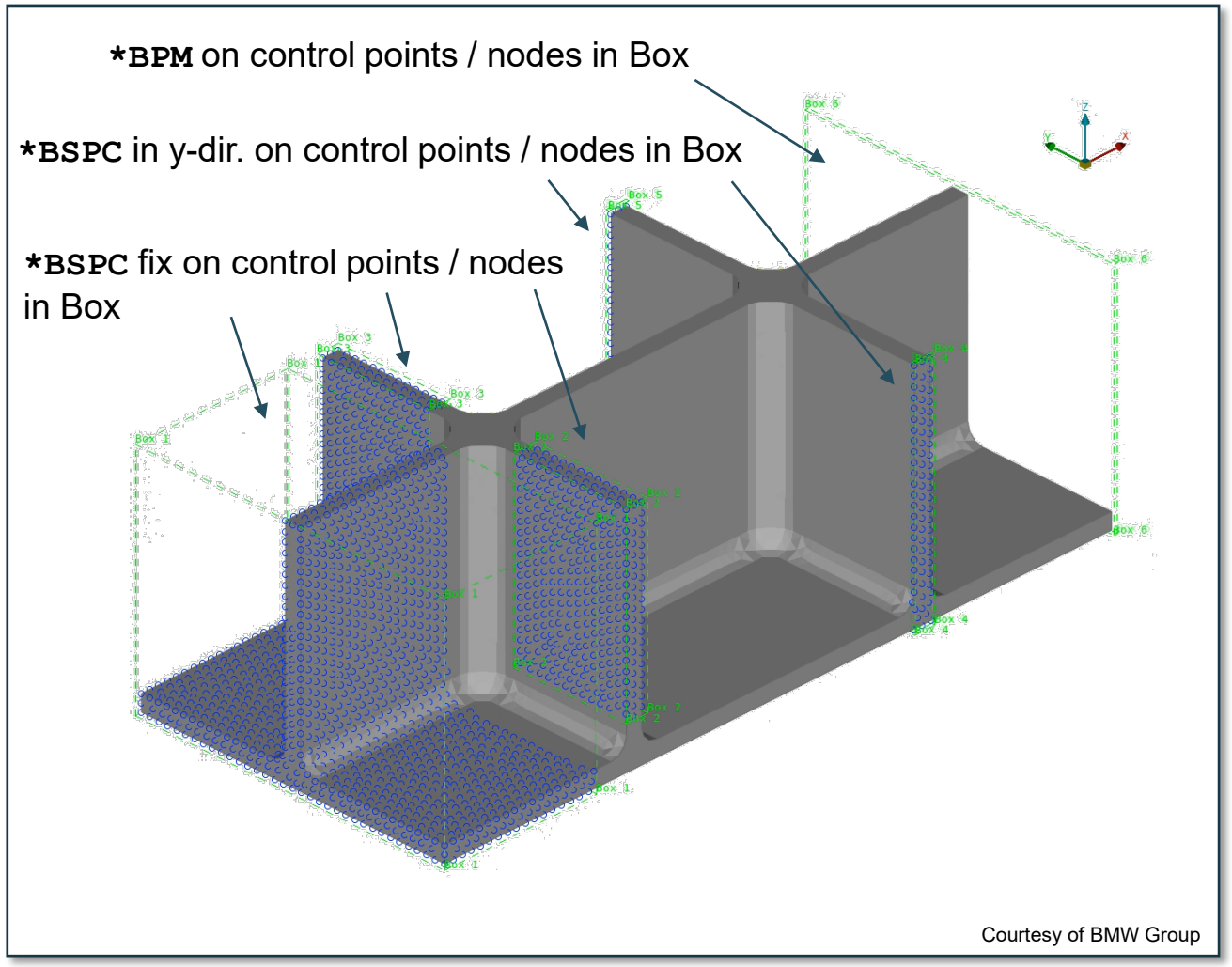
- Contact force between sphere and cube: → **Larger discretization possible for trimmed IGA!**



Examples

Academic Cast Component: Problem Definition

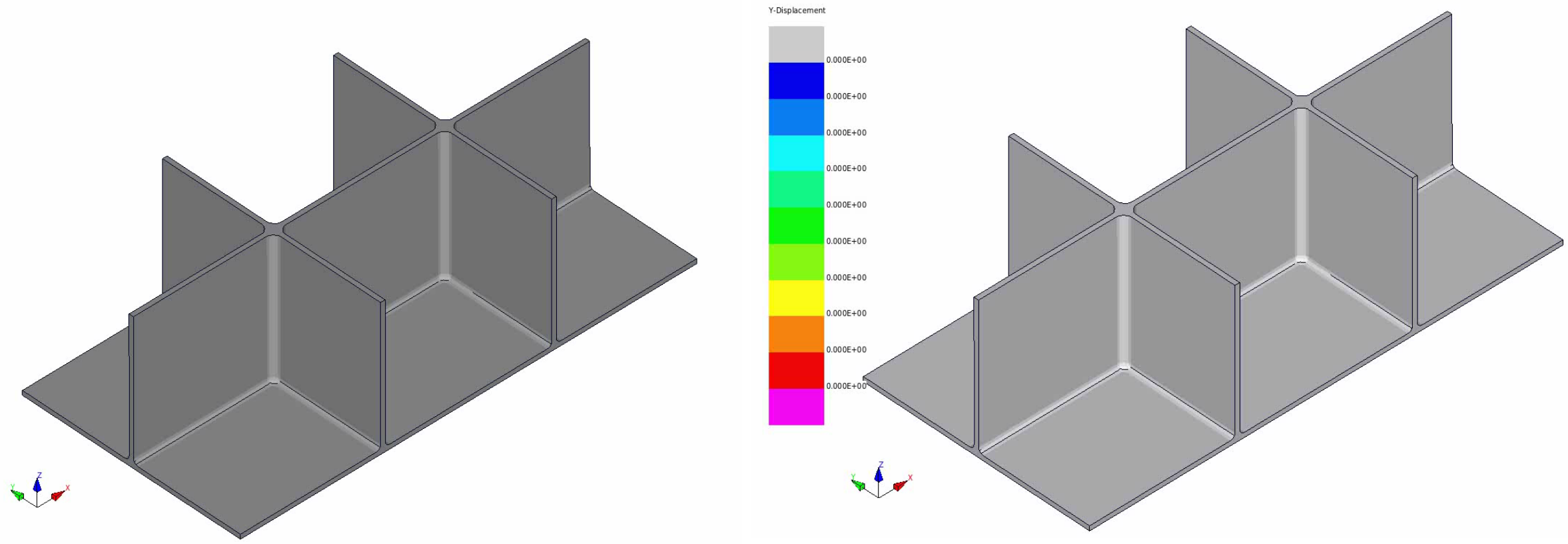
- Cast Component
  - FE solid: ELFORM=13 (1-point tet)
  - Trimmed tri-quadratic B-spline solid
- Boundary conditions via Box-definition
  - Fixed on left side
  - Prescribed vertical motion on right side
- Settings FE
  - Mesh: 0.5mm / 1mm / 2mm
- Settings trimmed IGA
  - B-Spline mesh: 2mm / 4mm / 8mm



Examples

Academic Cast Component: Deformation

IGA 2mm

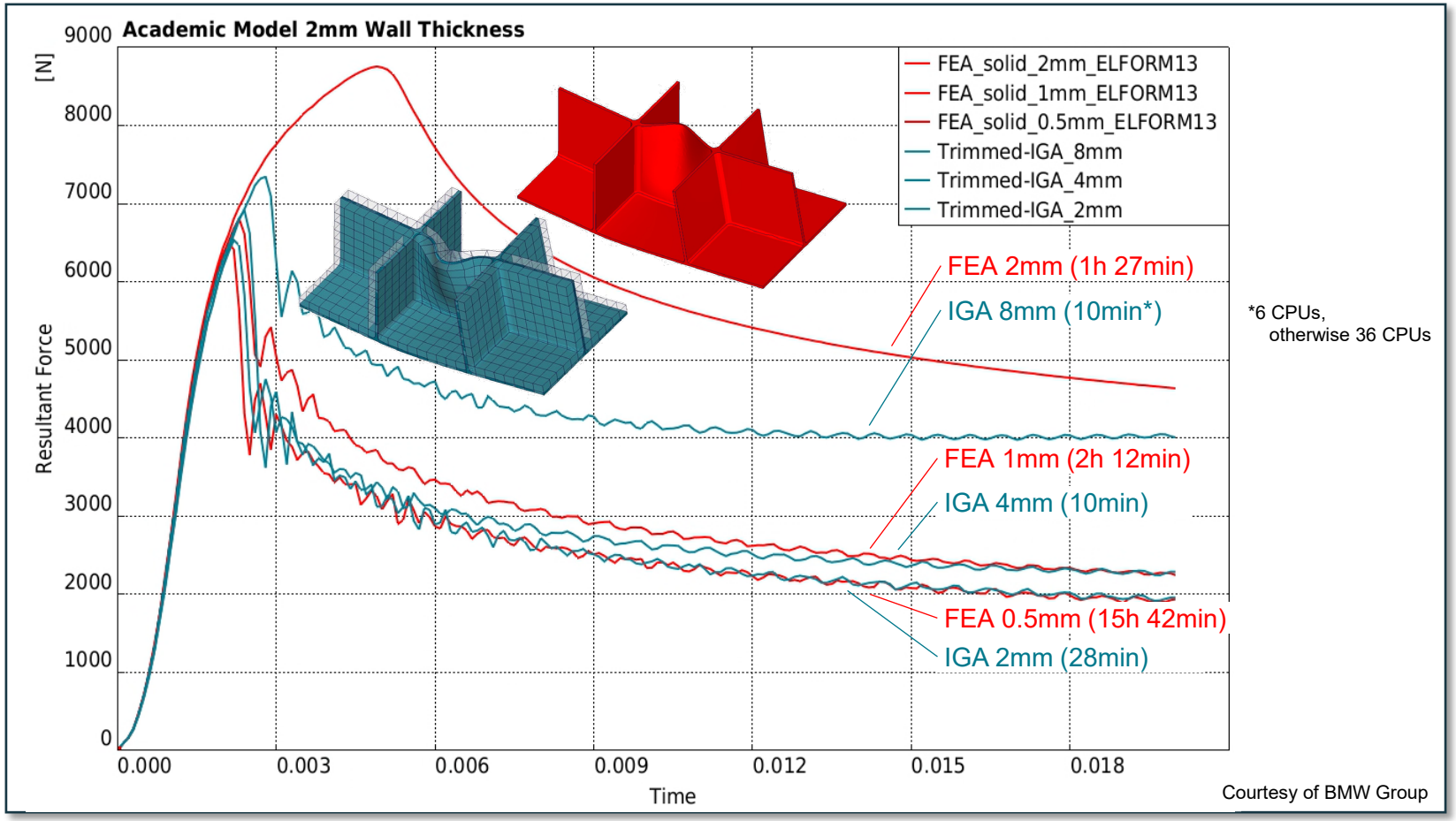


Courtesy of BMW Group

Examples

Academic Cast Component: FEA vs. IGA

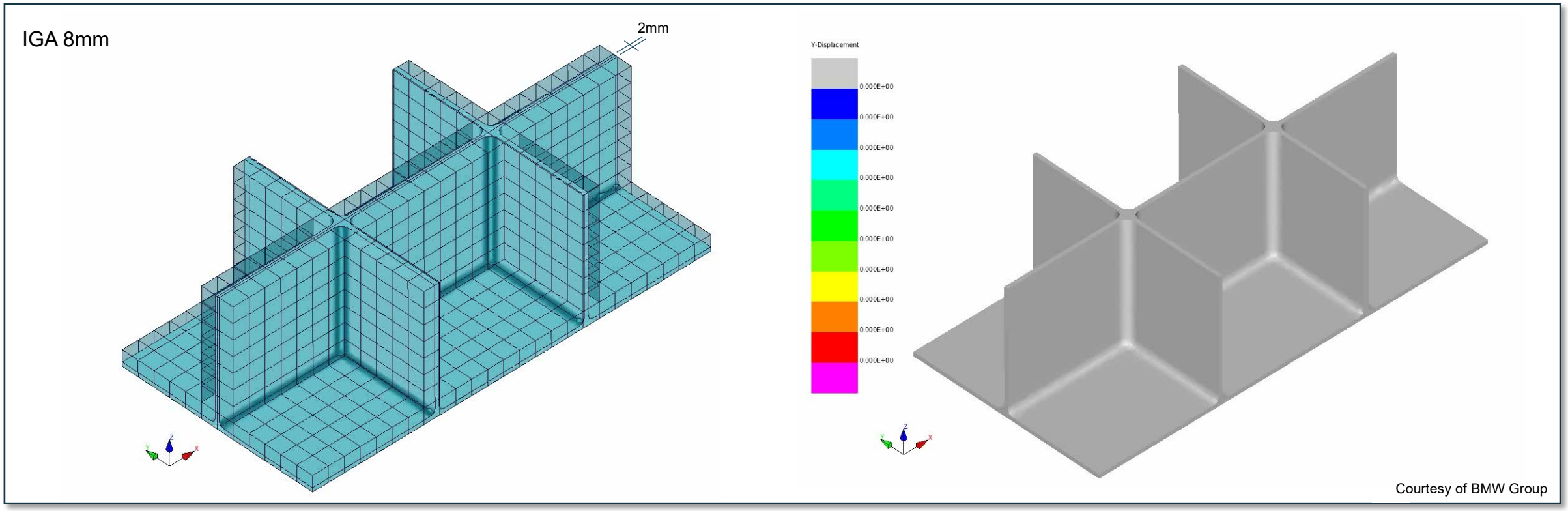
- Resultant Force and computational time
- Comparable accuracy:
  - FEA_1mm – IGA_4mm
  - FEA_0.5mm – IGA_2mm
- Finest trimmed IGA model is 3x faster than coarsest FE model!
- Larger time step for trimmed IGA (at least 4x higher here)
  - Feasible time step for full vehicle simulations could be achieved with 4mm trimmed IGA solids



Examples

Academic Cast Component:

- Coarsest trimmed IGA model (8mm)
  - Wall thickness 2mm
  - Can already correctly depict buckling behavior!

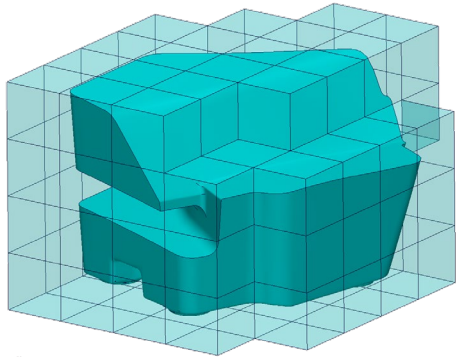


Outline

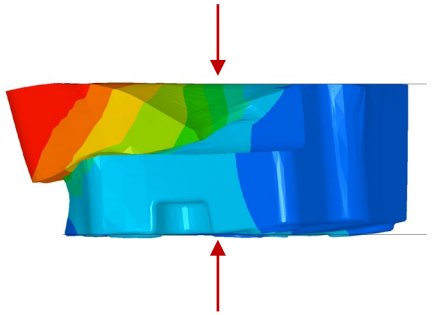
1. Motivation
2. Trimmed B-Spline solids
3. Current workflow
4. Examples
5. **Conclusion and Outlook**

Conclusion

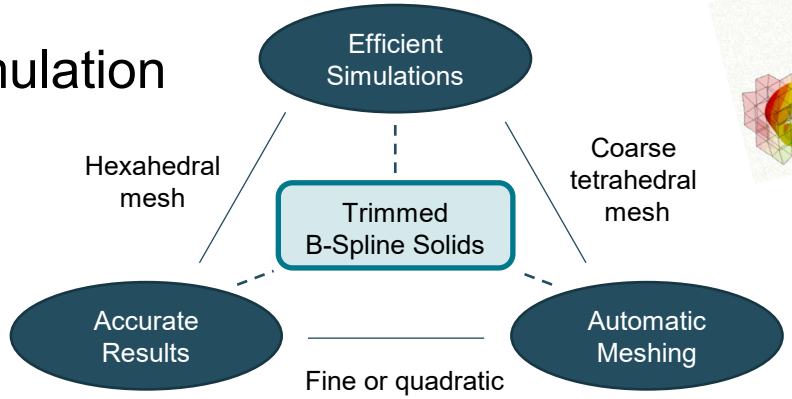
- Embedding approach using B-spline background grid
- Decoupling of
  - Mechanics (B-spline elements as primary DOFs)
  - Geometry (fine interpolation mesh)
- Larger element sizes for similar accuracy
- Larger stable time step possible
  - Faster solution time or
  - Feasible time step for full vehicle simulation
- **Potential to resolve goal conflict !!!**

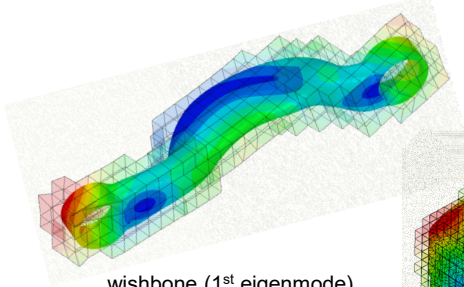


mechanics (coarse)

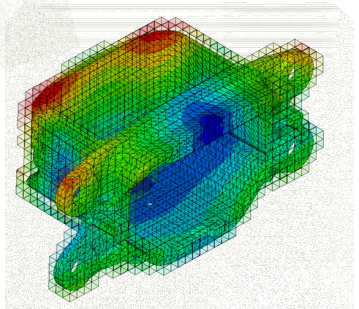


geometry (fine)





wishbone (1st eigenmode)

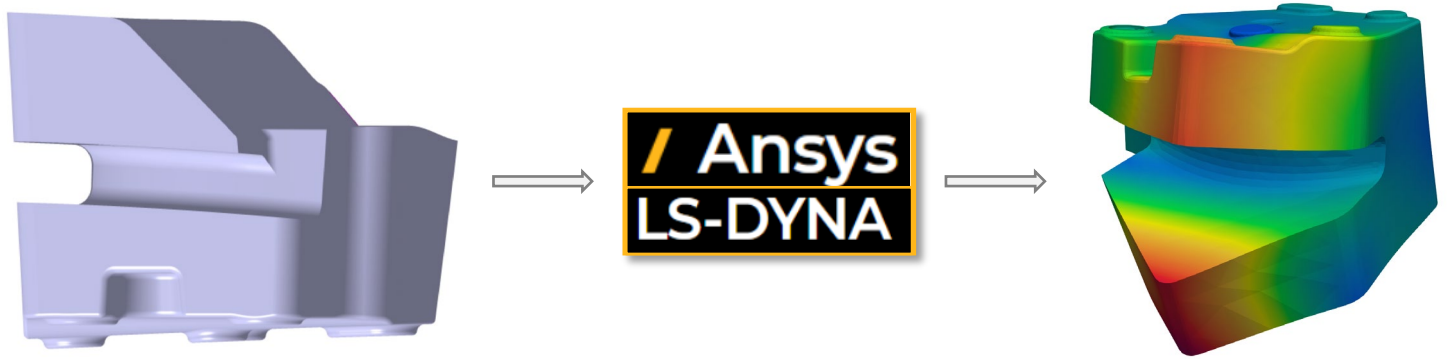


gearbox bearing housing (1st eigenmode)

Courtesy of BMW Group

Outlook

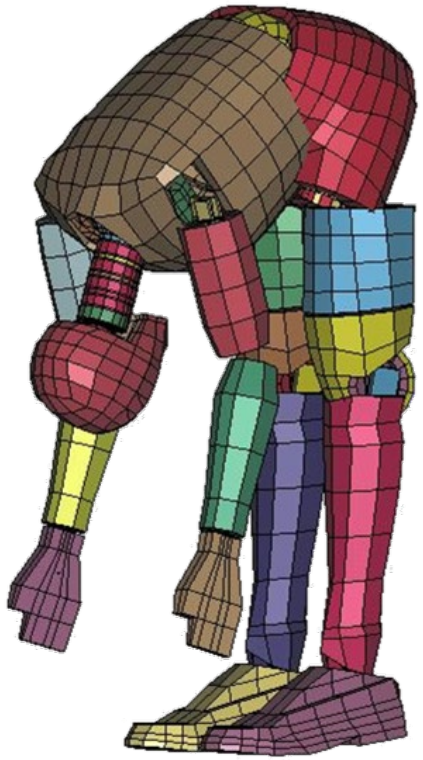
- Properly integrate current external preprocessing step into LS-DYNA
  - Efficient integration rules
- Establish an industrial workflow
- Apply to more complex models
  - Might need to adjust stabilization schemes
- Study effects of:
  - Geometry representation via interpolation elements for contact
  - Size, position and alignment of B-spline grid
- Add material failure
- … and more



1st eigenmode

M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

Thank You



DYNAmore GmbH
Industriestr. 2
70565 Stuttgart-Vaihingen
Germany

Tel.: +49 - (0)711 - 459 600 0
Fax: +49 - (0)711 - 459 600 29
info@dynamore.de

www.dynamore.de
www.dynaexamples.com
www.dynasupport.com
www.dynalook.com

DYNAmore worldwide
Germany ▪ France ▪ Italy ▪ Sweden ▪ Switzerland ▪ USA

Find us on