


A vectorization approach for multifaceted solids in VecGeom

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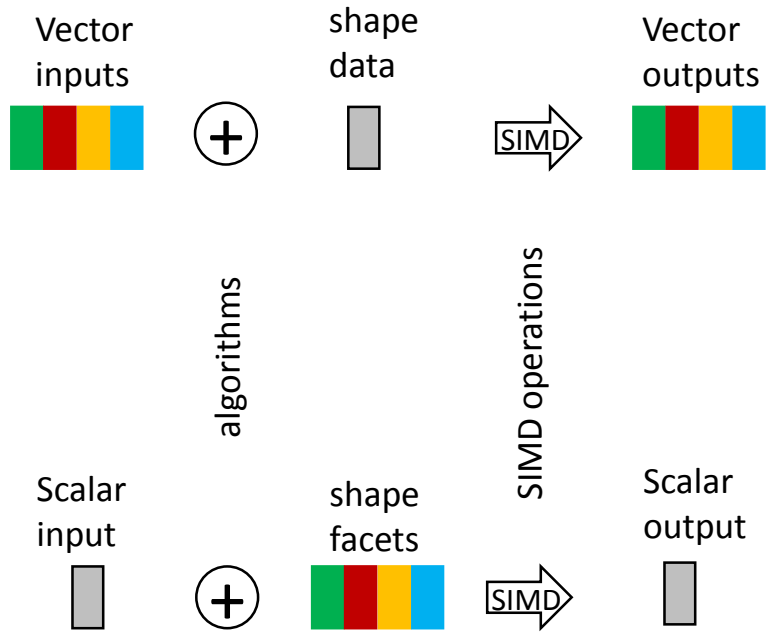
Context

- Geometry modeling is a performance-critical component for detector simulation and tracking
  - Locating tracks, computing line/solid intersections, surface normals, …
- VecGeom development started 5 years ago aiming to optimize this functionality for multi-particle queries
  - Vectorize on multiple inputs provided by GeantV as “baskets” of tracks
- VecGeom started an important R&D on vectorization techniques
  - Resulting in the VecCore vectorization library
    https://github.com/root-project/veccoreVecGeom
- Extended USolids effort for unifying/replacing the existing geometry solids algorithms (AIDA project)

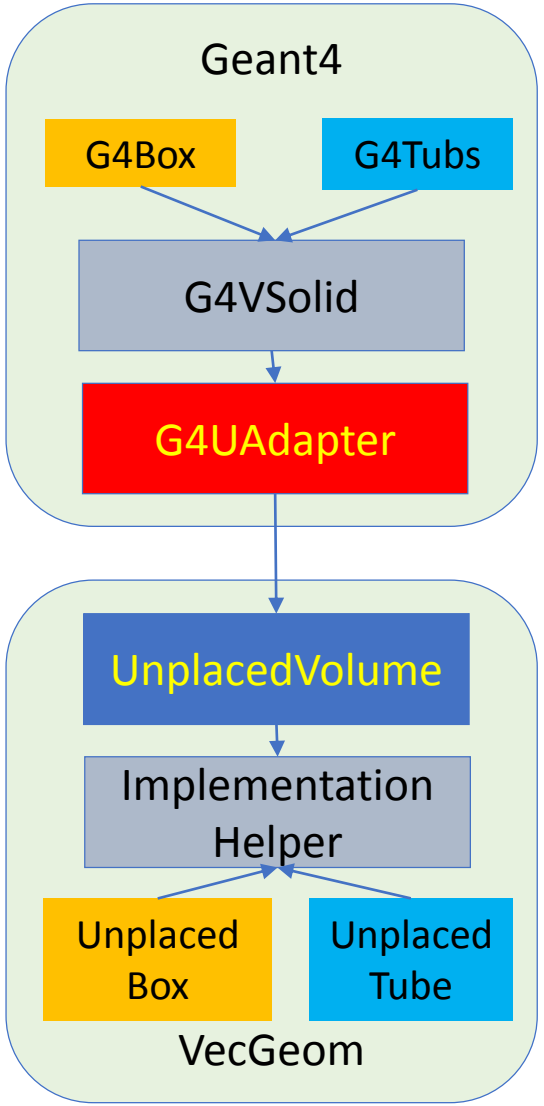
VecGeom = vectorized geometry

- Many particle input -> vectorization on input data
  - Using SIMD operations based on VecCore
  - Close to ideal efficiency for simple solids, not so good for very complex ones
  - Complexity (branching, early returns) creates bottlenecks for vectorization
- Single particle input -> vectorization on internal loops
  - Multiple facets (trapezoids, polyhedra, tessellated, extruded solids), or multiple sections of same type (polycones)
  - Very important optimization mode for scalar clients (Geant4, tracking)



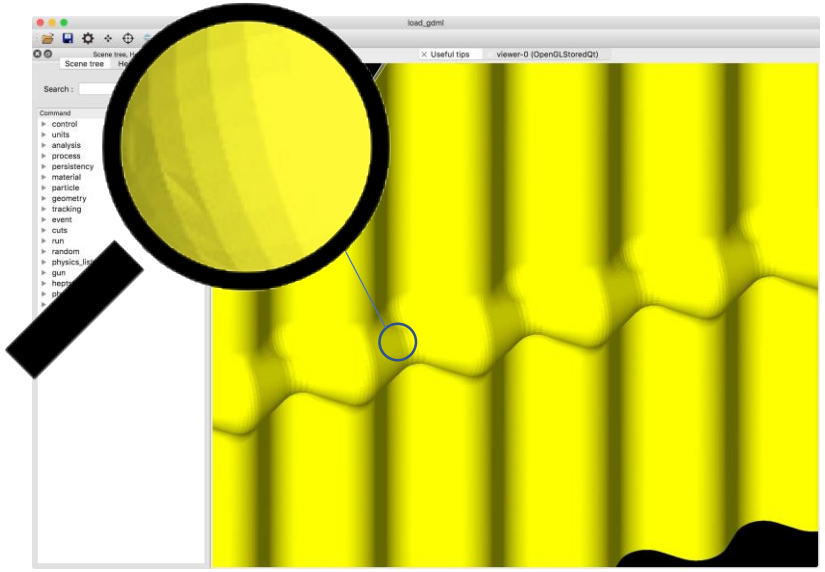
VecGeom & Geant4

- VecGeom solids can be used instead of native Geant4 solids since release 10.2
  - Activated with compilation option – transparent to users
- Used in production by CMS in 2018
  - Overall simulation time benefits of ~7-13%
  - Other experiments investigating this option
- Most benefits are due to internal vectorization of complex solids (polycones, polyhedra)
  - Worth extending vectorization in scalar input mode for more multi-faceted solids



The obvious candidate: tessellated solid

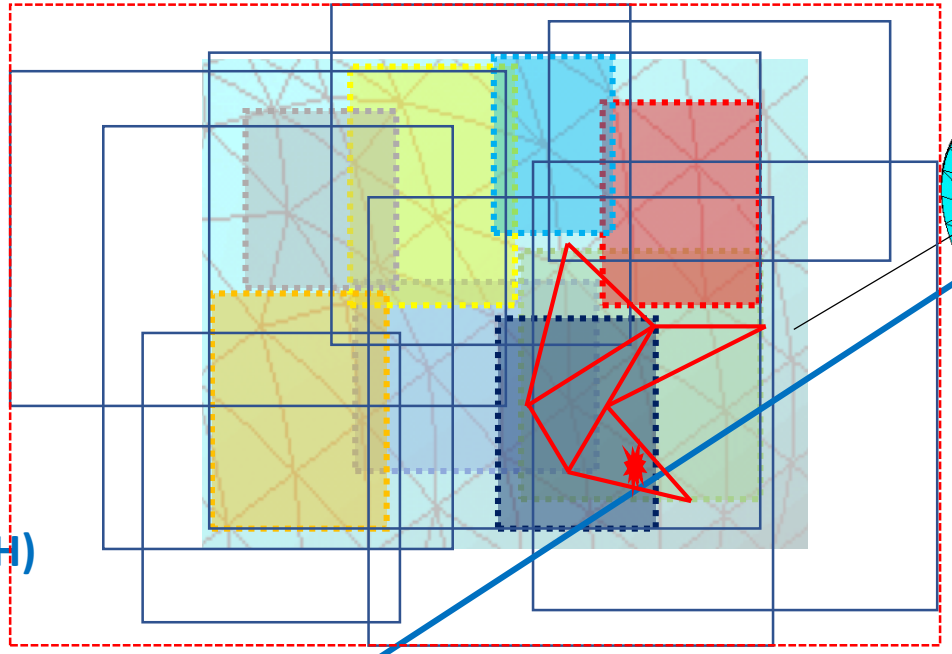
- Simulation of complex surfaces is needed in certain cases
  - Medical applications, applications sensitive to material budget, space applications for shielding studies
- Surfaces are represented as meshes of connected facets (coming from CAD programs)
  - Vectorization seems natural for the loop over facets
- A better approach is to pre-select the facets to be checked
  - In most cases not all facets have to be checked. Can we select the subset of candidates also in vectorized mode?
  - In Geant4 voxelization is used for this purpose



The LHCb RF-foil loaded from GDML as tessellated solid (164k facets) and visualised in Geant4 through VecGeom

Multi-level vectorization

Group neighbour triangles in clusters, 4 per cluster. Store data in *vecCore::Double_v*



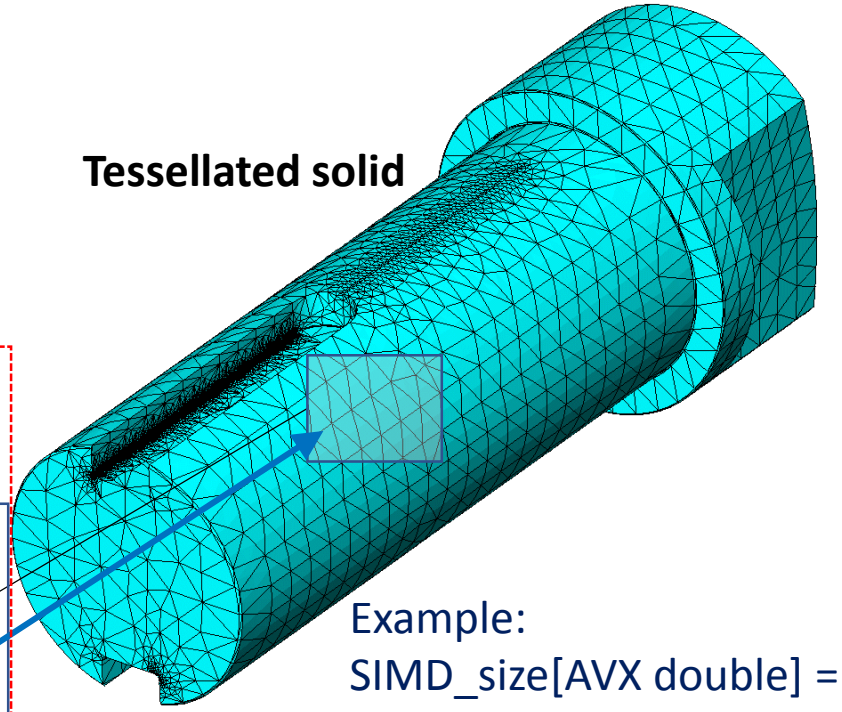
Make groups of bounding boxes of clusters, 8 per group

Continue grouping by 8 and make "super" bounding boxes -> bounding volume hierarchy (BVH)

Vectorize in float computation of distances to super-boxes to select only hit candidates

Repeat the same with the content of the boxes being hit, until we get the candidate clusters

Tessellated solid



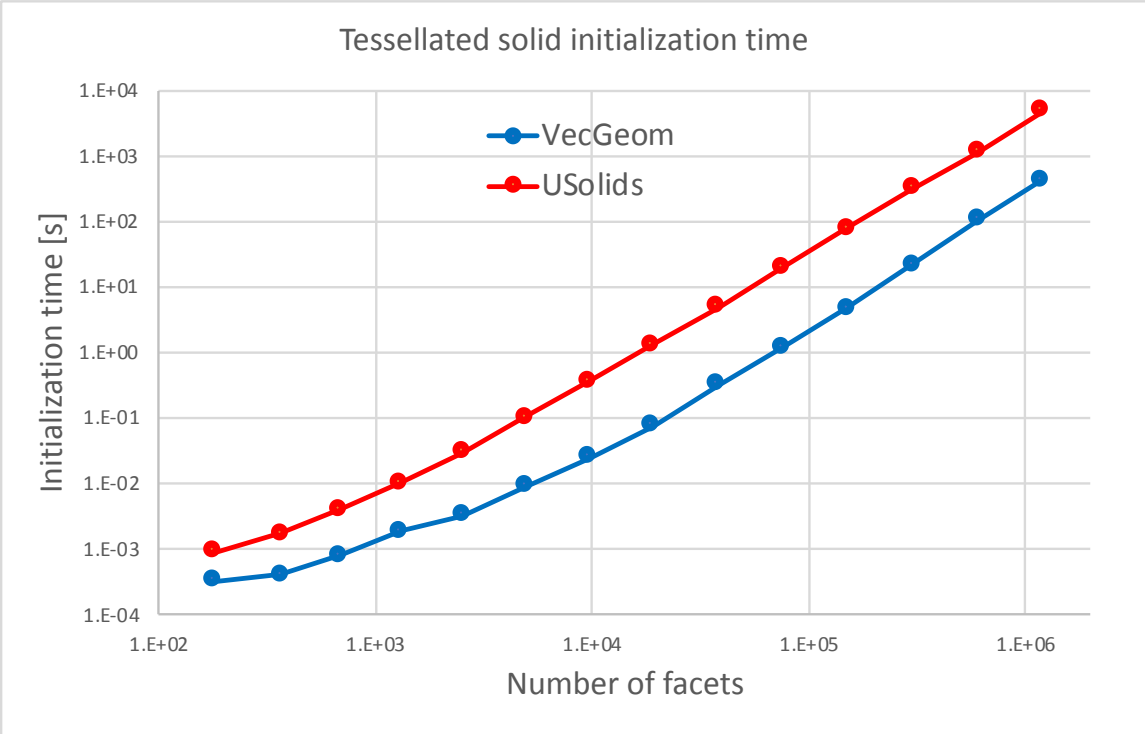
Example:
SIMD_size[AVX double] = 4
SIMD_size[AVX float] = 8

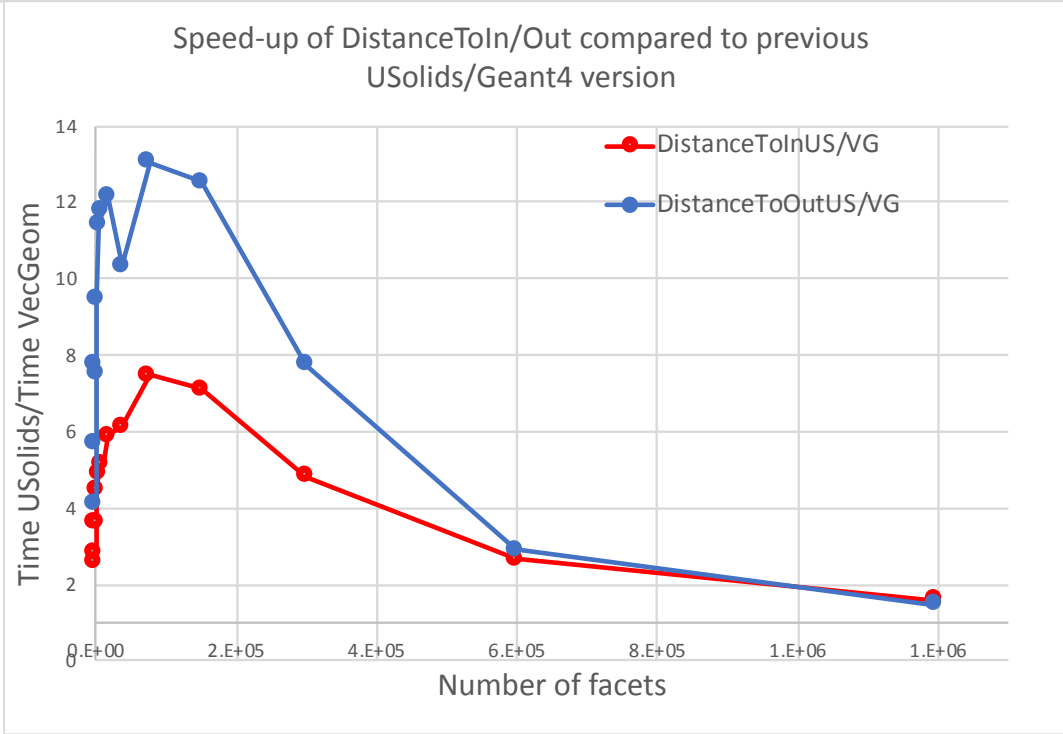
Vectorize in double computation of distances to triangles in each cluster

Tessellated solid performance

- O(10) speed-up compared to Geant4 in both initialization and run time for up to 100K facets

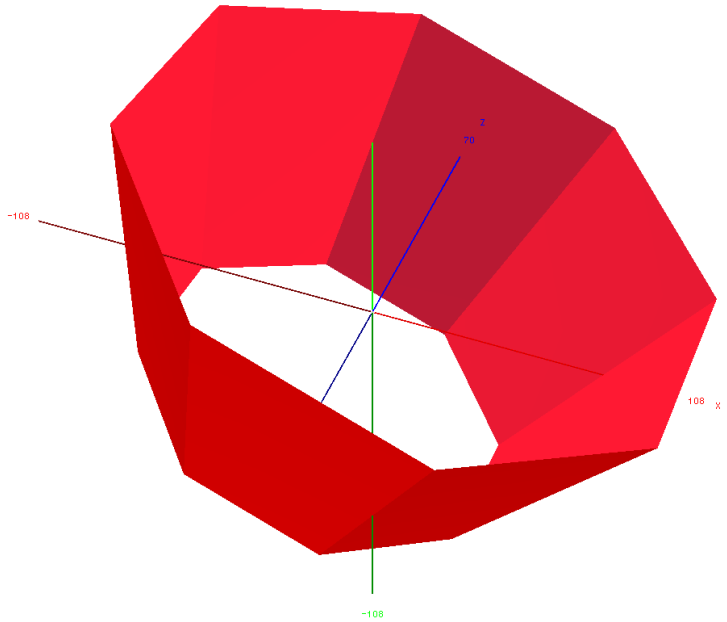
AVX double





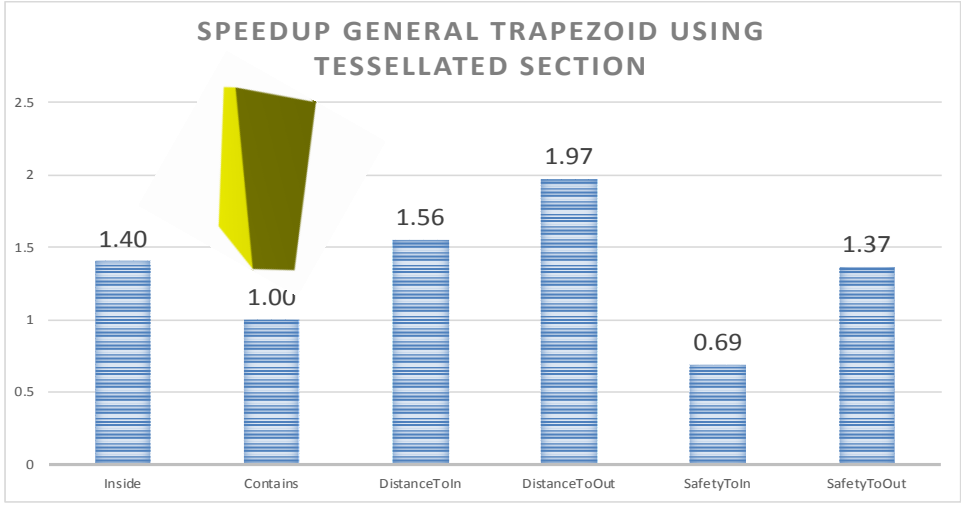
Extending multi-faceted approach

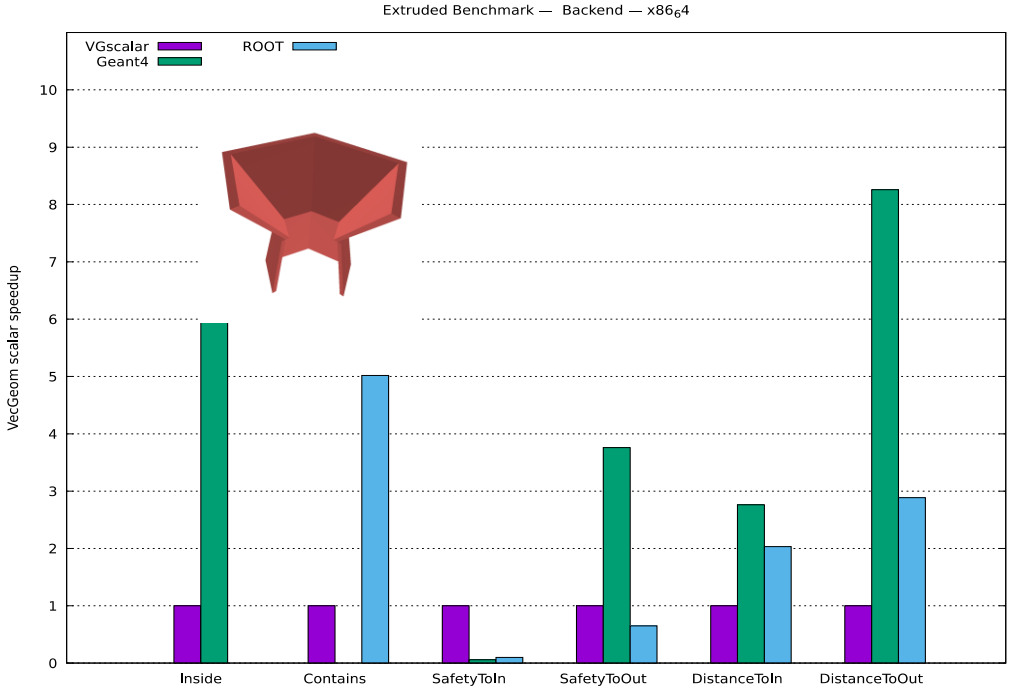
- Generalized to more multi-faceted solids
  - Trapezoids, polyhedra, extruded solids
- Created a new SIMD helper class
  - Representing a surface made of quadrilateral tiles, organized in clusters of size = vector length
  - Delimited by two Z planes
  - Using explicit vectorization on tiles based on VecCore



Tessellating other solids

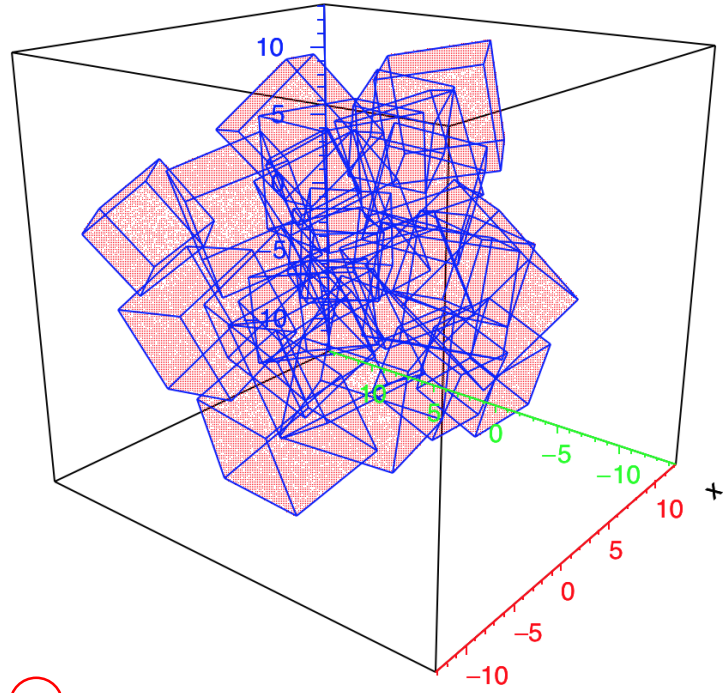
- No benefits measured for simple solids (box, simple trapezoids)
  - Faster without loops
- Other solids already vectorized in the scalar case -> marginal gain
  - Polyhedron, Trapezoid
- Important improvements observed for previously non vectorized cases
  - General planar trapezoids
  - Extruded solids

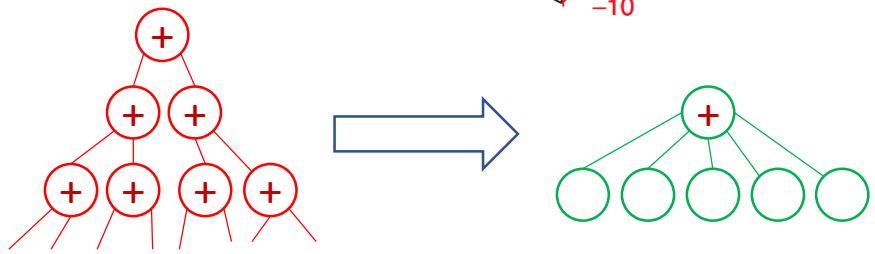




Other scalar optimizations: multi-unions

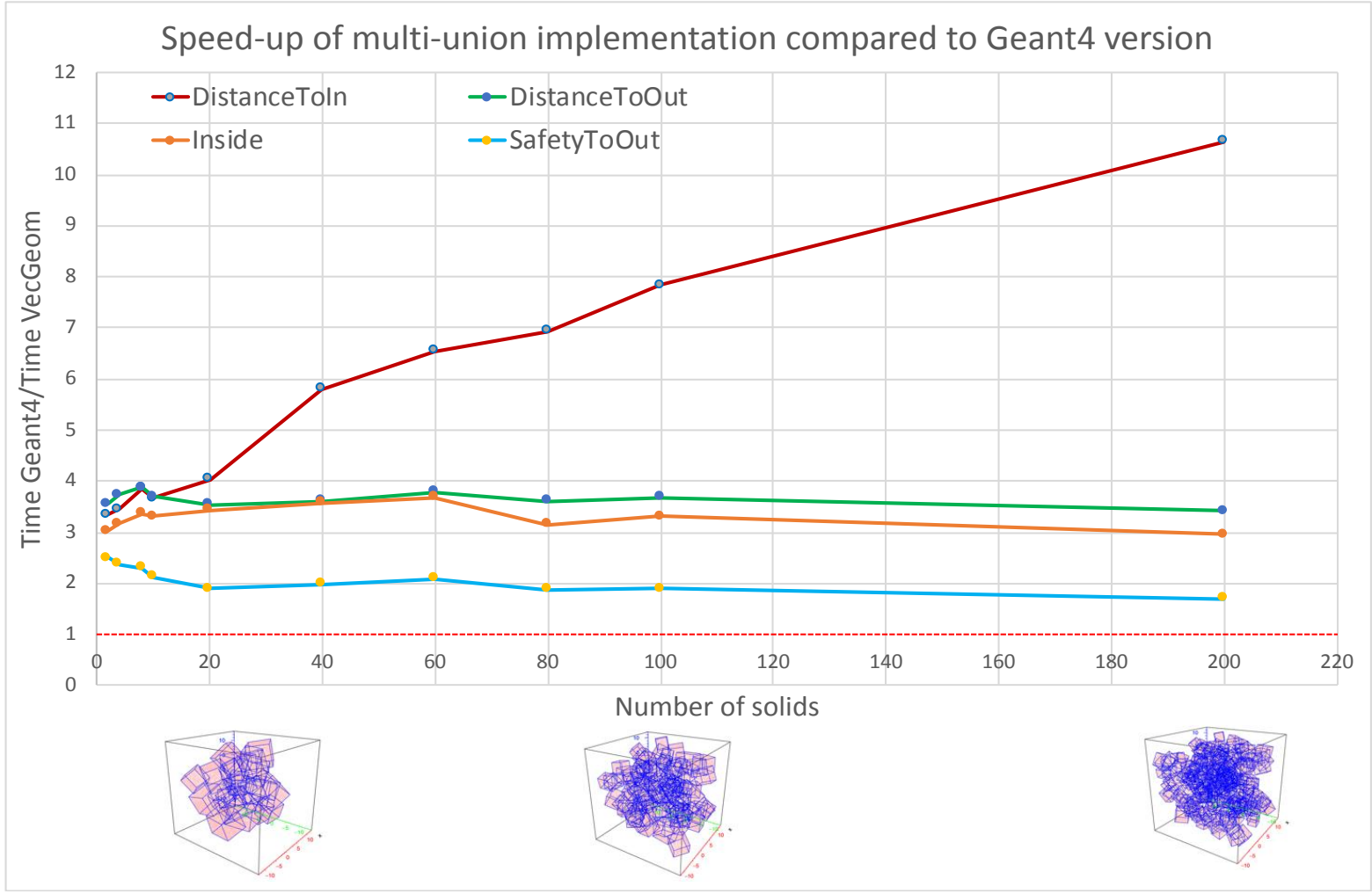
- Boolean unions are represented as binary trees
  - Pathologically slow in simulation - too many individual checks
- Multi-unions representing nodes at same level
  - Implementation in Geant4 using voxelization helper
- Re-implemented in VecGeom based on Bounding Volume Hierarchies (BVH)
  - Vectorized search of candidates





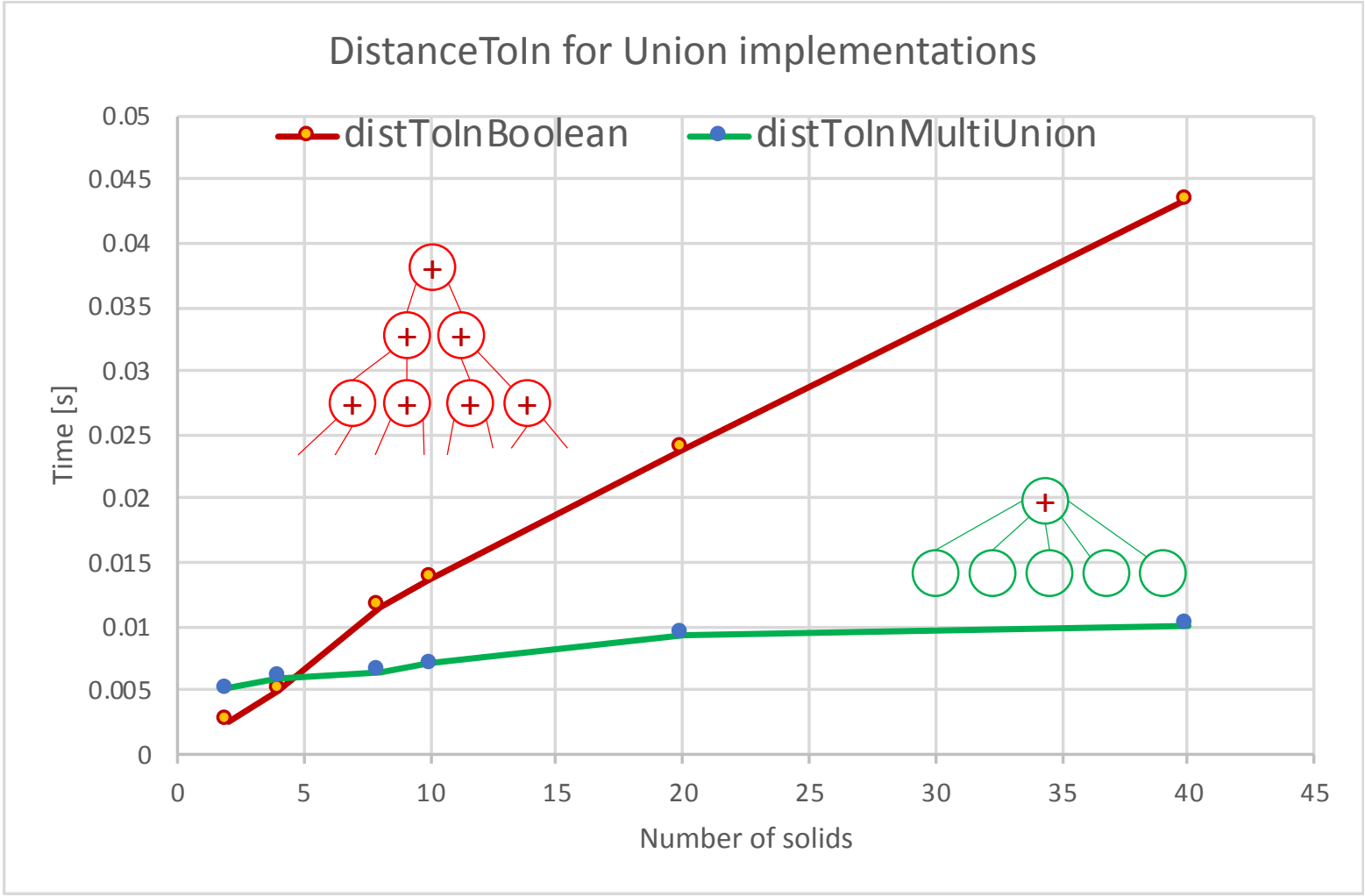
Benefits of using VecGeom multi-union

3x-4x speed-up compared to corresponding implementation in Geant4 for up to several hundred components



Replacing Boolean union with VecGeom multi-union

- Implemented automatic conversion of Boolean volumes to the new multi-union structure
- Much better performance for large number of components



Conclusions

- VecGeom library became production quality
  - Can be used transparently with Geant4 simulations
- Scalar optimizations become very important
  - Achieving vectorization for solids having many facets
- Several vectorized optimizations explored for many solids
  - Bounding volume hierarchies, tessellated clusters and sections, multi-union solids
  - Important performance gains in some cases
- These new features available in release 1.0 of VecGeom library

Contributors

- *CERN-EP/SFT + AIDA 2020: G. Amadio, J. Apostolakis, G. Cosmo, A. Gheata, M. Gheata, P. Mato, W. Pokorski, E. Tcherniaev*
- *J. Martinez Castro, A. Miranda Aguillar (Mexico), P. Canal, G. Lima (FNAL), R. Sehgal (BARC), S. Wenzel (CERN-ALICE), D. Savin (GSoC student)*

- *Repository for VecGeom*
  - *https://gitlab.cern.ch/VecGeom/VecGeom*
- JIRA issue tracking tool
  - *https://its.cern.ch/jira/projects/VECGEOM*