OAK RIDGE National Laboratory

ORANGE surface geometry progress

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CELERITAS

U.S. DEPARTMENT OF ENERGY

Geant4 Collaboration Meeting
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ORANGE: Oak Ridge Advanced Nested Geometry

- Many nuclear engineering codes use “unbounded” surfaces and constructive solid geometry
  - MCNP, KENO, earlier codes: >40 years of history
  - Quadric surface cards, CSG cell cards
  - Neutral particles or no magnetic fields
- 2017: Shift GPU code (part of Exascale Computing Project) uses simple but efficient surface-based reactor model (nested cylinders and arrays)
- 2020: New CPU geometry for Shift
- 2021: Initial GPU port for Celeritas
- 2023: GPU port integrated into Shift

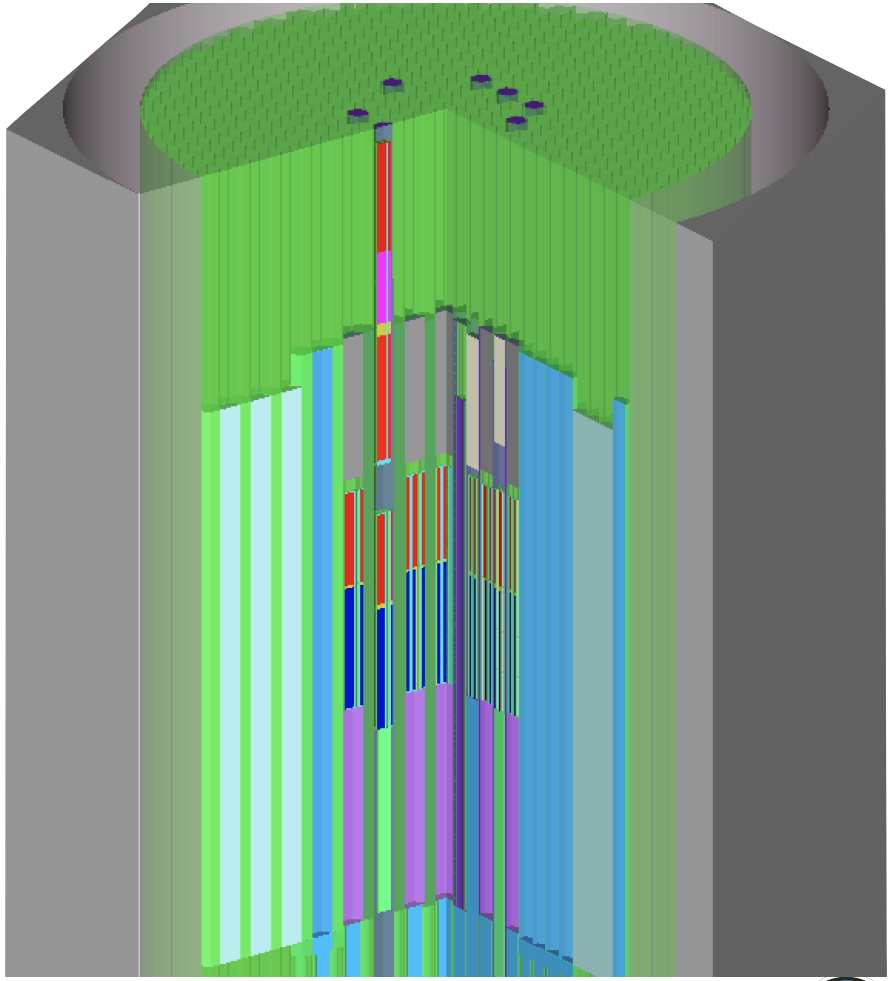


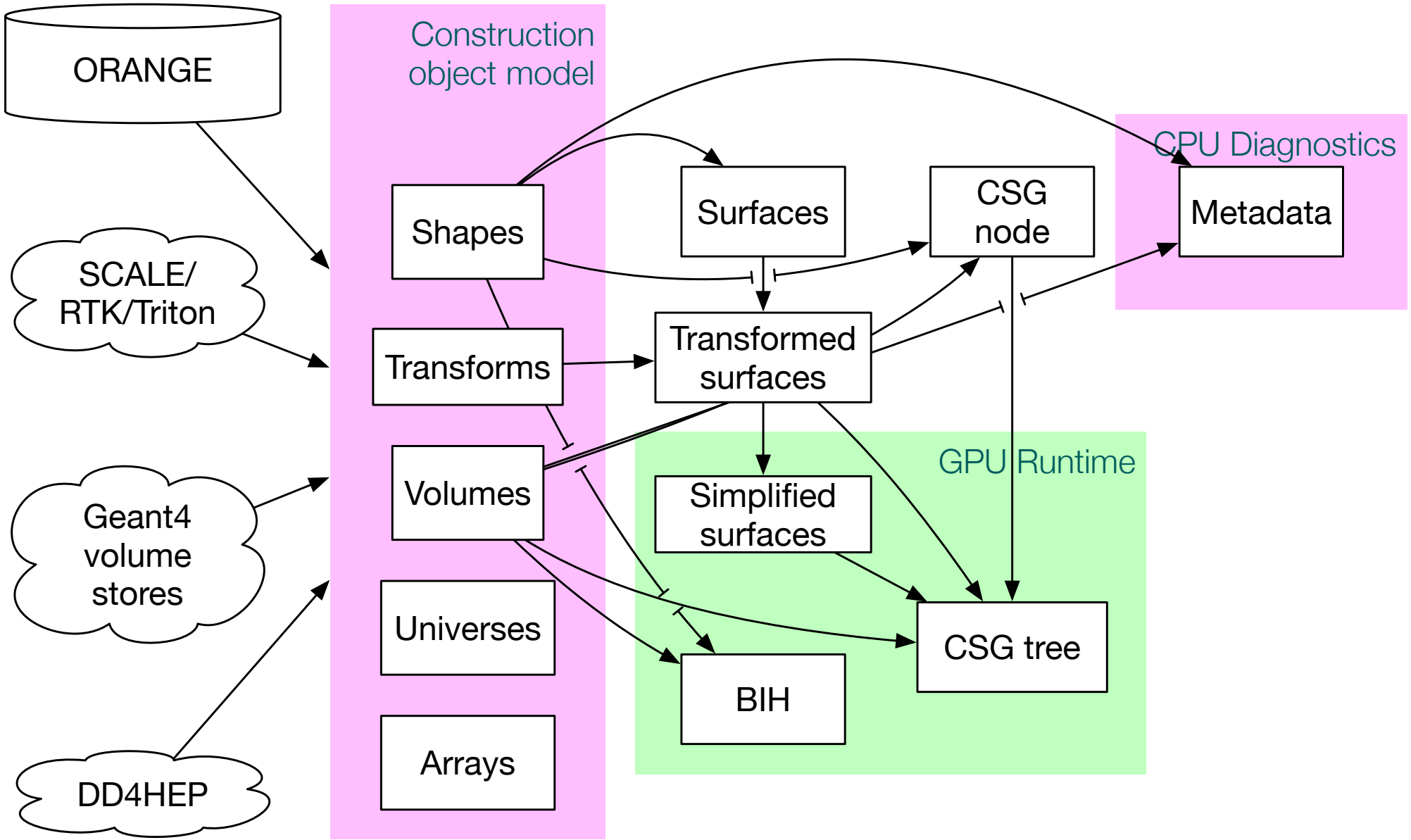
Image credit: Steve Skutnik (ORNL)

Methods

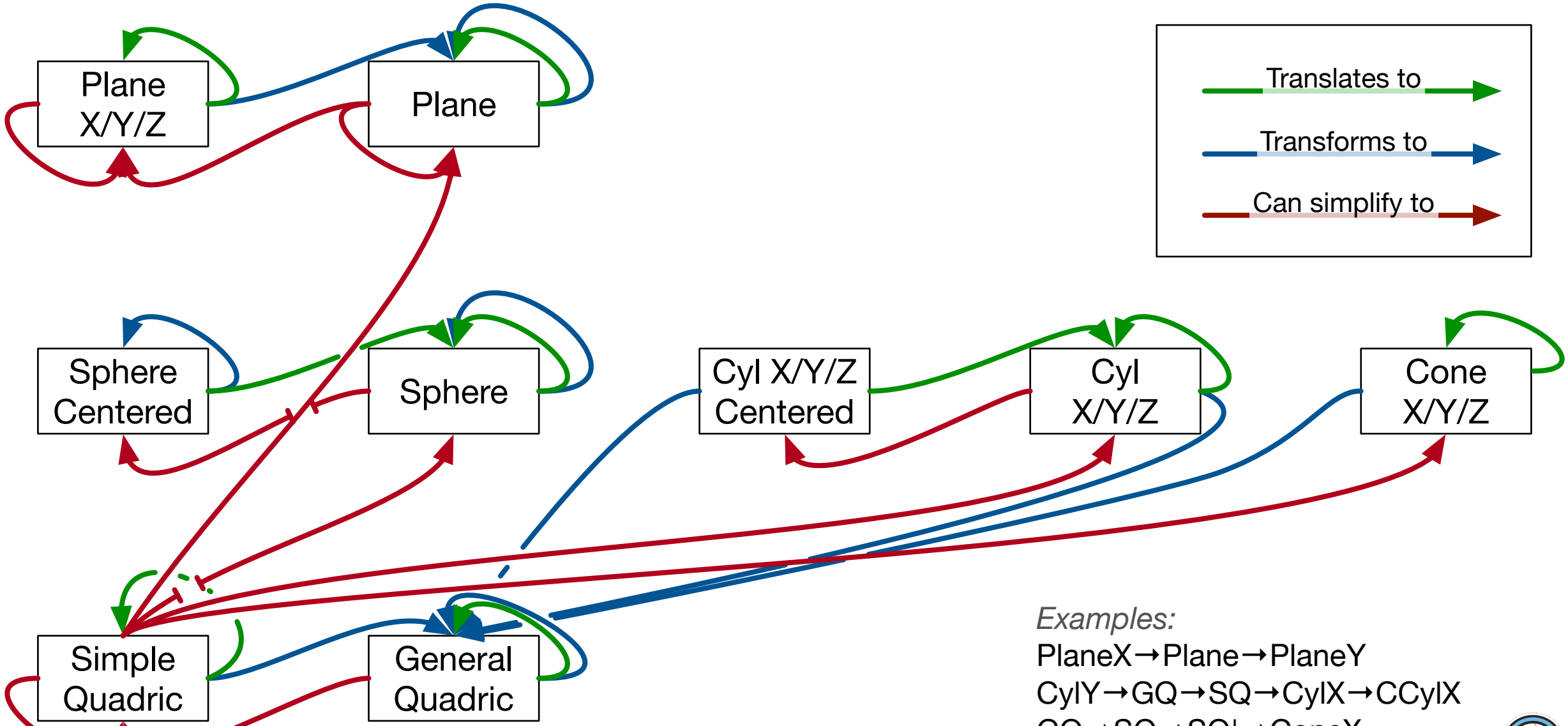
Results

Continuing work

User-to-runtime construction



Surface transformation and simplification



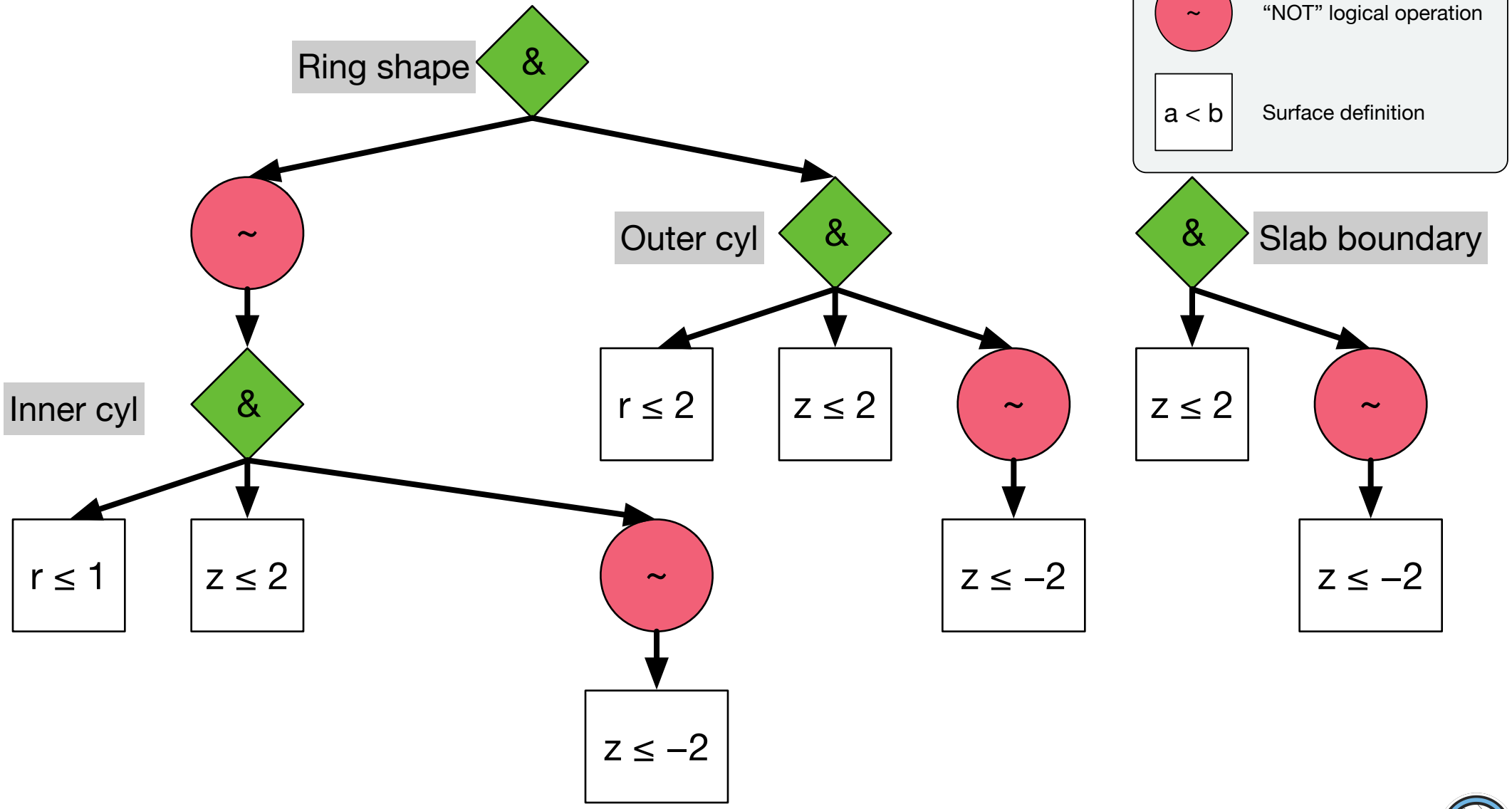
Examples:

PlaneX→Plane→PlaneY

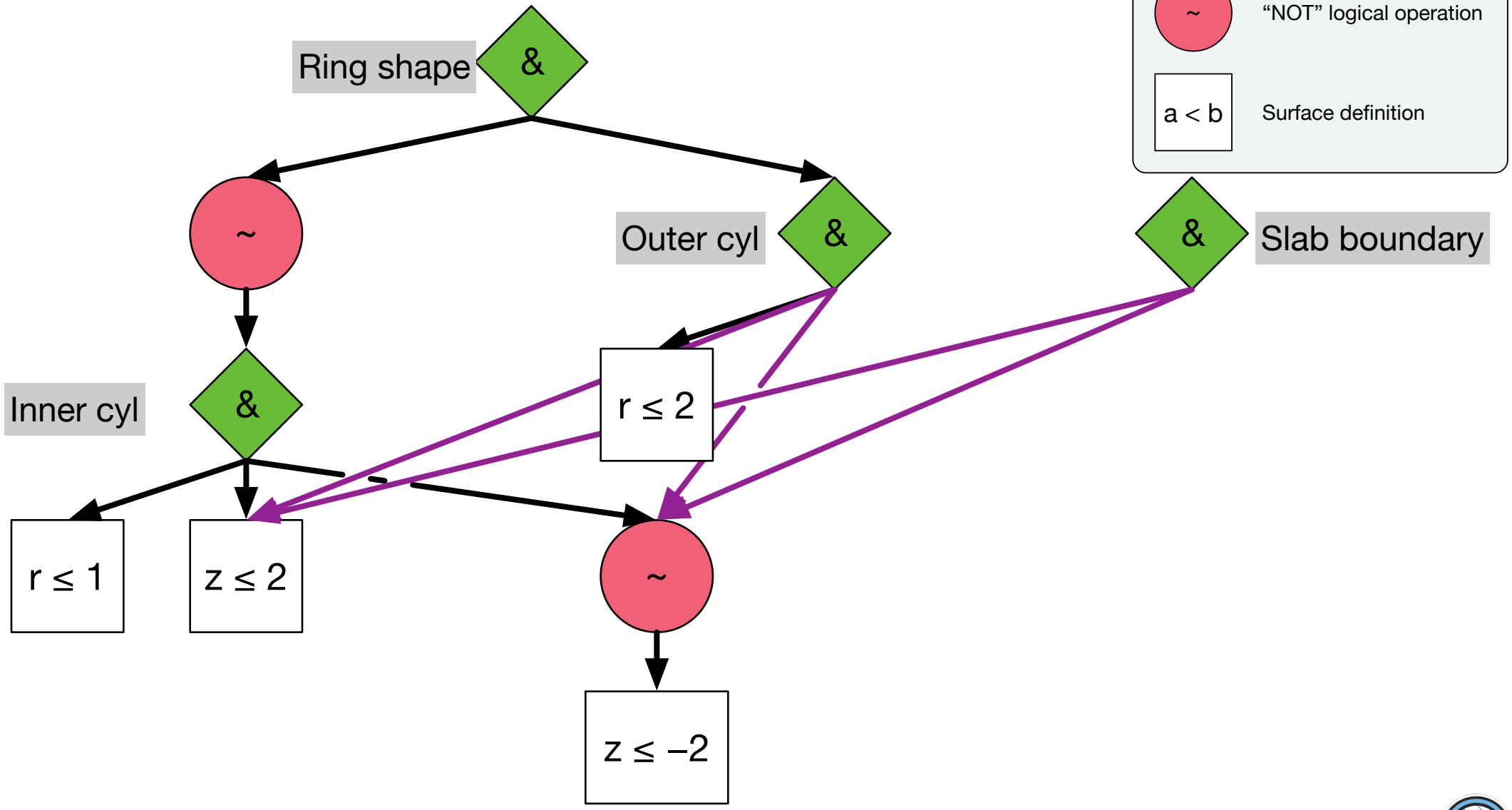
CylY→GQ→SQ→CylX→CCylX

GQ→SQ→SQ'→ConeX

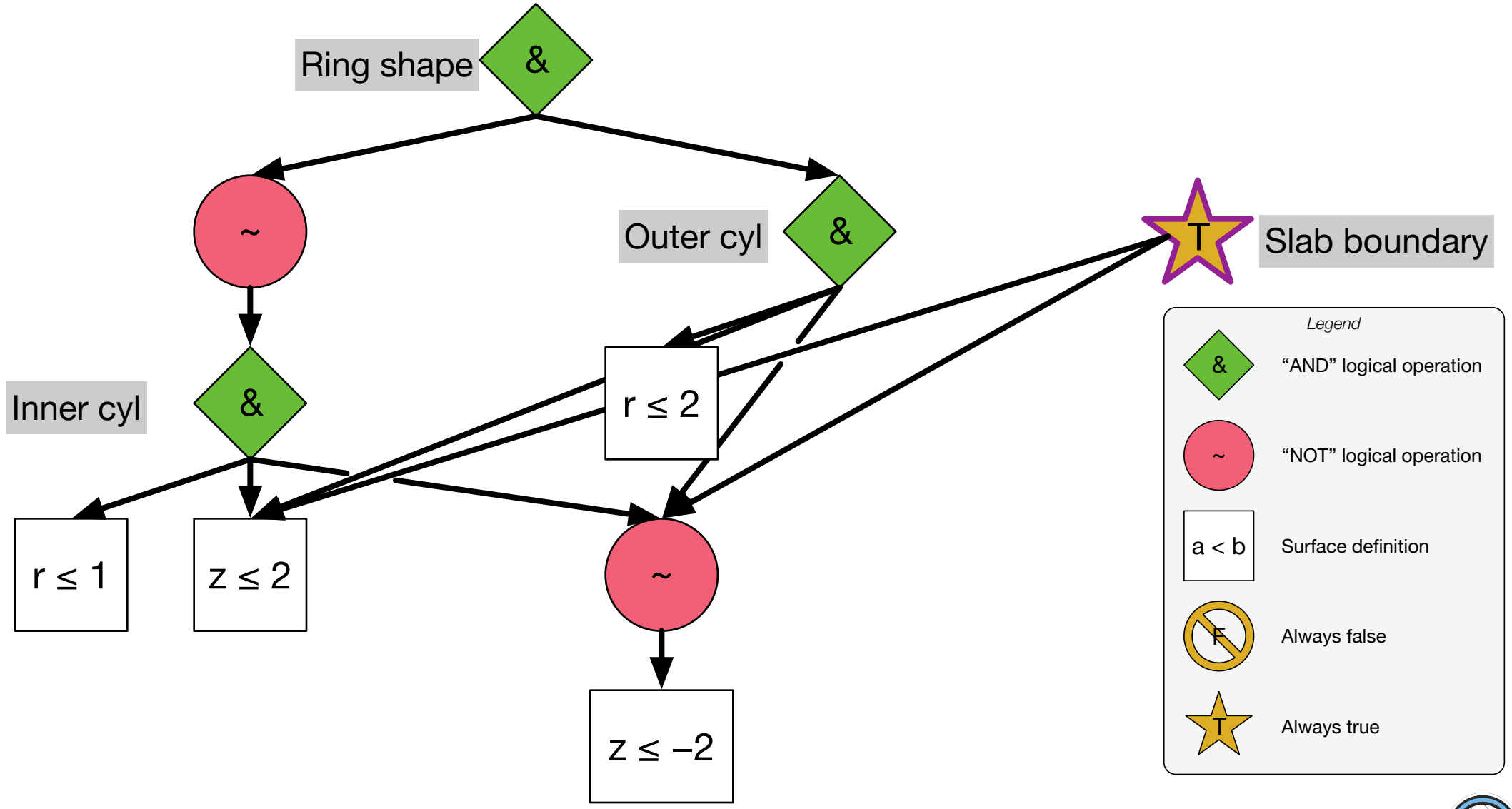
CSG tree preprocessing: define shapes (1/5)



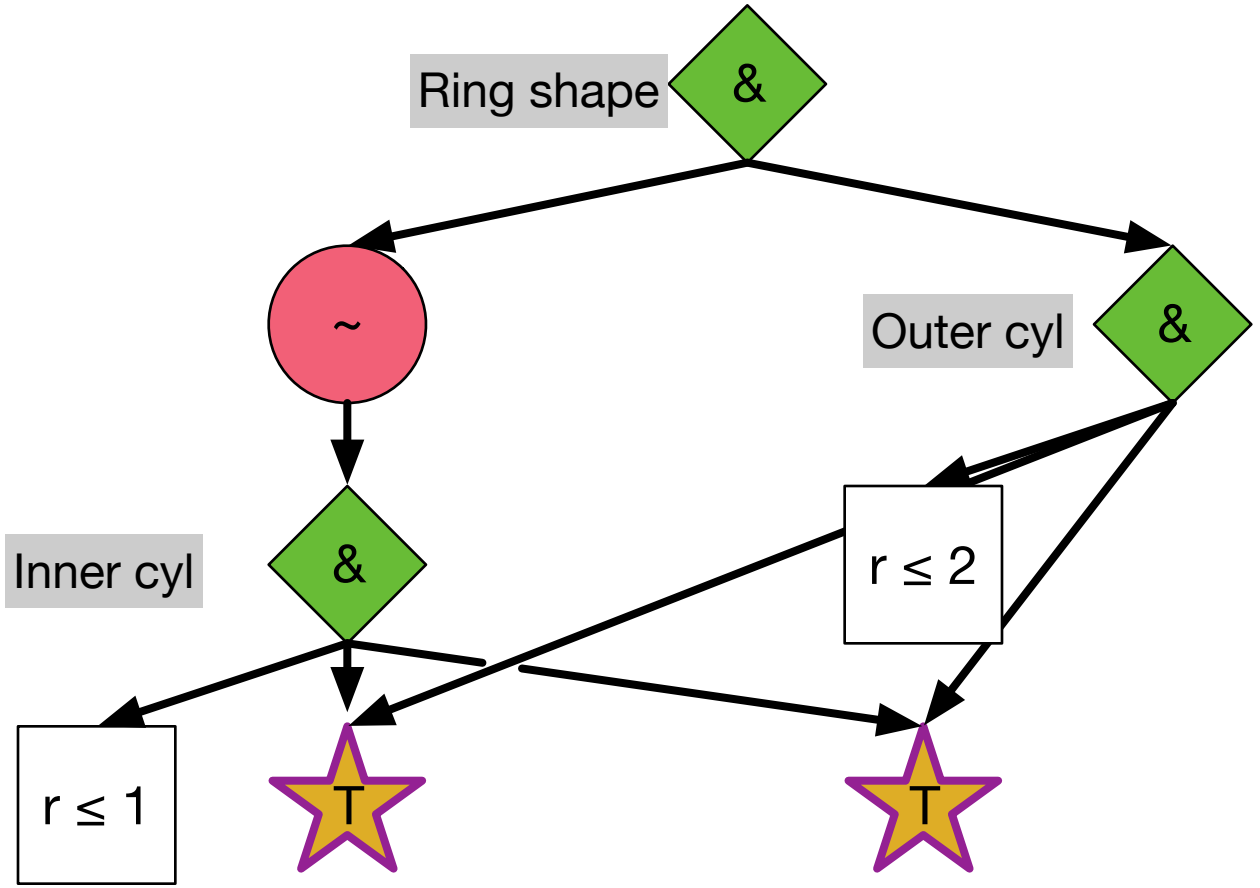
CSG tree preprocessing: deduplicate (2/5)

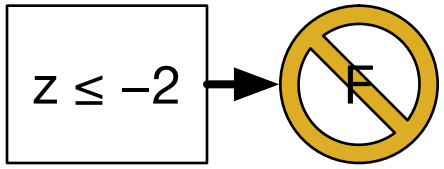


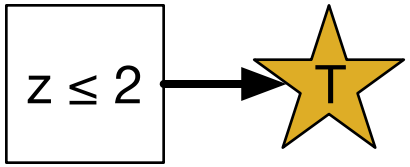
CSG tree preprocessing: replace with truth (3/5)



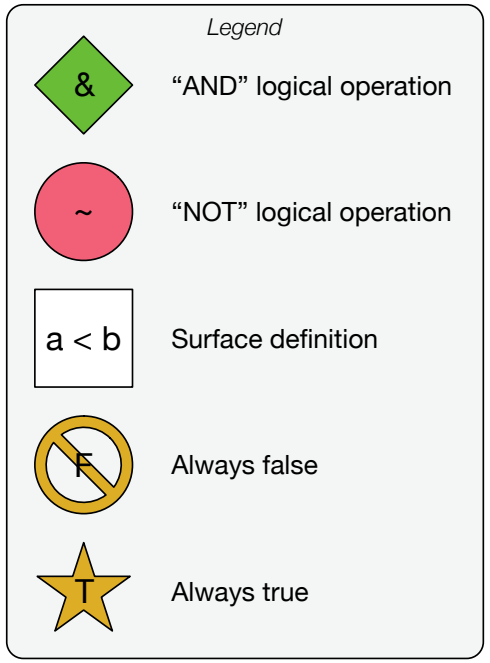
CSG tree preprocessing: apply logic (4/5)



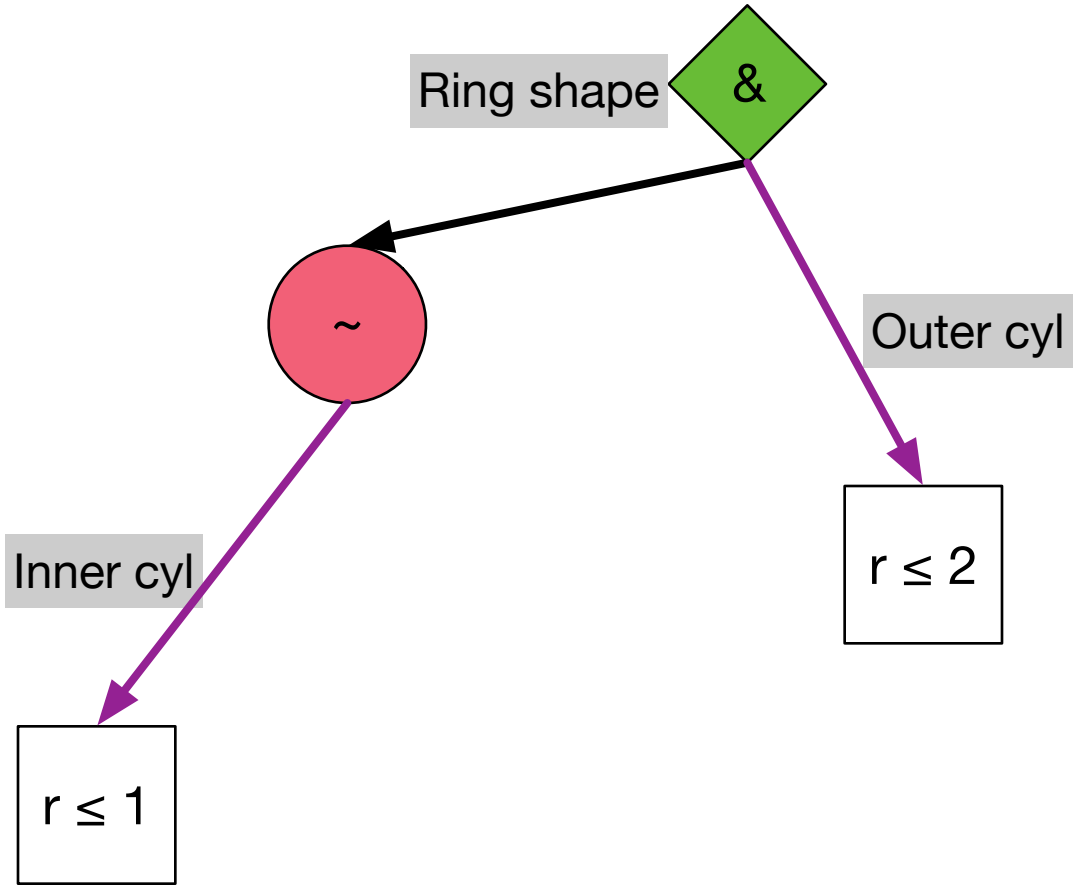


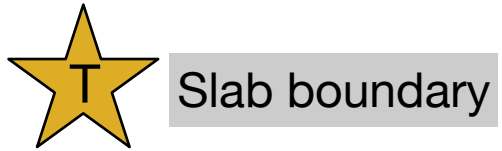


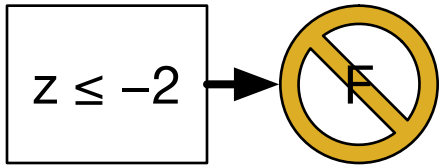
Slab boundary

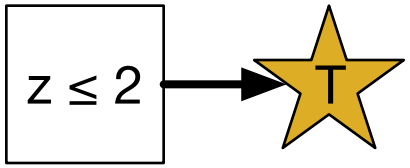


CSG tree preprocessing: simplify expression (5/5)



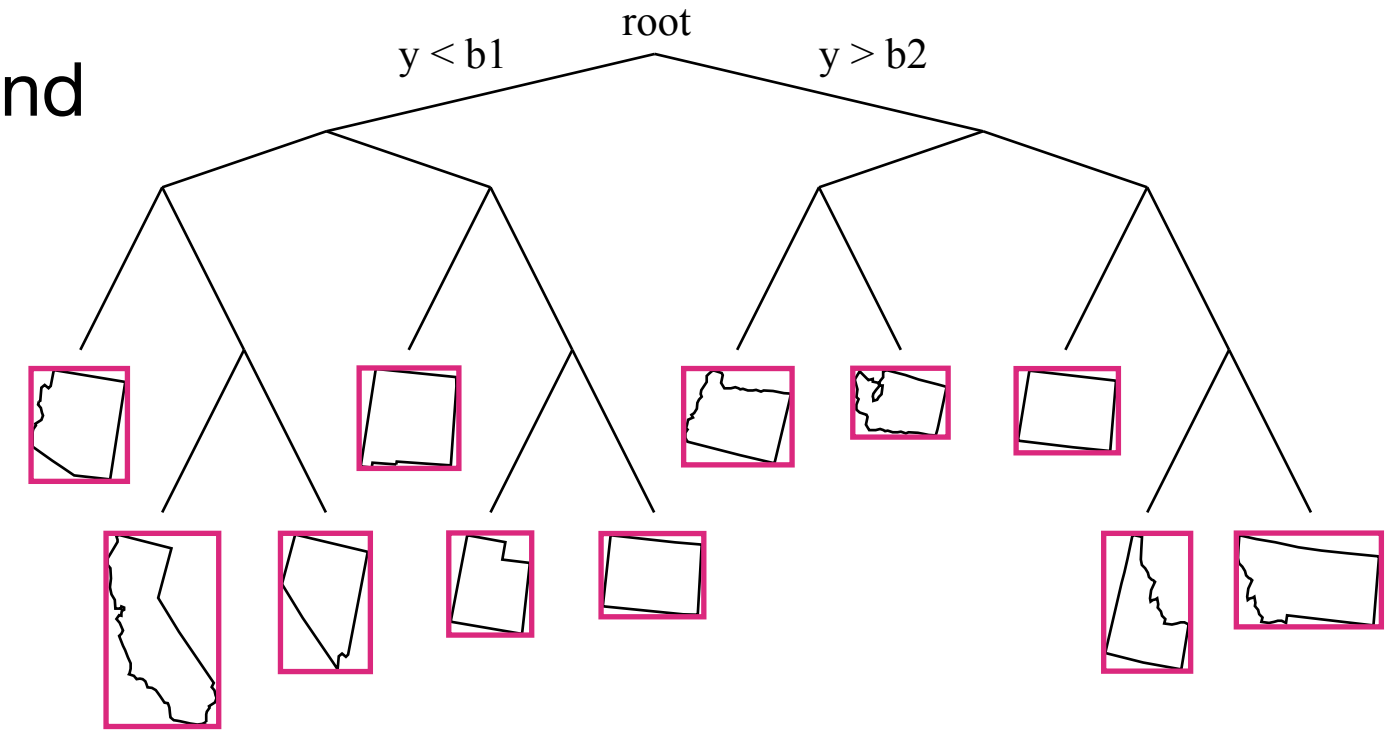






Acceleration: bounding interval hierarchy

- Inputs: volume bounding boxes
- Recursive partitioning scheme
- Tree traversal at initialization and surface crossing
- Low memory requirements
  - Single-precision bounding boxes
  - Tree nodes are ~16B



Methods

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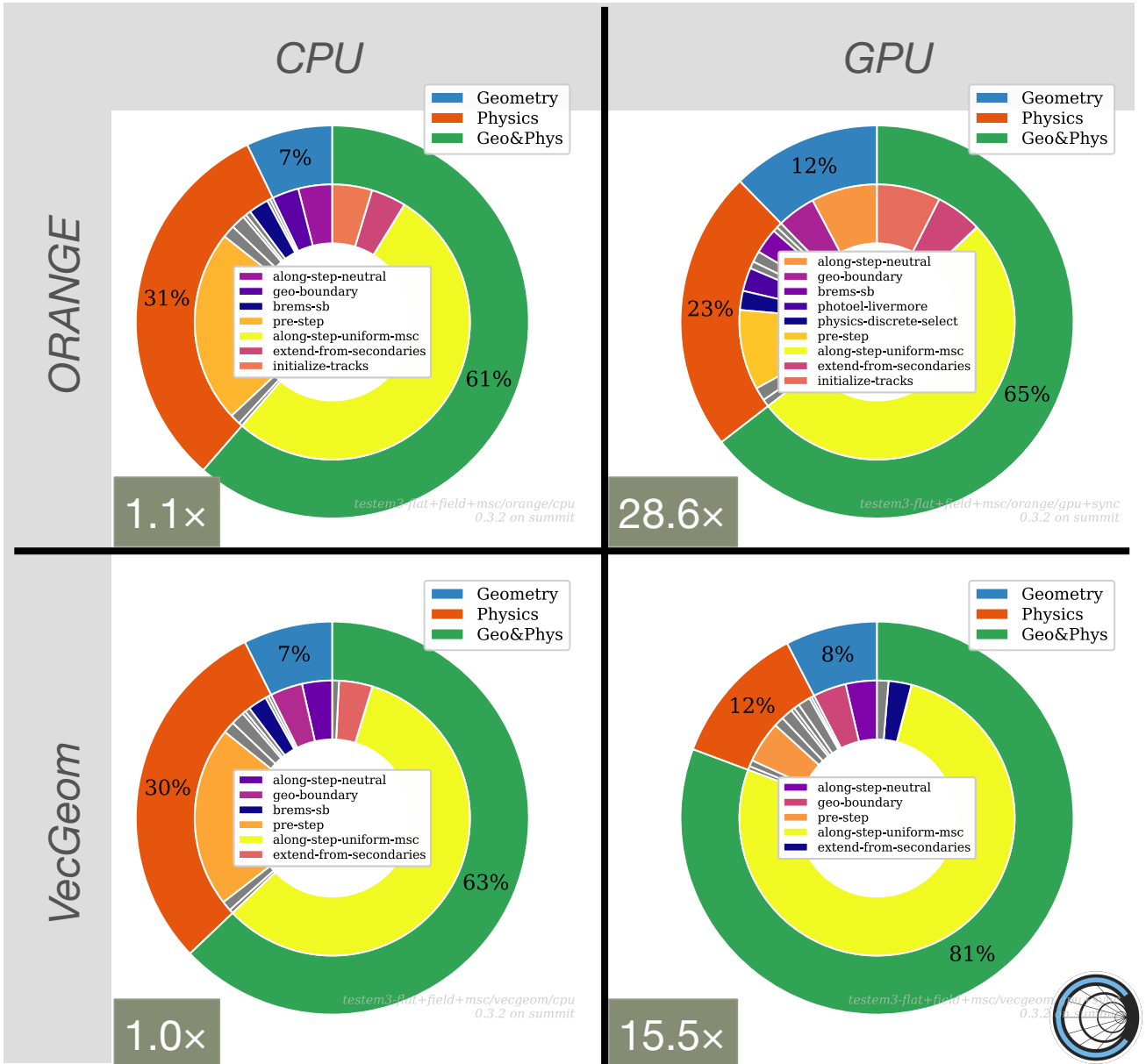
Continuing work

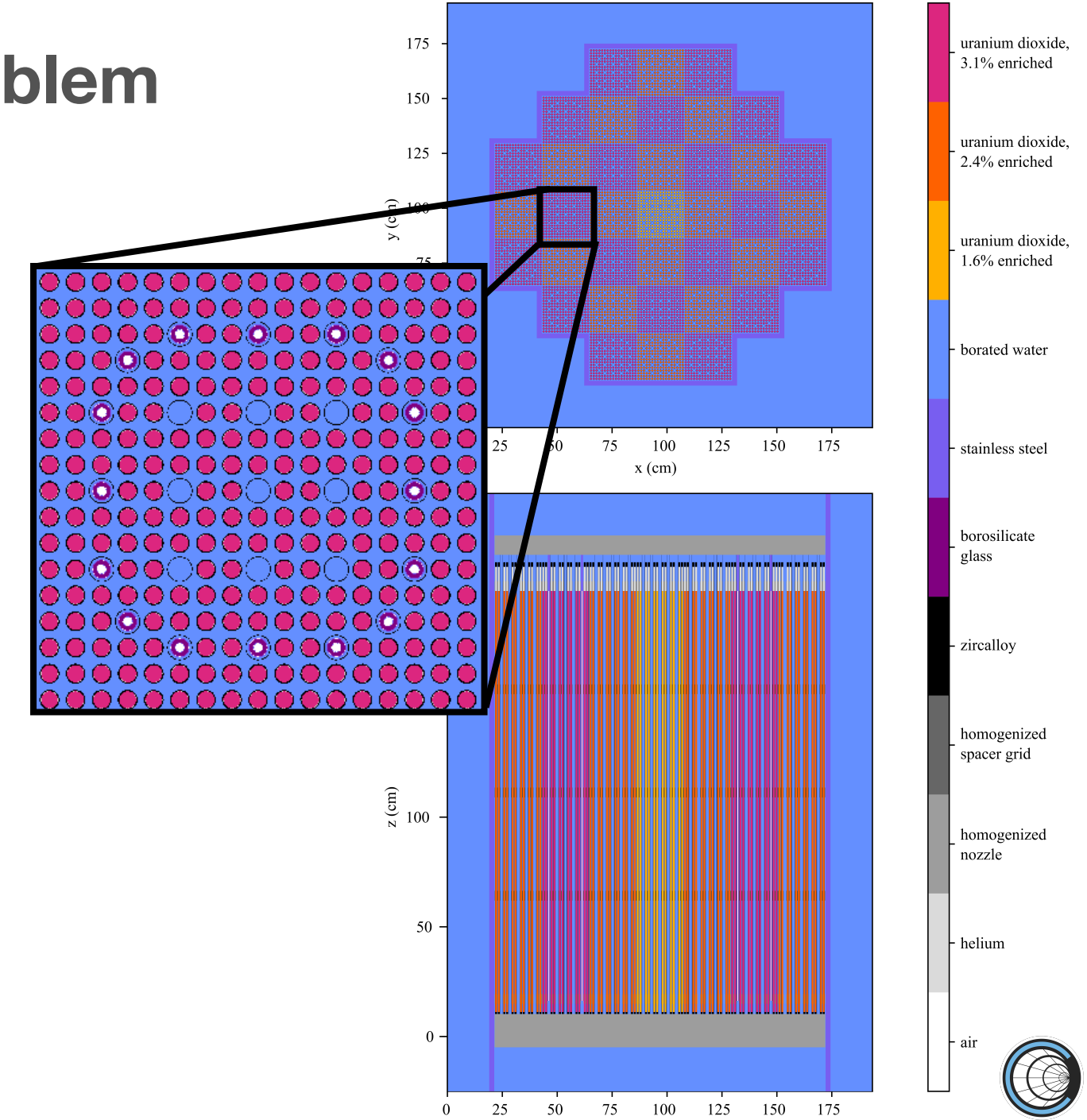
Current ORANGE/VecGeom performance for TestEM3

- VecGeom 1.x navigation on GPU known to be suboptimal
- Results from Summit
  - 7 CPU Power9 cores vs 1 V100 GPU
  - 1T uniform field
  - 1300 × 10 GeV e^- per event × 7 events
  - Speedup relative to CPU VecGeom



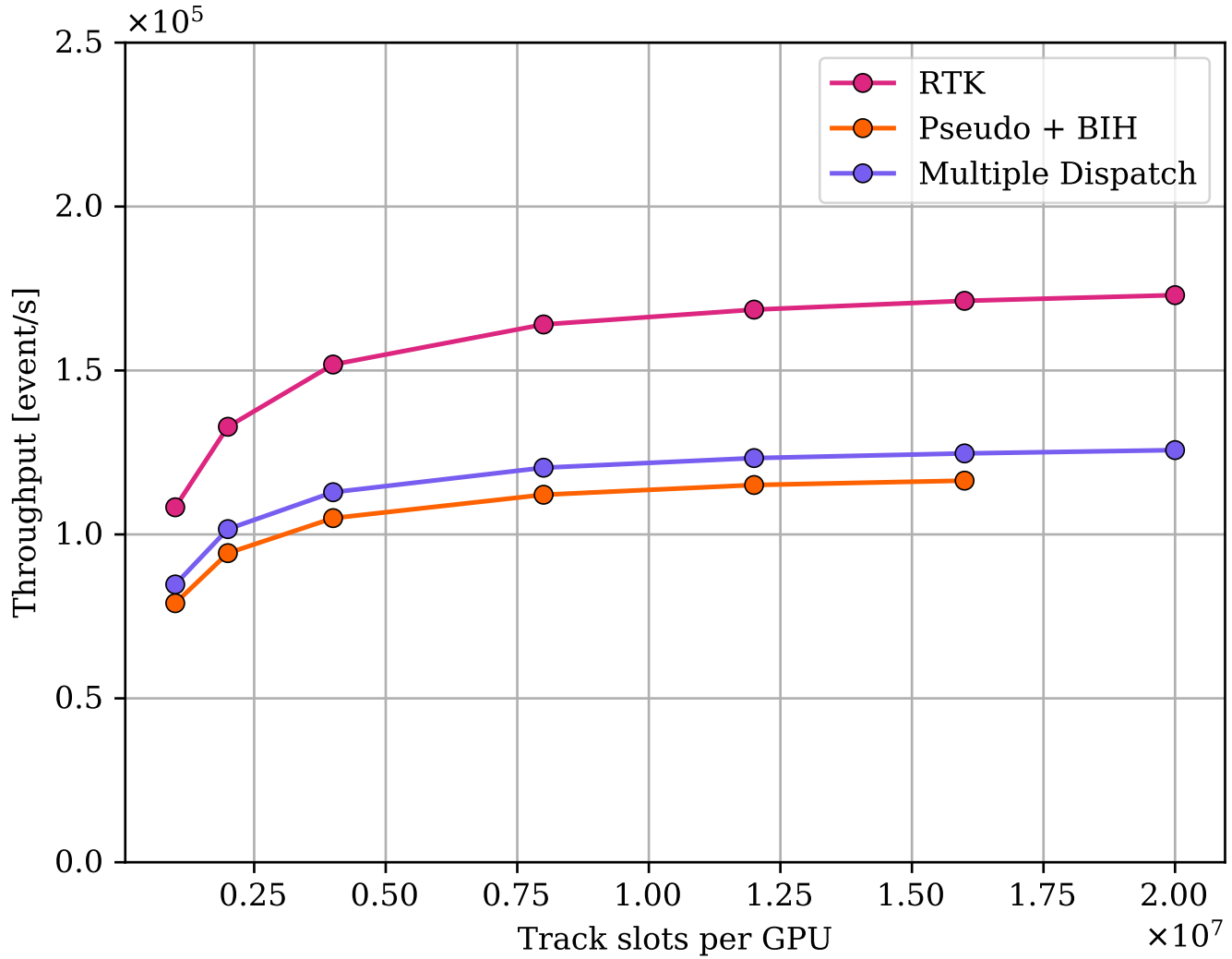
Small Modular Reactor problem

- Array of array of “pin cells”
- Water and uranium
- Neutron-only physics
- Shift MC transport code
  - Frontier (AMD MI250x)
  - Summit (Nvidia V100)

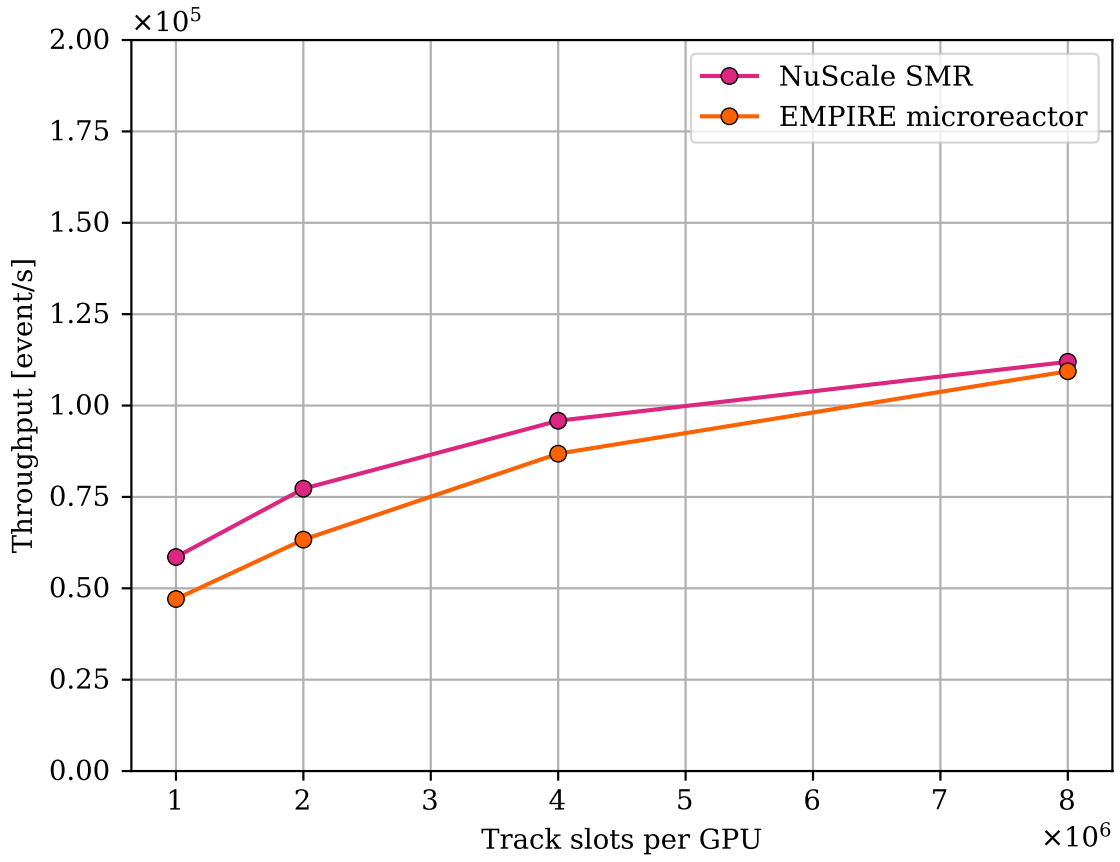


SMR on Frontier (AMD MI250)

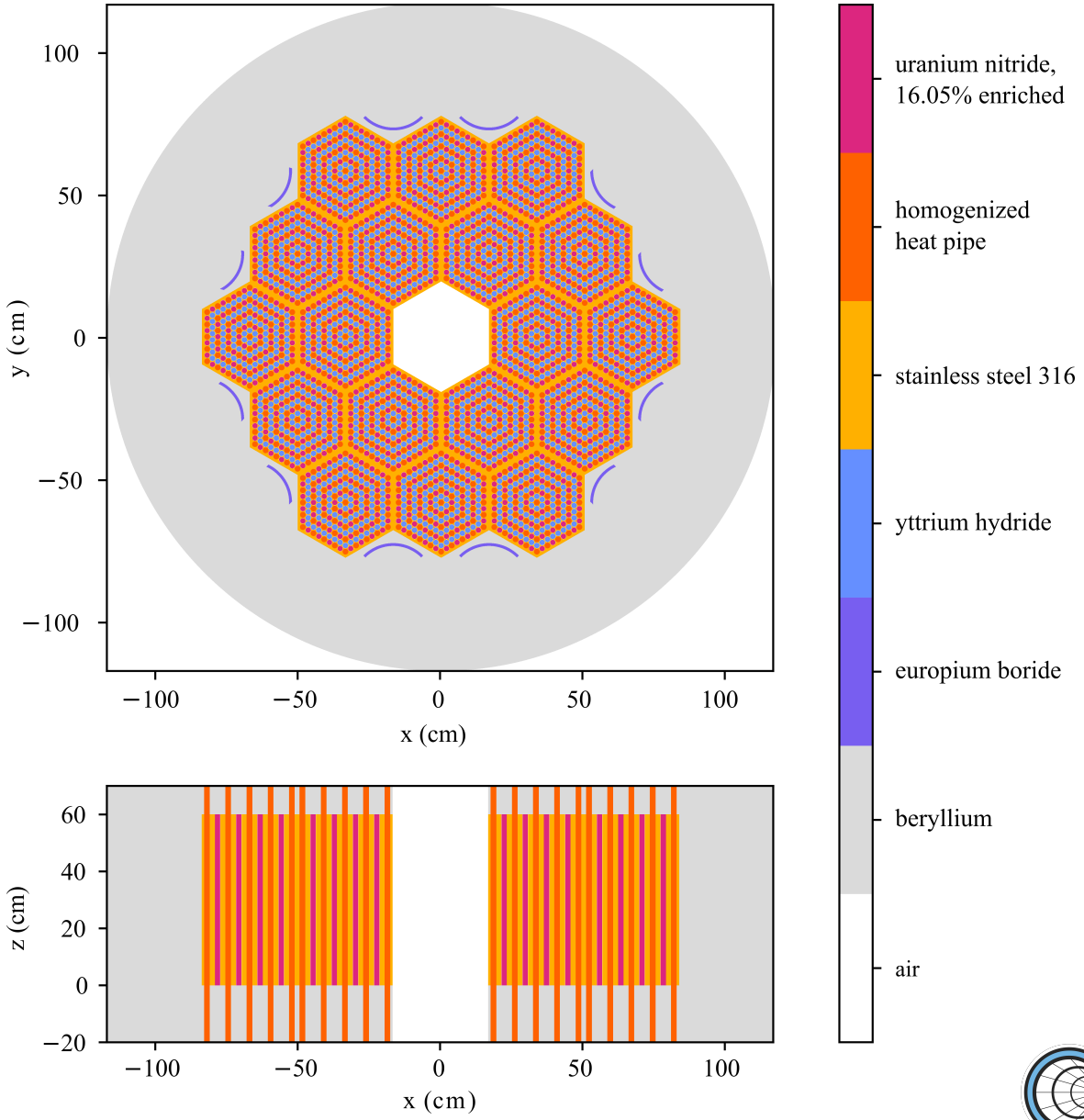
- Template metaprogramming "multiple dispatch" is faster (and more memory efficient) on AMD for this problem
- ORANGE is 30% slower than "reactor toolkit" geometry
  - RTK is highly specialized and extremely limited
  - Highlights performance/functionality tradeoff



EMPIRE: advanced reactor geometry



Summit (Nvidia V100 GPU)



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Optimization

- Comparisons between templated dispatch vs expanded universes
- Deduplication of local logic definitions to reduce memory bandwidth
- Accessing data with `__ldg` to improve caching
- Intersecting quadric surfaces with volume bounding boxes to precalculate “surface segment” BIH for surface intercept acceleration

Detector geometry support

- Convex solids defined, all surfaces but toroid implemented
- Limited conglomerate/partial shapes (no polycone)
- Tracking simultaneously at multiple levels currently required
- Extremely limited safety calculation
  - Vecgeom 1.x safety calculation so expensive it actually *slows down* field propagation
  - Can limited-distance surface intercepts (especially using BIH) be fast enough that we don't need safety during field propagation?
  - Can we replace MSC range limiting with rejection, modification to the true path, ...?
  - Is there an efficient alternative to the Geant4 approximation of skipping MSC if the slowing down range is much less than safety?

Acknowledgments

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https://github.com/celeritas-project/celeritas