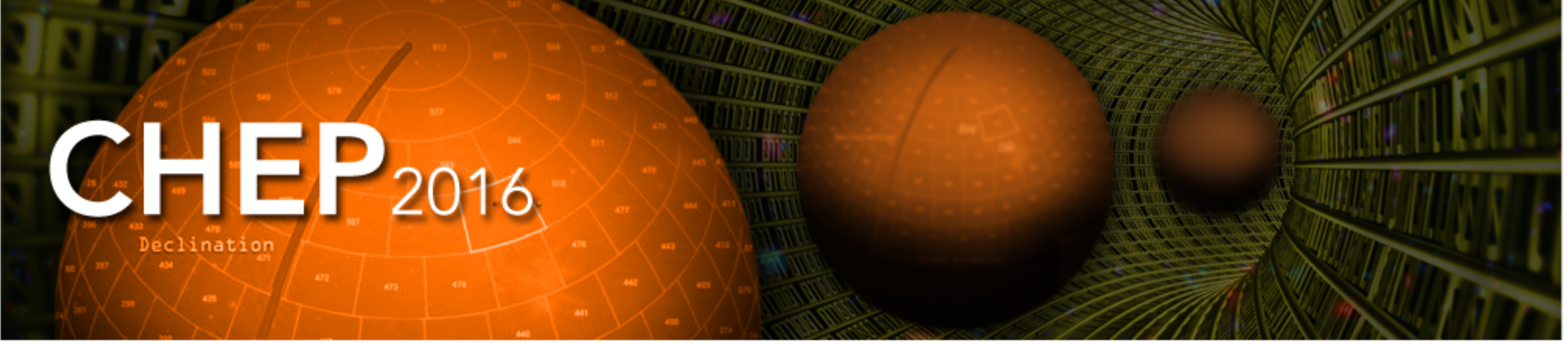

22nd International Conference on Computing in High Energy and Nuclear Physics, Hosted by SLAC and LBNL, Fall 2016

Accelerating Navigation in the VecGeom Geometry Library

Sandro Wenzel / CERN
with Yang Zhang / KIT
for the VecGeom developers

CHEP16@San Francisco
12.10.2016

"Offer geometry library with API for vector transport in Geant-V
… targeting use of SIMD from ground up"

"Effort to improve speed, algorithms, code, maintenance burden, …" of geometry code for the benefit of Geant4 / TGeo…"

VecGeom = Geometry Primitives (USolids)

+ Geometry Model / Navigation

+ Many-Particle API

gitlab.cern.ch/VecGeom/VecGeom

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AIDA 2020

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The VecGeom Project

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Focus of previous development …

Today: Acceleration the navigation module

- Explicit SIMD vectorization
- navigator code specialization
- Focus on one-particle features as needed by Geant4 !!

gitlab.cern.ch/VecGeom/VecGeom

Shape-Primitives Status: The ALICE Use-Case

- VecGeom now has all shape-primitives to satisfy needs of most HEP experiments (Xtruded added recently)
- For ALICE simulations (Pb-Pb), demonstrate that VecGeom offers very significant performance gains for the most CPU relevant shape-primitives

Primitive	Safety	Dist2In	Dist2Out	Contains	CPU% Sum
Pgon	2.05	2.52	0.18	1.18	**5.93**
Xtru	0.56	0.68	0.20	1.81	**3.25**
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% of CPU cost of shape primitives (TGeo) in typical ALICE Pb-Pb simulation

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up to **9x faster** than existing code

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- Depending on experiment, **a few % in CPU simulation cost gainable by switching to VecGeom primitives** (integration effort into G4/TGeo under way)

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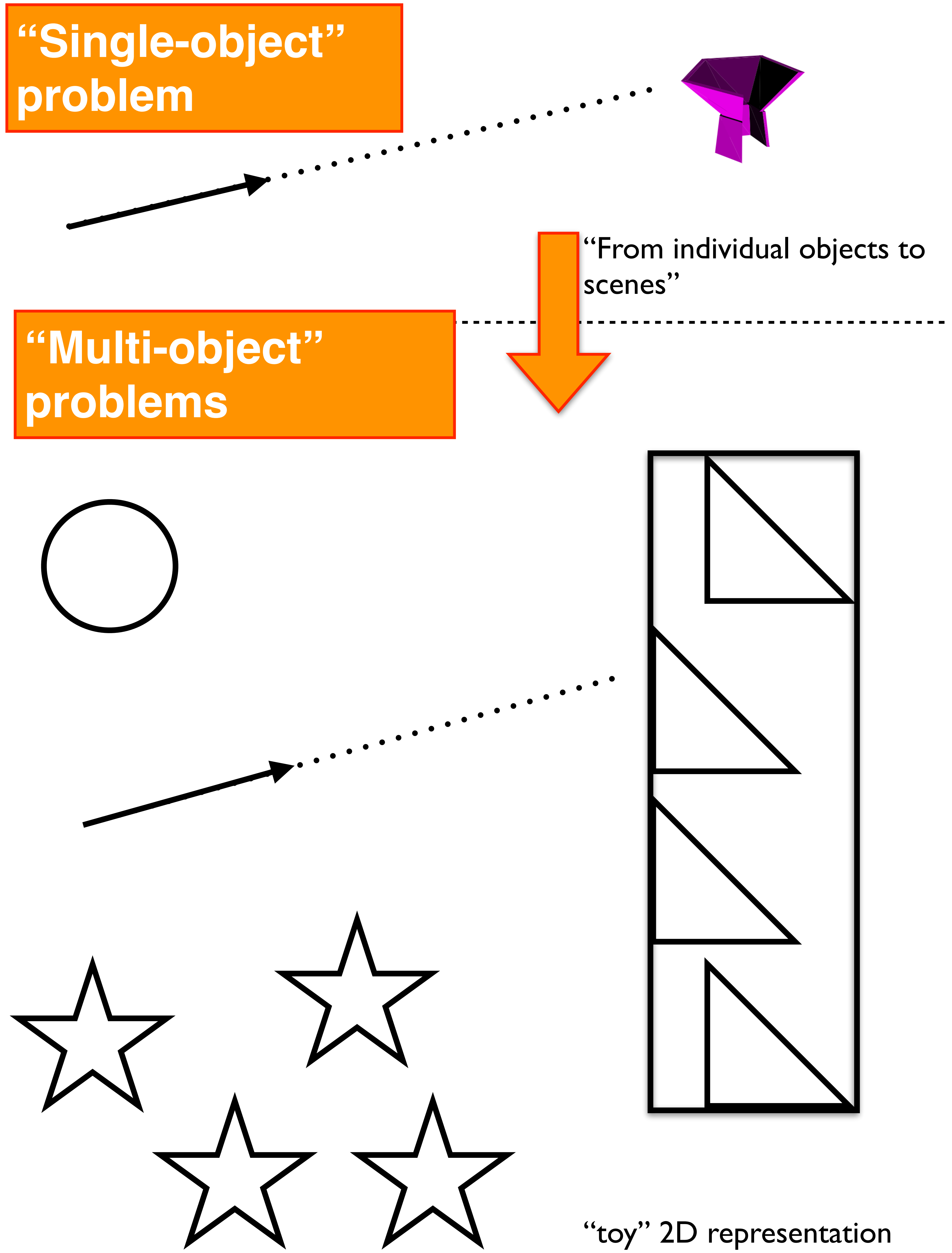
  - provides next colliding object + distance in a "multi-object" scene
  - provide object after the next boundary crossing
  - simulations spend significant time in navigation module (ALICE ~30% with TGeo, similar in CMS, …)



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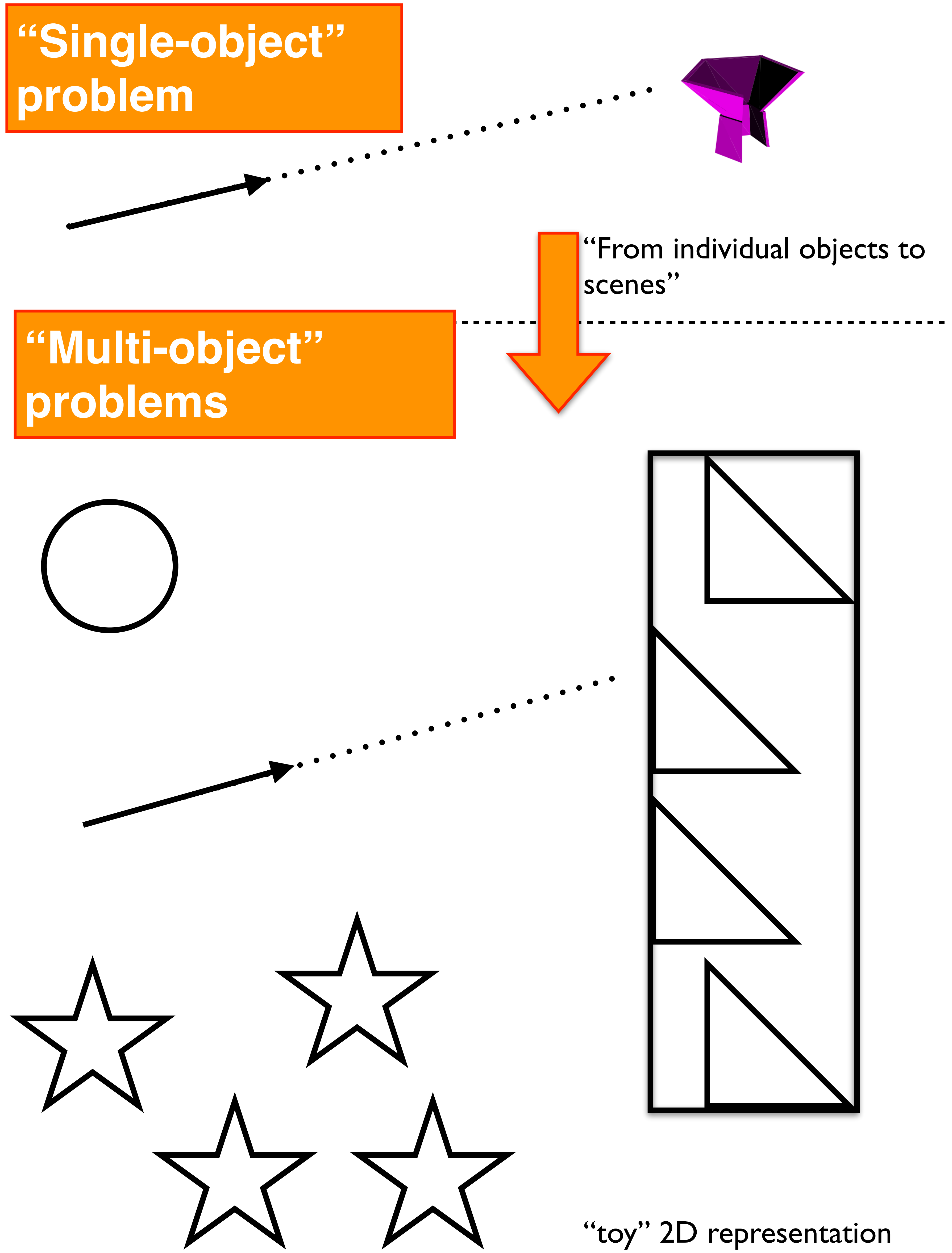
- **Goals / Targets:**
  - Implement navigation system in VecGeom
  - **Implement acceleration structures for fast candidate rule-out (scaling ~log(N) - see voxel techniques of G4/TGeo)**
  - **Target explicit SIMD acceleration**



SIMD Acceleration of „Voxel" Navigation

- Canonical solution for fast hit-detection: tree structures, lookup structures, bounding boxes, …
- **How to combine this with SIMD paradigm?**

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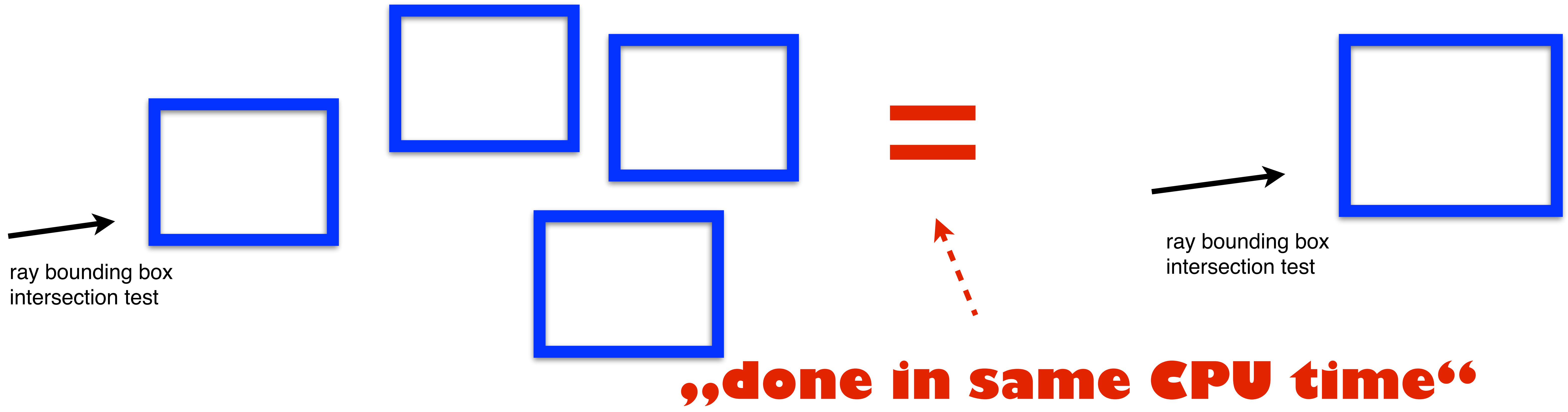

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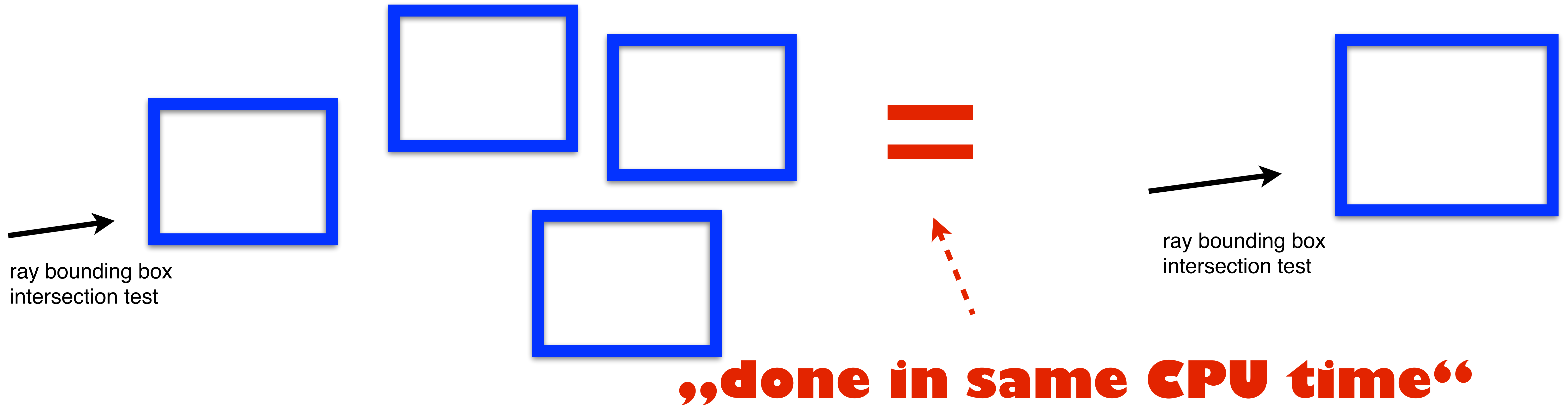


get **SIMD gain** from treating **group of boxes** in parallel

get **scaling** from **hierarchies** of bounding box groups (forming **regular trees**)

Inspired from e.g.: Shallow bounding volume hierarchies for fast SIMD ray tracing of incoherent rays (DOI: 10.1111/j.1467-8659.2008.01261.x) + CPU ray-tracing libraries: Intel Embree, …

Regular Tree Building via Clusterization

- **Basic algorithm:**
  - let S == elements in SIMD register
  - cluster objects into groups of S objects (we use a variation of k-means)
  - identify bounding boxes of grouped objects as daughters of a tree node
  - iterate this process

- Algorithm illustrated here for SSE (= 2 double numbers per register)

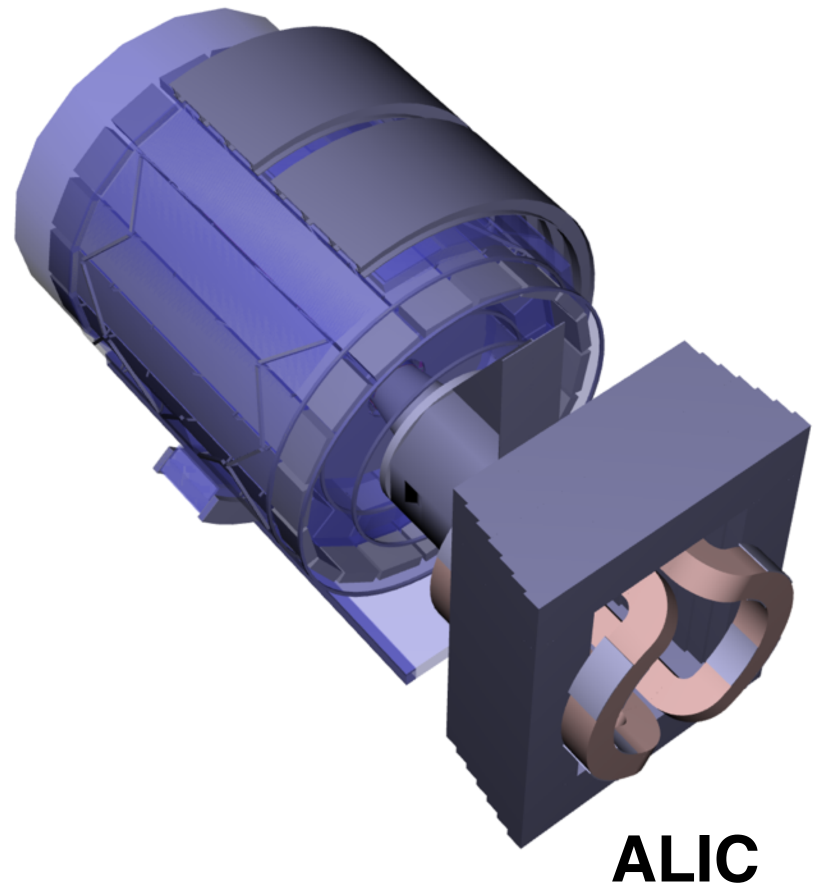
Benchmark SIMD-Trees: Local Benchmark

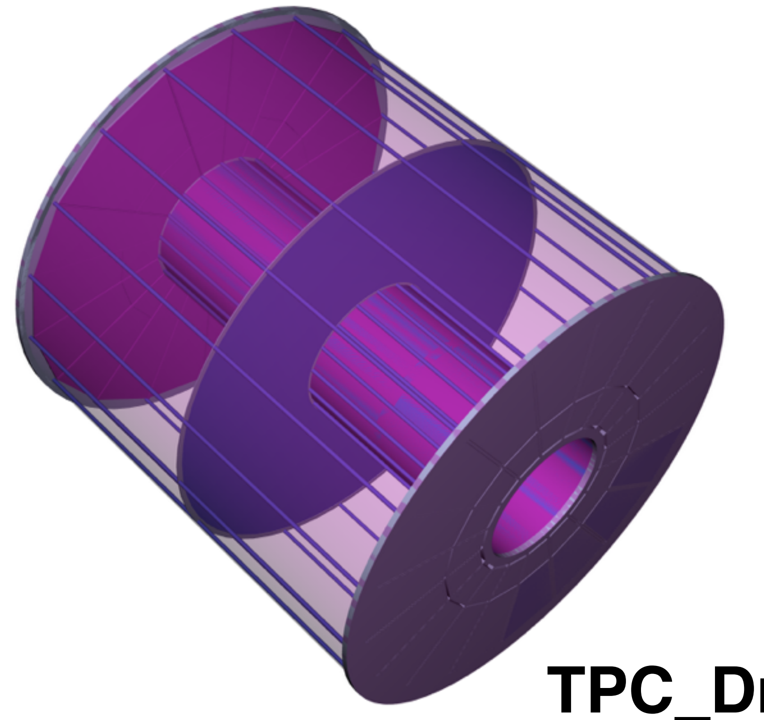
- Test approach on various detector volumes
  - most important complex volumes from ALICE: ALIC + TPC_Drift
  - a complex volume from CMS: MBWheel (~600 daughter volumes)
- Perform local navigation benchmark*: One step + boundary crossing in the given volume for 0.5 million different tracks

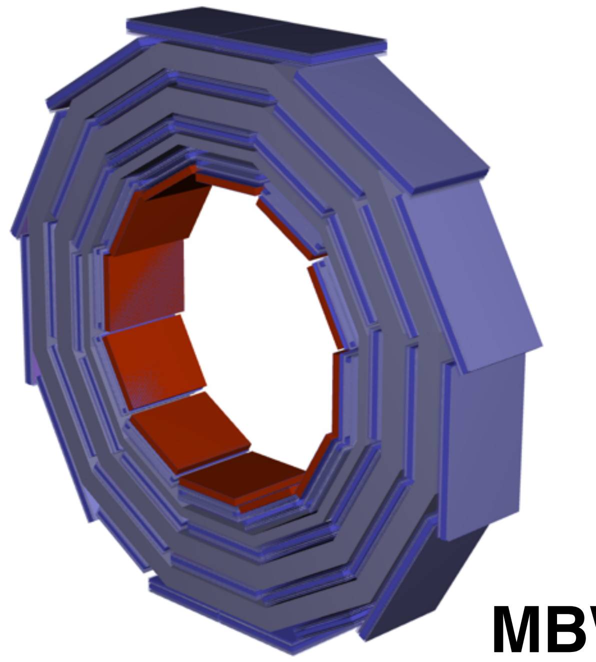
Volume	Daughters	G4	TGeo	VecGeom (SSE4.2)	VecGeom (AVX2)
ALIC (ALICE)	65	0.74	1.07	0.30	0.23
TPC_Drift (ALICE)	641	14	2.2	1.2	0.9
MBWheel (CMS)	~600	0.84	1.09	0.49	0.35

numbers are time in seconds; **worst is red**; **best is blue**

- Demonstrating **overall speedup >2x in navigation** compared to existing solutions
- Demonstrating **gain from SIMD vector unit** (see change SSE4.2 to AVX2)





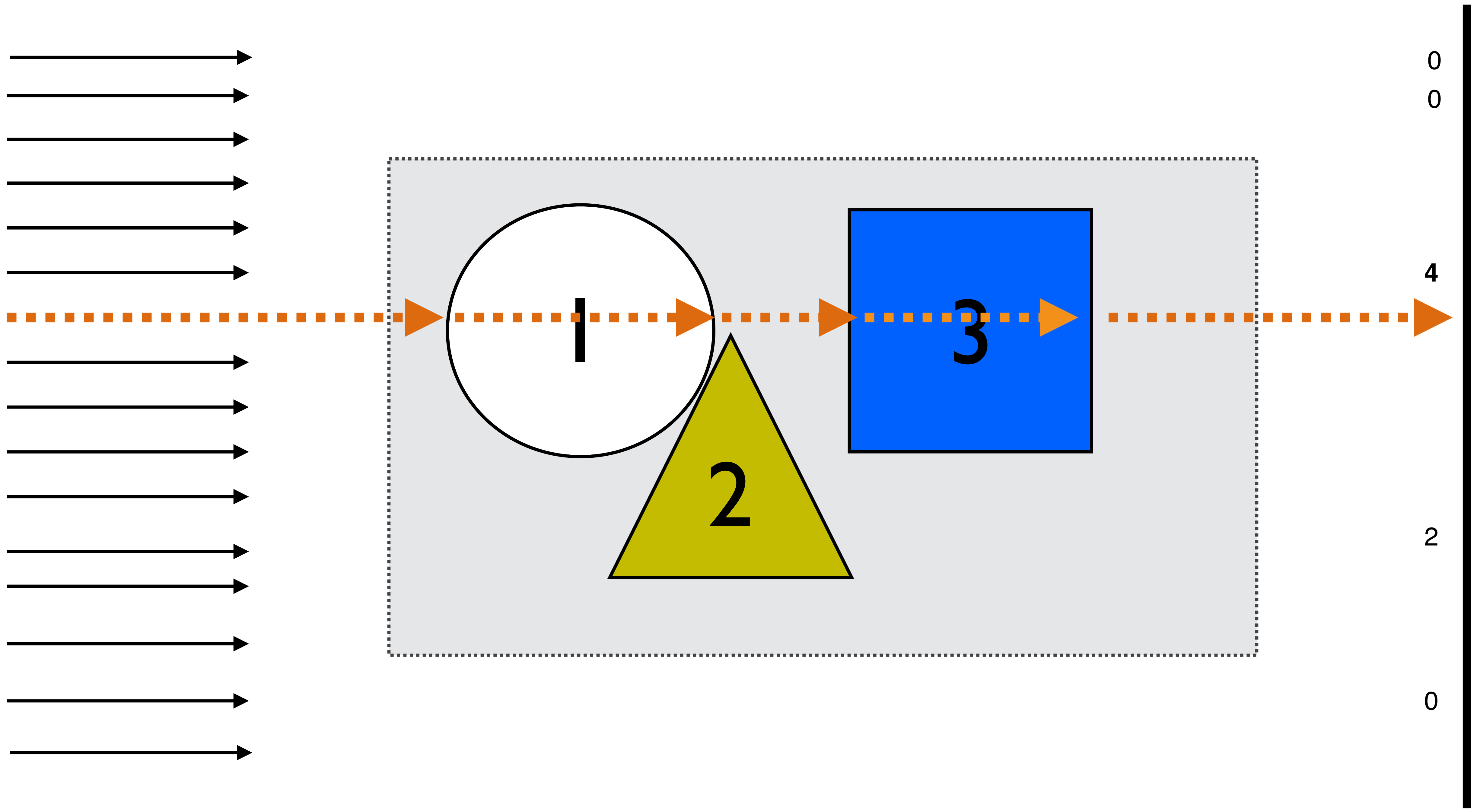


*All packages used in standard release mode without particular tuning

Testing VecGeom in "Toy" Simulations

- **Evaluate VecGeom** (solids + navigation) on complex modules for **multiple steps**

- **"XRayBenchmarker" test**:
  - follow geantinos through geometry - pixel by pixel
  - record some information on screen behind object
  - do same with G4 / TGeo

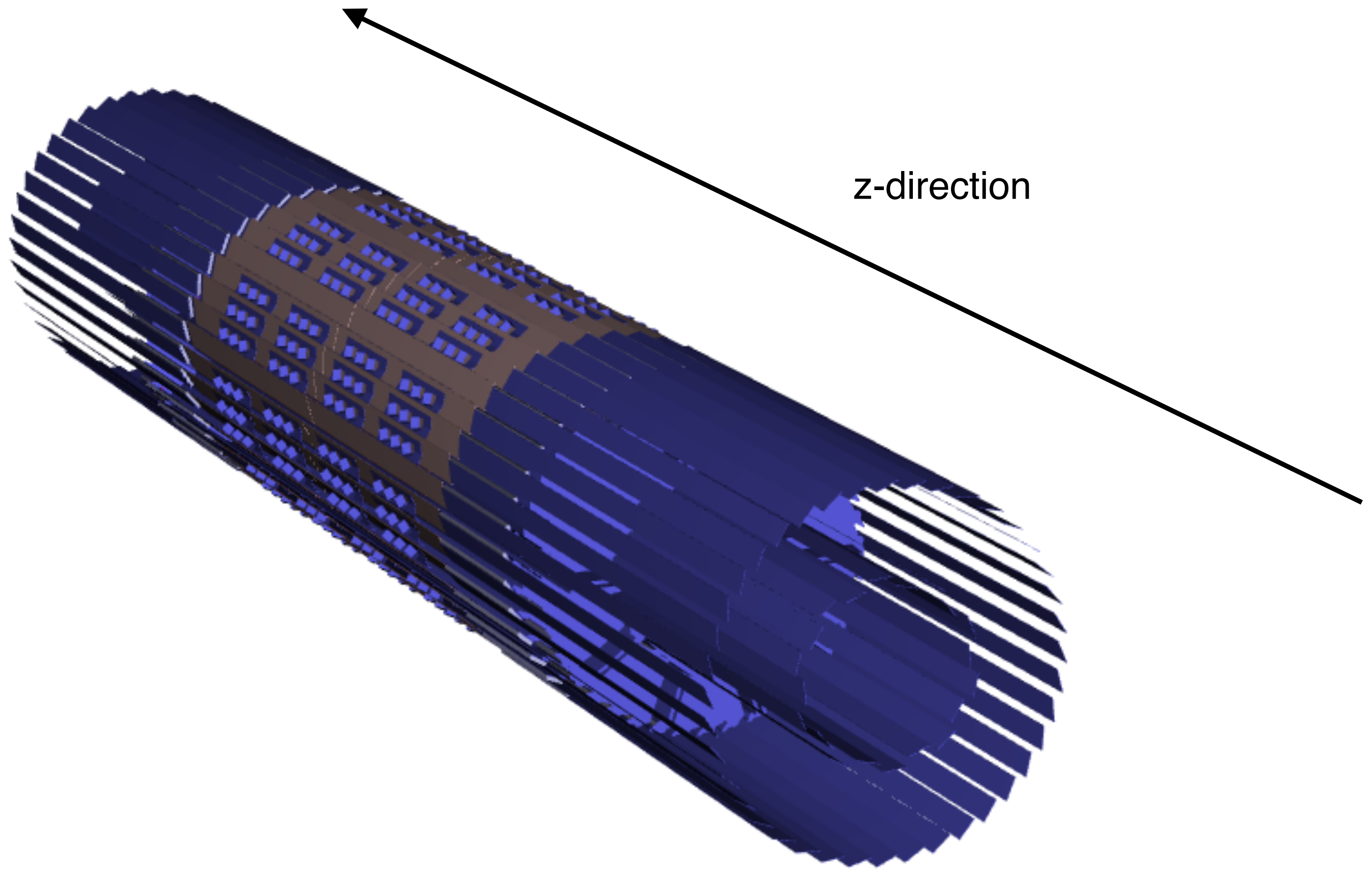


screen; **pixel** records some scalar tracking information (number of boundaries crossed) and can be converted to an image

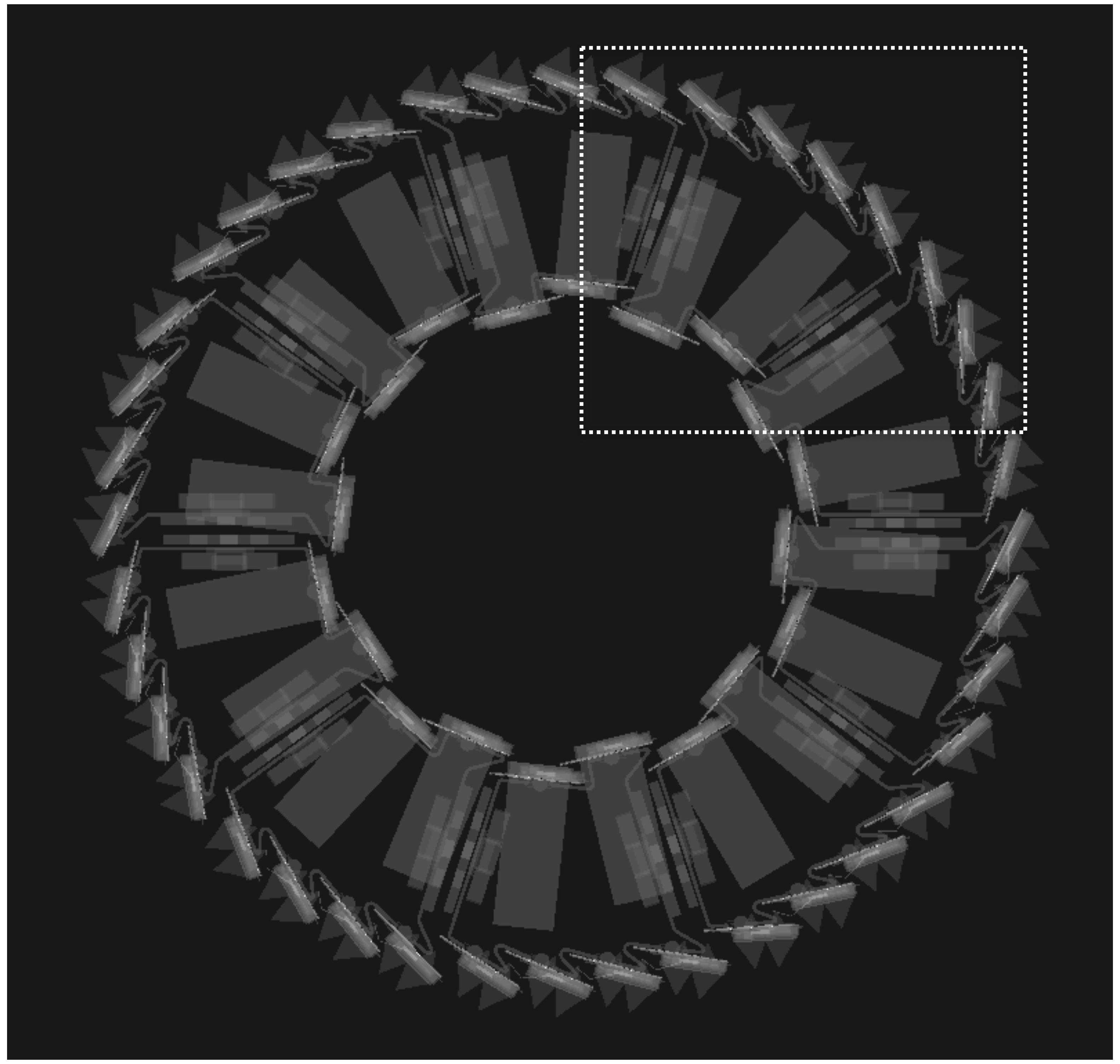
- **perfect** for **validation** of navigation algorithms

- good to get a **global idea of library performance**

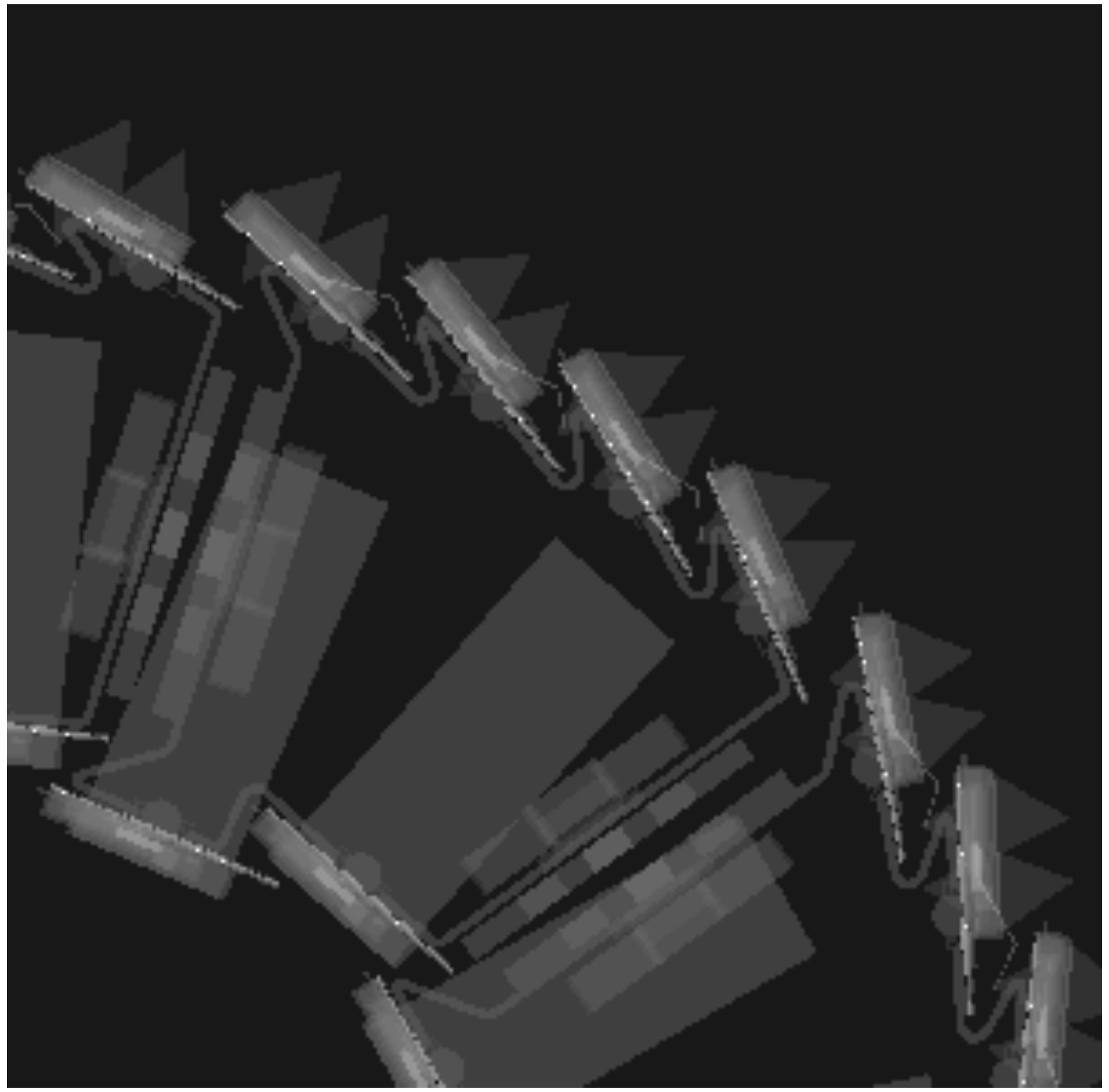
Geantino-XRay: Global Performance



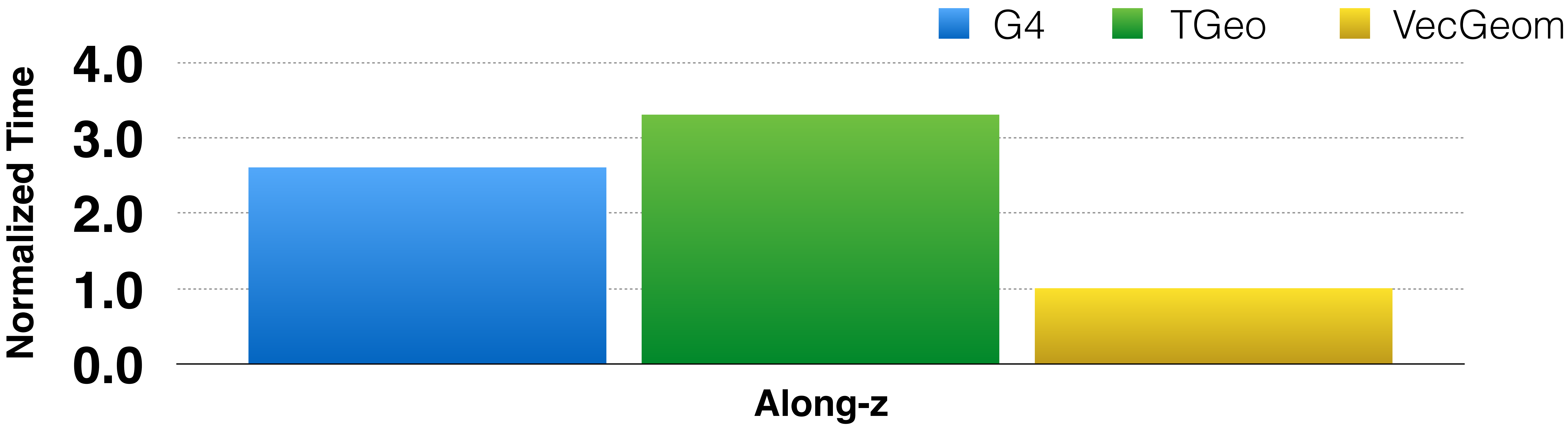
view along z-direction



zoom



- Example for ALICE ITSSPD module
- Perfect agreement between G4/ TGeo/VecGeom
- Observe generally **factors > 2.6x** speed improvement against other packages
- Another indication of global performance advantage of VecGeom



“Production” … to current R&D

Further R&D in Navigation Optimization

- VecGeom offers faster navigation compared to G4/TGeo!! … **Can we do more? (other than different acceleration structures)?**

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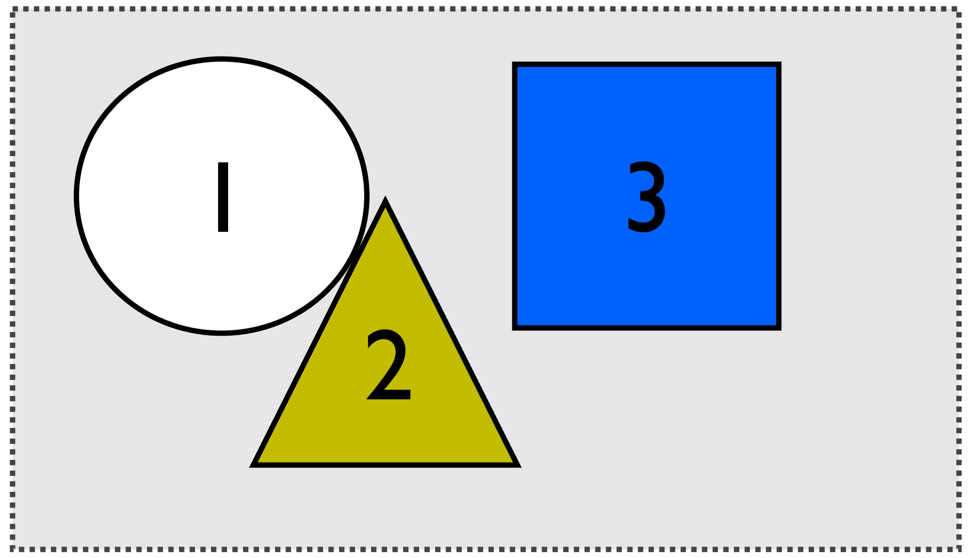
  - etc…



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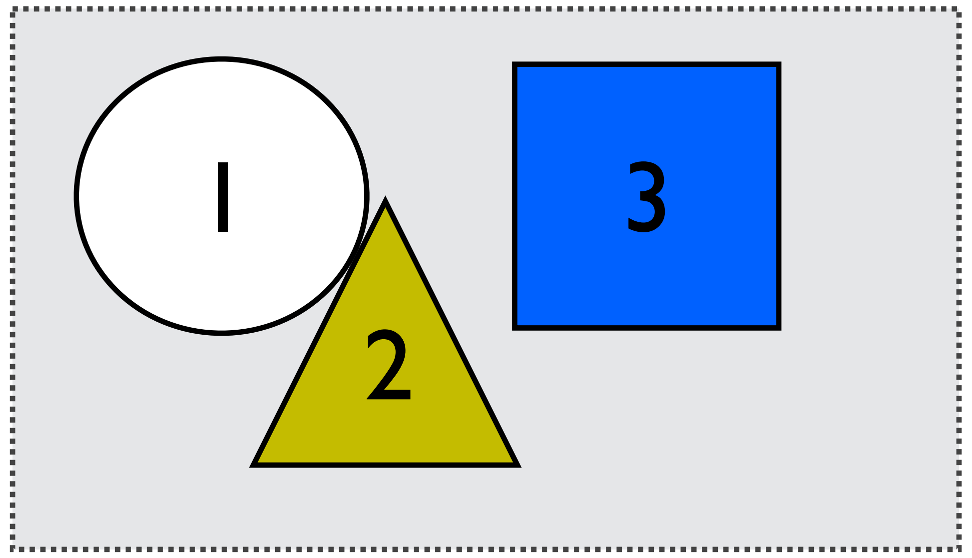

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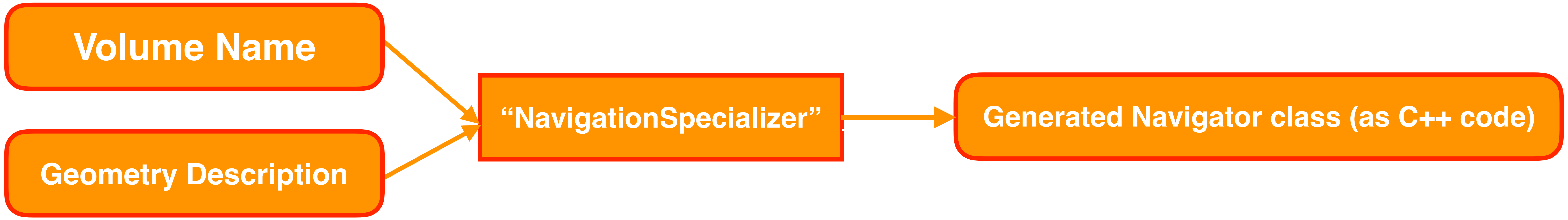
- HEP detectors are pretty static objects; most things are known at compile time or constant during (long) run-time
- Opportunity to pre-analyse + pre-compute + compile-time optimize
- **R&D goal:** Exploit these opportunities via **volume-specialized navigator algorithms** produced via automatic C++ code generation

- A prototype service to generate volume-specialized navigator algorithms has been implemented
  - considerably reduced virtual functions
  - reduce time spent in coordinate transformation (via compile-time lookup structures)
  - put static neighbourhood information for fast relocation



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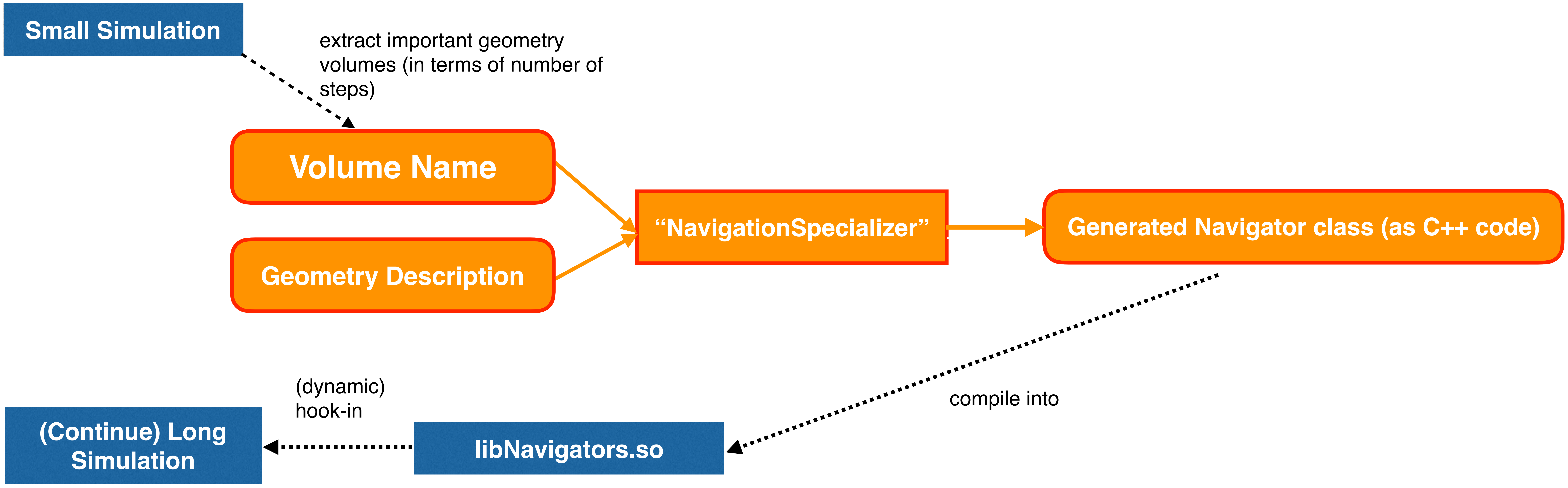
- Can be embedded into a (JIT) workflow of a simulation



Specialized Navigator Improvement: Benchmark examples

- Extracted important ("showering") volumes (in terms of number of steps) in an ALICE Pb-Pb simulation

- Measure time to perform a "step" in these volumes

PRELIMINARY !!

Volume	G4	TGeo	VecGeom General	VecGeom Specialized	EXTRA SPEEDUP
ZNST	0.24	0.28	0.10	0.06	1.67
ZPST	0.25	0.29	0.11	0.06	1.83
DCML	0.24	0.28	0.12	0.06	2.00
voRBCuTube	0.16	0.24	0.10	0.06	1.67
ZNGx	0.09	0.18	0.06	0.03	2.00
AFaGraphiteCone	0.74	0.36	0.11	0.03	3.67

numbers are time in seconds; **worst is red**; **best is blue**

- Navigator specialization delivers extra speedup kick; making gain compared to G4/TGeo even more significant

- In context of Geant-V: This technique reduces the non-vectorizable parts of navigation and makes multi-particle SIMD gains possible or more efficient.

Summary

- Presented advances in navigation module of VecGeom
- **Have (first) SIMD enabled navigation acceleration structures in production**:
  - Shown to generally outperforming existing solutions in Geant4/TGeo
- Showed **an avenue** to further improve navigation performance
  - By automatic navigator code specialization (R&D prototype status)
  - Lot's of work to be done…

"VecGeom navigation is more than an interesting alternative to Geant4/TGeo navigation and could be beneficial to simulation frameworks **NOW**"

Backup section

Miscellaneous Information

- SIMD Vectorization
  - Achieved via exlicit SIMD programming using C++ wrapping libraries such as Vc, UMESIMD, …
  - Using our abstraction layer "VecCore"
- Navigation System
  - In contrast to G4/TGeo; VecGeom navigator classes are state-less, facilitating easy use for multi-threading and multi-particle queries
  - Navigation state is carried in separate classes which become part of a track - property
- (Preliminary) Impact of VecGeom for Geant-V
  - VecGeom is used as one of the native navigation system in Geant-V (the other being TGeo)
  - VecGeom reduces overall simulation memory consumption over TGeo by factors > 2
  - measuring a "simulation speed gain" over TGeo by factors > ~2
- Benchmark setup:
  - All benchmarks presented here were run with tag "W40-16" of VecGeom
  - Benchmark machine: Intel(R)-Core(TM) i7-5930K running CERN CC7
  - compiler gcc4.8.5
  - Vc 1.2.0 backend with native (=AVX2) instruction set (unless otherwise specified)