GeantV: Parallelization for the future of particle transport simulations

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Plan of Attack

- What does our detector simulation software look like now? (Event-level parallelism, scalar processing)

- Where do we want to be? (Track-level parallelism, multi-particle processing (SIMD))

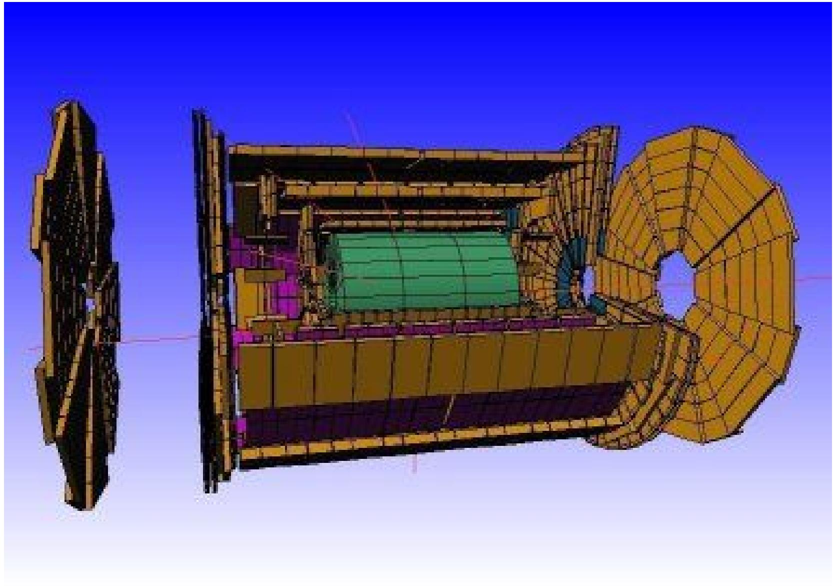
- What have I done to help us get there? (GeantV Calorimeter Application)

Background: What is Geant4?

- C++-based toolkit used to simulate the passage of particles through matter

- Geant4 is the dominant full detector simulation program in HEP and has been for years

- Initial release was in 1998, replacing Fortran-based Geant3

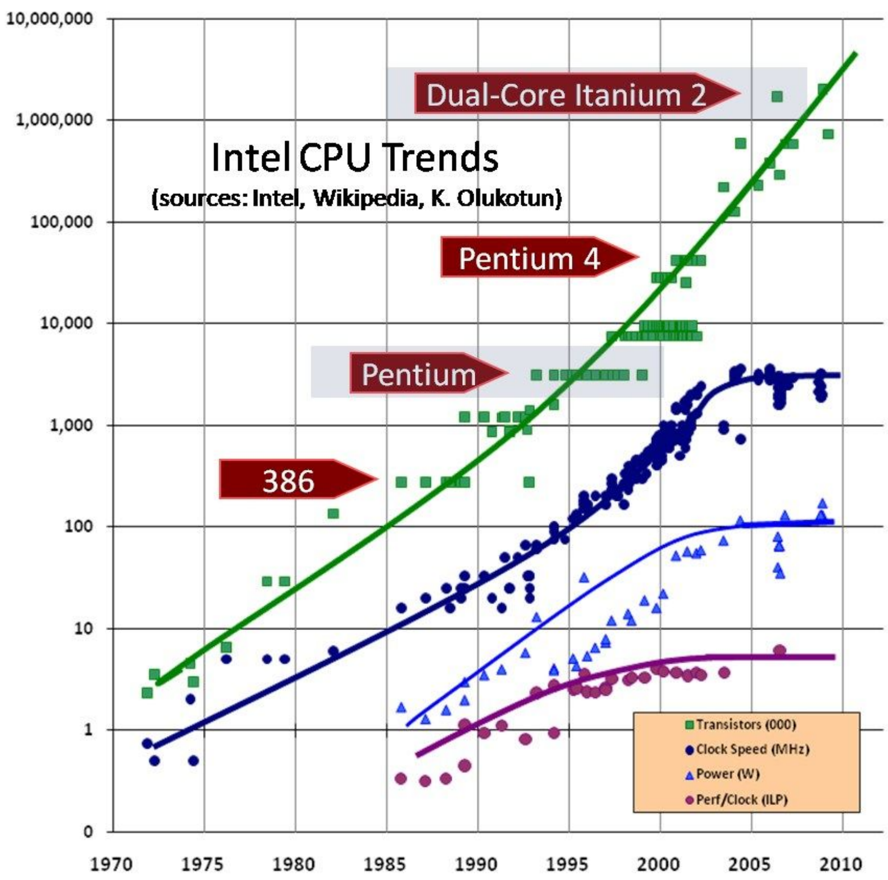


Geant4 picture gallery -- ATLAS Detector

What’s the problem?

- Problem: Geant4 can't use processor cores efficiently (event-level vs. track level)
  - It can't be easily restructured to include this support

- Computers of the future will not have higher CPU speeds; they will have more cores



From GeantV Community Meeting, 10/2016

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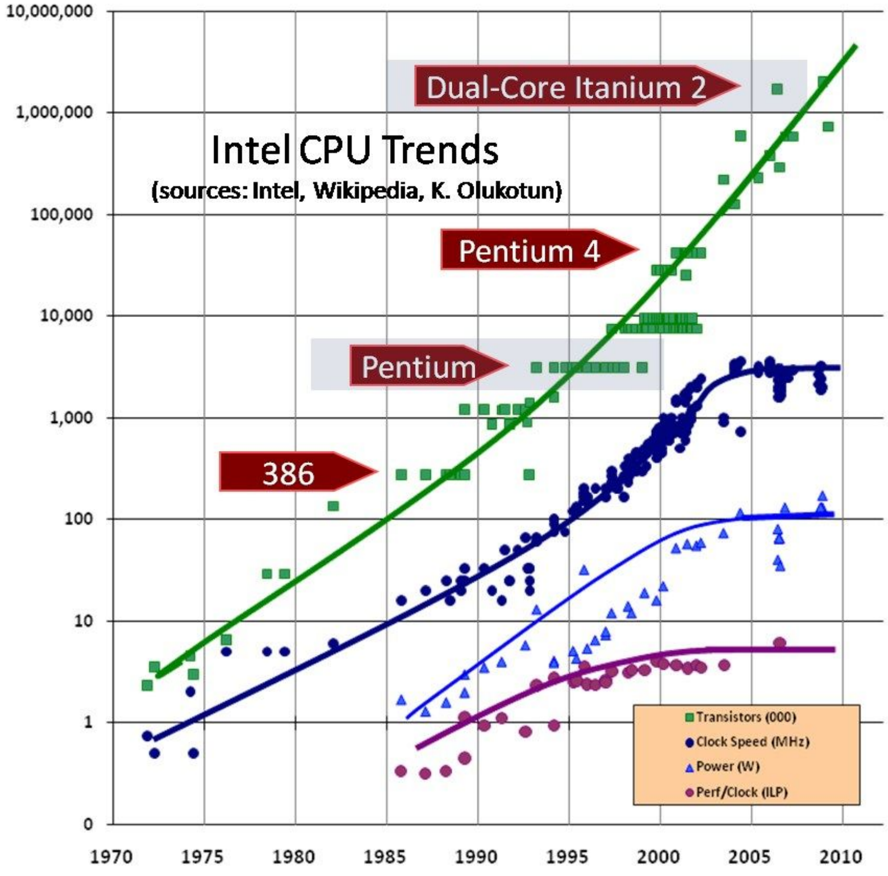
- Particle transport simulation is a natural application for parallel processing



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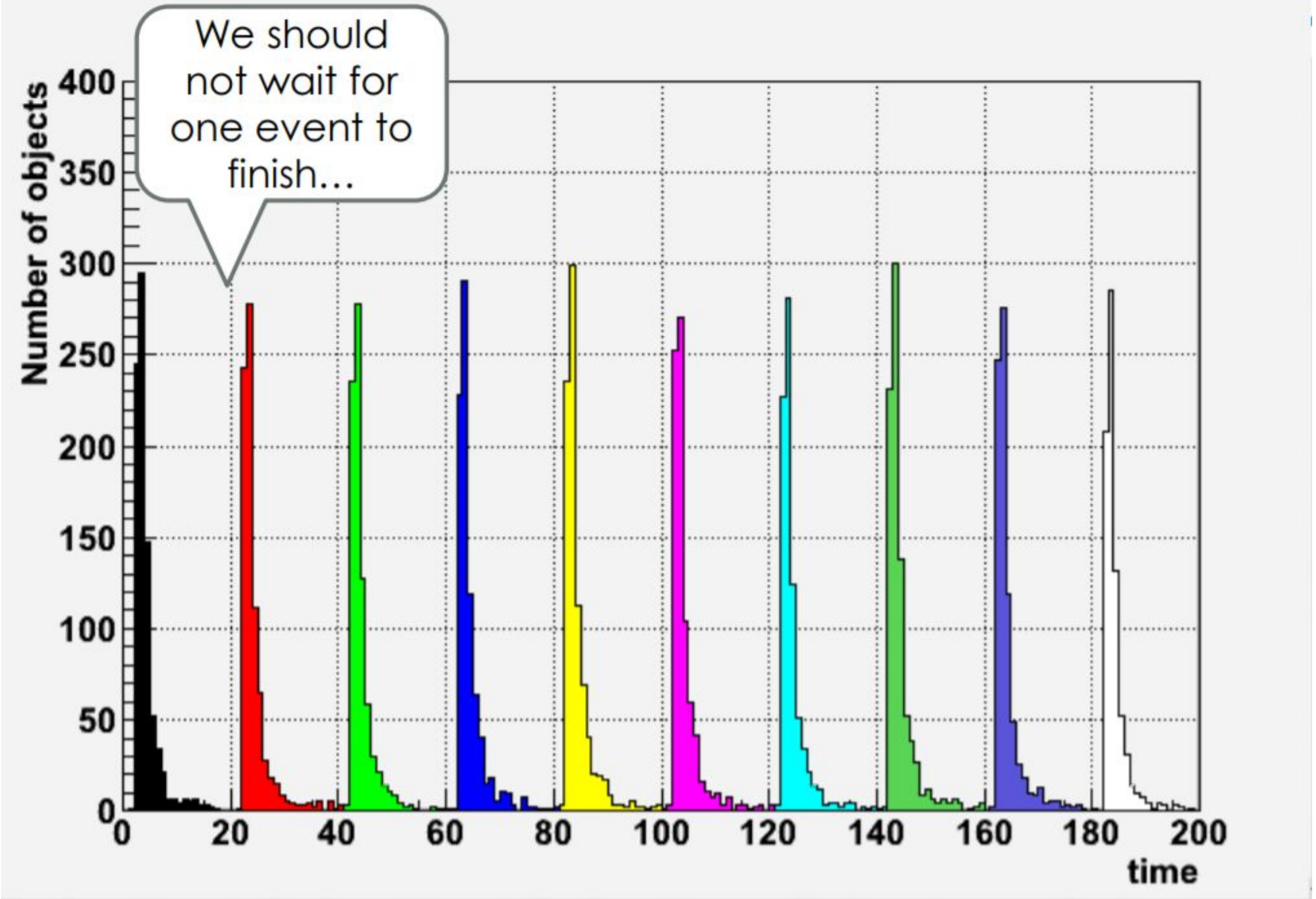
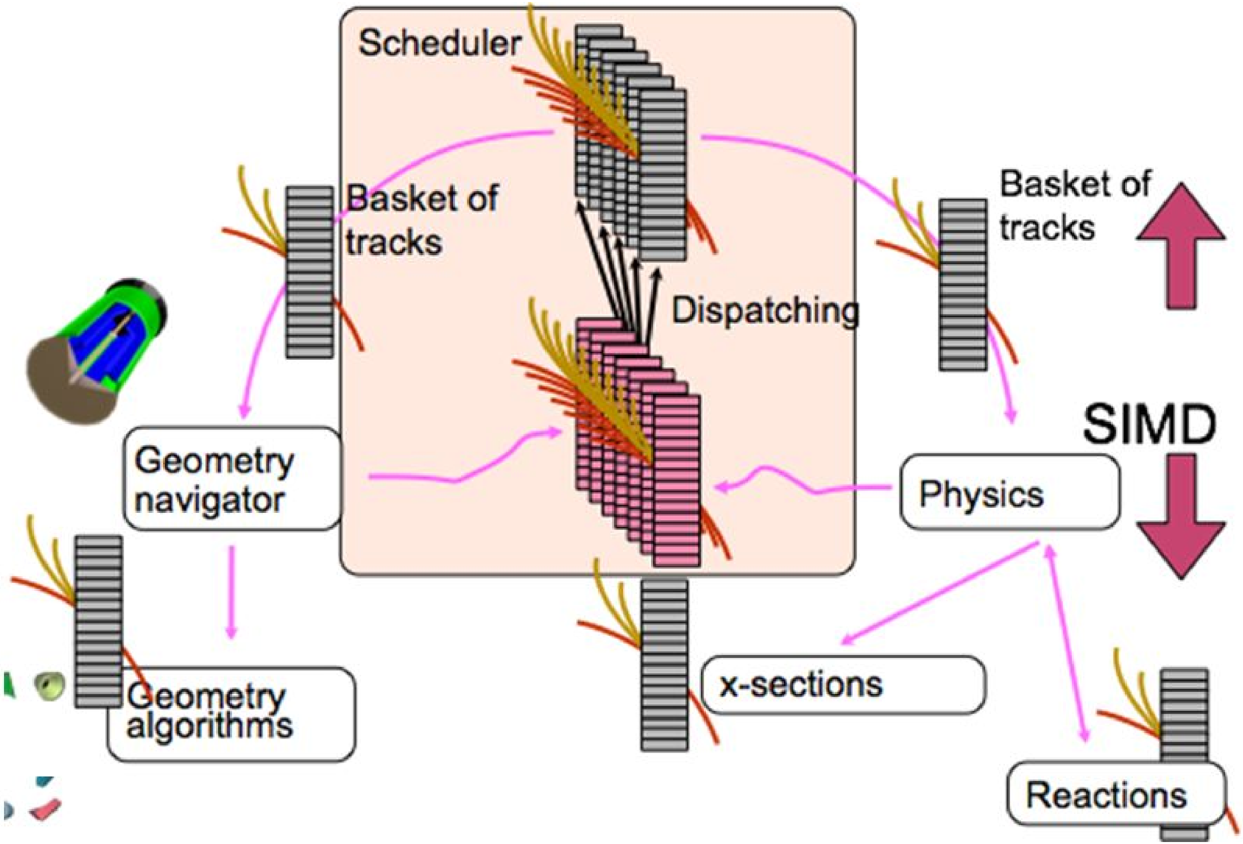
Particle Transport is a Natural Fit for Parallelization



CHEP 2012, New York, Re-thinking Particle Transport in the Many-Core Era

GeantV Structure



Intel Talk by A. Gheata, Feb. 28 2017

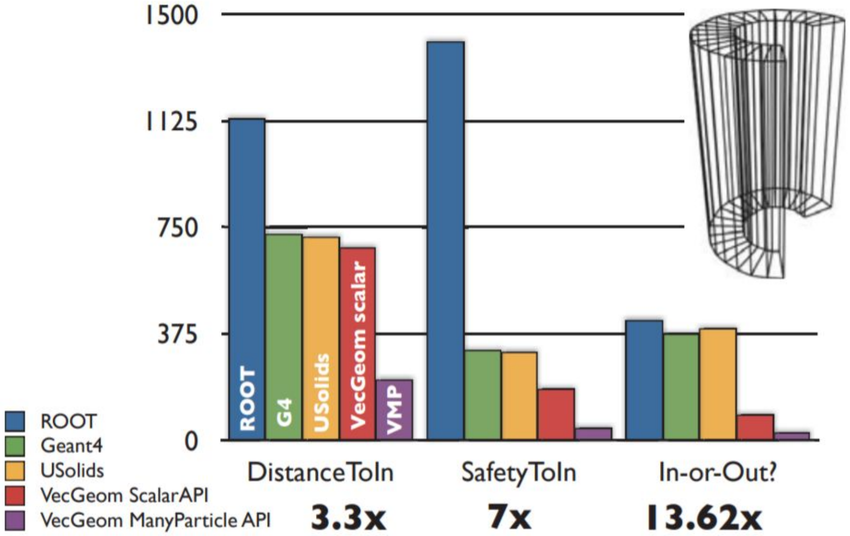
Geant V Speedup Potential

Current performance targets: **3x to 5x increase** (moving towards 10x or more in the long term)

Certain vectorized components already show an **order-of-magnitude** improvement over Geant4 (VecGeom)

Some full applications currently yield up to 5x speedup

- e..g. CMS application yields 3-5x speedup even when running in single-threaded mode
- More development must occur to achieve consistent speed gains



Above: CPU time required for three essential geometry navigation algorithms

2015 J. Phys.: Conf. Ser. 608 012023

Project status: Early June

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Incident Particles

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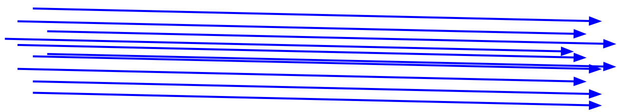
- Energy
- Direction



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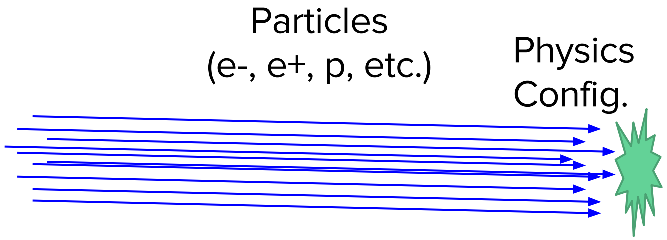

Physics configuration

- Physics list
- Production cuts

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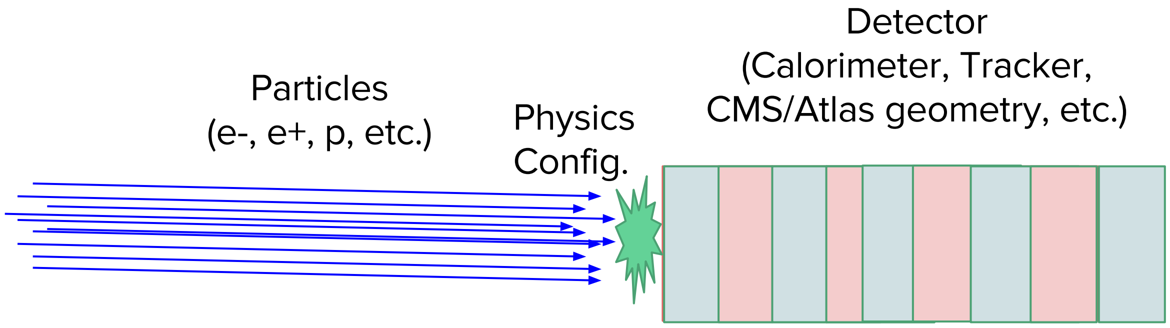

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Detector
- Materials
- Geometry

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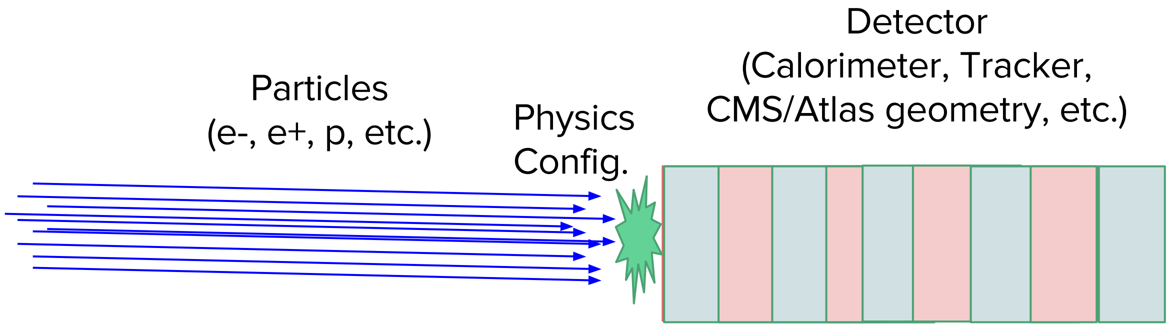

Physics configuration

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Detector

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- Geometry

GeantV wasn't defining this itself!
(circa June 2017)

June Workflow: Defining and testing a calorimeter

Define calorimeter parameters

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Define calorimeter parameters → Create geometry in Geant4

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Define calorimeter parameters → Create geometry in Geant4 → Export geometry to ROOT

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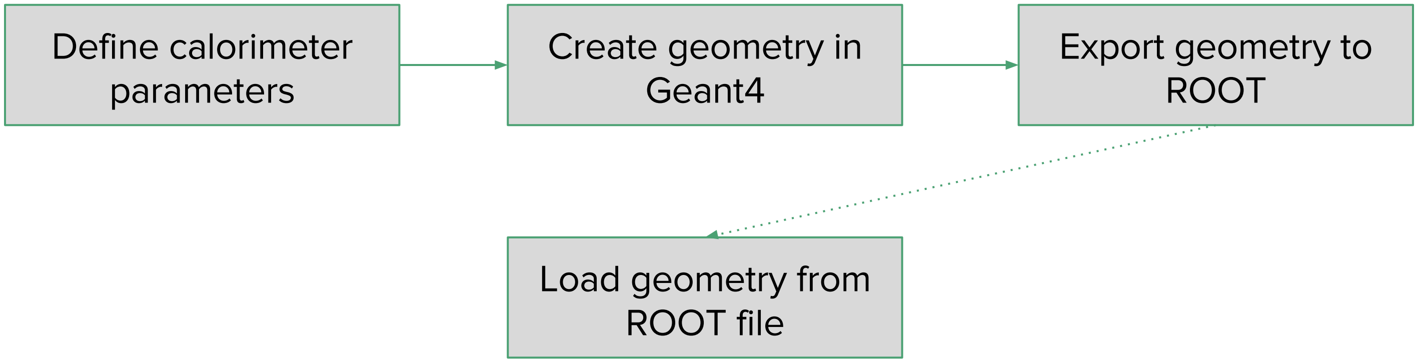

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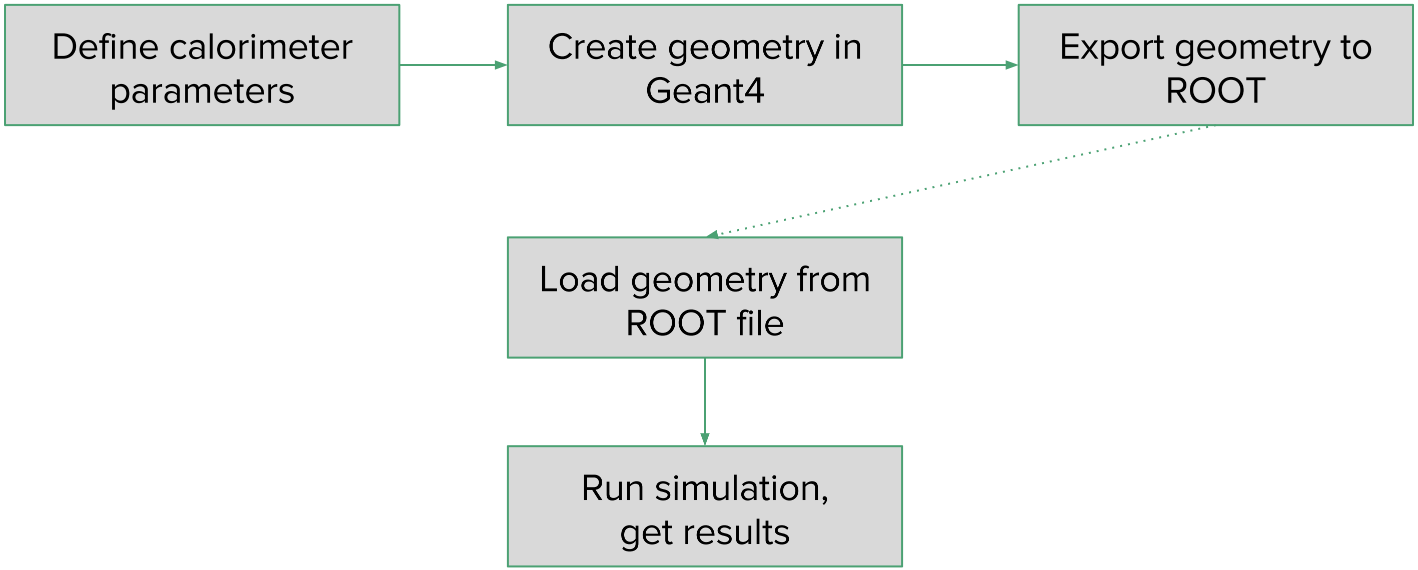

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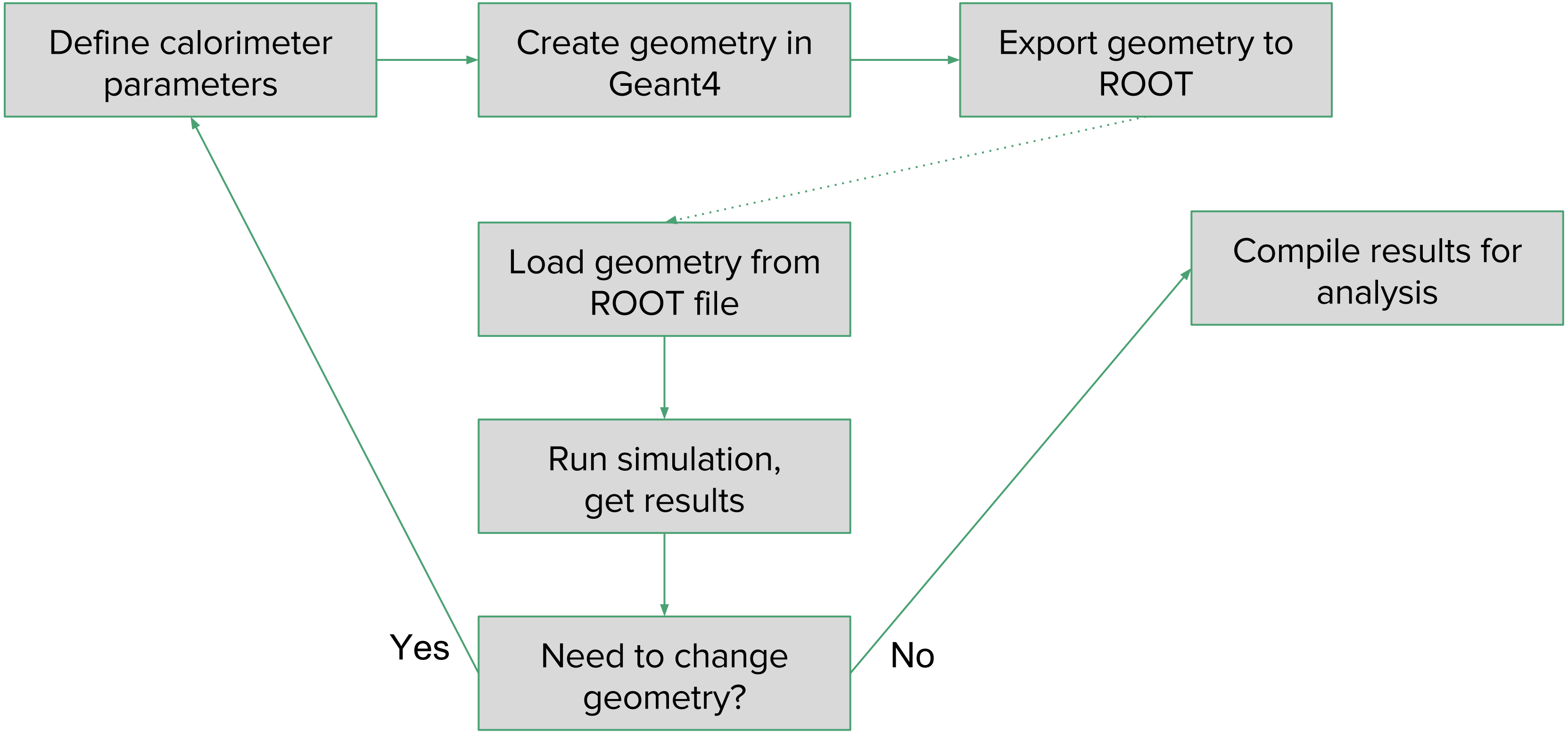

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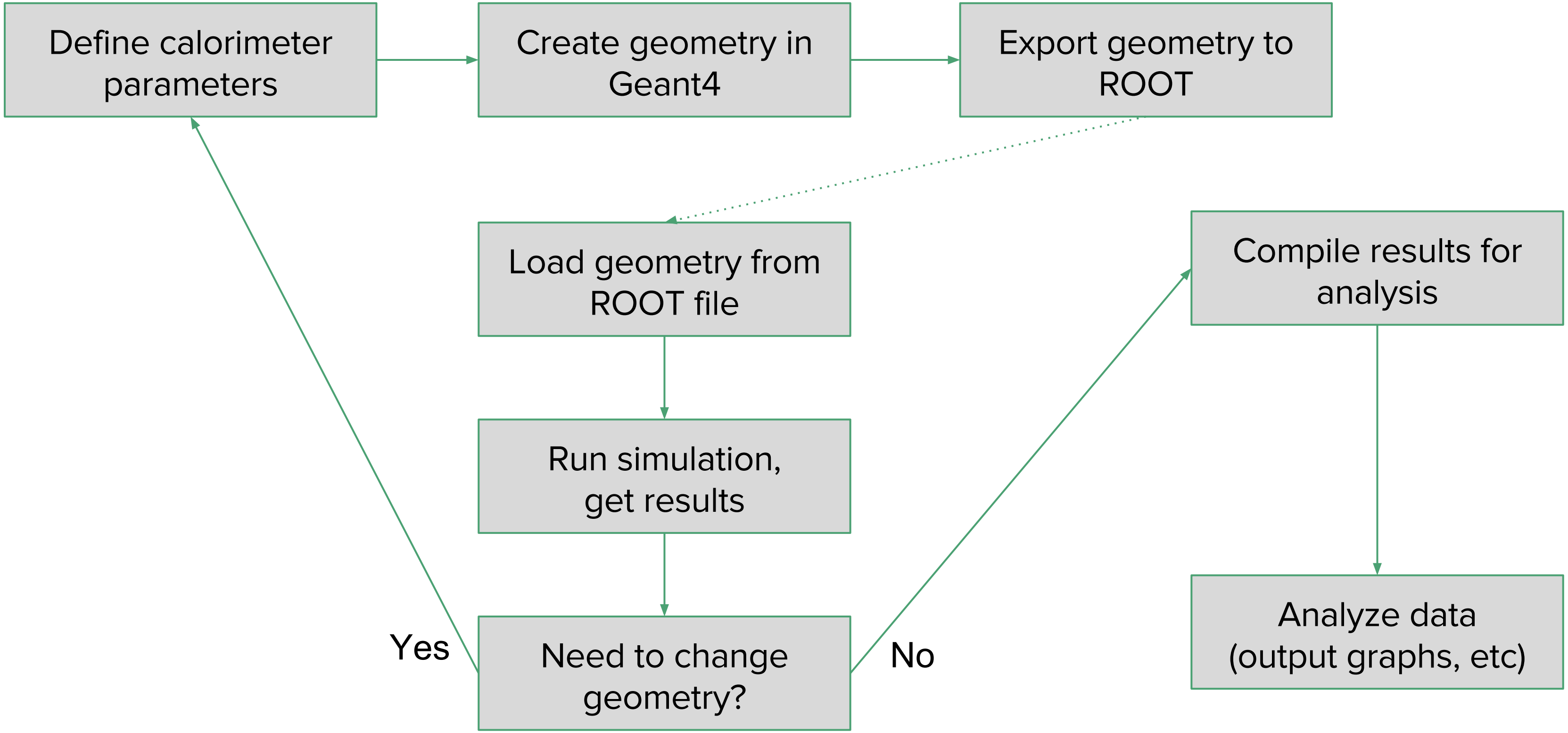

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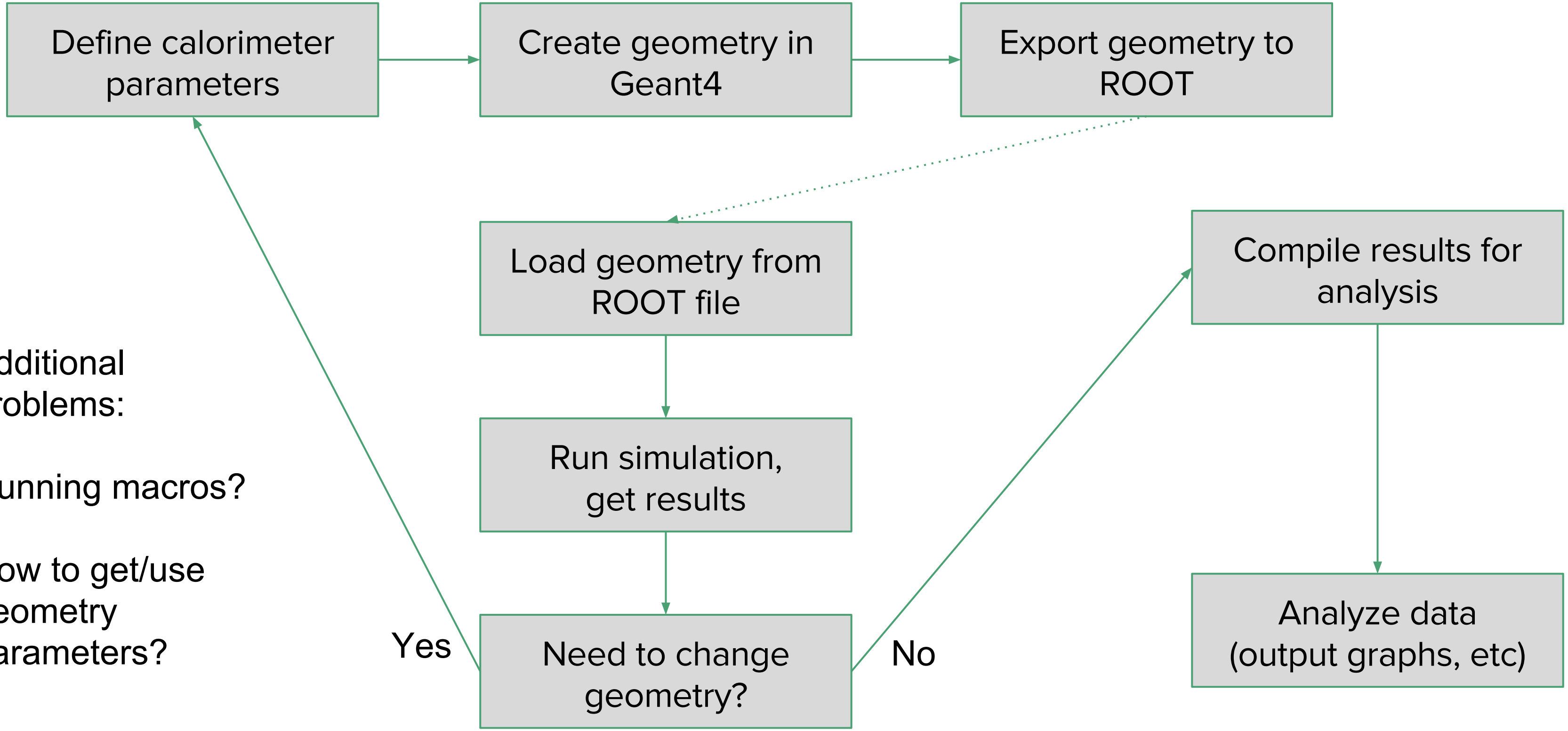


Additional problems:

Running macros?

How to get/use geometry parameters?

Project Goals:

- Provide an example implementation of a user-defined detector, including geometry and materials

- Allow for this detector to be fully customizable without need to recompile

- Use “real physics” (as opposed to tabulated physics)
    - Tabulated physics: Results sampled from Geant4 sims
    - Real physics: Native GeantV models

GeantV Real Physics Calorimeter -- Project Result

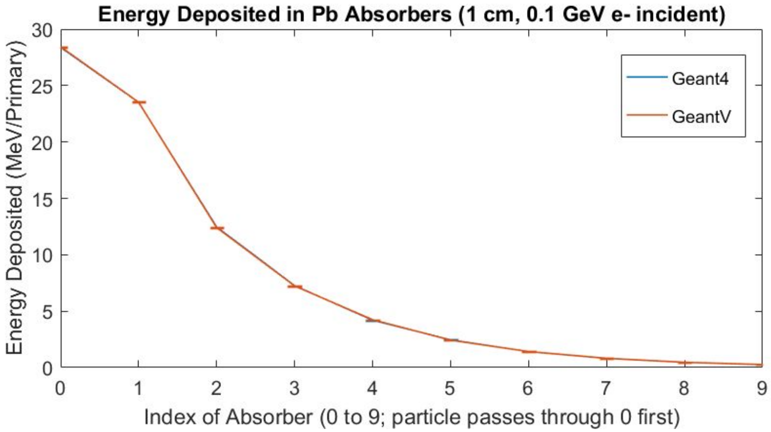
- An application has been written which creates a user-defined calorimeter

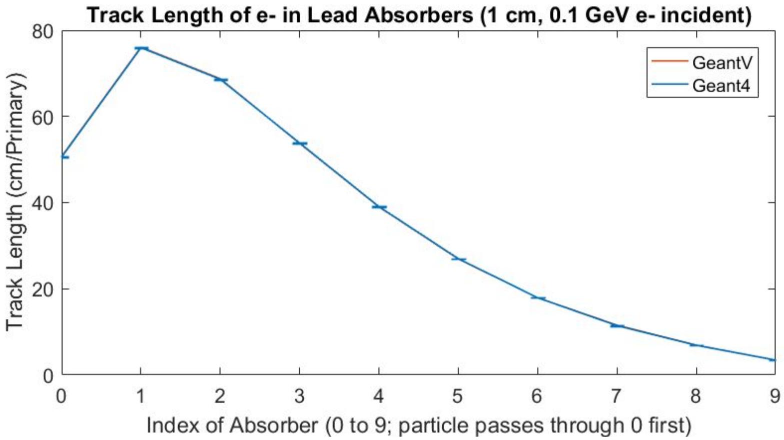
- Application inputs:
  - Number of layers
  - Number of absorbers per layer
  - Absorber properties (thickness, material)
  - Particle beam inputs (type, energy)
  - Production cuts (length, energy)

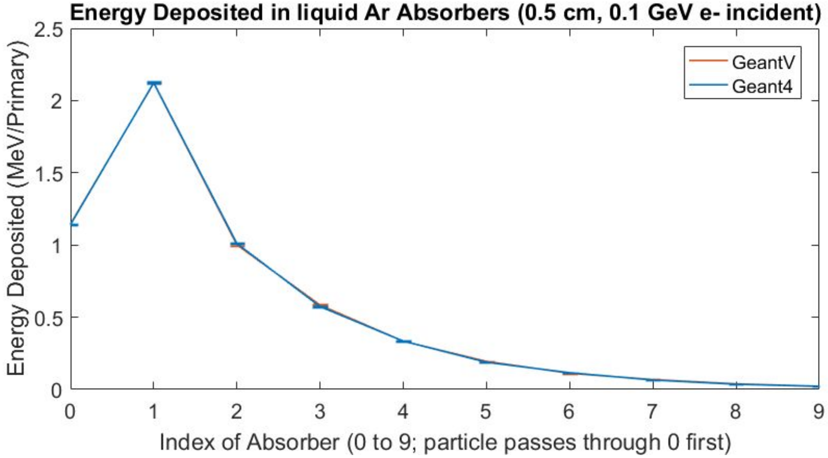
```
          |<----layer 0---------->|<----layer 1---------->|<----layer 2---------->|
          |                       |                       |                       |
          ==========================================================================
          ||               |      ||               |      ||               |      ||
          ||               |      ||               |      ||               |      ||
  beam    ||   absorber    |  gap ||   absorber    |  gap ||   absorber    |  gap ||
======>   ||               |      ||               |      ||               |      ||
          ||               |      ||               |      ||               |      ||
          ==========================================================================
```

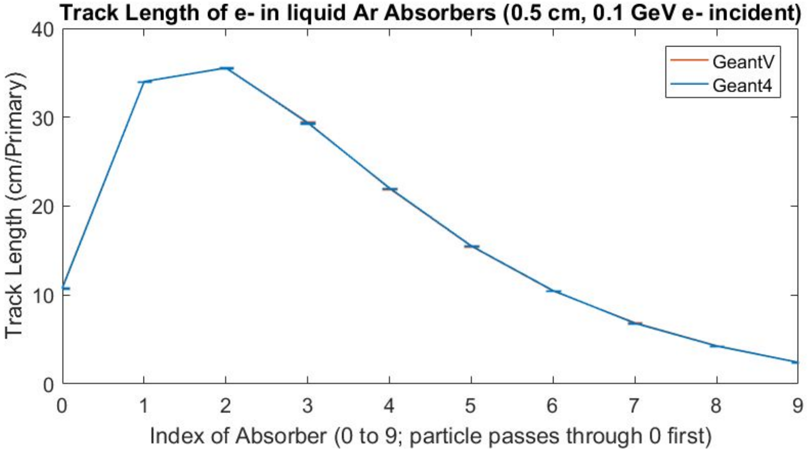
- Application Outputs (per primary per absorber):
  - Energy deposited in each material
  - Charged/neutral track length in each material
  - Number of secondaries of each type produced (gammas/electrons/positrons)
    - *All of these outputs include std. deviation*(!)

Output comparison to Geant4 -- Perfect match









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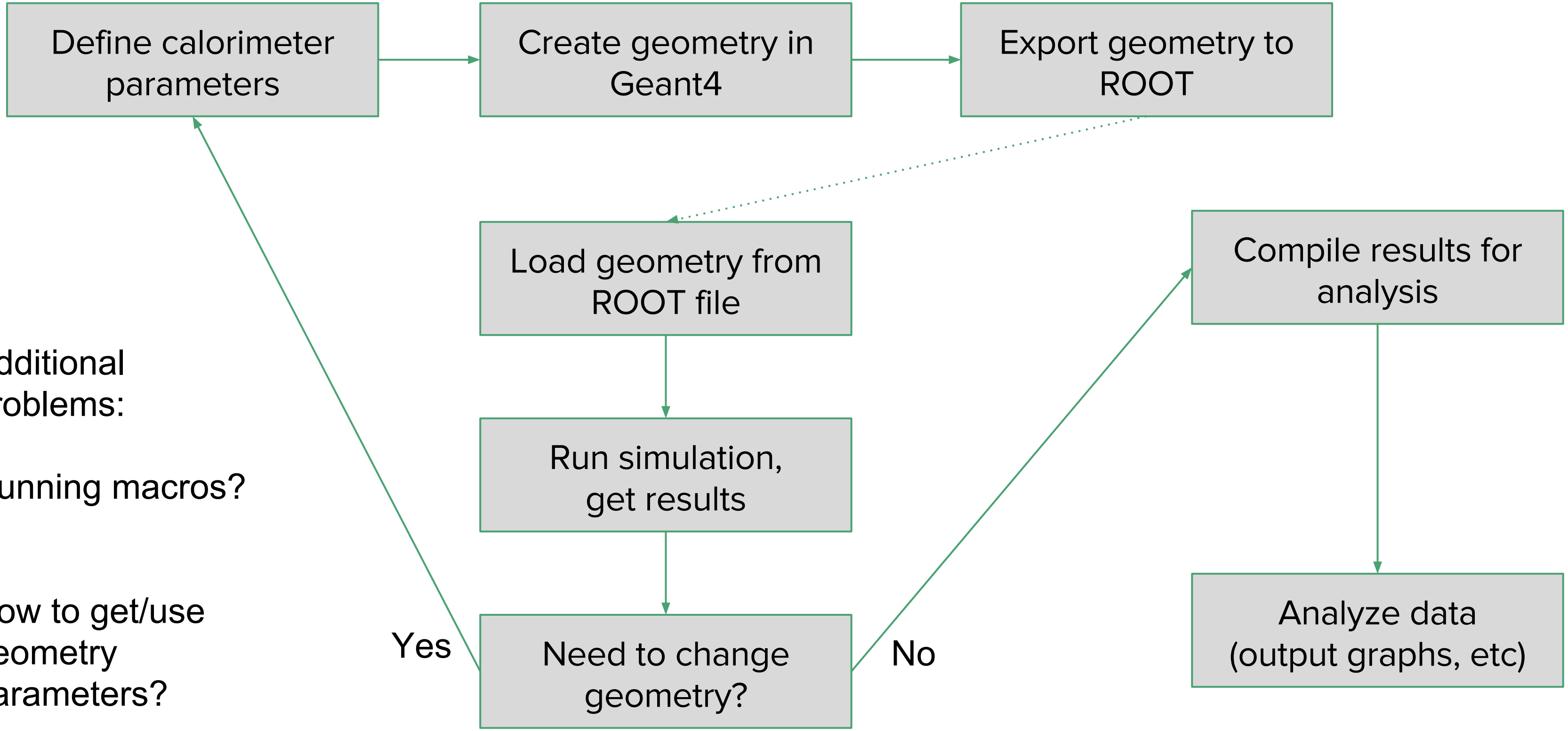

Additional problems:

Running macros?

How to get/use geometry parameters?

Current Workflow: Defining and testing a calorimeter

Create geometry in GeantV → Define calorimeter parameters → Run simulation, get results → Analyze data (output graphs, etc)

Additional problems:

Running macros?
easy

How to get/use geometry parameters?
Use get methods

Summary

- Geant4 is important to computational physics, but can't utilize the full potential of modern hardware

- GeantV is a promising improvement for the future, and it shows great potential for improved simulation speeds

- My contribution: A customizable calorimeter, fully native to GeantV, that serves as one of the first completely standalone examples of a user-defined GeantV application