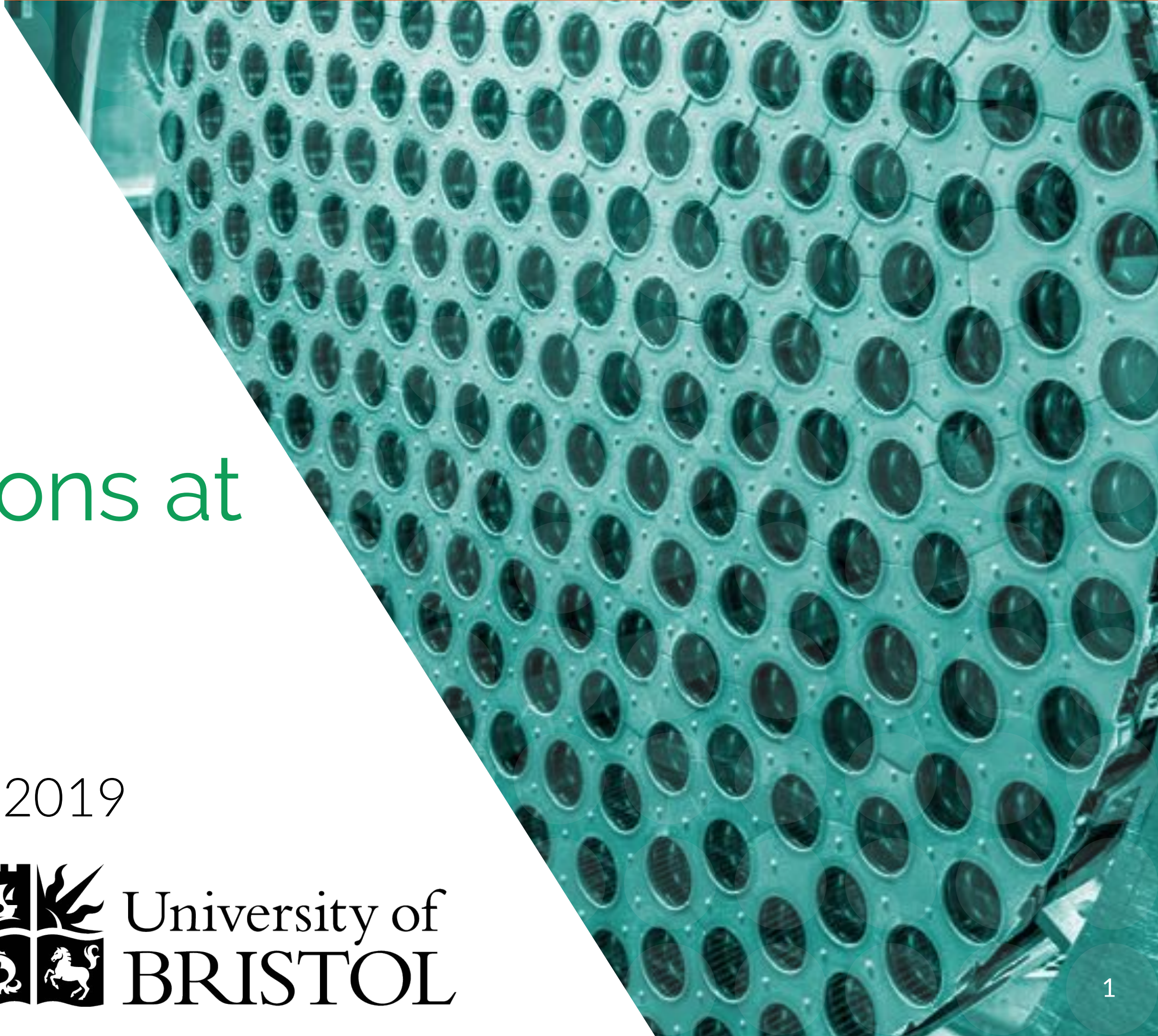
Simulations at LZ

Luke Kreczko
29th October 2019



DANCE 2019

University of BRISTOL

Outline

- Introduction
- From Nuclear and electron recoils to pulses
- Wishlist
- Summary

Simulation goals

Electrons, photons and electric signals

Describe low-energy liquid Xenon interactions with

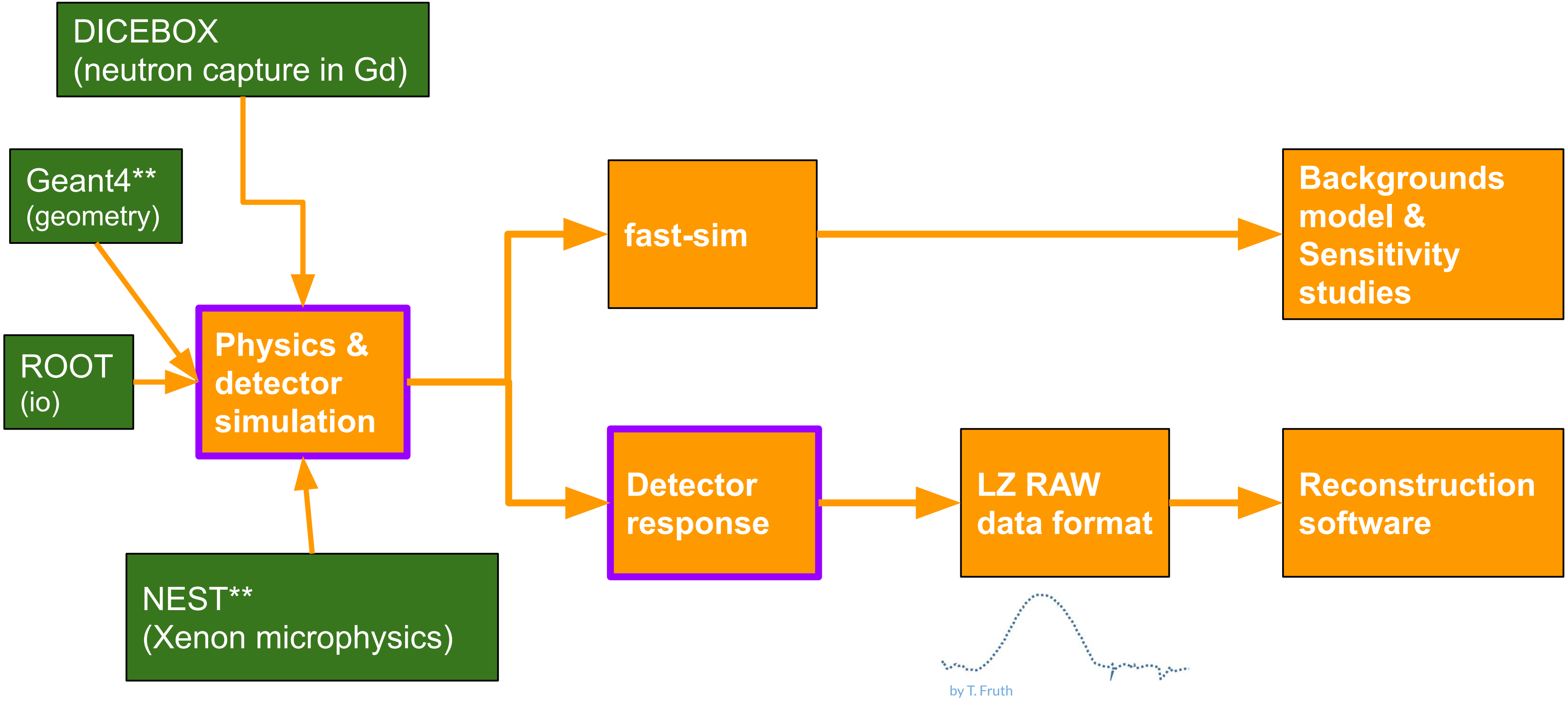
- Electrons → electron recoils (ERs)
- Nuclei → nuclear recoils (NRs)
- WIMPs → similar to NRs

Photon (175 nm) & low-energy electron propagation

- **Drifting low-energy electrons in electric field**
- **Millions of photon through a transparent medium**

Accurate PhotoMultiplier Tube (PMT) response

- **Photon pulses as close to real data as possible**

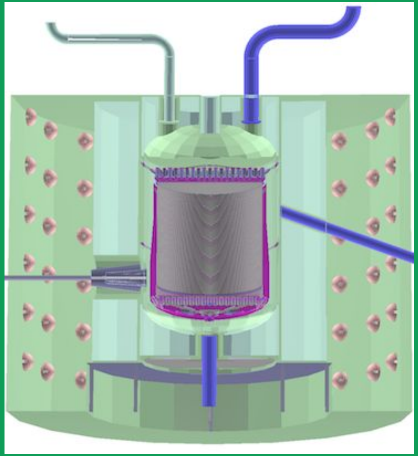


Simulations workflow

** see talks later today

Physics & detector simulation

Constructing the detector



While not as big as collider experiments there is a lot of attention to detail

- Every component with **significant mass or high amounts of radio-impurities** and close to active xenon target is included
- Components that influence light collection with their **optical properties**
- **TPC grid wires & PMT arrays with all their support structures & cables**

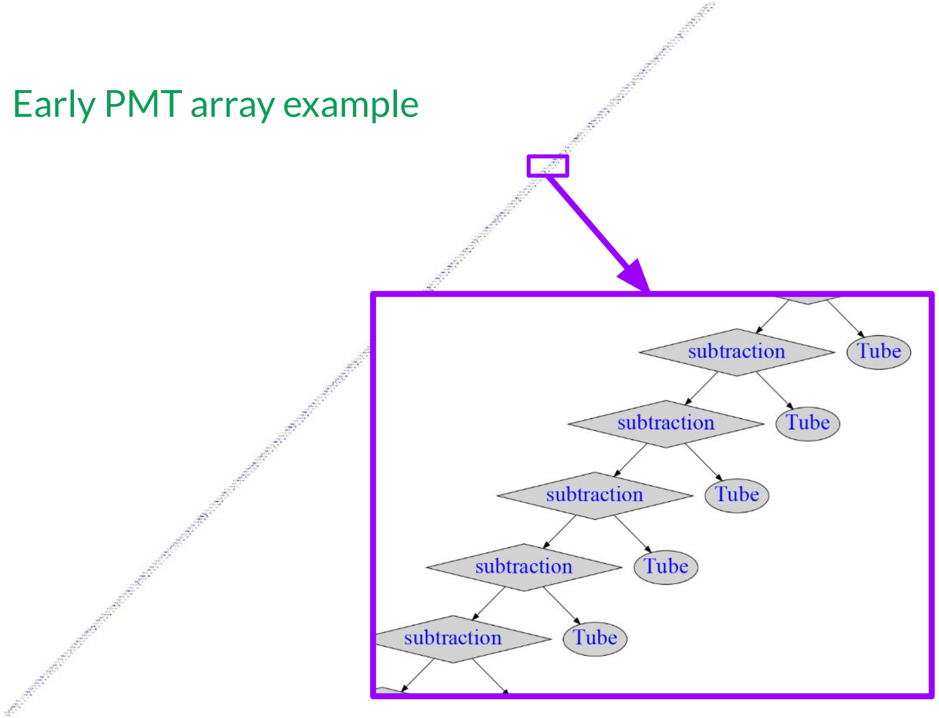
Physics & detector simulation

Constructing the detector

Tempting to construct detector geometry in simple ways

- Leads to inefficient lookup structure for Geant4

Early PMT array example



Xenon micro-physics

Using **NEST** to calculate

- photon & electron production for recoils
- Amount of recombination

Custom code for electron transport

- Low-energy **e$^-$** in electric field believed inefficient in G4
- Custom code "teleports" e$^-$ given a field map
  - Includes effect of impurities on photon absorption & electron lifetime

Generation of tracks for e$^-$ and photons only thing that is Geant4-native

Custom isotope decays

Backgrounds, calibration sources, etc.

Using custom decay tree for isotope decays

- Multiple particle emission from a source with or without time delay
- Detector **volume as source** with given activity
- Different sources emit particles at different times → global time ordering

S2 lightmap

Each electron which enters the gaseous xenon phase will result in S2 photons

- Tracking **millions of photons** in Geant4 takes a lot of time (and uses a lot of RAM)

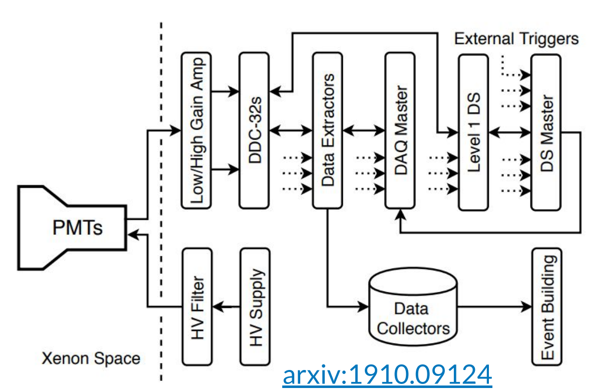
Instead we generate a **lookup map**: given some parameters, which PMT is a photon likely to hit

- Photon simulation is aborted for S2
- S2 signal is approximated with lookup table

Detector electronics response

Full signal chain (PMT response, trigger logic)

- Pulse generation, gain & gain resolution
- Transit times, quantum efficiency and double photoelectron probability
- Dynode effects, dark rate, afterpulsing
- Outputs digitized PMT waveform
  - Includes trigger decisions
- Can either **simulate full electronics** or **sample pulses from a database**



arxiv:1910.09124

Continuous Integration

Validation powered by
scikit-validate

FAST HEP

lzbot @lzbot · 3 days ago

BACCARAT CI Report

Pipeline summary

Current pipeline: https://lz-git.ua.edu/sim/BACCARAT/pipelines/9292

name	status	log	software versions
quick-checks:centos7	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
build:centos7	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
unit-tests	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
build:docs	✅	log (raw)	python=3.6.5, gcc=7.3.0, geant4=10.3.2, root=6.16/00
build:debug	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
test:centos7	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
validation:centos7	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00
build:profile	✅	log (raw)	python=2.7.15, gcc=7.3.0, geant4=10.3.2, root=6.16/00

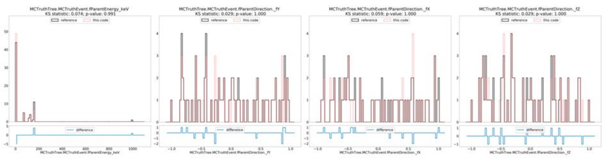
Validation report

job	status	summary	details	mismatch
validation:centos7	failed	4/3773 distributions differ (10 unknown)	details	▶ Display the names of the 4 differing distributions

Detailed validation report for validation:centos7

Overview

Distributions in disagreement with reference



Wishlist

Saving personpower for “expert level tasks”

- detector construction
  - feedback on bad use (e.g. like clang-tidy)?
    - geometry.cpp, line 234 - detected Solid with depth > 10
  - How to optimize for GPUs?
- Liquid Xenon microphysics in Geant4?
  - Community wide evaluation of accuracy?
- Easy way to **offload photon simulation to GPU**
  - Ideally available as Geant4 plugin (i.e. without explicit geometry import). Chroma? Opticks?
- **Electronic response**: Unaware of any common tools

Summary

- Presented overview of LZ simulation chain
  - Detector simulation & liquid xenon physics
  - Signal simulation for PMTs
- Build on top of existing frameworks in HEP (ROOT, Geant4)
  - Specific items covered by NEST & custom software
- **Is there common ground between experiments to consolidate software?**

Thank You

Backup slides