Geant4 Performance: Fermilab Intensity Frontier Experiments

Robert Hatcher

Fermilab

Geant4 Collaboration Mtg 2015-09-28

Parallel Session 1B - Computing Performance

A Variety of Applications

- See Plenary: Geant4 user requirements from Intensity Frontier Experiments for some background material

- Beamline simulations
  - Experiments on the same beamline can often share the same simulation of the beam, but there are several beamlines
  - 2 μ + 3.5 ν (NuMI LE vs. ME = 1.5)

- Detector simulations
  - Experiments on the same beamline have different needs when it comes to detector simulations, varied technologies
  - 2 μ + ~14 ν (including Near/Far, DUNE prototypes)

- Actual statistics are difficult to obtain/summarize — many different activities, no centralized accounting, simulation intermixed w/ reconstruction, shared efforts (ν beamlines)

Intensity Frontier at FNAL

Active, rich & varied program.

Projects include flagships for Fermilab's future.

Muon Experiments

including both μ source and detectors

muon g-2

mu2e

Neutrino Beams

present & future (and recent past)

- NuMI (Main Injector)
  - LE & ME target/horn configurations
- Booster Neutrino Beam
- LBNF under design

Neutrino Detectors

including test beam related experiments

MINOS [+] ‡ (Near & Far detectors - magnetized)

MINERvA ‡ (fine grained & multi-target material)

NOvA ‡ (Near & Far detectors - off-axis)

LArIAT / ArgoNeuT †
(same small LAr detector in test beam / NuMI beam)

SBND
(Short Baseline Near Detector Expt, formerly LAr1ND)

ANNIE
(to study neutron production in water using BNB ν)

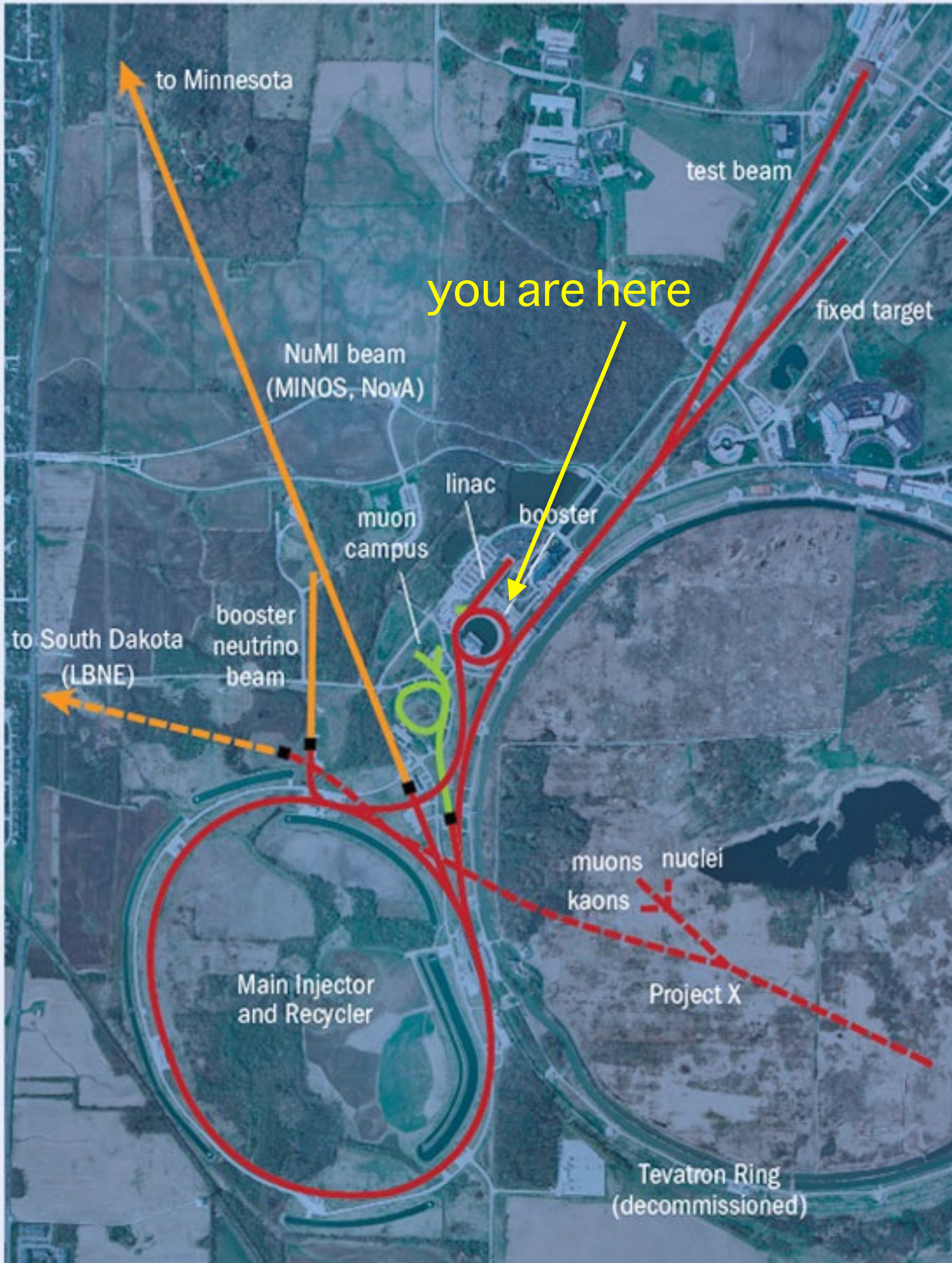
μBooNE

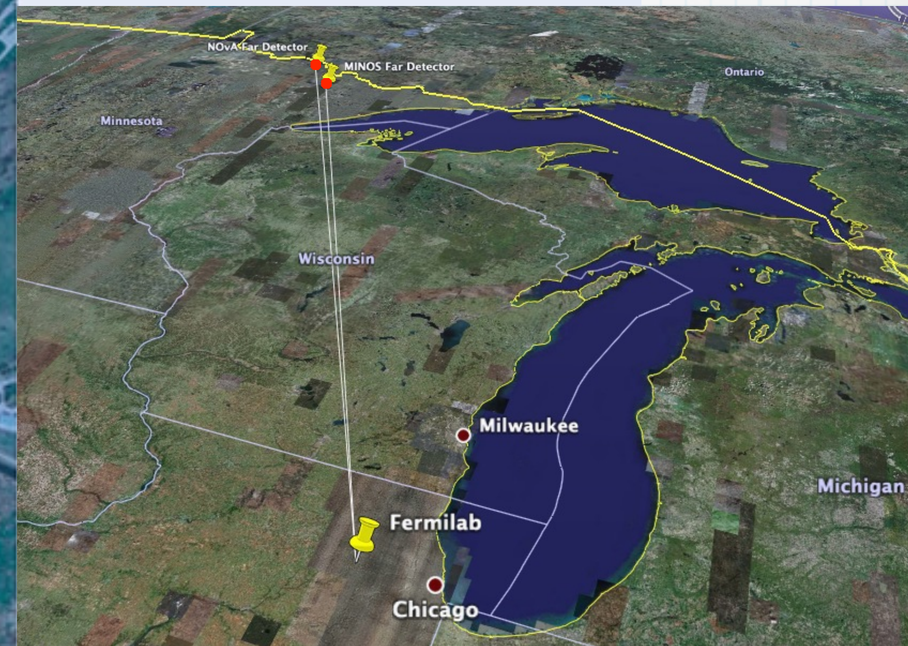
miniBooNE †

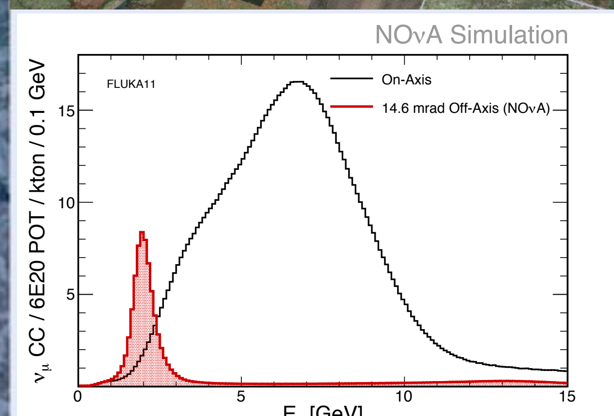
ICARUS-T600
(to be refurbished & moved from Gran Sasso National Lab in Italy to serve as BNB Far Detector)

DUNE
(Deep Underground Neutrino Experiment, formerly LBNE)
(Near & Far detectors + test beam prototypes at CERN)

† ran previously
‡ currently running







protons
neutrinos
muons
target

north

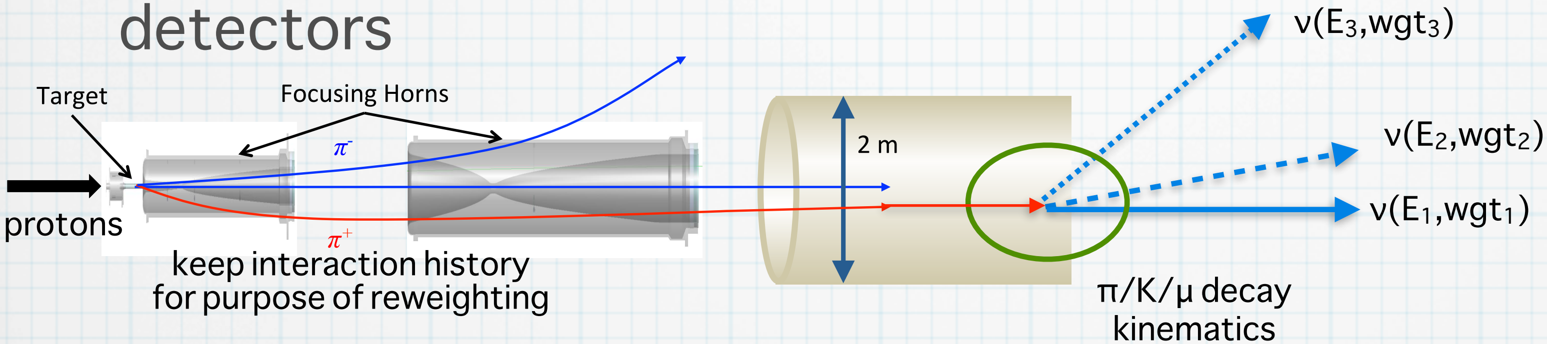
dashed lines indicate planned facilities

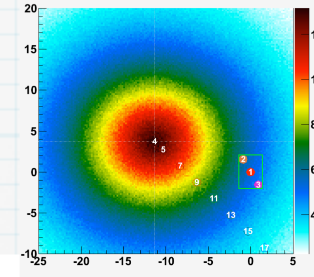
Mu2e

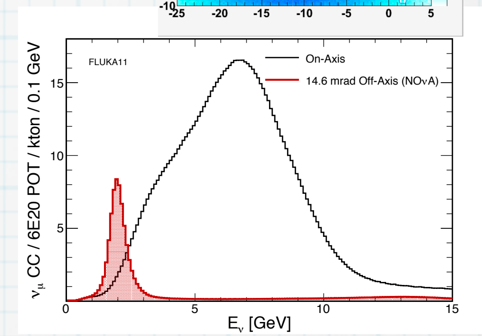
- simulation of 8 GeV protons on W target
  - 4.9.5p01 → 4.9.6p02 w/ G4beamline (QGSP_BERT_HP)
  - 4.9.6p04 for the detector (Shielding-like PhysicsList)
- Recent Production
  - General background studies (outer detector element focus)
    - ~9 - ~38 sec/event; 0.7×10^6 CPU-hours
  - General background studies (inner detector element focus)
    - ~3.5 sec/event; 5×10^6 CPU-hours
  - Cosmic ray background studies
    - ~0.1 ~ 0.2 sec/event; 10×10^6 CPU-hours
- Done over several month period, but was not time critical so while speed improvement would be nice it wasn't vital
- Dominant: Geant4 vs. reconstruction
  - Reco part is negligible in standard production at this time
- Plans: Sequential, MT, track parallelism?
  - No plans to move to MT at this time

On ν Flux Simulation Reuse

- Neutrino beamline simulations are inherently without a reconstruction component. They are factorized from event generation to allow reusing the results for different detectors







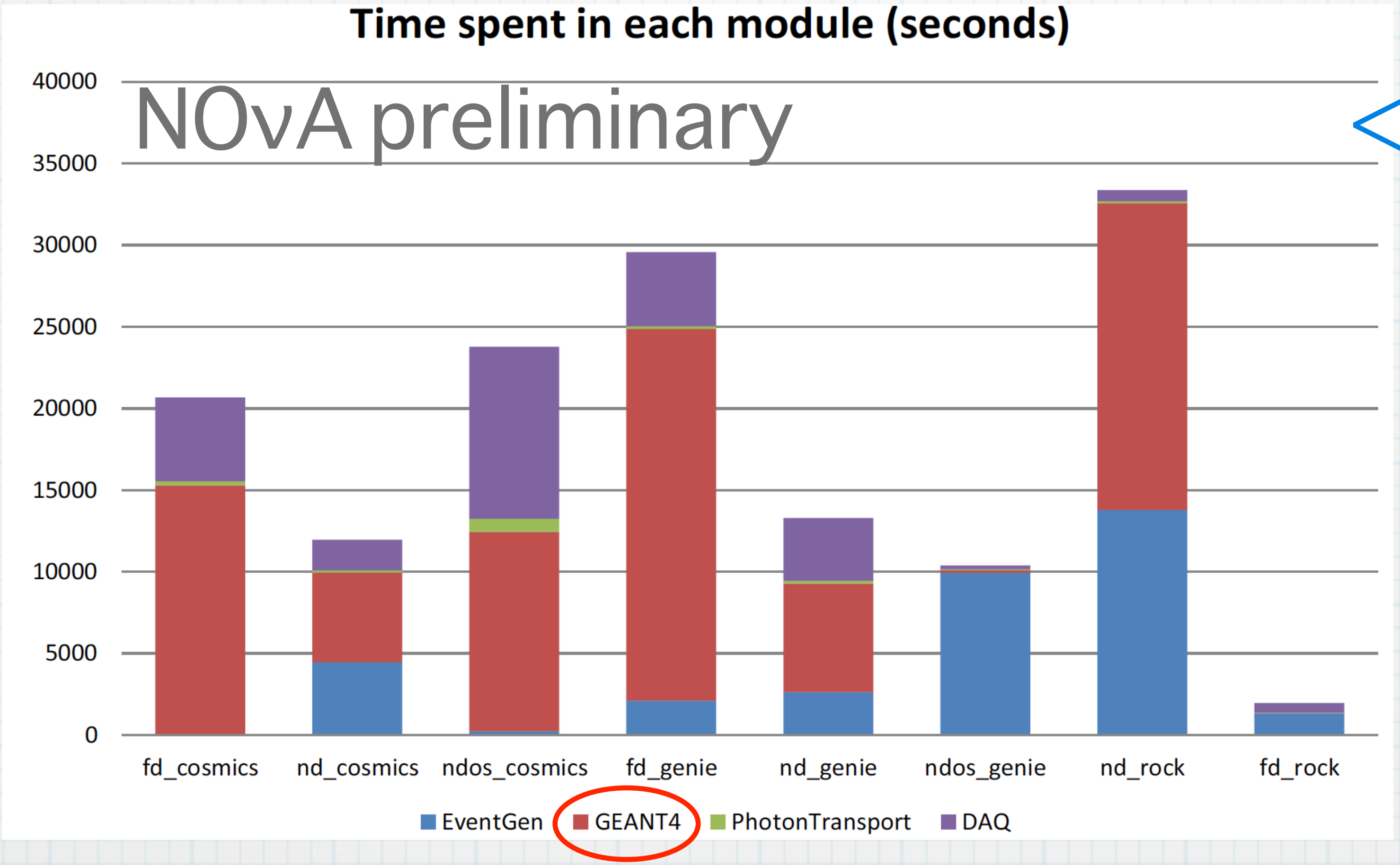
- This is natural, since simply accepting default random decay from G4 would have $\mathcal{O}(10^{-10})$ probability of actually intercepting the desired detector for the far detectors (735 - 800 km away = tiny solid angle)
- NOvA near detector sees an observable change of energy spectrum and intensity across the face
- CPU cost of evaluating energies/weights is incorporated into event generation (GENIE) or a separate step; in some cases it is non-trivial but also better than re-running for each detector from scratch
- No memory pressures, nor expected significant gains from MT

ν Beamlines

	primary interaction	geant4 version	physics list	
Booster	8GeV p ➛ Be	?	?	
NuMI	120GeV p ➛ C 5-40 GeV π ➛ C, Al, He, Fe 50-100 GeV p ➛ He,Fe	4.9.2.p03 (Minerva) 4.9.6.p04 (NuMI-X)	FTFP_BERT FTFP_BERT	~24-36 hr/file; 500K proton/file full set of files: 1000-2000 per config large sets are necessary for statistics in the high energy tail in the on-axis case config = target (LE,ME) & horn positions + horn current (200kA,off,-200kA, others) small installation target offsets ~ 200 sets/year NuMIX ~13 sets Minerva (LE configs, no align studies) off-axis μBooNE sees lower Eν from NuMI ➠ need to push CPU-saving rejections to lower thresholds ➠
LBNF (DUNE)	60-120GeV p ➛ C (Be) secondary interactions will also be important	4.9.6.p04 investigating 4.10.1.p02	QGSP_BERT (w/ FTFP_BERT [_HP] comparisons)	~1.5hr/file; 100K proton/file production set: 5000 files Genetic optimization effort: ~100,000 CPU-hr/run × several rounds Alignment studies comparable

ν Detector Simulation

- Three simulation sub-components generally done together
  - Flux + GENIE [ν+(A,Z)➛final state particles leaving the nucleus]
  - Geant4 propagation for energy depositions
  - light collection / transport + FE electronics & DAQ



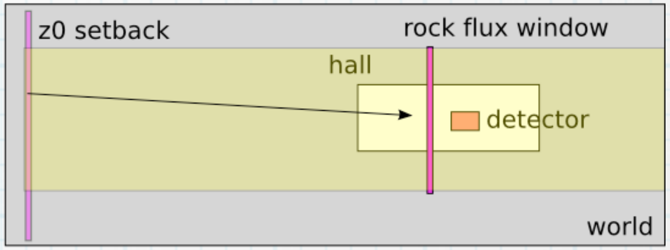
ratios and total times will vary w/ the experiment, backgrounds sources, etc.

(don't take absolute time too serious — some were constrained by what resources were available; also I'm not sure of the normalization)

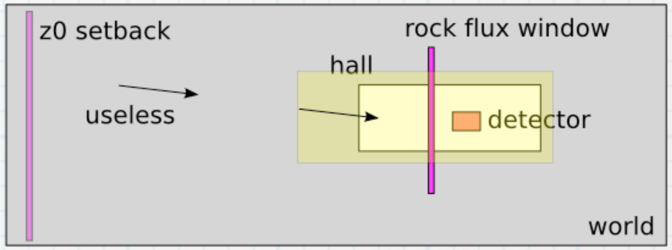
Det Simulation — ν Events

- NOvA FarDet events with the vertex in the detector: G4 ~1% of the sim time
  - simulation ~19sec/evt; reco adds ~6s/evt
- Events w/ vertices in the detector volume are often not the major consumers of CPU
  - For the recent analysis NOvA NearDet “rock” events were so expensive that NOvA was forced to make due with old files even though the flux and GENIE were updated
  - Combination of GENIE & Geant4 CPU costs
    - no breakdown available at this time
  - GENIE optimization: consider only an expanding volume depending on ν energy
  - Have a G4 module to cull particles during propagation stage; but gave significant discrepant results — needs revisiting & retuning

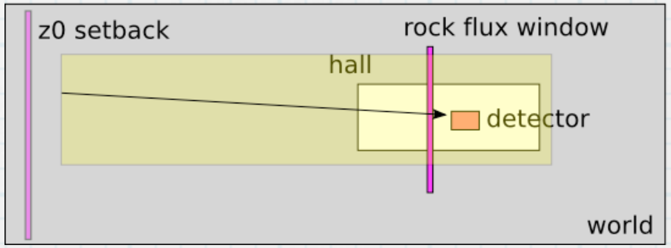
No GeomSelector



RockBox: 2 GeV

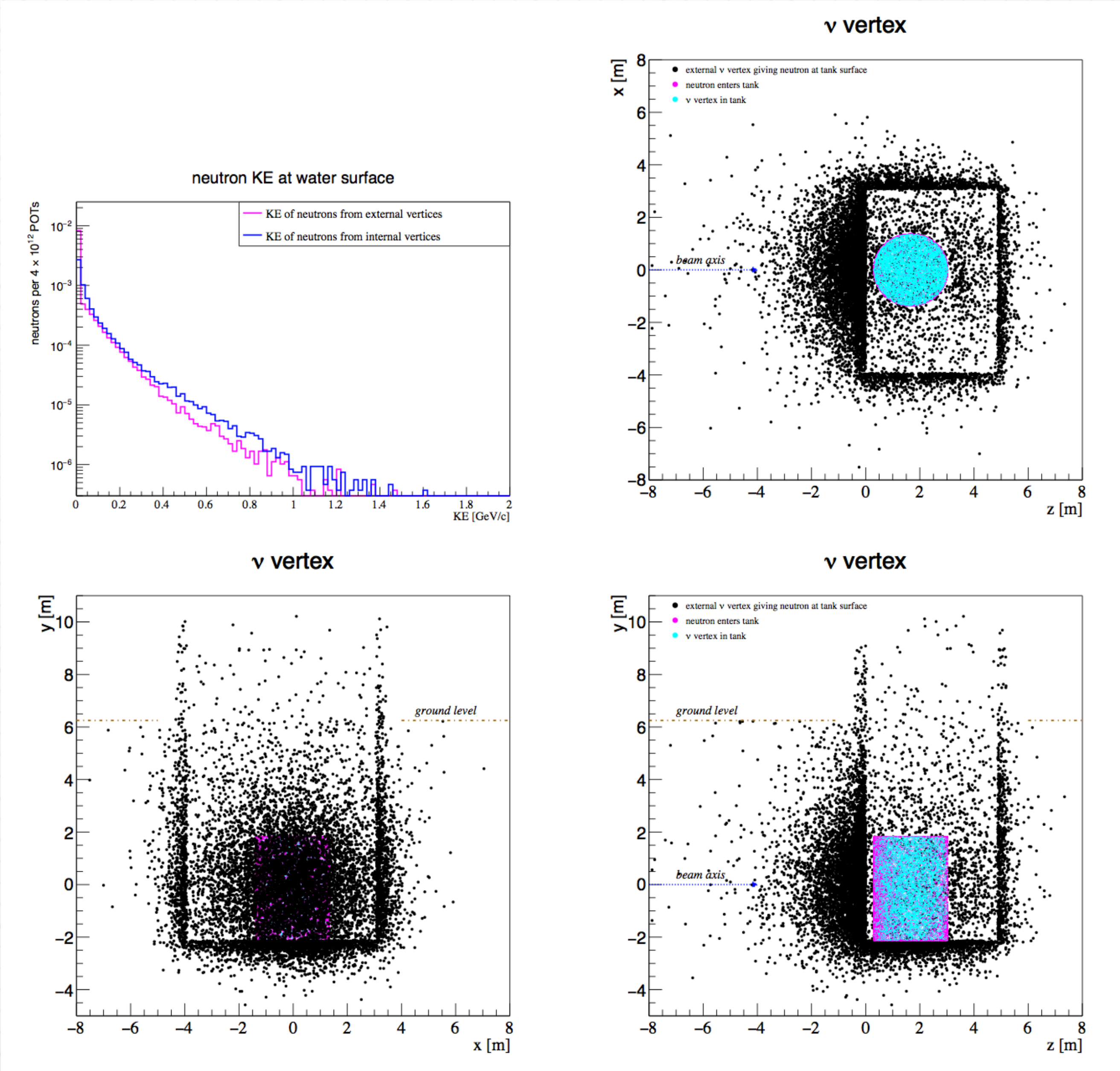


RockBox: 80 GeV



Det Simulation — ν Events

- ANNIE background: neutrons from "rock"



Robert Hatcher

Det Simulation — Cosmics

- Generally an external cosmic ray generator: CRY or CORSIKA
- Normally flux is "known" at the surface, needs to be propagated through overburden of a few meters to 2.4km
- Events with isolated μ ranging out in active volume are important for calibration
    - well understood dE/dx = knowledge of energy a distances upstream of end
    - for NOvA they must not be too vertical
- Cosmics not crossing the detector can, via spallation or other processes, cause background events in the detector
    - rare interesting processes can be lost to rare backgrounds — need lots of simulations to explore all corners of phase space

ν Det Simulation — Photons, radiological sources, super nova bursts, & proton decay

- ANNIE - water Cherenkov obviously needs photon support
- Some LAr detectors will have photodetector as well as TPC drifts
  - use voxels to record energy depositions; and perform e^- drift and use parameterized photon responses outside G4
  - photon libraries themselves often generated using Geant4
- Early DUNE radioactive decay simulations seemed to be time intensive — details are unclear.

ν Detectors

	technology	geant4 version	physics list	photons	
μBooNE	Liquid Argon (LAr) TPC	4.9.6.p04 larsoft common base	QGSP_BIC + custom photons	✅	
DUNE FD	multi-tank LAr TPC	4.9.6.p04 larsoft common base	?	✅	
LArIAT ArgoNeut	LAr TPC	4.9.6.p04 larsoft common base	QGSP_BERT, BIC, INCLXX	✅	4.9.6 Kaon response in Bertini cascade is problematic. move to 4.10.1.p02 soon?
Minerva	solid scintillator WLS fiber collection	4.9.4.p02 (Gaudi) v10r6p13/v10r9p1	?	❌	
NOvA	liquid scintillator WLS fiber collection	4.9.6.p04	QGSP_BERT_HP	❌	2 detectors × various beam configs
ANNIE	Water Cherenkov	?	?	✅	

Questions?

“Summary”

- Hard to generalize; uses are many and varied
- Numbers are hard to get
  - many expt don’t generally “know” them; they aren’t carefully tracked nor centralized in any way (effort underway towards this)
    - even if they know MC “generation” times it is often convoluted with reconstruction done in the same job pass (to minimize file handling)
  - some uses are simply sized to match resources and statistical errors are subsumed into the analysis

- Generally, if new technology (MT, track parallelism, multi-cores, etc) came completely for free with no extra thought necessary, well, no one would turn it down.
  - but manpower is in short supply; smaller experiments don’t have huge army hordes to throw at tasks, and often lose experts when they move on (graduate, leave the field, leave for the collider expt)
  - CDF/D0 use to have whole teams of people pushing processing through; for these expts it’s a “a guy” … part time, as a side task

General Simulation Workflow & Products in Neutrino Experiments

- We factorize the steps to make them tractable problems
  - Simulation of the beamline
  - Simulation of the detectors
- Different energy scales
- Even detector simulations have large variation in needs due to a variety of technology