The Use of Geant4 by the Cosmic & HEP Intensity Frontiers

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for the Fermilab: MINOS+, NOvA, Minerva, DUNE(LBNE), microBooNE, ANNIE, LArIAT/ArgoNeuT, SBND(LAr1ND),ICARUS,Mu2e, g-2 Experiments

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for the: LZ, CDMS (…) Experiments

Geant4 Collaboration Mtg Plenary 2016-09-12

Cosmic & Underground Interests

taken from 2015 talk

- Phonon / solid state physics
  - phonon and e/h models in Ge at 0 K
  - extending Ge to Si
  - lattice parameterizations for Al, W, Si
  - phonon splitting process for boundary reflections
  - phonon particle-hole pair conversion models

- Radioactive decay physics
  - levels & lifetimes; full features in biased mode
  - channels incl: β-delayed neutron emission; spontaneous fission; decay by proton, neutron emission or double beta

Cosmic & Underground Interests

- Low energy physics
  - scintillation in noble liquids
  - correlation of gammas from nuclear de-excitations
  - (α, n) reactions at < 7 MeV
  - photo nuclear models for < 20 MeV (especially photo-neutrons)

- High energy hadronic physics
  - Nucleus-nucleus models for > 500 GeV/N

- Neutrinos
  - coherent elastic neutrino scattering
  - interface to GENIE
  - biasing

Cosmic Open User Requirements

- Correct treatment of gamma cascades after neutron capture in Gd and Xe, requested by LZ (UR-31)
  - The cascades now appear to be OK, as of patch 02 on 10.2. We await confirmation from LZ.

- Neutron production in muon showers at the %-level (UR-32)
  - FNAL TF, LZ expts — follow up?
  - languishing on Geant4 side for lack of resources

Muon Expts: g-2 & μ2e

- Emphasis on spin aspects of radiative μ decay, μ capture
  - μ expts care obviously, but ν expts also use Michel electrons for calibration and μ+ vs. μ-
- Backgrounds (especially when looking at rare processes)

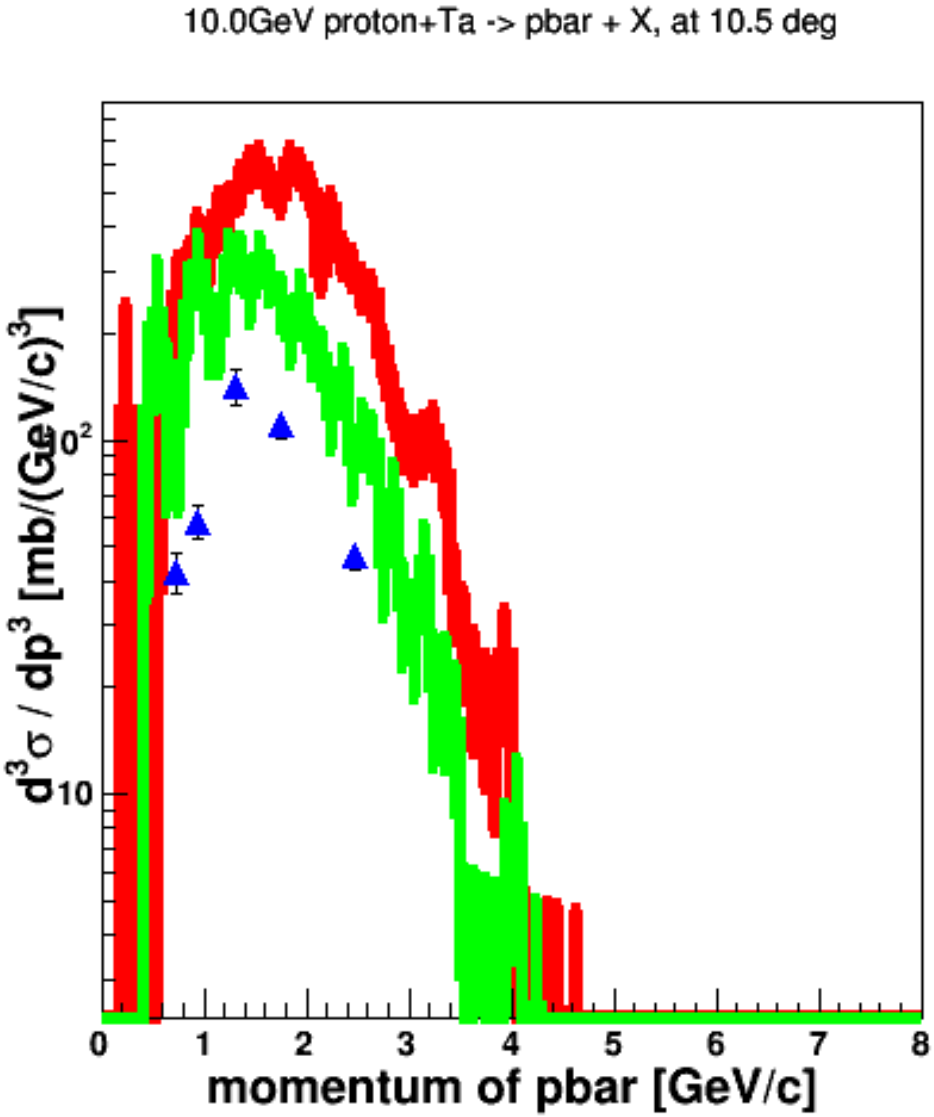
Muon Expt: g-2

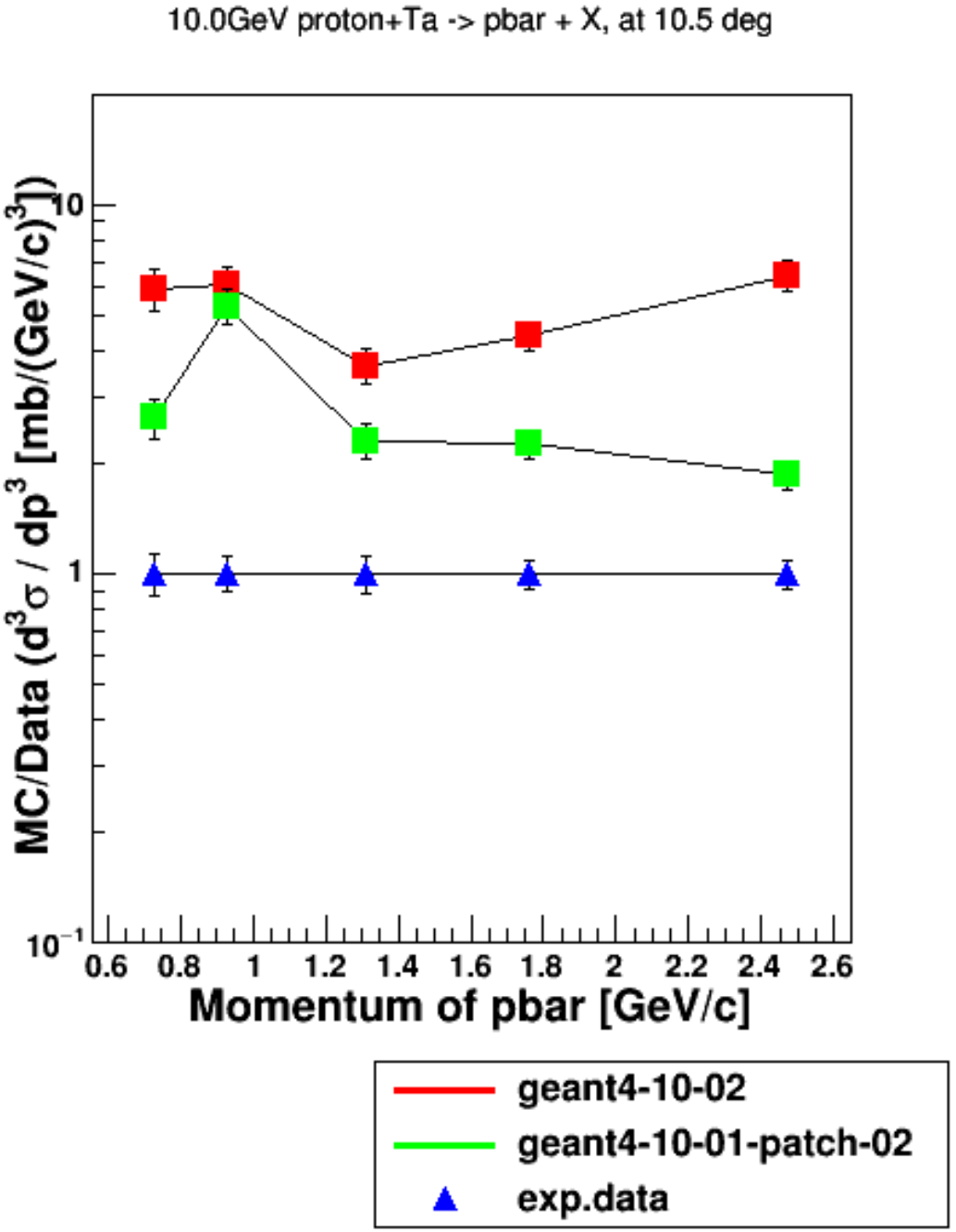
- Transitioning from 4.9.6p04 to 4.10.2.p02 (w/ USolids)
- According to current knowledge, problems previously reported by g-2 are addressed in the 10.2.p02 release
- Working on integration of ParaView and Geant4 for visualization and data analysis
  - http://www.paraview.org/

Muon Expt: μ2e

- In particular is sensitive to antiproton cross-sections and details of neutron production in π & μ capture
- Currently using 4.9.6p04 with plans to start migration to 4.10.2.p02 in the near future
- Many of the problems previously reported by μ2e are addressed in the 10.2.p02 release
- Outstanding issue with the anti-proton production for proton beam described in UR-28 (their 3rd most dominant background).
- A new request related to the previous one would be to provide an option to enable a (artificially biased) enhanced anti-proton production to allow dedicated studies of anti-protons (Mu2e has a version of it based on Geant4 9.6.p04 modified FTF model, but the modification has some energy non-conservation issues).

Muon Expt: μ2e





Neutrino Experiments

- Many orders of magnitude in energy
- Essentially all particle species to some extent/experiment

- Beamlines - 8, 120 (possibly 60, 80) GeV protons on C, W or Be
  - primary concern is hadron production in large regions of phase space
  - secondary production in focussing elements
  - production not measured in situ
    - only via secondary measures (muon monitor, ν beam itself)

Neutrino Experiments

- Detectors - run the gamut of technologies
  - solid scintillator (+ magnetized steel)
  - liquid scintillator (variety of readout schemes)
  - water Cherenkov
  - liquid Argon TPC
  - studies underway of: High Pressure TPC, Straw Tubes + ECal
    ...
- ν products generally energies of few MeV to ~25 GeV
- EM Showers (NOvA), hadronic response (Minerva)
- Non-beam physics
  - cosmic rays (higher muon energies)
  - radiological backgrounds
  - proton decay

Neutrino Experiments

- Beam Simulations use a range of releases
  - Minerva is holding to 4.9.2p03 (FTFP_BERT) for now; reweighting hadron production to data
    - would need to regenerated / re-validate
    - investigating focussing differences using G4Cone vs. G4PolyCone in modeling the horns
  - NuMI-X is using 4.9.6p02, working the transition to 4.10.X; need to re-implement / validate geometry due to loss of BREPPolycone
  - LBNE/DUNE is using 4.10.1p03 (QGSP_BERT); might move to p03 for Qt support (Fermilab issue?)

Neutrino Beam Requirements

- Minerva wants to pass along a patch for extracting struck nucleus (in a mixture) for each hadronic interaction
  - NuMI-X / LBNE will probably want this
- Reweightable uncertainties for systematic uncertainties estimation (DEV-29).
  - Evolved into ongoing program investigating adjustable model parameters (Julia Yarba)
- Generally “cpu performance” is not a driving issue
  - physics fidelity is primary concern
  - exception: LBNE genetic / annealing algorithm for beamline optimization

Neutrino Experiments

- Detector Simulations
  - Most are transitioning from 4.9.6p03 to 4.10.X
  - LArSoft
    - Had desire for Cerenkov/scintillation processes no generating stacked photons to track, but simply get the number (DEV-249)
      - appears to have been answered (xrays-V10-02-05)
    - Was using parallel geometry to limit step size (300μm); attacking the problem using standard G4 tools is more performant.
  - Working w/ GENIE (ν interaction generator) for sharing nuclear break-up, intranuclear effects.

Summary

- Overall not so different from last year
- Often users aren't prioritizing activity on Geant4 as a concern; more interested in things they directly control

Backup Material

- What follows is mostly last year's talk

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)

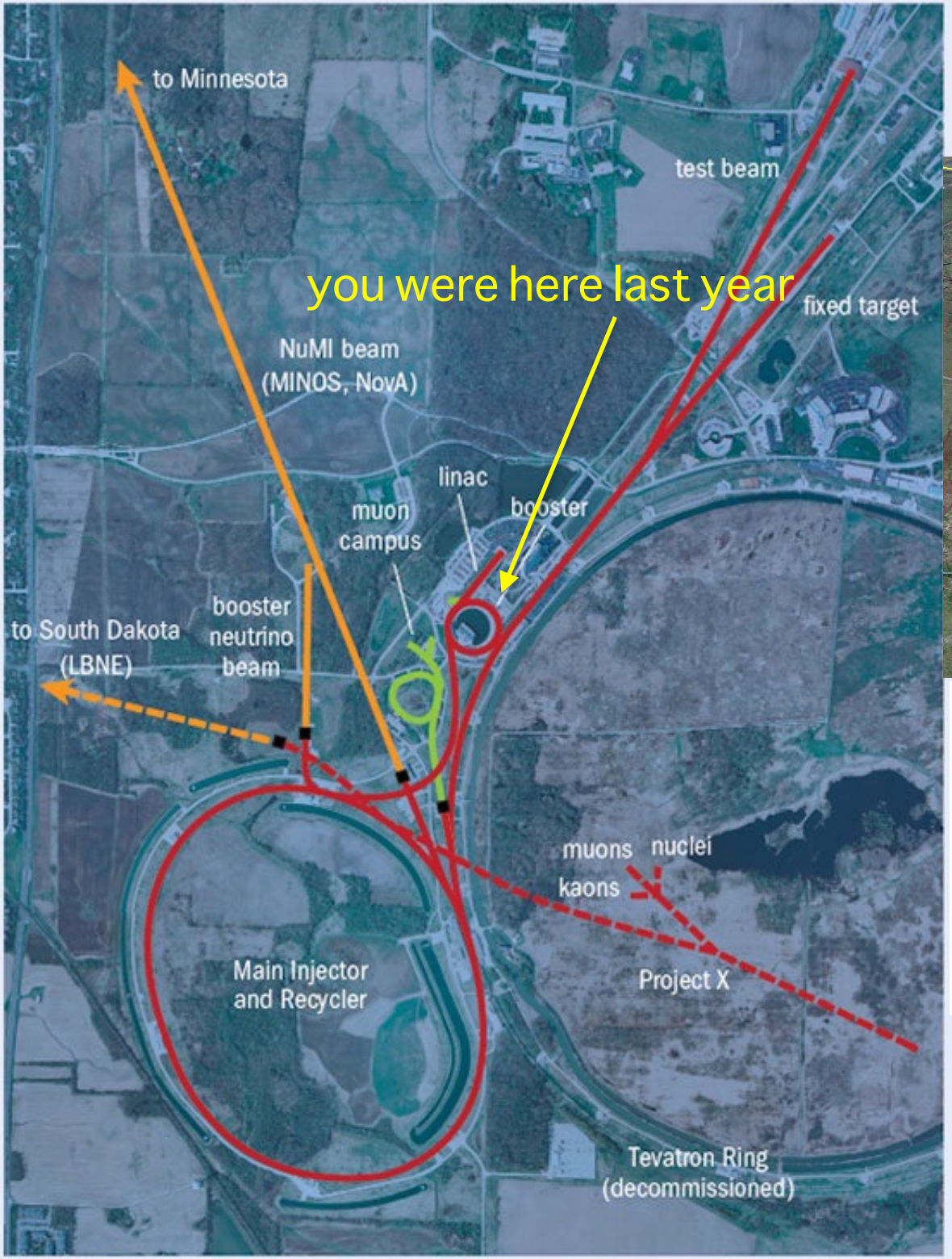
μBooNE

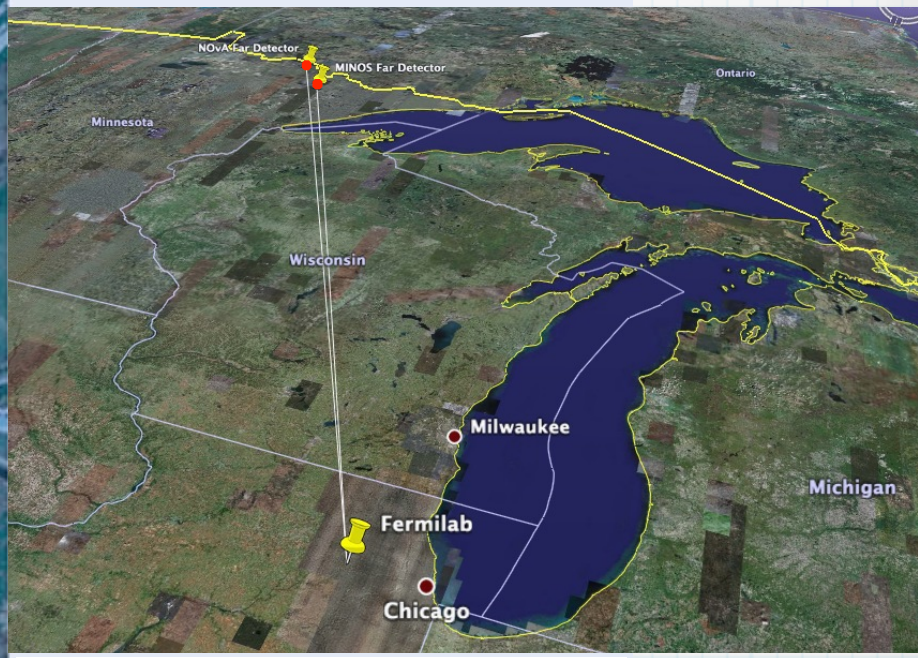
miniBooNE †

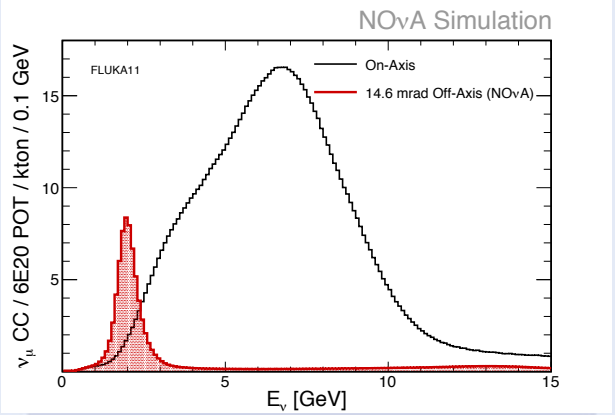
ICARUS-T600
(to be refurbished & moved from Gran Sasso National Lab in Italy to serve as BNB Far Detector)

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

† ran previously
‡ currently running





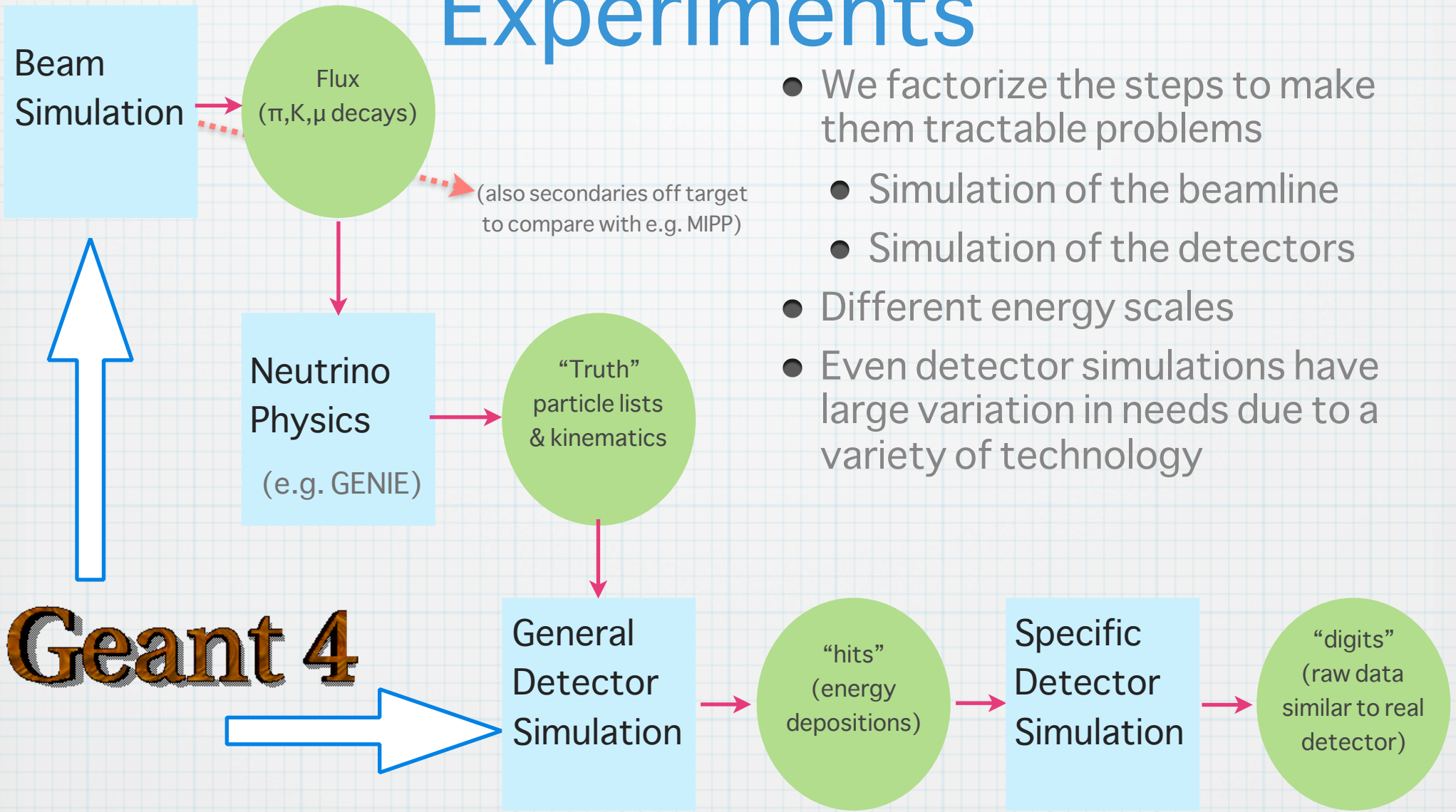


protons
neutrinos
muons
target

north

dashed lines indicate planned facilities

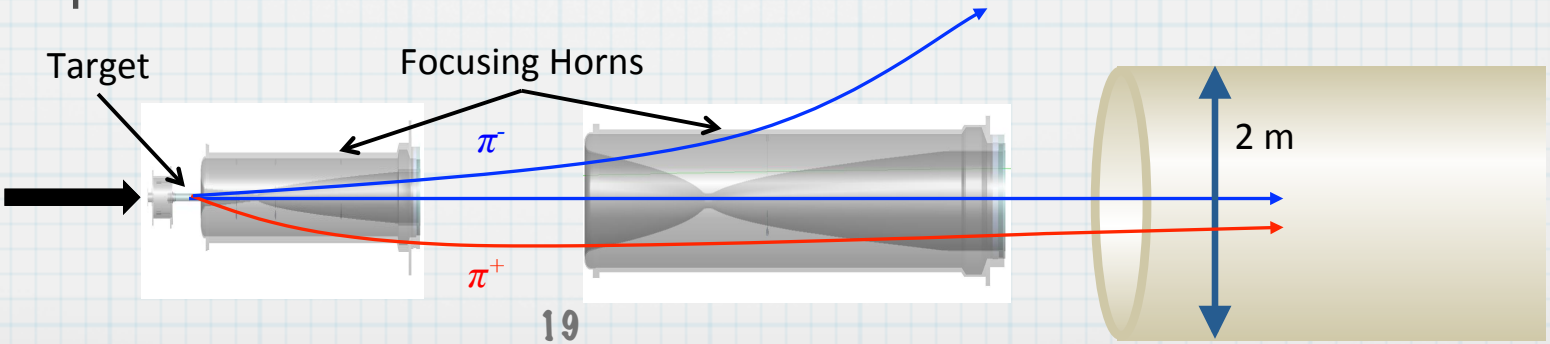
General Simulation Workflow & Products in Neutrino Experiments



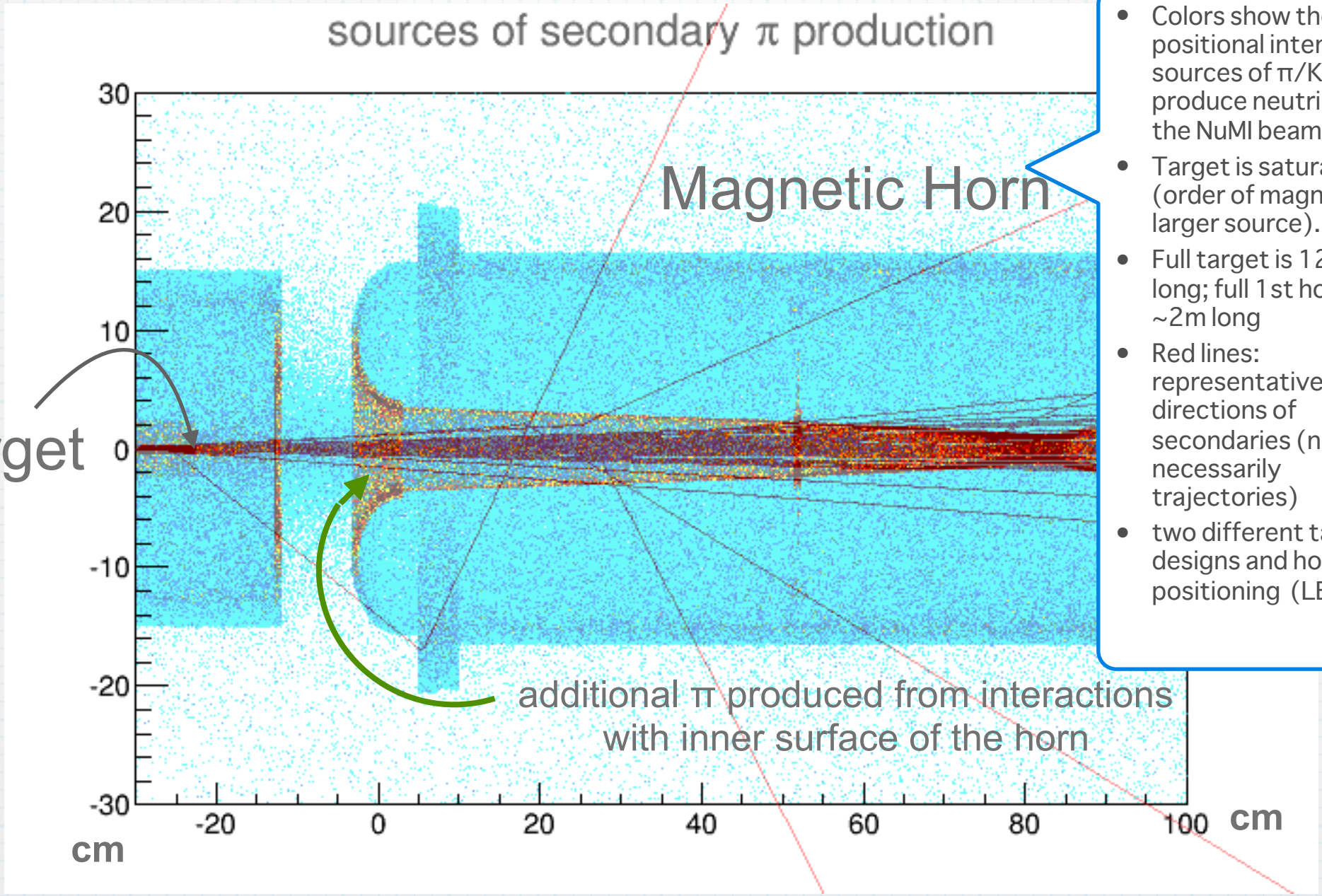
- We factorize the steps to make them tractable problems
  - Simulation of the beamline
  - Simulation of the detectors
- Different energy scales
- Even detector simulations have large variation in needs due to a variety of technology

Beamline Simulations

- 8 or 120 GeV protons impinging on C, Be, or W targets
  - LBNF(DUNE) studying possibility of 60-80 GeV
  - production of secondaries is important in both forward (ν) and backward (π in Mu2e) hemispheres
  - secondaries produce further tertiary products that also contribute to the the ν flux in non-negligible fashion; roughly 30% of ν come from a further hadronic interaction in target or horn system
- Details and accuracy are critical elements in predicting flux
  - sometimes limiting factor for the experiment
  - important to know how uncertain the prediction is
- Off-axis ν expts are sensitive to different areas of hadronic production phase space (p_t vs. p_z)
- "Booster" expts will observe NuMI's off-axis ν flux as well



NuMI Target & Horn



- Colors show the positional intensity of sources of π/K that produce neutrinos in the NuMI beamline.
- Target is saturated (order of magnitude larger source).
- Full target is 123cm long; full 1st horn is ~2m long
- Red lines: representative directions of secondaries (not necessarily trajectories)
- two different target designs and horn positioning (LE & ME)

Detector Simulations

- Detector response to signal and background processes
  - Generally a full zoo of particles from 25 GeV down to ~MeV
  - Many detector technologies: scintillator (solid plastic & liquid), liquid argon (LAr), BaF_2/PbF_2 crystals, straw drift tubes
  - Magnetized steel or transport spaces
  - Some LAr experiments use optical photon detectors
    - speed is an issue here, generally used to produce parameterize distributions rather than tracking individual events
  - Both hadrons & leptons: e.g.
    - electron showers are important for NOvA physics signature
    - Minerva is sensitive to correct hadronic response
    - muon experiments need spin handled correctly
    - mu2e has an anti-proton induced background
  - Some ν detectors also looking at non-beam sources
    - cosmic rays, radiological sources, proton decay

Usage

- Wide spectrum of Geant4 versions in use
  - Mostly 4.9.6p03/04, but some hold out as far back as 4.9.2
    - a few “standard” (pre-4.9.6p04) builds have local mods to incorporate known fixes
  - some are exploring use of 4.10.x, but not in production for ν
    - a variety of issues for the reluctance to move forward
- PhysicsLists: predominantly FTFP_BERT (ν flux), QGSP_BERT_HP (ν detectors), modified Shielding (Mu2e)
  - also pursuing tuned lists that are variants, e.g NuBeam
- Beamline simulations are stand-alone applications run as a separate step, prior to detector event generation
  - the reuse of beamline sim products argues to keep these as separate steps; both complicated in their own way, so leave them factorized; efficiency gained by sharing amongst experiments.
- Detector simulations (generally) use Geant4 embedded as a job module in the ART framework

Desires/Concerns

In no particular order:

- Model parameter variation for study of systematic errors
  - this is critical; if not officially supplied experiments will do it themselves in some fashion
  - simply changing PhysicsLists isn't deemed sufficient
- Users find validating and comparing geometries difficult
  - having within Geant4 a means to validate that the only changes are as intended and that there weren't knock-on effects
  - standardization of GDML w/ other simulations (MARS, etc) both R&W
- Always a desire for improved visualization (including fields); additional guidance on using existing visualization tools

Desires/Concerns (continued)

- Emphasis on spin aspects of radiative μ decay, μ capture
  - μ expts care obviously, but ν expts use Michel electrons for calibration and μ^+ vs. μ^-
- Mu2e request: improve antiproton cross-sections and details of neutron production in π & μ capture
- More guidance on PhysicsList choices and validation
  - further development of new lists / customization
  - communication/tools for evaluating version change impacts
- Allowing external packages (e.g. GENIE) access to intranuclear models, nuclear de-excitation, hadronization
- Documentation of pointer ownership (status from last year?)
  - who relinquishes control, who is just sharing
  - potential for memory leaks and/or double deletion

Desires/Concerns (continued)

- Photon transport speed issues
  - though probably never going to be fast enough to do “in situ”
- ART developers (framework used by many of the newer experiments, i.e. all but MINOS, Minerva, MiniBooNE) have expressed interest in integrating Multi-Threading into the ART framework
  - may need require some tweaks to make the two compatible