Simulating radiative effects in GEANT4

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Overview

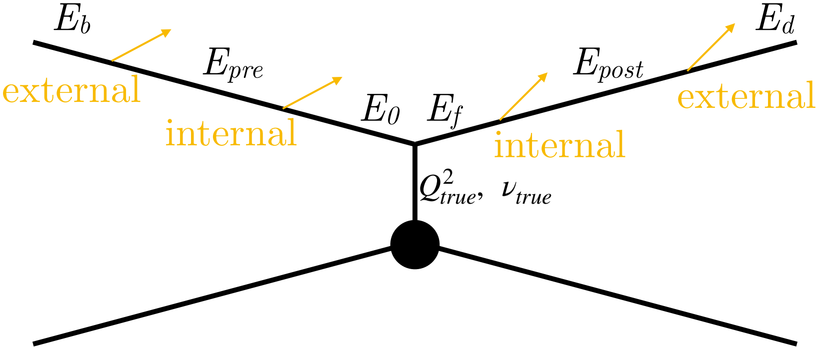
1. Introduction
2. Simulation overview
3. Preliminary results

Motivation

Do radiative effects cancel when measuring cross section ratios?

- Investigate with GEANT4
- Simulate passage of electrons through all material upstream of spectrometer
- Include complete definition of target gases and cell geometries to identify differences (if any) in radiative effects between targets
- Examine bin smearing resulting from radiative effects

Radiative kinematics



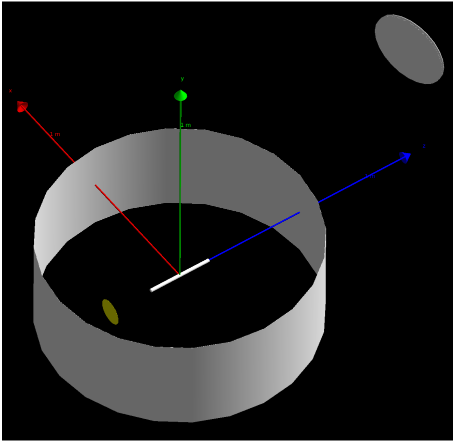
Observed kinematics calculated from beam and detected energy:

$$Q^2_{obs} = 2E_bE_d(1-\cos\theta) \qquad \nu_{obs} = E_b - E_d \qquad x_{obs} = \frac{Q^2_{obs}}{2M\nu_{obs}}$$

True kinematics calculated from initial and final energy of the Born diagram:

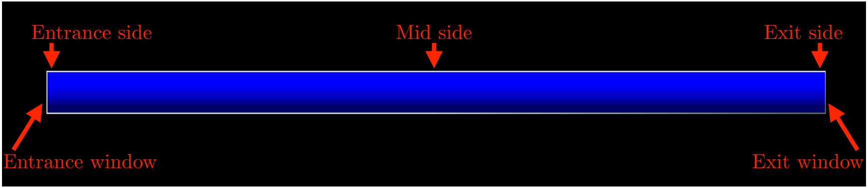
$$Q^2_{true} = 2E_0E_f(1-\cos\theta) \qquad \nu_{true} = E_0 - E_f \qquad x_{true} = \frac{Q^2_{true}}{2M\nu_{true}}$$

Geometry



- Air in world volume
- Vacuum in scattering chamber
- 0.2003 mm beryllium window upstream of target
- Target cell details on next slide
- 0.406 mm aluminum scattering chamber window
- 81.6 cm separation between chamber window and Q1
- 0.305 mm Kapton Q1 window
- Detector directly behind Q1 window

Target cell

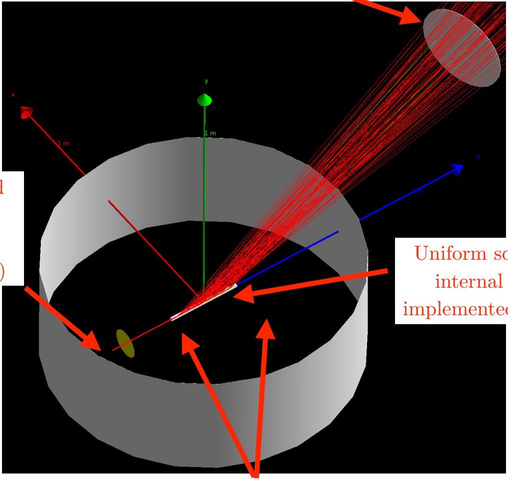


- Cell thickness (gray) from TGT-RPT-17-007
- Gas volume (blue) based on densities from TGT-CALC-17-020
  - Hydrogen: $(^1\text{H})_2$ gas at $\rho = 2.832$ mg/cm^3
  - Deuterium: $(^2\text{H})_2$ gas at $\rho = 5.686$ mg/cm^3
  - Tritium: $(^3\text{H})_2$ gas at $\rho = 3.404$ mg/cm^3
  - Helium: (^3He) gas at $\rho = 2.135$ mg/cm^3
  - Pressure calculated for ideal gas at $T = 45$ K

Control flow

Scattered electrons detected immediately past Q1 window

Electrons generated upstream of Be window (10.6 GeV, 2mm x 2mm raster)



Uniform scattering including internal bremsstrahlung implemented (details to follow)

Pre- and post-scattering ionization and external bremsstrahlung handled by GEANT4

Uniform scattering

Uniform scattering process implemented with `G4VDiscreteProcess`

- Non-physical! Does not sample from cross-sections
- Looking for thorough coverage of phase space

Each scattering event follows these steps, where E_{pre} is the GEANT4 track energy at scattering:

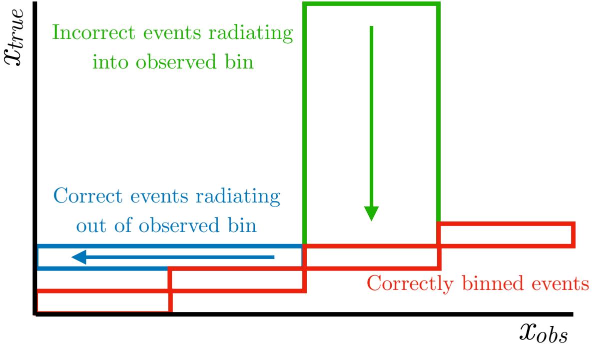
1. Sample uniformly from $\cos\theta$ (range depends on HRS angle) and ϕ
2. Given θ, sample uniformly from $0 < Q^2_{true} < 2E_{pre}E_{pre}(1 - \cos\theta)$
3. Apply internal bremsstrahlung using equivalent radiator (Mo and Tsai) to obtain E_0
4. Calculate E_f, ν_{true}, and x_{true}
5. Apply internal bremsstrahlung once again to obtain E_{post}
6. Set new electron energy and angle due to "scattering"

Detection and cuts

- After scattering, electrons continue to radiate externally until detected
- Beam energy E_b and detected energy E_d are used to calculate observed kinematic variables
- The following cuts are applied:
  - $|\theta_{TRANSPORT}| < 0.06$
  - $|\phi_{TRANSPORT}| < 0.03$
  - $|\delta p/p| < 0.04$
  - Scattering vertex within $|z| < 10$ cm by design

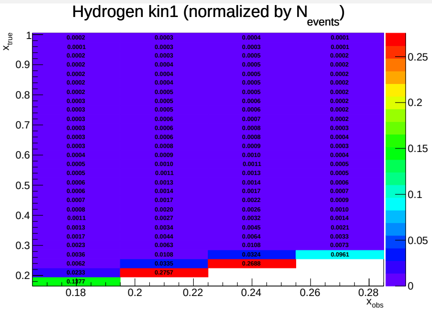
Bin smearing

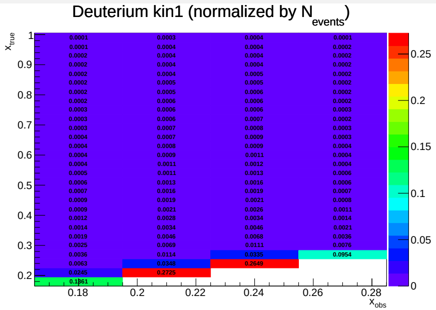
We are interested in smearing between x_{true} and x_{obs} bins
$\rightarrow$ look at histograms of x_{true} vs. x_{obs}

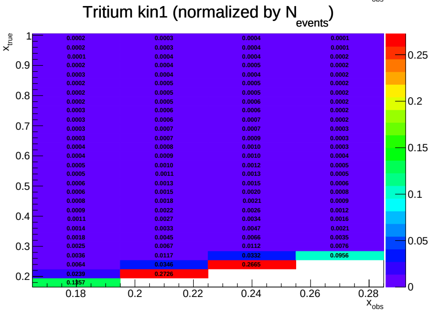


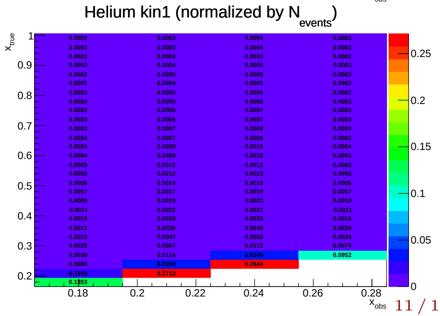
- Absolute bin contents are not relevant
- Normalize by total number of events to obtain percentage of events that are (or are not) binned correctly

Simulation results





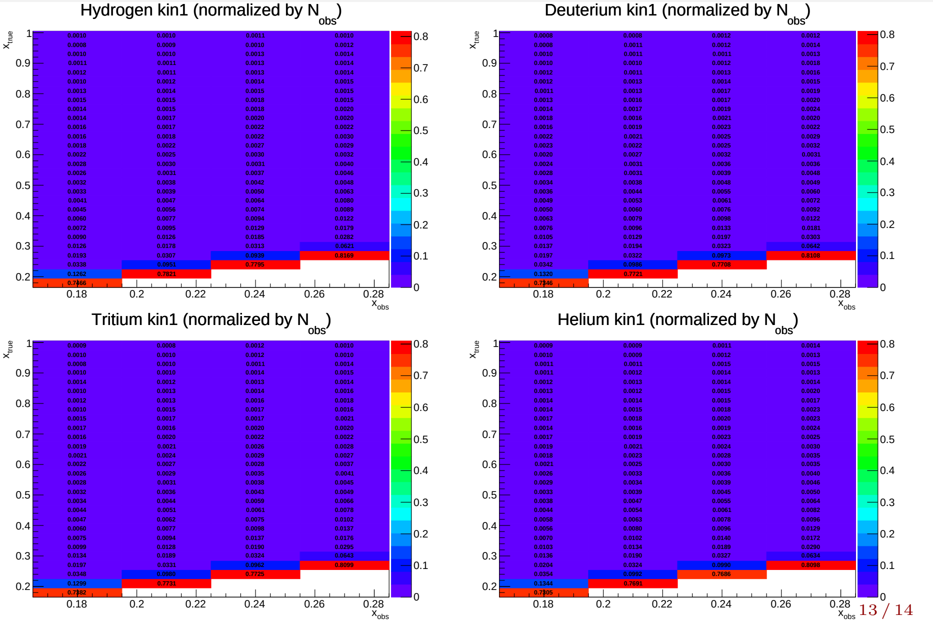




Summary

- GEANT4 program simulates bin smearing due to radiative effects (shown here for kin 1)
- Simulation underway for other kinematic settings
- Additional analysis of output needed to answer final question... ...do radiative effects cancel in cross section ratios?

x_{obs} column normalization



x_{true} row normalization