Results from `g4rc`

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- Decided to abandon cross section models in `g4rc`
  - Troubleshooting issues not best use of time
  - Significantly slowed simulation (and lots of events are necessary)
  - Any radiative corrections used will come from `externals` anyway

- For bin smearing study:
  - Simulated $> 10^9$ events for each target
  - Simulated KIN1, where radiative effects are the largest
  - Analysis method and results shown here

Material

Material	X_0 (g cm^{-2})	ρ (g cm^{-3})	Instance (thickness)
Beryllium	65.19	1.848	Beamline window (0.2003 mm)
Aluminum	24.01	2.699	Target cell (*) Scattering chamber (0.406 mm)
Air	36.62	1.205×10^{-3}	Chamber to Q1 (81.6 cm)
Kapton	40.58	1.420	Q1 window (0.305 mm)
Hydrogen	63.04	2.832×10^{-3}	Target gas (*)
Deuterium	125.97	5.686×10^{-3}	Target gas (*)
Tritium	189.88	3.404×10^{-3}	Target gas (*)
Helium	67.42	2.135×10^{-3}	Target gas (*)

**thickness depends on target and/or scattering angle*

- When available, X_0 obtained from PDG
    - For tritium and helium, X_0 obtained from $A \leq 4$ approximation
- Target gas densities obtained from TGT-CALC-17-020 (D. Meekins)
- All other densities obtained from PDG

Total radiation length

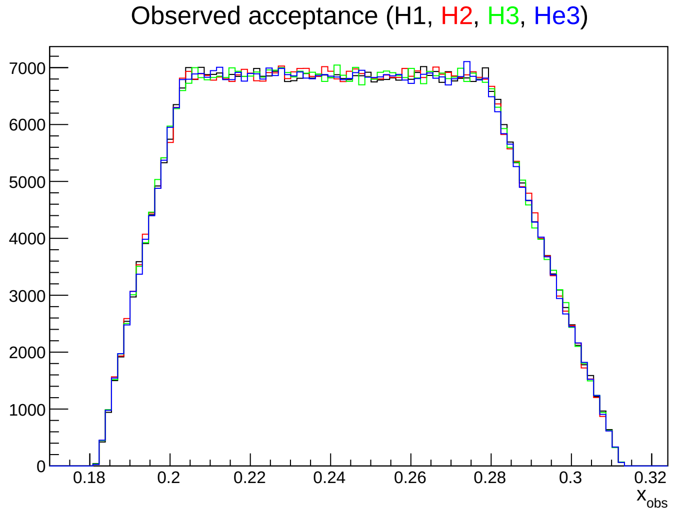
- Sum total radiation length traversed by electron scattered at $z = 10$ cm, $\theta = 17.577°$
- Use average of target cell side measurements (entrance, middle, exit) for cell exit thickness

Radiation length (%)

	Hydrogen	Deuterium	Tritium	Helium
Be window	0.057	0.057	0.057	0.057
Al cell entrance	0.350	0.242	0.284	0.228
Target gas	0.101	0.102	0.040	0.071
Al cell exit	1.581	1.473	1.591	1.718
Al chamber window	0.456	0.456	0.456	0.456
Air drift	0.269	0.269	0.269	0.269
Kapton window	0.107	0.107	0.107	0.107
TOTAL	**2.920**	**2.705**	**2.804**	**2.906**

Binning

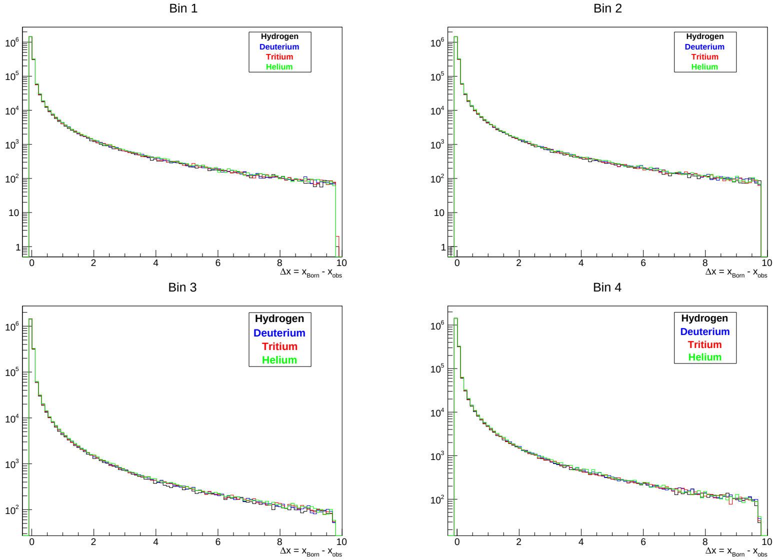
Binning is based on observed x distribution



Bin in range $0.20 < x < 0.28$ with a bin width of 0.02

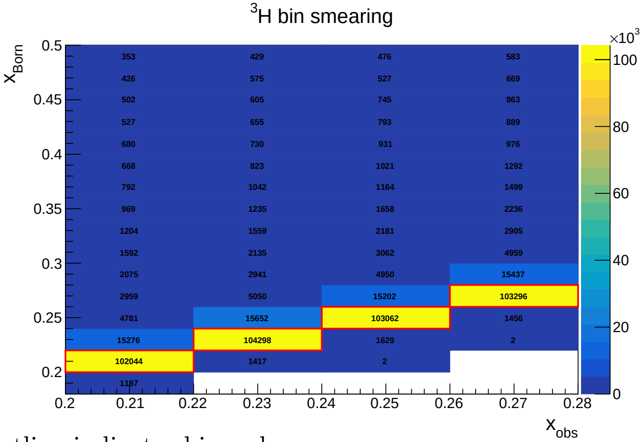
Δx distributions

High-level look at radiative effects: 1D distribution of $\Delta x = x_{Born} - x_{obs}$



Smearing matrix

Looking closer: 2D bin smearing matrix (*not full data set*)



- Red outline indicates bins where $x_{Born} = x_{obs}$
- For illustrative purposes, x_{Born} axis has been truncated at 0.5
- Neat plot, but limited usefulness

Quantifying radiative effects

- Δx and smearing matrix give a broad look at radiative effects
- However, a more quantitative description required for rigorous comparison of targets
- Description must take into account two effects of radiative processes:
  - missing events that *should* be observed in bin but *are not*
  - spurious events that *should not* be observed in bin but *are*

Defining event cuts

Cuts on Born variables:

BORNACC $\equiv |\theta_{Born}| < 0.06$ & $|\phi_{Born}| < 0.03$ & $|(\delta p/p)_{Born}| < 0.04$
$(in\ Born\ acceptance)$

BORNBIN $\equiv x_{min} \leq x_{Born} < x_{max}$
$(in\ Born\ x\ bin)$

BORN $\equiv$ BORNACC & BORNBIN

Cuts on observed variables:

OBSACC $\equiv |\theta_{obs}| < 0.06$ & $|\phi_{obs}| < 0.03$ & $|(\delta p/p)_{obs}| < 0.04$
$(in\ observed\ acceptance)$

OBSBIN $\equiv x_{min} \leq x_{obs} < x_{max}$
$(in\ observed\ x\ bin)$

OBS $\equiv$ OBSACC & OBSBIN

Counting electrons

For each bin, count number of events in five categories:

$$N_{Born} = N(\text{BORN})$$

$$N_{obs} = N(\text{OBS})$$

$$N_{good} = N(\text{BORN \& OBS})$$

$$N_{rad}^{out} = N(\text{BORN \& !OBS})$$

$$N_{rad}^{in} = N(\text{!BORN \& OBS})$$

If three of these are known, other two can be found by:

$$N_{Born} = N_{good} + N_{rad}^{out}$$

$$N_{obs} = N_{good} + N_{rad}^{in}$$

Probabilities

For a random event from Born bin, what is the probability that it...

- ...stays in the correct bin? $P_{good}^{Born} = \frac{N_{good}}{N_{Born}}$

- ...radiates out of the correct bin? $P_{rad}^{out} = \frac{N_{rad}^{out}}{N_{Born}}$

For a random event from observed bin, what is the probability that it...

- ...belongs in this bin? $P_{good}^{obs} = \frac{N_{good}}{N_{obs}}$

- ...radiated in from a different bin? $P_{rad}^{in} = \frac{N_{rad}^{in}}{N_{obs}}$

Radiative correction factor

Using these numbers and probabilities,

$$N_{Born} = \left(\frac{P_{good}^{obs}}{P_{good}^{Born}} \right) N_{obs} = \left(\frac{1 - P_{rad}^{in}}{1 - P_{rad}^{out}} \right) N_{obs}$$

$$\equiv R_c \, N_{obs}$$

where R_c is the "radiative correction".*

**Obtaining absolute radiative correction using this method is not quite this simple*

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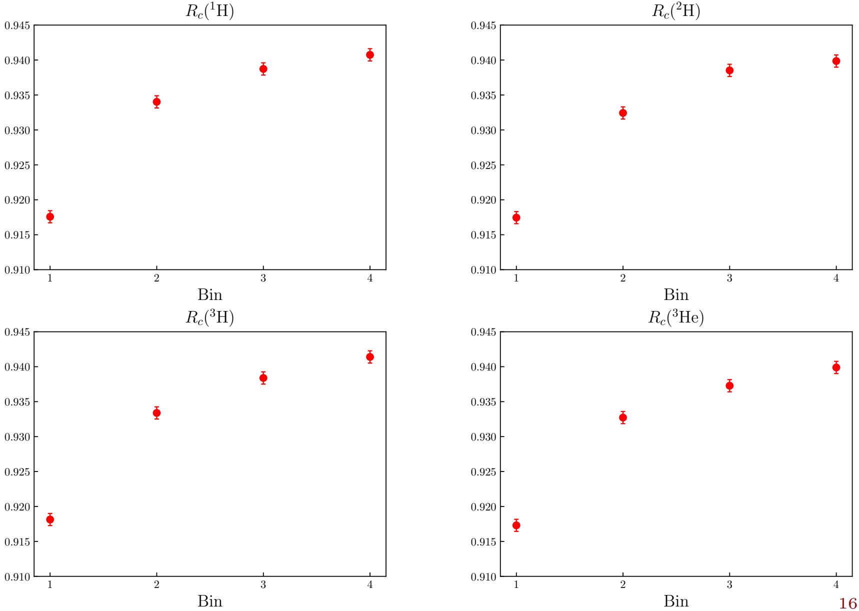
Yes.

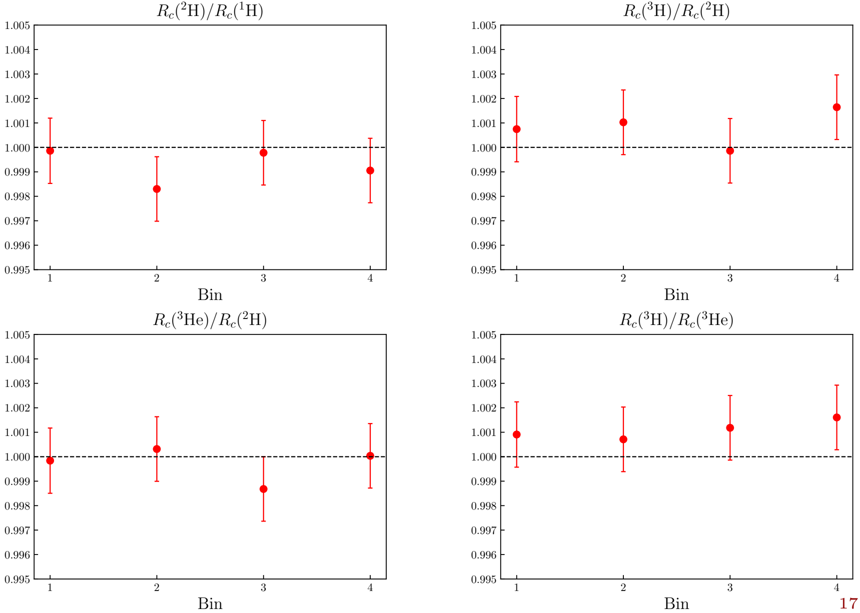
- Probability approach is transparent to the processes being corrected (events radiating in vs. events radiating out)
- Simply stating N_{Born}/N_{obs} is rather opaque
- However, they are mathematically equivalent

**Obtaining absolute radiative correction using this method is not quite this simple*

"Radiative correction"

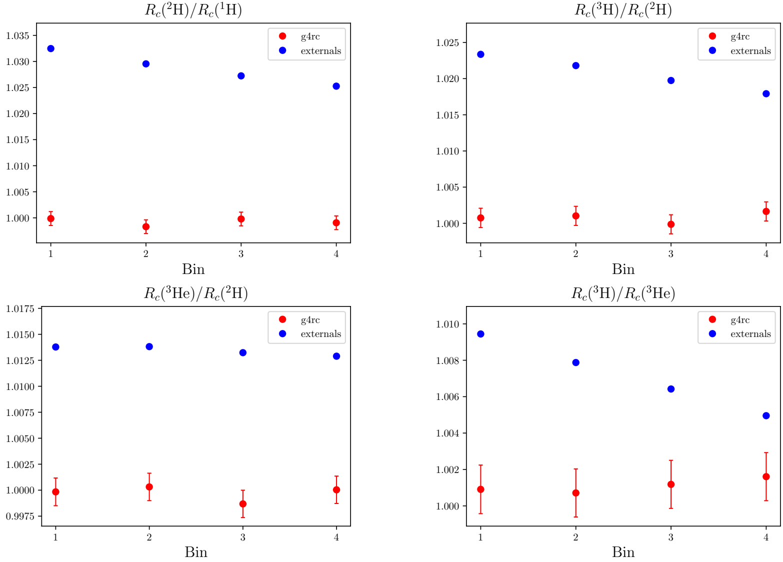


Radiative correction ratios



Comparison to `externals`

Use bin averages from `g4rc` to calculate radiative correction from `externals`



Cross checking results

- `g4rc` indicates that radiative effects in ratios cancel to $<0.2\%$
- If one assumes that this result is not correct, what possible oversights could be giving the false cancellation?
- Most obvious (at least to me) possibilities:
  1. GEANT4 is not simulating the differences in target gases

     $\rightarrow$ *rerun simulation with thicker targets*
  2. Non-uniform sampling (i.e., physical cross sections) cause net bin migrations that don't cancel between targets

     $\rightarrow$ *redo analysis with different non-uniform weights for each target*
  3. Suggestions?

Working on finishing these cross-checks ASAP