Optimizing energy and acceptance for PREX-II

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Approach

Explore how error in neutron radius changes with beam energy and acceptance

- Run `g4hrs` with beam energies between:

$$900 \leq E \leq 1063 \text{ MeV}$$

- For each E, examine acceptances with average momentum transfer of:

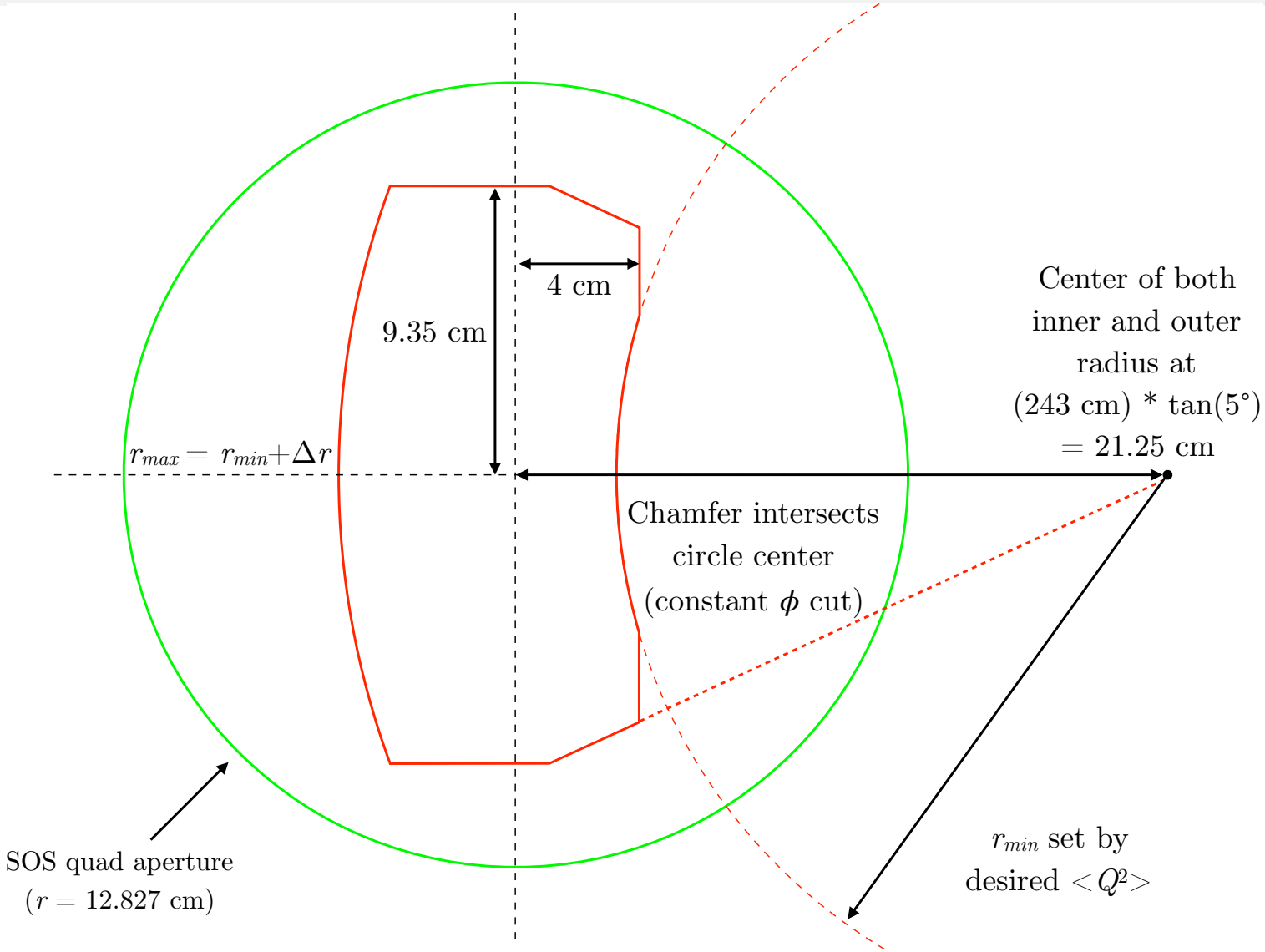
$$\langle Q^2 \rangle = Q^2(E,\ 5^\circ) \quad , \quad \langle Q^2 \rangle = Q^2(E,\ 5^\circ) \pm \Delta Q^2(E)$$

- For each set of $(E,\ \langle Q^2 \rangle)$, vary collimator acceptance defined by:

$$\Delta r = r_{outer} - r_{inner},$$

  the difference between the outer and inner collimator radius

Collimator definition



Scan acceptances in the range $0.02 \text{ m} \leq \Delta r \leq 0.12 \text{ m}$

Assumption

This study counts *all* electrons passing through the collimator and entering Q1 in the acceptance, which is used to determine:

- Total rate R
- Rate-averaged momentum transfer Q^2, asymmetry A, and sensitivity S

The fractional error in the neutron radius depends on these quantities as:

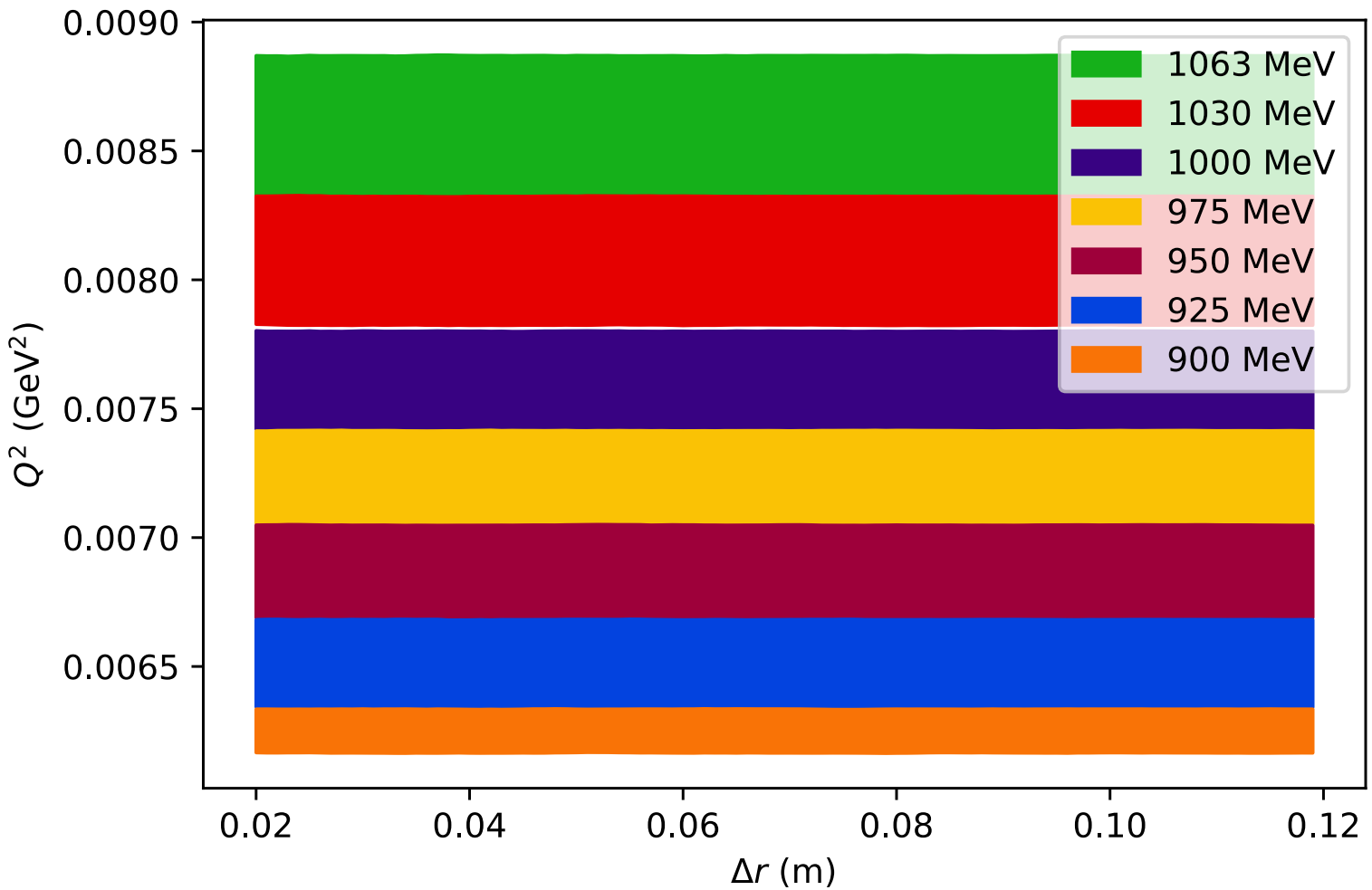
$$\frac{\delta A}{A} = \sqrt{\sigma_{stat}^2 + \sigma_{sys}^2}$$

$$\sigma_{stat} = \frac{\sigma_{det}/\sqrt{R \times d \times 24 \times 3600}}{PA}$$

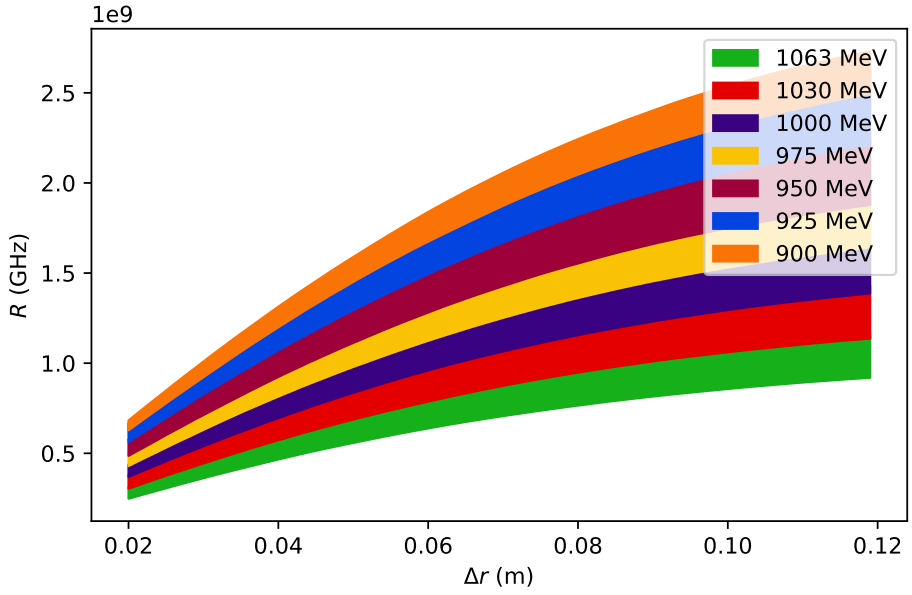
$$\frac{\delta R}{R} = \frac{\delta A}{A} \times \left(\frac{0.01}{S}\right)$$

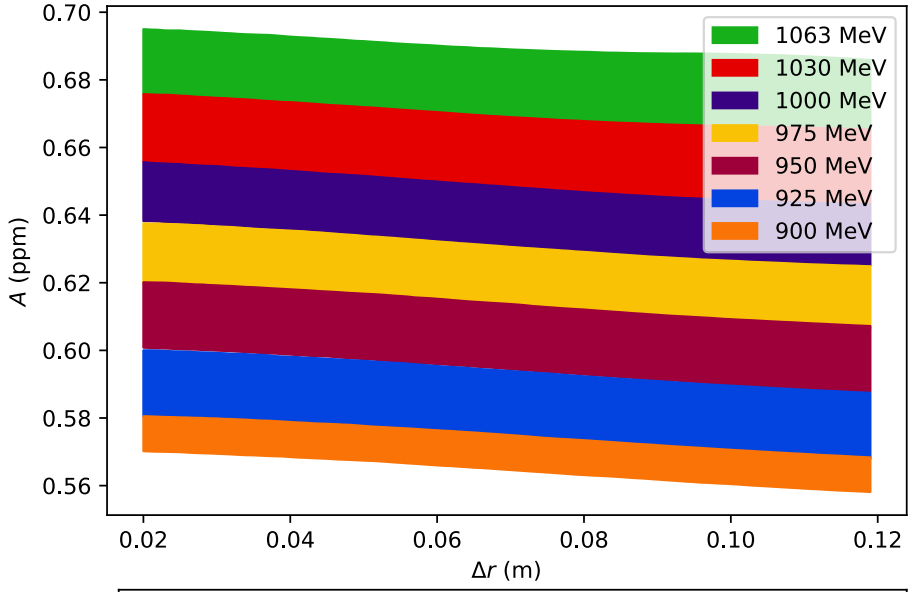
Phase space coverage

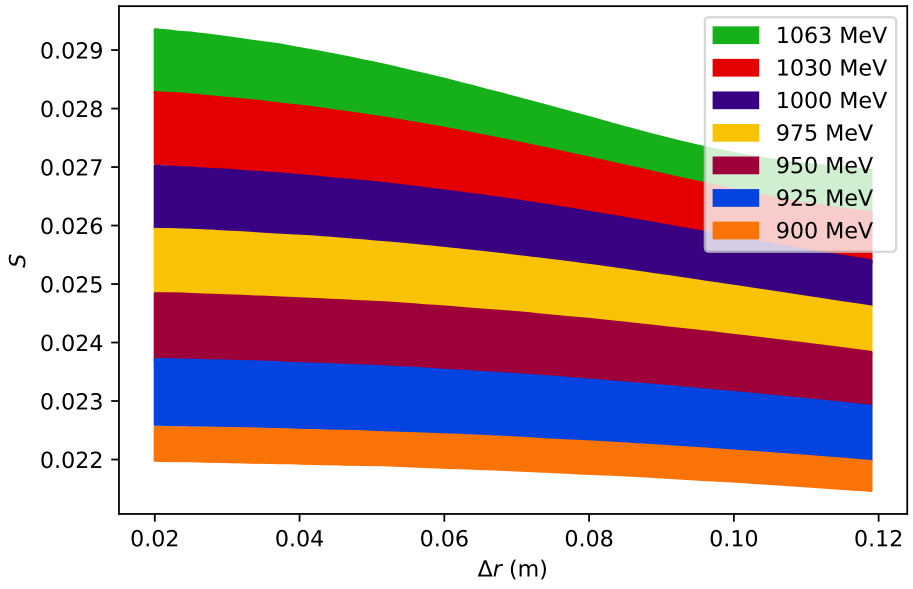
Values of ΔQ^2 chosen for each energy to provide nearly complete Q^2 coverage in region of interest

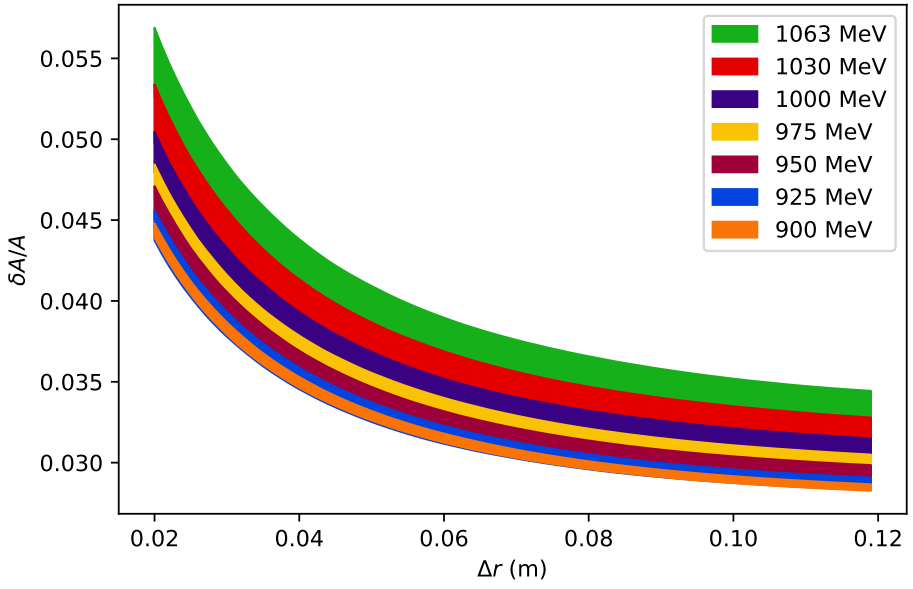


Results

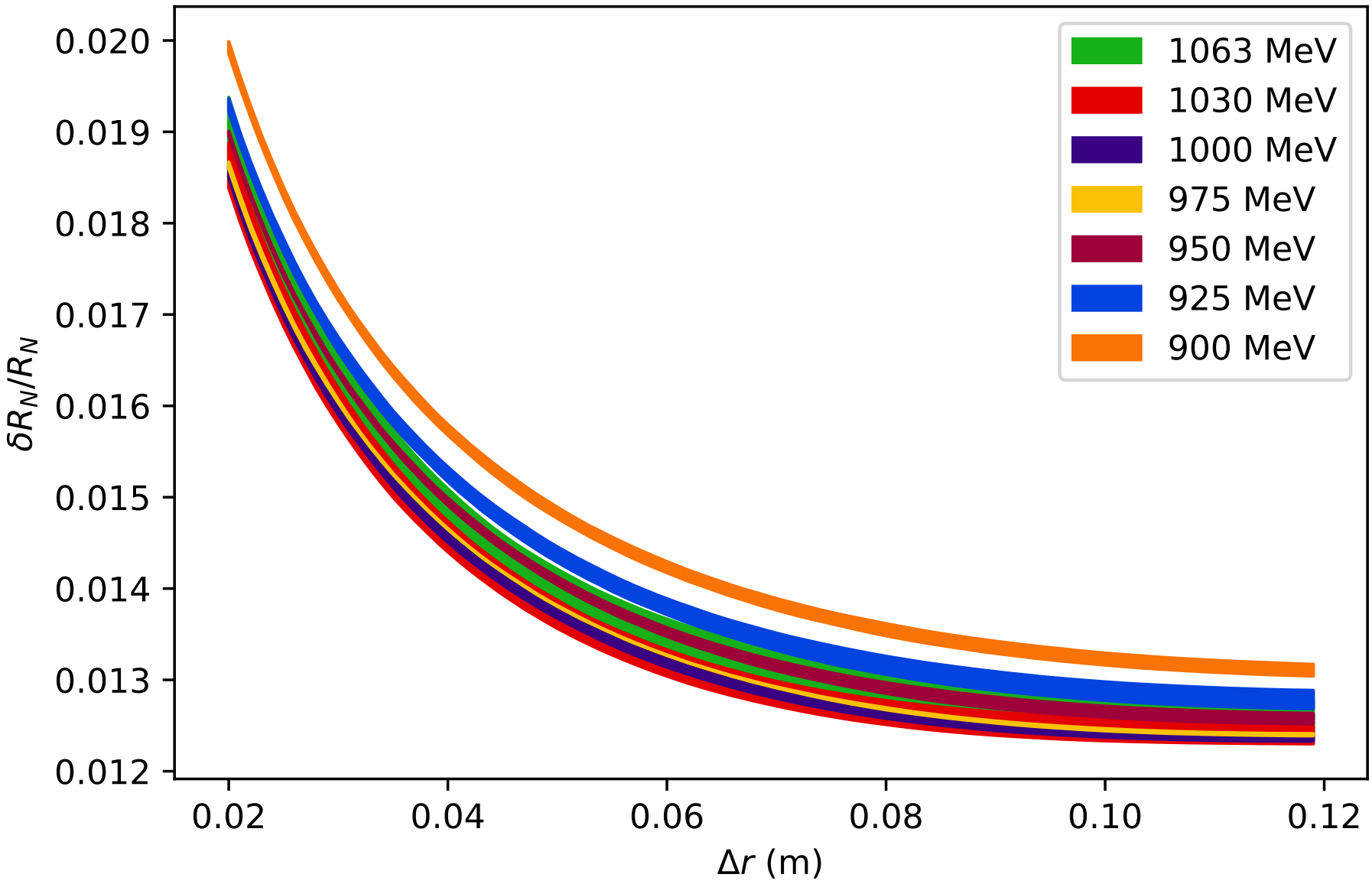

1e9
R (GHz)
Δr (m)
1063 MeV
1030 MeV
1000 MeV
975 MeV
950 MeV
925 MeV
900 MeV


A (ppm)
Δr (m)
1063 MeV
1030 MeV
1000 MeV
975 MeV
950 MeV
925 MeV
900 MeV

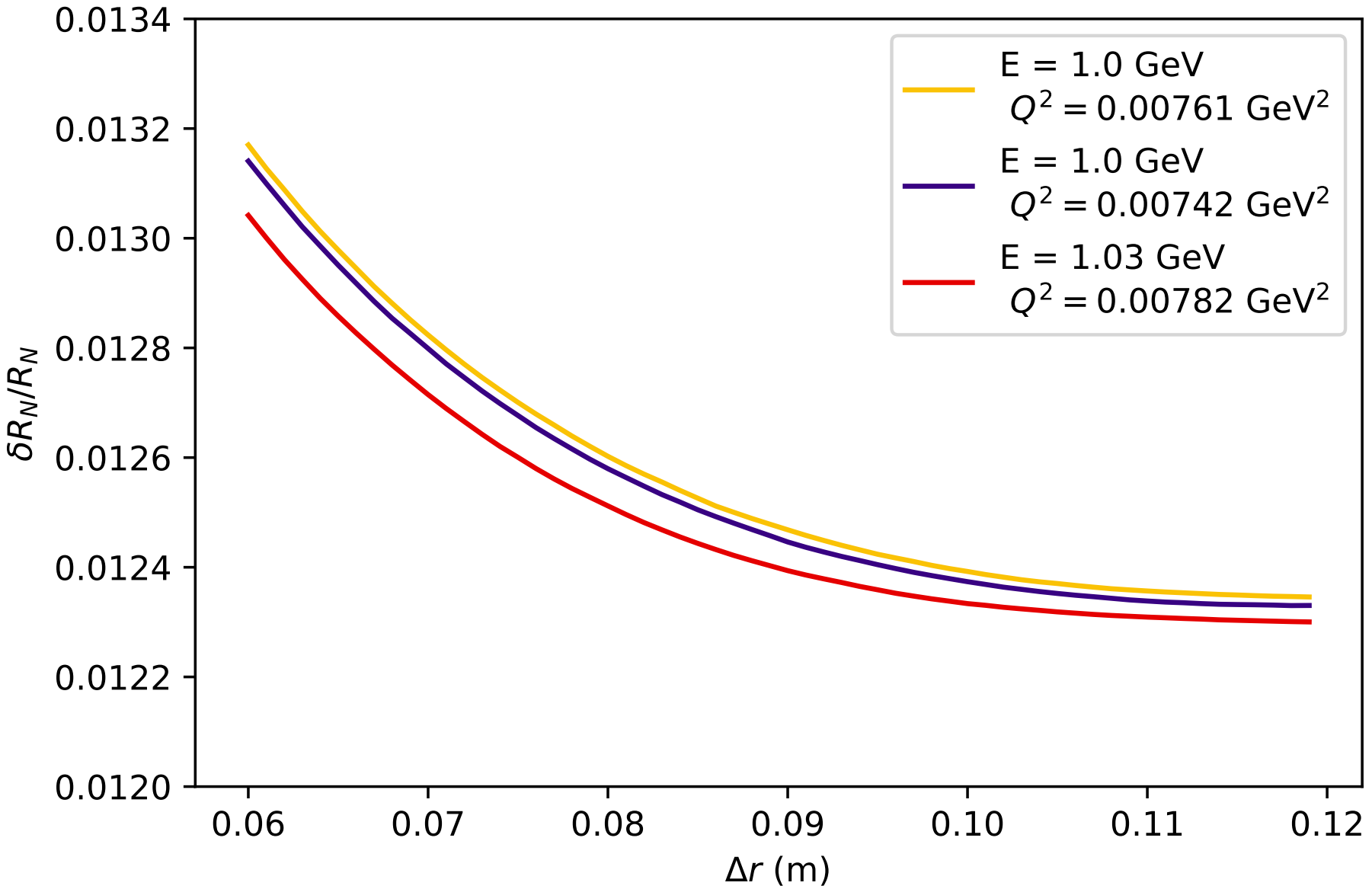

S
Δr (m)
1063 MeV
1030 MeV
1000 MeV
975 MeV
950 MeV
925 MeV
900 MeV


δA/A
Δr (m)
1063 MeV
1030 MeV
1000 MeV
975 MeV
950 MeV
925 MeV
900 MeV

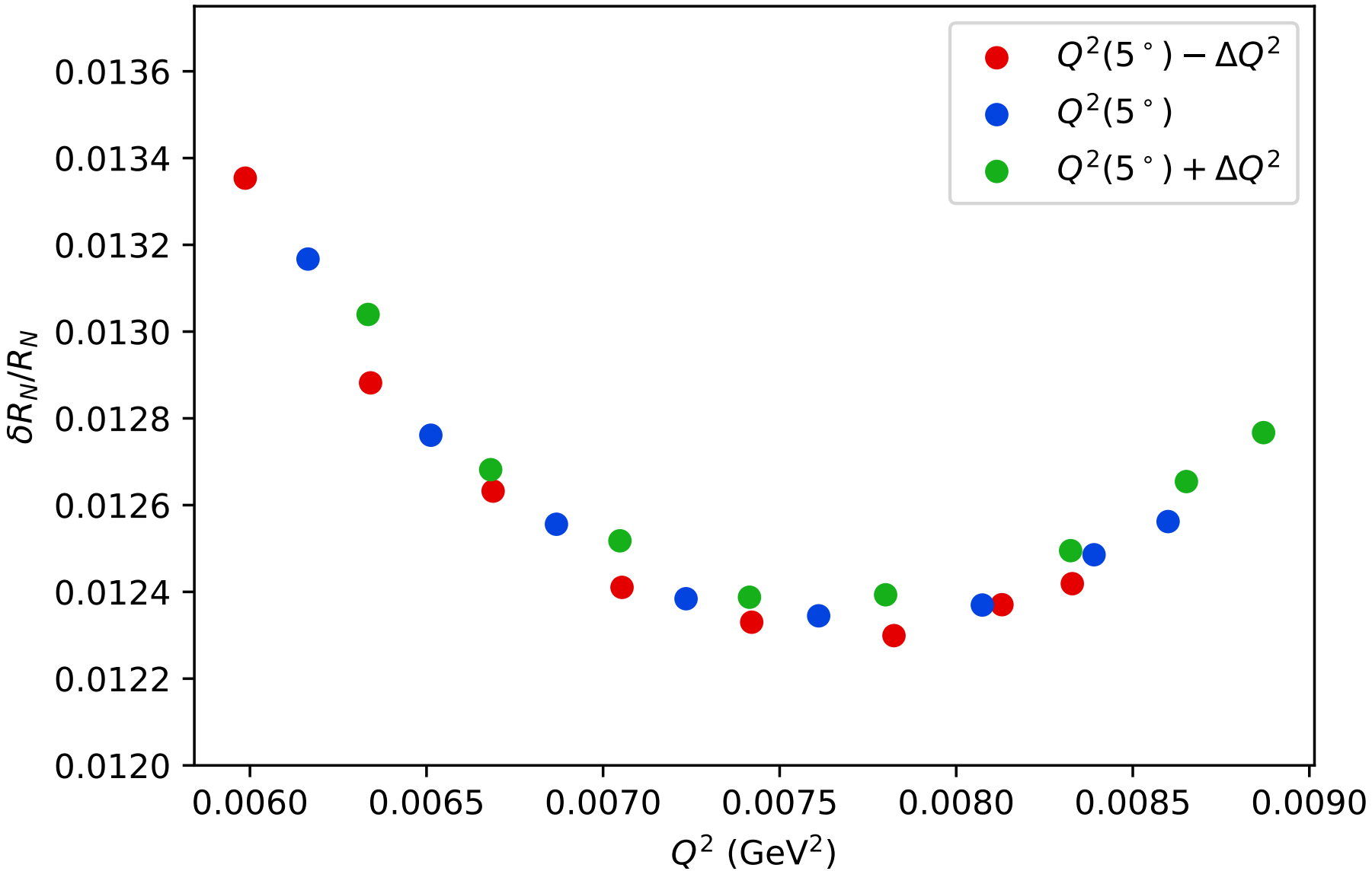
Neutron radius error



Best acceptance curves



$\delta R/R$ vs. Q^2



Summary

- `g4hrs` yields minimum $\delta R/R \approx 0.0122$, very close to the PREX-II proposal value of $\delta R/R = 0.012$
- `g4hrs` shows $\delta R/R$ minimum at $Q^2 \approx 0.0075 - 0.0080$ GeV^2, opposed to the PREX-II proposal value of $Q^2 \approx 0.00675$ GeV^2
- The estimates from `g4hrs` count all electrons passing collimator in the acceptance. What happens when a realistic detector cut is applied?