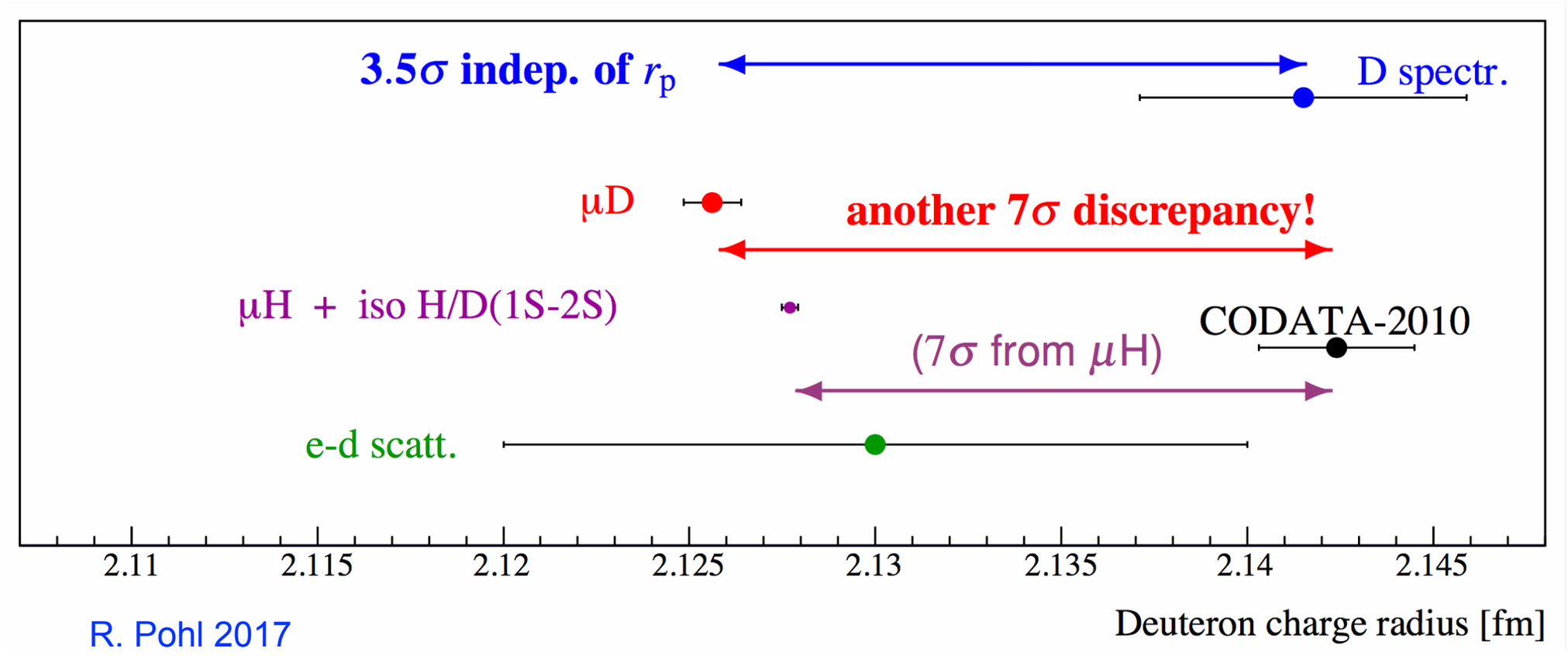
DRad Proposal Discussion

Deuteron Charge Radius

- "Proton Charge Radius Puzzle" is still unsolved after seven years
- There is a newly developing "Deuteron Charge Radius Puzzle"

H/D isotope shift:	$r_d^2 - r_p^2 = 3.82007(65)$ fm2
Muonic deuterium:	$r_d = 2.12562(13)_{exp}(77)_{theory}$ fm
Electronic deuterium:	$r_d = 2.14150(450)$ fm

- New ed cross-sections at low Q^2 will be a critical input to reduce theory error in r_d extracted from μD spectroscopy



R. Pohl 2017

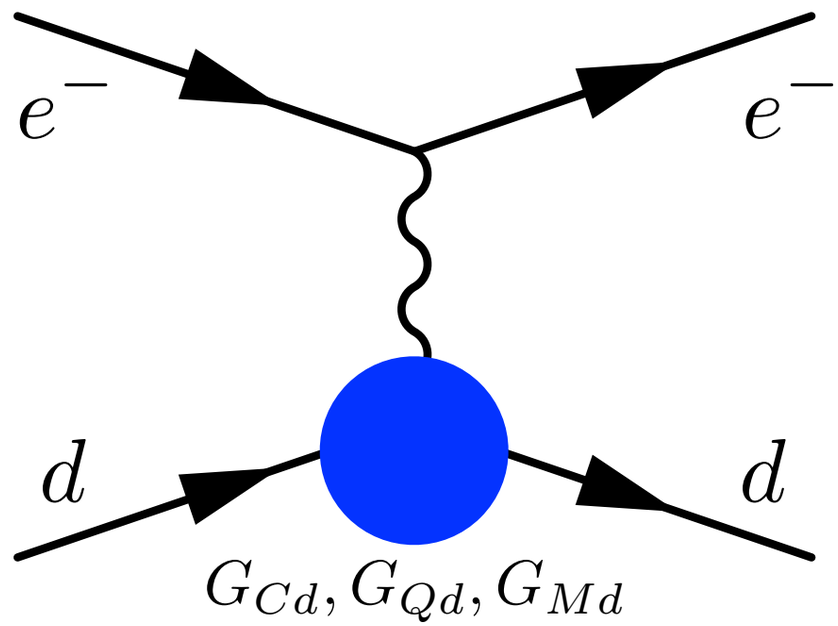
Proposed Experiment

- Elastic ed cross section:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_{\mathrm{NS}} [A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}]$$

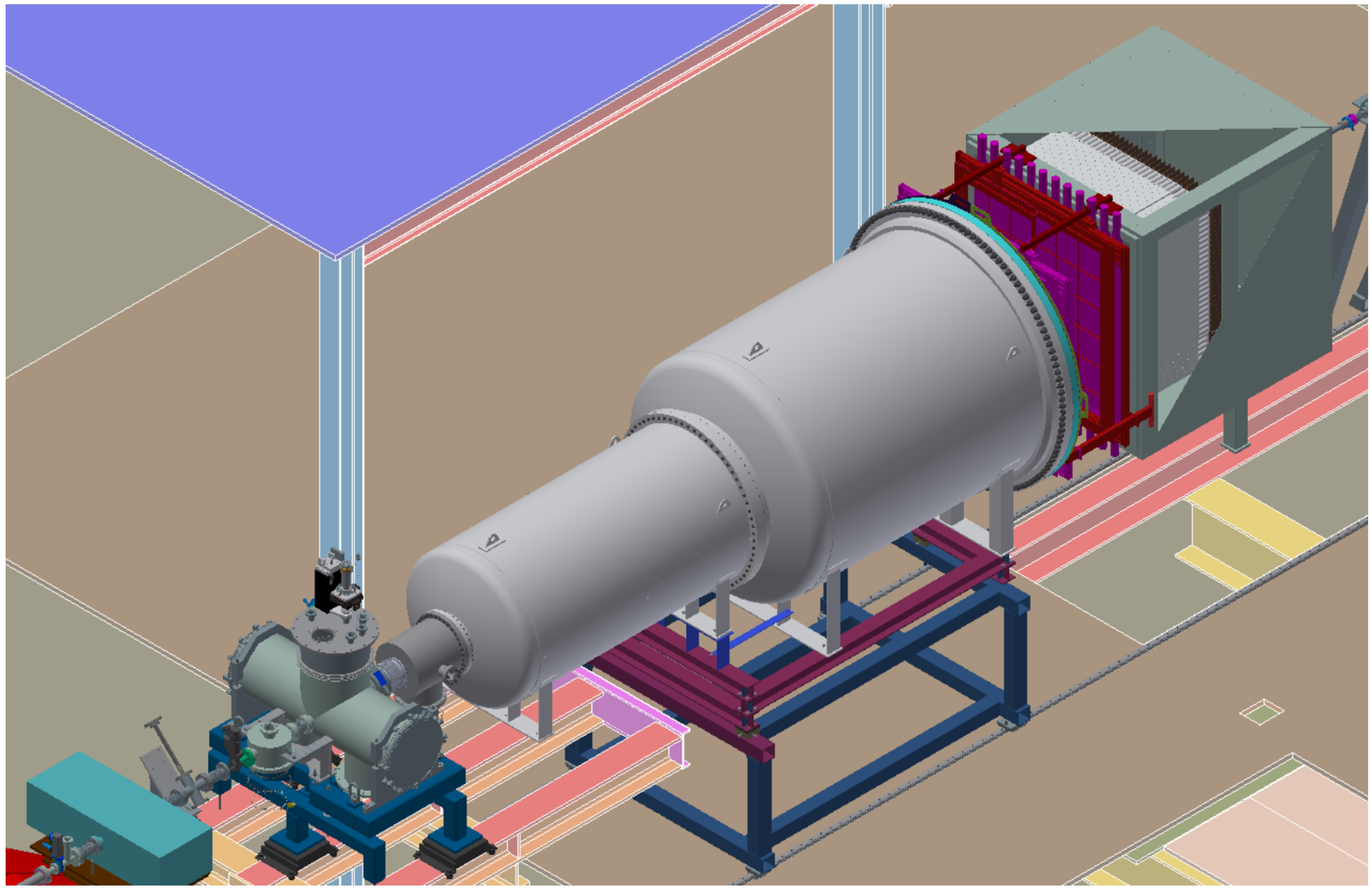
- $A(Q^2)$ and $B(Q^2)$ are related to deuteron charge (G_{Cd}), electric quadrupole (G_{Qd}) and magnetic dipole (G_{Md}) form factors:
  - At low Q^2 contributions from G_{Qd} and G_{Md} are small
- Measure ed->ed elastic (quasi-elastic) cross sections at very low Q^2 range: $2\times10^{-4} \sim 5\times10^{-2}$ GeV^2
  - Cover relatively large Q^2 range in one kinematics setting
  - simultaneous detection of ee->ee Moller scattering process
  - Controlled systematics at sub-percent precision

$$r_d^2 = -6[\frac{\mathrm{d}A(Q^2)}{\mathrm{d}Q^2}]_{Q^2=0}$$



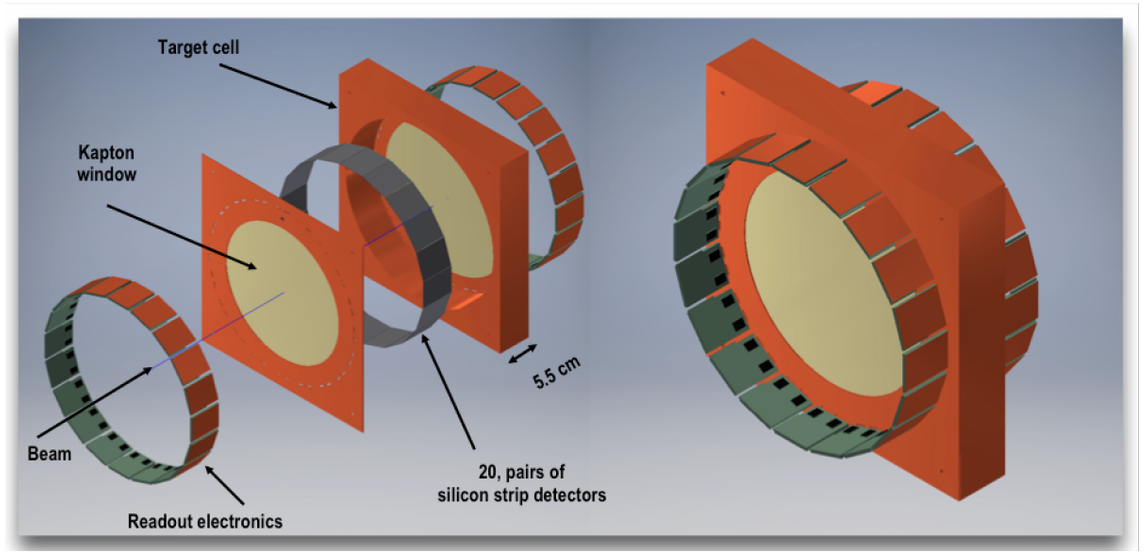
Proposed Experiment

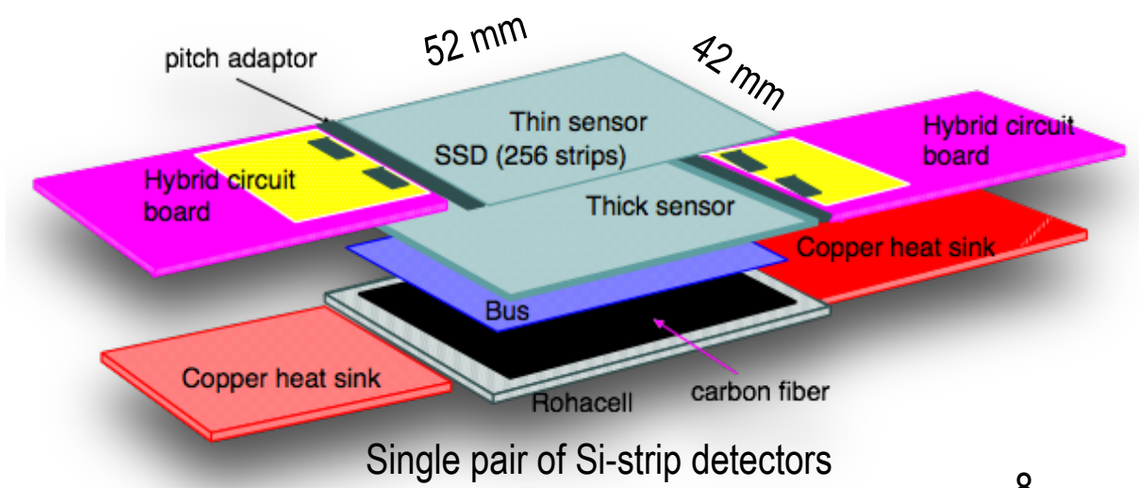
- Based on PRad experiment setup, three additions:
  - Cylindrical recoil detector for reaction elasticity (new)
  - Additional GEM detector for scattered electron tracking (new)
  - Veto counters for timing (PrimEx veto counters)



Si-strip Cylindrical Recoil Detector

- Detection of recoiled deuterons to select elastic events in ed scattering and reject proton backgrounds
- Based on CLAS12 Barrel Silicon Tracker (SVT)
  - Consist of 20 panels of twin, single-sided Si-strip detectors (42x52 mm^2)
  - thicknesses (to be optimized): 200 μm (down), 300 μm (up)
  - 20 sided polygon arrangement with around 13 cm radius
  - 256 strips on each sensor: angular resolution 5 mrad (phi) 20 mrad (theta)
  - Inactive SiO_2 layer can be as thin as 0.5 um

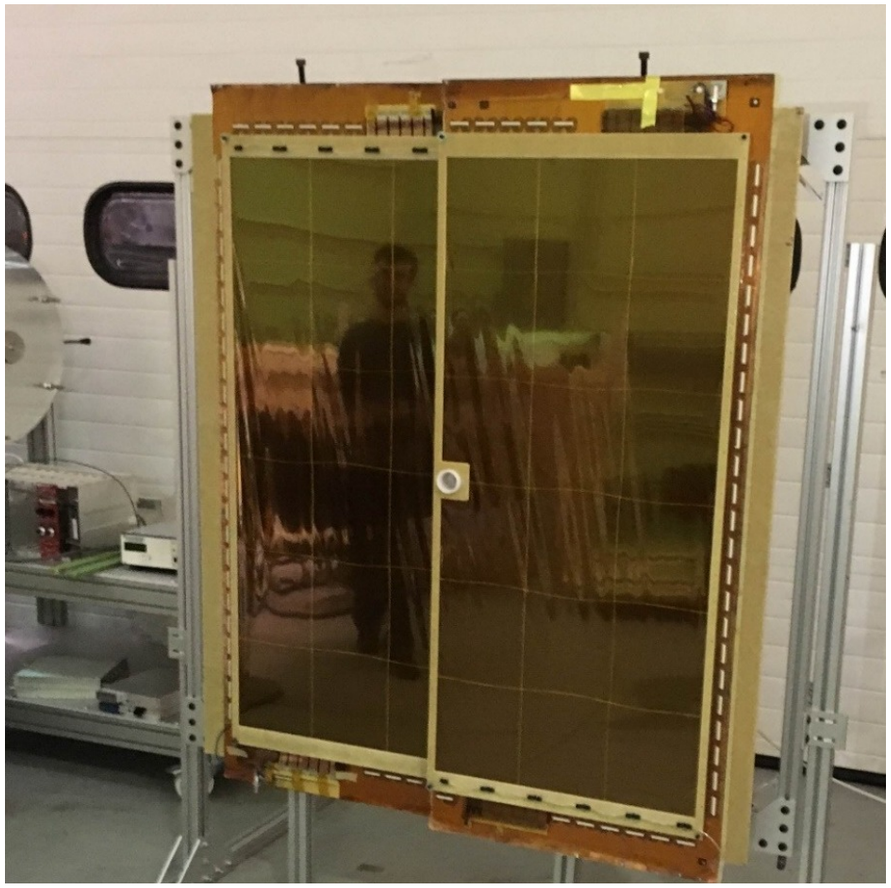


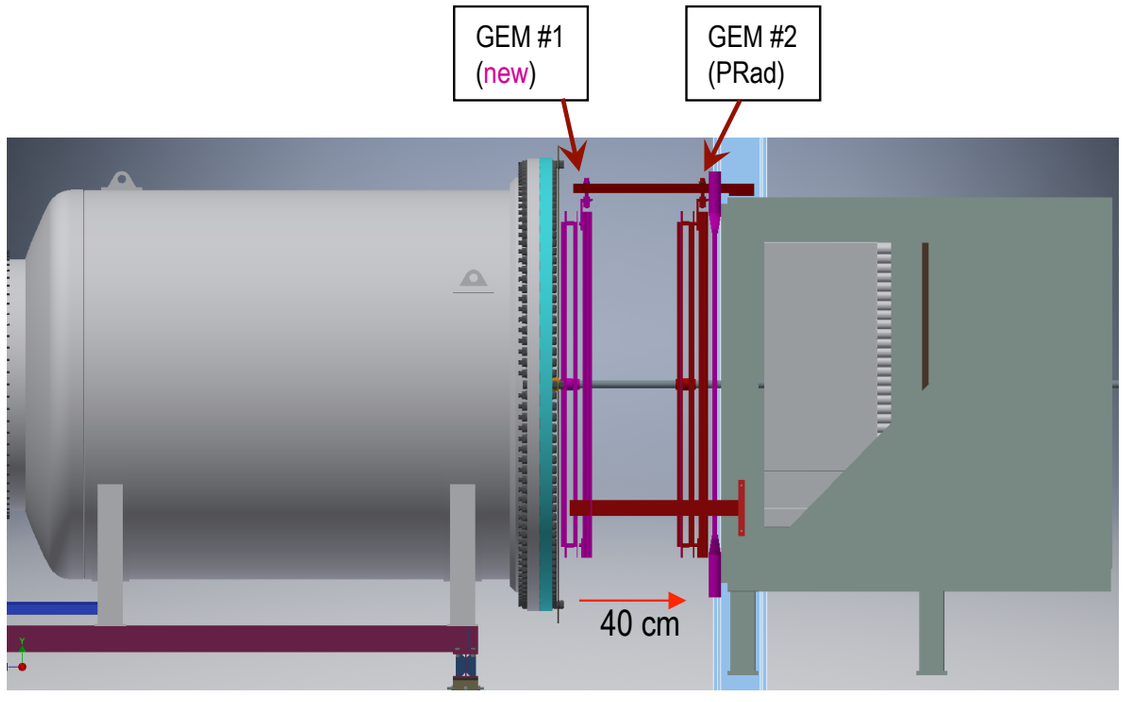


Single pair of Si-strip detectors

Second GEM

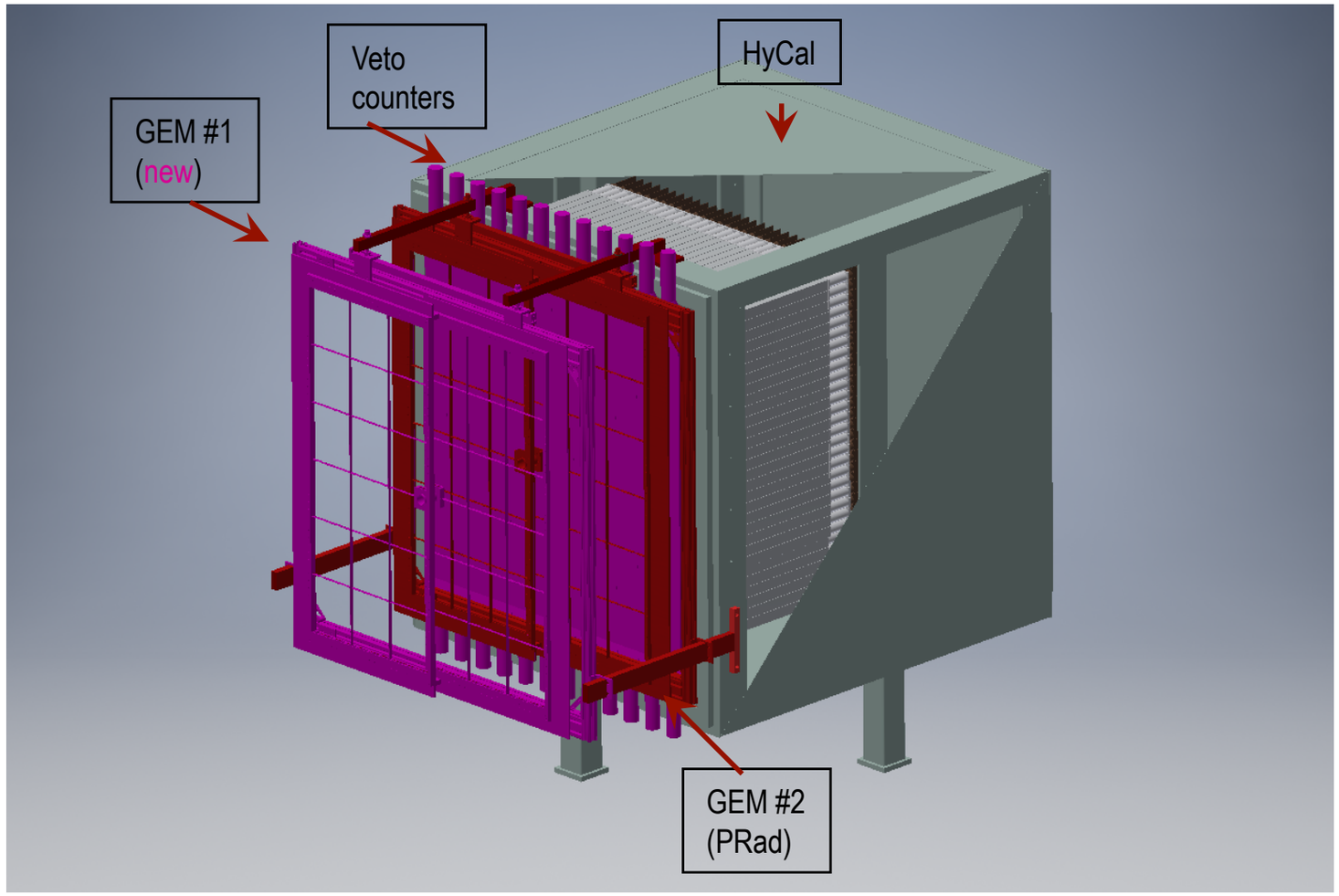
- Based on PRad GEM detector
  - Twice less material (0.25% r.l. vs. 0.5% r.l.)
  - The second GEM is located at 40 cm distance from the first GEM
  - Will provide tracking for the scattered electrons
  - Better control of beam line background, especially at very small angles (electron scattering angle less than 1 deg)





Veto Scintillators

- PrimEx veto counters for timing in scattered electrons (< 1 ns time resolution)

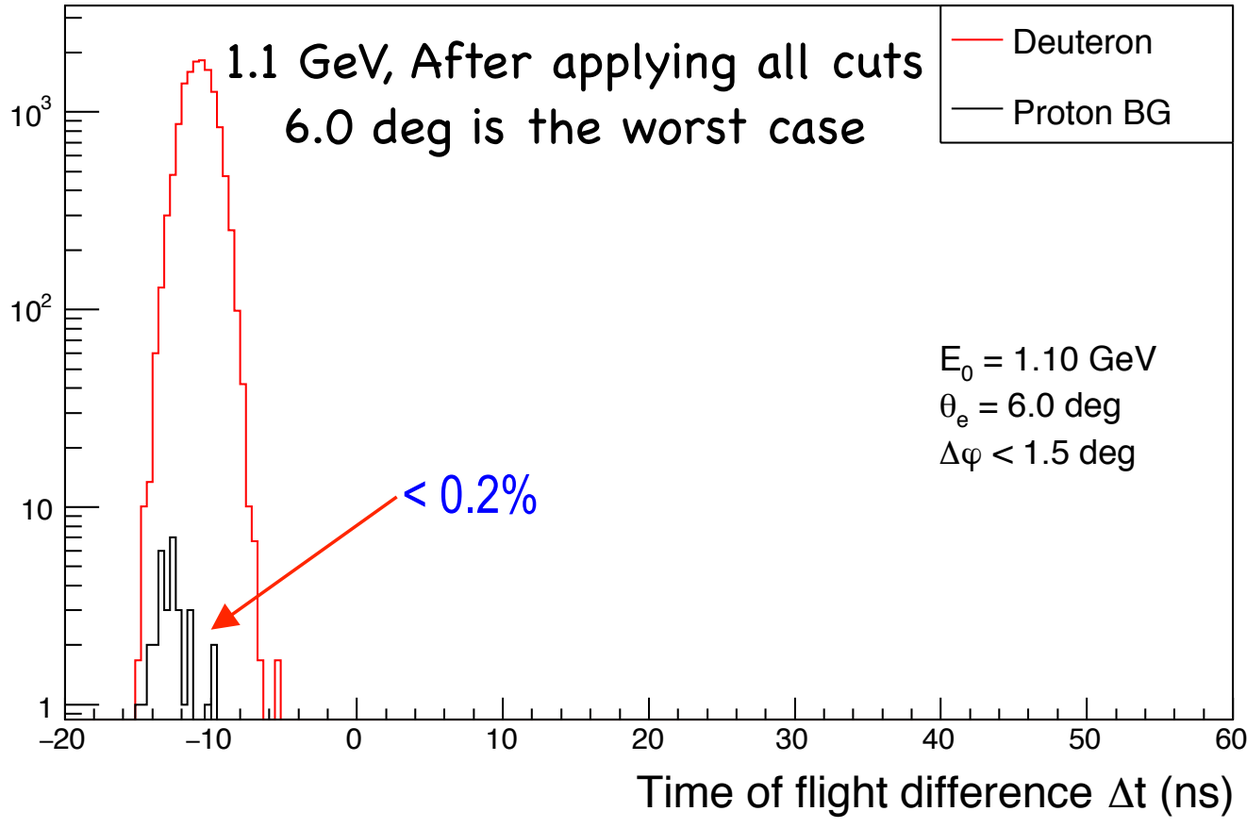


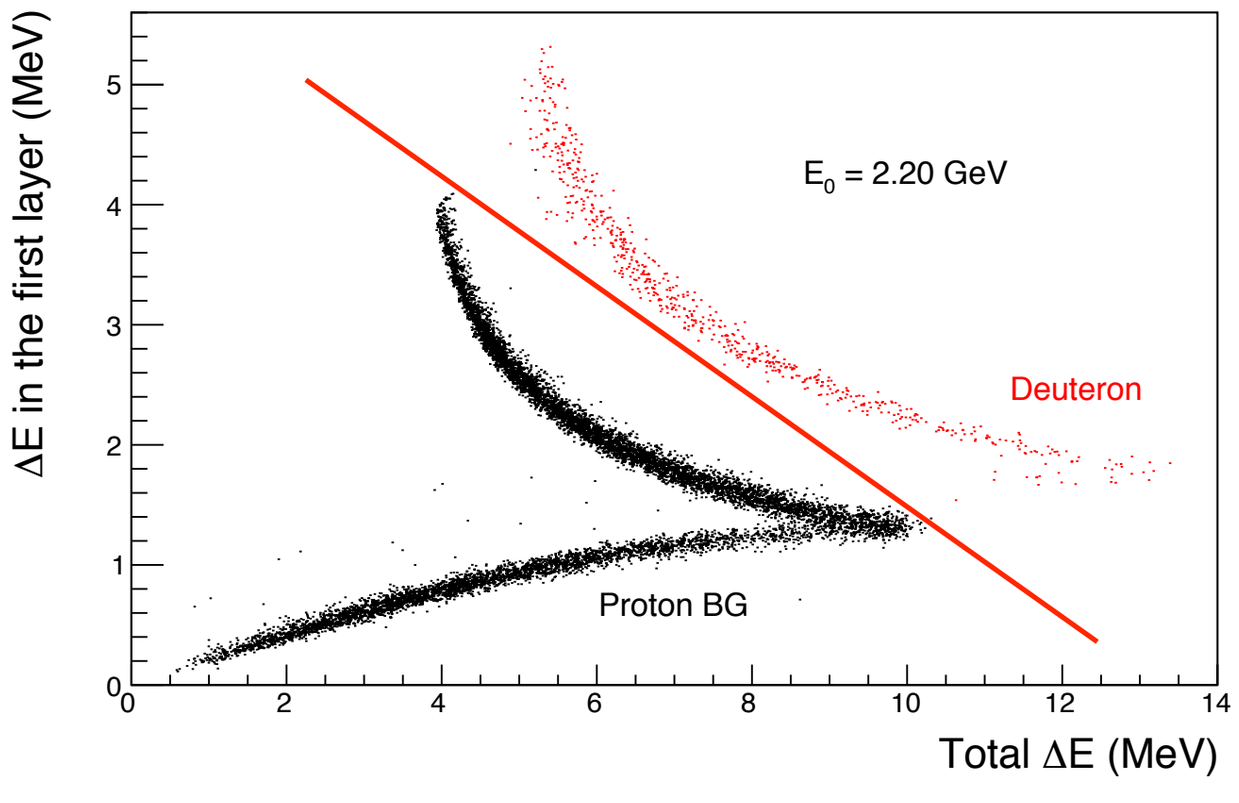
PAC 45 Report

- Issues from PAC45:
  - A complete assessment of the systematic corrections and associated systematic errors in $\delta r_d/r_d$ will only be possible after the analysis of the PRad experiment has finished.
  - The new recoil silicon strip detector for the detection of the scattered deuteron is instrumental to discriminate elastic ed scattering from background, however it is not clear how the efficiency of this detector for the lowest energy deuterons can be determined and calibrated.
  - Extrapolation from protons or higher energy deuterons leads to systematic errors which cannot be quantified.
  - The target experiment error $\delta r_d/r_d$ = 0.5% is too large to give a definitive answer to the primary question.

Simulation

- Simulation results in proposal:
  - Resolutions, kinematics and etc.
- PID for recoiled particles (protons and deuterons)
  - For 1.1 GeV, a cut on time-of-flight between scattered electron and recoiled particles together with a cut on dE in the Si-strip detector
  - For 2.2 GeV, a cut on dE in the first layer vs. total dE in the Si-strip detectors alone is already very effective for PID



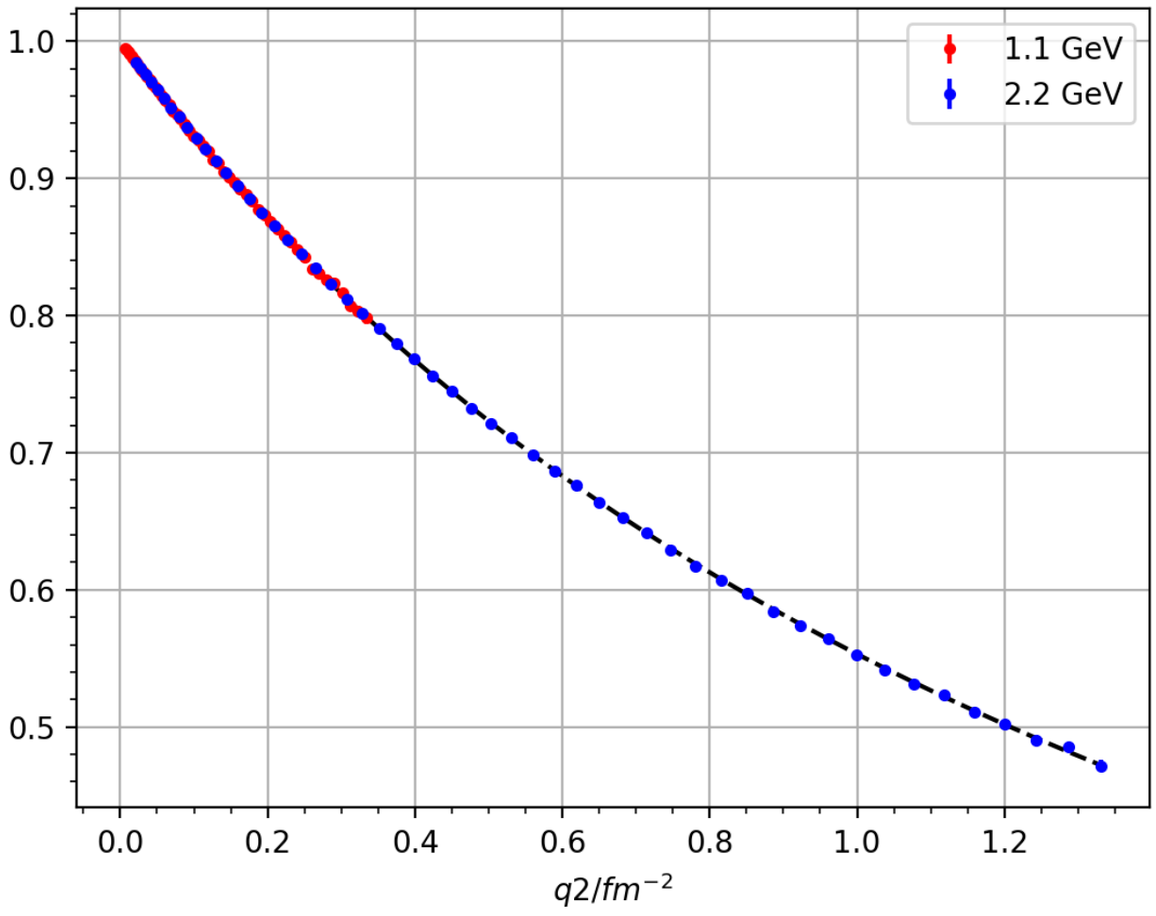


Status Update

- Fitter study for DRad:
  - 3 deuteron parameterizations from t20 result (Alexander uses the first parameterization in his radiated event generator)
  - Repeat the method in Xuefei's paper for deuteron to select a robust formalism to fit the radius and the conclusion is similar, so choose the (1, 1)-order rational-function to do the fitting
- Simulation for deuteron proposal
  - Use Alexander's event generator with radiative effect (soft-photon approximation, parameterization from Eur. Phys. J. A 7(2000)421)
  - 150M ed events at 1.1 GeV and 100M ed events at 2.2GeV as proposed
  - Detector resolution added
  - Radiative correction added following the same method used in PRad
  - Systematic uncertainty added (use 0.5% for cross-section written in the proposal, haven't update with PRad systematics)
  - The simulation results are separated into 500K events segments, and use bootstrap method to estimate the uncertainty

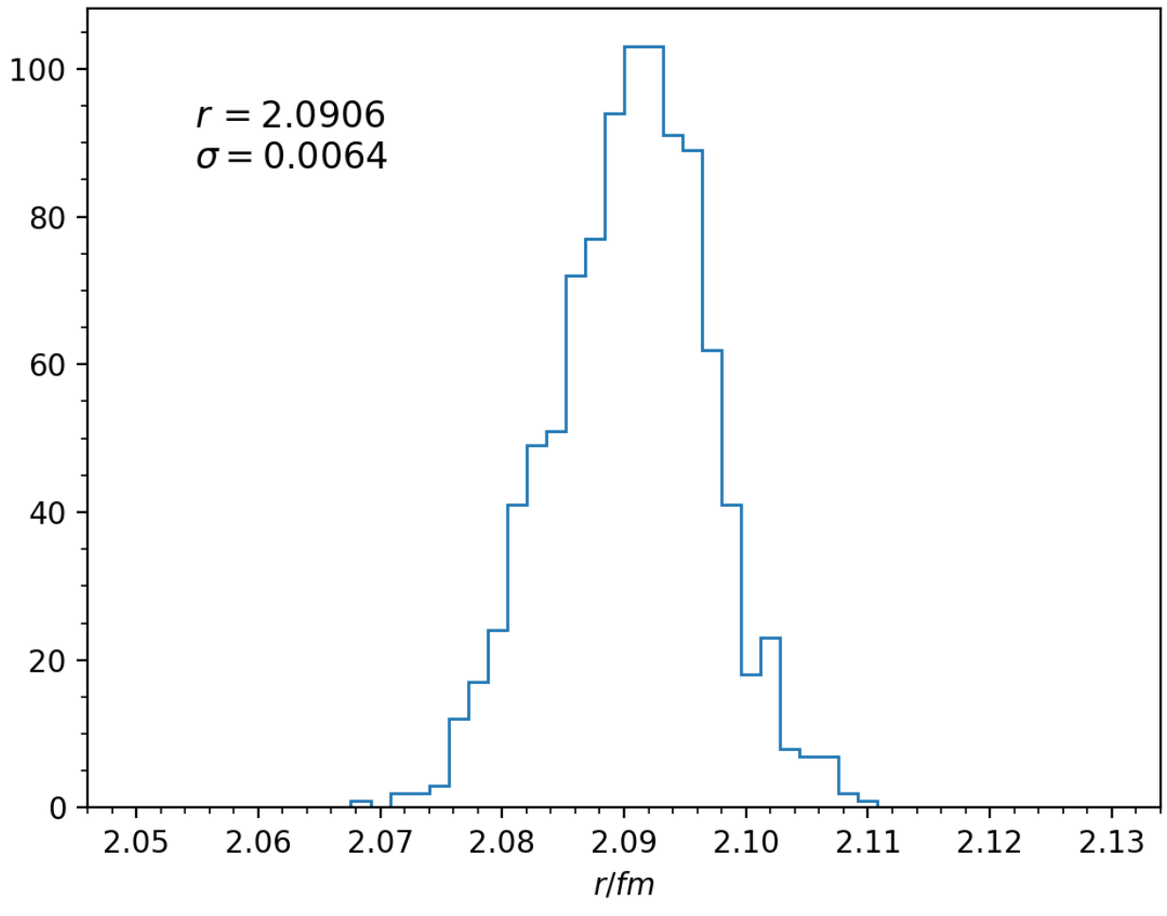
Status Update

One of the fits



The point is drawn with error bar, however the error bar is not large enough to be seen

R distribution for 1000 fittings



The bias is 0.0034 fm (0.16%)
The standard deviation is 0.0064 fm (0.30%)
0.34% in total

Status Update

- Plan:
  - Since we have PRad systematics budgets now, we could estimate a more reasonable uncertainty budget for DRad
  - Repeat previous procedure with new estimation to see the uncertainty we could reach for the proposed experiment

Item	R_p uncertainty (fm)	DRad?
Event selection	0.0092	
Acceptance	0.0054	
Beam background	0.0039	
Detector efficiency	0.0045	
Beam energy	0.0084	
HyCal response	0.0032	
Inelastic ep	0.0051	
Radiative corrections	0.0070	
Total	0.0175	