Plans for the HyCal Upgrade

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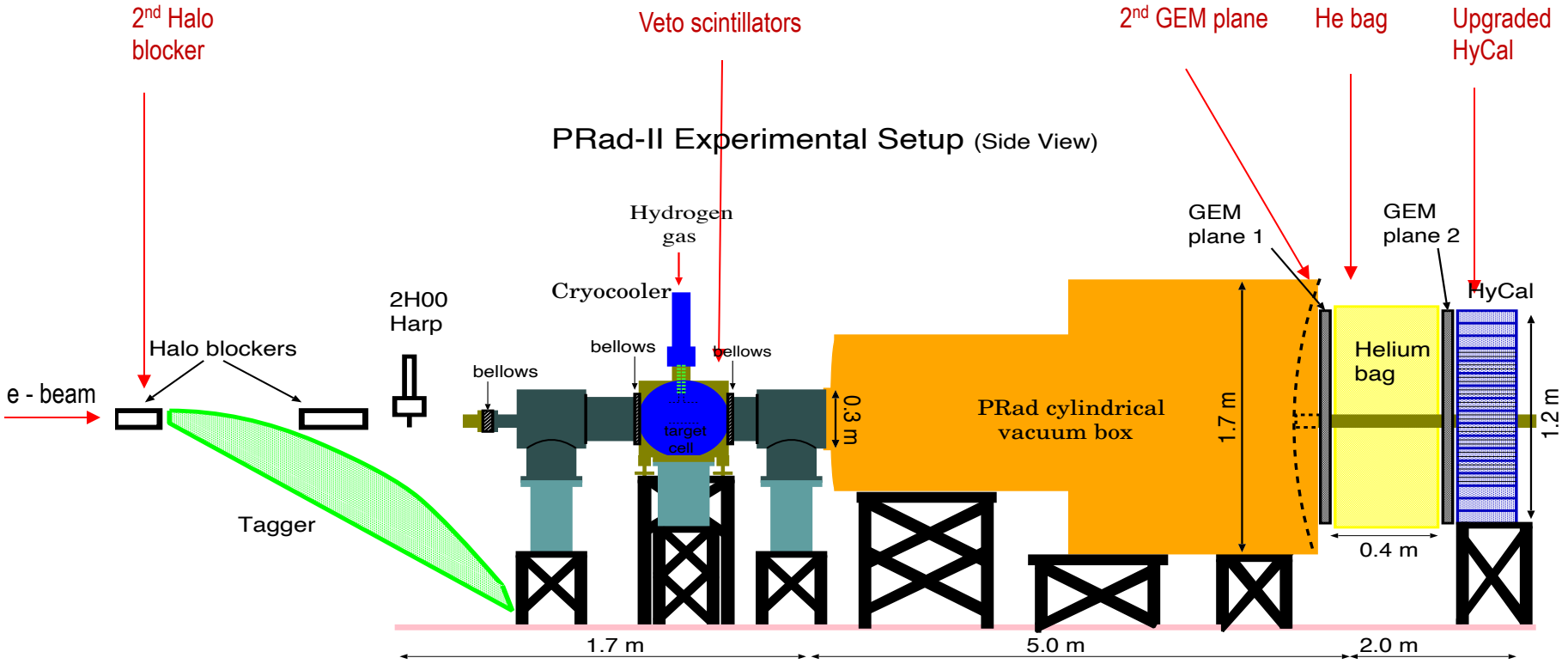
for the PRad collaboration

- some technical aspects of the upgrade
- funding and timeline
- reasons for the upgrade
- contributions to the PRad-II results

HyCal Calorimeter is one of the Major Detectors for PRad-II

- PRad-II is designed to perform the best ep-scattering experiment to extract the proton radius with accuracy better than the current eH spectroscopy experiments.
- Access to one more order of magnitude less Q^2 range ($Q^2 = 2\times10^{-5}$ GeV/c^2)



HyCal Upgrade: Technical Issues

- HyCal upgrade:

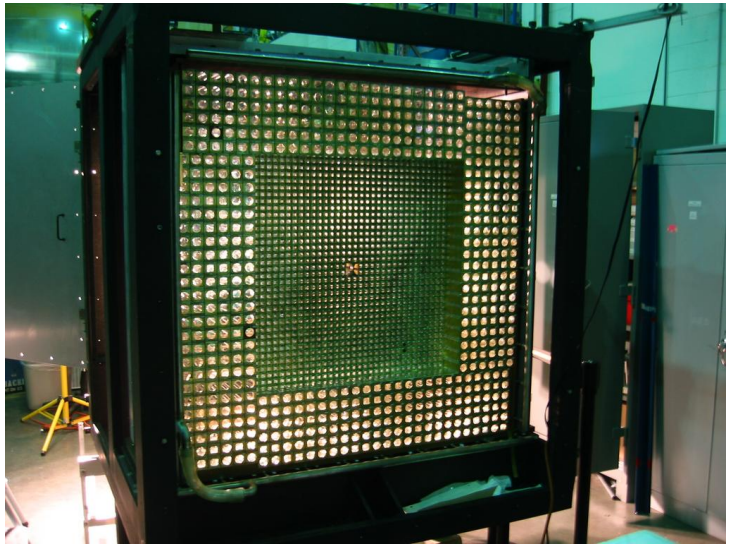
➢ Replace 576 Pb-glass (4x4x40 cm^3) Cherenkov detectors with 2300 $PbWO_4$ crystal (2x2x18 cm^3) based detectors.

➢ Needs: 2300 $PbWO_4$ crystals and PMTs.

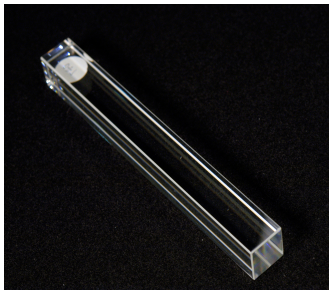
✓ HyCal structure in Hall B, in most part, will stay the same:
- current frame;
- cooling system with the chiller;
- moving transporter;
- cable holding structure;
- stand/moving table.

✓ Engineering drawings for module assembly are available.

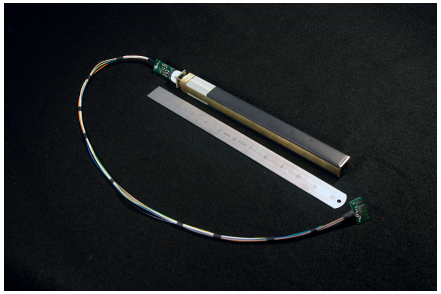
✓ Most of assembly tools are still available.



Front view of HyCal before Light Monitoring System



$PbWO_4$ crystal



Fully assembled $PbWO_4$ based module

HyCal Upgrade: Funding and TimeLine

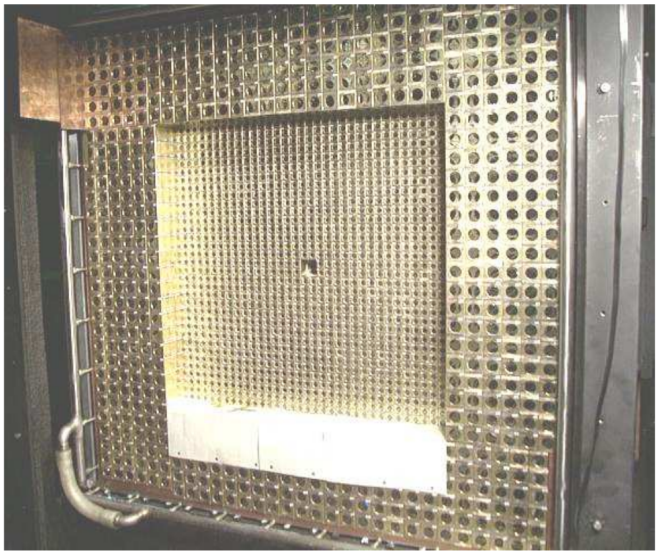
- Funding:
  - PRad collaboration will seek outside funding for this upgrade.
  - ✓ NSF RI-1 pre-proposal is submitted in January 2021 (including ~$5.M for the HyCal upgrade, total: $8.M, this is bi-annual competition, decision for the full proposal will be made in April 2021).

- Timeline (estimated):
  - assuming full proposal invitation in April, funding decision for the proposal is scheduled sometime in fall 2021.
  - assuming approval of our proposal, funds will be available in the beginning of 2022.
  - Procurement of all parts, delivery, tests and assembly will take about 2 years.
  - With this scenario, the PRad-II will be ready to run in 2024.

Reasons for the HyCal Upgrade

- The PRad method is based on 2 major concepts:
  - ✓ measure the ep-elastic cross section in relatively large Q^2 range with one experimental setting;
  - ✓ use detection system uniform vs. scattering angle.

- The current HyCal is not a uniform calorimeter!
  Consist of 2 parts with different position and energy resolutions and assembled differently:
  - ✓ 1152 $PbWO_4$ crystal based detectors (inner part); (good energy and position resolutions);
  - ✓ 576 Pb-glass based detectors (outside part) (3x worse energy and position resolutions);
  - ✓ existence of the “transition region”.



Front view of HyCal before Light Monitoring System

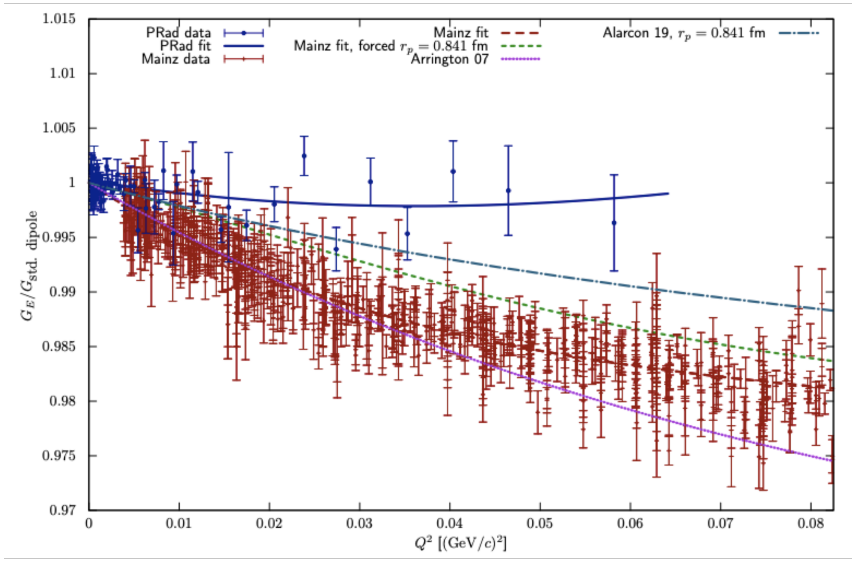
- Effects of the current HyCal in the PRad result:
  - ✓ ep-inelastic contributions (at larger angles);
  - ✓ event selection (at larger angles);
  - ✓ GEM detection efficiency (at larger angles).

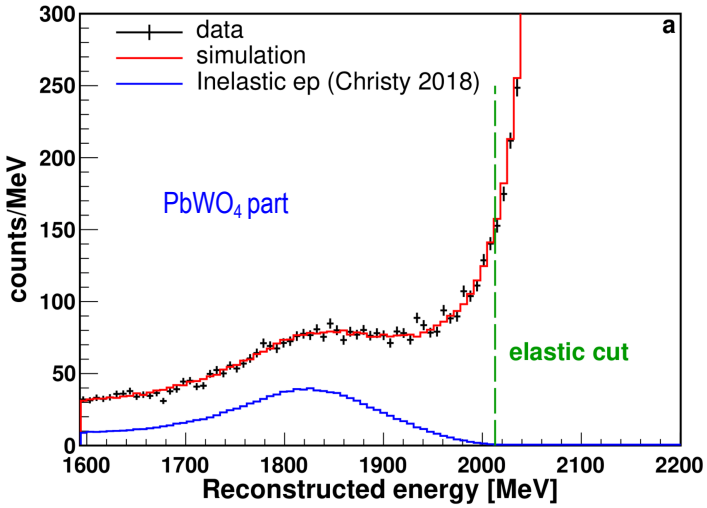
Upgraded HyCal: Direct Impact to the PRad-II Results

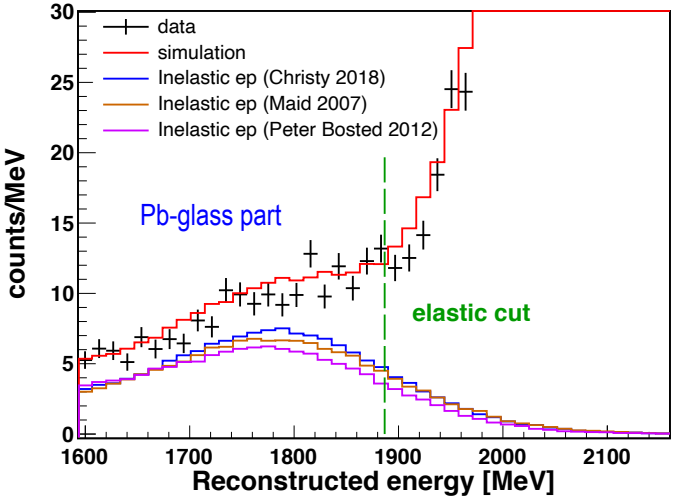
Upgraded HyCal will be critical to reach the projected accuracy in the PRad-II experiment.

- Differences in form factors between PRad and other recent ep-experiments is ~ 1 - 2 % at relatively larger Q^2 range.
- The ep-inelastic contribution in PRad at this Q^2 (Pb-glass part) are also at ~ 2% level.

- The HyCal energy resolution is critical to control this background.

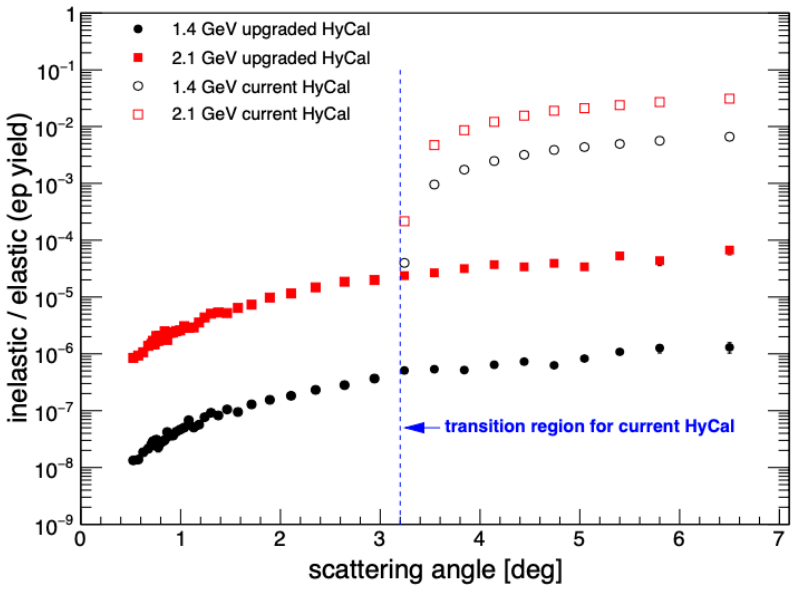


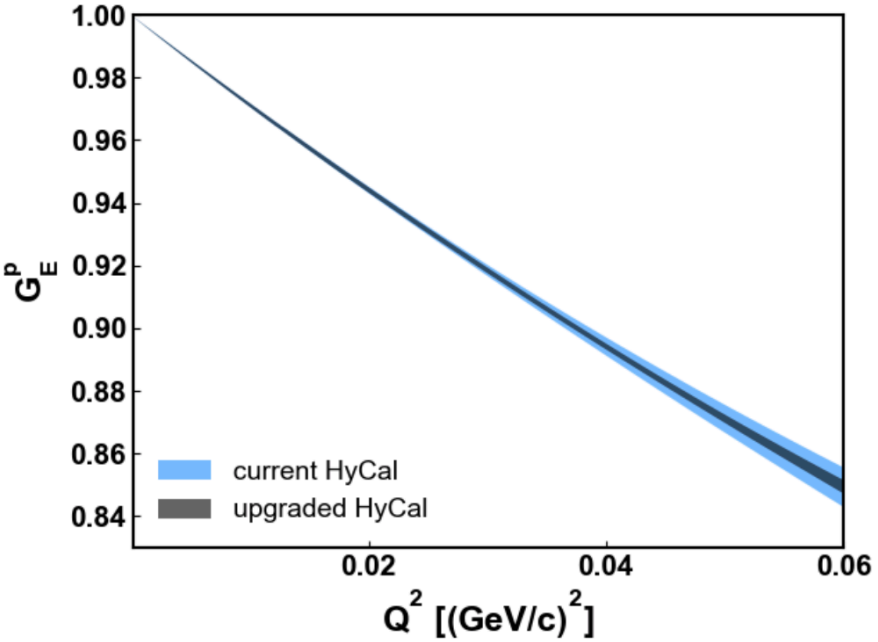




Upgraded HyCal: Direct Impact to PRad-II Results (cont.)

- HyCal upgrade will also provide:
  - ✓ ~ 3 times better energy (and position) resolutions at higher Q^2 range, the only tool for the ep-inelastic background subtraction.
  - ✓ improvements in the event selection process, very important.
  - ✓ Improvements in GEM detection efficiency measurements, very important.
  - ✓ make uniform detector response for entire Q^2 range, critical for the proton radius extraction.
  - ✓ will help in experimental test of radiative corrections, very important.





Projected Uncertainties with and without HyCal Upgrade

Sources	PRad δr_p [fm]	PRad-II δr_p [fm]	PRad-II δr_p [fm] w/o HyCal upgrade and with 2 new GEM planes
Stat. uncertainty	0.0075	0.0017	0.0017
HyCal non-uniform response	0.0029	0.0001	0.0013
Inelastic *ep*	0.0009	0.0001	0.0009
Event selection	0.0070	0.0027	0.0034
GEM efficiency	0.0042	0.0008	0.0027
Acceptance & beam energy related	0.0034	0.0003	0.0003
Beam background	0.0039	0.0016	0.0016
Radiative correction	0.0069	0.0004	0.0004
G_M^p parameterization	0.0006	0.0005	0.0005
Total systematic	0.0115	0.0032	0.0049
Total uncertainty	0.0137	0.0036	0.0052

- Without HyCal upgrade the estimated total uncertainty will be 45% larger.
- This estimation is based on the current ep-inelastic models.

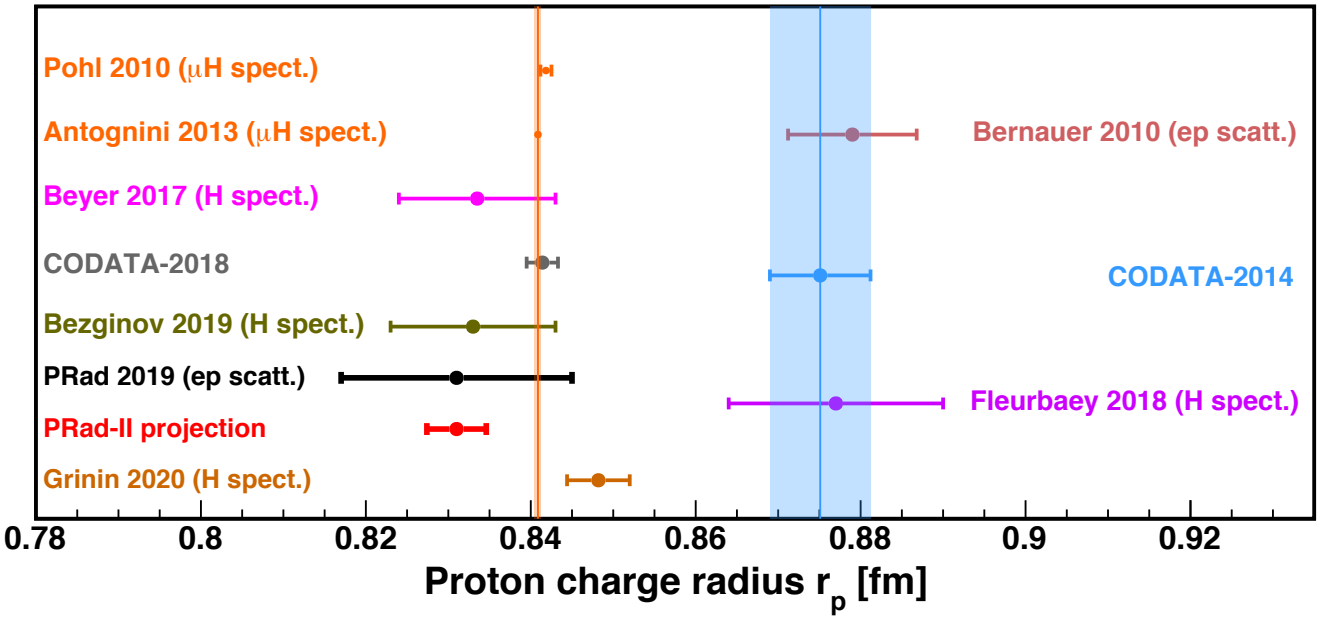
Summary on the HyCal Upgrade

- The PRad method, with all proven advantages however, has one sizeable disadvantage:
  - ✓ about two orders of magnitude less energy resolution.
- With the current HyCal, subtraction of the ep-inelastic contributions at relatively high Q^2 range was and will be mostly model dependent.
- The current form factor differences are in the range of 1 to 2 percent.
- The PRad-II is designed to perform the most accurate ep-scattering experiment for the proton radius extraction, in part to address these differences.
- The HyCal upgrade is an experimental/technical challenge but, with your support, the PRad collaboration is willing to try it.

Thank you!

PRad-II Expected Accuracy

- Approved by Jlab's PAC-48 in August, 2020 (with C1 condition)
- Expected total uncertainty: 0.43% (a factor of 4 improvement over PRad)



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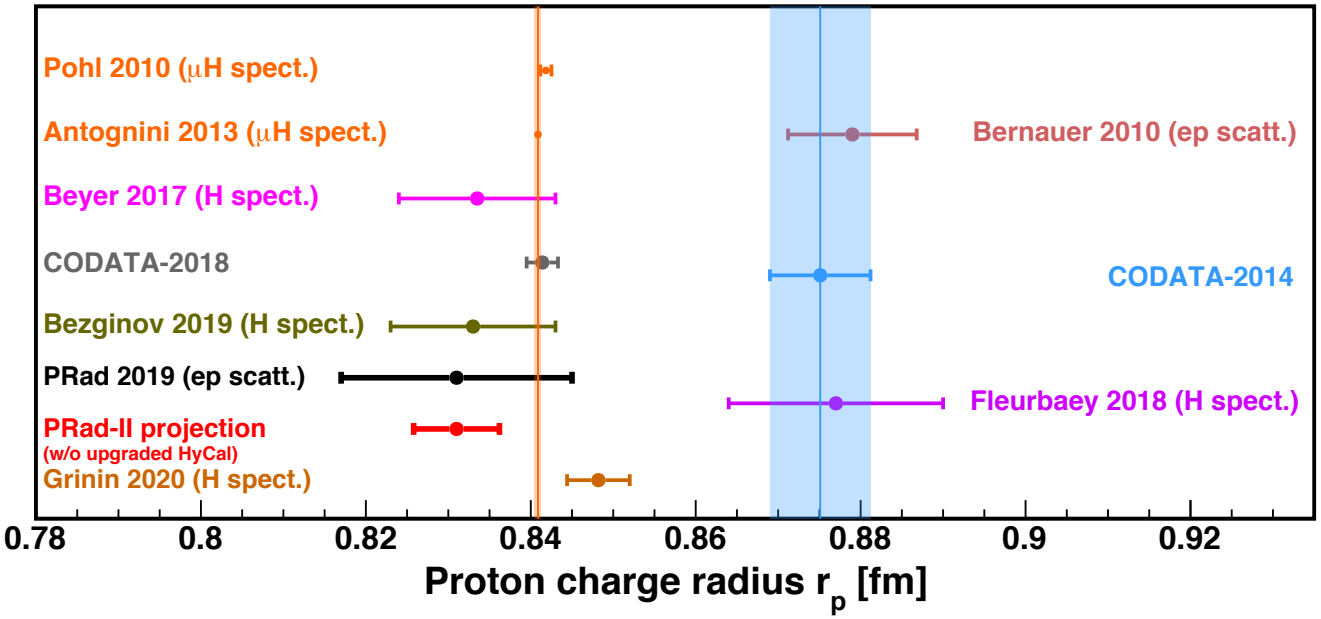

Submitted NSF RI-1 Summary Budget

Table 2: *Subsystems and responsible institutions for the upgraded PRad-II detector system*

Subsystem	Institution	Cost ($ Million)
$PbWO_4$ crystals and assembly gain monitoring & cables	North Carolina A&T State University	3.664
PMTs, bases and HV	Mississippi State University	1.485
fADC based readout electronics	Duke University	2.133
Two planes of GEM detectors and readout electronics	University of Virginia	0.798
Total cost		8.08