PAC48 Issues and Answers

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for the PRad collaboration

- PAC48 Report
- Issue #1, tracking detectors
- Issue #2, HyCal upgrade
- Issue #3, blind analysis

PAC48 Report

PR12-20-004
Scientific Rating: A
Recommendation: C1
Title: PRad-II: A New Upgraded High Precision Measurement of the Proton Charge Radius
Spokespersons: A. Gasparian (contact), H. Gao, D. Dutta, D. W. Higinbotham, E. Pasyuk, N. Liyanage, C. Peng, K. Gnanvo.

Motivation: Precision information on the size of hadrons can be obtained both from electron scattering and from atomic spectroscopy. It came as a big surprise that the extraction of the proton charge radius from muonic hydrogen Lamb shift measurements is in strong contradiction with the values obtained from electron-proton scattering. This 'proton radius puzzle' has triggered a large activity worldwide.
In this context, the PRad Experiment has pioneered a new technique to extract the proton radius in elastic electron scattering. Instead of using the traditional experimental technique based on magnetic spectrometry, the experiment has adopted a new calorimetric method for low Q2 elastic scattering, using a windowless target and simultaneously recording Møller scattering for normalization of the measured cross-sections. In principle, this avoids individual point to point normalization uncertainties, which would impact the measured Q2 spectrum.

The results obtained by this pioneering experiment (recently published in Nature) are in apparent conflict with all previous modern electron scattering experiments, especially at high values of Q2 . A new experiment with a much improved control of radiative corrections (which at the moment account for the largest part of the systematic uncertainty), with larger data sets, and which makes use of a blind analysis, is imperative to clarify the current status and to reach for the ultimate precision in ep scattering.

PAC48 Report (cont.)

The proposed experiment aims at reducing the total uncertainty down to 0.54%, which is 3.8 times smaller than what PRad achieved, by upgrading the experimental setup.

Measurement and Feasibility: The experiment relies on the PRad setup undergoing a variety of upgrades, in particular:

1. improving the overall tracking capabilities of the setup by adding a second plane to the tracking detector,
2. adding new rectangular cross-shaped scintillator detectors to separate Møller events in the angular range 0.5^{o} to 0.8^{o},
3. upgrading the HyCal by replacing the lead glass blocks by PbWO4 and converting its readout to FADC based one,
4. improving radiative correction calculations by going to NNLO.

Three beam energies are requested, namely 0.7, 1.4 and 2.1 GeV. The lowest and highest beam energies will allow to cover the Q2 range from 4 × 10-5 to 0.06 GeV2 . The 1.4 GeV run will serve as an important cross-check for possibly unaccounted systematics.

PAC48 Report (Issues and Summary)

Issues:

- The μRWell technology (point 1 above) has never been used in a running experiment, and its reliability and radiation hardness have not been fully demonstrated. Since the main reduction on the total uncertainty arises from the addition of a second tracking station, the PAC recommends considering a second GEM station instead, further relying on the present GEM technology to reduce t he risks of jeopardizing the final physics goal.
- The upgrade of HyCal (point 3 above) implies 1500 additional PbWO4 crystals and a new electronic readout. The cost estimate is about $5M. While it is clear that the new readout based on FADC will strongly increase the rate of data taking (and thus reduce the statistical uncertainty), the PAC could not be convinced on the necessity of the costly replacement of the crystals for reaching t he final uncertainty on the proton radius.
- The PAC strongly suggests the planning of a blind analysis to convincingly reduce possible bias stemming from the normalization and the Q2 -dependence of the form factor. In particular, all radiative correction calculations and their implementation in the Monte Carlo simulation should be fixed before the fit for the proton radius.

Summary: Given the compelling physics case and the current tension between the form factor data of PRad and all previous ep scattering experiments, the PAC strongly supports the request for 40 days of beam time, pending a thorough technical investigation of the actual benefits or necessity of the HyCal upgrade and the adoption of the μRWell technology.

Tracking Detectors

- Issue #1

"The μRWell technology (point 1 above) has never been used in a running experiment, and its reliability and radiation hardness have not been fully demonstrated. Since the main reduction on the total uncertainty arises from the addition of a second tracking station, the PAC recommends considering a second GEM station instead, further relying on the present GEM technology to reduce the risks of jeopardizing the final physics goal."

Answer:

- We agree and following the PAC48 recommendations we made a decision to build two planes of GEM detectors to provide a reliable tracking system in the PRad-II experiment.

HyCal Upgrade

- Issue #2

"The upgrade of HyCal (point 3 above) implies 1500 additional PbWO4 crystals and a new electronic readout. The cost estimate is about $5M. While it is clear that the new readout based on FADC will strongly increase the rate of data taking (and thus reduce the statistical uncertainty), the PAC could not be convinced on the necessity of the costly replacement of the crystals for reaching the final uncertainty on the proton radius."

Answer:

- We share the PAC48 concerns on this part: the HyCal upgrade is costly and technically challenging.
- Possibly we did not provide enough information at the PAC48 to support this particular upgrade.
- As we presented here and described in our Technical Review Document:
  - ✓ PRad-II is designed to perform the most accurate ep-scattering experiment for the proton radius extraction, in part to address the existing form factor differences in a model independent way;
  - ✓ without the HyCal upgrade PRad-II will not reach the projected ± 0.0036 fm (0.43%) uncertainty, it will be about 45% larger and will partially model dependent, due to ep-inelastic contributions;
- With the support of this Committee the PRad collaboration is willing to:
  - ✓ seek external funding to provide the HyCal upgrade;
  - ✓ upgrade HyCal in 2-3 years (parallel to other detector upgrades);
  - ✓ perform the experiment to reach the accuracy level stated in the PAC48.

Blind Analysis

- Issue #3

"The PAC strongly suggests the planning of a blind analysis to convincingly reduce possible bias stemming from the normalization and the Q^2 -dependence of the form factor. In particular, all radiative correction calculations and their implementation in the Monte Carlo simulation should be fixed before the fit for the proton radius."

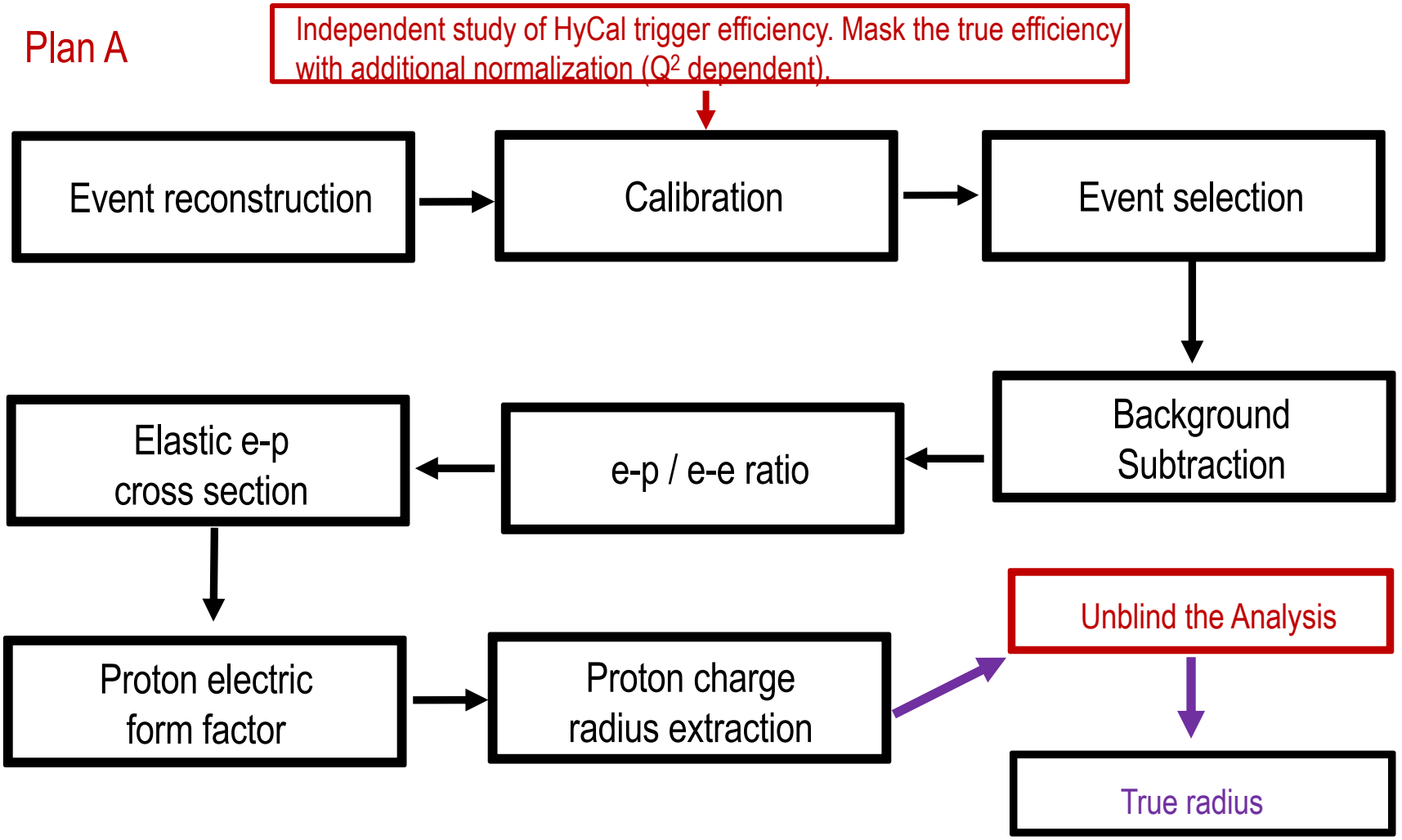
Answer:

- We fully agree with the PAC48 recommendation on the PRad-II data analysis process to conduct with a "blind analysis" method. Currently we have three different university groups capable of independently analyzing the PRad-II data. This number may increase before the experiment.

- We plan to implement the "blind analysis" method in the PRad-II data analysis process, according to flow-charts presented on the next two slides.

Plan: Blind analysis for extraction of r_p for PRad-II (Plan A)

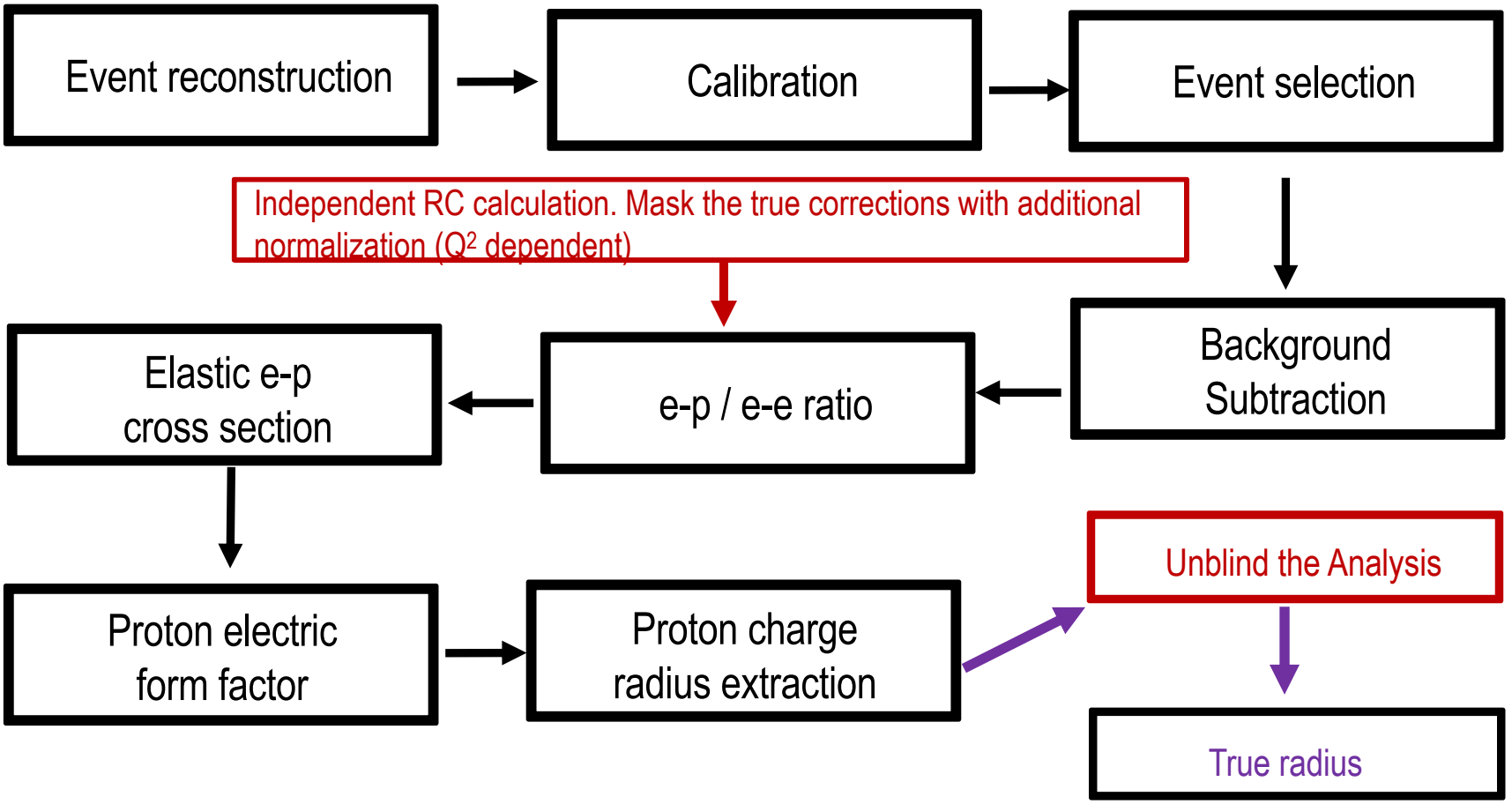
Plan for blind analysis for PRad-II



Plan: Blind analysis for extraction of r_p for PRad-II (Plan B)

Plan for blind analysis for PRad-II

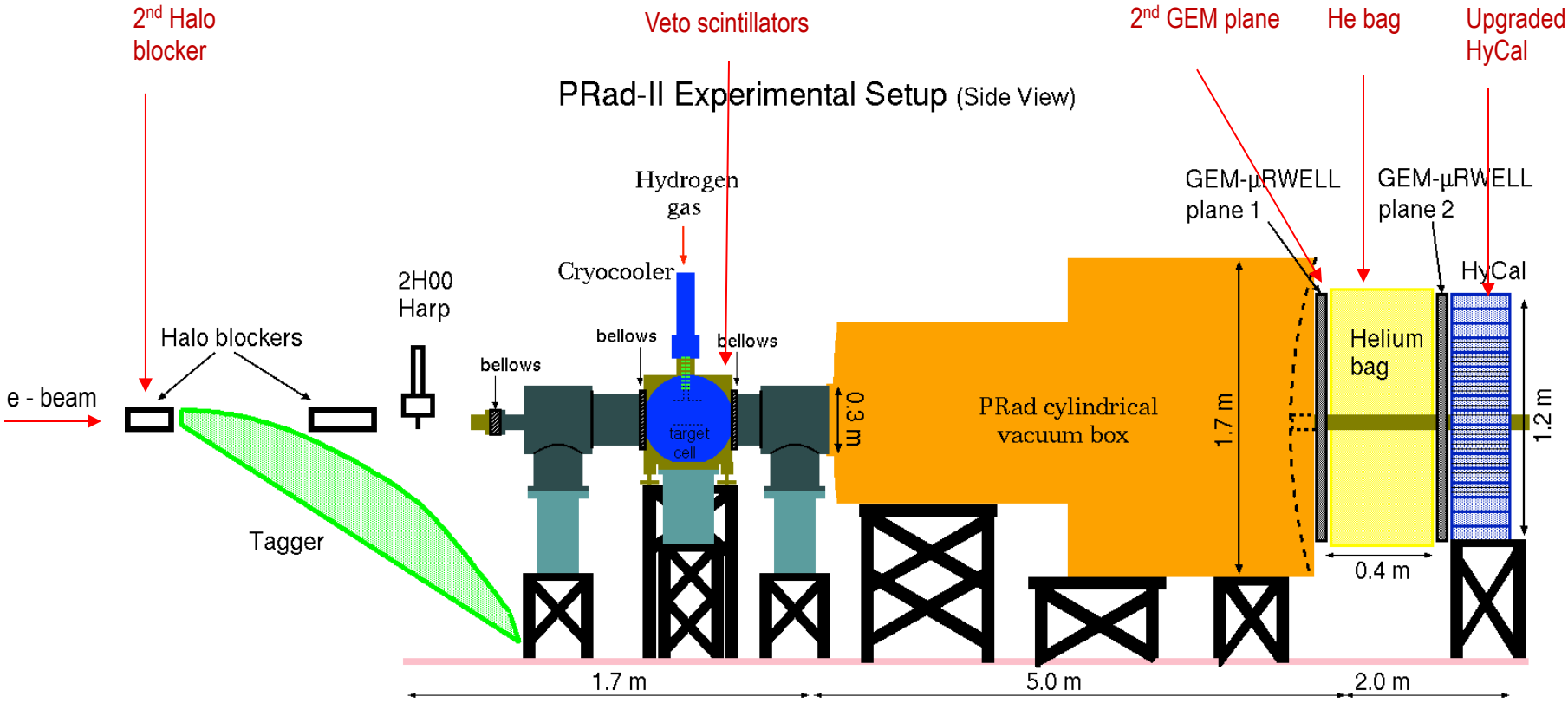
Plan B



Thank you!

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)



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.

Submitted NSF RI-1 Summary Budget

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

Subsystem	Institution	Cost ($ Million)
$PbWO_4$ detector modules HV supply, cables and assembly	North Carolina A&T State University	4.1
fADC based readout electronics	Duke University Mississippi State University	1.95
Gain monitoring system Front end patch panel	Mississippi State University	0.1
Two planes of GEM detectors and readout electronics	University of Virginia	0.95
Total cost		7.1