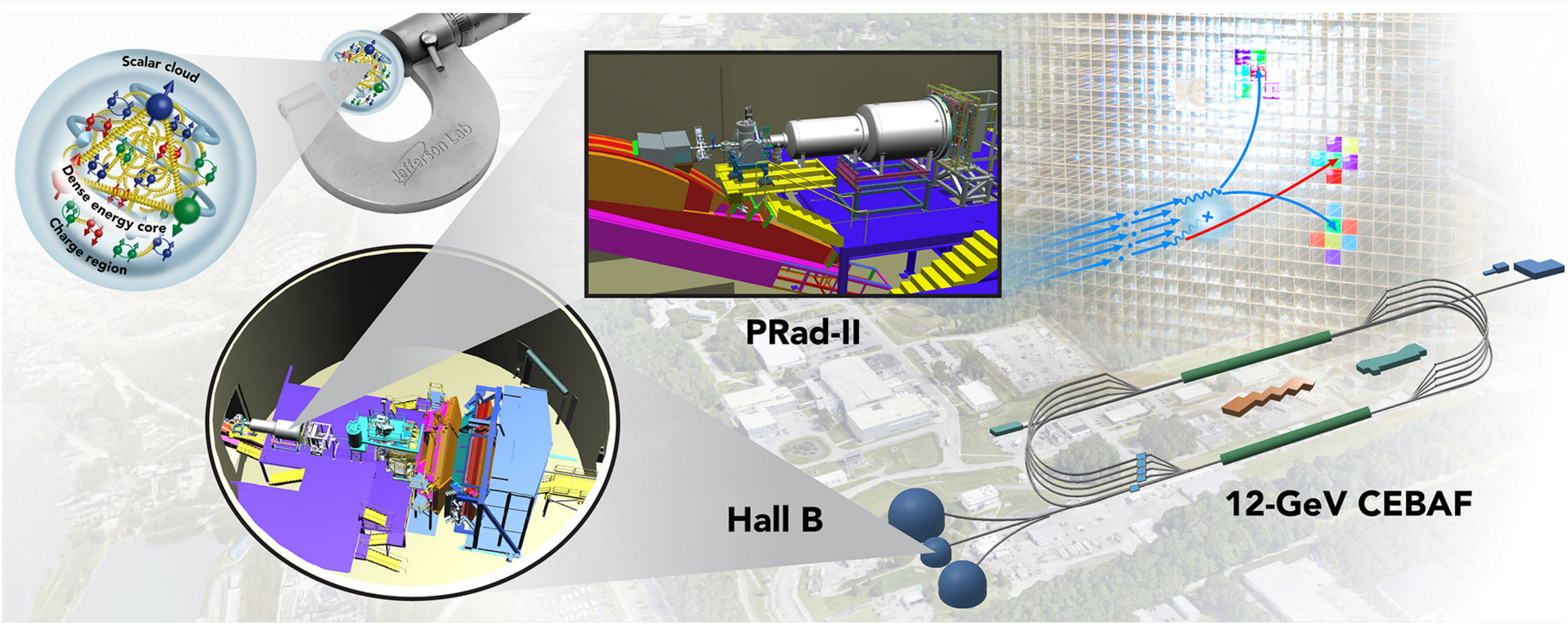
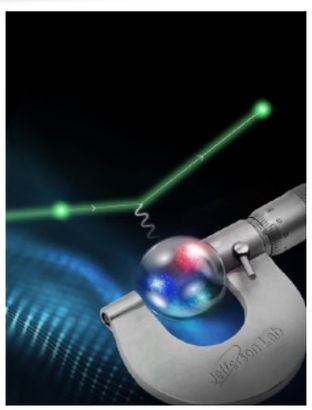
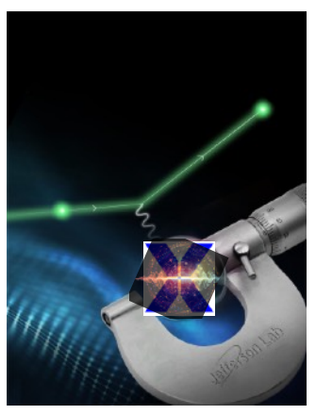
# A Magnetic-Spectrometer-Free Forward Angle Physics Program in Hall B

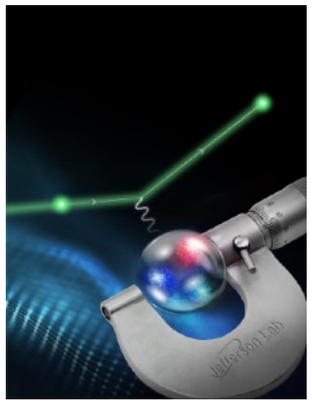



**Dipangkar Dutta (Mississippi State)**
**for the PRad/X17 Collaboration**

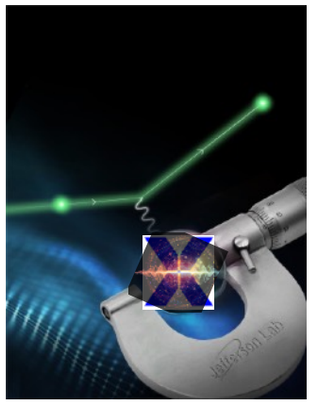
# A Magnetic-Spectrometer-Free Forward Angle Physics Program in Hall B



1. Precision charge radii measurement of low-mass nuclei (D, 3He, 4He, …) using the PRad apparatus

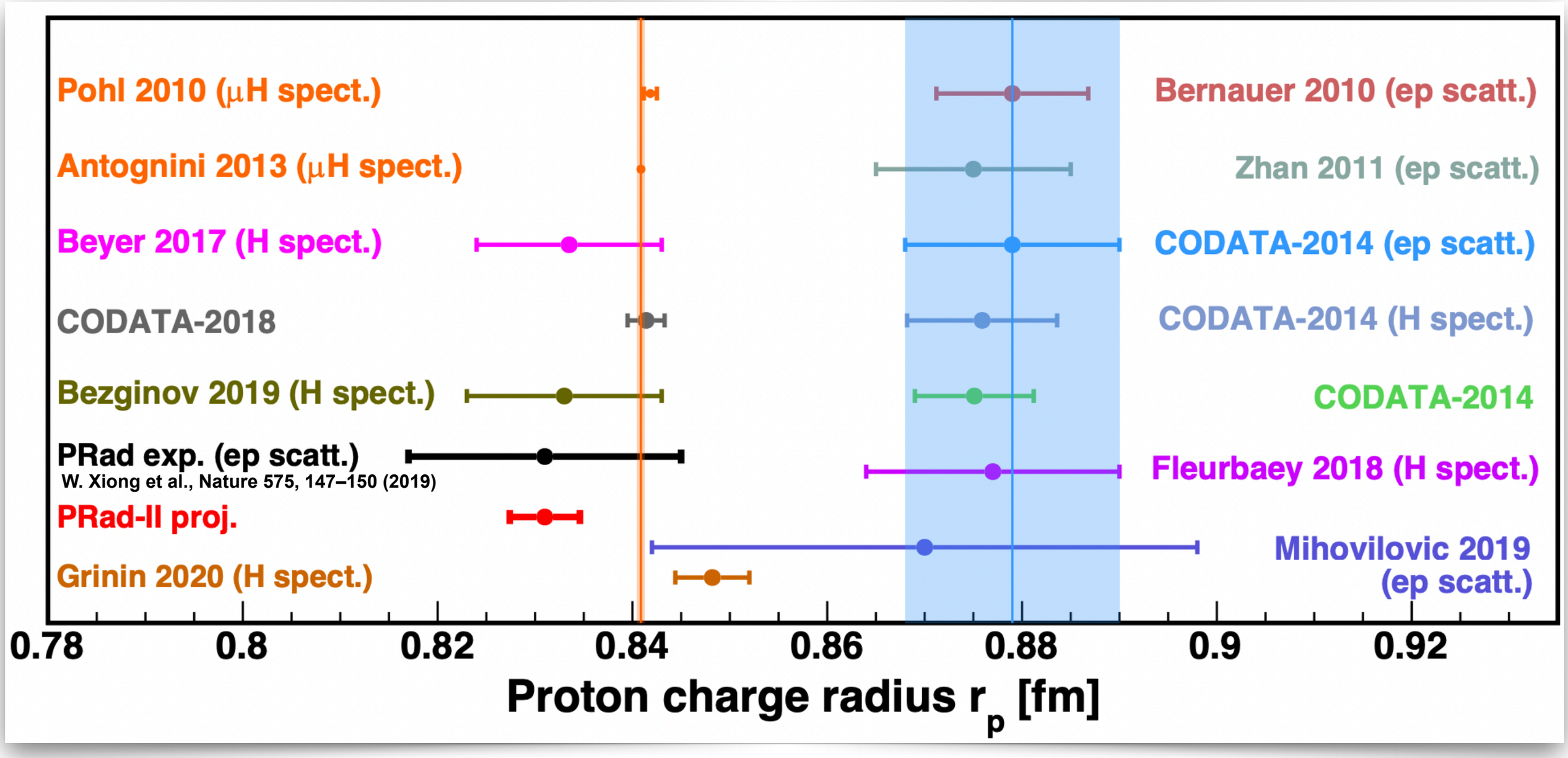
2. X17 type search experiments with electron beam

3. High sensitivity search experiments with a positron beam



4. High precision Primakoff measurements on atomic electrons with CEBAF energy upgrade

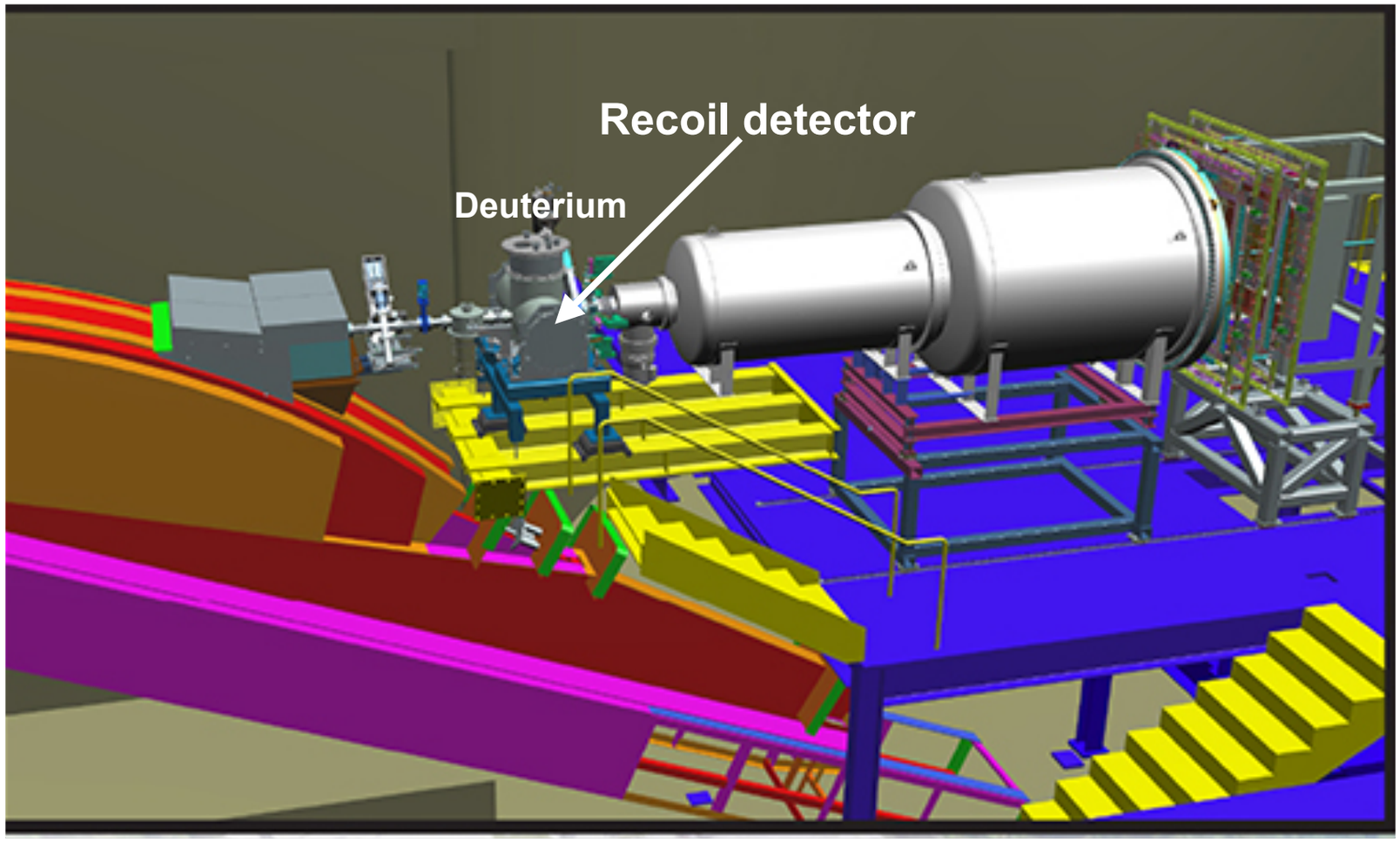
# Magnet-Free Technique: Proven by PRad, Confirmed by PRad-II



# PRad-II significantly surpassed PRad in many performance parameters

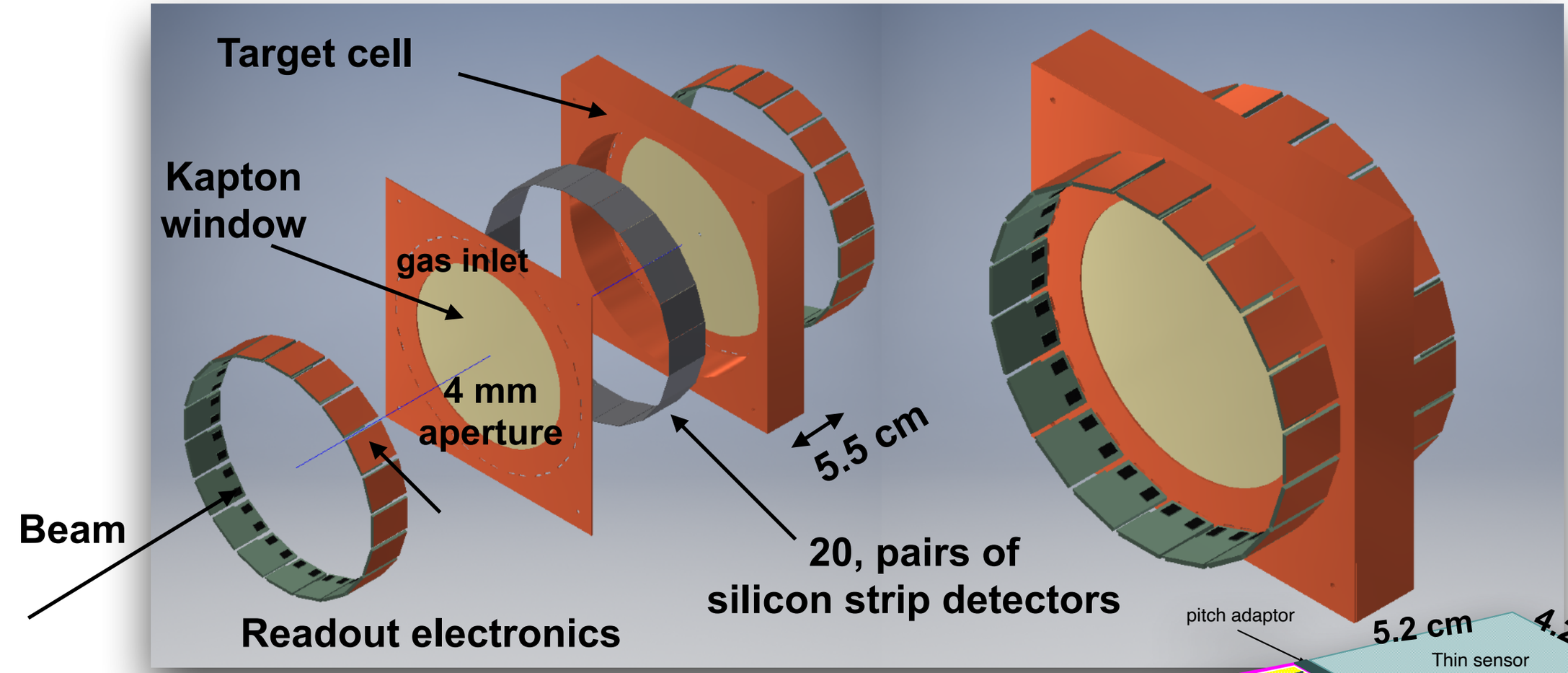
| | PRad-II | PRad |
|---|---|---|
| Vacuum Chamber | **0.012 mTorr** | 0.5 mTorr |
| $H_2$ cell /chamber pressure | **1030 / 4.3 mTorr** | 470 / 2.7 mTorr |
| $H_2$ gas flow | **1300 sccm** | 600 sccm |
| $H_2$ gas density | **5.5 x $10^{18}$ H/cm$^2$** | 2 x$10^{18}$ H/cm$^2$ |
| Beam current | **up to 700 nA** | 50 nA |
| Luminosity | **2.6 x $10^{31}$ /cm$^2$** | 6 x $10^{29}$ /cm$^2$ |
| Beam background | **~ 2% of *ep* events** | ~10 - 30% of *ep* events |
| DAQ rates | **20-25 kHz** | 4-5 kHz |
| GEMs | **2-planes with tracking** | 1-plane, no tracking |
| Veto counter ($Q^2$ range) | **~ $10^{-5}$ GeV$^2$** | ~ $10^{-4}$ GeV$^2$ |
| HyCal | only $PbWO_4$ **+ FADC readout** | $PbWO_4$ + Pb-glass |

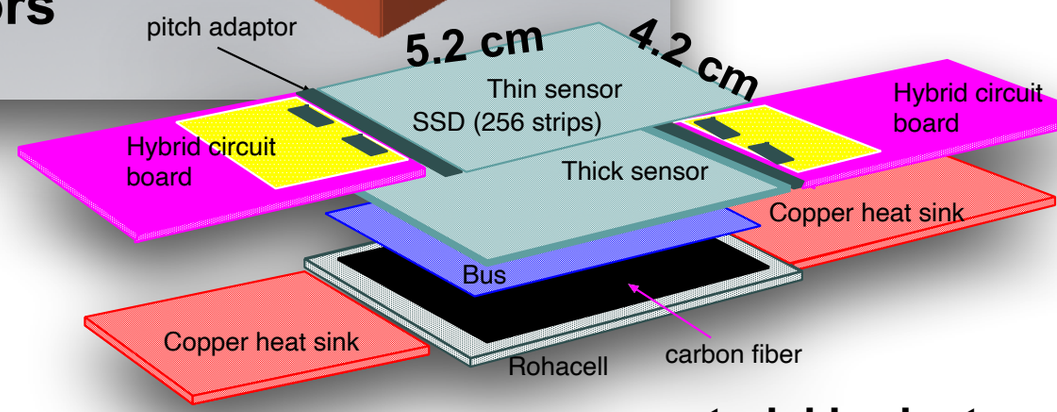
# DRad: a natural extension of the magnetic-spectrometer-free technique




- High resolution $PbWO_4$ calorimeter (magnetic spectrometer free)
- Windowless, high density gas flow target (reduced backgrounds)
- Simultaneous detection of elastic and Møller electrons (control of systematics)
- Vacuum chamber with one thin window, & two GEM chambers (better resolution)
- $Q^2$ range of $2x10^{-4} – 5x10^{-2}$ $GeV^2$ (lower than all previous electron scattering expts.)
- Add a cylindrical recoil detector for ensuring elasticity of reaction.
- Precise extraction of the charge form factor and charge radius $r_D$

# The elasticity of e-D scattering will be ensured with a cylindrical Si-strip-based recoil deuteron detector.



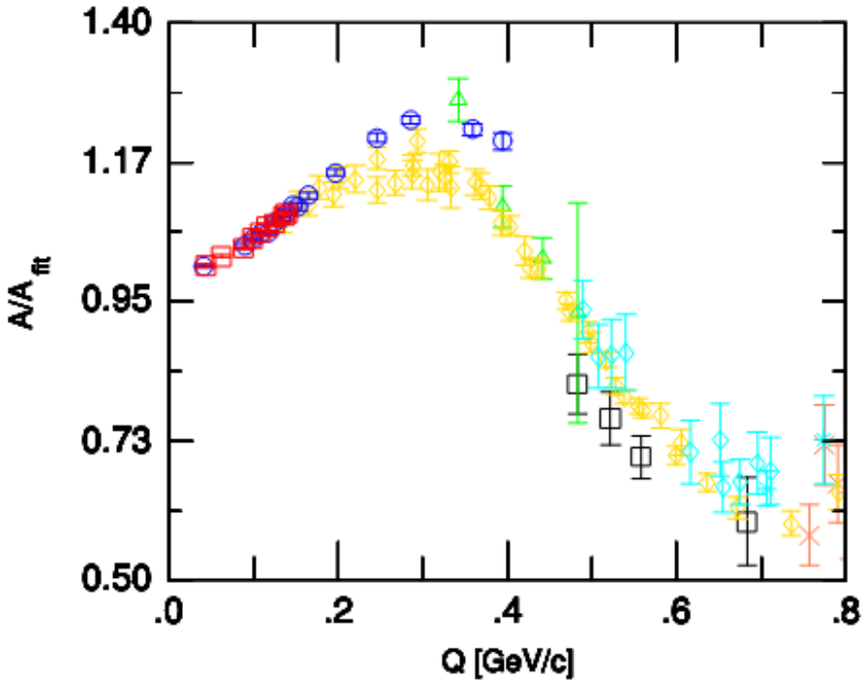

Based on CLAS12 Barrel Si tracker (SVT)

- consists of 20 panels of twin, single-sided Si-strip detectors (size; 42x52 mm$^2$);
- thickness: inner, ≈ 200 μm, outer ≈ 300 μm (to be optimized);
- 20 segment arrangement with R=13 cm radius (to be optimized);
- 256 strips on each segment, angular resolution: δφ ≤ 5 mrad, δθ ≤ 20 mrad
- Passivation layer ~ 0.1 μm ( can be as low as 0.01 μm).

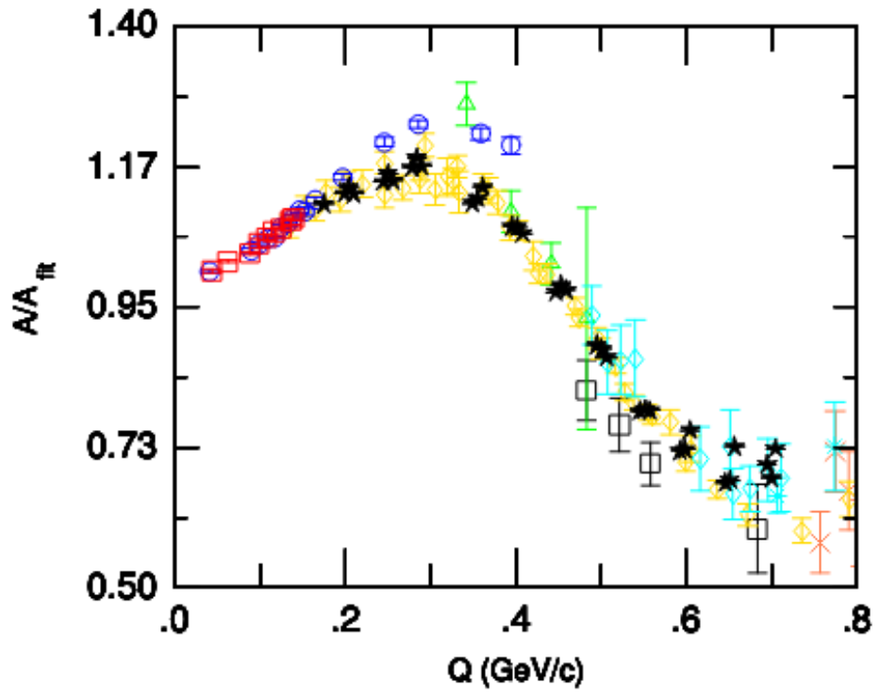
**material budget < 1% r.l.**

# There is a urgent need for high precision *e-D* scattering cross section and charge form factor data

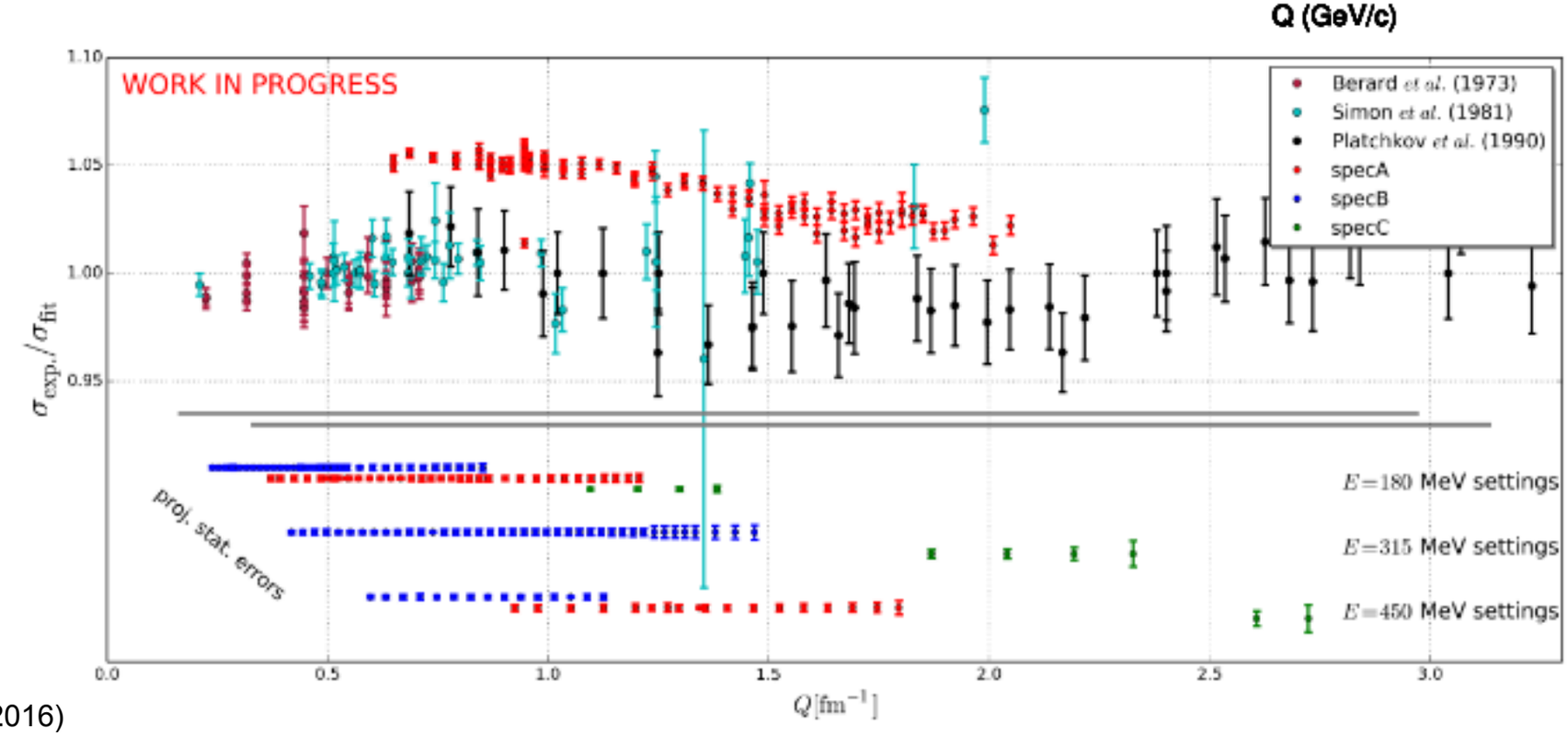
Figs. from Byungwuek Lee's PhD thesis (LEDEx experiment @ JLab)




| Experiment | $Q$ (GeV/c) | Symbol | Year and Reference |
|---|---|---|---|
| Monterey | 0.04 - 0.14 | □ | 1973 [8] |
| Mainz | 0.04 - 0.39 | ○ | 1981 [9] |
| Saclay ALS | 0.13 - 0.84 | ◇ | 1990 [10] |
| Orsay | 0.34 - 0.48 | △ | 1966 [11] |
| Stanford | 0.48 - 0.88 | □ | 1965 [12] |
| DESY | 0.49 - 0.71 | ◇ | 1971 [13] |
| CEA | 0.76 - 1.15 | × | 1969 [14] |
| JLab Hall C | 0.81 - 1.34 | ★ | 1999 [15] |
| JLab Hall A | 0.83 - 2.44 | □ | 1999 [16] |
| SLAC E101 | 0.89 - 2.00 | + | 1975 [17] |



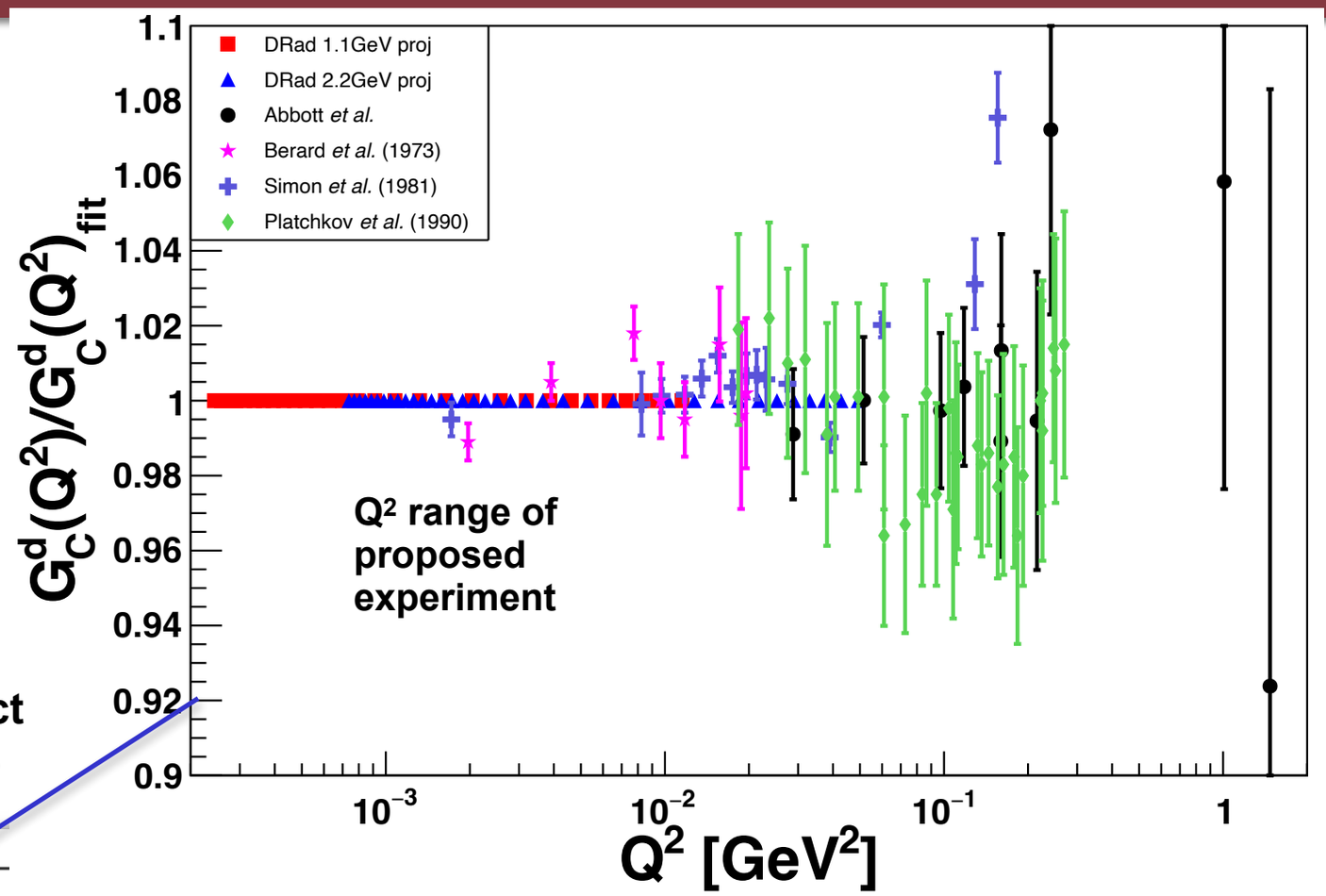

More recent experiment at Mainz



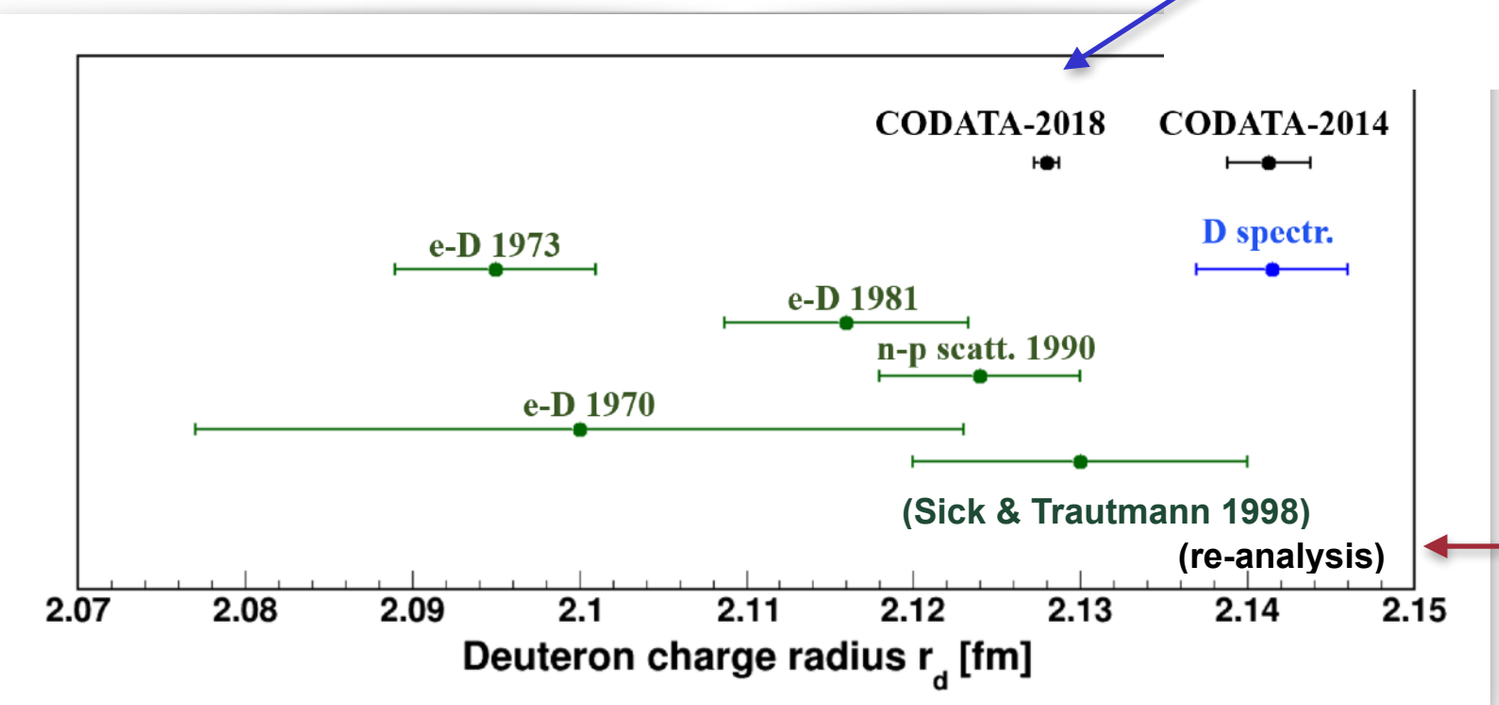

B.S. Schlimme, et al. EPJ W of C, 113, 04017 (2016)

# The program will provide precision Deuteron charge radius and much more

- existing data from old methods
- large uncertainty
- all used magnetic spectrometer method
- normalized *eD* to *ep* cross section
- large bgd. from target windows




used to extract charge radius

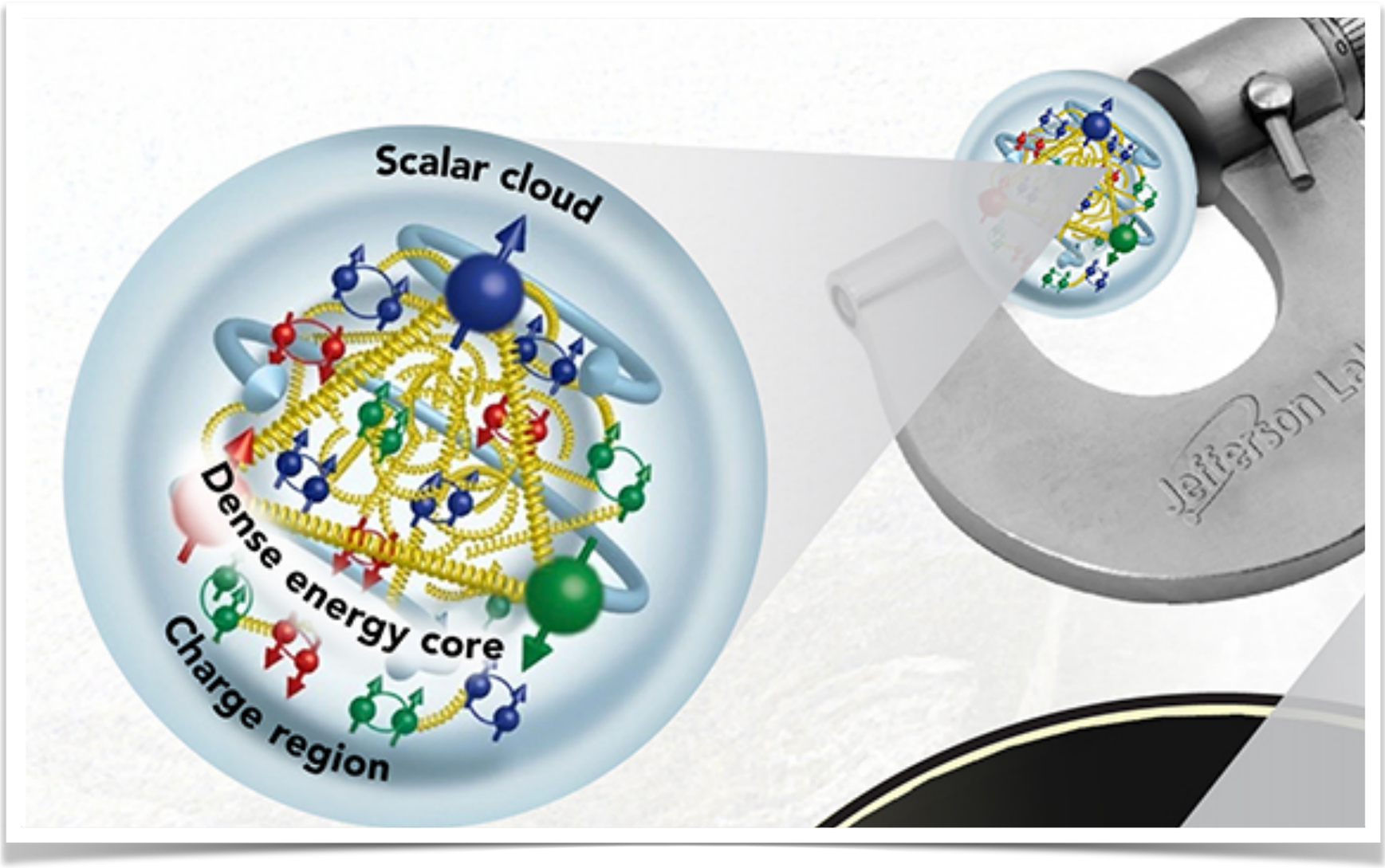



Most recent extraction of charge radius is a reanalysis of old data.

**Situation points to an urgent need for a new high precision *eD* experiment**

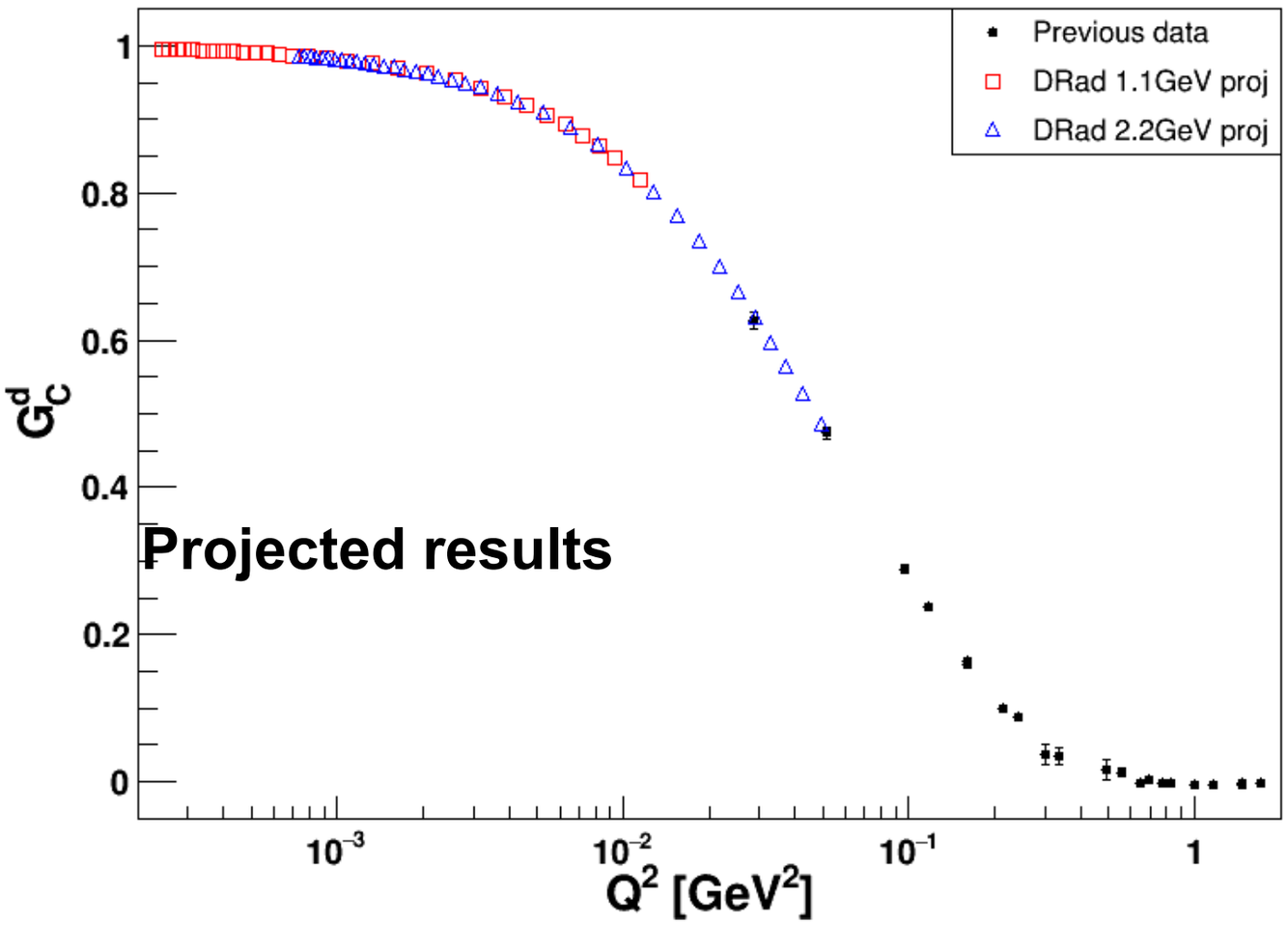
# The deuteron "structure radius" is the point-nucleon matter radius and a direct test of $\chi$EFT

$$r_{str}^2 = r_d^2 - r_p^2 - r_n^2 - 3/4m_p^2$$



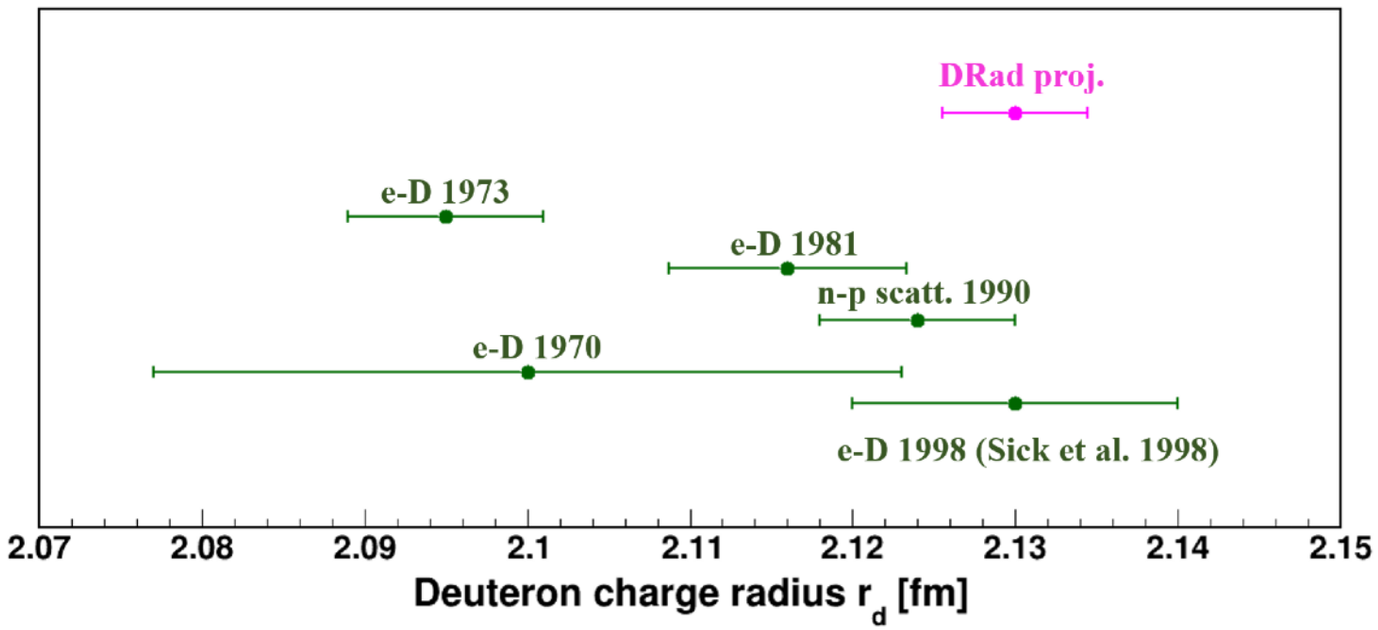

**PRad, DRad charge radii and the J/$\Psi$ based mass radius measurement will provide contrasting physics with a precise anchor for lattice calculations.**

# The estimated total uncertainties is about a factor of 2 better than the best extraction to date



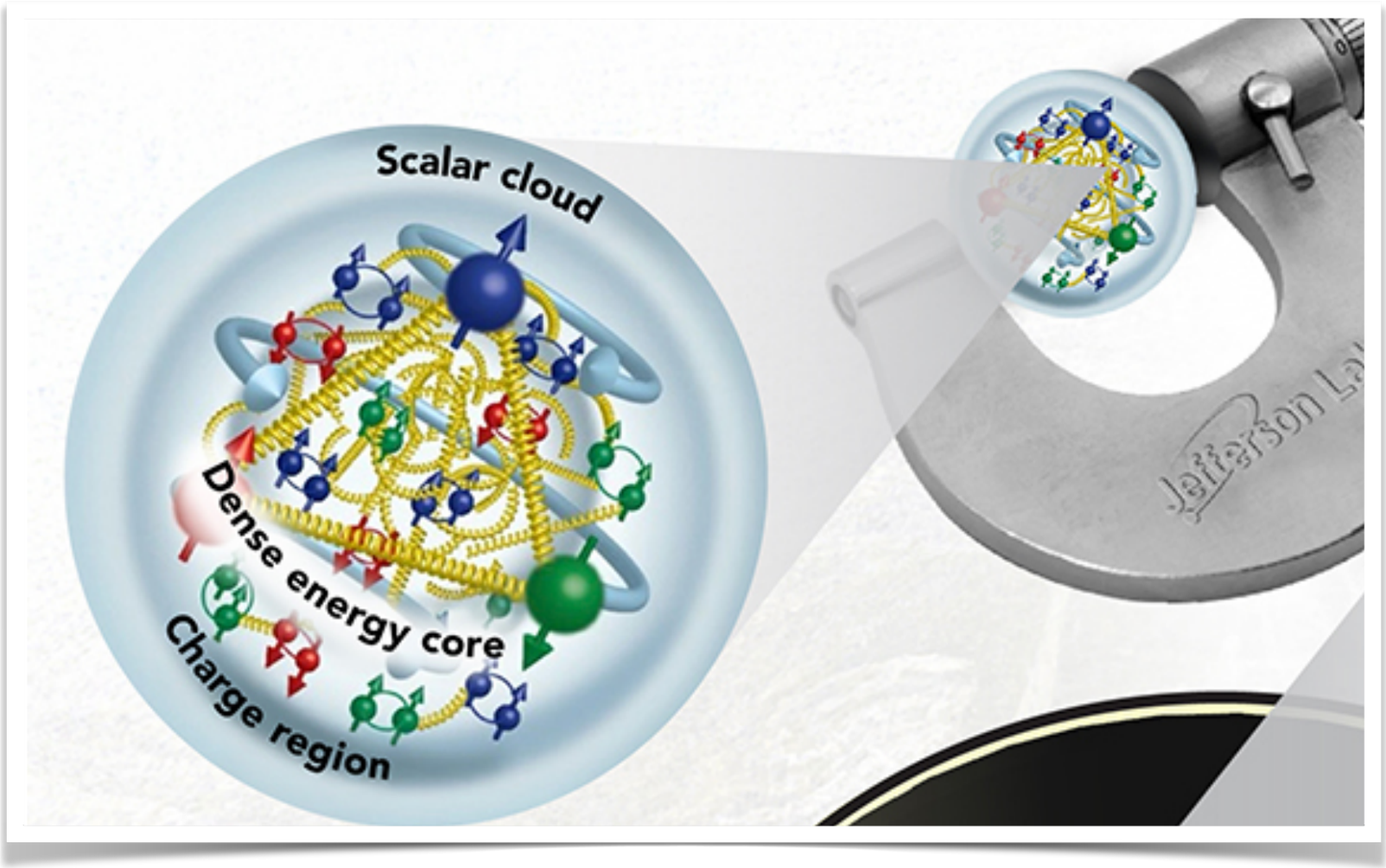

**Estimated from 10,000 mock data sets smeared by systematic and statistical uncertainties.**

**systematic uncertainty**
**= $(R_{smear} - R_{unsmear})/R_{unsmear}$**



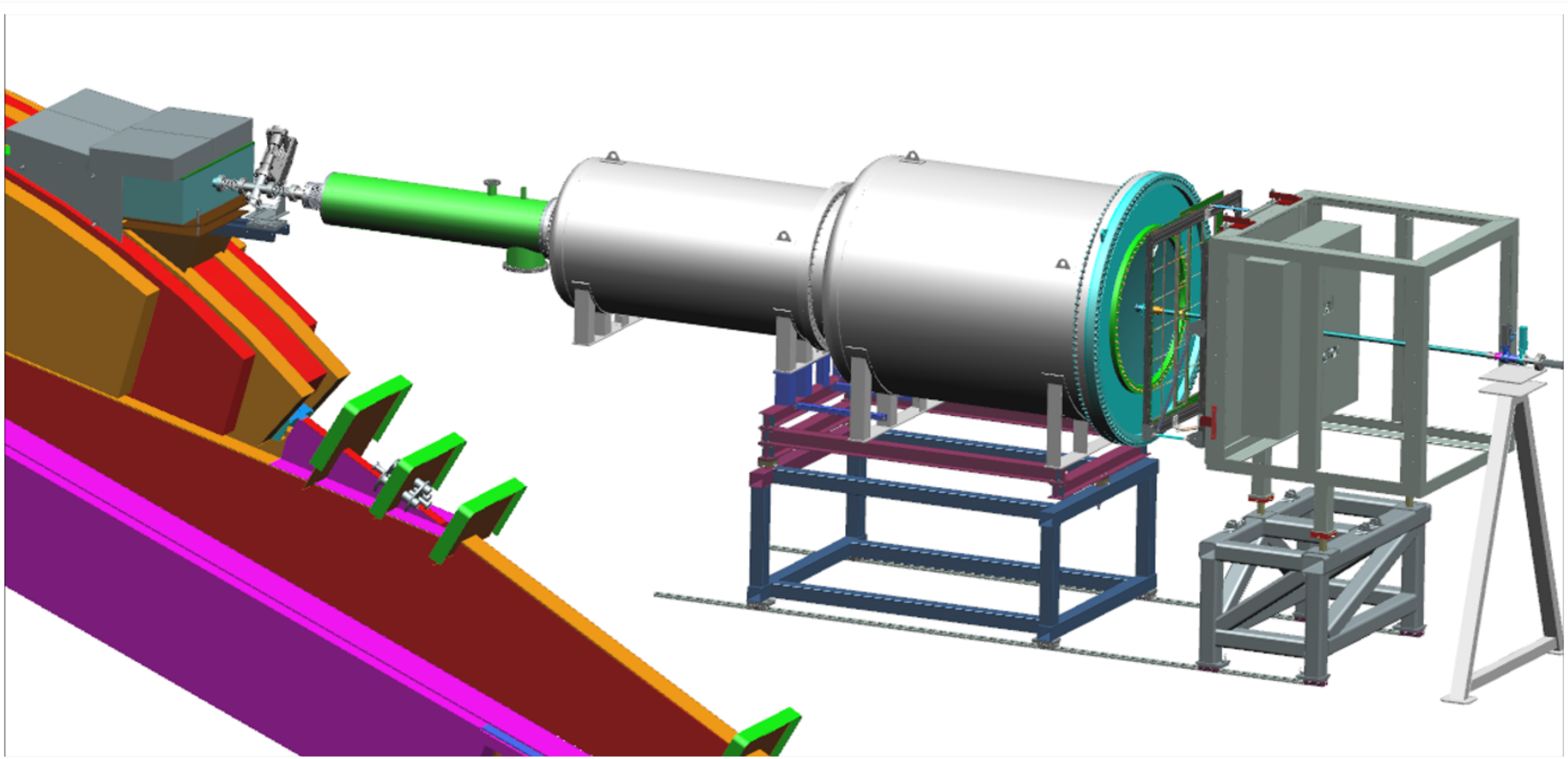
# $^4$He is the natural reference nucleus for a nuclear charge-vs-mass comparison

**$^4$He is spin-0 and isospin-0: Its charge radius therefore fixes its matter radius directly.**



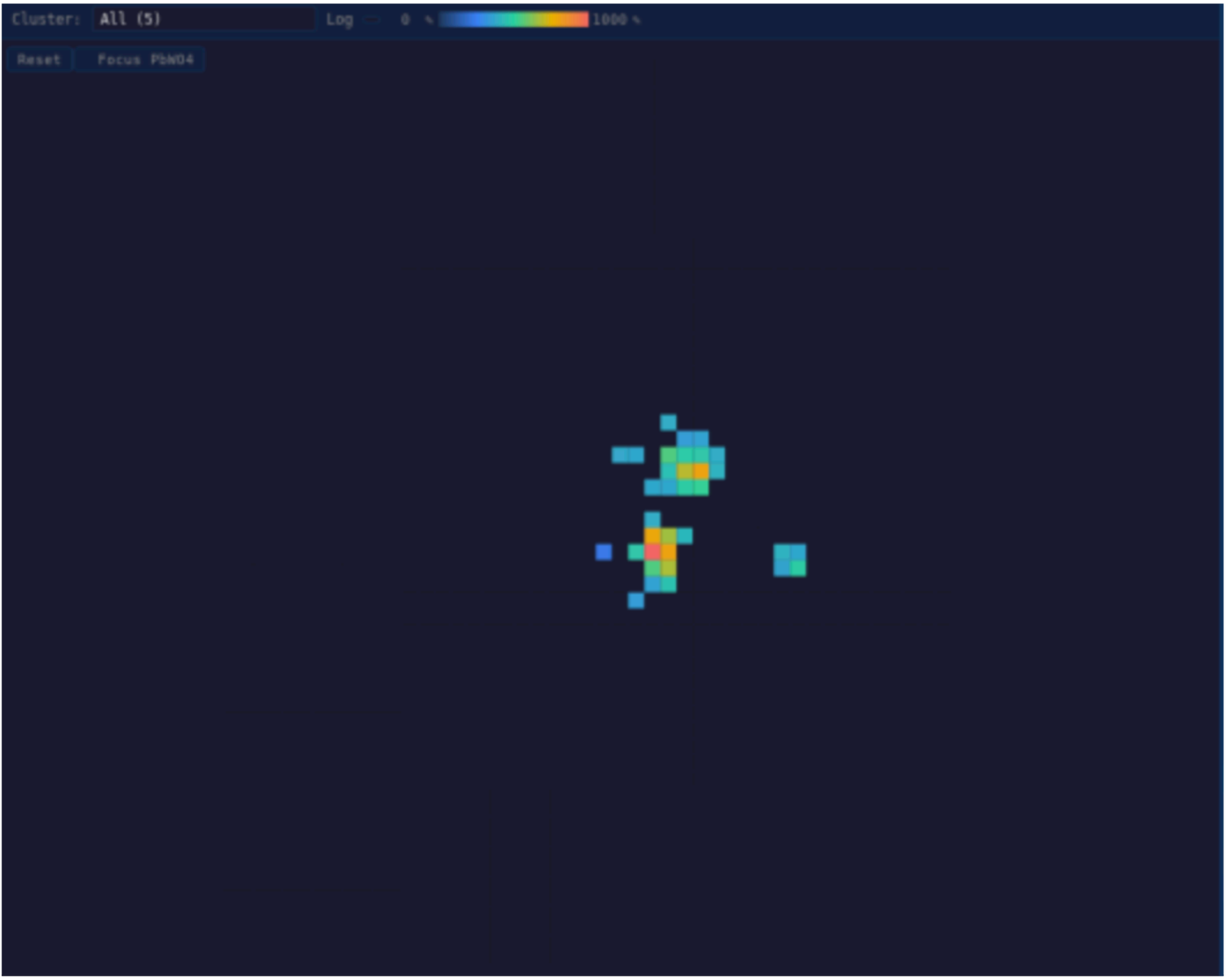

**DRad setup can be used for $^3$He and $^4$He charge radii measurements, providing nuclear-structure input for muonic helium, and e vs μ validation**

# The X-17 apparatus provides a unique window into the 0.5 - 105 MeV, e-to-μ mass desert

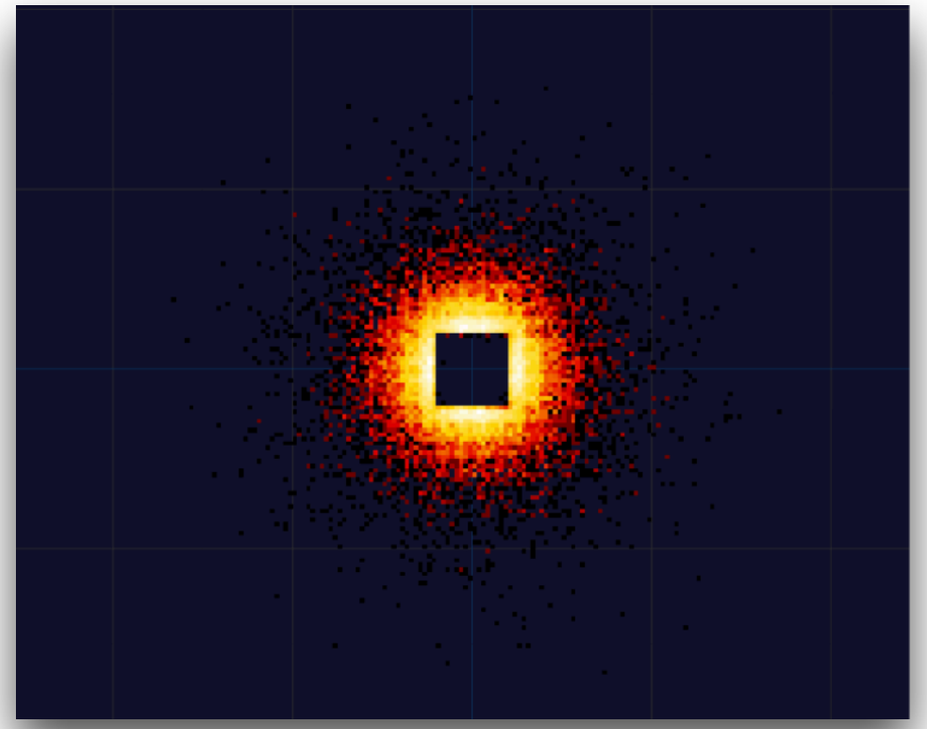


# The X-17 experiment demonstrated the advantage of the magnetic-spetrometer-free method

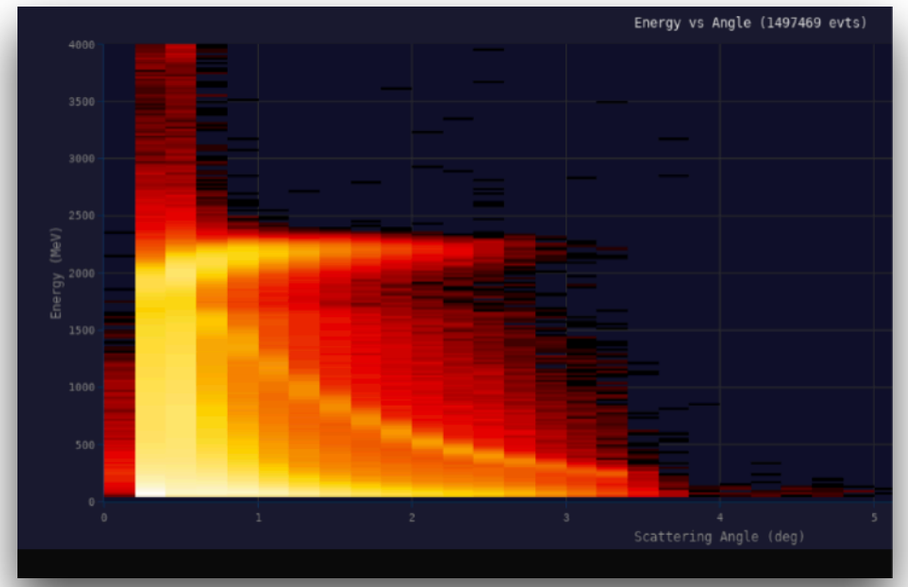
## 3 nA on Ta target




one 3-cluster event on the HyCal



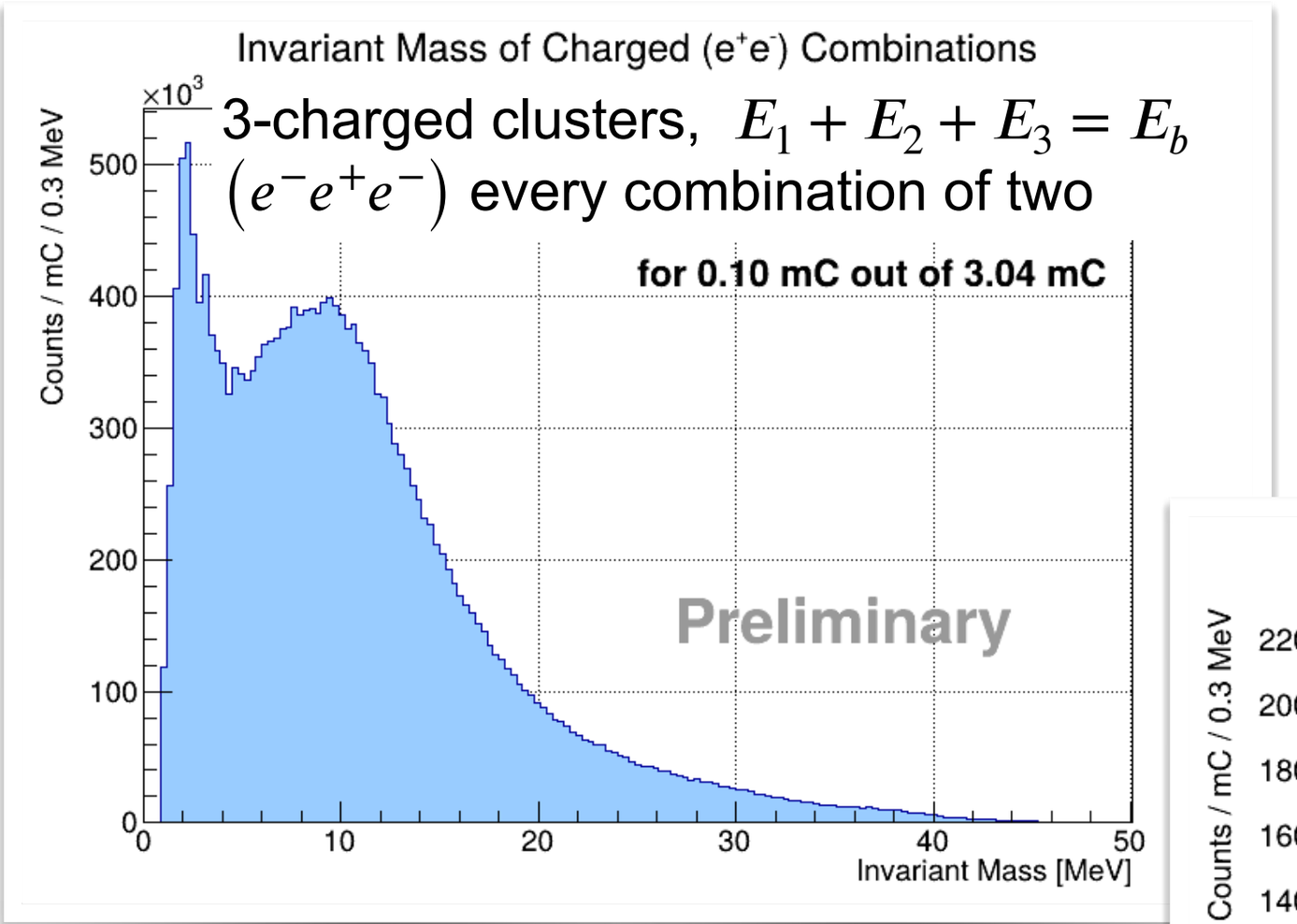
distributions of clusters on the HyCal

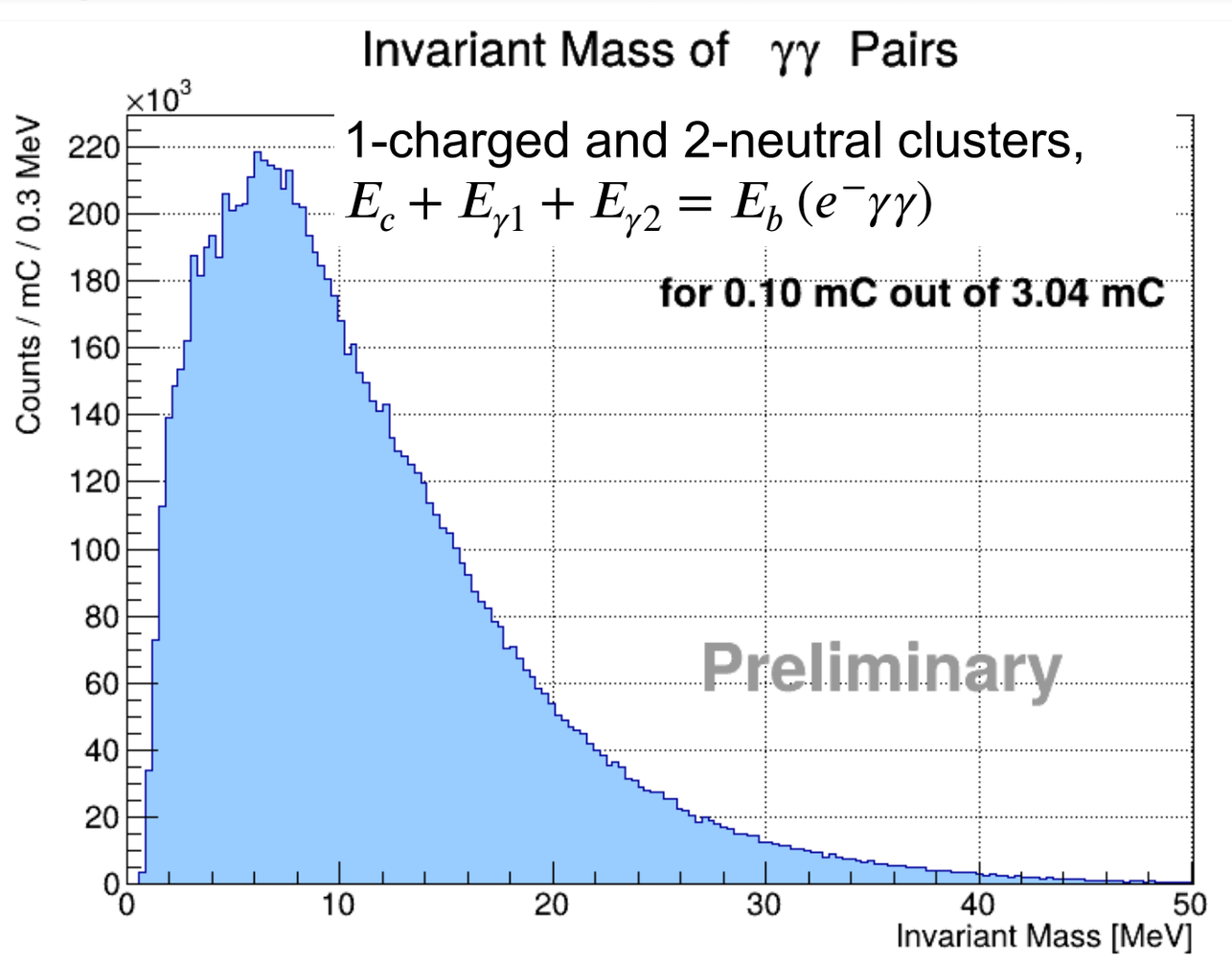



Energy (MeV)

Angle (deg)

# The invariant mass spectra demonstrated the first detection of all final state particles

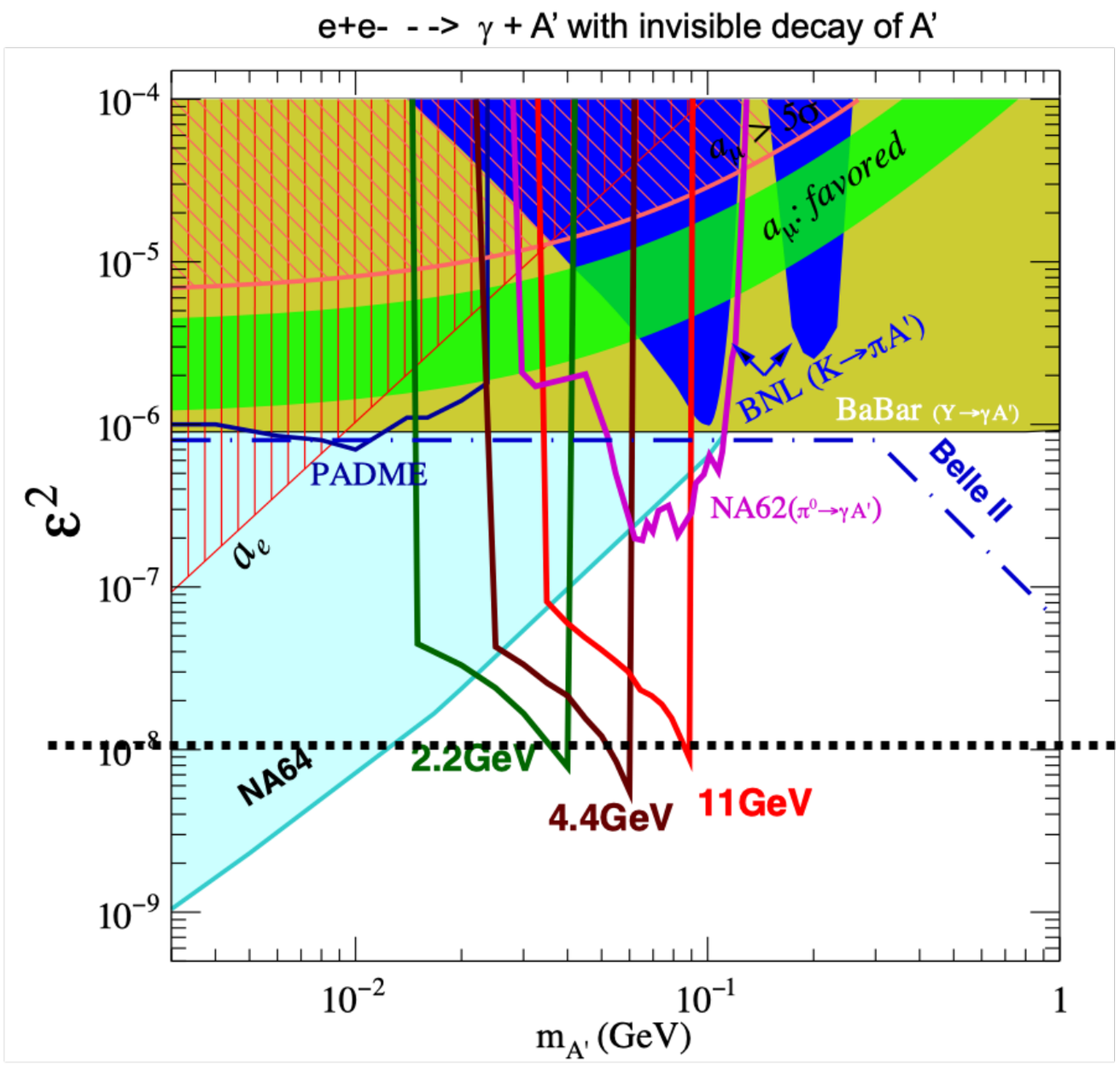



**Additional statistics would provide discovery potential/ sharpen limits**

# The JLab positron beam with PRad setup would provide additional unique dark photon searches

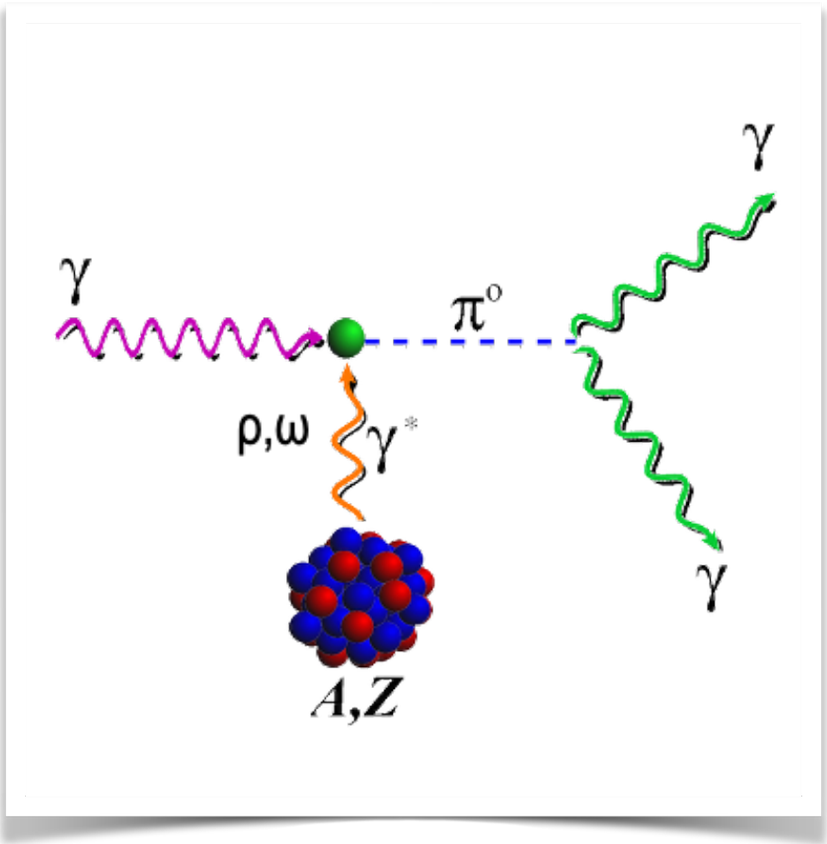
## Allows one photon detector probing A' decays to invisible particles



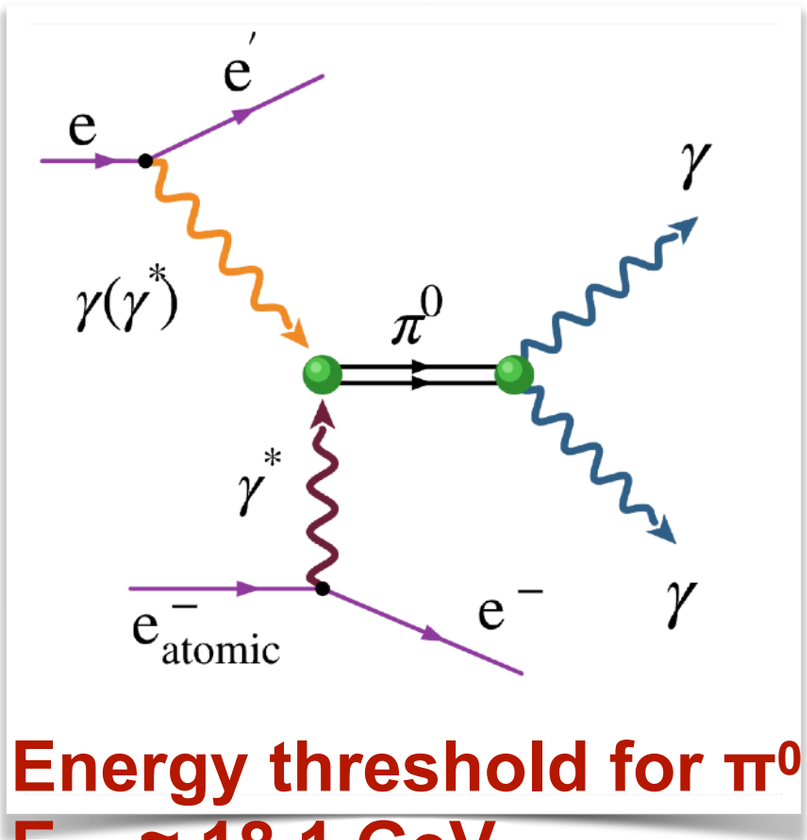

**Positron A' collaboration : B. Wojtsekhowski et al., conditionally approved by PAC-52**

image from B. Wojtsekhowski

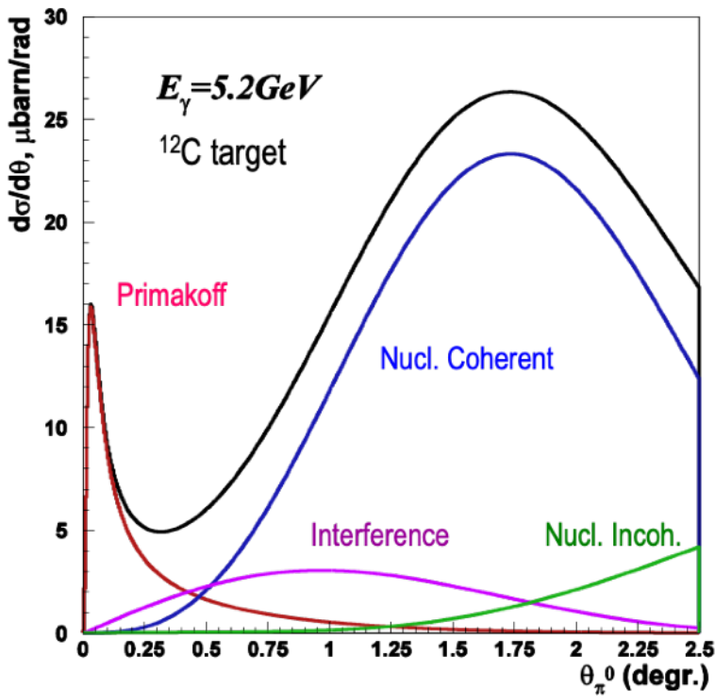
# A JLab energy upgrade would enable to most precise determination of $\pi^0$ lifetime



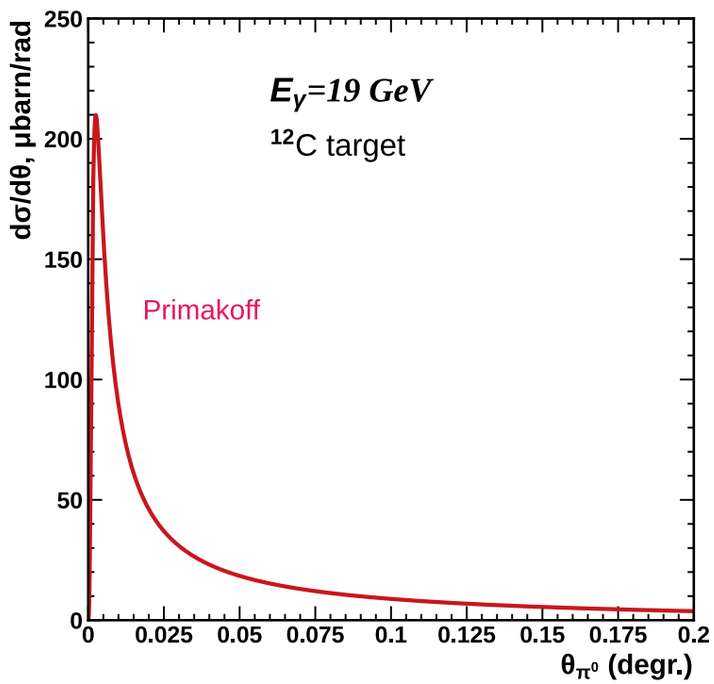

⇒




**Energy threshold for $\pi^0$**
**$E_{\gamma^*} \approx 18.1$ GeV**



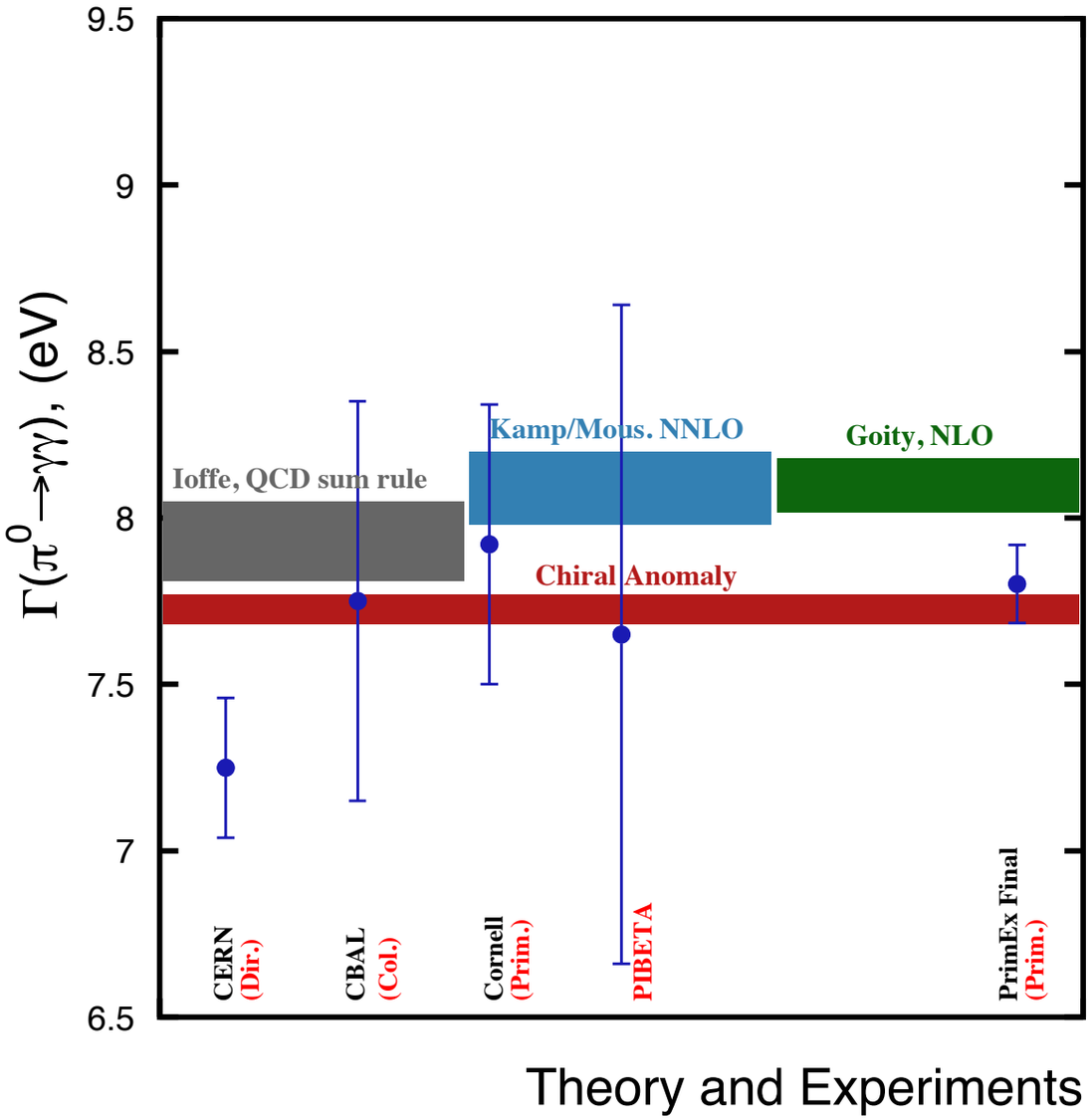

⇒



# The X17 apparatus with detection of all three final state particles (e, $\gamma\gamma$) allows high precision

## PrimeX result had total uncertainty of ±1.5%

I. Larin et al. , Science 368, 506–509 (2020)




## Contribution from nuclear background ±1.0%

**The detection of all four final state particles (e,e,$\gamma\gamma$) would allow high precision measurement of the $\pi^0$ transition form factor (TFF)**

# Summary

- The PRad experiment demonstrated the novel magnetic-spectrometer-free technique in electron scattering.
- The recently completed PRad-II has reconfirmed the method and improved on it
- The same technique along with a recoil detector would allow high precision measure of deuteron and helium charge radii.
- These would provide unique tests of theory and unique input to the charge-vs-mass radius comparison.
- The X17 experiment demonstrated the advantages of the magnet-free technique and provides a unique opportunity to explore the e-to-μ mass desert.
- The JLab positron beam will allow additional new dark photon search for invisible decays.
- An energy upgrade would allow high precision measurements of the pi0 lifetime and pi0 TFF

This work was supported by US DOE grant DE-FG02-07ER41528