NREC WORKSHOP 2024

DIRECT DETECTION OF RADIATIVE PHOTONS IN PRAD DATA

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For PRad/PRad-II Collaboration

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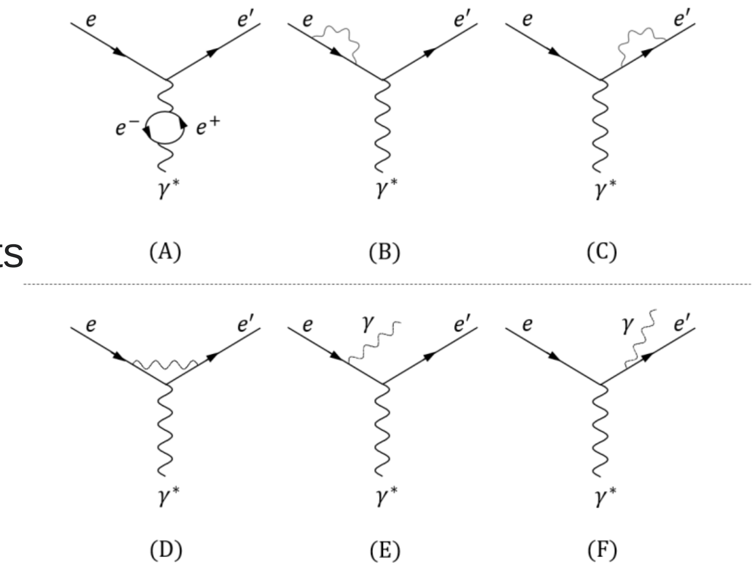
Radiative Effects

An unwanted “background” for all electron scattering measurements

- Reality is complicated
  - Higher order contributions from loop diagrams, internal Bremsstrahlung, straggling effects due to external materials
  - Measured cross sections are obfuscated by the radiative effects
  - Unavoidable for all electron scattering experiments
- Depends on the process and the experimental settings
  - Efforts from both theorists and experimentalists
  - Internal and external radiative correction



Radiative Correction Recipes

- The most famous recipes
  - Mo&Tsai

- Modern precision electron scattering experiments
  - Require precise QED radiative corrections
  - NLO beyond URA for ep and ee (e.g., Akushvich et al. 2015)
  - Higher order calculations (e.g., MCMULE)
  - Monte Carlo simulation for external radiative effects

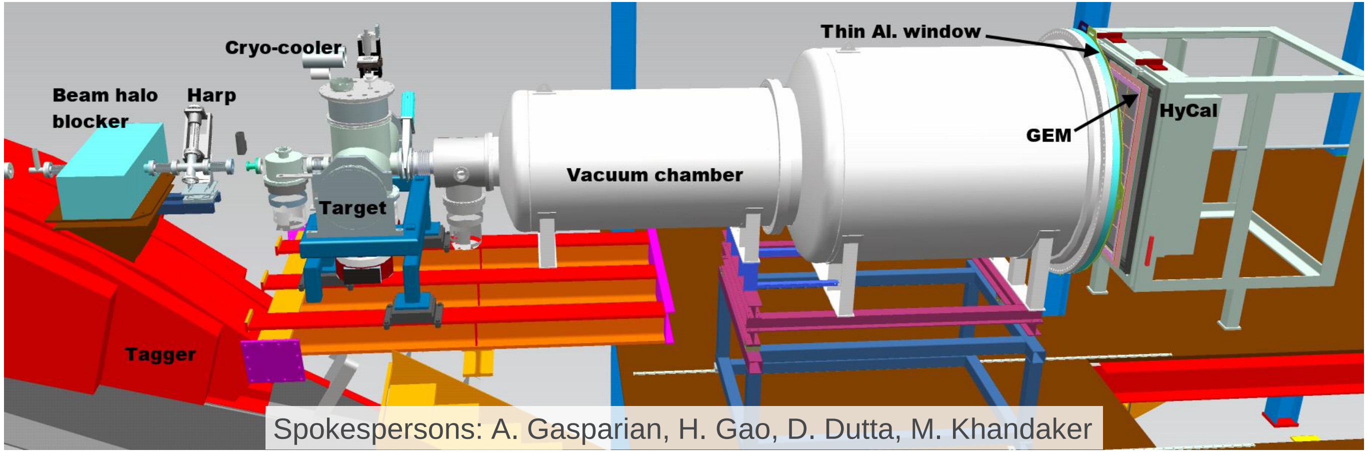
- Only indirect tests from experimental inputs
  - Data after correction
  - Large discrepancy reported between Mo&Tsai and de Calan, Navelet, and Picard 1991
  - **PRad data may provide direct test to the calculations of radiative effects**

D. Dutta's talk on Tuesday

PRad Experiment at JLab

Precision measurement of the proton charge radius

- Experimental data taken in 2016 summer at Hall B, Jefferson Lab
- Measured proton electric form factor (G_E) at unprecedented low Q^2
  - Elastic electron-proton scattering normalized by Moller process
  - Four momentum transfer square (Q^2) from $2x10^{-4}$ to 0.06 GeV^2/c^2

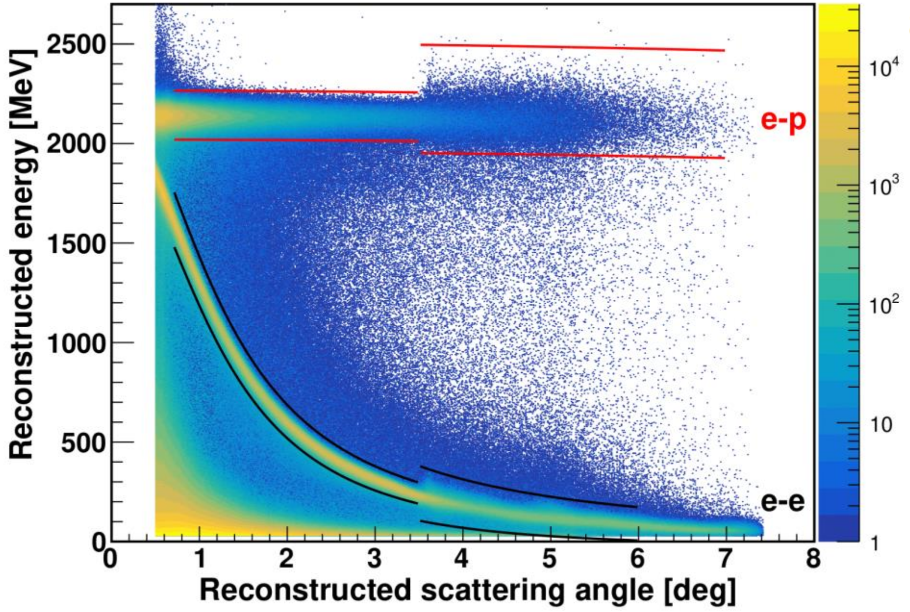


Spokespersons: A. Gasparian, H. Gao, D. Dutta, M. Khandaker

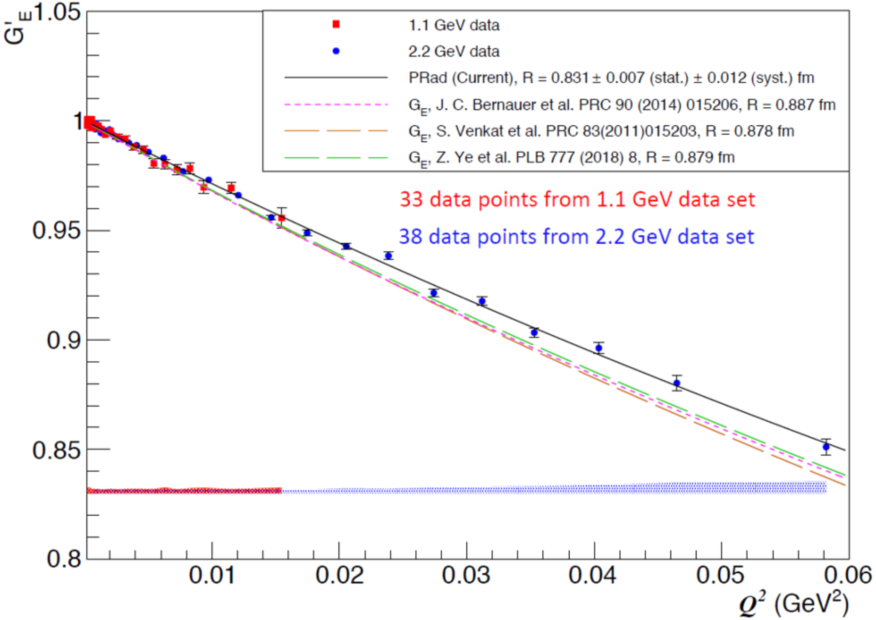
Experimental Data from PRad

Elastic *e-p* process and Møller process

Events Distribution



Proton Electric Form Factor G'_E

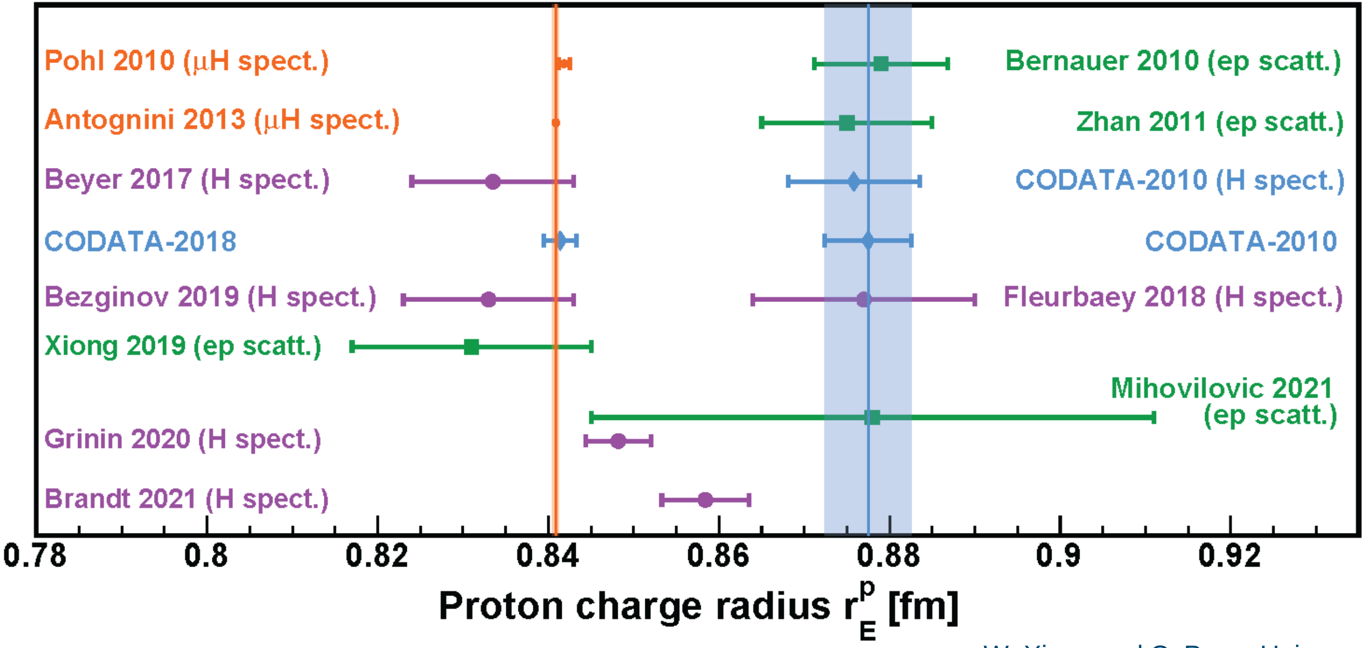


W. Xiong et al., Nature 575, 147-150 (2019)

J. Zhou's talk on Wednesday

Proton Charge Radius

Data tension on the scattering experiments



W. Xiong and C. Peng, Universe 2023, 9(4), 182

Proton Charge Radius

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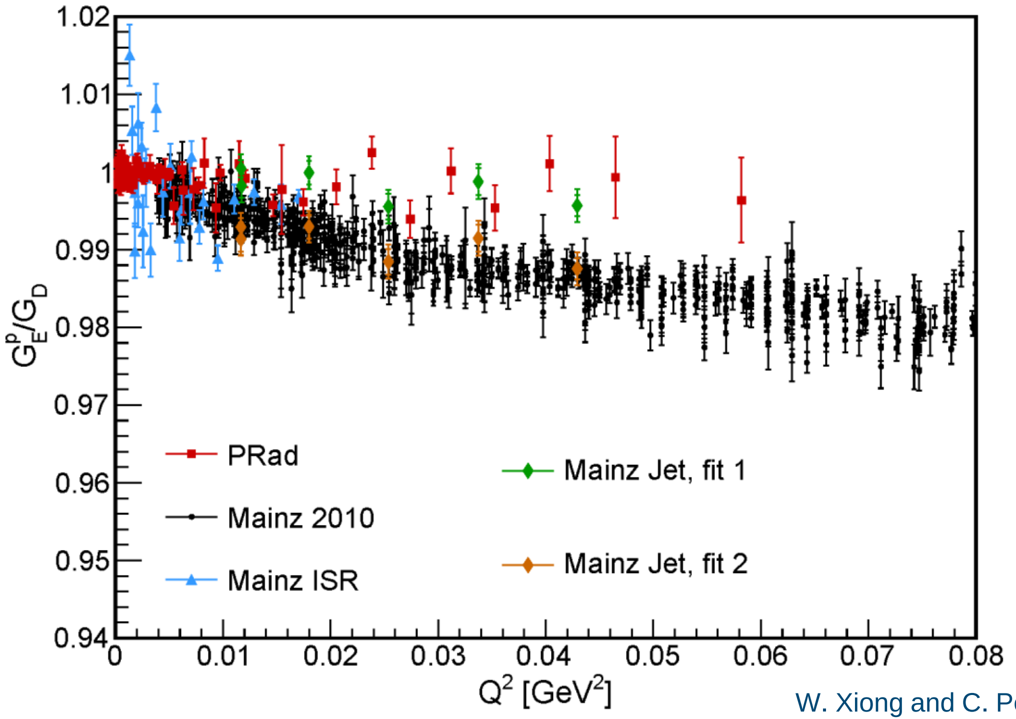
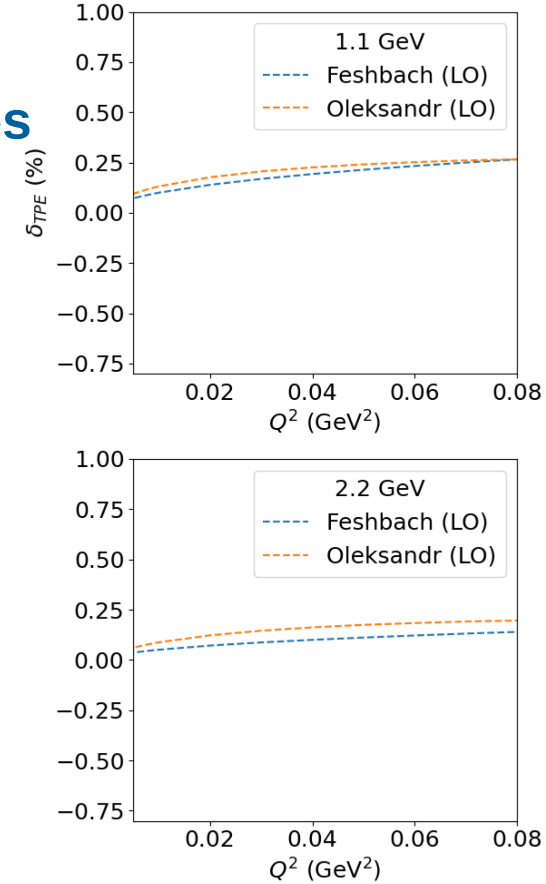


W. Xiong and C. Peng, Universe 2023, 9(4), 182

Radiative corrections for PRad

One of the major systematic uncertainty sources

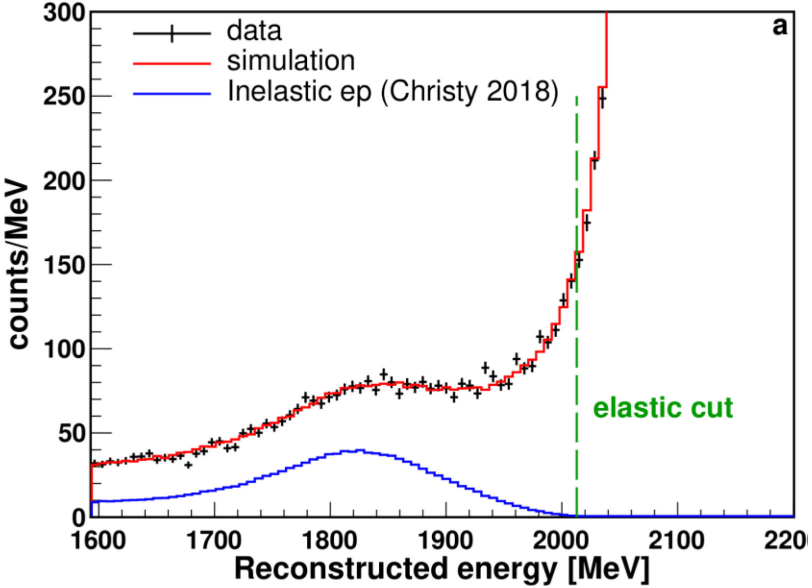
- NLO calculations beyond URA (Akushvich et al. 2015)
  - ~10% correction to the measured cross sections
- TPE (factorized part) contribution from
  - H. Feshbach
  - O. Tomalak
  - < 0.2% for the experimental kinematic range
- External radiative correction is handled by GEANT4 simulation
  - Event generators with radiative photon emissions
  - Iterative process til data and simulation converge



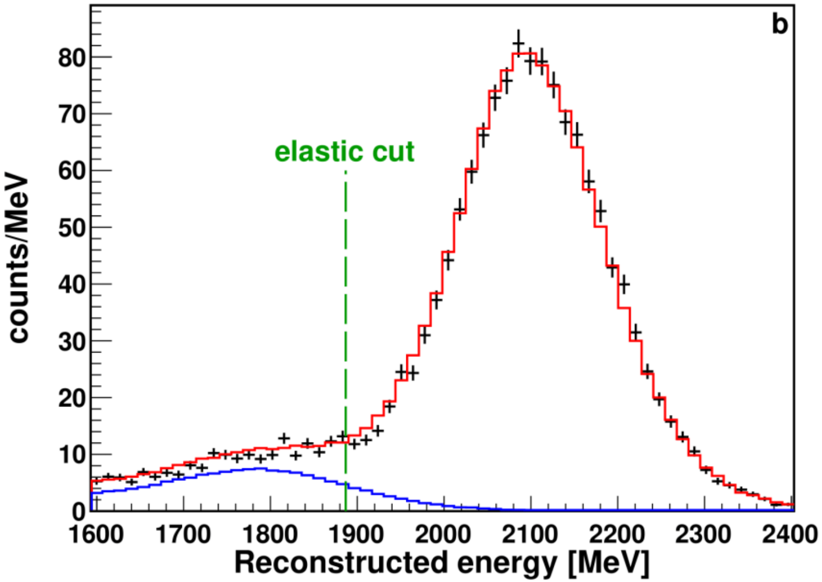
Simulation with Radiative Effects

Comparison with experimental data

- E' spectrum of scattering electrons



$3° < \theta_e < 3.3°$ ($PbWO_4$ blocks)



$6° < \theta_e < 7°$ (Lead glass blocks)

Direct Measurement of Radiative Photons

High precision calorimeter and neutral particle identification

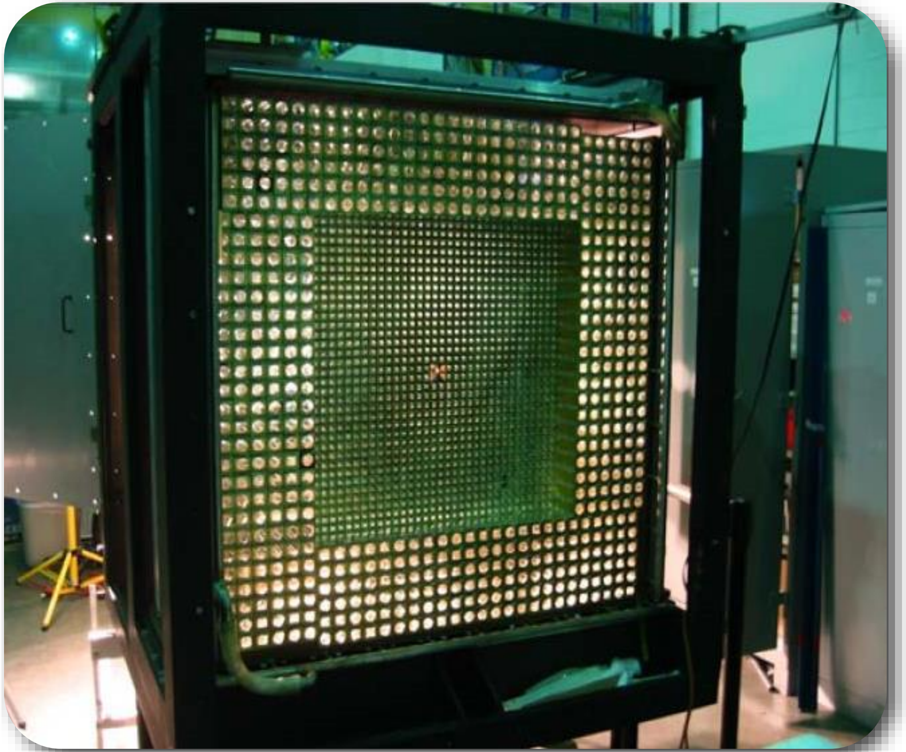
- Data and simulation agree well
  - Indirect test of radiative corrections
  - Both non-radiative (dominant) and radiative contributions

- PRad detectors could detect radiative photons
  - Calorimeter to measure the photon energy and position
  - GEM serves as neutral particle identification
  - Limit on the energy/spatial resolution for the low energy photons
  - Limit on the GEM detection efficiency

PRad Detector System

High precision calorimetry

- Hybrid EM calorimeter (HyCal)
  - Inner 1156 PbWO4 modules
  - Outer 576 lead glass modules
- High resolution and efficiency
  - $2.6\%/\sqrt{E}$ for both e, γ
- Scattering angle coverage: ~ 0.7° to 7.0°
- Full azimuthal angle coverage
  - For PbWO4: up to 3.3°



PRad Detector System

Gas Electron Multiplier Detectors

- Two large area GEM detectors
- Small overlap region in the middle
  - Systematics control of the efficiency
- Excellent position resolution
  - 72 µm (for charged particles)
- Insensitive to neutral particles
  - Neutral/charged PID

Events with Explicit Radiative Photons

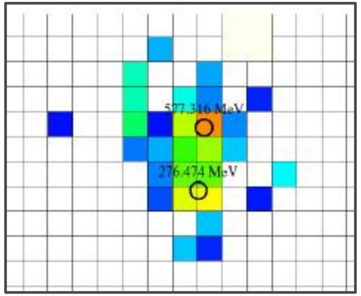
Hard photon emission

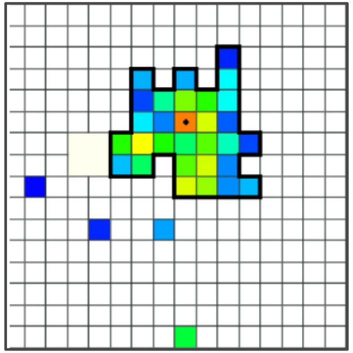
- PRad detector system can measure radiative photons
  - HyCal cluster splitting – distance at ~ 3 cm (an opening angle of $0.3°$ at the maximum distance)
  - Photon energy measurement with HyCal – down to 20 MeV
  - Neutral particle (gamma) identification with GEMs

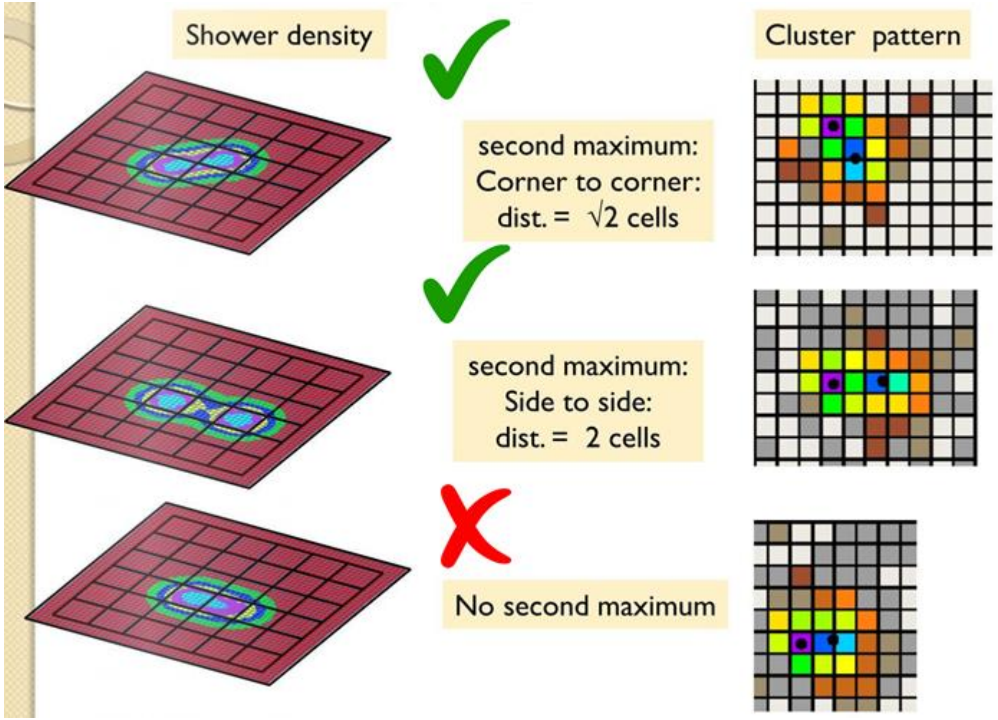
- Explicit radiative event selection
  - ep – coincidence of scattered electron and the radiative photon(s) + elasticity
  - ee – coincidence of two electrons and the radiative photon(s) + elasticity + coplanarity

Separation of Radiative Photons

- Cluster splitting on HyCal
  - Minimum separation ~3 cm
  - Energy threshold on 20 MeV (maybe lower but resolution will be bad)





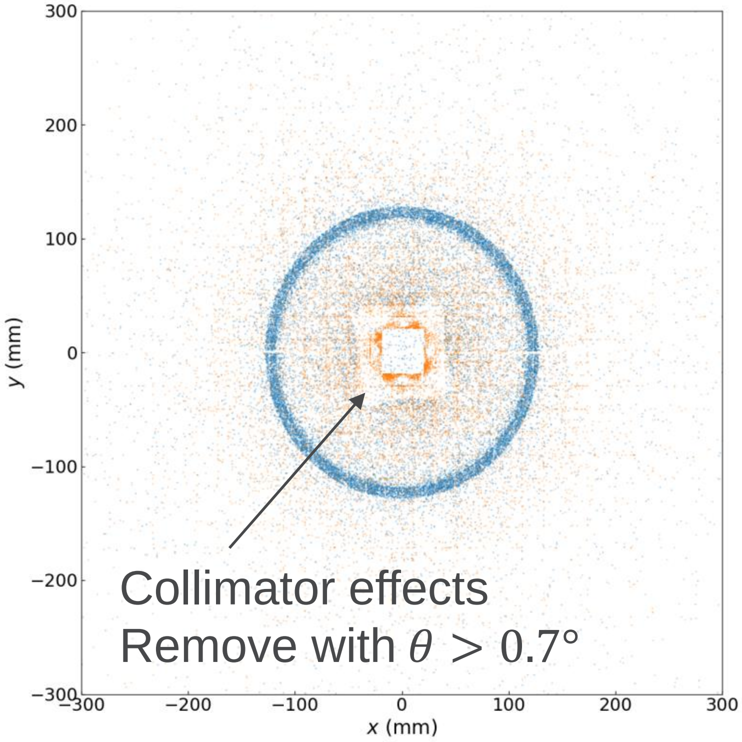


I. Larin, HyCal Clustering

Møller Ring with Radiative Photons

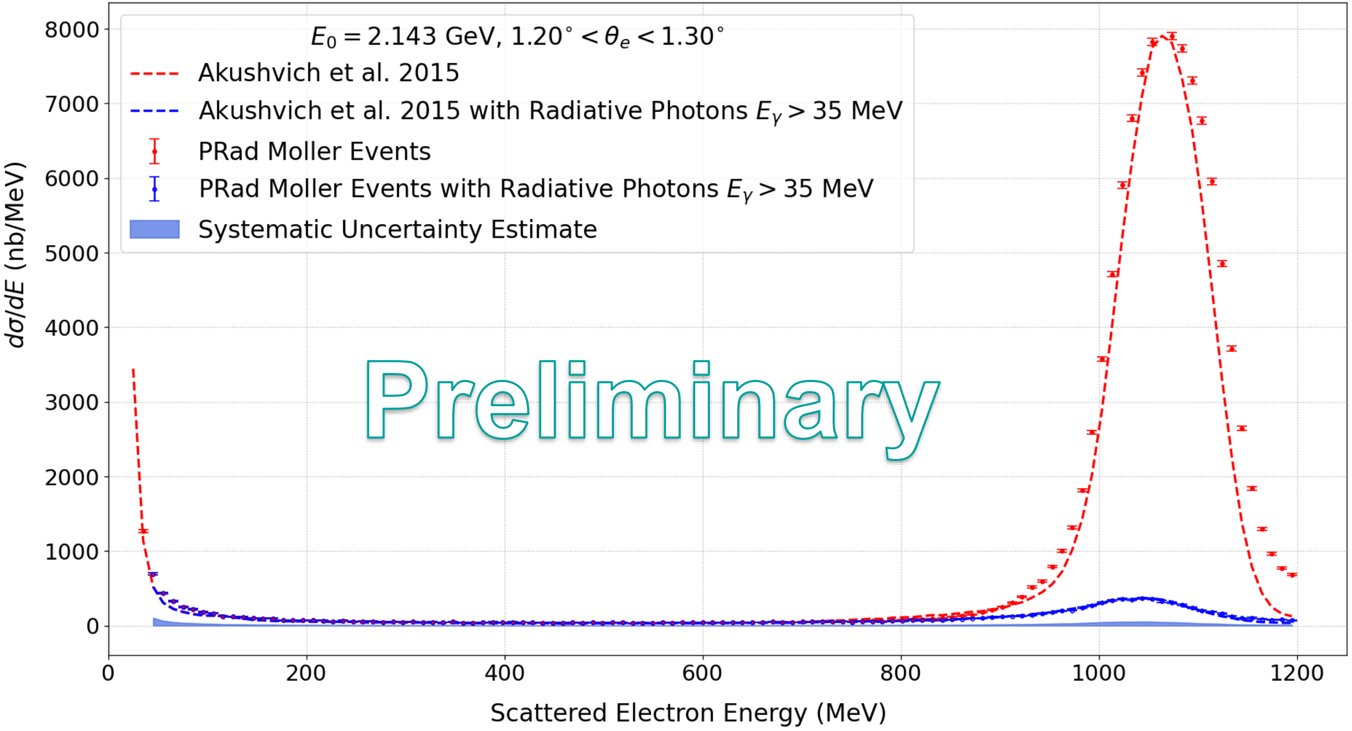
Geometrical distribution

- The symmetric Moller ring selection
  - Single-arm selection at $1.2° < \theta_e < 1.3°$
  - Elasticity cut with 3.5 σ_E
  - Co-planarity cut
  - Geometrical cut to remove collimator effects
- Radiative events selection
  - Requiring one photon



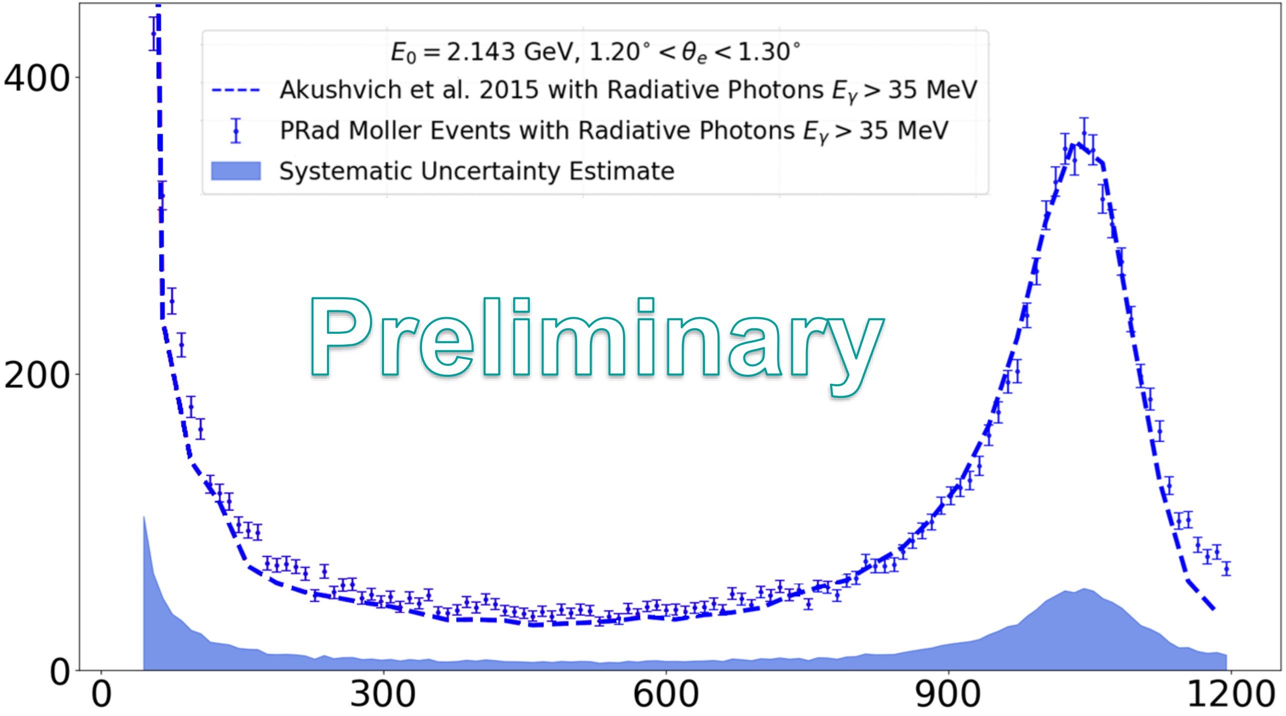
Radiative Møller Events

Scattered electron energy distribution



Radiative Møller Events

Scattered electron energy distribution



Future Results and Improvement from PRad-II

- Radiative photon distributions
  - Opening angle θ_γ and energy E_γ
  - All Møller events
  - Elastic *ep* events

- Improvement with PRad-II data
  - Higher statistics (critical for two-dimensional distribution of radiative photons)
  - Better PID efficiency with two GEM planes

Summary

- Direct measurement of radiative photons in PRad data
  - Experimental input to the direct test of radiative corrections for *ep* and *ee* scattering
  - Negligible effect on ISR due to window-less target
  - Measurement of radiative photon distributions
  - Limitation on the minimum photon energy and PID efficiency

- Expect a significant improvement from PRad-II
  - Wider kinematic coverage, higher statistics
  - Better PID and efficiency with two GEM detectors

THANK YOU

Simulation vs. Data