Using R_function to study the high-resolution spectrometer HRS acceptance for the 12 GeV era experiment E12-06-114 at JLab

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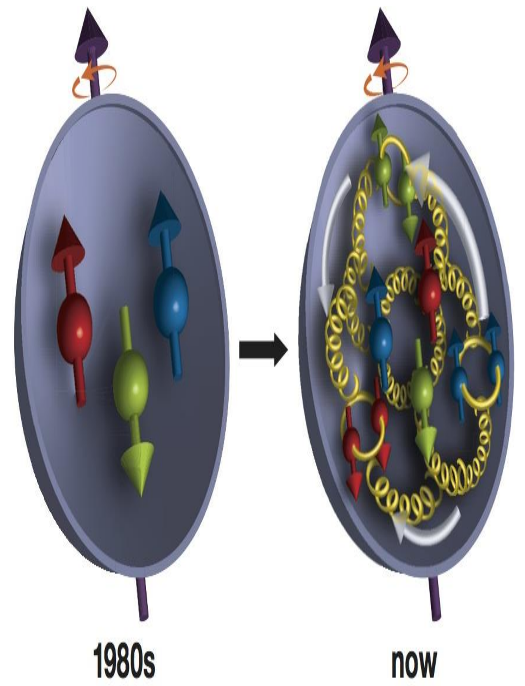
Abstract

The aim of this study is to model the High-Resolution Spectrometer (HRS) acceptance in an accelerator based study of the internal structure of the proton to the 1% level. The HRS acceptance is a 4-D region of space, depending on the four correlated target variables (y_{tg}, θ_{tg}, φ_{tg}, δp_{tg}). Due to the 4-D structure the acceptance region is difficult to visualize. The R-function, which defines the distance of a particle from the HRS acceptance bound, provides a convenient way to make a single cut and select electrons in the 4D-space. Preliminary results show that the R-value from experimental data agrees with R-value from the simulated data. In the future, we will optimize the simulation for better agreement with the experiment.

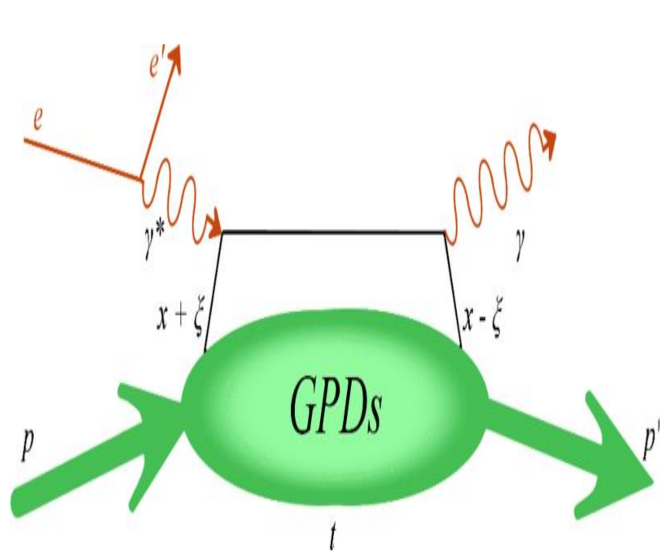
Introduction

- Nucleons are the building blocks of the atomic nuclei.
- Our initial understanding of nucleons was that they were fundamental particles.
- Deep Inelastic Scattering experiment showed that they have internal structure (quarks and gluons).
- Quantum chromodynamics (QCD) is the theory that describes the interaction of the quarks and gluons.
- Two experimental methods were used to study the structure of nucleons:
  - Elastic Scattering ➡ The spatial distribution.
  - Deep Inelastic Scattering ➡ The momentum distribution.
- Still much is left unknown about the structure of nucleons.



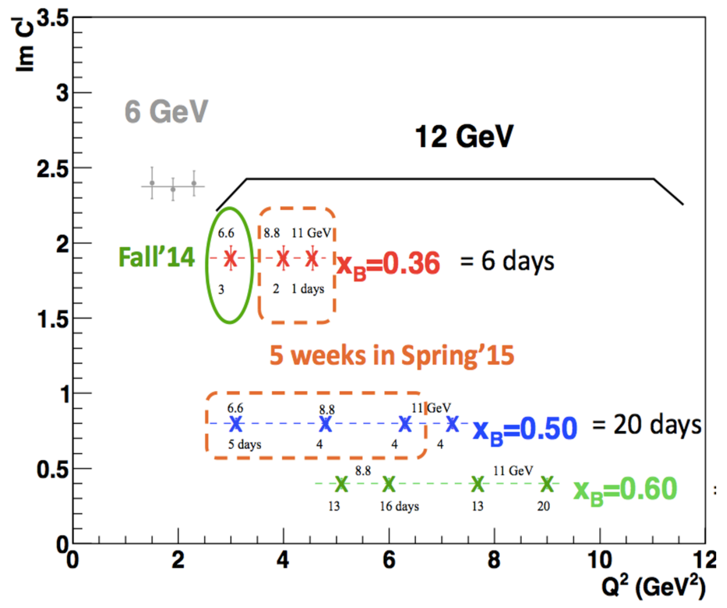
Generalized Parton Distributions (GPDs)

- GPDs were introduced to parametrize nucleon structure and a great deal of effort has been invested in their measurement.
- GPDs provide simultaneous information about both the spatial and momentum distribution of the partons within the nucleon.
- Deep Virtual Compton Scattering (DVCS) is the golden process for probing GPDs.
- In the DVCS process, the electron interacts with an individual quark, giving the quark an enormous amount of momentum. This quark gets rid of its excess energy by emitting a high energy photon. The quark remains a part of the intact target proton.



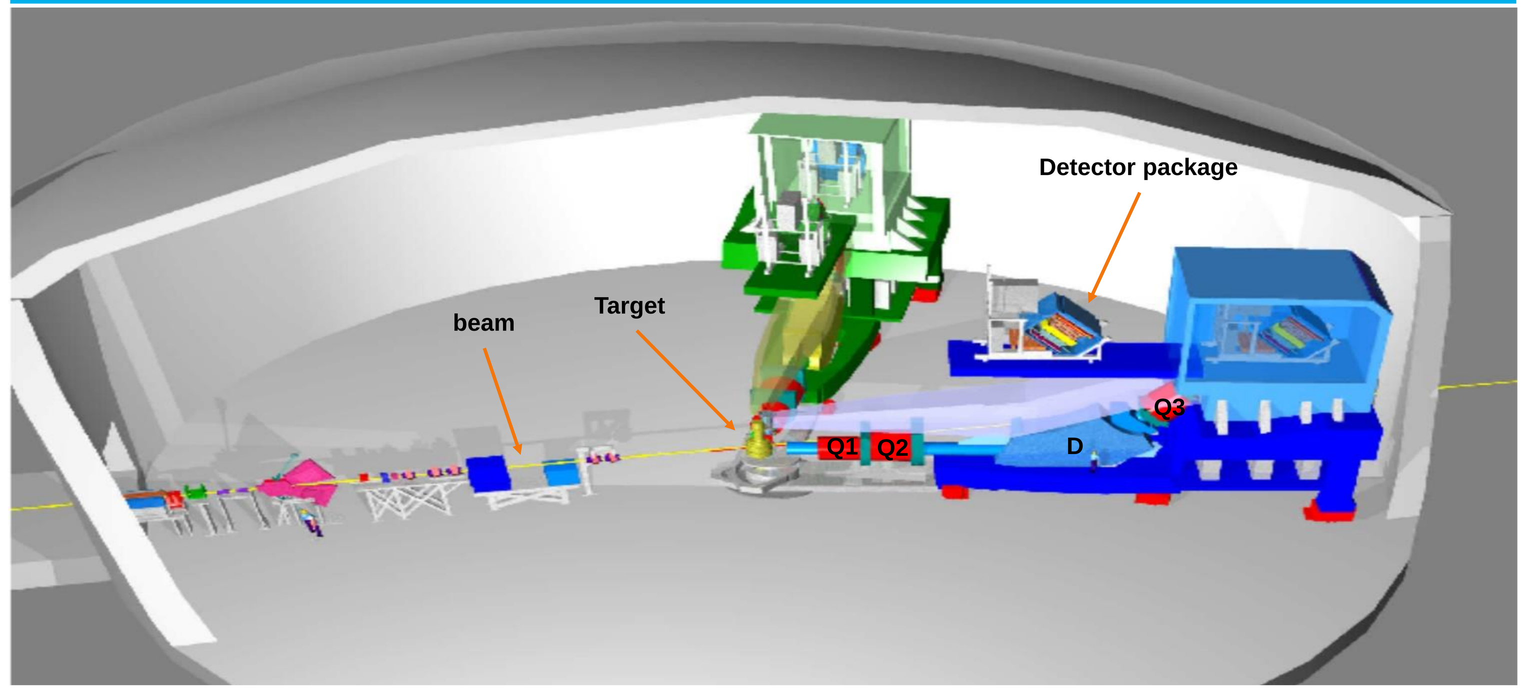
DVCS Experiment Goal

- DVCS1 and DVCS2, which were conducted in 2004 and 2010 at JLab, showed hints of the validity of the GPD formalism in parametrizing proton structure.
- Experiment E12-06-114 (DVCS3) was conducted in 2016 and the goal is to test the formalism of the GPDs:
  - Q^2 Scans at several Bjorken variable X_B to validate GPDs formalism and find the minimum 4-momentum transfer of the virtual photon Q^2 at which factorization holds.
  - Measure the DVCS cross sections at fixed X_B over the full range in Q^2 accessible for k ≤ 11 GeV.



Scaling tests of the DVCs cross-section [1]

DVCS Experimental Setup (JLab Hall A)

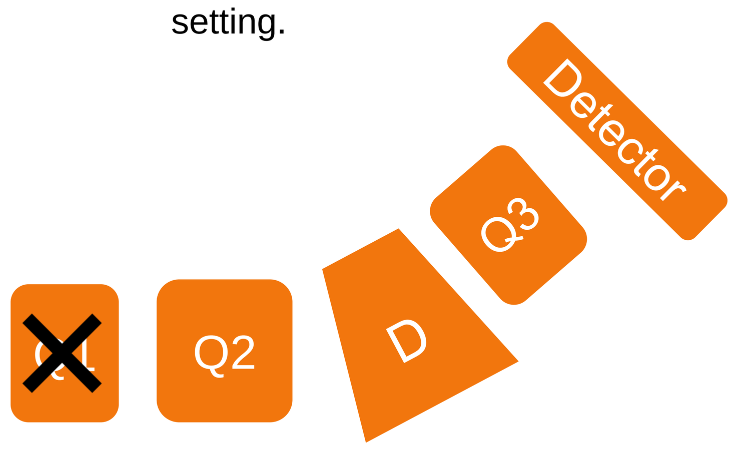


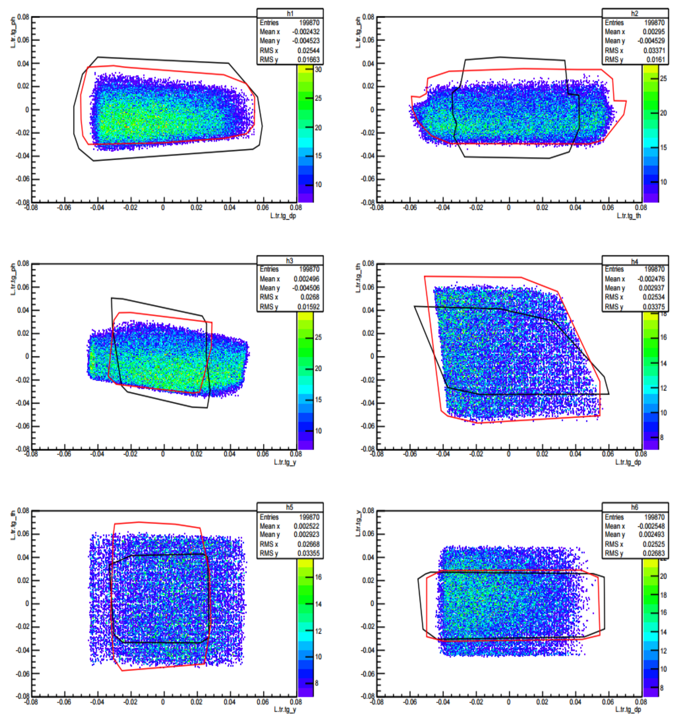
- HRS identifies scattered electrons with excellent momentum precision, $\frac{\sigma(\delta p)}{P} < 10^{-4}$.
- HRS configuration is Q_1 Q_2 D Q_3.
- Quadrupoles Q_1 and Q_2 focus the particles into the dipole.
- Dipole D selects particles according to their momentum and sends them to a detector package.
- Quadrupole Q_3 focuses the interesting particles in the detector hut.

Why R_function?

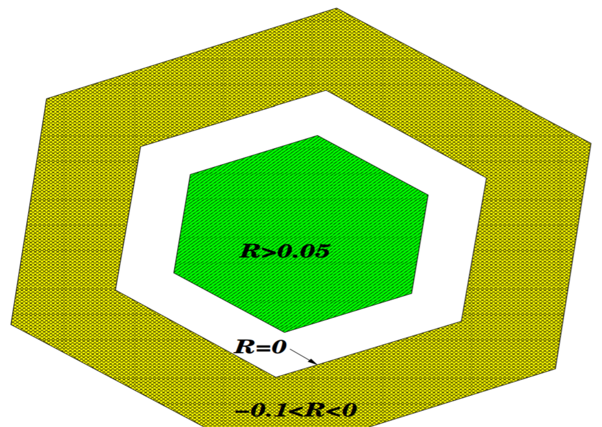
- The HRS acceptance is a 4-D region of space, depending on the four correlated target variables (y_{tg}, θ_{tg}, φ_{tg}, δp_{tg}).
- The 4-D acceptance region is difficult to visualize.
- The R-function, which defines the distance of a particle from the HRS acceptance bound, provides a convenient way to make a single cut and select electrons in the 4D-space.

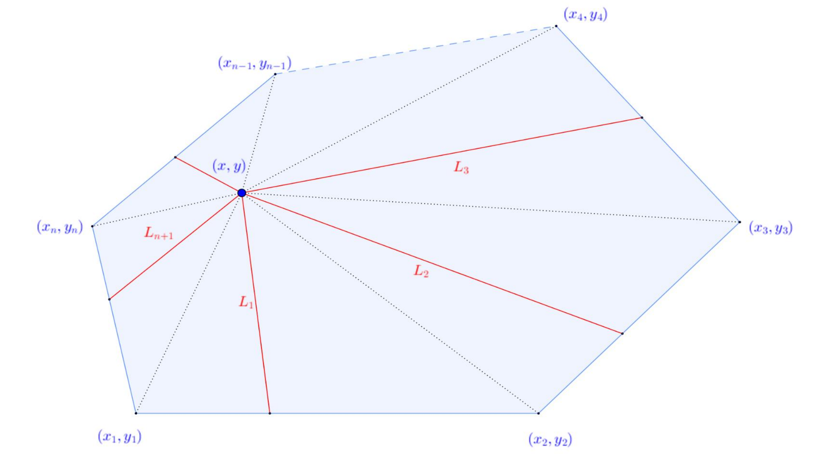
- Q_1 detuned for most of Spring and Fall 2016.
- HRS Acceptance region is different for each kinematic setting.
- Need R-Function for each kinematic setting.





General R_function Definition for one plane of the polygon

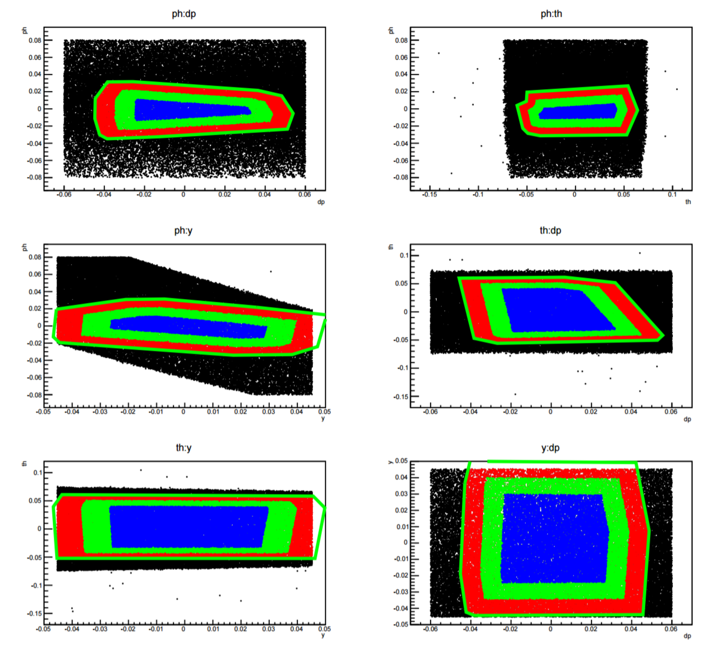




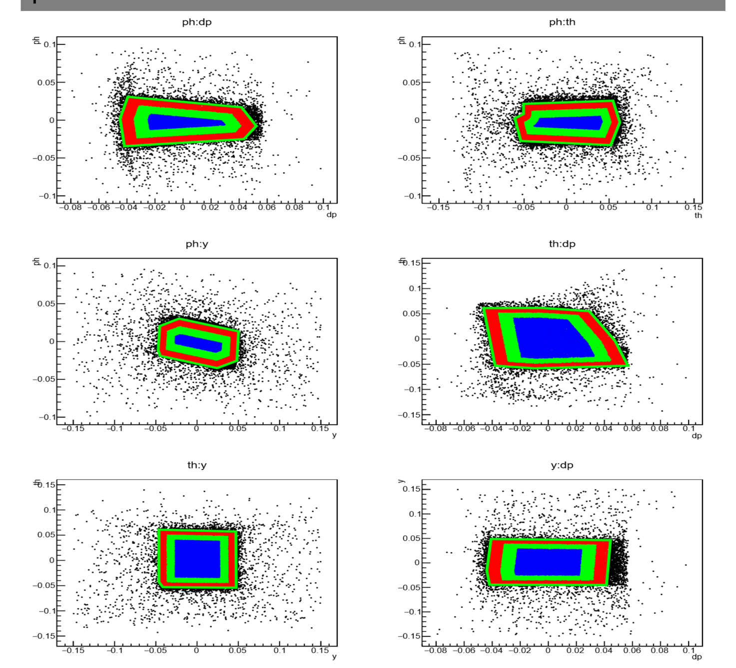
- R_function>0 inside the boundary, R<0 outside the boundary, and R=0 on the boundary [3].
- R_value for one plane=min(L_1,L_2,L_3,L_4,.., L_{n-1},L_n)
- R_value = min(R_value1,…..,R_value n)
- R(y,θ,φ,δ)=min (R(φ, θ),R(φ, δ),R(φ,y),R(θ, δ),R(θ,y),R(y, φ))

Defining the boundary and Calculating R-value

R-2D for the simulated data in each plane using the same boundary that is defined by the data target variables

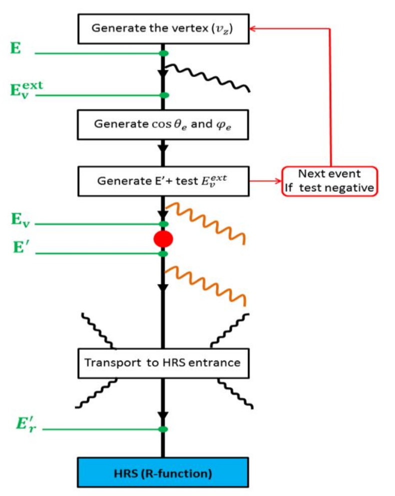


R_2D for the experimental data in each of the six planes.



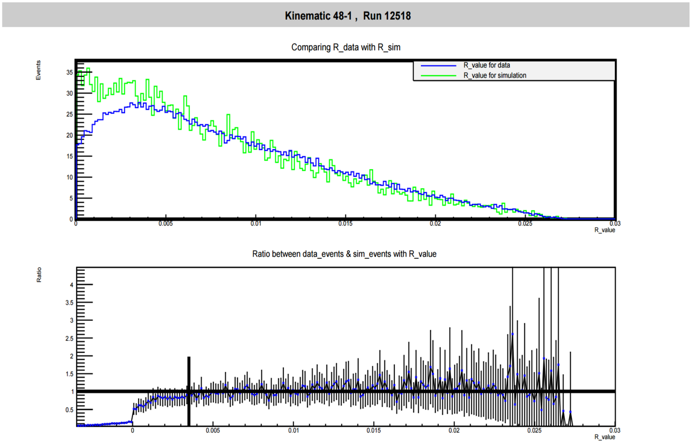
Monte-Carlo simulation

- Monte-Carlo's main aim is:
  - Evaluate the effective acceptance in the phase space.
  - Apply the radiative correction.
- Monte-Carlo simulation is based on the GENT4 toolkit.
- Geant4 is a detector simulation toolkit written in the C++ language.
- In this code, most of the Hall A experimental setup was included.
- Diagram representing the main steps of the Monte-Carlo simulation [2].



Comparing R_value for the experimental data and the simulated data

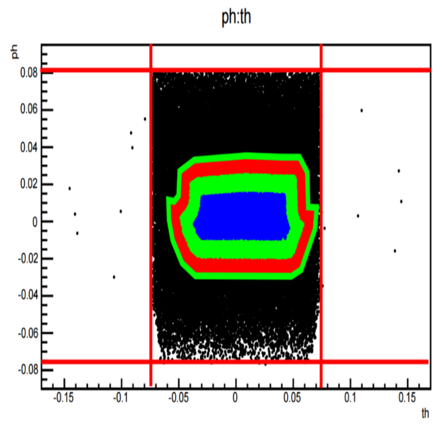
- Agreement between R-value of the experimental data and simulated data demonstrates the effectiveness of the acceptance analysis results.
- Selecting events when the ratio between experimental data and simulated data becomes constant.
- R-cut > 0.0035 eliminates the events on the edge.
- 66% of the data corresponding to the good electrons are selected with R-cut > 0.0035.



Preliminary Results

- $\Omega=\frac{N_{survived}}{N_{total}} \times \Delta\theta \times \Delta\varphi$
- The solid angle of a detector is related to the number of scattered electrons.
- Understanding the solid angle is a vital component for determination of the probability of an interaction.

Kin	# Run	#sim-events	# sim-events R>0	Solid angle/ msr
48-1	12518	56162	12200	5.21
48-2	13009	35469	7351	4.9
48-3	12868	68697	13007	4.48
48-4	13111	84892	14634	4.08
36-2	14150	65617	1719	6.32
36-3	14480	58672	16756	6.76
60-1	15017	205013	43163	5.05
60-3	14628	119391	16660	3.34
Nominal solid angle				6.7



References

[1] http://hallaweb.jlab.org/collab/meeting/2017-winter/Georges.pdf
[2] M. Defurne, PhD Thésis, Université Paris-SUD, 2015.
[3] Z. Chai, PhD thesis, Massachusetts Institute od Technology, 2003.