Hall A DVCS Experiment Plan

May 6, 2002

1 Introduction

Deep exclusive experiments have become the subject of considerable interest at several laboratories since it is possible to extract information on a new class of parton distributions, namely the Generalized Parton Distributions (GPD's). The GPD's contain a wealth of information about the transverse momentum and angular momentum carried by the quarks in the nucleon. They can be accessed through hard exclusive electroproduction of mesons and photons [**?**]. The E00-110 experiment[1] plans to measure for the first time the **exclusive** $ep \to ep\gamma$ reaction in the Bjorken regime (fixed x_B, large Q^2 and $Q^2 >> -t$, where t is the momentum transfer to the proton).

We will measure the beam helicity asymmetry of the $ep \to ep\gamma$ process in Hall A at 6 GeV. A schematic overview of the experimental setup illustrating the detection of the proton and photon around the virtual photon direction is shown in Fig. 1. The kinematics covered in the experiment (see Table 1) allows us to perform a Q^2 scan from 1.5 GeV^2 to 2.5 GeV^2 at fixed $x_B \approx 0.35$. At this kinematics, the asymmetry is dominated by the DVCS -Bethe-Heitler (BH) interference, which is proportional to the imaginary part of the DVCS amplitude amplified by the full magnitude of the BH amplitude. We expect to achieve 8% precision on the measurement of the VCS amplitude. If the scaling regime is reached, this corresponds to an 8% measurement of a linear combination of three of the GPDs.

The azimuthal dependence of the asymmetry around the virtual photon direction allows us, *at each Q^2 point,* to separately measure a higher twist term together with the leading twist term since they have different azimuthal angular dependences. The higher-twist term will be determined to within 8% of the expected value of the leading twist term.

s GeV^2	Q^2 GeV^2	$-t$ range GeV^2	θ_e deg	$\theta_{\gamma*}$ deg	P_e GeV	P_p GeV/c
5.5	2.5	0.15/0.45	25.1	-13.2	2.2	0.40/0.80
4.5	2.0	0.15/0.30	19.2	-17.3	3.0	0.40/0.80
3.5	1.5	0.15/0.30	14.7	-22.6	3.8	0.40/0.80

Table 1: Kinematics for E00-110. $\theta_{\gamma*}$ is the angle between the virtual photon and the beam, θ_e is the scattered electron angle, P_e and P_p' are the momenta of the scattered electron and recoil proton. The values for t and P_p are the approximate minimum and maximum values for a single kinematic setting, as defined by the angular acceptances of the photon calorimeter and proton detector.

2 Experimental Equipment

We will use the CEBAF polarized electron beam with a 15 cm LH_2 target and detect the scattered electrons in the Left HRS in its standard configuration. In addition, a specialized target chamber, and two new detectors for the detection of photons and protons will be built by the DVCS collaboration. As shown in Fig. 1, the DVCS Calorimeter consisting of PbF_2 total absorption blocks will detect the forward photons. Surrounding the calorimeter will be the Proton Array consisting of plastic scintillator blocks to detect the recoil protons. A sampling ADC system, the Analog Ring Sampler (ARS), along with customized trigger electronics will be used in order to deal with the high singles rates and pile up expected in the experiment.

2.1 Electromagnetic Calorimeter

The DVCS experiment requires an electromagnetic calorimeter with about 100 msr solid angle acceptance, better than $5\%\sqrt{E}$ energy resolution, and about 2 mm spatial resolution. In addition, the calorimeter should operate in high singles rate (≥ 2 MHz) environment with long term gain stability and linearity of about 1%.

Lead Fluoride (PbF_2) is an attractive Cerenkov medium for electromagnetic calorimetry, in a compact form factor, to meet the above requirements. Some basic properties of PbF_2 are listed in Table 2.1 and compared with $PbWO_4$ and Pb-Glass. Both PbF_2 and $PbWO_4$ (Lead Tungstate) are high density crystals facilitating compact geometry compared to Pb-Glass for a total absorption calorimeter. As a scintillator, $PbWO_4$ offers higher light output and can achieve high energy resolution. However, $PbWO_4$ has a stronger temperature dependence of the light-yield and is less radiation hardy compared to PbF_2. In addition, as a scintillator

$PbWO_4$ is more sensitive to neutrons and other hadronic background. Although Pb-Glass and PbF_2 are both cherenkov media, a number of effects combine to give PbF_2 higher performance in timing, energy, and spatial resolution. Hence, for the high rate, high resolution, and high stability needs of the DVCS experiment, PbF_2 is the natural choice.

The DVCS calorimeter consists of 132 PbF_2 crystals arranged in a rectangular grid of 11x12 cells with the front face of the calorimeter at 70 cm from the interaction point. A schematic view of the calorimeter cells is shown in Fig.2. Each crystal is a rectangular block of $30 \times 30 \times 186$ mm^3 with surfaces polished to optical quality and flatness better than 0.3 mm. The transverse block dimension of 30 mm is chosen so as to fully contain the electromagnetic shower in a cluster of 3x3 blocks. The depth of 186 mm corresponding to 20 radiation lengths offers full development of the shower longitudinally. The crystals will be wrapped with a 80μ thick layer of Tyveck to provide a diffused reflective surface to maximize light collection. A 50μ thick layer of black PVC over the Tyveck layer forms the light seal.

Each crystal will be viewed by an 8-stage mesh dynode Hamamatsu R5900 PMT. These PMT's are the choice of the ATLAS experiment at CERN and offer superior timing and linearity. In view of the high singles rate, the PMT's will operate at low gain ($\approx$10,000). Customized HV divider chain to ensure linearity and pre-amplifiers to boost the signal suitable for readout by the ARS ADC's is being developed by LPC, Clermont-Ferrand. We are presently studying options for optical and mechanical coupling of the PMT's to the crystals.

The energy resolution in a 3x3 array PbF_2 calorimeter was measured at Mainz to be about 3% at 1 GeV. This is a factor of 2 better than the Pb-Glass. Based on earlier measurements, we can expect a transverse spatial resolution (1σ) of 1.5 mm. The angular resolution of an array at 1.1 meter will be a combination of the vertex resolution and the calorimeter resolution. The vertex is determined by the electron arm transverse resolution of 1 mm (σ) and the electron and photon angles. We can expect 3 mr angular resolution for the photons.

Since the total solid angle of the PbF_2 calorimeter is essentially unchanged from the DVCS proposal using a Pb-Glass calorimeter, the total accidental rate for photons above 500 MeV (2 to 20 MHz) is unchanged. However, we can expect slightly improved timing resolution for the PbF_2 relative to Pb-Glass. Thus the coincidence to accidental signal to noise ratio is no worse with PbF_2, and maybe slightly better. The pile-up in each block will be worse. Each PbF_2 block at 1.1 m will subtend a solid angle of 0.744 msr (vs 0.1 msr for the Pb-Glass at 4m).

(**Please Update/complete - Ron/Kathy**)

	Pb-Glass TF-1	PbF_2	$PbWO_4$
Index of Refraction	1.65	1.85	1.85
Radiation Length X_0 (cm)	2.5	0.93	0.89
Moliere Radius r_0 (cm)	3.3	2.2	2.2
Density ρ (g/cm^3)	3.86	7.77	8.28

Table 2: Comparison of Pb-Glass, PbF_2, and $PbWO_4$ Cerenkov properties.

2.2 Proton Array

At the current stage of design, the scintillator ring is composed of 100 blocks of Bicron BC408 plastic scintillator. The ring is more highly segmented on the inner part, which corresponds to the lowest scattering angles. The blocks all have the same length, 30 cm, chosen to get the highest light output for recoil protons from 400 MeV/c to 1 GeV/c (DVCS protons). Each of those blocks will be read by a XP-2972 PMT and the readout will use the ARS sampling system.

Once the geometry of the active material is finalized, we will start working on the frame which will hold this detector together. We plan on starting the frame design in may (as well as the holding system). The drawings should be ready by september, which will leave 3 months to build the system before the end of the year. The scintillator array will then be put together at Jefferson Lab, tested with cosmics and if possible, with real beam. (**Please Update/complete - Charles/Franck)**

2.3 Target Chamber

The DVCS experiment will use the Hall A cryogenic target system with a 15 cm LH_2 target. Our GEANT simulation indicate that there are two main sources of electromagnetic background contributing to high singles rate in the DVCS detectors: Moeller electrons from the hydrogen target and the aluminum target windows, and secondary scattering of the primary beam from the narrow exit beam pipe and thick scattering chamber walls in the standard target chamber. Furthermore, the large geometrical acceptances of the proton array and the calorimeter is incompatible with the opening window of the existing target chamber. We plan to construct a new spherical scattering chamber to address these requirements.

The target chamber consists of a 1.2 m diameter aluminum sphere with 10 mm wall thickness as illustrated in Fig. ??. The standard cryotarget assembly will be mated vertically with the chamber via a 1 m diameter circular flange on the top. the beam entry port will be consistent with the existing 1" beam entry pipe.

However, the exit beam pipe will be a new six-inch diameter 8 mm thick aluminum cylindrical section to replace the existing conical beam pipe. In order to reduce total mass seen by the exit beam, the 6" exit pipe will be directly welded to the scattering chamber eliminating thick steel flanges. For the scattered electron detected by the Left HRS, the scattering chamber will have a rectangular port spanning 6° to 30° consistent with the vertical acceptance of the HRS. The HRS port will have a 15 mil vacuum window. Additional small view ports for inspection and survey will be provided. The 6" port with a turbo-pump on the top-hat of the cryotarget will be used for pumping down the new scattering chamber.

In order to reduce electromagnetic background from the beam entry and exit windows of the standard "beer can" aluminum target cells, we plan to develop a custom target cell with Beryllium windows. Development work on such a target cell is proceeding at California State University by our collaborator Dimitri Margaziotis.

The DVCS calorimeter and the proton array will be mechanically integrated into a common super structure. The estimated weight of the whole assembly is under 1 Ton. While the present hexagonal platform under the scattering chamber is adequate to handle the load, it is too small to accommodate the foot print of the DVCS detector. We plan to re-inforce the exiting platform with a 12' diameter circular stage. The DVCS detector assembly will be supported by the new platform. Angular positioning mechanism to move the detector in the range of 13 to 60° is being designed.

2.4 Data Acquisition System

The ARS system is described in length in the DVCS proposal. It is essential to evaluate the volume of data coming from the scintillator array, going in the data stream. In the following, we assume that one trigger event is an electron-photon coincidence. The rate of those is estimated to be of the order 400 Hz (this is calculated assuming a coincidence window of 100 ns and the rates given in Table 5 of the proposal).

The data acquisition electronics for the whole setup will be located on the Left HRS detector hut. The RCS team has tested the DAQ for the calorimeter, using a Linux PC platform to run CODA. Additional elements of DAQ have to be developed to acquire data from the ARS system used for the scintillator array. We plan to start this work in september 2001 as both the ARS system and the scintillator array setup will be finalized by then. All of the cables needed for the calorimeter are at Jefferson Lab, and will be handled by the RCS collaboration. Additional cabling will be needed for the scintillator array since its electronics will also be on the main electronics platform on the spectrometer. Nevertheless, only 120 additional cables have to be handled. We plan to use the high voltage cables

Institution	Contact	Contribution ($)
CEA, Saclay	Franck Sabatie	40,000
Rutgers University	Ron Ransome	49,905
Old Dominion University	Charles Hyde-Wright	52,000
LPC, Clermont-Ferrand	Pierre Y. Bertin	113,350
Jefferson Lab	Sirish Nanda	292,047
	Total	587,517

Table 3: Funding by Institutions

from the RCS veto detector for our scintillator array PMT's. It is very likely that we will also use the signal cables from the RCS veto detector for our scintillator array signals.

(**Please Update/complete - Pierre**)

3 Funding

The principal responsibilities for carrying out the DVCS experiment resides with the spokespersons. The new subsystems to be built will be the responsibilities of the following collaborators:

- **Proton Array:** Old Dominion University and Saclay
- **EM Calorimeter:** Rutgers University
- **DAQ/Electronics:** LPC, Clermont-Ferrand
- **Target System:** Jefferson Lab

The total project cost for the DVCS experiment is estimated at about $577k with a breakdown by funding source as shown in Table 2.

A detailed cost estimate based on the conceptual design of the experiment is given in Table 3.

4 Schedule

- **January 2002:** Hamamatsu PMT's order placed
- **March 2002:** Proton scintillator blocks ordered

Item	Institution	Specification	Quantity	Cost($)	Jlab Contrib
Calorimeter					
PbF_2 Crystals	Rutgers/Jlab	SICCAS 30x30x186 mm^3	145	116,435	84,315
PMT	LPC/CF	Hamamatsu-R5900U	145	27,550	
Base/Amplifier	LPC/CF	Custom	145	14,500	
High Voltage	Jlab	LeCroy 1461N	145		*
Low Voltage	Jlab	HP	1	4,000	4,000
Gain monitor	Saclay	Scanning LED	1	8,000	
Mechanical	Rutgers			12,000	
Assembly/Test	Rutgers			5,750	
Proton Array					
Scintillators	ODU	Bicron BC408	100	42,000	
PMT	LPC/CF	Photonis-XP2972	110	26,300	
Base/Amplifier	ODU	Custom	110	16,500	8,250
Gain monitor	ODU	LED/fiber	1	4,000	2,000
Mechanical	Saclay	Custom	1	32,000	
Assembly/Test	ODU		1	10,000	
DAQ/Electronics					
Readout ADC's	LPC/CF	ARS/VME	20x16ch	20,000	
PMT monitor	Los Andes/Jlab	VME	4x64ch	12,000	12,000
Trigger System	LPC/CF	Custom	1	25,000	
VME Crates	Jlab		4	14,000	*
Crate Controller	Jlab	PPC	4	16,000	*
Target Chamber					
Spherical Chamber	Jlab	1 cm thick	1	63,000	63,000
Beam/HRS Interface	Jlab	1"Entry/6"Exit	1	11,000	11,000
Target Cell Dev	Jlab/CSULA	Be window	2	10,000	10,000
System Integration					
Support Platform	Jlab	12' round table	1	15,000	15,000
Delay Cables	Jlab	RG213/50m	250	44,500	44,500
HV Cables	Jlab	SHV	250	*	*
Patch Cables	Jlab	BNC/Lemo	500	17,982	17,982
Assembly/Test	Jlab			20,000	20,000
Total				587,517	292,047

Table 4: Institutional responsibilities and budgetary cost estimate for the DVCS Experiment. The cost estimate does not include manpower and installation in the Hall. * Presently available in the Hall A inventory.

- **June 2002:** PbF_2 crystals ordered from SICCAS
- **July 2002:** Final Design Review
- **September 2002:** Jlab Readiness Review.
- **December 2002:** Scattering chamber procurement
- **February 2003:** Proton Array completed
- **March 2003:** Calorimeter assembly completed
- **June 2003:** DVCS detector integration and test
- **July 2003:** Experiment ready to install in Hall A

References

[1] Hall A DVCS Collaboration proposal, Experiment 00-110: `http://www.jlab.org/exp_prog/proposals/00/PR00-110.pdf`.

[2]

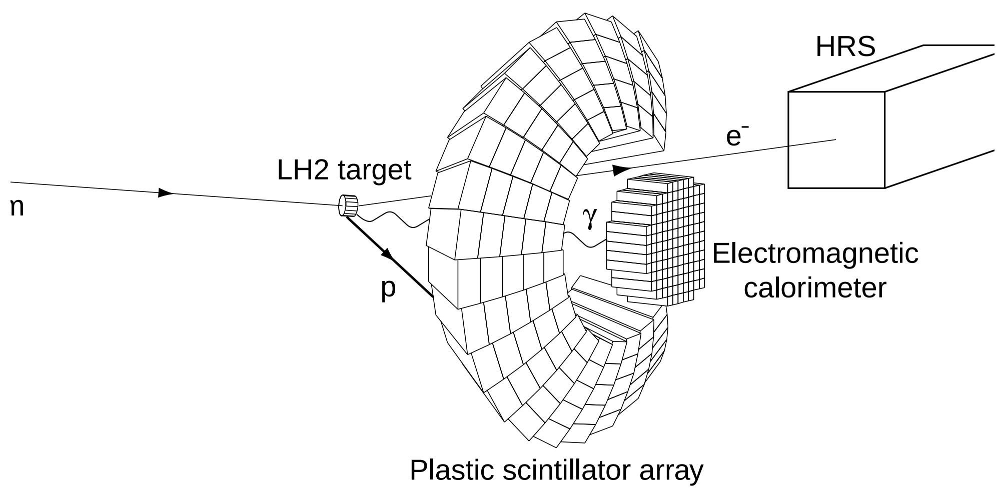

Figure 1: *Schematic three-dimensional view of DVCS setup, including target, electron spectrometer, photon calorimeter, and proton array.*

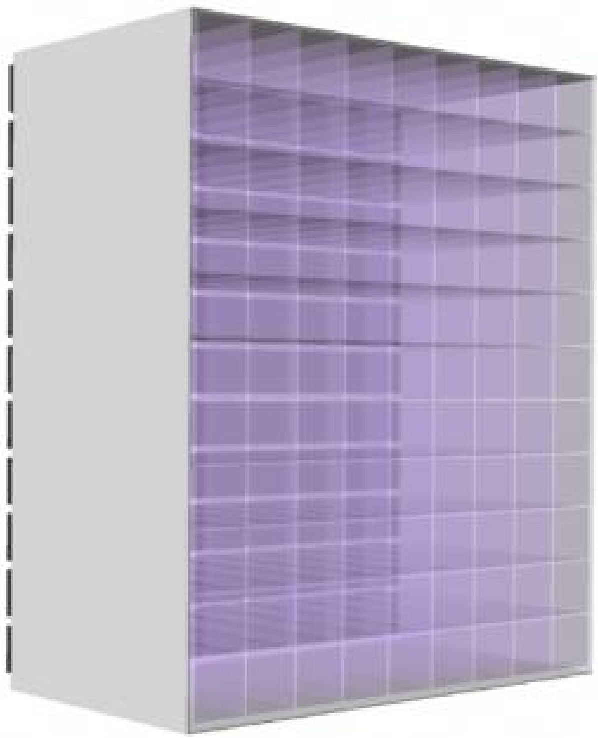

Figure 2: *Schematic view of the DVCS Calorimeter with an array of 11x13* PbF_2 *blocks in a rectangular stack. Individual block size is 30x30x180* mm^3.

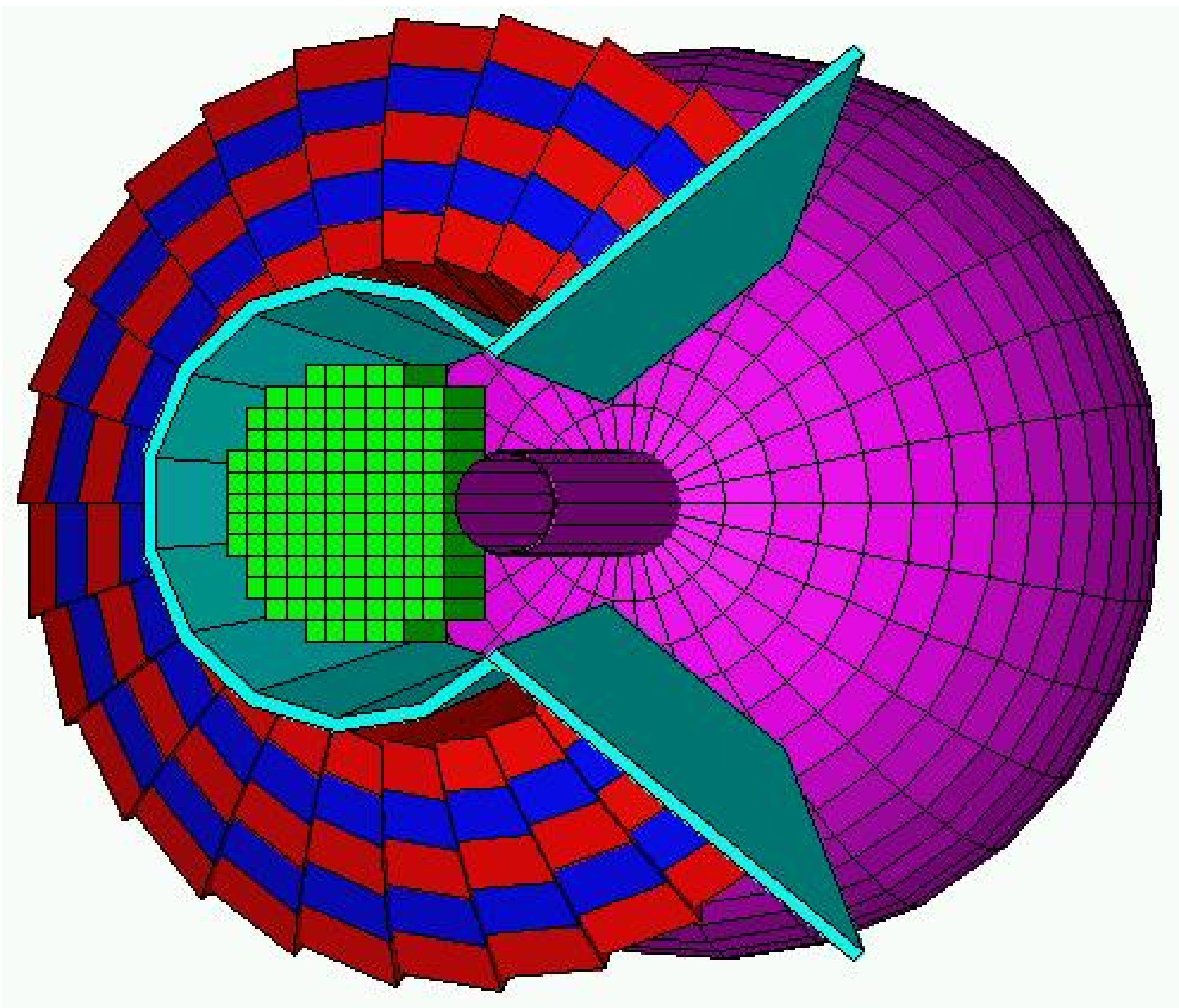

Figure 3: *Geant simulation model illustrating the DVCS detector setup with a spherical scattering chamber and 15 cm diameter exit beam pipe.*