Commissioning Plan for Hall A DVCS Experiments E07-007 and E08-025

Charles E. Hyde[1,2], Carlos Muñoz Camacho [1], Alexandre Camsonne [3] ,
Malek Mazouz[4], Julie Roche [5] , and the Hall A DVCS Collaboration

[1] *Laboratoire de Physique Corpusculaire, Université Blaise Pascal, 63177 Aubière, FRANCE*

[2] *Department of Physics, Old Dominion University, Norfolk VA, 23529, USA*

[3] *Jefferson Laboratory, 12000 Jefferson Ave, Newport News VA, 23606, USA*

[4] *Faculté des Sciences, Monastir Tunisia and*

[5] *Ohio University, Athens OH, USA*

I. EQUIPMENT DESCRIPTION

The E07-007 and E08-025 experiments include the standard Hall A cryotarget with 15 cm H_2 and D_2 cells and the left High Resolution Spectrometer (HRS-L). The cryotarget is housed in a special spherical scattering chamber of 3/8 in Al. On the spectrometer side, there is a thin wall window. In addition to the HRS-L, there is a dedicated electromagnetic calorimeter of 208 PbF_2 crystals, each viewed by a mesh dynode hamamatsu PMT. All analog signals from the calorimeter are carried by cables to the HRS-L detector hut.

A. Data Acquisition Electronics

Each PMT of the PbF_2 array is readout by a trigger Fast ADC and a 1 GHz Analog Ring Sampler (ARS). The Fast ADC is gated by an electron trigger from the HRS-L. The integrated pulse of all 208 channels is digitized and then local sums are created to validate the electron trigger. In parallel, all ARS channels are stopped, holding 128 analog samples in each channel. Following a validation, all channels are digitized in parallel (128 μs total) and stored in a FIFO buffer memory on each VME board. In the absence of a validation, the ADC memory is cleared and all ARS channels are restarted. If a global sum is formed in the Calo trigger of all 208 channels, then the validation time is 450 ns. On the other hand, if local sums of 2×2 'towers' are made, then the validation time is 510 ns.

B. Commissioning Goals

The essential challenge of the beam commissioning period is to bring on-line the data acquisition system, including the HRS DAQ, the Calo trigger and the ARS readout. In addition to the functionality of the system, this also includes setting the proper timing to obtain the correct coincidence signals. Secondary tasks are to verify the optics of the HRS-L and to perform elastic calibrations of the calorimeter.

II. COINCIDENCE TRIGGER

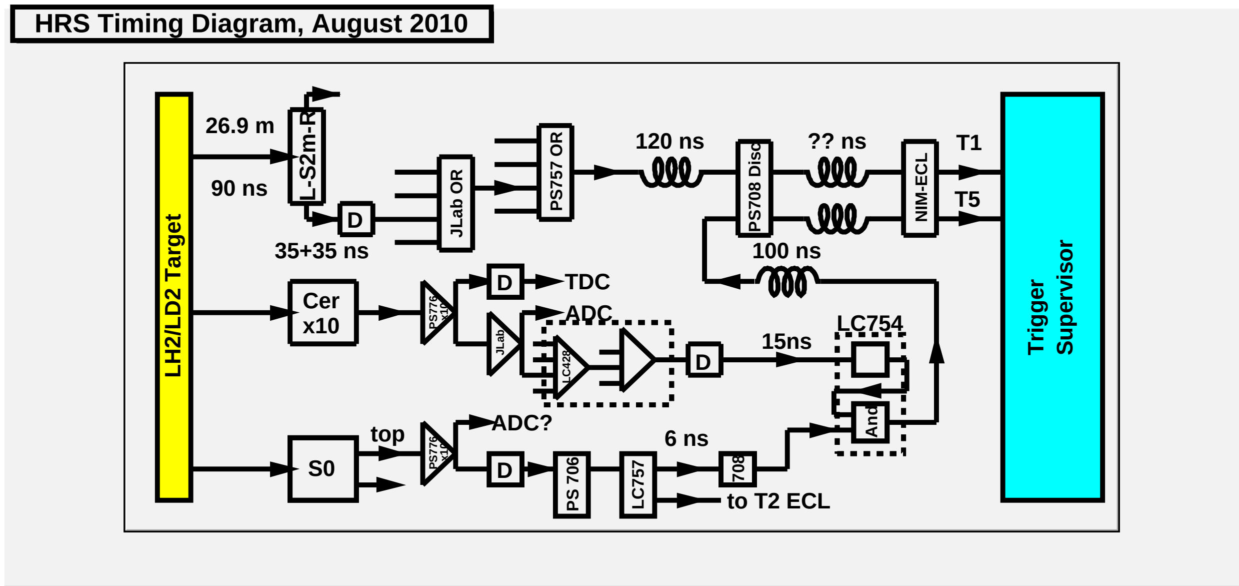

FIG. 1: HRS trigger timing as installed, 1 Aug 2010. Preliminary. 'D' is either a PS706 or PS708 discriminator. Estimated time from event at target to S2m trigger signal at module P/S 757 is 190 ns (10 ns per module, plus 35 ns (?) cable from NIM discrimininator mounted on S2 plus estimated 35 ns propagation time in PMT). Formation time of Čerenkov logic signal not certain. Possibly 10 ns slower than S2m due to 5" PMT and slightly more cabling (not linear modules are faster than logic modules, see Appendix C.

Pierre Bertin organized the integration of Calorimeter trigger into the HRS DAQ for E00-110 in 2004. His notes are on the elog at `https://hallaweb.jlab.org/dvcslog//coda/61`. There are some changes on the HRS side for 2010. In particular, we will use the OR of the 16 left PMTs of S2m as the basic trigger – possibly with an AND with the Čerenkov signal.

- The primary goal of the trigger is to acquire coincidence $(e, e'\gamma)X$ data, The Calo trigger is initiated by the HRS trigger. At the same time, the ARS is stopped. A

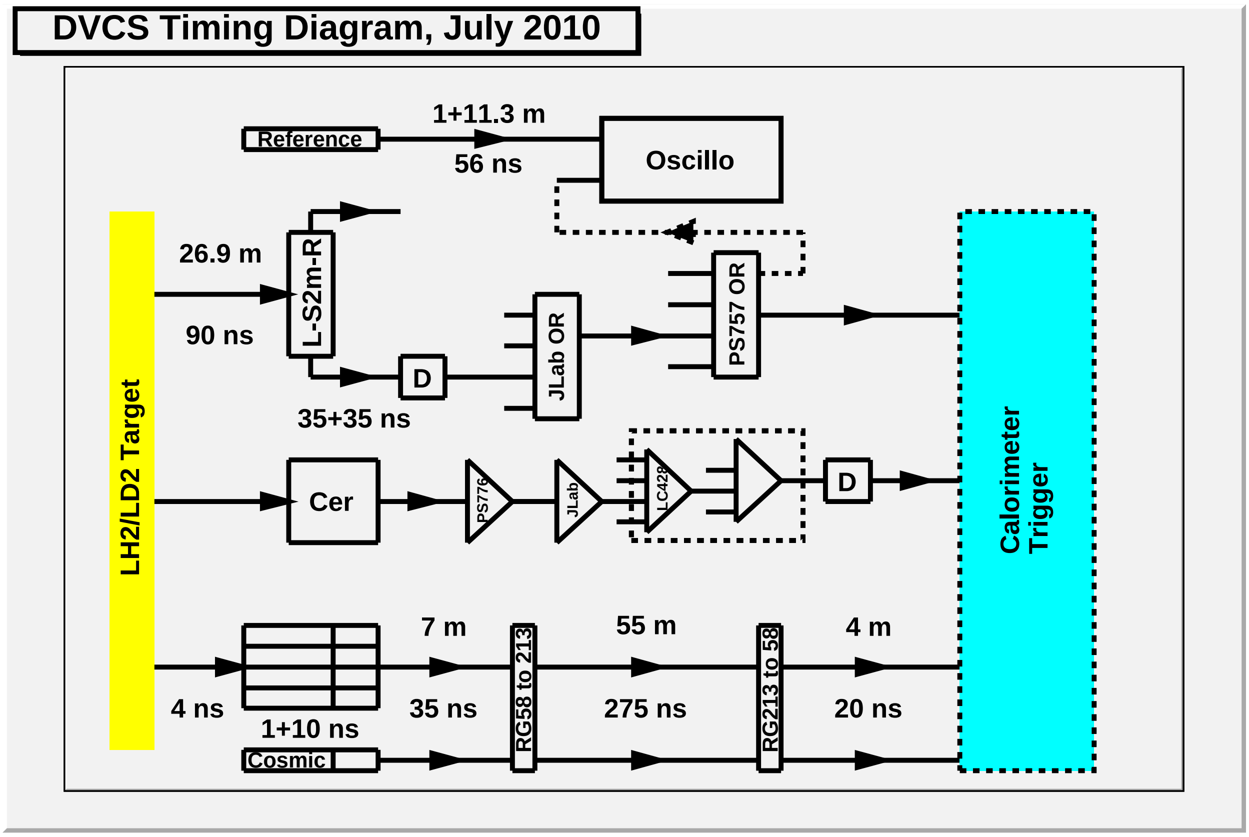

FIG. 2: Preliminary Timing Diagram for DVCS. Bogdan Wojtsekhowski measured a timing delay of the S2m signal of 2-8 ns (varying with paddle) relative to the analog signal from the Reference scintillator, which spans the full length of S2.

validation signal from the Calo trigger provides the trigger signal to the Trigger Supervisor (TS) module (VME-9 module in HRS hut). This signal also initiates the ARS digitization.

- The secondary goal of the trigger is to acquire random $(e, \gamma)Y$ data. This can be accomplished by sending a prescaled clock to the logic unit forming the trigger. This prescaled clock must also be 'ORed'with the validation signal to force ARS readout. This will create an unbiased sample of the ARS pile-up. This pile-up can be then be injected into the simulation.

- The tertiary goal of the trigger is to acquire random $(e, e')x$ data. This can be accomplished by sending a prescaled trigger in 'OR' with the clock signal (above). This will also readout the calorimeter, but in a biased sample. This sample is intended as a luminosity monitor of the DIS rate.

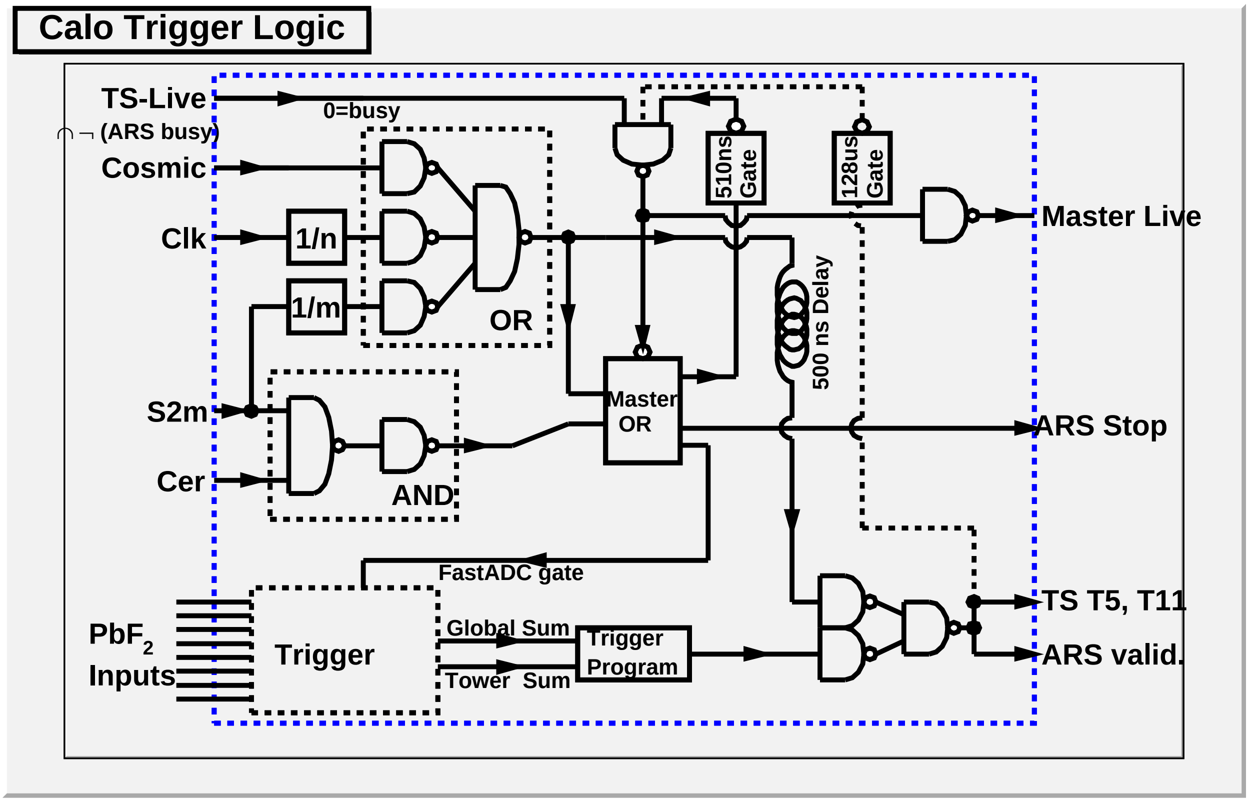

FIG. 3: Calorimeter Trigger logic diagram. The FPGA can be programmed to select prescale factors for the secondary HRS-singles and random clock triggers. In separate NIM logic, a Cosmic trigger must be created from the four Cosmic PMTs. In order to have a single arm HRS trigger and a 'single arm' Calo clock trigger, the trigger validation must be forced for these two trigger types, as well as for the Cosmic trigger.

The HRS trigger timing is illustrated in Figure 1. The front end timing of the HRS, Calorimeter, and Cosmic signals is illustrated in Figure 2.

The suggested programmable logic in the Calo trigger module is illustrated in Figure ??. All trigger decisions must be made before a signal is sent to the standard Trigger Supervisor (TS). Thus all HRS signals to the TS must be sent through additional programmable delay (LeCroy 4516 CAMAC) of approximately 510 ns.

A key element to the commissioning of E00-110 was the installation of an oscilloscope, with a web interface, in the hut to examine the analog coincidence between the HRS trigger and an individual PbF_2 block.

III. HRS OPTICS CALIBRATION

A standard set of optics calibration include

- DIS C(e, e') data on the set of "optics foils" to establish the vertex reconstruction in the spectrometer. This can be done in the 5 Pass Kin III kinematics of $\theta_e = 21.43°$ and $k' = 2.600$ GeV/c. If the targets are 100 mg/cm^2 C each, then the count rate will be ~ 200 Hz per foil (see Table II, Section B). This should be repeated on the Al foils 15 cm apart ("empty target"). This measurements should be done with the collimator in place.

- Sieve-slit elastic H(e, e') data. The holes in the sieve are 1 mm in radius at a distance of 108 cm. Thus each hole subtends a solid angle of 2.7μsr. At a beam energy of 5.562 GeV, the smallest scattering angle that will produce a scattered electron energy below 4.3 GeV is 18.2° at a Q^2 of 2.39 GeV^2. In these kinematics, the elastic cross section is $\sim 2 \cdot 10^{-3}\,\mu$b/sr. At a beam current of 10 μA (luminosity of $4 \cdot 10^{37}$) this yields 1000 events per sieve hole, in 3.5 hours. If this study is deferred until four pass beam of 4.462 GeV is available, then at 15° the differential cross section is 0.04 μb/sr, yielding 1.4K events per hour per sieve hole.

IV. ELASTIC *ep* CALORIMETER CALIBRATION

The HRS-L must be set to positive polarity, to detect the recoil protons in coincidence with elastic electrons in the calorimeter. A small adjustment to the trigger timing may be necessary (see Pierre's DAQ Philosophy note).

We expect to perform three elastic calibrations during the experiment. Once at the beginning, once near the middle of the experiment, and once near the end. It maybe useful to perform the middle calibration at 4 Pass. This will also enable us to perform an optics calibration of the beamline collimator.

A. Kinematics at 5 Pass Running

The beam energy is 5.562 GeV. The suggested elastic setting (Eric FUCHEY) are:

- Fixed calorimeter angle : 22.6°.

- Three HRS-L (proton) settings: $(\theta_p,\, p_p)$
  - $(37.0°, 2.405\,\mathrm{GeV/c})$,
  - $(34.76°,\, 2.607\,\mathrm{GeV/c})$,
  - $(33.29°,\, 2.748\,\mathrm{GeV/c})$

The settings and elastic rates are summarized in Table I. It should be safe to run at a luminosity of $2 \cdot 10^{37}/\mathrm{cm}^2/\mathrm{sec}$, since the calorimeter is at a relatively large angle.

TABLE I: Elastic Calibration Settings at 5 Pass ($k_e = 5.562$ GeV). The calorimeter is fixed at $-22.60°$, 5.50 meters from the target center. Counting rates are calculated per crystal for a luminosity of $2 \cdot 10^{37}$.

$\theta(\mathrm{HRS}) = \theta_q$ (°)	$p(\mathrm{HRS}) = \lvert\mathbf{q}\rvert$ (GeV/c)	θ_e (°)	k' (GeV/c)	$d\sigma/d\Omega_e$ μb/sr	Rate per Crystal (per hour)	Time (hour)
$\theta(\mathrm{Calo}) = -22.60°$, $L(\mathrm{Calo}) \geq 5.50m$, $\mathcal{L} = 2 \cdot 10^{37}/\mathrm{cm}^2/\mathrm{s}$.						
+37.00	+2.405	−21.68	3.918	$5.5 \cdot 10^{-4}$	1200	1
+34.76	+2.607	−23.49	3.729	$2.7 \cdot 10^{-4}$	580	2
+33.29	+2.748	−24.79	3.597	$1.7 \cdot 10^{-4}$	360	3
$\theta(\mathrm{Calo}) = -14.78°$, $L(\mathrm{Calo}) \geq 1.10m$, $\mathcal{L} = 1 \cdot 10^{37}/\mathrm{cm}^2/\mathrm{s}$.						

Appendix A: DIS Rates

The DIS cross section is (PDG review) :

$$\frac{d\sigma}{dx_{\mathrm{Bj}}dy} = \frac{4\pi\alpha^2}{xyQ^2}\left[\left(1 - y - \frac{x_{\mathrm{Bj}}^2 y^2 M^2}{Q^2}\right) F_2(x_{\mathrm{Bj}}) + y^2 x_{\mathrm{Bj}} F_1(x_{\mathrm{Bj}})\right], \tag{A1}$$

where $y = q \cdot p / k \cdot p = \nu/M$ is the inelasticity invariant. We can simplify with the leading-twist Callen-Gross relation

$$2x_{\mathrm{Bj}} F_1(x_{\mathrm{Bj}}) = F_2(x_{\mathrm{Bj}}). \tag{A2}$$

Also, the Jacobian for the transformation to laboratory variables is

$$\frac{\partial(x_{\mathrm{Bj}}, y)}{\partial(\Omega, k')} = \frac{1}{2\pi}\frac{\partial(x_{\mathrm{Bj}}, y)}{\partial(\cos\theta_e, k')} = \frac{k'}{2\pi M\nu} \tag{A3}$$

Therefore, in laboratory variables, the DIS cross section (neglecting F_L) is

$$\frac{d\sigma}{d\Omega dk'} = \frac{4(\hbar c)^2\alpha^2}{Q^4}\frac{kk'}{\nu}\left(1 - y + \frac{y^2}{2} - \frac{x_{\rm Bj}^2 y^2 M^2}{Q^2}\right) F_2(x_{\rm Bj}) \tag{A4}$$

At $x_{\rm Bj} = 0.36$, $F_2 \approx 0.3$. The DIS rates are tabulated in Table II.

TABLE II: DIS rates at a luminosity $\mathcal{L} = 10^{37}/\text{cm}^2/\text{s}$, or a 2.5 μA beam on a 1 g/cm^2 Hydrogen target.

k (GeV)	Q^2 (GeV^2)	$x_{\rm Bj}$	k' (GeV)	$d\sigma/d\Omega dk'$ $\left(\frac{nb}{sr \cdot GeV}\right)$	$\Delta\Omega\Delta k'$ (sr GeV)	σ (nb)	Rate Hz
	Kin I						
5.562	1.50	0.36	3.341	62.	$1.6 \cdot 10^{-3}$	$9.9 \cdot 10^{-2}$	990
3.362	1.50	0.36	1.141	10.	$0.55 \cdot 10^{-3}$	$5.5 \cdot 10^{-3}$	55
	Kin II						
5.562	1.75	0.36	2.971	33.	$1.40 \cdot 10^{-3}$	$4.6 \cdot 10^{-2}$	464
4.462	1.75	0.36	1.871	15.	$0.90 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$	133
	Kin III						
5.562	2.00	0.36	2.614	18.	$1.30 \cdot 10^{-3}$	$2.3 \cdot 10^{-2}$	230
4.462	2.00	0.36	1.501	0.75	$0.72 \cdot 10^{-3}$	$5.4 \cdot 10^{-3}$	54

Appendix B: Inclusive (e, π^-) Rates

In 2002, Pavel Degtiarenko used his DINREG code to calculate inclusive yields in our configuration at 6 and 11 GeV. The inclusive π^- yields at 6 GeV on a deuterium target are displayed in Figure 4. The yield on a proton target should be a factor of two lower.

For the Kin II setting at $k = 5.562$ GeV, $k' \approx 3$ GeV and $\theta_e = 36.4°$, we can estimate an approximate π^- yield of $\leq 10^{-10}$/MeV sr per incident electron. The anticipated beam current on the Deuterium target is 2.4 μA and the spectrometer acceptance (Table II) is ~ 1 MeV sr at this setting. This gives an estimated inclusive π^- rate in the HRS-L of ~ 1 KHz. Neglecting possible dependence on the incident energy, the π^- rate at the lower energy setting, with $p_\pi = 2$ GeV/c and $\theta = 16°$ could be as much 10 KHz.

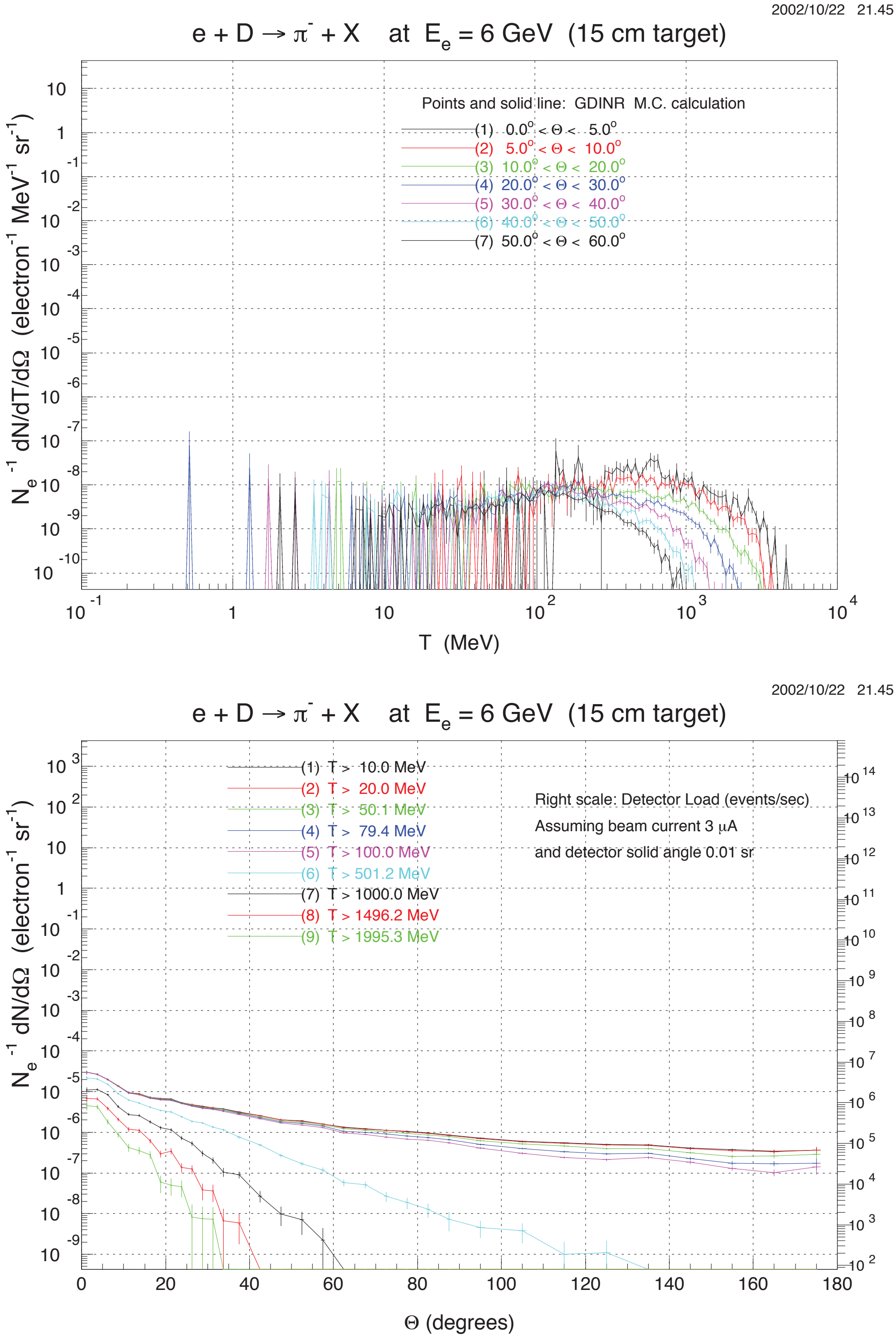

FIG. 4: DINREG results for inclusive π^- production on a 15 cm LD_2 target.

Appendix C: NIM Logic Modules

Here are some of the NIM and CAMAC modules used in the standard Hall A trigger. P/S refers to Philips Scientific modules. LC refers to LeCroy.

- P/S 706: Sixteen channel 100 MHz leading edge discriminator. Two bridged outputs per channel. Propagation delay $\leq$ 9 ns.
- P/S 708: Eight channel 300 MHz leading edge discriminator. Two bridged outputs per channel plus one logic complement output. Propagation delay $\leq$ 8 ns.
- P/S 776 Sixteen channel dual amplifier. Two linear outputs per input. Used for splitting Čerenkov signal between trigger and ADC. Fixed gain $\times 10$. Typical delay 3 ns.
- P/S 757 Mixed Logic Fan-In Fan-Out. Logic OR of $8 \times 2 \cdot 1 \times 16$ input channels. OR and NOR output. NIM and TTL compatible. Propagation delay $\leq$ 8 ns.
- P/S 754 Quad Four-Fold Logic Unit. Propagation time $\leq$ 8.5 ns.
- LC 428 Quad Linear Fan-In Fan-Out. Gain $\times 1$. Propagation delay 6 ns. DC offset adjustment.
- LC 4516 Programmable Logic (CAMAC). Estimated delay (from schematic) 20-30 ns. 16 channels, 3 inputs each.
- LC 4518 Programmable Delay (CAMAC). 16 channel ECL logic delay. Fifteen increments of 1, 2, or 8 ns per channel.
- JLab NIM to ECL Logic Fan-Out. 16 channels. Also 4 NIM outputs: each the OR of four input channels. Used for first stage of OR of 16 paddles of S2m trigger scintillator. Transition delay 5 ns.

Note also RG-58 and RG-213 cables have a propagation delay of 5 ns/m (velocity 20 cm/ns).