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FIRST e^-/γ COMMISSIONING RESULTS FOR THE GLUEX EXPERIMENT/HALL D AT CEBAF*

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Abstract

Experimental Hall D, with flagship experiment GlueX, was constructed as part of the 12 GeV CEBAF upgrade. A new magnetically extracted electron beam line was installed to support this hall. Bremsstrahlung photons from retractable radiators, are delivered to the experiment through a series of collimators following a long drift to allow for beam convergence. Coherent Bremsstrahlung generated by interaction with a diamond radiator will achieve a nominal 40% linear polarization and photon energies between 8.5 and 9 GeV from 12.1 GeV electrons, which are then tagged or diverted to a medium power 60kW electron dump. The expected photon flux is 10^7-10^8 Hz. This paper discusses the experimental line design, commissioning experience gained since first beam in spring 2014, and the present results of beam commissioning by the experiment.

HALL DESIGN AND CONSTRAINTS

Design constraints in the layout of Hall D included a project requirement that the Hall be 100m from the road, thus resulting in an 8 degree pitch in the ramp relative to the North Linac elevation. [1] Space constraints for optical elements resulted in a sensitivity to the input envelope and an inability to null leakage vertical dispersion at the bottom of the ramp. This provides for interesting tuning idiosyncrasies including nulling horizontal and minimizing vertical dispersion to the 5C00 retractable dump, envelope matching with the dispersion leakage, and correcting any leakage at the top of the ramp using the dipole string and pairs of quadrupoles on the ramp. The electron dump has a safety limit of the lower of 60 kW or 5 uA with an administrative limit of 3 uA imposed by the Hall at any energy. Design Twiss parameters are shown in Fig. 1.

GlueX is the flagship experiment of the new experimental Hall D, its goal being to provide critical data needed to quantitatively understand quark and gluon confinement in quantum chromodynamics (QCD). GlueX uses the photo-production of exotic hybrid and light mesons via the coherent bremsstrahlung technique to produce a linearly polarized photon beam of up to 9 GeV, as these mesons explicitly manifest gluonic degrees of freedom in the confinement regime, and thus of great interest to study. [2]

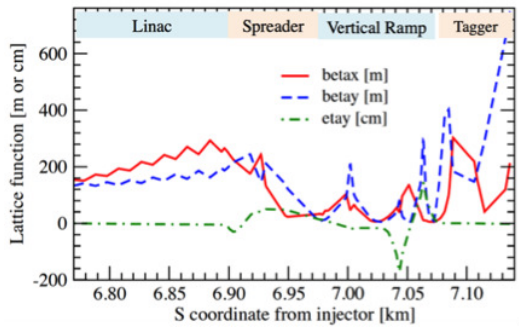

Figure 1: Twiss Parameters in Hall D.

ENGINEERING RUN I (SPRING 2014)

A number of 12 GeV project goals were accomplished during this run, most notably delivering beam of at least 2nA at above 10 GeV to both the 5C00 retractable dump as well as the tagger dump through the 12 GeV capable beam line at 5.5 passes. Emittance measurements & differential orbit data was taken throughout the machine for summer analysis. The analysed data was later fed into the model via body gradient error correction, synchrotron light losses, etc. Spring saw first beam through vast portions of the upgraded accelerator (passes 4+) with first beam in arc 10 on 2 May 14. Sixth pass beam was then sent through the North Linac, threaded through the B-spreader, arriving for the first time at the 5C00 dump at 3:53 on 3 May14, after which orbits & path length were optimized. [3] Numerous differential orbit measurements were conducted for later analysis & testing on the two new synchrotron light monitors was performed.

Following the setup of CEBAF at a familiar energy (6.1 GeV) so as to not stress RF/magnets while treading first beam through the reassembled machine, the total energy was scaled to 10.5 GeV. Scaling went less than ideally & the machine had to be setup again from first principles at the higher energy resulting in a delay of several days. Beam returned to the 5C00 dump at 2:53 on 7 May 2015 with ~80% transmission. Path length, dispersion corrections, & envelope matching in the machine later improved transmission. Differential orbit data was collected to characterize the problems, localizing them to parts of the spreaders & recombiners, where they were then minimized with orbit & optics changes. In preparation to send beam to the Tagger dump a set point based on the Tosca model was found (8.21 MG*cm), & a compromise set point of 8 MG*cm selected to start with to account for synchrotron light losses. After continued improvements to orbit, optics, & path length beam returned to the 5C00 dump at 20:24 7 May 14.

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Initial attempts to send beam up the ramp with even minimal beam triggered a radiation monitor (CARM) interlocked to the Personnel Safety System (PSS) dropping the machine state & gun high voltage. This CARM should not have functioned in this capacity with adjacent machine segments in a personnel exclusion state. A decision was taken by Safety System Group (SSG) with the Radiation Control Group (RCG) to disable the malfunctioning CARM's ability to trip the machine for commissioning purposes while remaining in an exclusion state for the test. Beam was threaded up the ramp leading to the Tagger using both correctors & an adjustment to the ramp dipole box supply (-0.72%) to empirically compensate for synchrotron light losses. The Tagger itself required significant adjustment (+2.67%) over the values in the optics deck. The mismatch in the integral Tagger field set point vice current was later sourced to several factors including Hysteresis protocol errors in mapping vice operation, use of a clip-on ammeter by the Hall during mapping, & straight-line vice curved path integrals in the Hall's modelling of the magnet as well as the accelerators failure to more methodically take synchrotron light losses into account during setup. The Tagger field was later measured correcting these issues providing a revised estimate of beam energy by the Hall of 10517 MeV. This is in line with independent Center for Advanced Study of Accelerators (CASA) analysis of beam energy showing delivered beam energy of 10516 ± 10 MeV using arcs as spectrometers, noting linac energies & degrees off crest, & accounting for cumulative energy loss due to synchrotron radiation of ~39 MeV. [4-6]

The first e^- beam arrived at the Tagger dump at 23:41 7 May 2014 with a rough orbit (beam +/- 2mm of zero) with scraping/halo evident on the last viewer. [7] As beam was visible on the dump the decision was taken to execute the test & refine beam quality later. The last position monitor in the line, between the Tagger & the dump, was found non-functional. Beam delivery was halted as RCG prepared to monitor the 1-hour dwell on the dump for the milestone. Beam delivery was resumed & a blown fuse replaced & the now functioning BPM calibrated, though it was later found rotated 90 degrees anti-clockwise. Rates of radiation production exterior to the Hall were high, though on par with RCG expectations given a shield wall was not yet in place; after the test it was decided not to send additional beam for ALARA (As Low as Reasonably Achievable, with respect to radiation) reasons & to defer further work until the shielding configuration was addressed. A later survey showed 200 mR/hr hot spots at the entrance to & flange exiting the Tagger as well as on a vacuum girder just downstream. [8, 9] Survey data & other radiological data gathered via dosimetry badges spread through the Tagger area & their dose analysis were later analysed by A. Deur & fed into the fall run plan. [10]

ENGINEERING RUN II (FALL 2014)

Spring experience significantly informed *elegant* [11] model improvement & development of fall plans for commissioning. Extensively preparations were made via weekly commissioning meetings between the experiment, CASA, Ops, RCG, & SSG in order to systematically develop, review, & refine beam delivery procedures for the Hall, place instrumentation, discuss controls, establish documentation, & so forth. Radiological studies carried out by RCG & A. Deur with film dosimetry badges & Self-Reading Pocket Dosimeters (SRPDs) during the spring run supplemented Monte Carlo calculations made by RCG (using the FLUKA package) & the Hall (using GEANT3/4) & helped inform the placement of ion chambers, scintillating PMTs (BLMs), & supplemental radiation monitors. This also informed the decision for fall commissioning to occur at the minimum visible beam current for ALARA purposes. A permanent shield wall was also installed at the bottom of the Tagger vault truck ramp with supplementary shielding added to the dump & about the entrance & exit of the Tagger. The commissioning process was also subjected to an extensive process of both external & internal reviews in the forms of an Accelerator Readiness Review by DOE, an Experimental Readiness Review conducted by the Lab, & an Internal Photon Commissioning review conducted by the Hall to subject the developed infrastructure & plans to scrutiny, comment, & modification.

Beam returned to the 5C00 dump on 22 Oct14. After the correction of a misalignment of a piece of beam pipe & with the blessing of the DOE site office, work towards the fall commissioning of Hall D began in earnest. A systematic campaign of emittance measurements & matching, dispersion corrections, & optics perturbations & measurements continued for the next several days in addition to normal maintenance activities resulting in CW beam reaching the AD00 dump on 27 Oct 14. Beam current monitor calibrations, BPM gain & timing optimization, and diagnostic radiological measurements proceeded as steering was refined. The minimum tune mode beam current visible on the stripline BPMs (800 nA) was determined & used to steer from 5C00 to AD00. Beam was steered to nominal zero & adjusted to minimize rates on radiation monitors & ion chambers in the hall. As a precautionary measure some electronics, mainly SiPMs, were removed from the Tagger for initial steer up for fear of radiation damage. Radiation rates have also shown themselves to be very sensitive to the veracity of the emittance match conducted to entrance to entrance of the line. Prophylactic radiation surveys were also carried out when beam reached each dump & when photons reached the Hall for the first time.

The fall run saw beam at 10.1 GeV with currents of 50-200 nA, both with & without secondary collimation on each of 3 amorphous radiators (0.2, 1.1 & 3.3 ×10-4 RL). Additionally, some solid targets were used (1cm High Density Polyethylene disk & Al barrel) which could be variably positioned several cm up & downstream (-32 - +12 cm) of the nominal center position of the cryotarget. Commissioning of the Hall D equipment occurred under "soft" conditions using low-intensity unpolarised photon beam <10 MHz/GeV at the end point with a solenoid current at 1200A vice nominal 1300A to better understand

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safe operation of the solenoid as well as to better understand quench problems with the magnet. Emittance measurements at the final wire scanners allowed for adjustment of beam convergence to the active collimator.

Internal goals to the hall included establishing CW beam to the tagger with acceptable radiation levels, threading unpolarised photon beam through the collimators, target location, & to the photon beam dump, the optimization & calibration of detectors, data acquisition & triggers, & the alignment of the detectors. Additionally, the physics division had a 12 GeV project milestone goal as follows: Detector Operational: Events recorded with I ≥ 2 nA electron beam at beam energy E > 10 GeV (5.5 pass). Hall D laid out a number of key performance parameter (KPP) goals which dictated achievement of the milestone. These KPP goals were as follows: Full detector running for at least an 8 hour shift with the solenoid at 1200A recording data from all subsystems, the ability to produce plots with coincidence of signals of in several detectors (Tagx, TOF, BCal, FCal, ST, PS), display events showing the correlation of hits in several detectors (CDC, FDC, ST, TOF, BCal & Fcal), determine target positions from tracking, & demonstrate particle identification using detectors. [12] This milestone was officially declared completed following the analysis of fall 2014 run data, thus completing the unpolarised portion of photon beam line commissioning. In keeping with these, a number of particles decays & reactions have been identified so far, including some using multiple detector coincidence. These include: $\pi^0 \rightarrow 2\gamma$ seen in FCAL, π^+/π^- events & (p)2π & (p)3π final states, $\lambda \rightarrow p^+ + \pi^-$, $\rho^0 \rightarrow \pi^+ + \pi^-$, $K_S \rightarrow \pi^+ + \pi^-$ (See Fig. 2), & $\omega(782) \rightarrow \pi^+ + \pi^- + \pi^0$ & standard p^+, e^-, γ. [13-16]

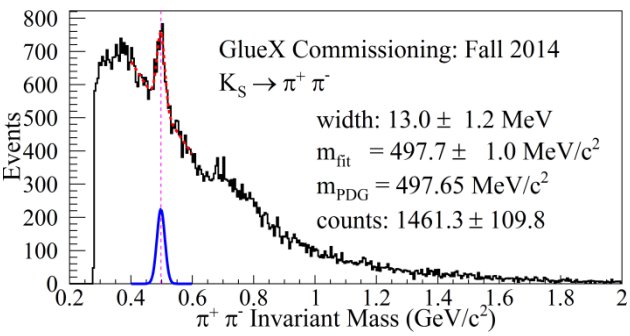

Figure 2: $K_S \rightarrow \pi^+ + \pi^-$.

This run also saw the commissioning of the remaining SLMs, nA BPM cavities, Active collimator (raw data), BLMs/scintillating PMTs, & Ion Chambers (functional checks & calibrations), scintillating hodoscope photon beam profile monitors in the Hall & the Beam Transport Monitor (a safety device to stop beam if either the Tagger or the ramp dipoles are not functioning appropriately).

ENGINEERING RUN III (SPRING 2015)

Run 3 again saw significant improvements to software & hardware for Hall D, including the repair of some diagnostics (wire scanners) & the addition of more shielding to the entrance & exit to the Tagger. The goniometer & Liquid Hydrogen (LH2) cryogenic target were also installed. The purpose of the spring 2015 run was primarily commissioning of the 750 MHz separator system at 10.557 GeV with physics conducted opportunistically. At this energy the system is slightly underpowered, able to achieve only 89% (14.5/16.5 mm) of the separation required, resulting in separator based scraping of 5th pass beam transmitting to Hall D, triggering conservatively set BLMs, Ion Chambers, & registering on the CARMs. This will be corrected over the summer down. This combined with several other issues encountered during the Spring run including the evolving status of Hall D procedures, Hall A's status as priority Hall as assigned by the nuclear physics division, & an offsite power failure damaging the cryogenic plant no photons made it to Hall D for the majority of the run. A decision was taken to operate the accelerator at 6 GeV for the balance of the run (until 5/3) based upon cryogenic availability, resulting in reduction of scope for Hall D commissioning activities & a factor of four reduction in photon flux through the active collimator. The Hall received photon beam for the first time this run on 24 Apr. 15 & thus far has managed to commission their goniometer & several diamond radiators (producing the first polarized photon beam into the Hall), had first beam on the newly installed LH_2 cryotarget, gathered data for triggering studies, gathered π^0 calibration data for BCAL / FCAL, opportunistically is commissioning the pair spectrometer, & commissioning of the fast feedback (FFB) system. Other priorities include completion of trigger optimization, establishment of 20 kHz block mode DAQ operation, & photon running with the solenoid at 1300 A (thus ramping it to 1350 A).

SUMMARY

Significant progress has been made D so far and things look promising for the fall 2015 run. Some outstanding items that are expected to be resolved there include the addition of a local oscillator to synch the Hall to the accelerator's master oscillator timing, completion of the commissioning of the nA BPM system, slow orbit locks, & finishing FFB integration. Also outstanding is the refinement of detector & pair spectrometer calibration, alignment, & triggering, commissioning of the Total Absorption Counter (TAC), LH2 target chamber alignment & commissioning, & the installation of a triplet polarimeter as well as FDirc bars/detectors (from BABAR) as a calorimeter upgrade to allow for increased sensitivity to η & J/Ψ detection as well as any activities not completed during the Spring run.

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