Simultaneous Beam Delivery with Parity Quality Beam

KLF Phase I ERR

Accelerator Parity-Quality-Beam Liaison: Riad Suleiman

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Introduction

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  - Injector Optimization
  - Sub-harmonic Beam Loading in SRF cavities

- KLF Laser Status

- Summary and Plans

Parity-Violating Experiments at CEBAF

PV Experiment	Energy (GeV)	Pol (%)	I (μA)	Target	A_{pv} (ppb)	Charge Asym (ppb)	Position Diff (nm)	Angle Diff (nrad)	Size Asym($\delta\sigma/\sigma$)
HAPPEx-I 1998 – 1999	3.3	38.8 68.8	100 40	^{1}H (15 cm)	15,050	200	12	3	<10^{-3}
G0-Forward 2003 – 2004	3.0	73.7	40	^{1}H (20 cm)	3,000-40,000	300±300	7±4	3±1	<10^{-3}
HAPPEx-II 2004 – 2005	3.03	87.1	55	^{1}H, ^{4}He (20 cm)	1,580	400	2	0.25	<10^{-3}
G0-Backward 2006 – 2007	0.359, 0.688	85.8	60	^{1}H, ^{2}H (20 cm)	9,700-37,400	-30±300	47±9	1.2±0.5	<10^{-3}
HAPPEx-III 2009	3.484	89.4	100	^{1}H (25 cm)	23,800	200±10	3	0.5±0.1	<10^{-3}
PVDIS 2009	6.067	89.0	105	^{2}H (20 cm)	60,000-160,000	100	100	40	<10^{-3}
PREx-I 2010	1.056	89.2	70	^{208}Pb (0.5 mm)	657±60	85±1	4	1	<10^{-4}
QWeak 2010 – 2012	1.162	88.7	180	^{1}H (34 cm)	226.5±9.3	20.5±1.7	-4.6±0.2	-0.07±0.01	<10^{-4}
PREx-II 2019	0.953	89.7	70	^{208}Pb (0.5 mm)	550±18	20.7±0.2	2.2±4	0.3±0.3	<6x10^{-5}
CREx 2019-2020	2.18	87.1	150	^{48}Ca (5 mm)	2668±113	-88±026	-5.2±3.6	-0.13±0.08	<6x10^{-5}
MOLLER 2026-2028	**10.8**	**90**	**65**	**^{1}H (125 cm)**	**35.6±0.74**	**<10**	**<0.6**	**<0.12**	**<10^{-5}**

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MOLLER Experiment

1. MOLLER Apparatus is designed for nominal beam energy: 10.8 ± 0.2 GeV with low RF trip rate (<6/hr)
2. 65 µA with 90% polarization (max 70 µA for target studies)
3. Fast helicity reversal:
    1. 1920 Hz, 10 µsec settle time, 64-window pattern, 128-window delay
4. Slow helicity reversals:
    1. Insertable half-wave plate (IHWP)
    2. Wien Filters (using new 200 keV injector)
    3. g_e-2 ($\Delta E \sim 0.10$ GeV)
5. Feedbacks on:
    1. Helicity-correlated beam charge
    2. Helicity-correlated position and angle
    3. Polarization orientation
6. Small helicity-correlated beam asymmetries
7. Adequate adiabatic damping of transverse phase-space (for both xx' and yy') – a factor of 100 is desired, a factor of 10 is required. Ideally, $\sqrt{P_f/P_{gun}} = \sqrt{10800/0.494} = 148$
8. Acceptable beam halo (MOLLER Halo Monitor: to be specified, Compton Polarimeter: <100 Hz/µA)

Running 4-Halls during Moller and KLF

- Hall A (MOLLER):
  - 0.26 pC @ 249.5 MHz (4 ns, 65 µA average beam current) at 11 GeV

- Hall B:
  - 0.002 pC @ 249.5 MHz (4 ns, 50 nA average beam current)

- Hall C:
  - 0.12 pC @ 249.5 MHz (4 ns, 35 µA average beam current)

- KLF:
  - 0.32 pC @ 15.6 MHz (64 ns, 5 µA average beam current)

Co-operation of MOLLER with KLF

- Issues:
  1. How would photocathode respond to such peak current variations?
     - ➢ Is there any time dependency in QE or polarization?
  2. Injector optimization for parity-quality-beam (Transmission and Beam Noise, Wien Flip) vs KLF?
  3. How would RF system respond to such current variations? Sub-harmonic Beam loading in Buncher and SRF cavities in Linacs?
     - ➢ Any changes to beam properties (e.g., energy spread)? Expected to be at 10^{-6} level in SRF cavities. Buncher cavities will be modeled and tested with beam.
- Experience: G0 Forward in Hall C (2003 – 2004)
  - ➢ 1.28 pC @ 32 MHz (32 ns, 40 µA), 3rd pass (3.0 GeV)
  - ➢ Note that this was the parity-violation experiment

Photocathode Effects

- Photocathode effects, e.g., Surface Charge Limit, will affect both charge in each bunch and charge asymmetry of each bunch, especially those close to KLF bunch, and overall average over whole beam

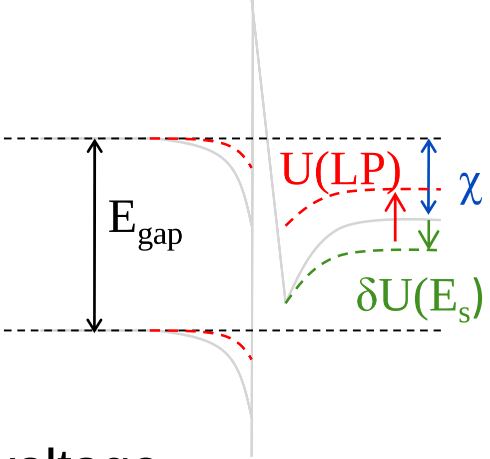
- Helicity correlated charge asymmetry on one beam affects other beams at CEBAF – specially high current beams

- Parity-violation experiments in either Hall A or Hall C had to perform charge asymmetry feedback on other hall’s beam – therefore, Hall D has to implement a charge feedback system:
  - Intensity Attenuator (IA) system on laser table
  - BCM in Hall D
  - Parity data acquisition system to measure charge asymmetry

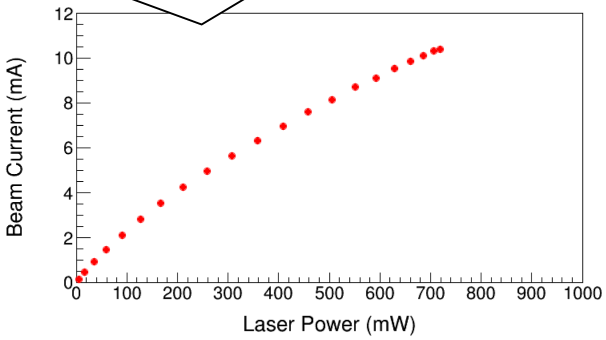
Surface Charge Limit

- ➢ Also known as Surface Photovoltage Effect, reduces NEA (χ) of GaAs: Photoelectrons trapped near GaAs surface produce opposing field that reduces NEA resulting in QE reduction at high laser power (LP),

$$QE = QE_0\left(1 - \frac{U(LP)}{\chi + \delta U(E_s)}\right)$$

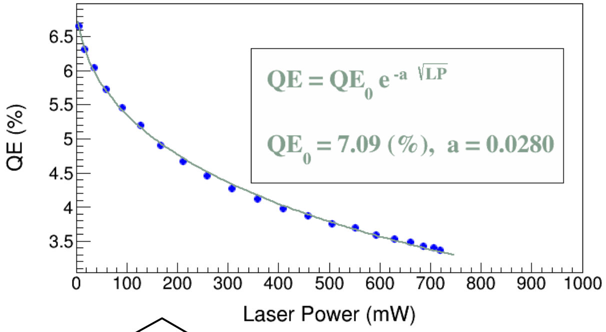


Bulk GaAs, 532 nm, 100 kV



Where U(LP) is up-shifting of potential barrier due to photovoltage.

- ➢ For heavily Zn doped GaAs surface, U(LP) → 0 (doping introduces high internal electric field to facilitate charge transport, increase diffusion length, and reduce chance of depolarization in active layer)



$$U(LP) \propto \sqrt{LP}$$

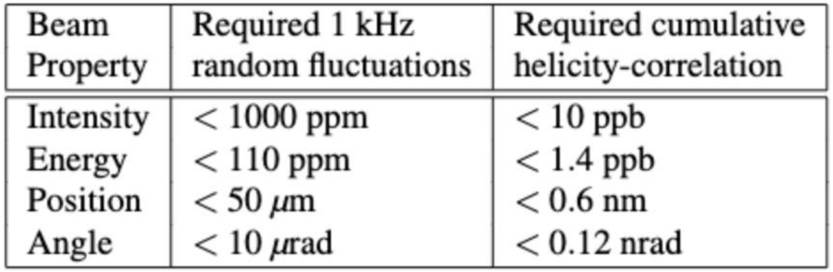
- ➢ Higher Gun HV suppresses photovoltage

Injector Optimization

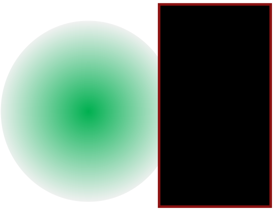
- Significant clipping of electron beam between photocathode and Hall can create excessive charge jitter or helicity correlated systematics on the beam. MOLLER requires very clean electron transmission from source to target with minimal beam interception. As a general rule, changes in mean value of charge asymmetry should be kept to less than 20 ppm, and width change less than 50 ppm, through injector and into hall (transmission of 95% can achieve this).

- MOLLER will use two Wien filters and Spin Solenoids to apply a spin rotation with a period of about 5-7 days. These are referred to as Flip-Right or Flip-Left settings. Preservation of beam properties under polarization reversal is key to utility of this flip.

Transmission and Beam Noise



Beam Property	Required 1 kHz random fluctuations	Required cumulative helicity-correlation
Intensity	< 1000 ppm	< 10 ppb
Energy	< 110 ppm	< 1.4 ppb
Position	$< 50\ \mu m$	< 0.6 nm
Angle	$< 10\ \mu rad$	< 0.12 nrad



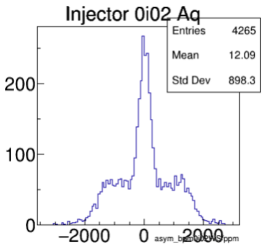
= noise + HCBA intercoupling

$$D_x \Rightarrow A_q$$

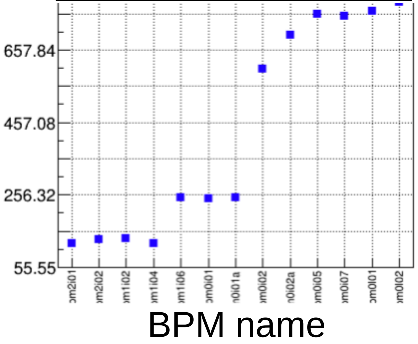
noise

HCBA intercoupling

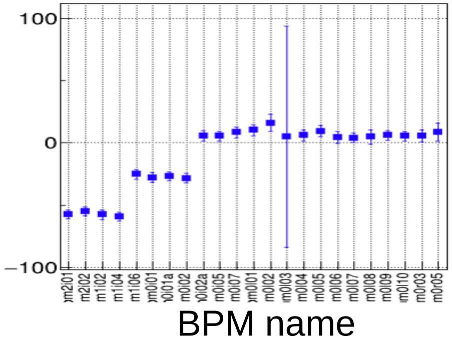
Aq distribution



Aq RMS



<Aq>

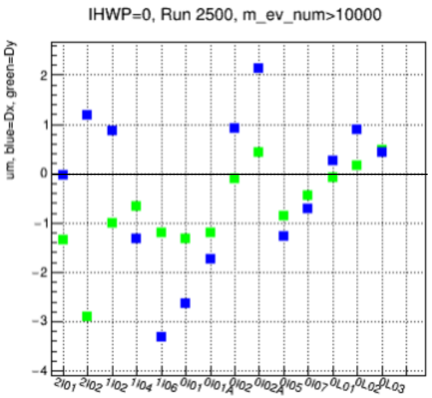


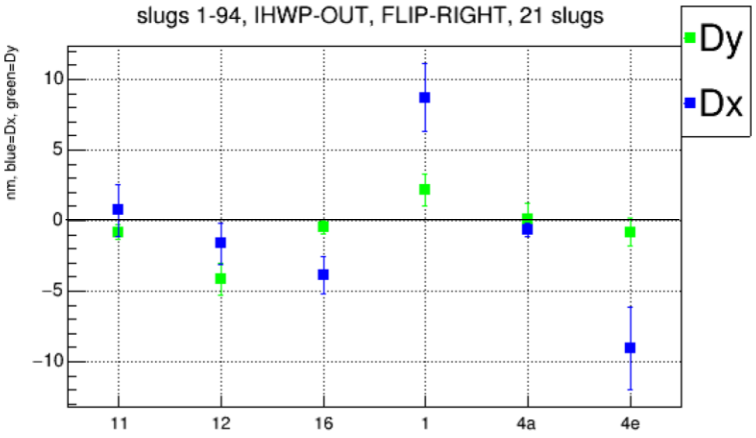
Poor beam transport can mess things up badly

Wein Flip

Injector **Hall A**

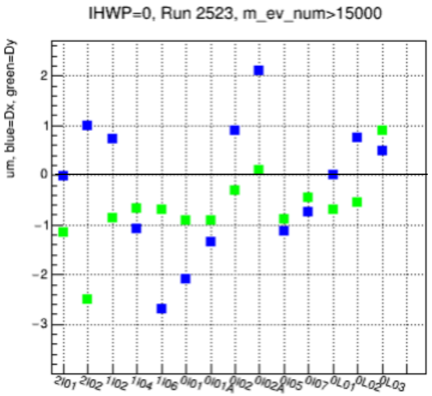
Flip Right:

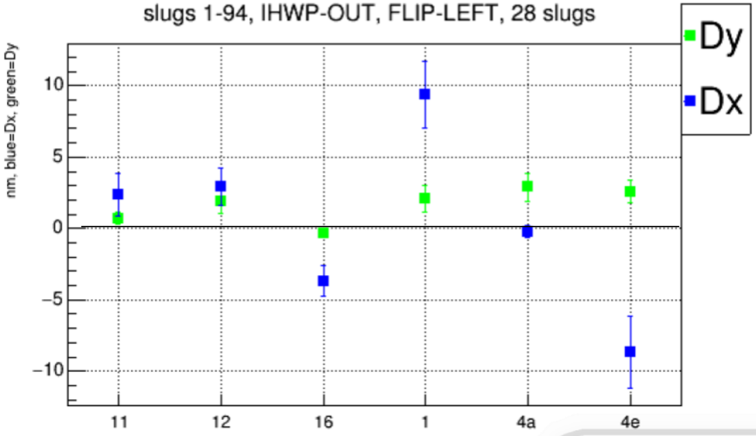




Symmetry is good for position difference cancellation, also good for spot size asymmetry cancellation.

Flip Left:

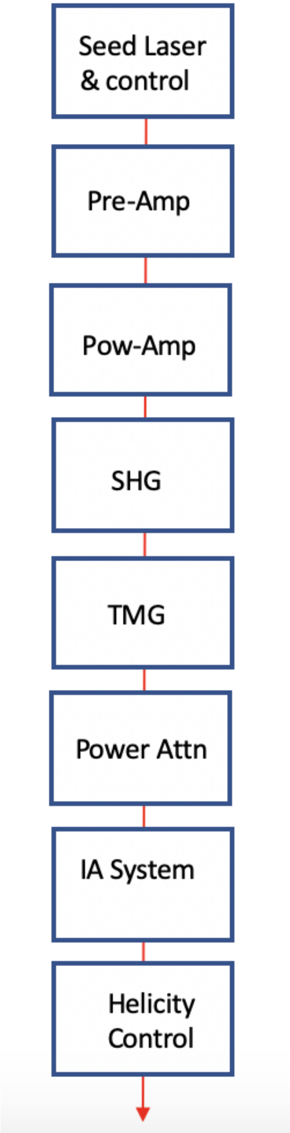




BPM name

BPM name

Hall D Low-rep Laser Status



Seed Laser & control

Pre-Amp

Pow-Amp

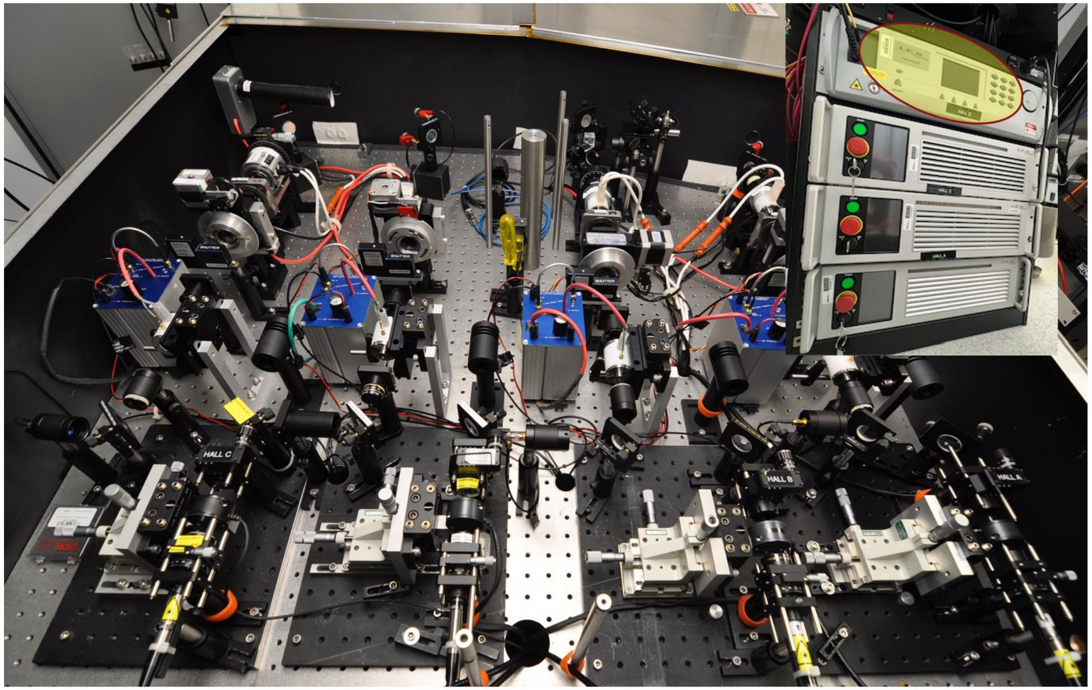
SHG

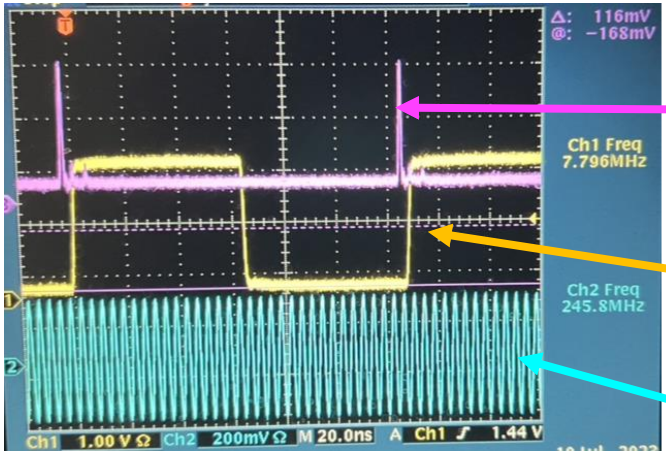
TMG

Power Attn

IA System

Helicity Control





Laser pulses

Low rep signal

249.5 MHz Laser RF

Technical Scheme and Key Components:

- A new 1560 nm Gain-switched seed
- 15.6/7.8 MHz RF signal by dividing 249 MHz by 16/32
- A new high pulse energy laser amplifier
- Use Existing SHG for 780 nm & rest of hardware downstream in D laser beam path

Status and Plans

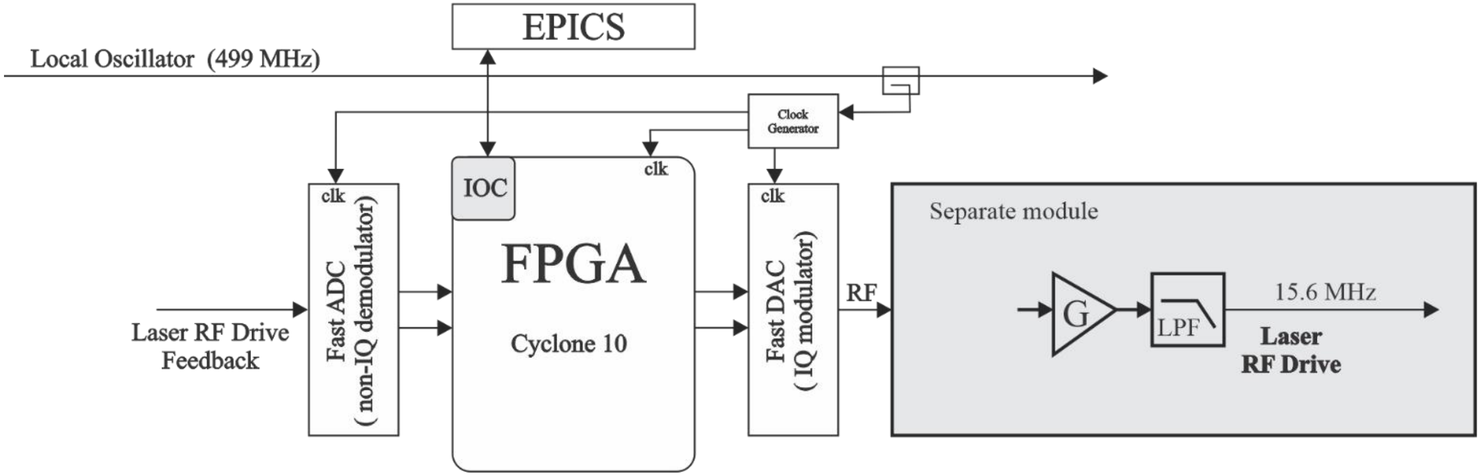
- Present status:
  - A temporary RF sync system is assembled and tested, providing stable phase at 15.6 and 7.8 MHz
  - A new Laser amplifier is tested at both 15.6 and 7.8 MHz with enough power (factor of 10 than required)
  - EPICS control tested

- Schedule:
  - Installation pending, conflict with other tasks and physics programs

- When available, experiment sending high charge beam to Hall D should be possible. Complete accelerator system test. Could add this to KLF injector test plans.

Low-Level RF (LLRF)

- Problem: 15.6 MHz oscillation phase locked to accelerator 1497 MHz
- Existing LLRF system can provide two frequencies: 499 MHz and 249.5 MHz. It utilizes heterodyning concept, using two local oscillator signals locked to the accelerator's 499 MHz reference. This ensures that drive signals are always locked to variable frequency of CEBAF accelerator.
- To add a low-frequency drive signal of 15.6 MHz, we are designing a direct drive channel, which would provide full amplitude and phase control. **To be ready by next SAD**.



Summary and Plans

- Are there conflicts between KLF and MOLLER?
- Photocathode effects
  - Requires change asymmetry feedback on KLF beam
- **Injector will be optimized for MOLLER**
- Beam loading should be modeled
- We need to perform beam studies of all potential issues
  - Install new Hall D low-rep laser with suitable LLRF