Precise and Ultra-Stable Laser Polarization Control for Polarized Electron Beams

RAYTUM PHOTONICS

Principle Investigator: Bo Guo
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2020 DOE-NP SBIR/STTR Exchange Meeting

Outline

- Company Overview
- Background and Motivations
- Project Task and Technical Approach
- Schedule and Current Status
- Progress and Results
- Acknowledgement

Company Overview

Headquarter in Sterling, VA

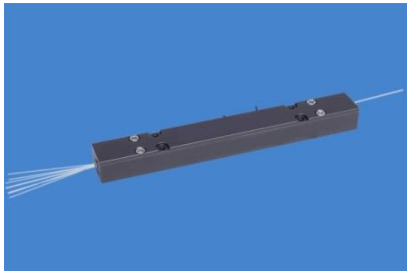
Columbia, MD

5,500 square feet of available work space, including

- **Multiple optical labs**
- **Optical clean room**
- **Chemical lab**
- **Fiber components assembly lab**

Company Overview

Core Capabilities:



Laser R&D:

High Power Diode Laser, High Power/High Energy Fiber laser/amplifier, and novel optical parametric oscillator for Quantum Network.

Optical Coating:

Provide customer-designed optical coating for application of fiber laser, mid-IR laser beam delivery, etc.

Fiber Optics:

Provide standard and customized Fiber Optical component and service

We have had collaboration and provided products to industries and research labs such as ORNL, JLab, etc.

Background and Motivation

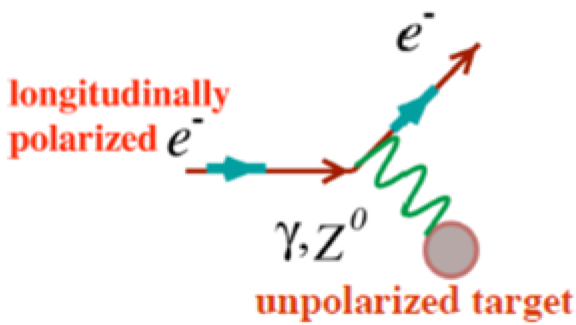
❖ Project Objective:

This SBIR program is to design, optimize, evaluate, and build a prototype of a **high Precision, highly stable and fast switching circular laser beam polarization flipping system.**

Especially to increase precision required by next generation Parity Violating Electron Scattering (PVES)

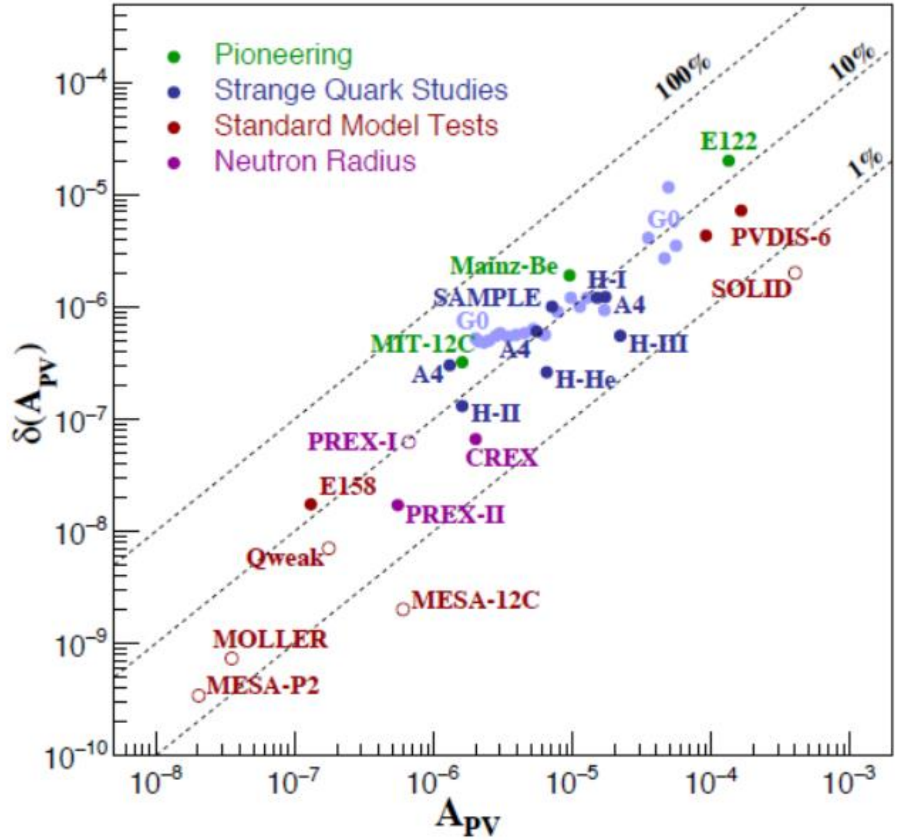
*Since first developed in E122 at SLAC in 1978, **PVES** has become a precision tool used in many physics program of experiments such as studying structure of protons and nuclei and searching for new Beyond the Standard Model (BSM) physics.*

Background and Motivation



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{M_\gamma^* M_W}{M_\gamma^2}$$

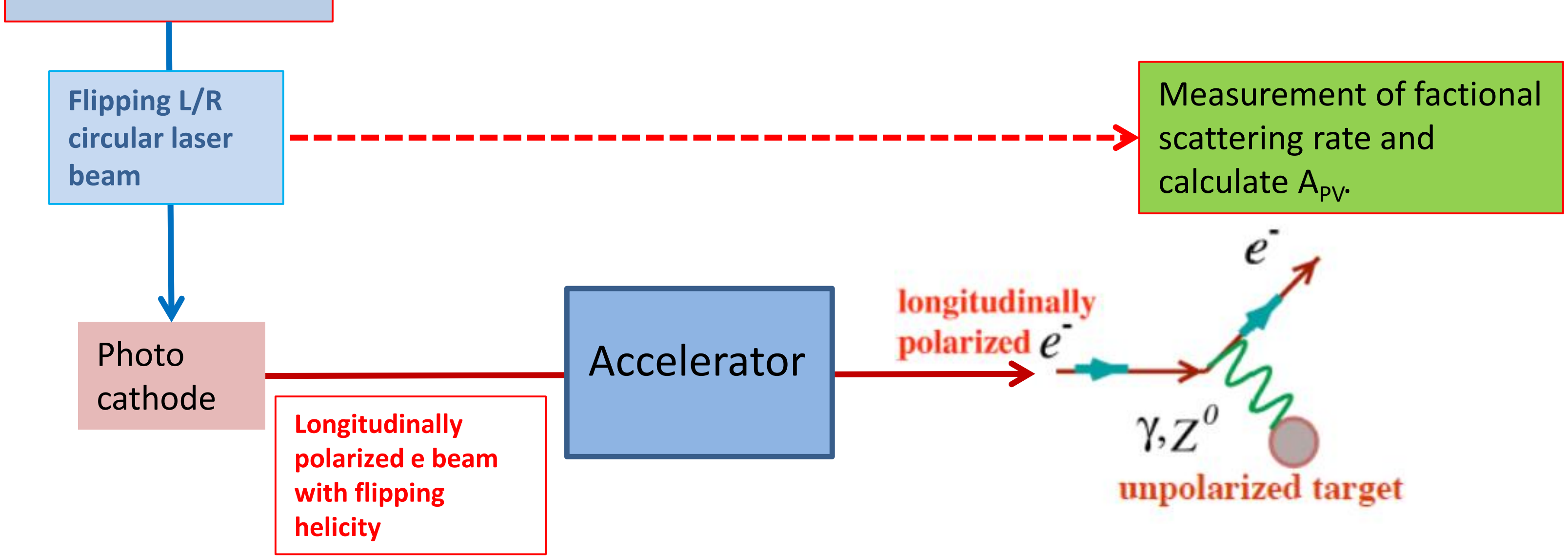
The measurement precision of A_{PV} is critical.



The properties of the incident electrons shall remain identical except the sign of polarization, but they tends to change due to various factors…

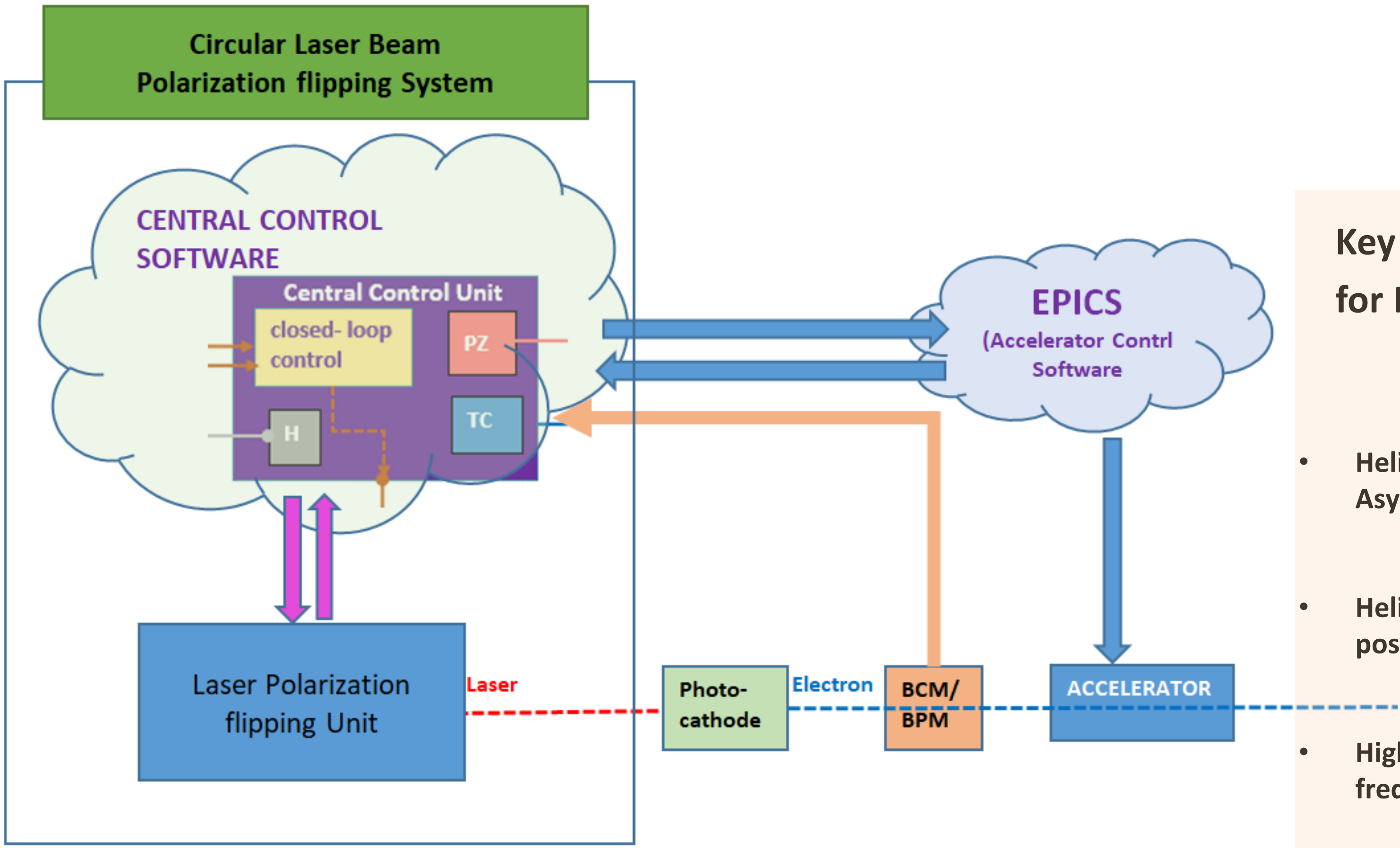
Circular Laser beam Polarization Flipping System in PVES

Rapid helicity flipping changes sign of electron polarization



The helicity correlated asymmetry causes uncertainty to the measurement of A_{PV}

Technical Approach

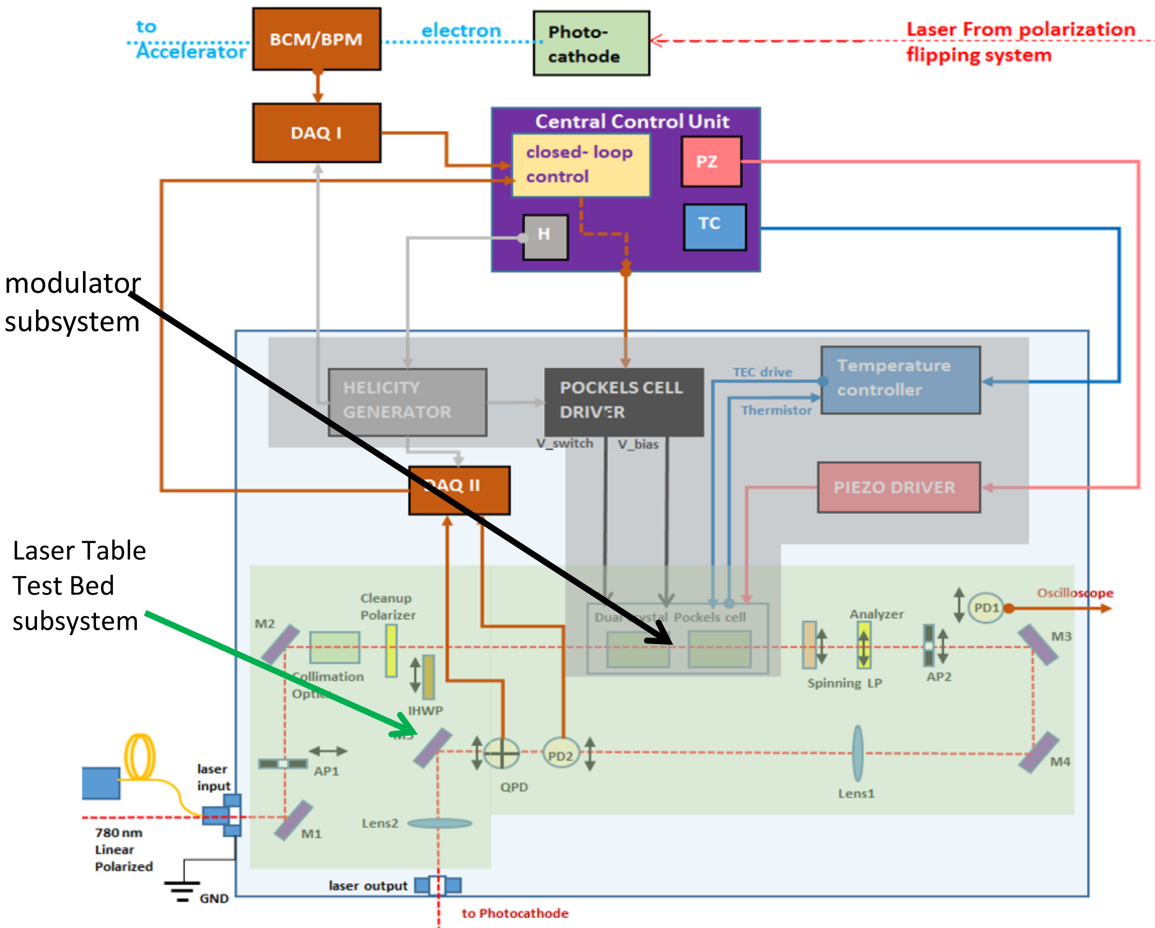


Key requirements for MOLLER beam

- Helicity correlated Asymmetry:
  ~ a few ppb
- Helicity correlated position difference:
  ~ 1 nm
- High Helicity flipping frequency
  1920 Hz

Circular Polarization Flipping System

Technical Approach



Parameter	Specification
Repetition rate	1920 Hz
Duty cycle	>95%
Spot size asymmetry (RMS)	$< 10^{-4}$
Position difference (no analyzer)	< 200 nm
Position difference (S1 or S1analyzer)	< 400 nm
Intensity noise	< 100 ppm
4-peak asymmetry	< 7,000 ppm
HC intensity asymmetry	< 500 ppm
Lifetime*	> 10,000 hrs

Schematic of Circular Polarization Flipping Laser Beam Unit

Modulator Subsystem Specification and Technical Approach

Targeted Modulator Subsystem Specification

Parameter	Specification
Clear aperture	8 mm
PER	>30 dB
Driving voltage (@780 nm, $V\pm_{\pi/2}$)	± 250V
Bias voltage	< 50V
Voltage resolution	0.01V
Operation frequency	1920 Hz
Residual linear polarization	< 5%
Settle time	< 25 us
Ringing variation after settle time	Within ± 10%
Temperature stability	Within ± 0.005˚C
Translation resolution	XY: 1 um, Z: 0.1 mm
Angle resolution	Pitch, Yaw: 50 urad, piezo Roll: 0.5 mrad, manual

Improvement from Phase I

- Dual crystal configuration with active individual cell alignment to cancel out inherent birefringence
- Improve transition performance by optimizing driver design
- Use Large beam size /Crystal size
- Closed loop control
- Implement better X/Y and Pitch/Yaw scan

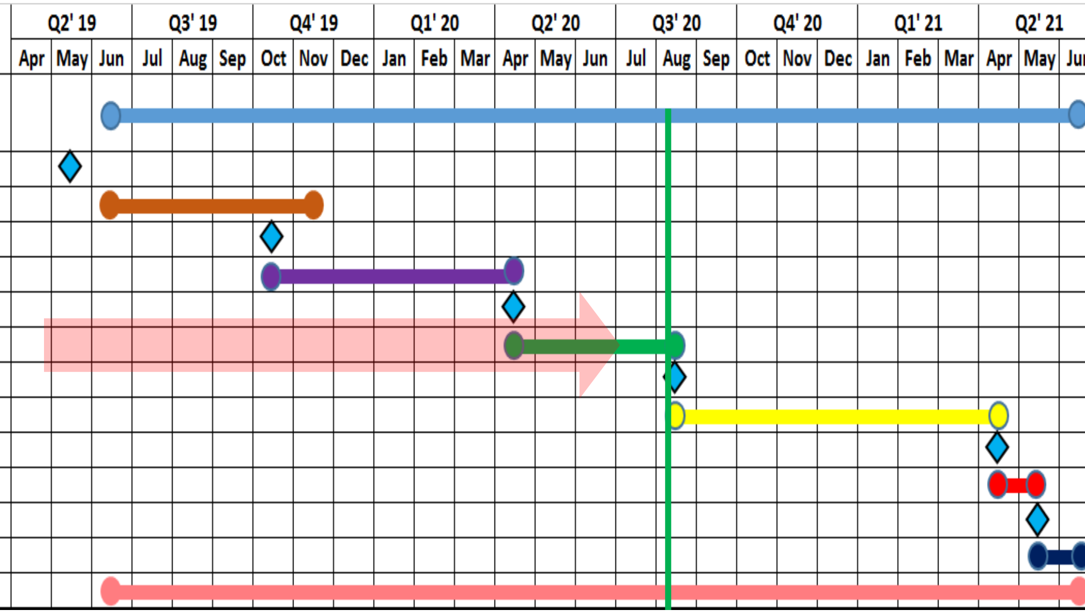
Same as in Phase I.

- Precise temperature control

Schedule and Current Status

The following table shows our proposed schedule and the progress (green arrow)

ID	Task Name	Duration
1	Precise and Ultra-stable Laser Polarization control for Polarized eBeam Generation	104w
2	Program Authorization	0w
3	Sytem Design	24w
4	System Design Review	0w
5	Labotory Verification of subsystems	29w
6	Laboratory subsystem Demonstration	0w
7	Design detailing	21w
8	Critical Design Review	0w
9	System Building and Test	38w
10	System In-house Evaluation and Delivery	0w
11	System Integration and Evaluation	5w
12	System Completion	0w
13	Final Report	4w
14	Program Management	104w



Modulator subsystem

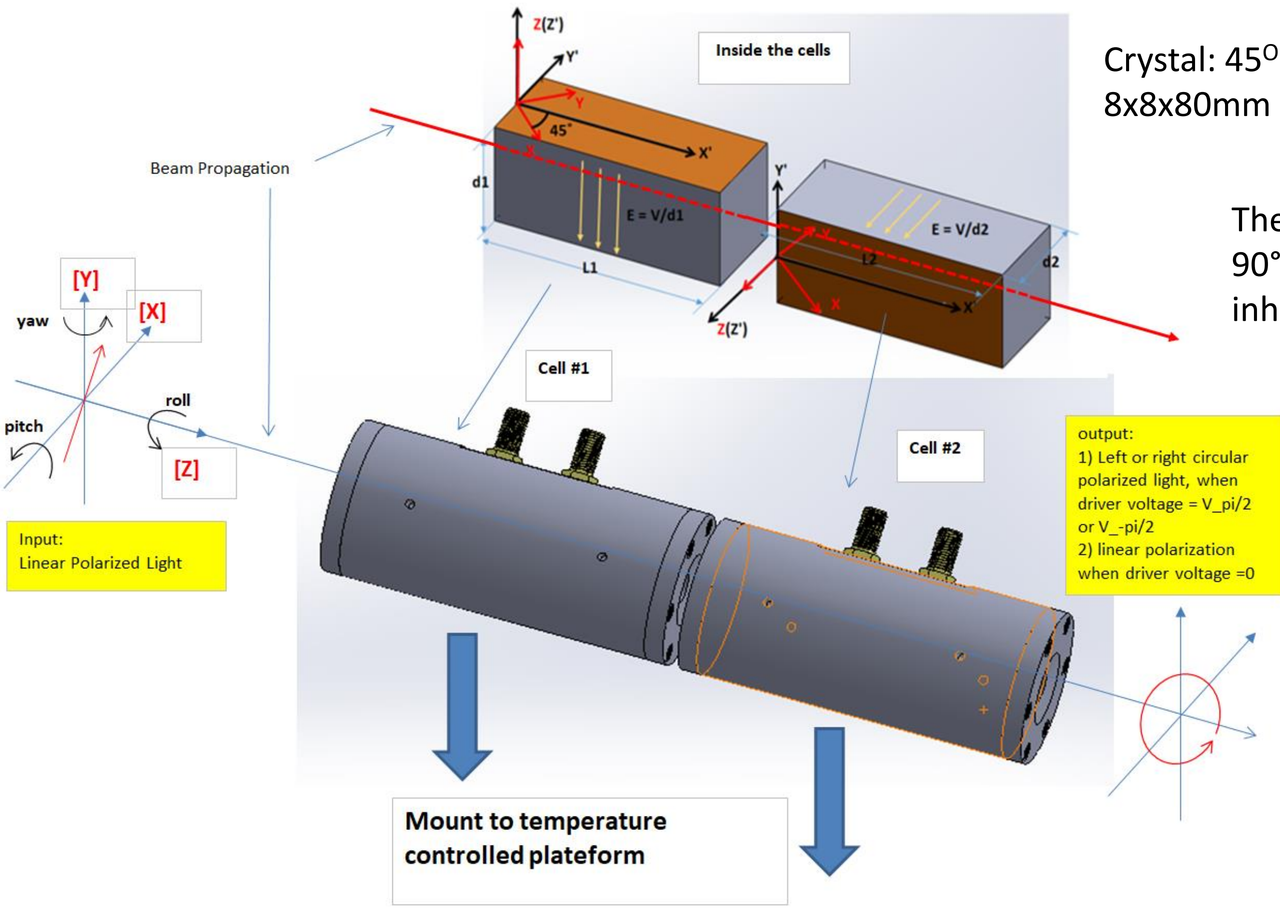
- Design of dual DKDP crystal EO modulator and alignment mount
- Design, build and evaluate high voltage driver for Pockels cell

Laser table test bed subsystem

- Detailed design of laser table test bed
- Purchase parts and equipment to build laser table test bed subsystem

Progress and Results

❖ Modulator Subsystem – Dual DKDP Pockels cell design



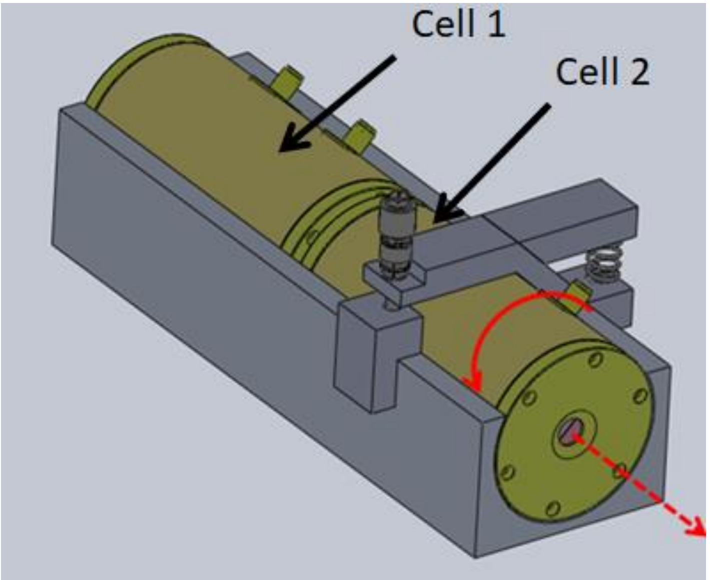
Crystal: 45^{O} Z cut
8x8x80mm

The crystal inside Cell2 is rotated 90° to Cell 1 so that the two crystal's inherent birefringence cancels out.

Progress and Results

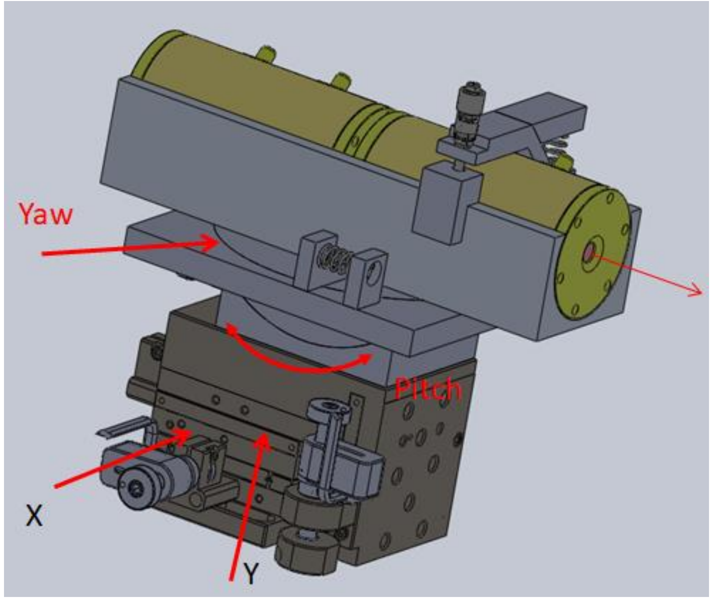
❖ Modulator Subsystem – Dual DKDP Pockels cell Mount design

Cell Relative Roll adjustable



The roll of Cell 2 can be actively adjusted during modulator subsystem building and testing to cancel out of the inherent birefringence

X/Y and Pitch/Yaw scan

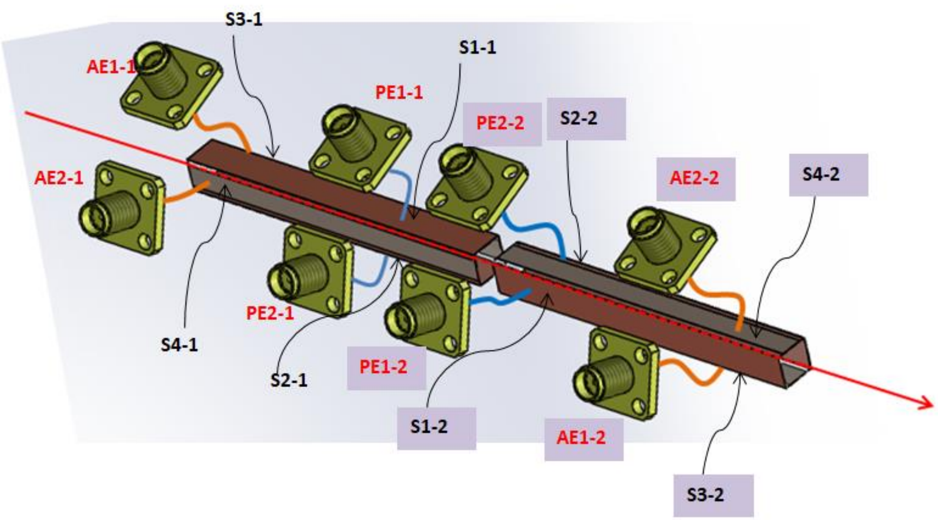


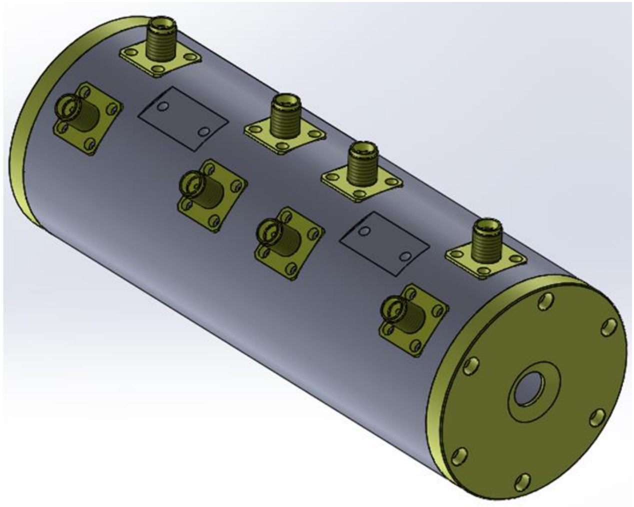
Picomotor actuator for scan driving.

- Software control
- Precise scan resolution
  X/Y: 1 um
  Pitch/Yaw: 50 urad

Non-uniformity compensation-control

Dual DKDP Pockels cell with ***auxiliary electrodes***



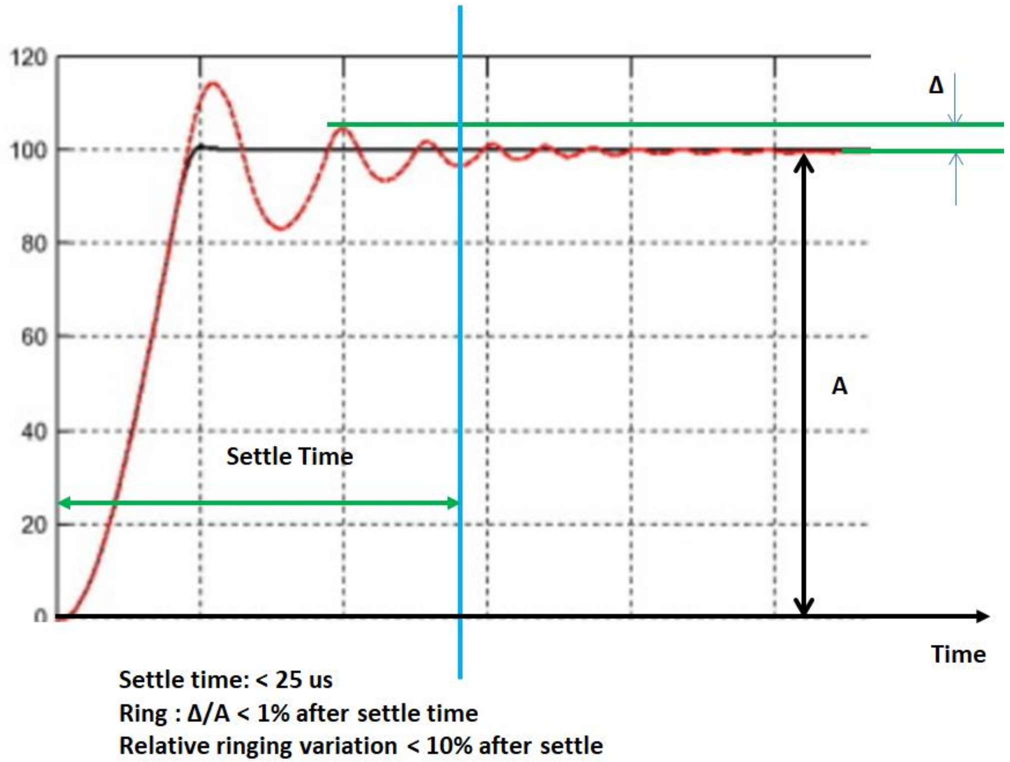


- We designed a dual DKDP Pockels cell with Auxiliary Electrode to suppress beam steering.
- The figure on the left shows auxiliary electrodes (AE) connection for the dual DKDP Pockels cells.
- The figure on the right is the mechanical model of such Pockels cell.
- We will also use a dual DKDP Pockels cell with Auxiliary Electrode to build a modulator subsystem to evaluate the performance improvement.

Progress and Results

❖ **Modulator Subsystem – Driver for Pockels Cell**

Transition Requirements for Driver Design



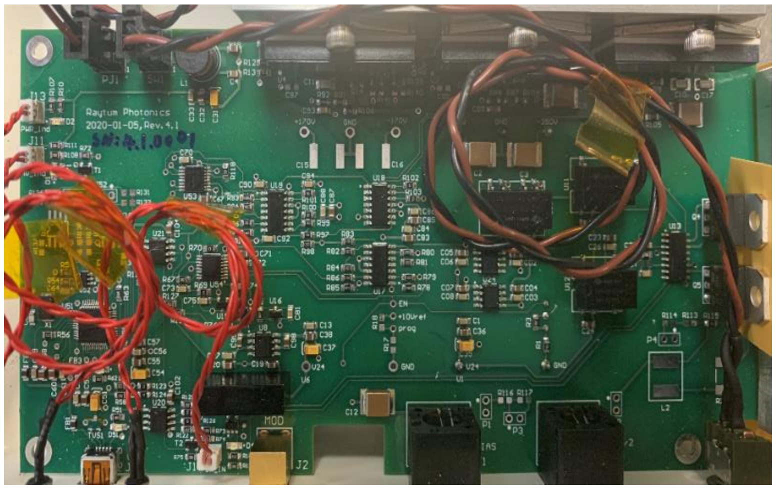
When the driver voltage switch between V±π/2, the transition performance shall meeting the specification shown left.

With <25 us settle time, dead zone < 5% for ~ 2kHz filling frequency.

With specified ringing specification, helicity correlated asymmetry specs can be met.

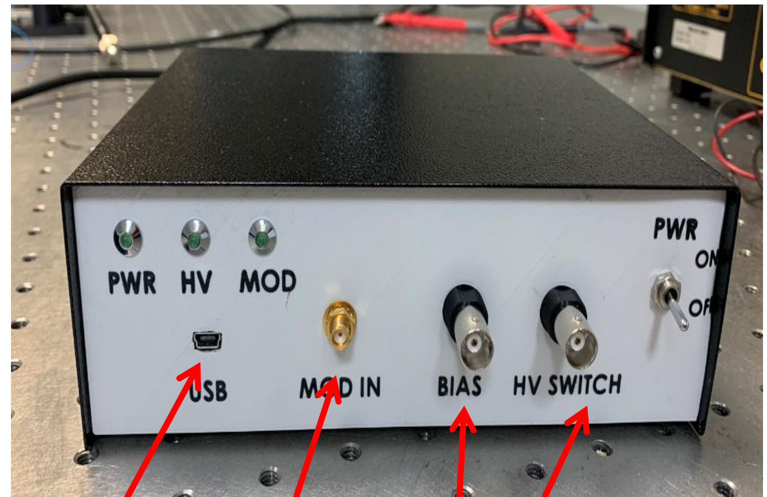
Progress and Results

High Voltage Diver PC board



- digital bi-level high-power switching design
- 5.5 mV resolution with precise voltage reference
- Rise time and ringing compromise

Modulator Diver front panel



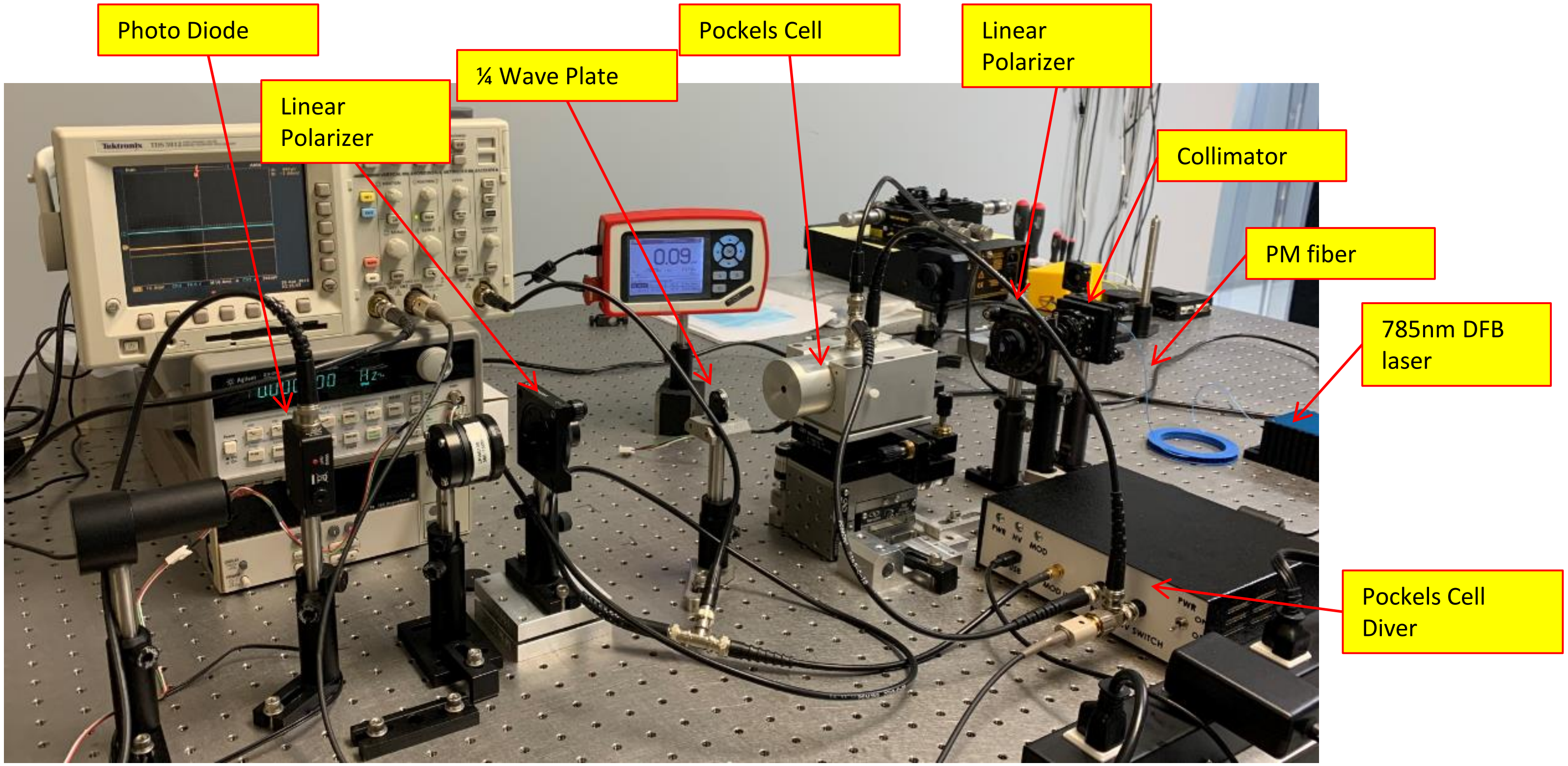
to computer
to set voltages

to function generator
to set frequency

to Pockels cell SMA connectors

Progress and Results

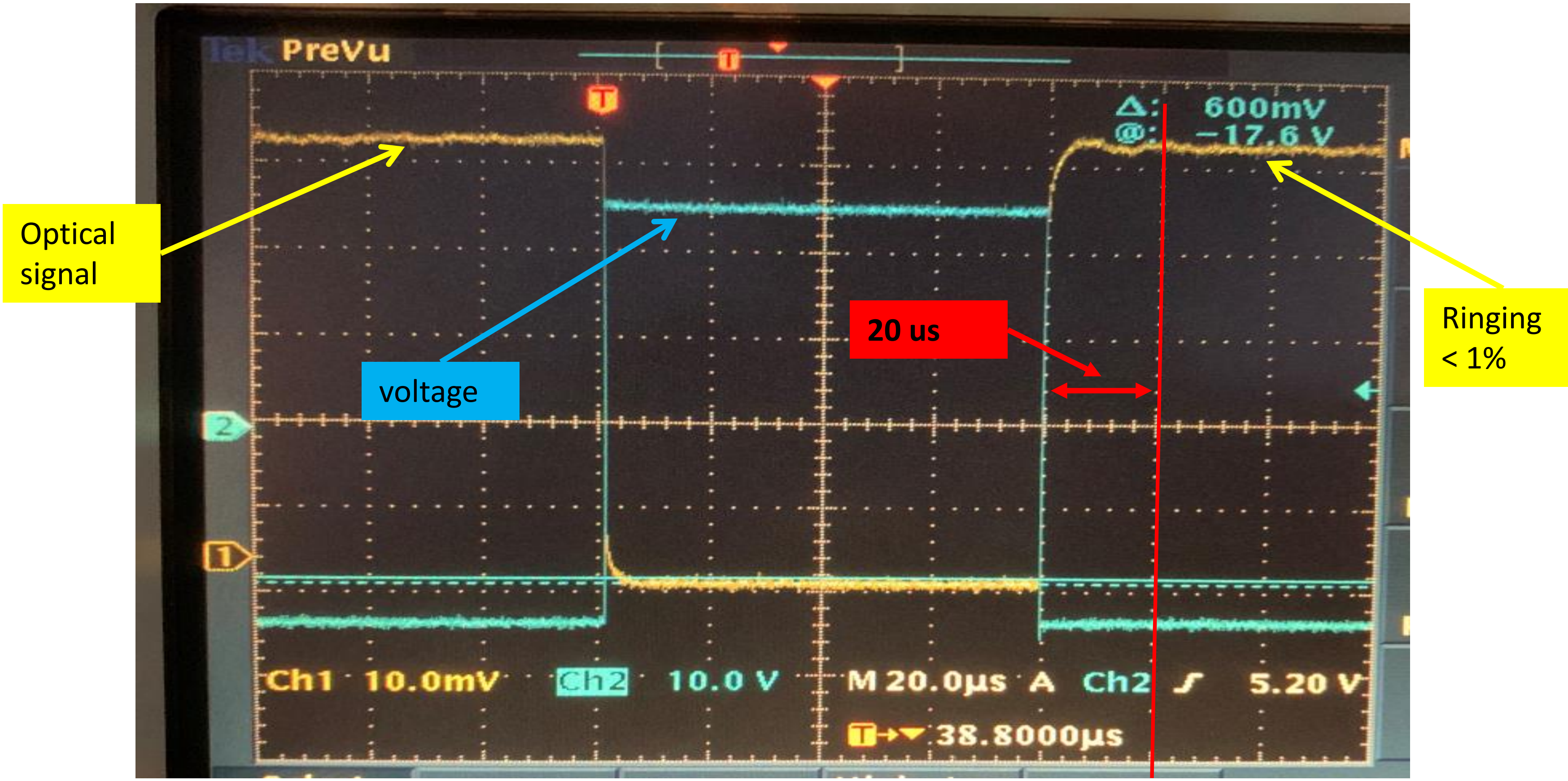
❖ Modulator Sub-system – 4.Pockels Cell Driver Evaluation



Experimental setup for high voltage driver evaluation

Progress and Results

Transition Characteristics Test Rsults



Progress and Results

Summary of Test Results

Target specs			Test results
Parameter	**Specification**	**Note**	**Subsystem Test results**
Clear aperture	8 mm		by design;
PER	>30 dB		will test after receiving crystal and modulator assembly
Driving voltage (@780 nm, $V\pm_{\pi/2}$)	± 250V	Within ± 10% range	227/-230 V, meet specs
Bias voltage	< 50V		-24 V, meet specs
Voltage resolution	0.01V		5.5 mV by design; verified in test
Operation frequency	1920 Hz		meet specs in test
Residual linear polarization	< 5%		will test after receiving crystal and modulator assembly
Settle time	< 25 us	Ringing < 1% after settle time	< 20 us for both rise and fall
Ringing variation after settle time	Within ± 10%		
Temperature stability	Within ± 0.005°C		meet specs in test, will test again after receiving crystal and modulator assembly.
Translation resolution	XY: 1 um, Z: 0.1 mm	Range: XY: ± 1.0 mm, piezo; Z: ± 2.0 mm, manual	by design, using Newport picomotor acctuator with 0.5" travel and 30 nm resolution
Angle resolution	Pitch, Yaw: 50 urad, piezo Roll: 0.5 mrad, manual	Range: Pitch, Yaw: ± 10 mrad, piezo Roll: ± 10 mrad, manual	by design, using Newport picomotor acctuator with 0.5" travel and 30 nm resolution by design, using Newport picomotor acctuator with 0.5" travel and 30 nm resolution

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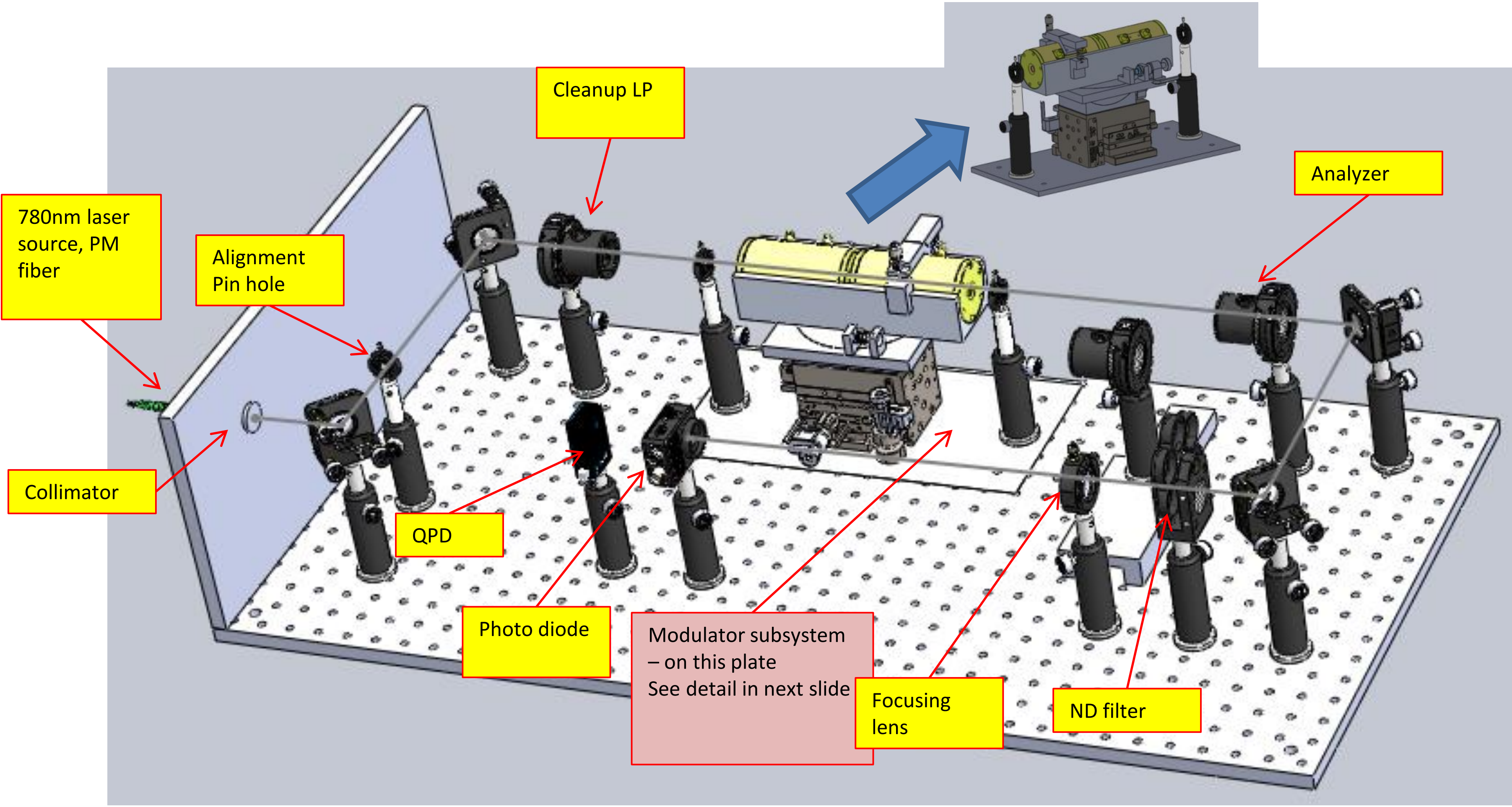
Results achieved

❖ Laser Table test bed Subsystem – 1. Mechanical design



Mechanical design of Laser Table Test bed

Acknowledgement

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- Collaborators: Shukui Zhang (Jlab), Kent Paschke (UVa) and other institutions
- And thank the kind attention from All of you