Precise and ultra-stable laser polarization control for polarized electron beam generation

RAYTUM PHOTONICS

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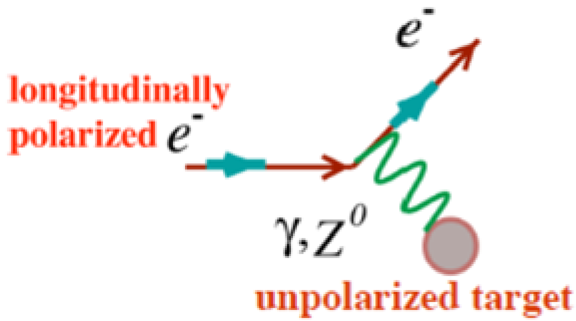
8/19/ 2021

Award Number:	DE-SC0018600
Topic Number:	29/e

Outline

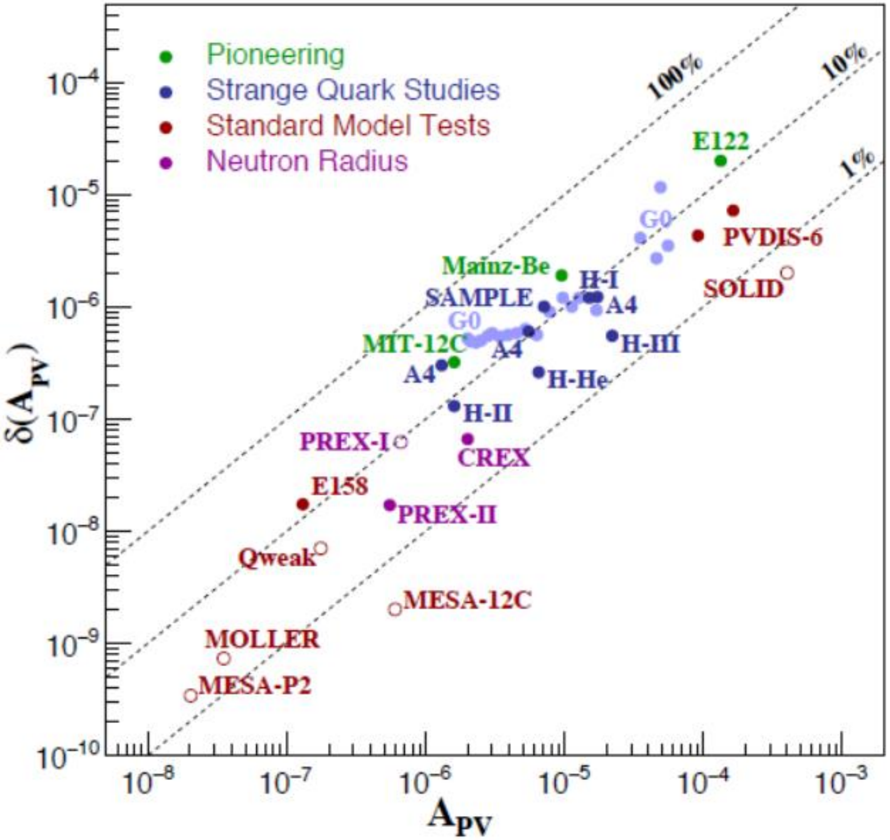
- Background and Motivations
- Project Task and Technical Approach
- Progress and Results

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

Circular Laser Beam Polarization flipping System

Rapid helicity flipping changes sign of electron polarization

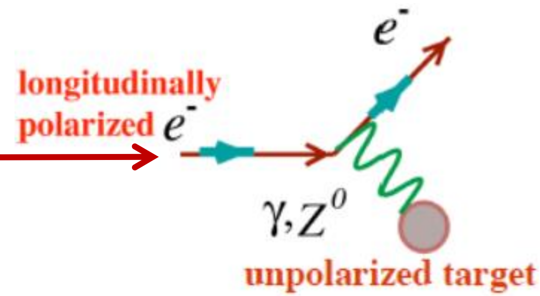
Flipping L/R circular laser beam

Measurement of factional scattering rate and calculate A_{PV}.

Photo cathode

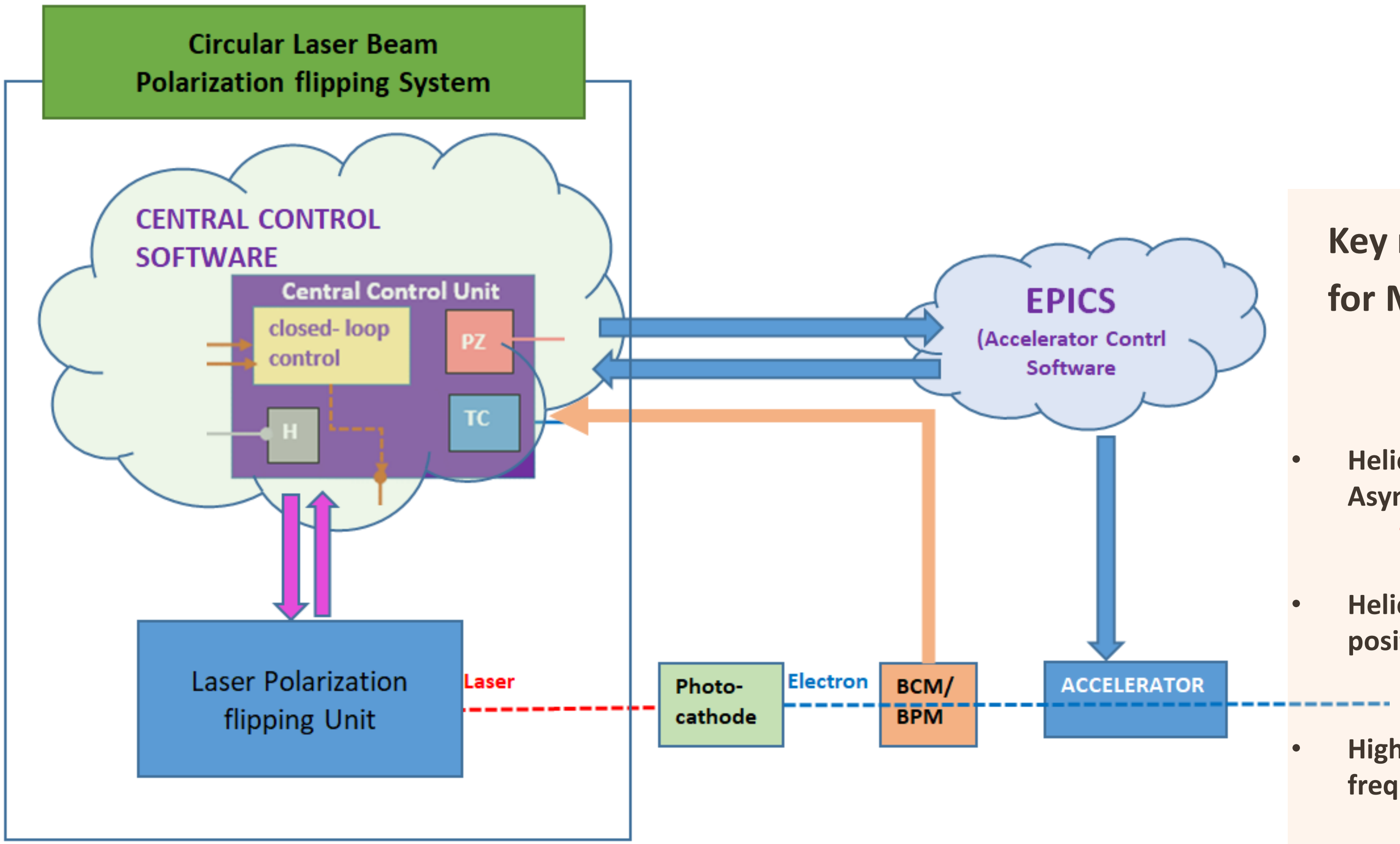
Longitudinally polarized e beam with flipping helicity

Accelerator



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

Technical Approach



Circular Polarization Flipping System

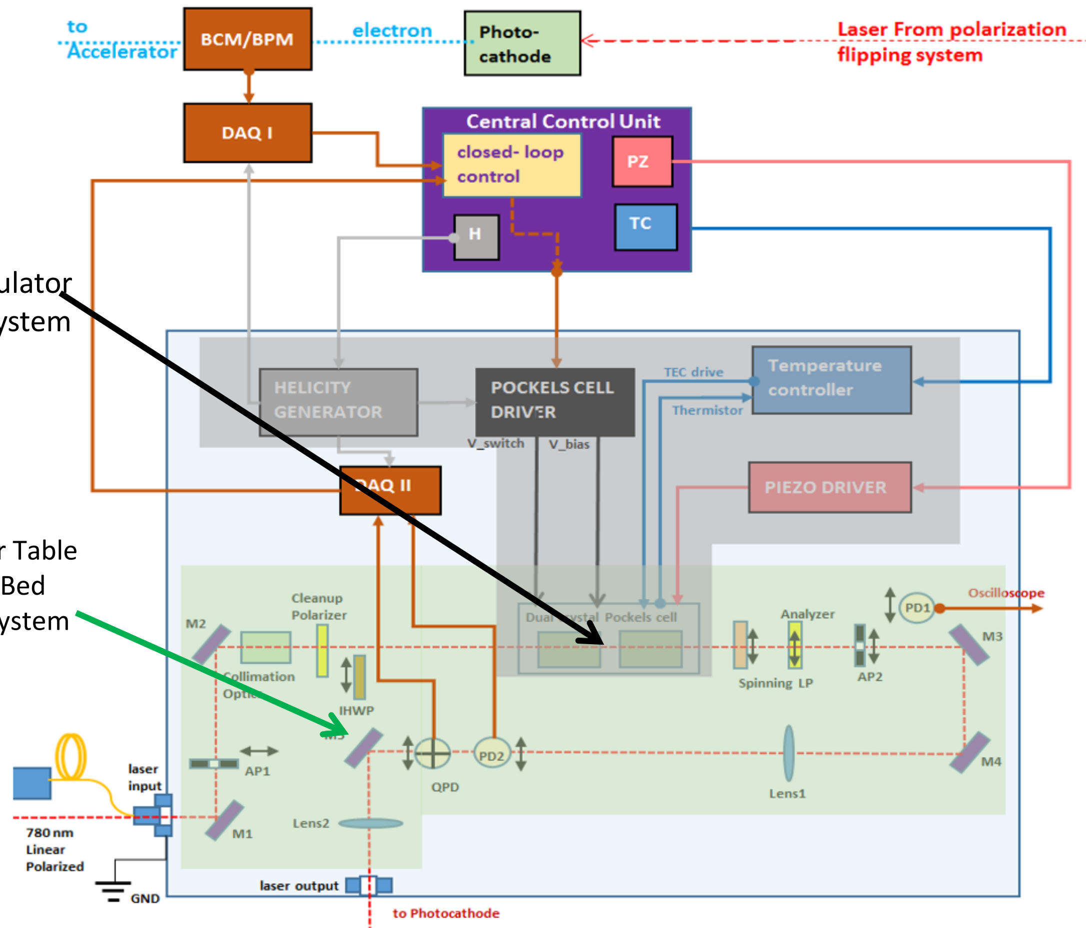
Key requirements for MOLLER beam

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

Technical Approach

modulator subsystem

Laser Table Test Bed subsystem



Schematic of Circular Polarization Flipping Laser Beam Unit

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

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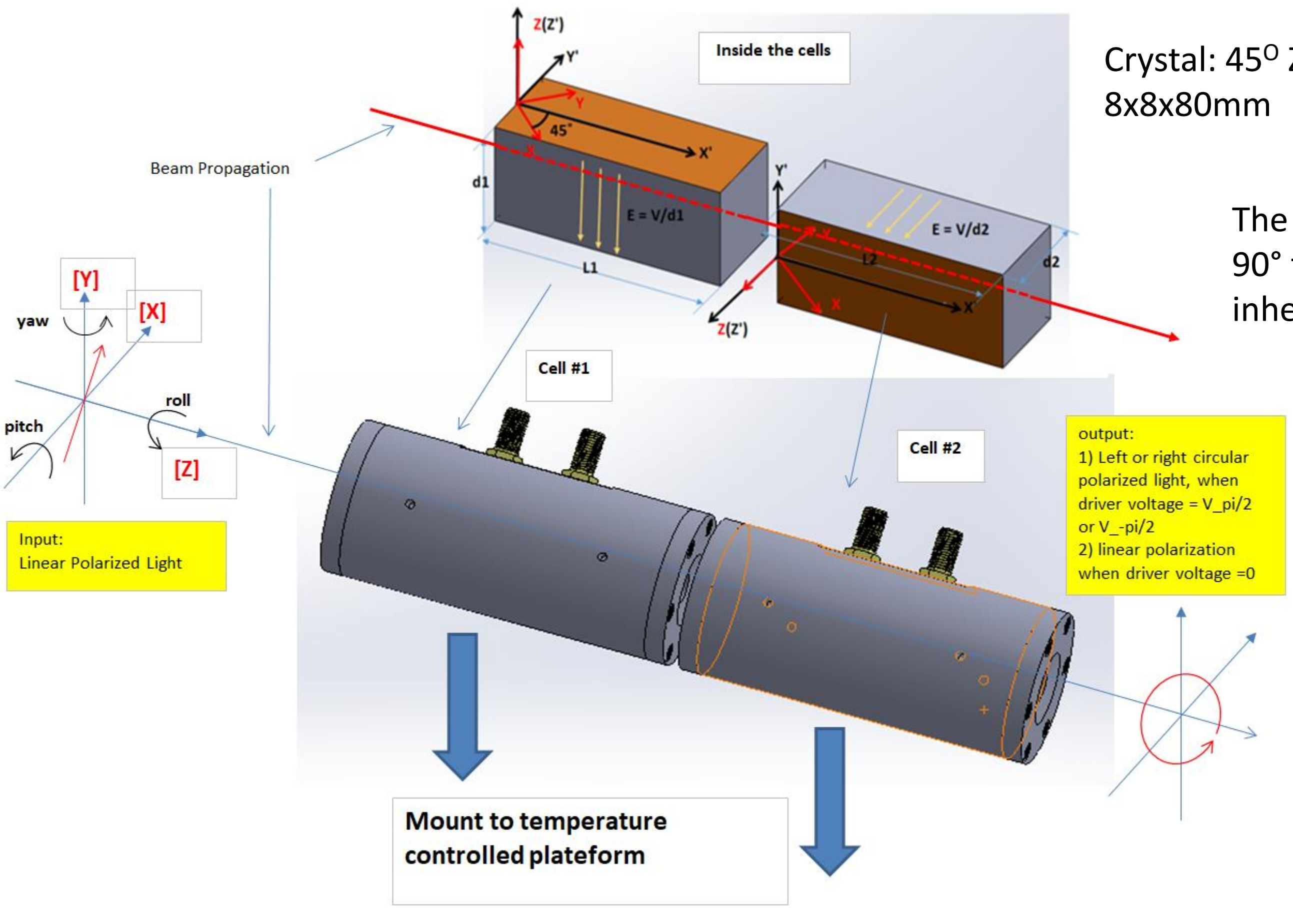
Pockels Cell Design

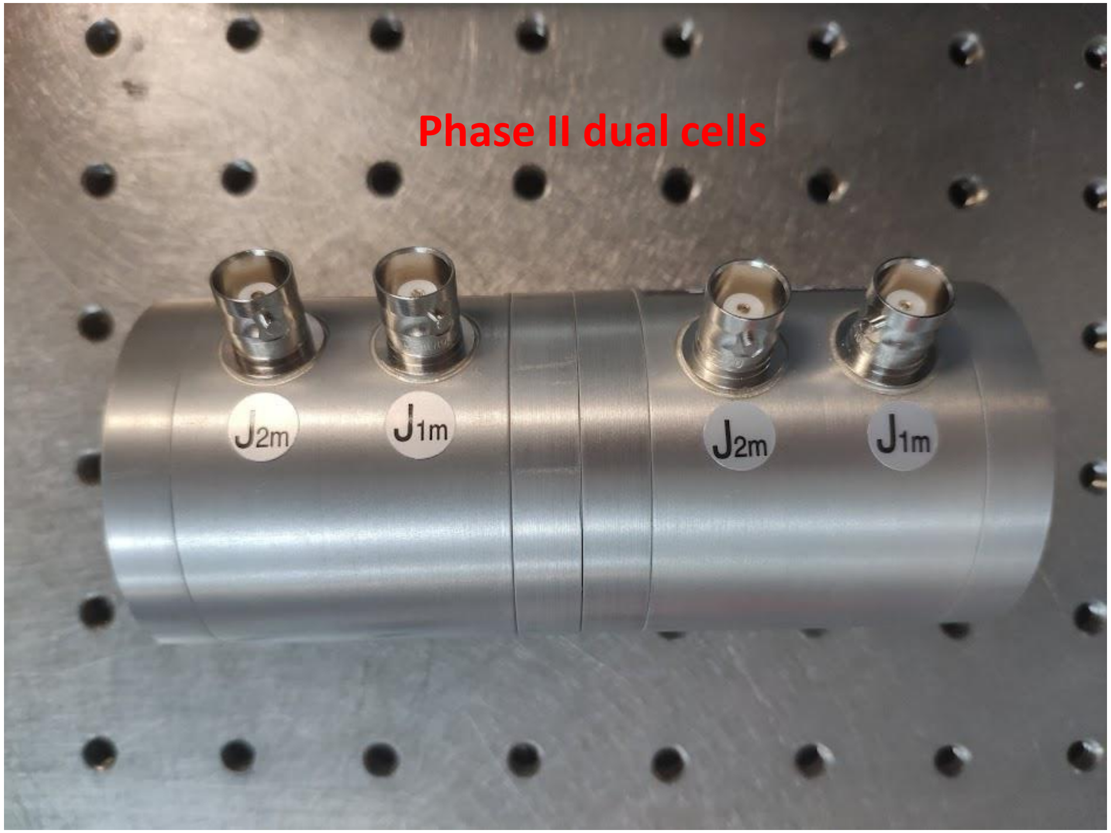
❖ **Modulator Subsystem – Dual DKDP Pockels cell design**

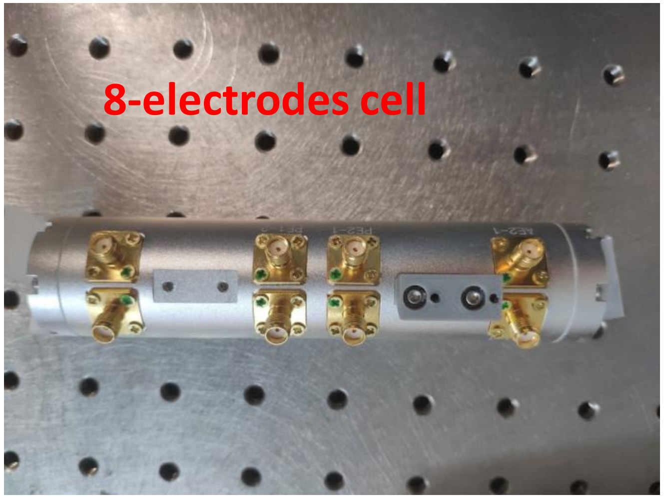


Crystal: 45^{O} Z cut
8x8x80mm

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

DKDP Pockels Cell Prototypes

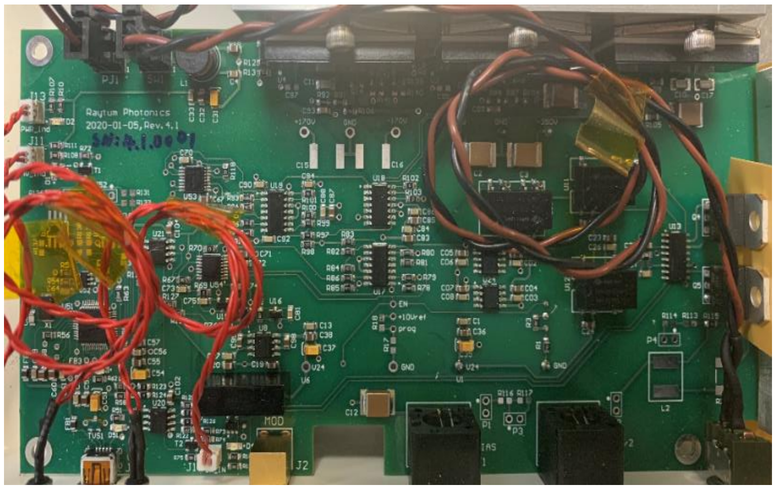




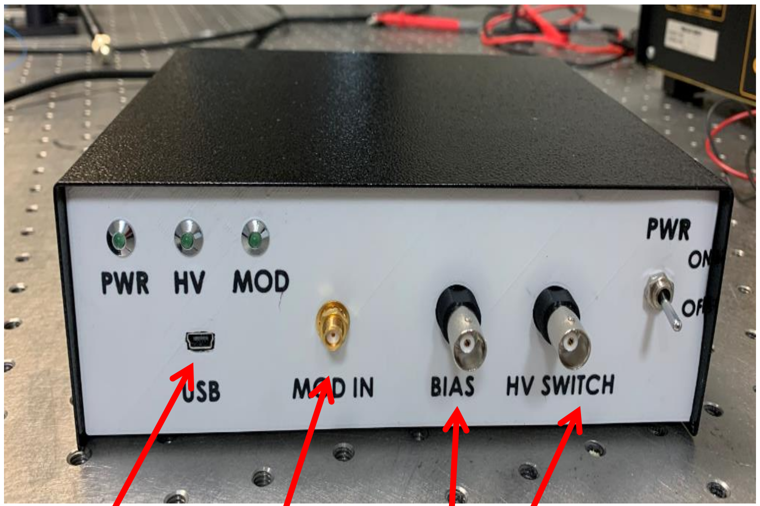
We designed several Pockels cells for testing and development of Phase I and Phase II.

High Voltage Driver

High Voltage Diver PC board



Modulator Diver front panel



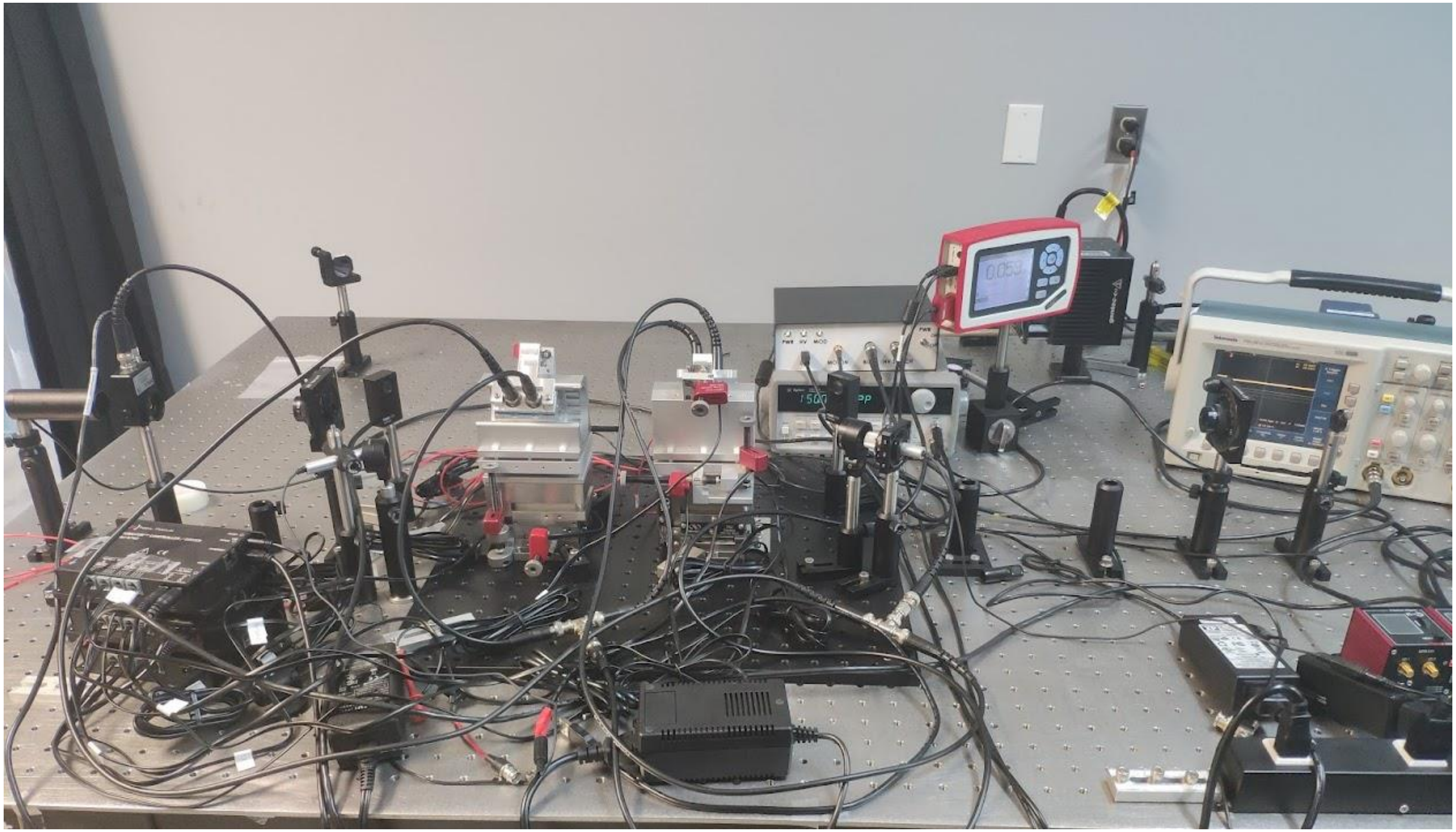
- digital bi-level high-power switching design
- 5.5 mV resolution with precise voltage reference
- Rise time and ringing compromise

to computer
to set voltages

to function generator
to set frequency

to Pockels cell SMA connectors

Test Bed



We also designed mount for Pockels cell with 5 axis Piezo-driver precise position control.

Testing with the Dual cell on the mount

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

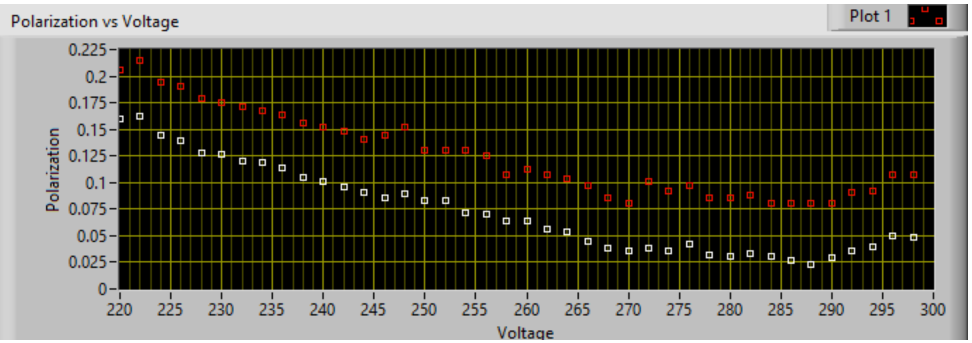
Improvement from Phase I

- **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**

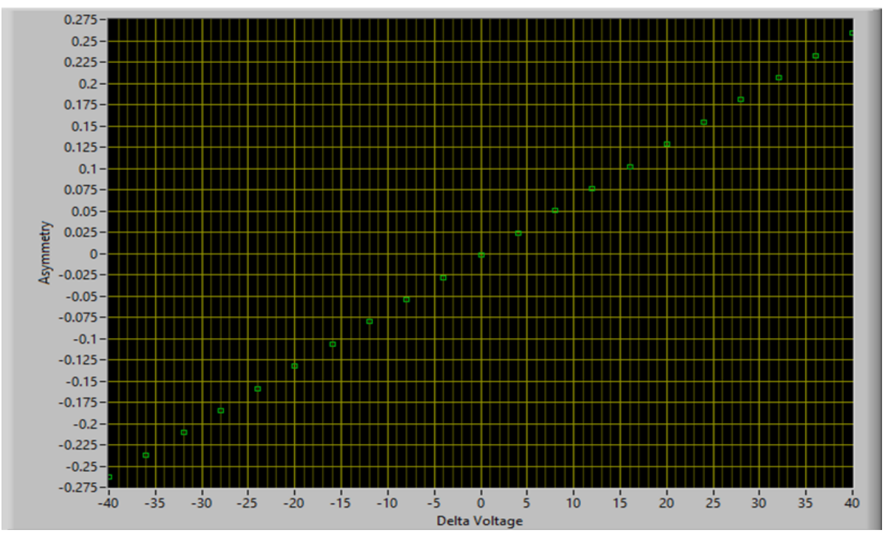
Same as in Phase I.

- **Precise temperature control**

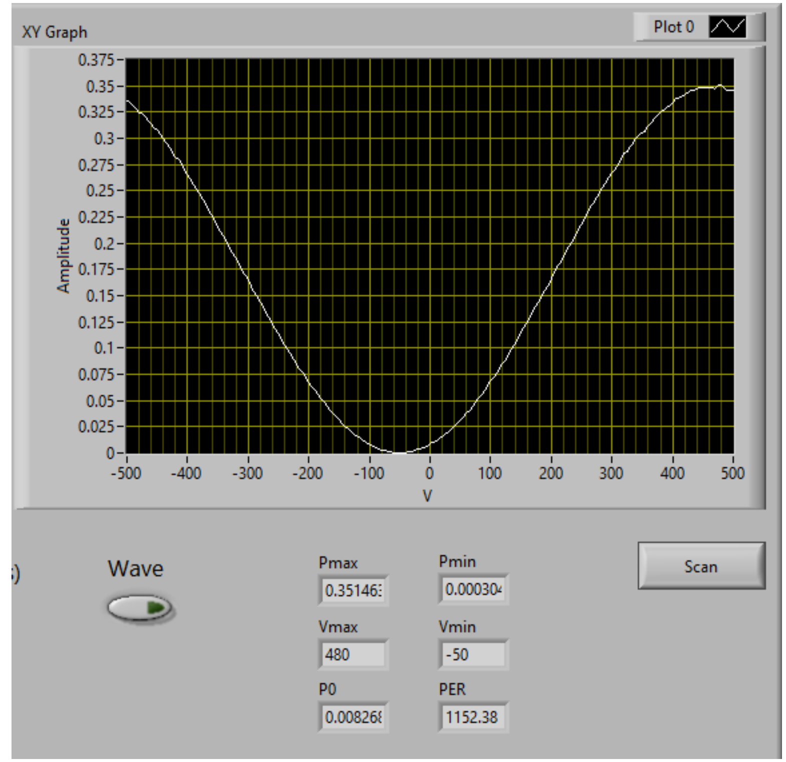
Performance (I)



We achieve a residual linear polarization ~ 2.5% during test on the DKDP dual cell system.



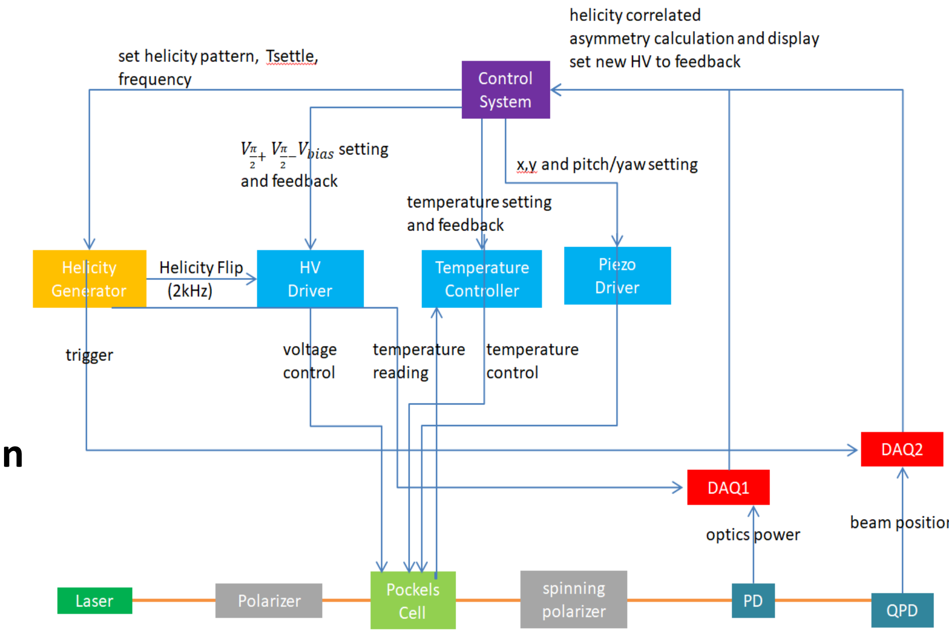
In our test we find the PITA slope is 6525 ppm/V, which is close to the prediction from the equation, 6280 ppm/V.

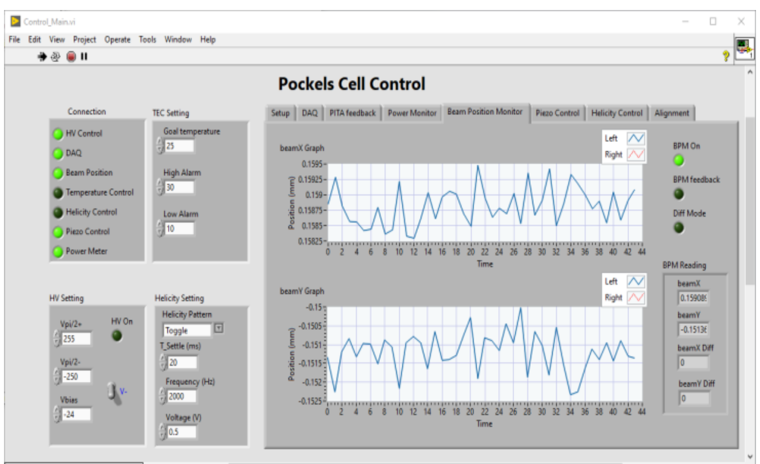


PER ~ 1000

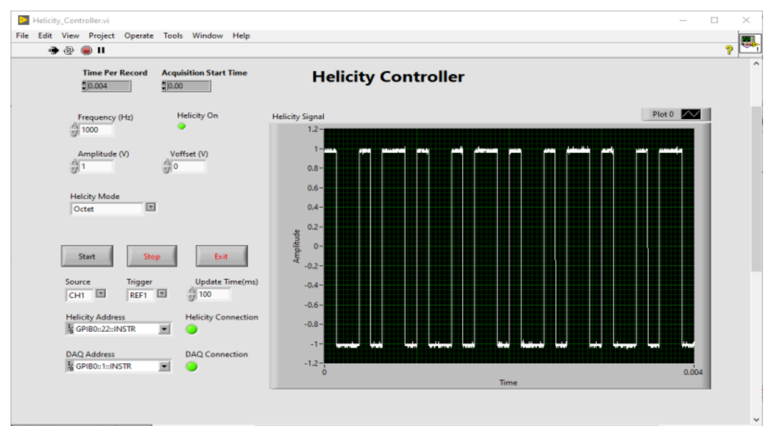
Control Software Development Using Machine Learning Technology

- Control Software Development:
- Helicity generator
- HV driver
- Temperature controller
- Piezo driver
- Optical power monitor
- Beam position monitor
- **Auto-Alignment Module/Data Collection**



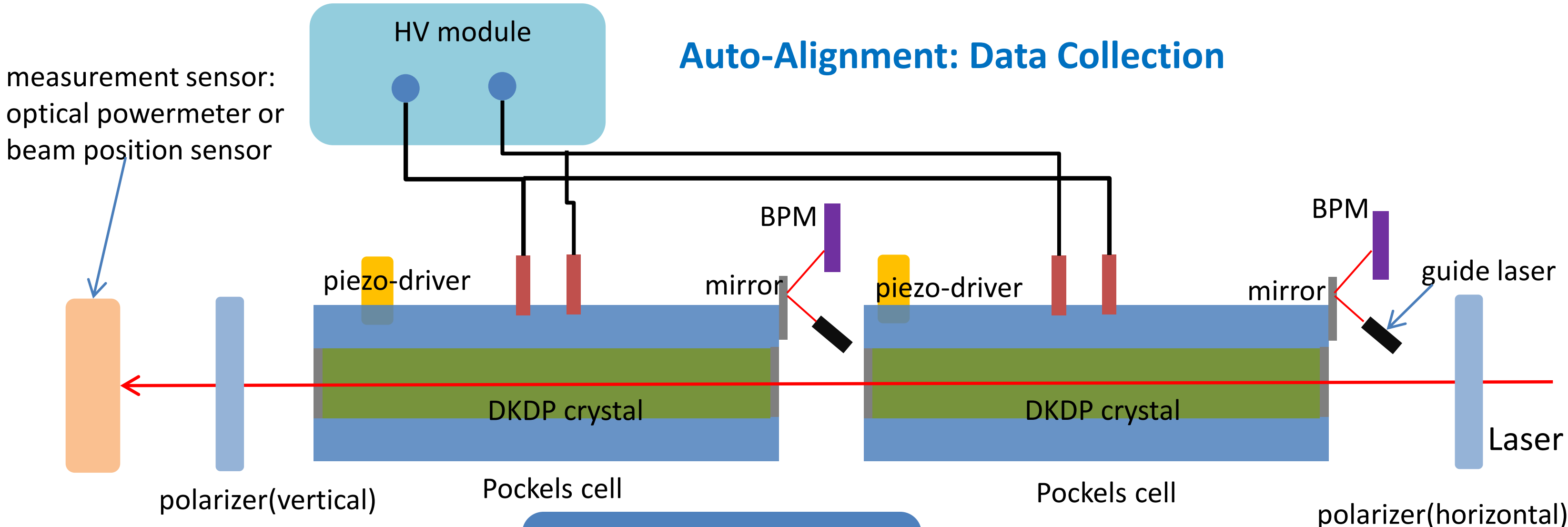


Beam position monitor interface

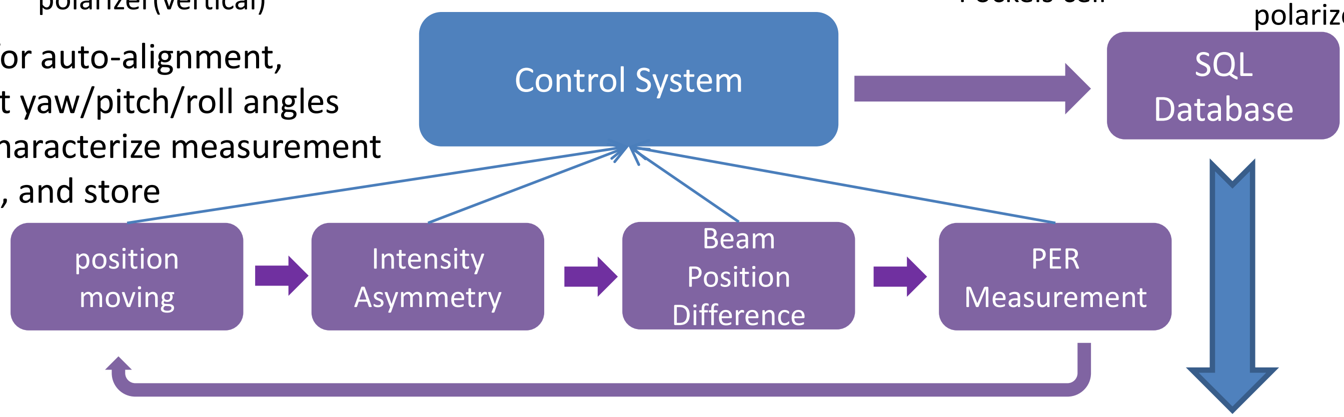


Helicity generator interface

System Description



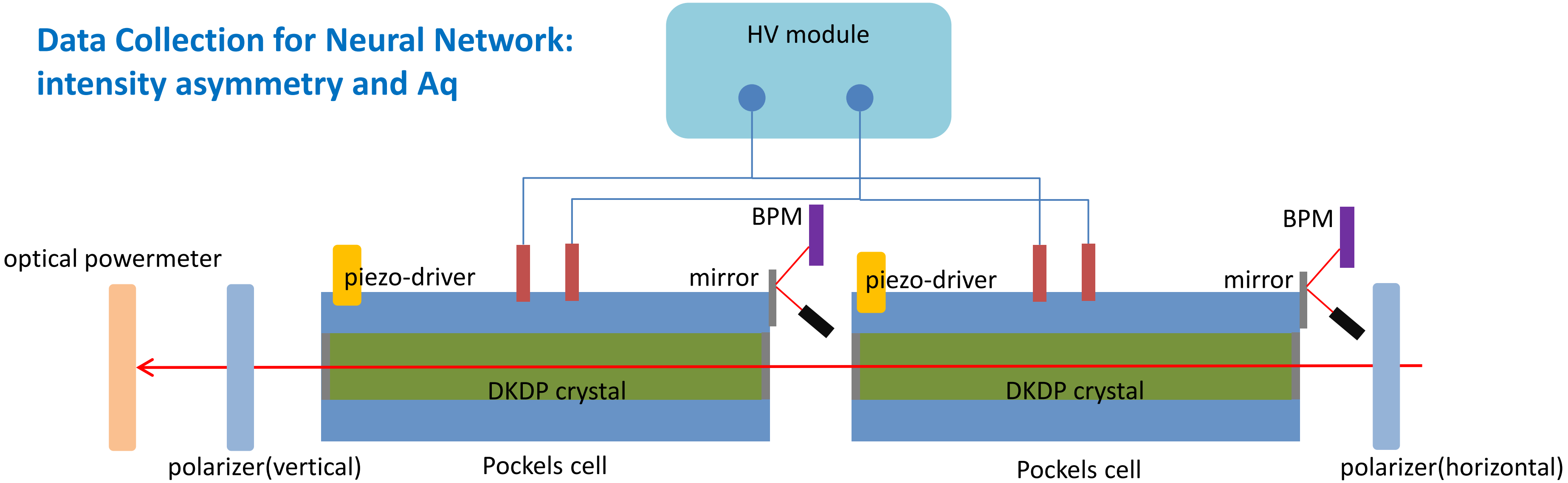
To build neural network for auto-alignment, we scan through different yaw/pitch/roll angles of Pockels cells, and do characterize measurement at each orientation angle, and store data in SQL database.

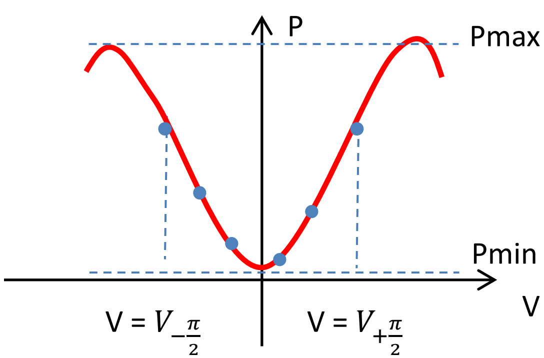


Cell1 roll	Cell1 pitch	Cell 1 yaw	Cell2 roll	Cell 2 pitch	Cell 2 yaw	PER	Aq	Dx	Dy
…	…	…	…	…	…	…	…	…	…

Data Collection I

Data Collection for Neural Network: intensity asymmetry and Aq

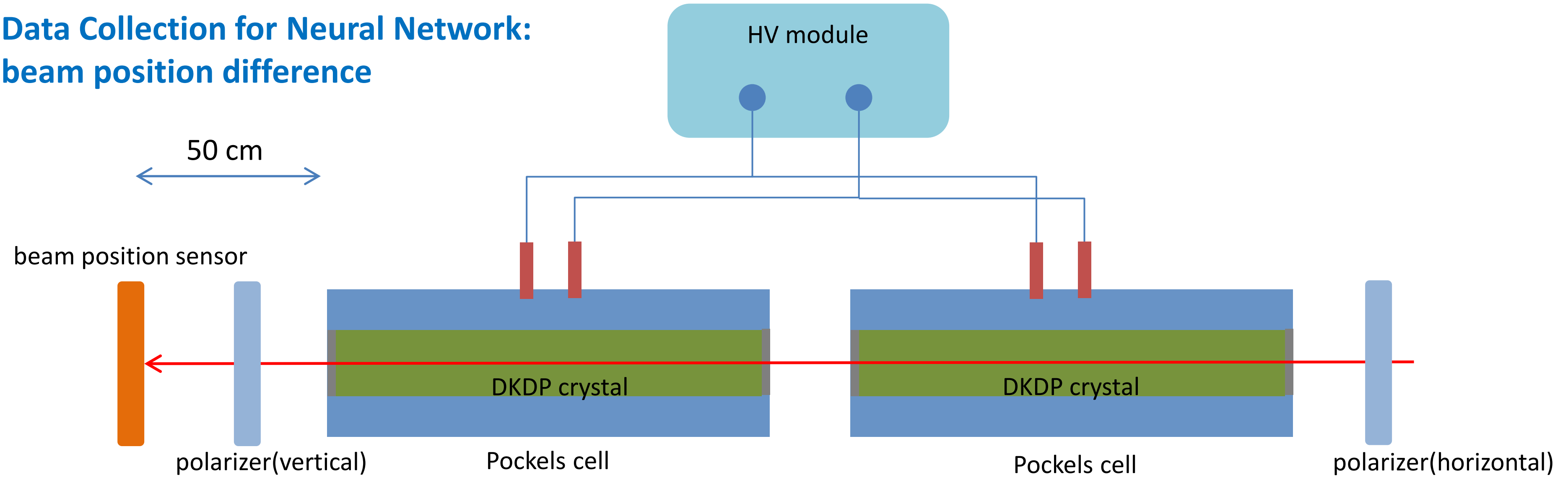


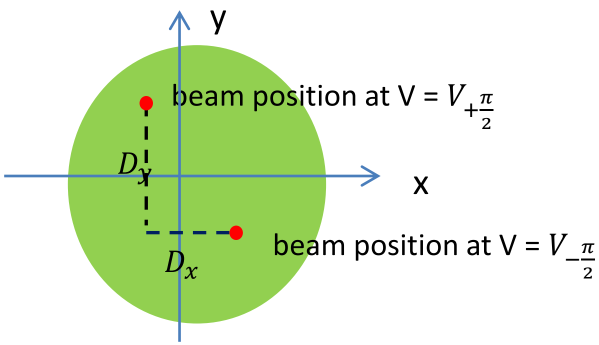


At each Pockels Cell orientation angle, we collect data for
PER : scan voltage applied on cell from -500 V to 500 V, PER = Pmax/Pmin
intensity asymmetry: asymmetry of optical intensity of two polarization states.

Data Collection II

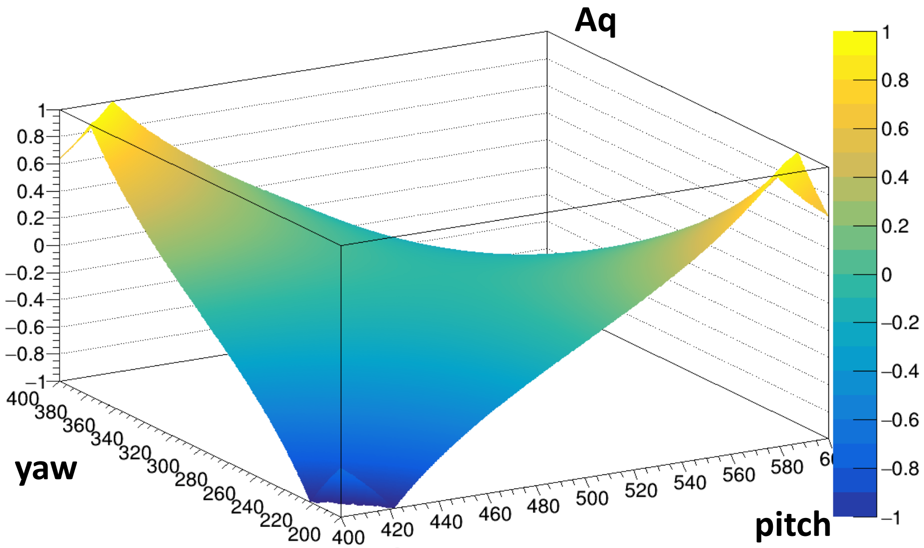
Data Collection for Neural Network: beam position difference

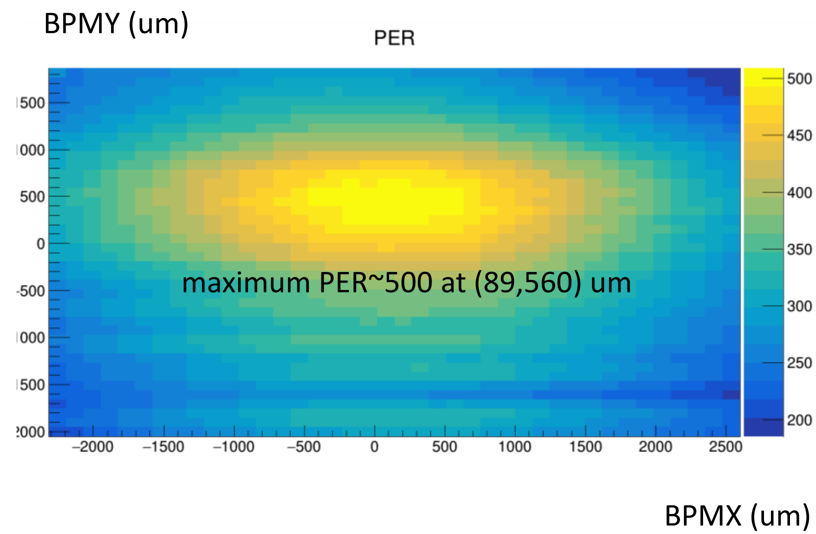


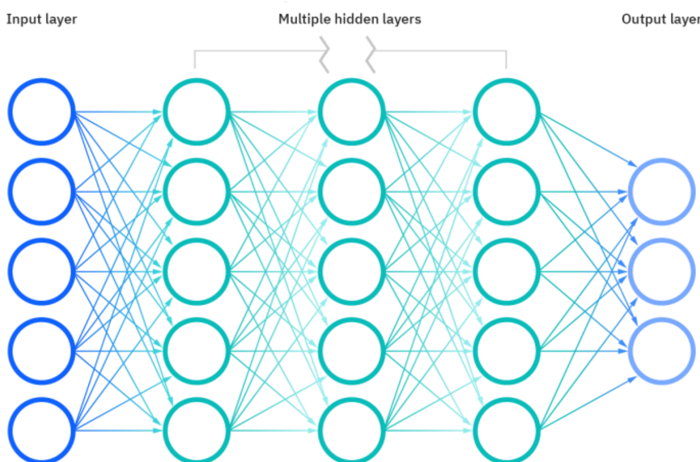


To measure beam position difference at every Pockels cell orientation angle:
We place a beam position sensor 50 cm downstream of the Pockels cell.
we measure beam position at two polarization states, then do the difference to get Dx and Dy.
To reduce the uncertainty, we repeat the measurement several times.

Progress and Results





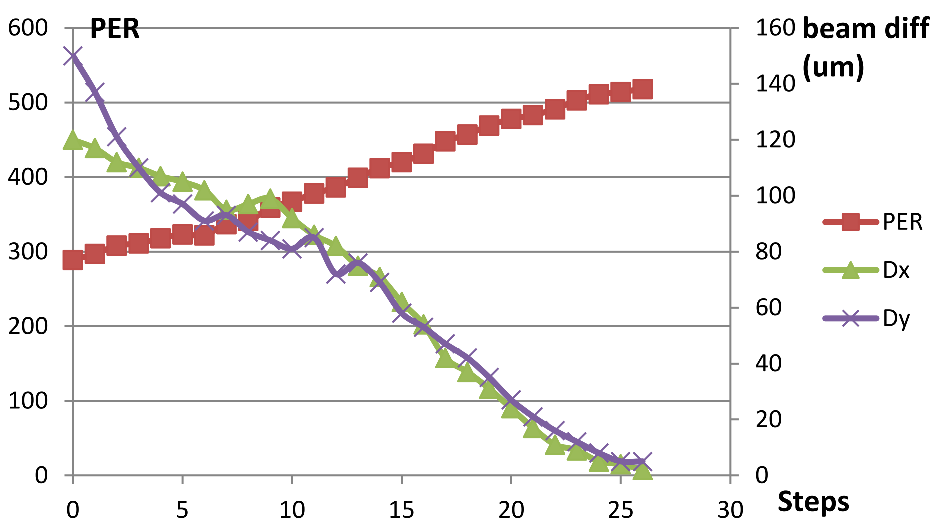


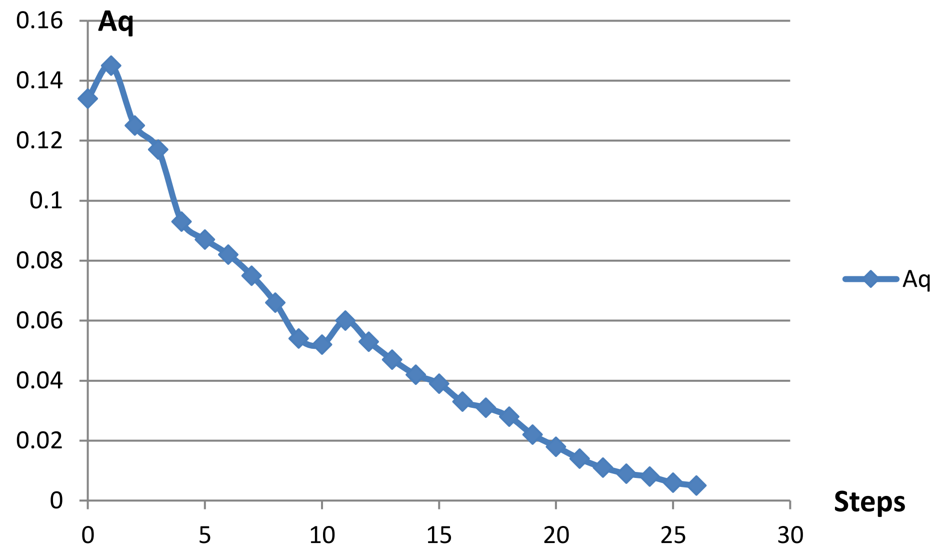
Mean error of built neural network

Model	PER	Aq (Intensity asymmetry)	Dx (beam position difference in x)	Dy (beam position difference in y)
ANN	4.8%	4.1%	3.8%	3.2%

Base on neural network build from data collection, we can build a 3 layer neural network with very good precision.

Progress and Results





Here is the result of auto-alignment:
We start with a state PER = 289, Aq(intensity asymmetry)=0.134, Dx (beam position diff in x) = 121 um, Dy (beam position diff in y) = 150 um,
after 28 steps, we reach the optimal position with PER = 512, Aq = 0.005, Dx = 2 um, Dy = 5 um.
The total auto-alignment process takes ~ 30 min.

Thank you!   Questions?