PVES source and polarimetry

-bias towards CEBAF-

Ciprian Gal UVa

PREX2/CREX Systematics

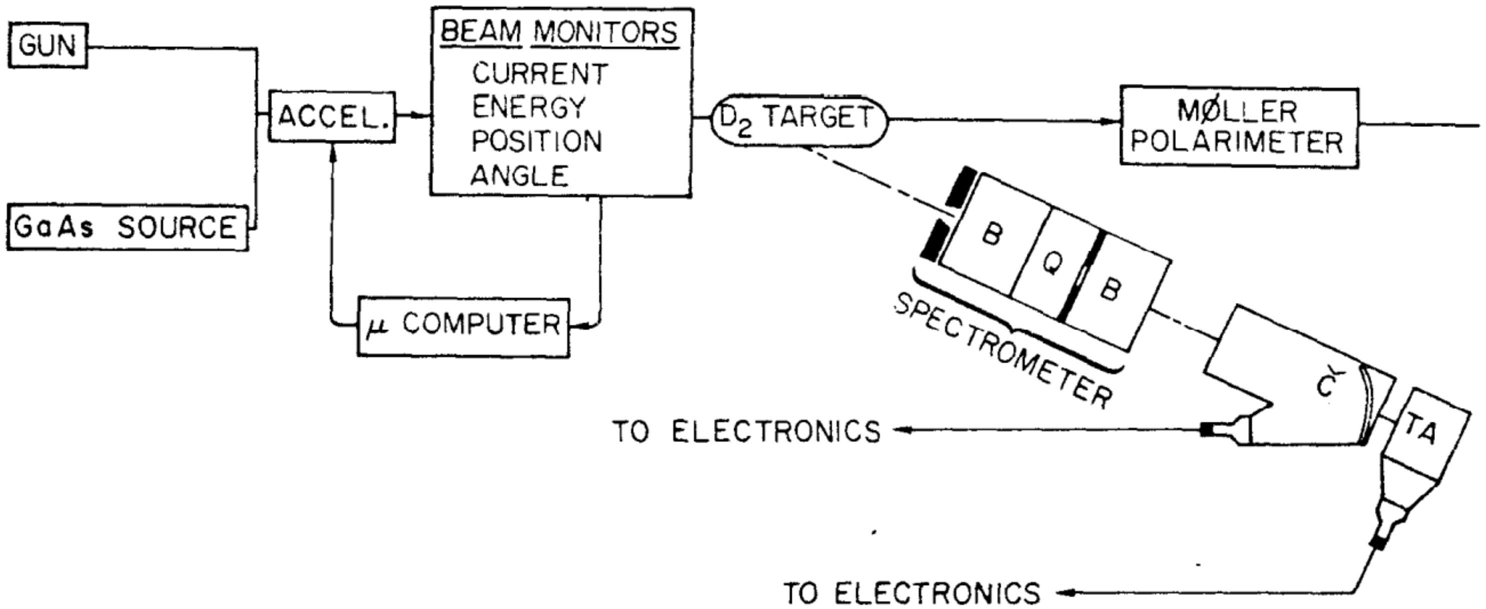
	PREX1 achieved	Qweak achieved	PREX2 needed	CREX needed
Polarization	1.3%	0.6%	1.3%	0.8%

***From Dustin's and Juliette's talks

Experiment	Beam Energy (GeV)	Beam Current (μA)	Charge Asymmetry (ppb)	Position Difference (nm)	Angle Difference (nrad)	Size Asymmetry (ppm)
HAPPEX-I	3.3	40	200	12	3	-
HAPPEX-2	3.0	55	400	2	1	-
PREX-I	1.1	70	85	4	1	<100
Qweak	1.1	180	~20	3	0.1	<100
PREX-II	1.0	70	<500	<2	<0.6	<100
MOLLER	11.0	85	<10	<1	<0.1	<10

**K. Paschke APS2016

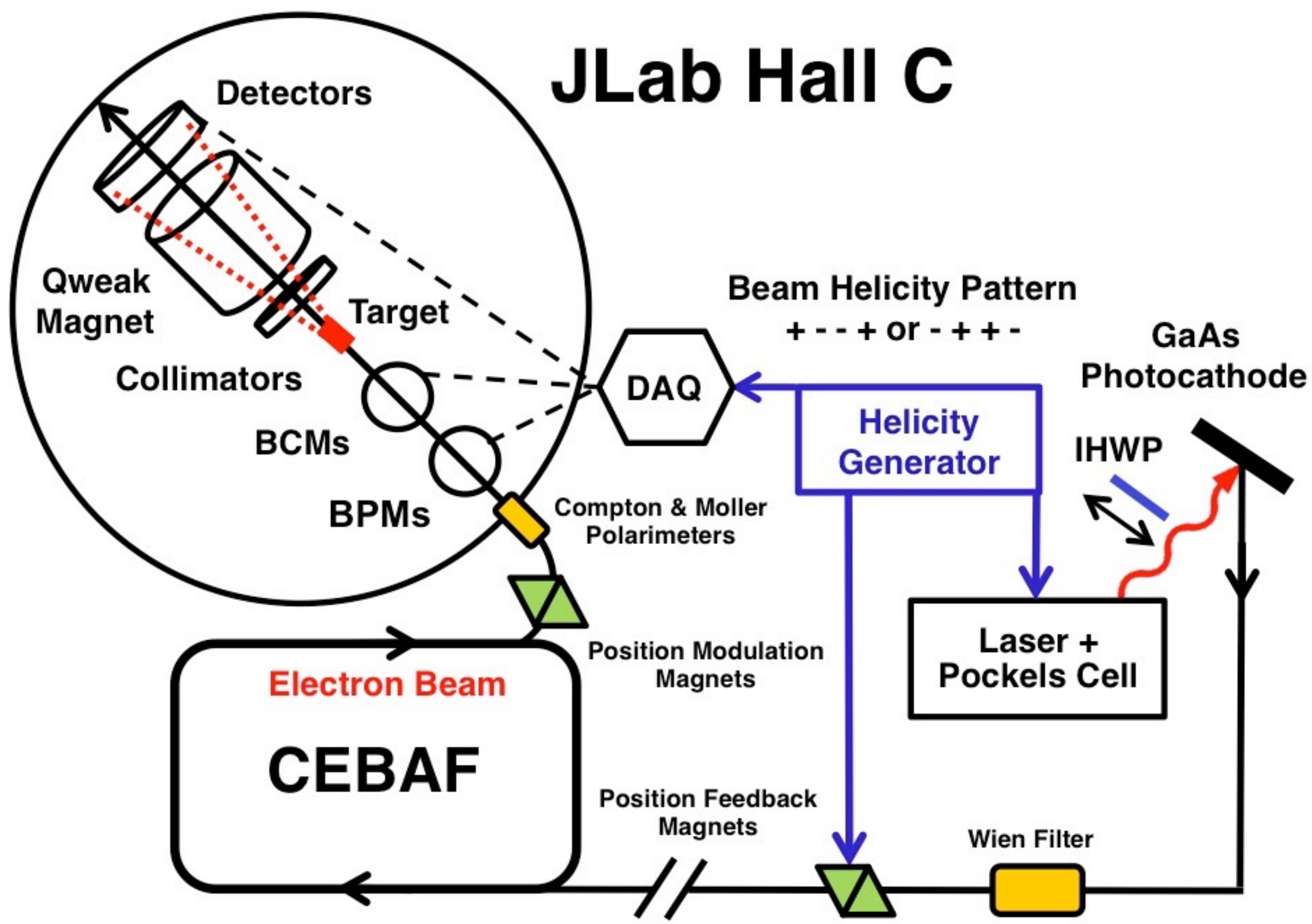
PVES setup overview



E122

Phys.Lett. B77 (1978) 347-352

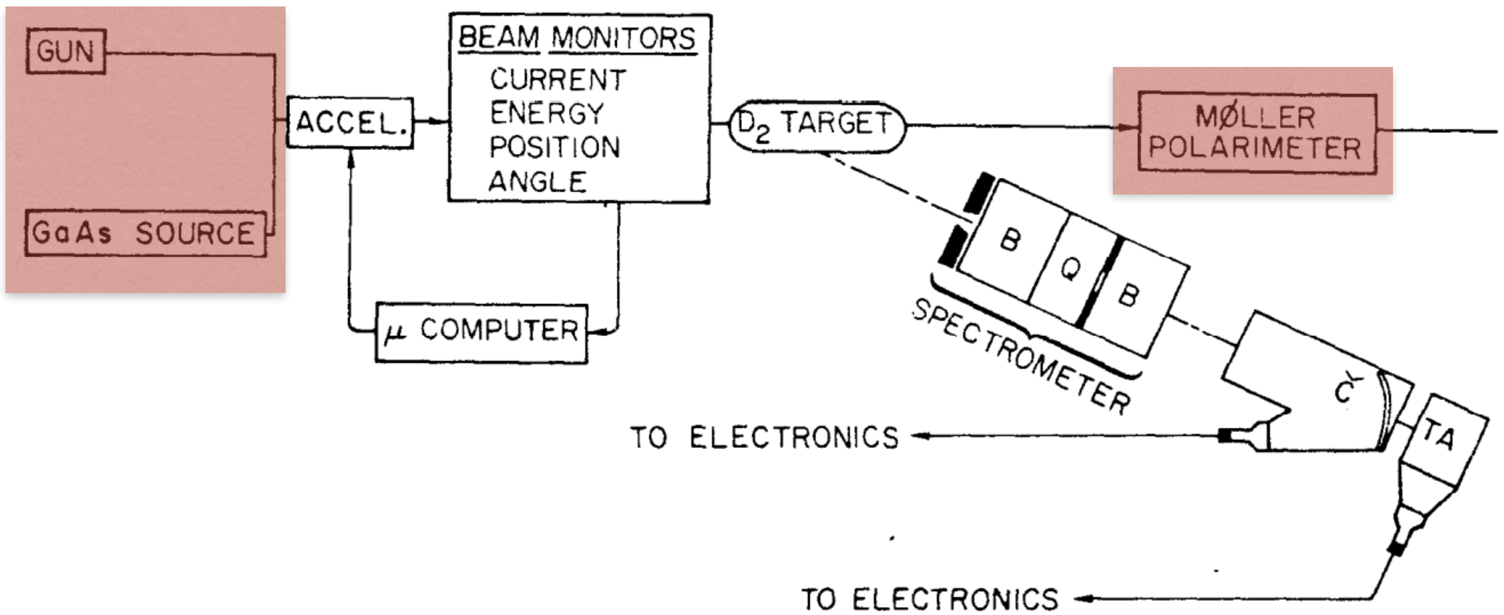
JLab Hall C



Qweak

Nature **557**, 207-211 (2018)

PVES setup overview



E122

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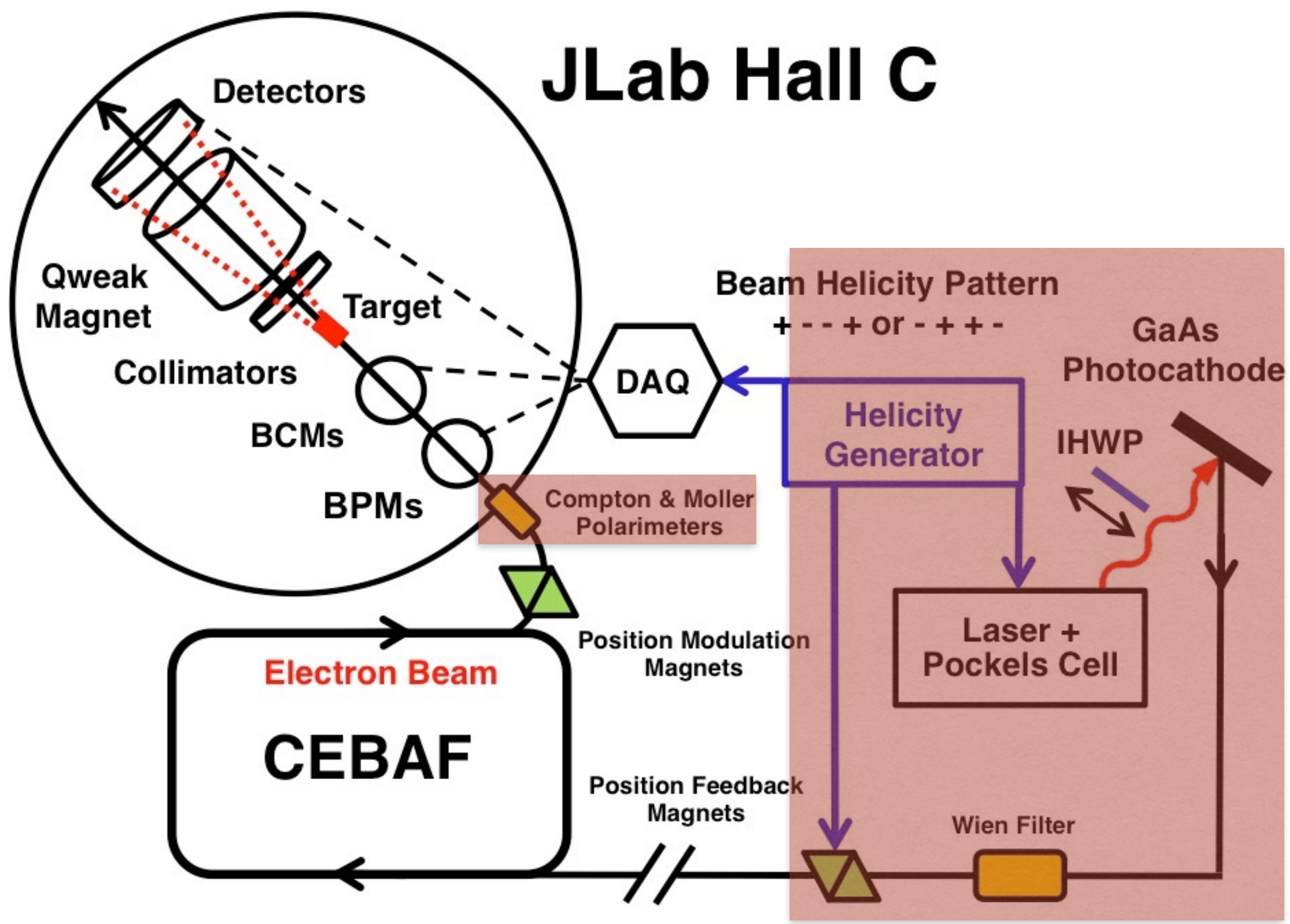
JLab Hall C



Qweak

Nature **557**, 207-211 (2018)

Happy 40th(+ε) Anniversary !!

SLAC-PUB-2148
July 1978
(T/E)

PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING*

...

ABSTRACT

We have measured parity violating asymmetries in the inelastic scattering of longitudinally polarized electrons from deuterium and hydrogen. For deuterium near $Q^2 = 1.6\ (\mathrm{GeV}/c)^2$ the asymmetry is $(-9.5 \times 10^{-5})\ Q^2$ with statistical and systematic uncertainties each about 10%.

(Submitted to Phys. Lett.)

http://inspirehep.net/record/130569/files/slac-pub-2148.pdf

“Of crucial importance to this experiment was the development of an intense source of longitudinally polarized electrons” (Prescott *et al* 1978)

Electron source

E122

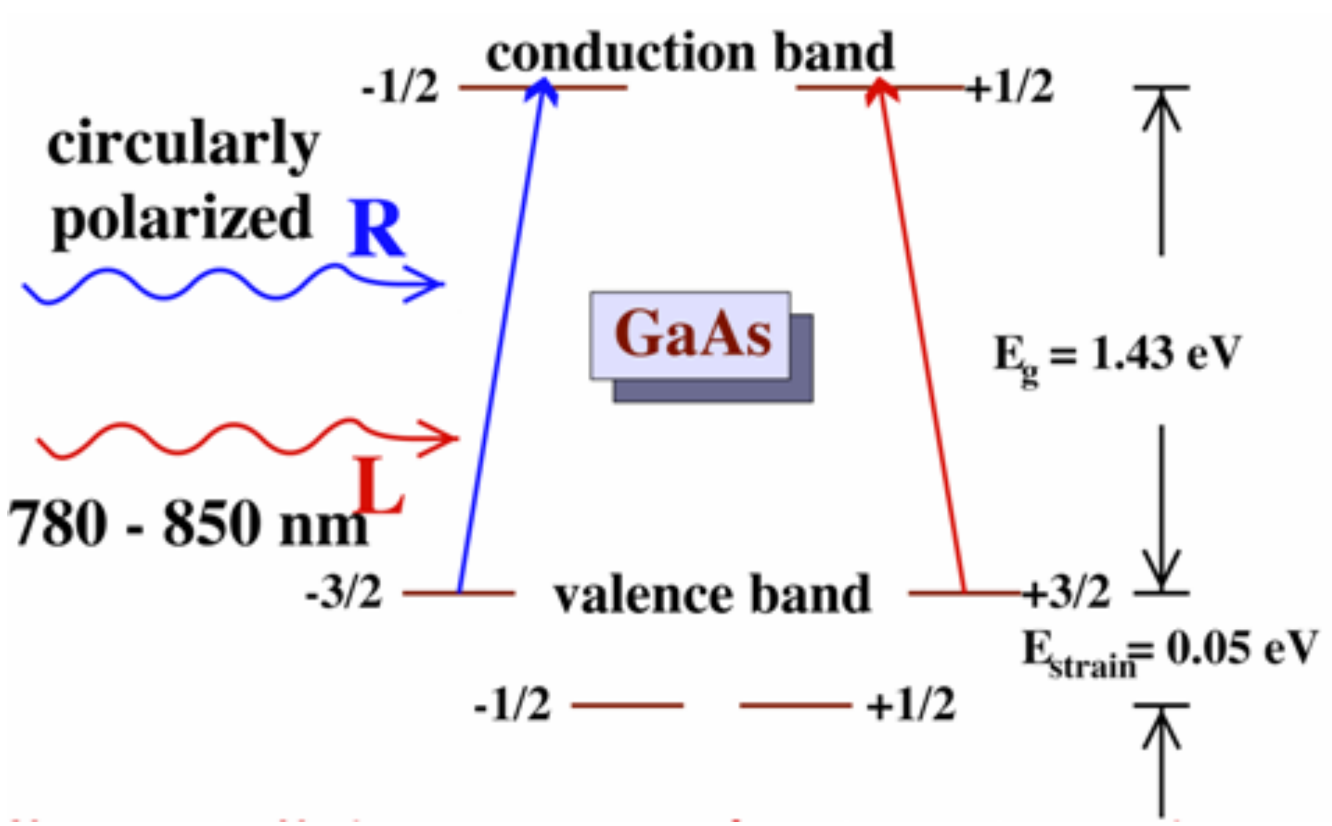
- Produced 37% polarized electrons
- 1.5 us pulses at 120 pulses per second
- random helicity for each pulse
- $4*10^{11}$ electrons per pulse (~8 uA current)

Present

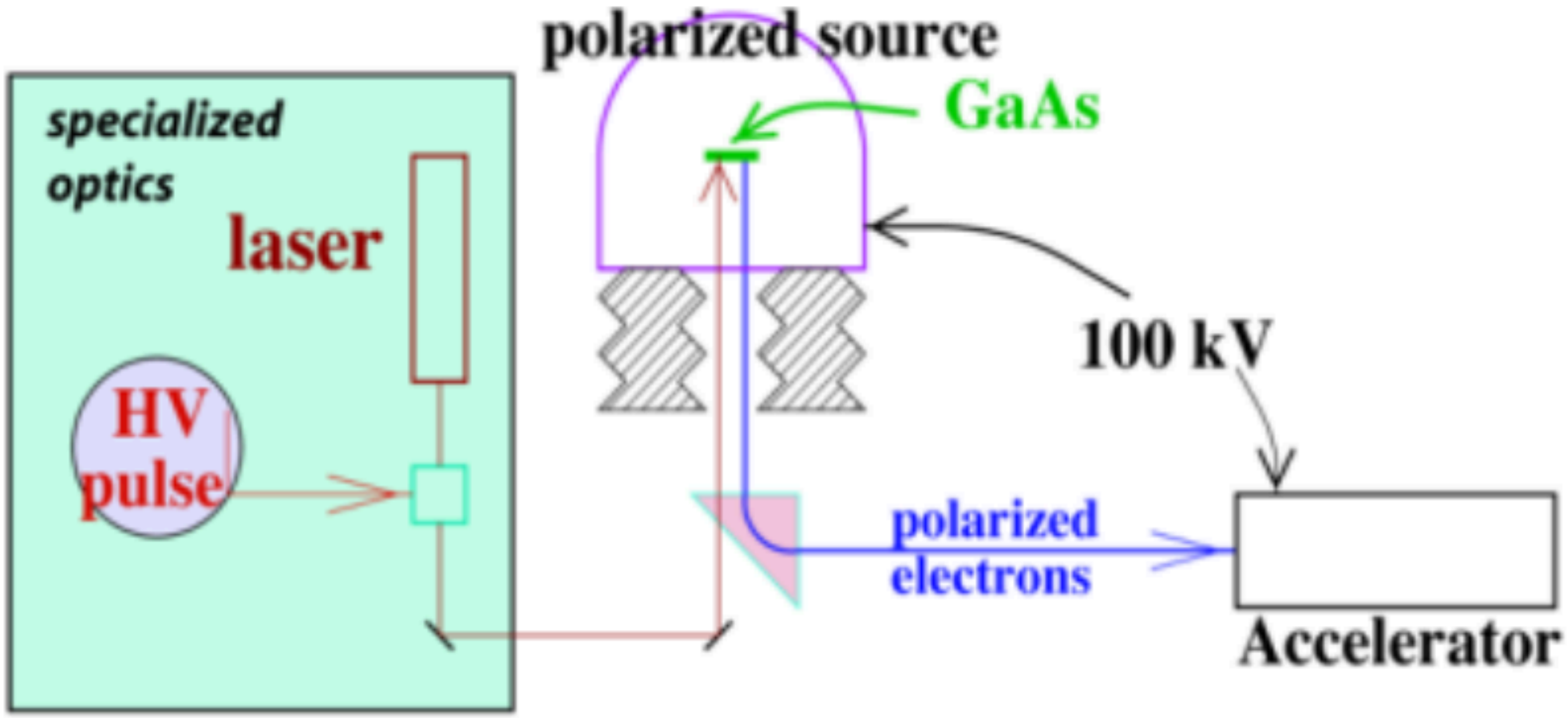
- Regularly produce ~90% polarized electrons (CEBAF) with superlattice cathodes that have high QE and lifetime
- up to 1kHz random helicity flip
- high electron current 180 uA

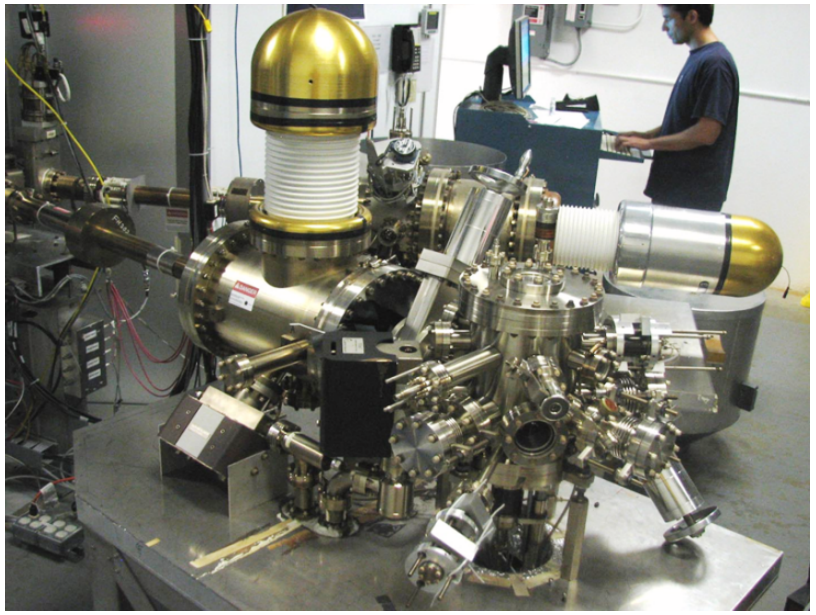
Future

- faster helicity flips of 2kHz with faster transition times will be needed for the next generation of experiments
- along with high polarization and high currents



Injector setup: basics



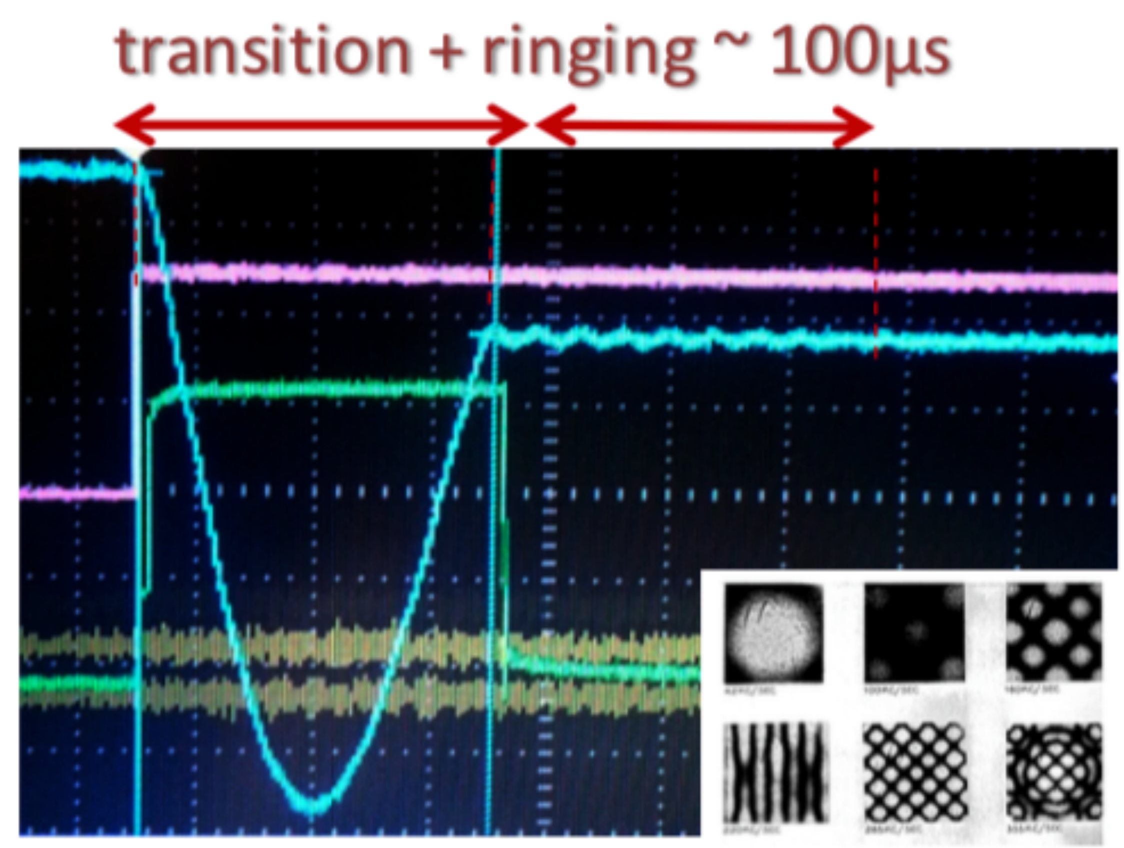


- A specially prepared laser is passed through a birefringent crystal and through photoemission from a strained GaAs superlattice cathode produces a highly polarized electron beam
  - the birefringent crystal (Pockels cell) is controlled with HV pulses to allow for the degree of circular polarization at the photocathode to be reversed quickly
- The electrons are then accelerated through to the desired energy

Injector setup: Pockels Cell

- The time scale at which things change in the experiment drive the helicity flip needed
  - Target density fluctuations require that MOLLER flips the helicity between the different electron helicity states at 2kHz

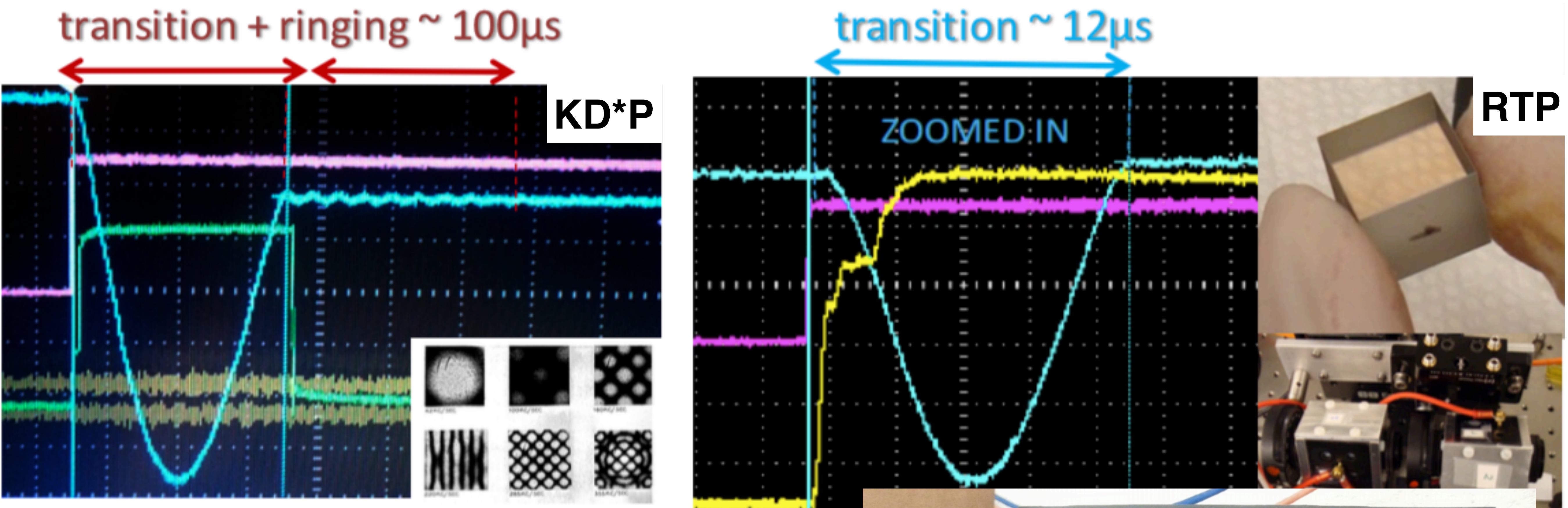
Scope trace of photodiode on laser table:



- With the current KD*P Pockels Cell we would have to live with a ~20% dead time due to instabilities after the helicity flip (ringinig)
- The MOLLER goal is to reach a ~2% dead time

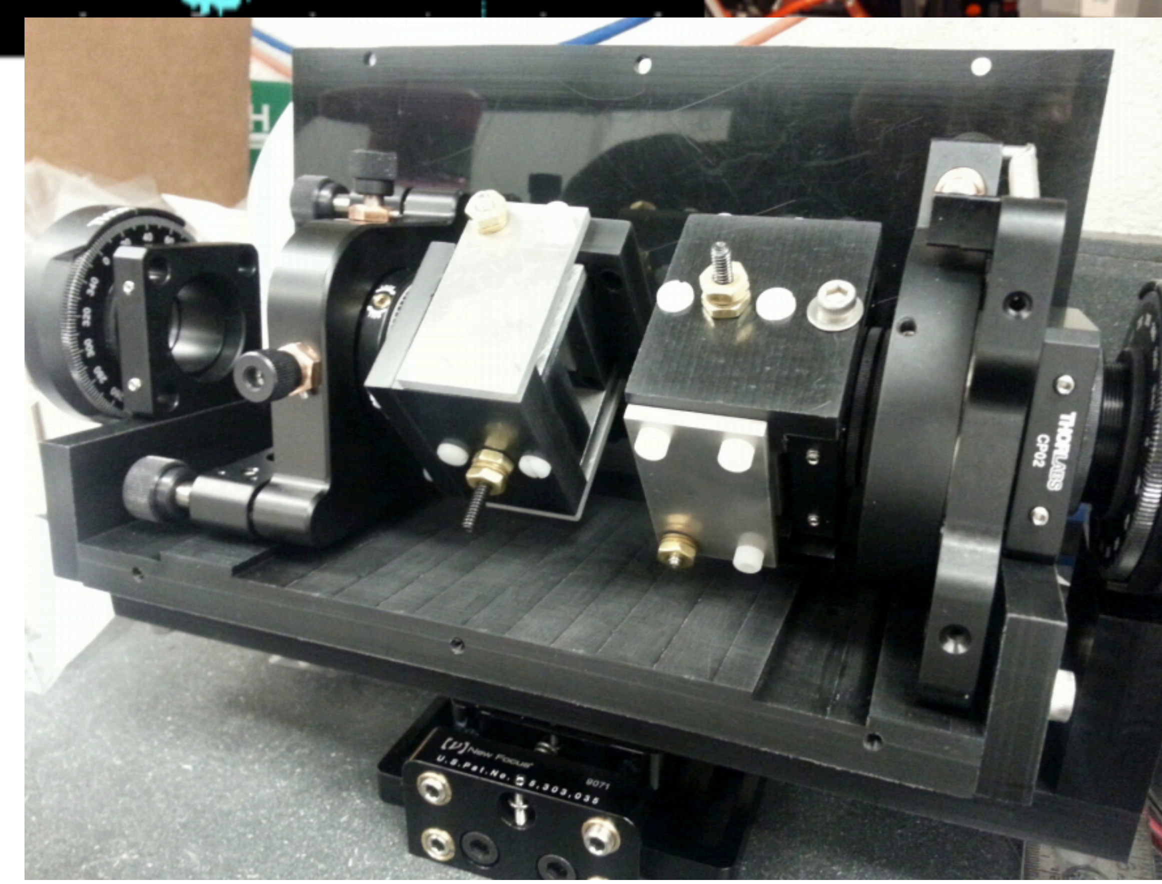
*****Research by C. Palatchi and K. Paschke**

Injector setup: Pockels Cell



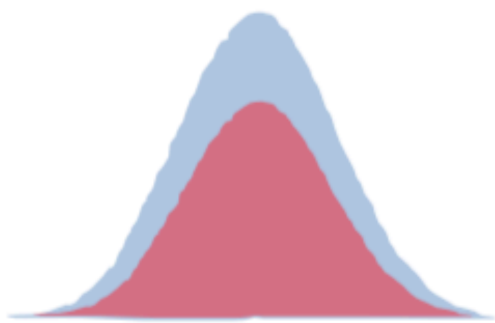
- The RTP system developed at UVa has an excellent transition period perfect for MOLLER, getting us close to the needed 2% dead time

- The system has been throughly tested at UVa and in the CEBAF injector

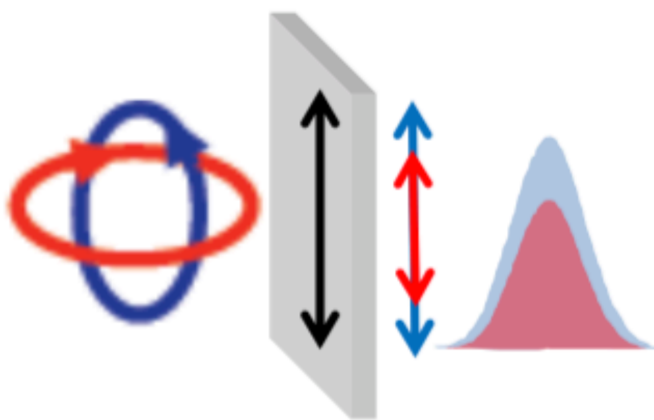


Injector setup: basics

Intensity Asymmetry

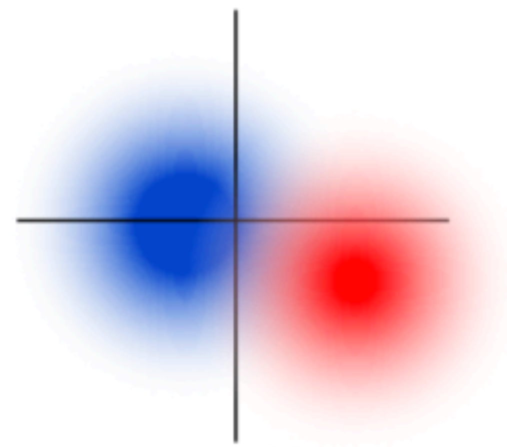


Intensity Asymmetry from Laser Polarization Asymmetry

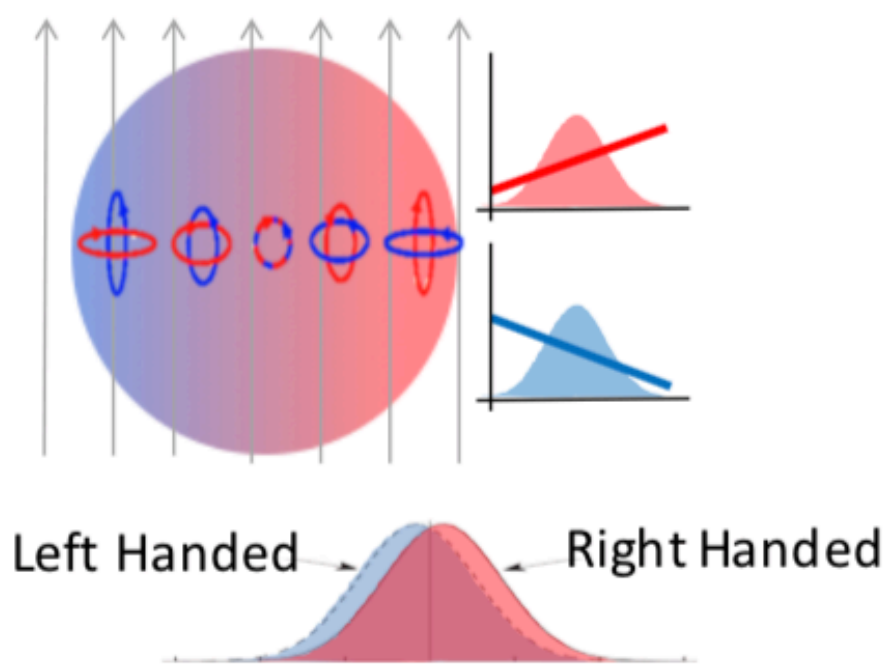


Polarizing element
(i.e. photocathode)

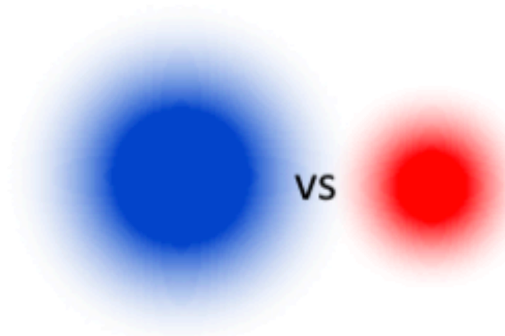
Position Difference



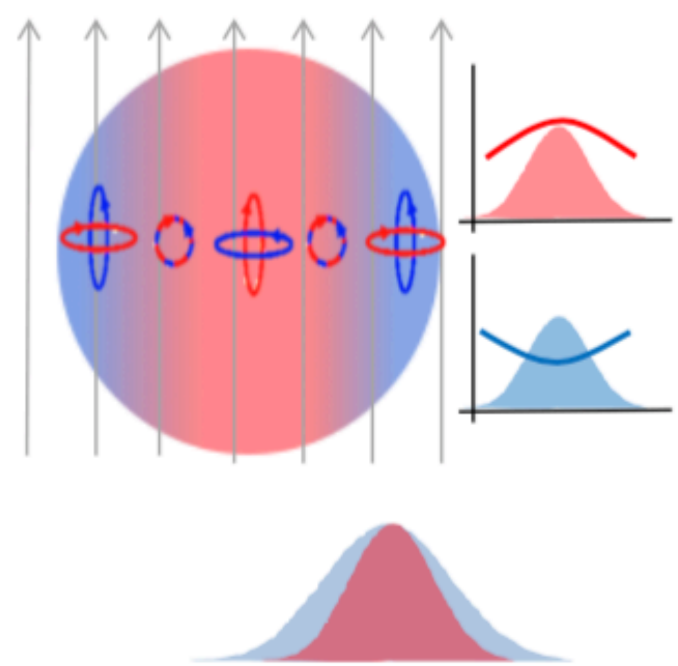
Position Difference from Polarization Gradient



Spot-size *Asymmetry*

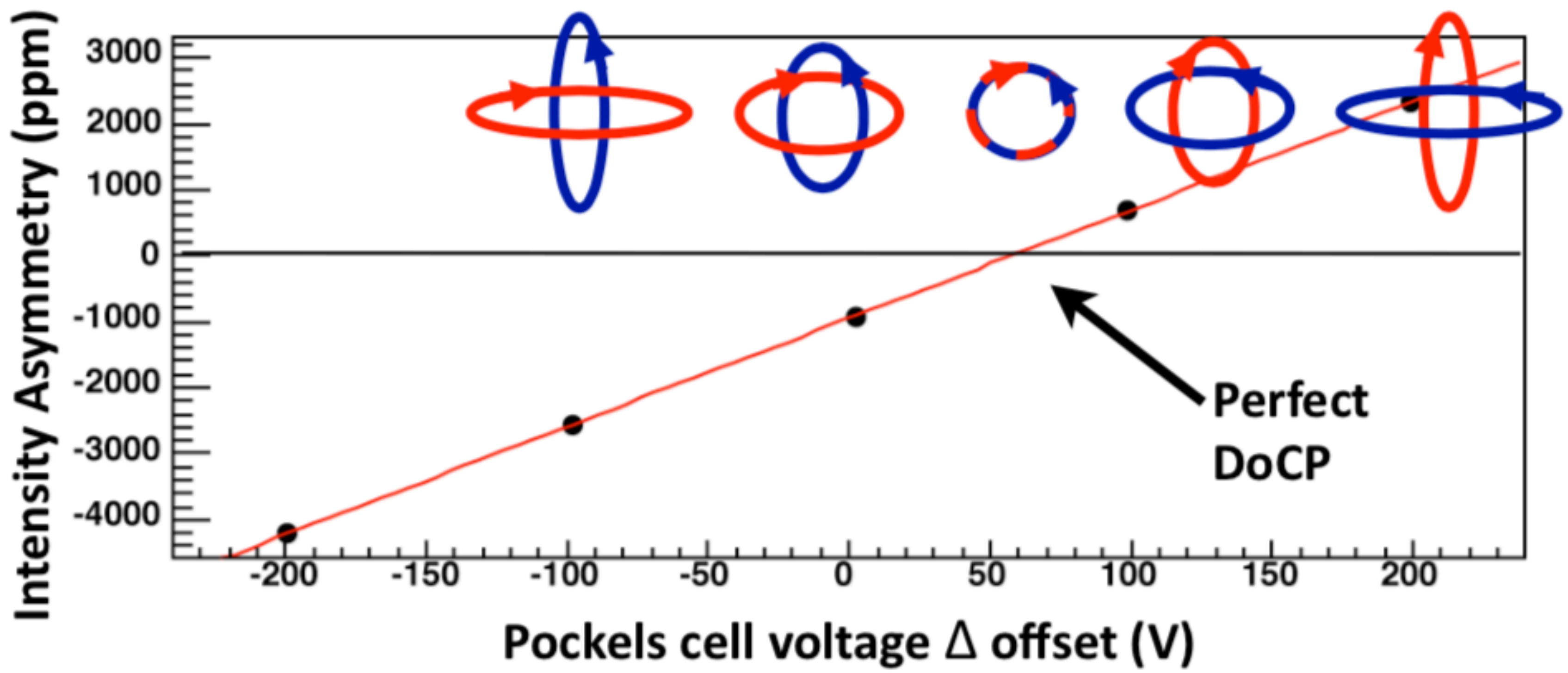


Spot-size Asymmetries from 2^{nd} moment Polarization Gradient



courtesy of C. Palatchi APS 2016

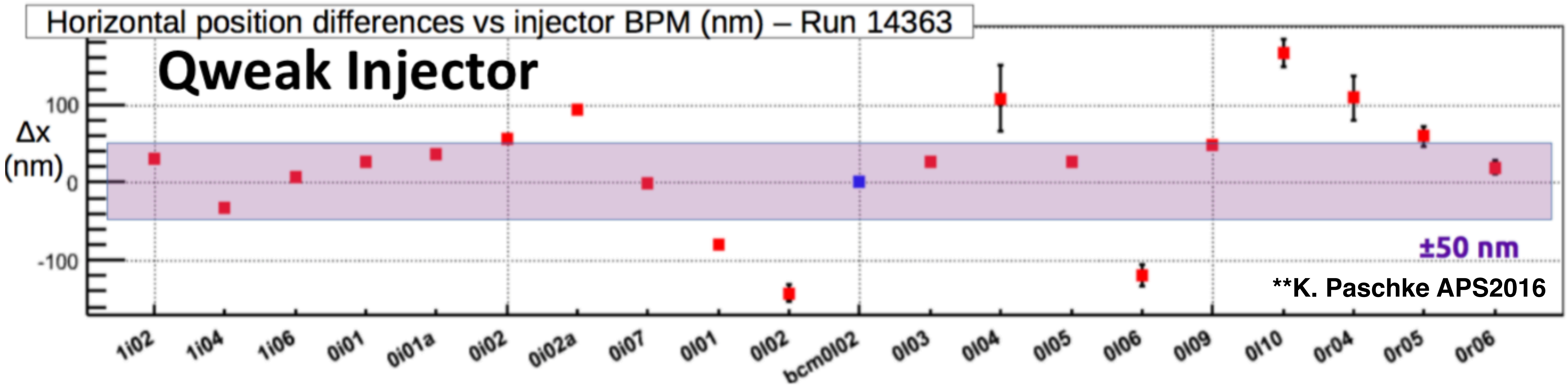
Injector setup: Aq



**K. Paschke APS2016

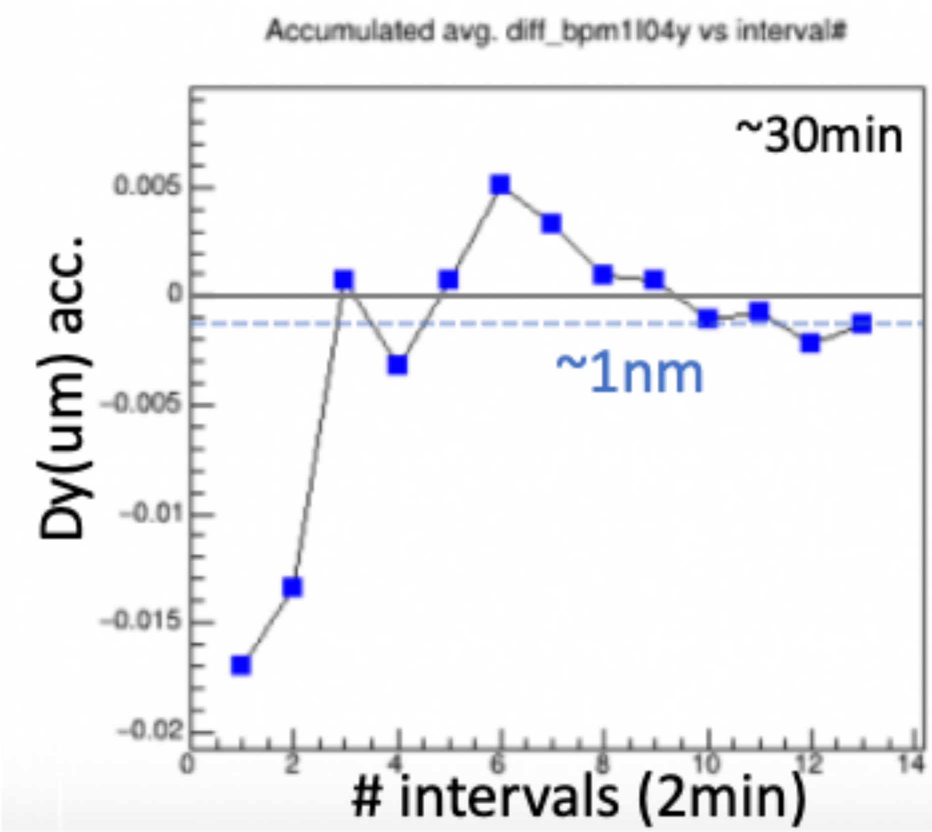
- By adjusting the HV on the PC one can empirically determine the correct configuration by measuring the charge asymmetry in the electron beam
  - the photocathode has a preferential axis that will have higher QE for light polarized along that axis

Injector setup: Δx

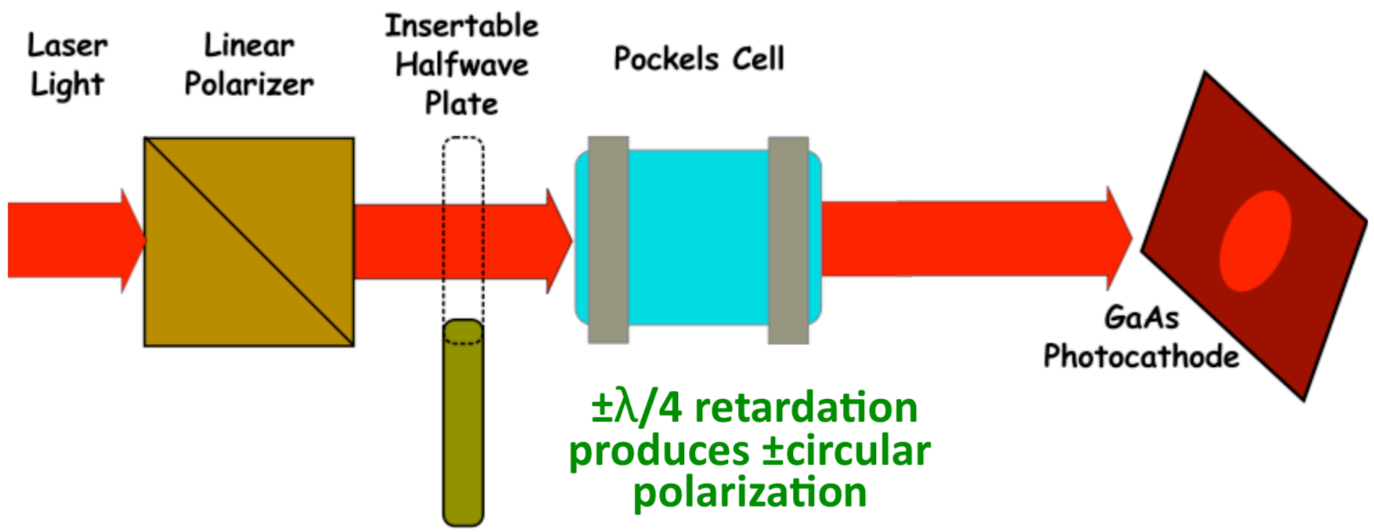


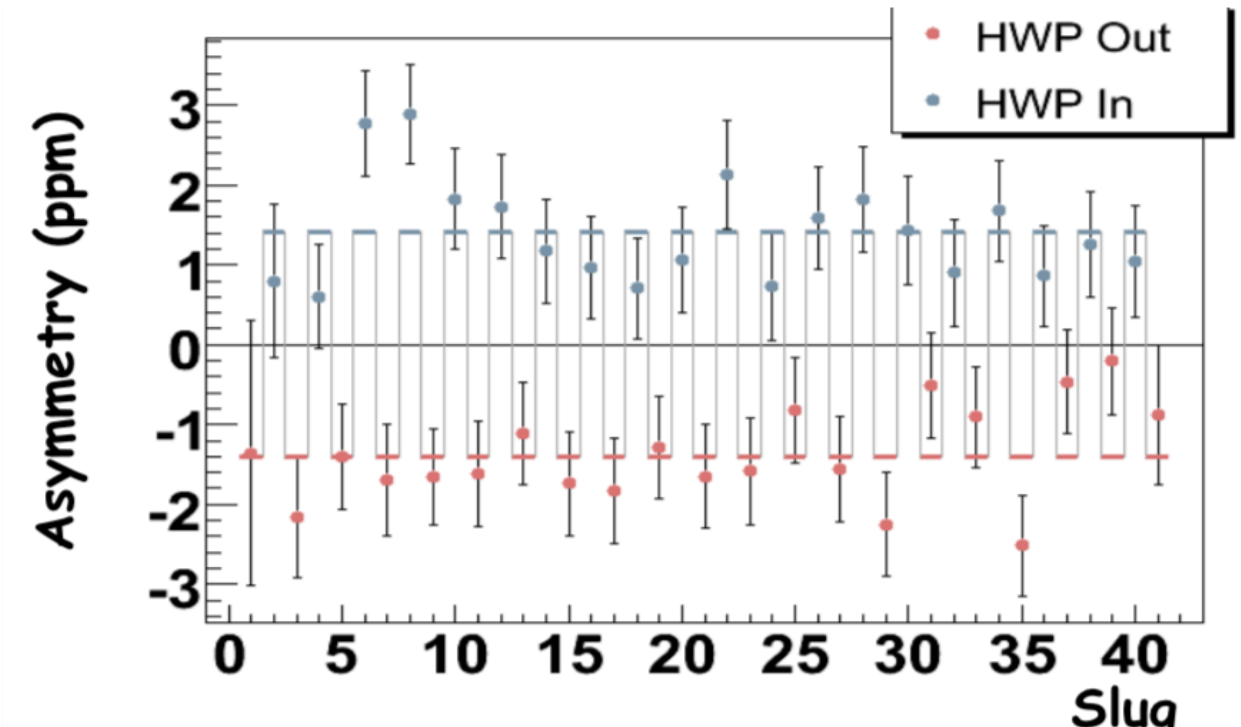
- With the new RTP system and feedback on the position differences in the injector we have achieved significant improvements compared to previous experiments

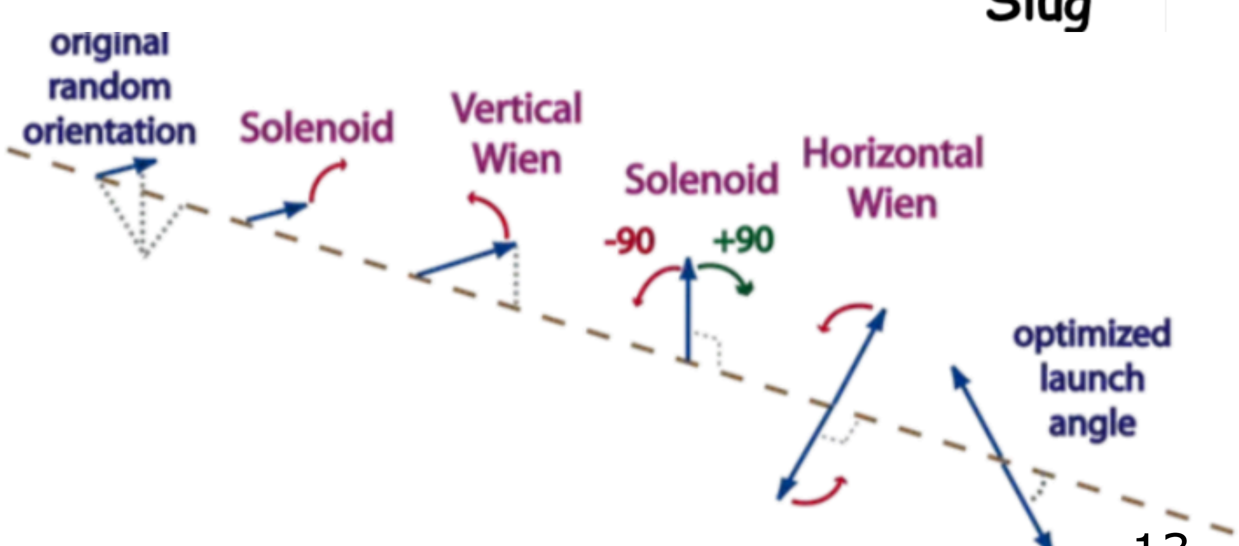
- Long term stability and further improvements are being worked on as we speak



Injector setup: slow reversals







- In addition to the fast reversal of the PC another important handle we have on systematics is through the use of slow reversals:
  - inserting a halfwave plate in the beam path flips the linear polarization
  - injector spin manipulation through the use of solenoids + 2 Wien rotators
  - g-2 rotations (for higher energies small fractional energy changes will lead to a spin flip)

PREX2/CREX Systematics

Experiment	Beam Energy (GeV)	Beam Current (μA)	Charge Asymmetry (ppb)	Position Difference (nm)	Angle Difference (nrad)	Size Asymmetry (ppm)
HAPPEX-I	3.3	40	200	12	3	-
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MOLLER	11.0	85	<10	<1	<0.1	<10

**K. Paschke APS2016

- The systematic uncertainties from the injector setup are well under control for PREX2/CREX and are on a very good path towards the next generation of precision experiments

Polarimeters

E122

- Moller polarimeter with precision of 3% stat and 5% systematic uncertainties

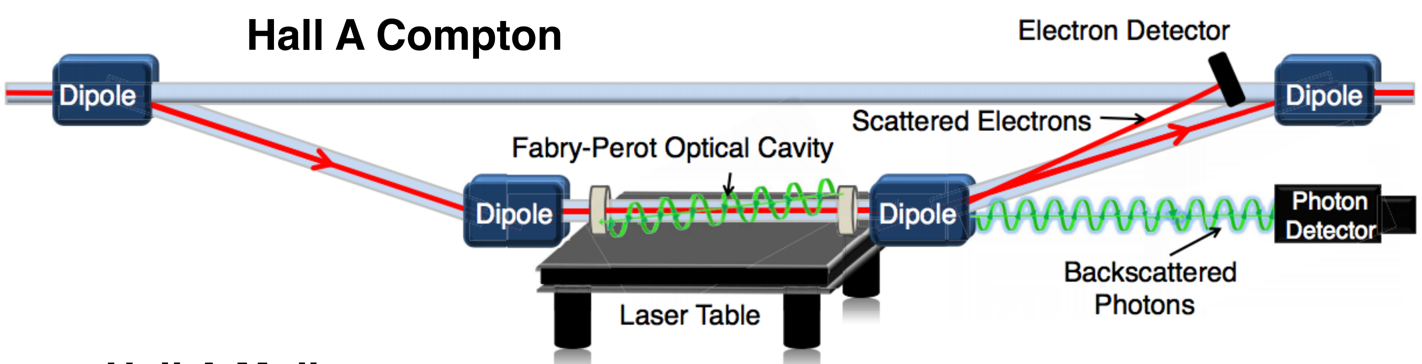
Present

- Three types of polarimeters: Mott, Moller and Compton
- Compton can be run continuously to monitor polarization stability
- All have achieved at least 1% uncertainty (0.5% precision reported by Hall C Moller)

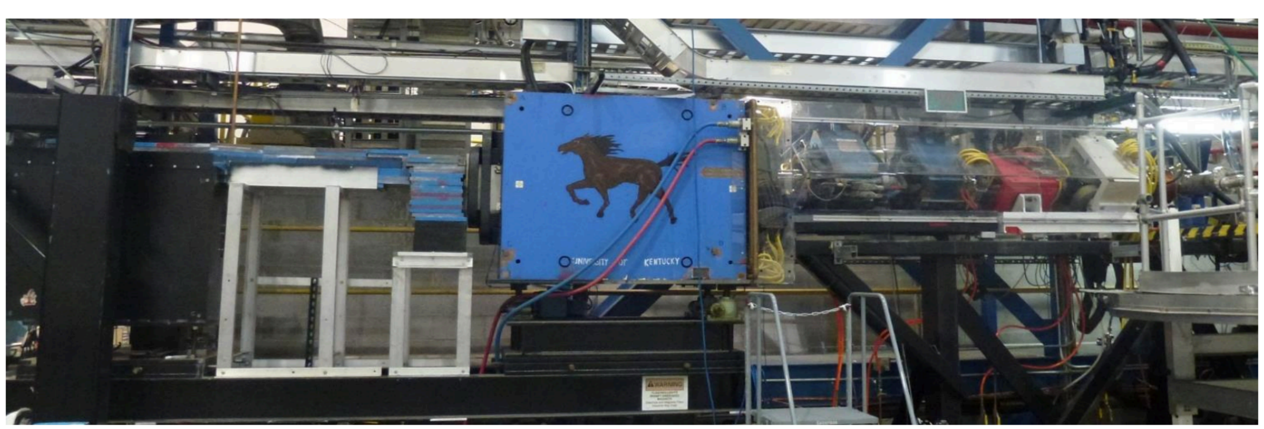
Future

- Plans in place for all three polarimeters to achieve 0.5% or better uncertainty in the next 5 years
- New double Mott polarimeter is being investigated for possible use in P2

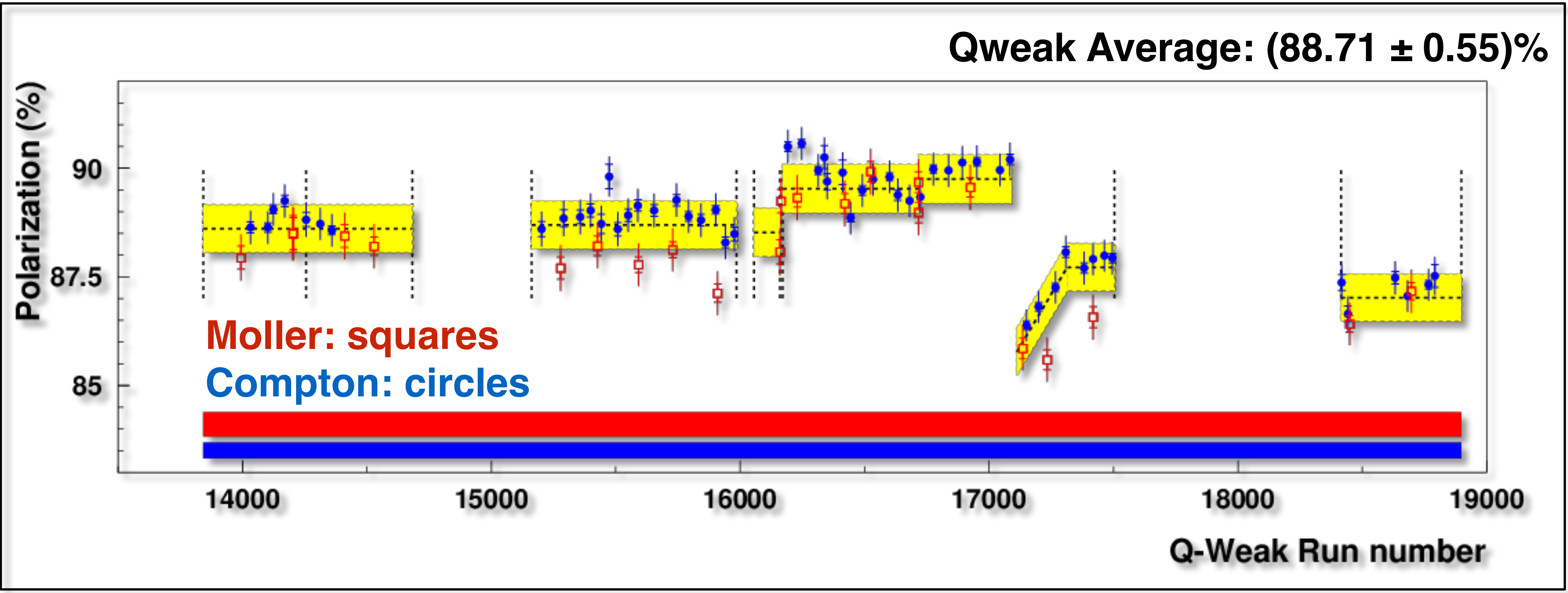
Hall A Compton



Hall A Moller



Polarimetry



- There are two polarimeters inside the hall (Compton and Moller) and one polarimeter in the injector (Mott)
- The PREX2/CREX needed precision should be achievable considering the improvements made for Qweak
- The next generation of PVES experiments (MOLLER) have a goal to reach 0.4% with both Compton and Moller polarimeters

Polarimetry - Intro

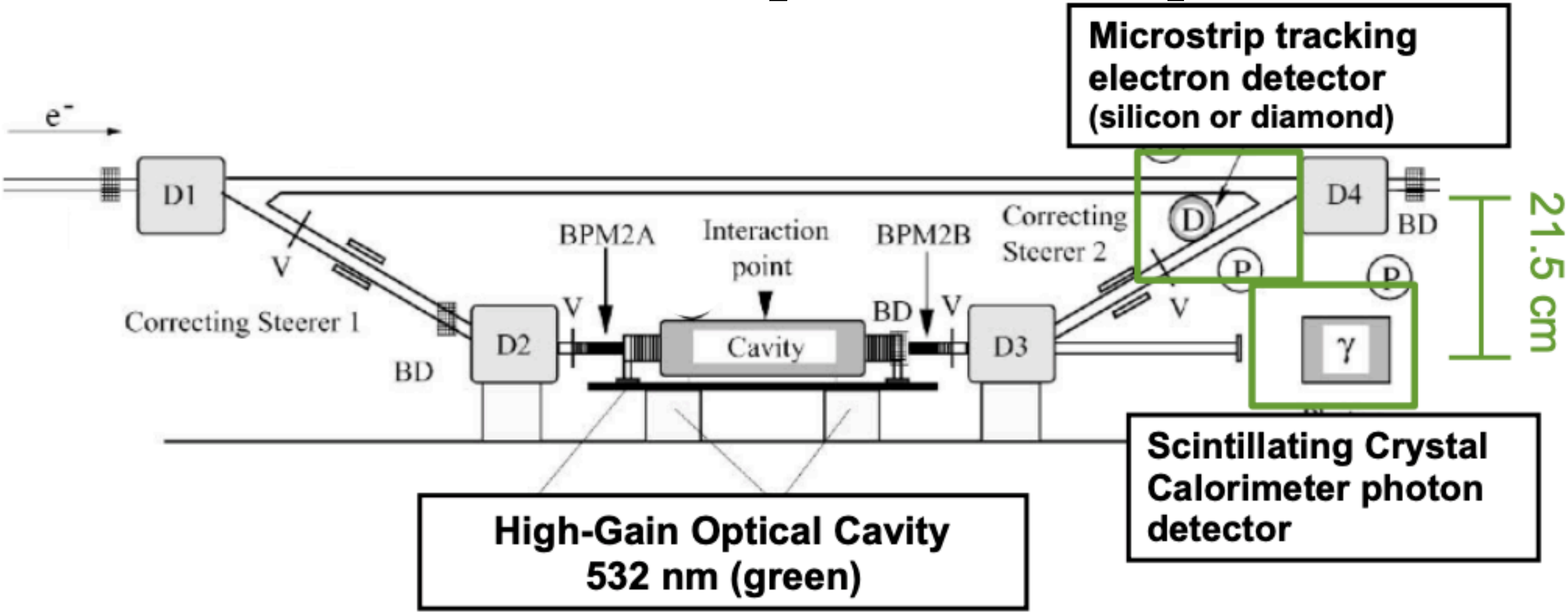
$$\text{Rate } \mathcal{R}^{\pm} = \left[\int \left(\frac{d\sigma^0}{d\Omega}\right) d\Omega\right] + \left[\int \left(\frac{d\sigma^{\pm}}{d\Omega}\right) d\Omega\right] \; P^{\pm}_{\text{Beam}} \; P_{\text{Target}}$$

$$\text{Assume } P^{\pm}_{\text{Beam}} = \pm P$$

$$\text{Asymmetry } \mathcal{A} = \frac{\mathcal{R}^+ - \mathcal{R}^-}{\mathcal{R}^+ + \mathcal{R}^-} = \frac{\langle\sigma^+\rangle P - \langle\sigma^-\rangle P}{2\langle\sigma^0\rangle} P_{\text{Target}} = \langle A_{zz}\rangle \; P \; P_{\text{Target}}$$

- We measure A and P_{target}, calculate A_{ZZ}
- Most of the uncertainties will either lie in how well we know the “target” polarization and how we calculate the A_{ZZ}

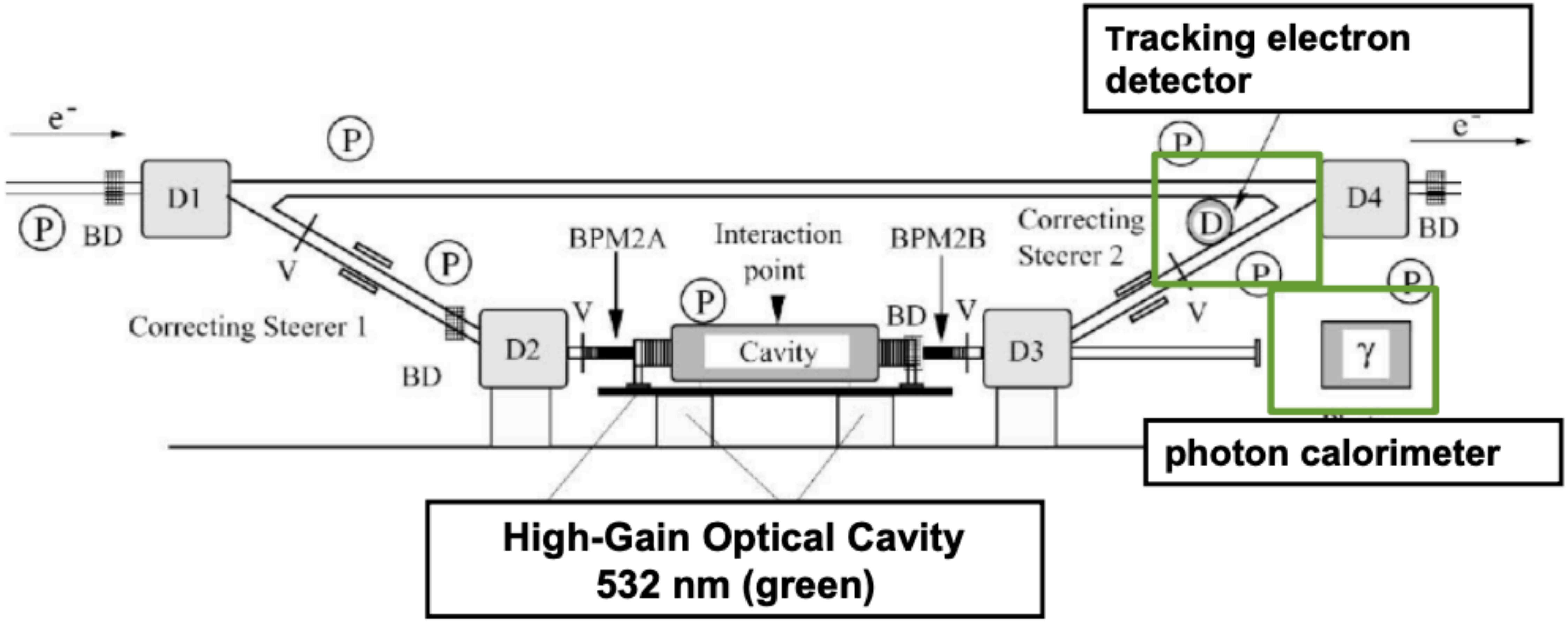
Polarimetry - Compton



Past Achievement
- HAPPEX-3 (2009): 0.8% at 3 GeV
- PREX(2010): 1.2% at 1.06 GeV
- Qweak (2012): 0.8% at 1 GeV

Goals
- PREX-2: 1.0% at 0.95 GeV
- CREX: 0.8% at 2.22 GeV

Polarimetry - Compton



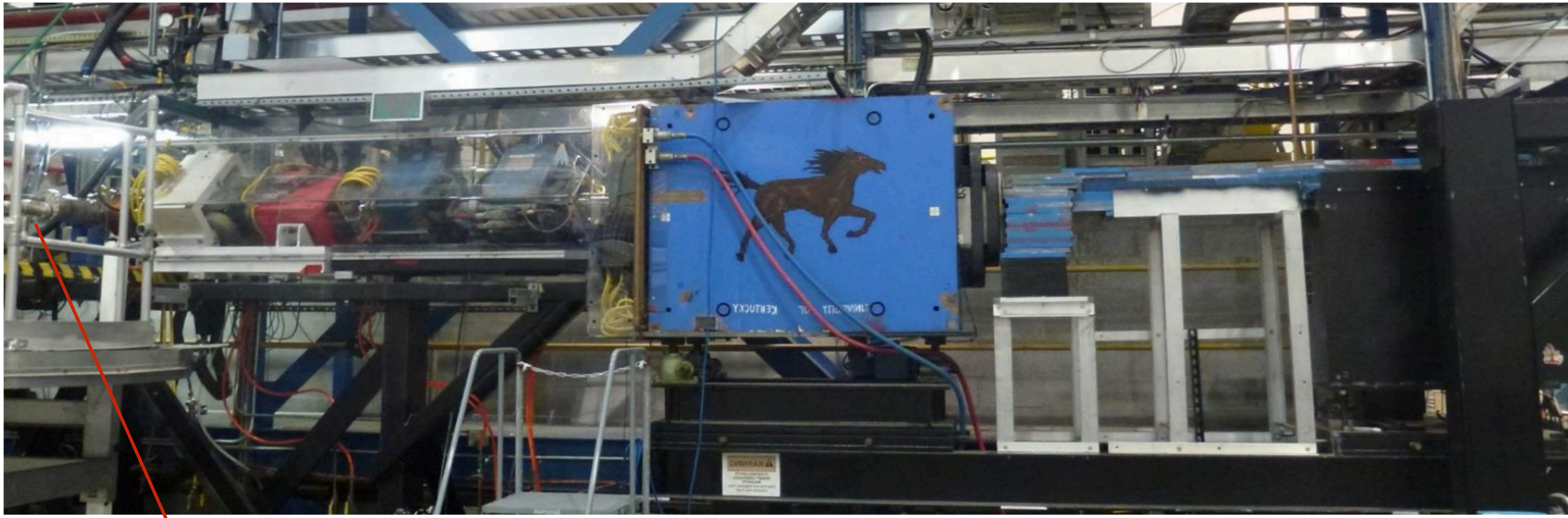
- Improvement made for Qweak reduced the uncertainty in the polarization state inside the cavity (from 0.8 to 0.2)

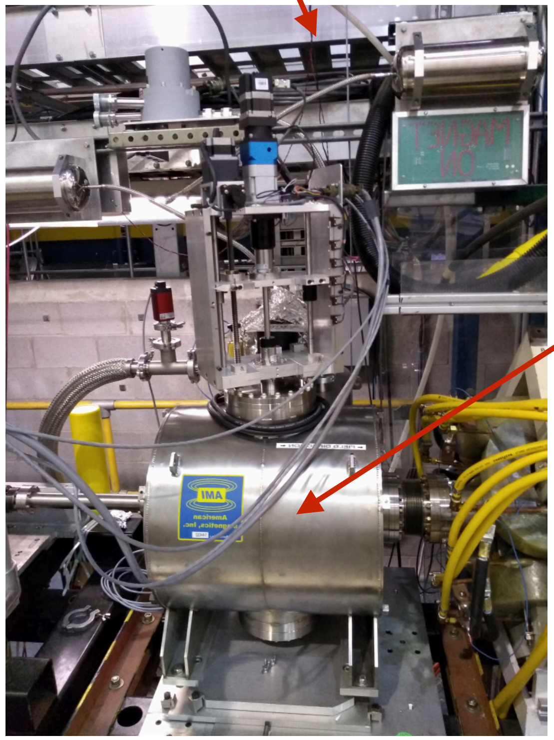
- With the current setup we need to further develop an electron detector that will robustly function at 11 GeV

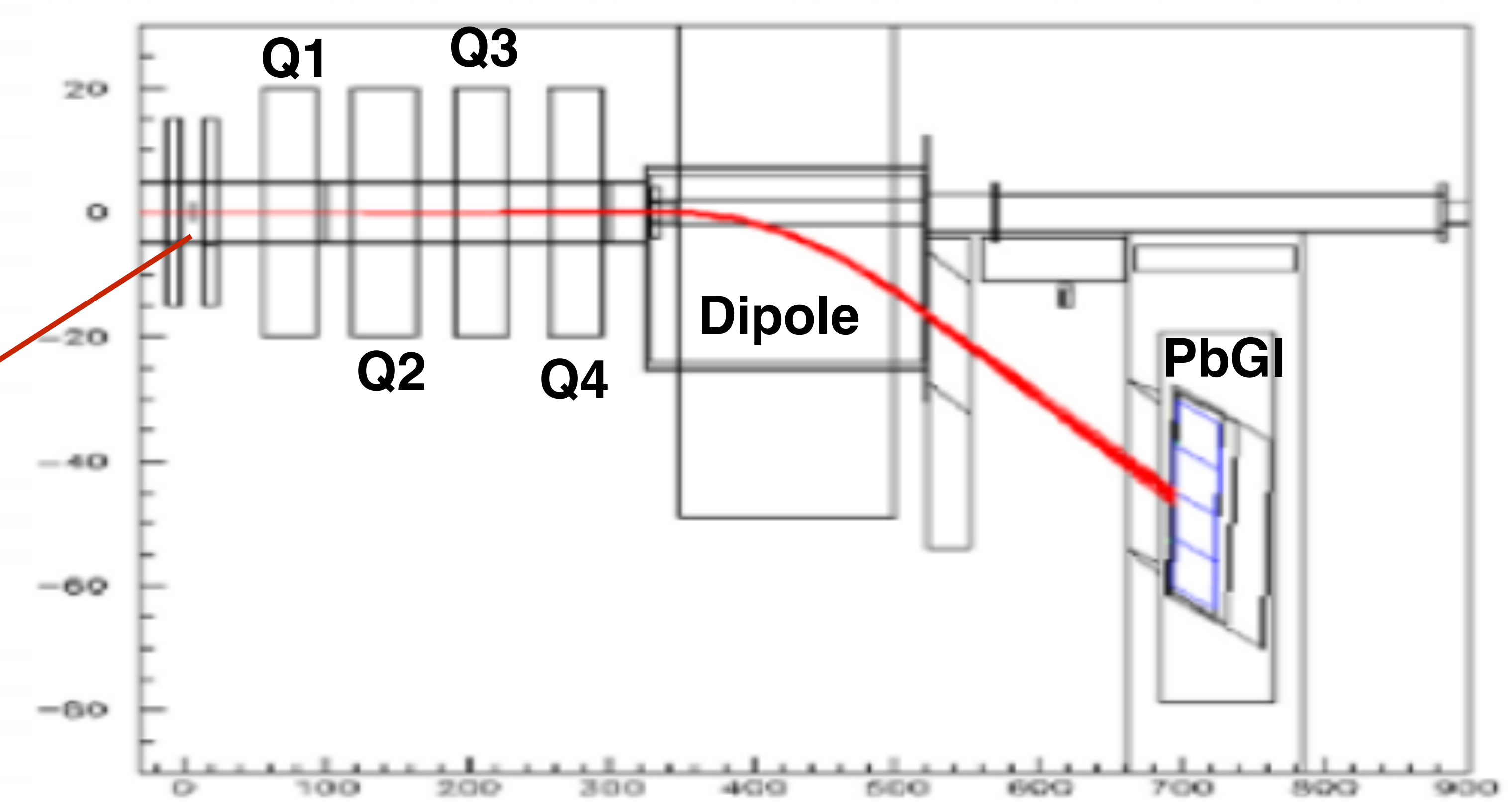
  - but we expect that the uncertainty goal is within reach

Relative Error (%)	electron	photon
Position Asymmetries	-	
E_{beam} and λ_{laser}	0.3	
Radiative Corrections	0.5	
Laser Polarization	0.2	
Background/Deadtime/Pileup	0.2	0.2
Analyzing Power Calibration / Detector Linearity	0.25	0.35
Total	0.38	0.45

Polarimetry - Moller







Polarimetry - Moller

- For PREX2/CREX the current level of understanding will reach the needed precision
  - already published 0.5% measurement with Hall A Moller polarimeter
- The next generation of PVES experiments (MOLLER):
  - Small improvements are being made to the solenoid around the target, the target holder mechanism
  - To tackle one of the largest systematics we plan to develop a Kerr effect measurements to enable the monitoring of the bulk polarization in the iron foil

Variable	Hall C	Hall A: Foil	
		Tilted	High Field
Target polarization	0.25%	1.50%	0.25%
Target angle	‡	0.50%	‡
Analyzing power	0.24%	0.30%	0.20%
Levchuk effect	0.30%	0.20%	0.20%
Target temperature	0.05%	‡	0.05%
Dead time	‡	0.30%	0.10%
Background	‡	0.30%	0.10%
Others	0.10%	0.50%	0.10%
Total	0.47%	1.8%	0.42%

PREX2/CREX Systematics

	PREX1 achieved	Qweak achieved	PREX2 needed	CREX needed
Polarization	1.3%	0.6%	1.3%	0.8%

*****From Dustin's and Juliette's talks**

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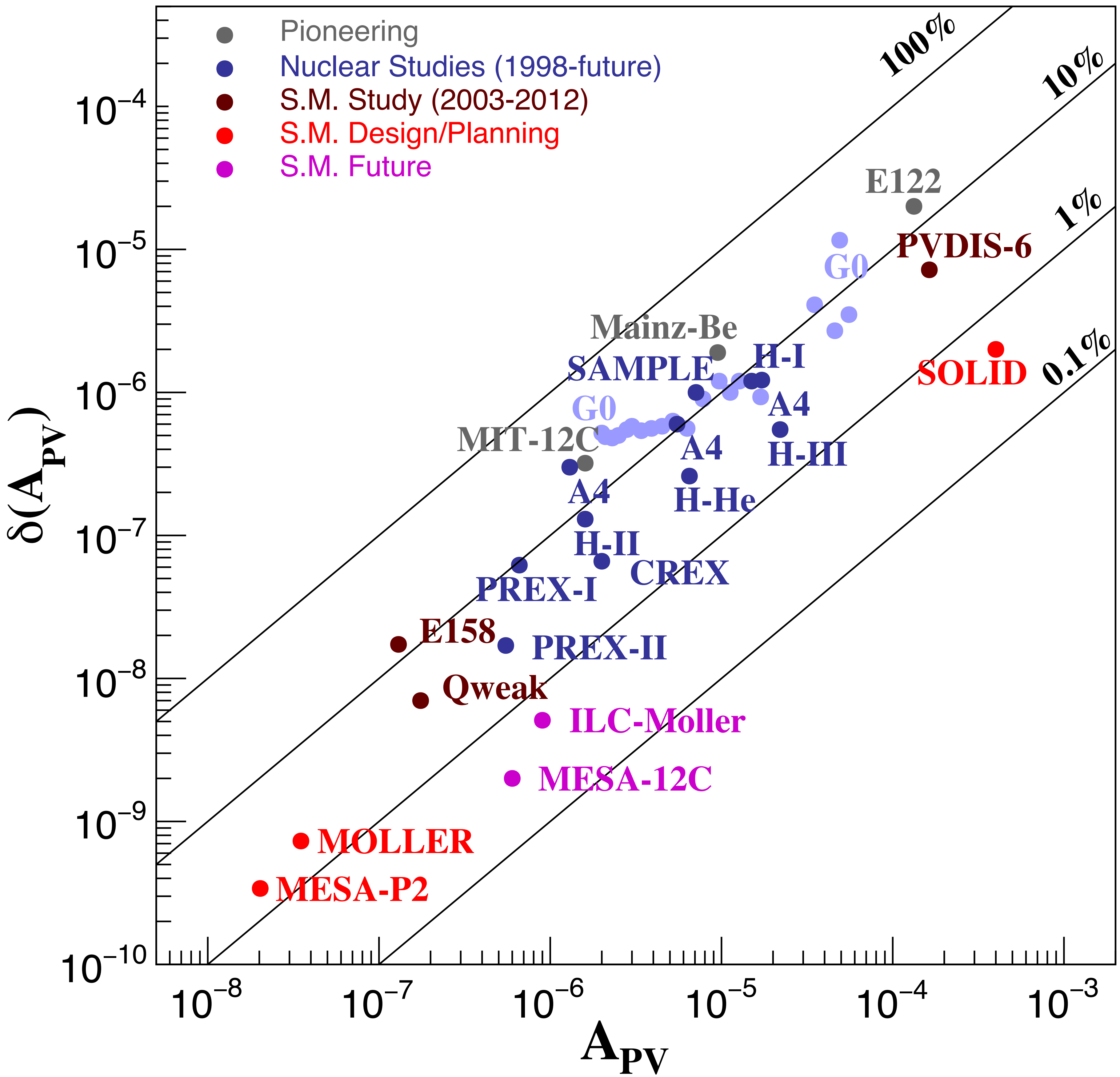
****K. Paschke APS2016**

Conclusions

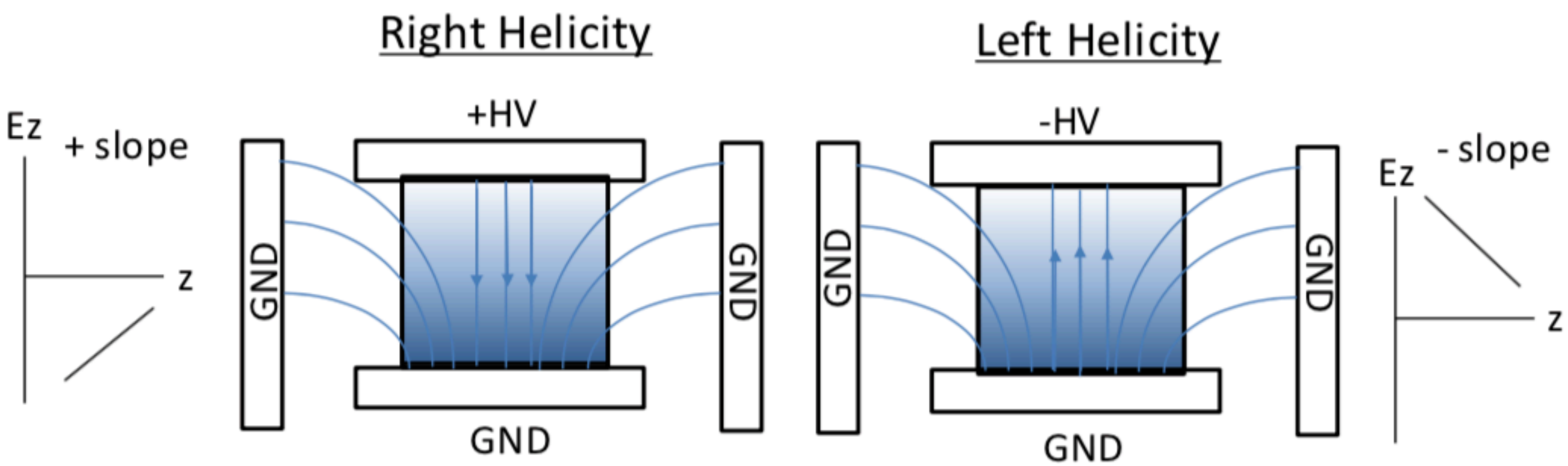
- PREX2 and CREX benefit from a lot of experience with previous PVES experiments at CEBAF
- The uncertainties needed for both experiments were surpassed for Qweak and so far all of our investigations show that we will be able to meet our goals

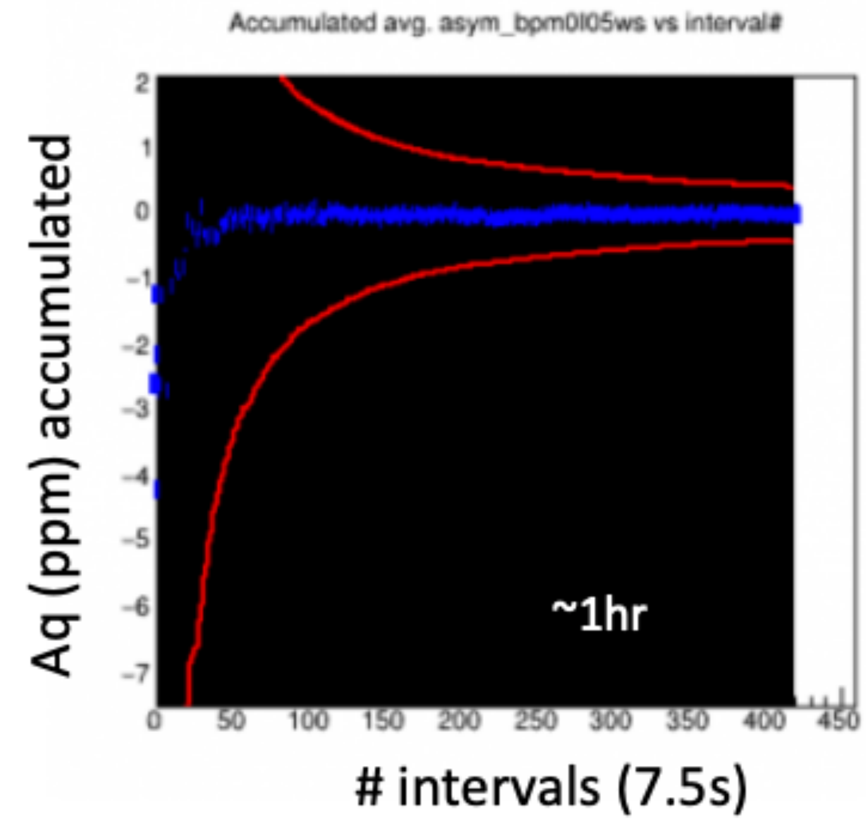
Backup

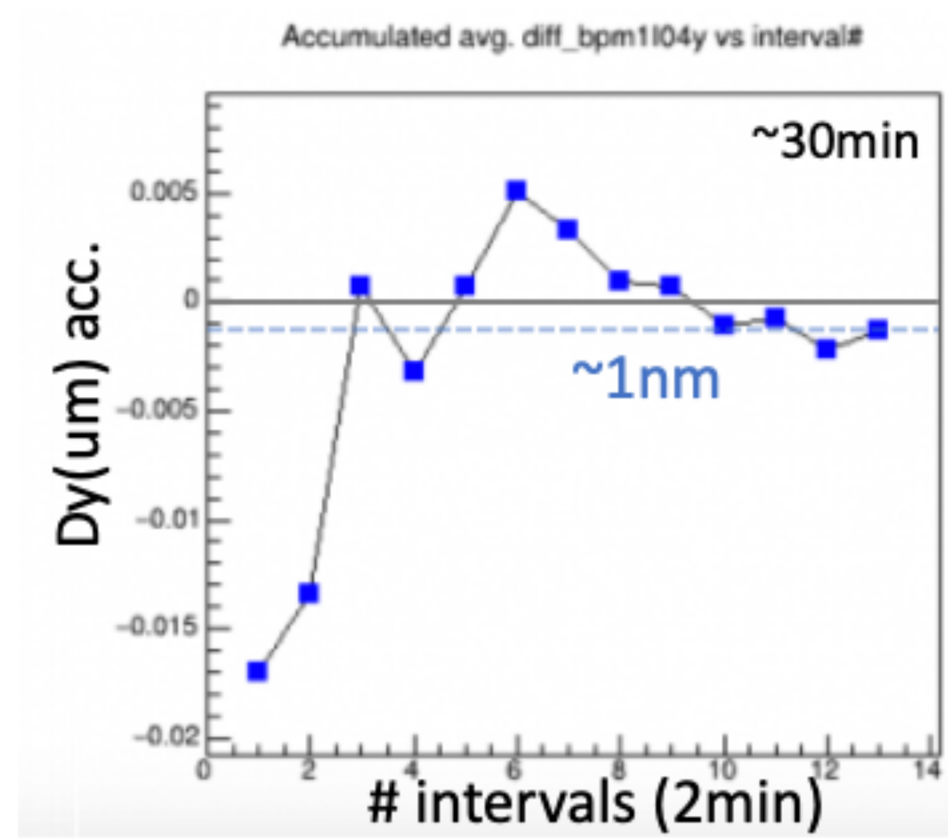
PVES landscape



Injector setup: Δx

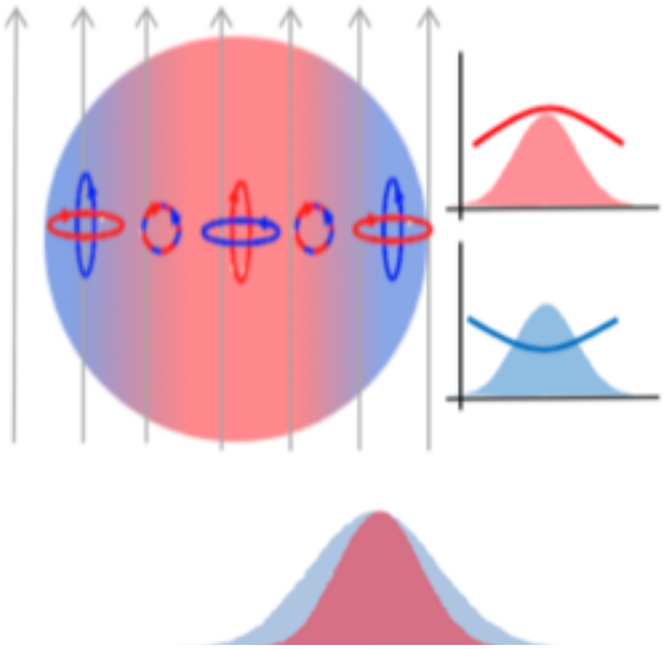


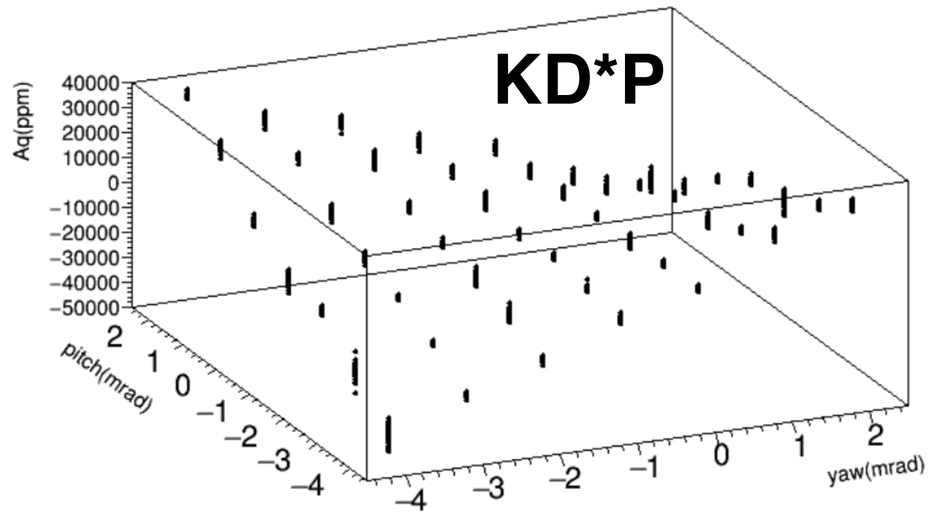




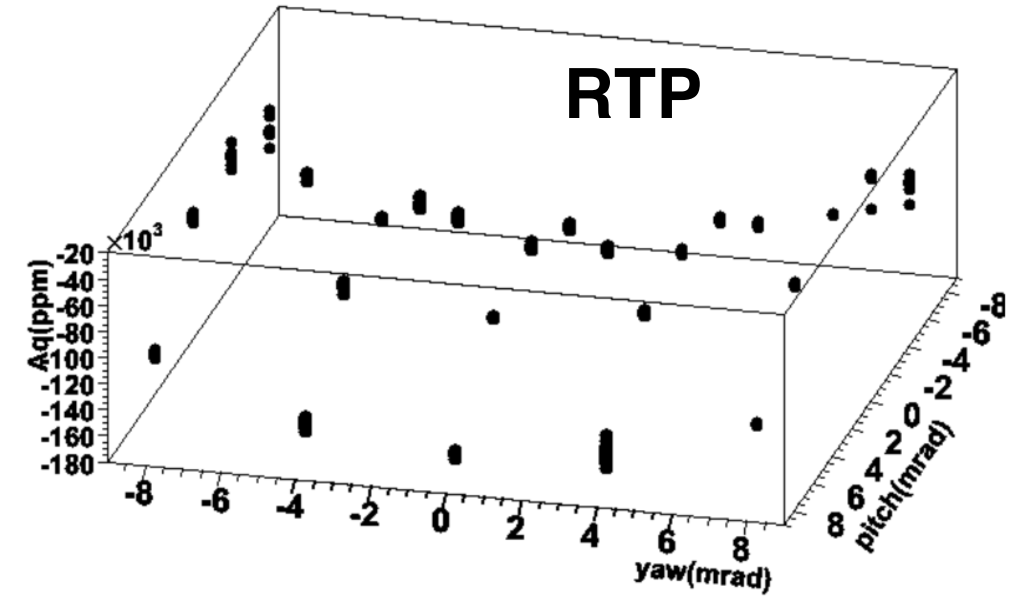
- Initial studies showed that the RTP PC had produced much larger position differences under similar circumstances than the KD*P
  - this was due to the x5 larger gradients in translations on the face of the crystal
- However, applying an electric field can correct these large gradients
  - a system was developed to actively adjust this electric field through a feedback mechanics
- In electron beam tests we have achieved ~1nm position differences with this system over 0.5h

Injector setup: Spot size

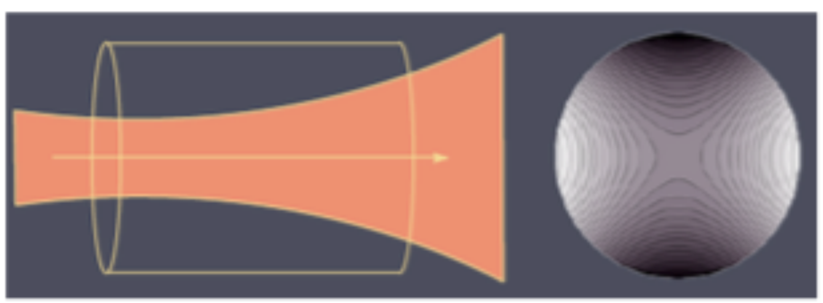




2100 ppm/ mrad^2



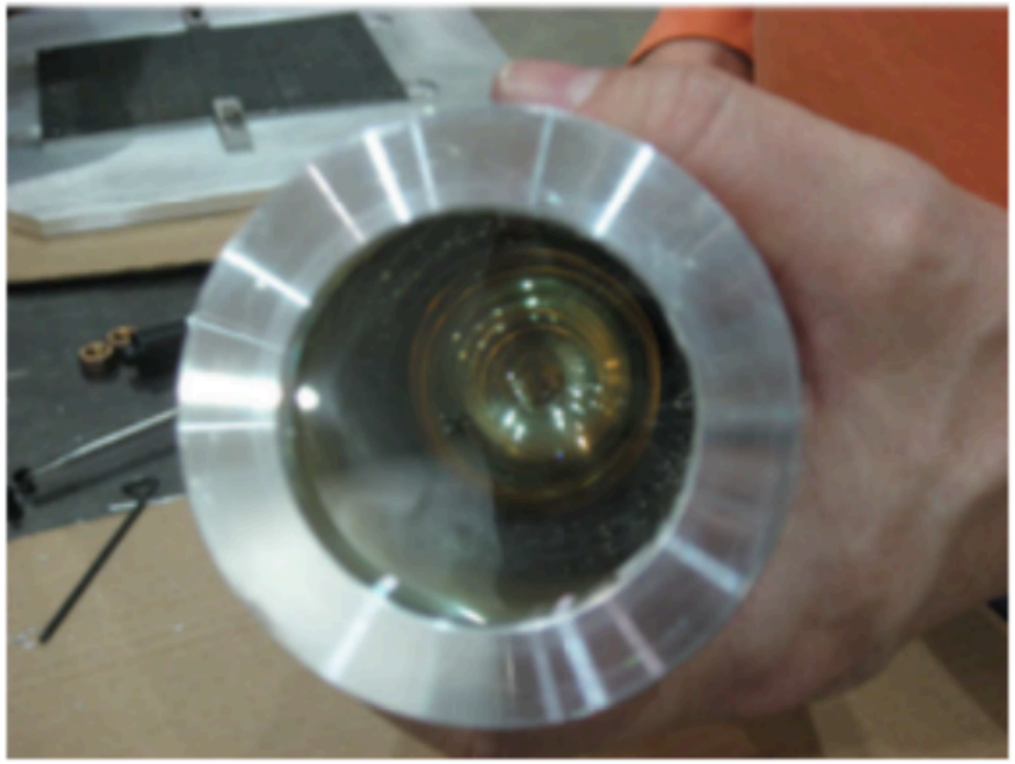
600 ppm/ mrad^2

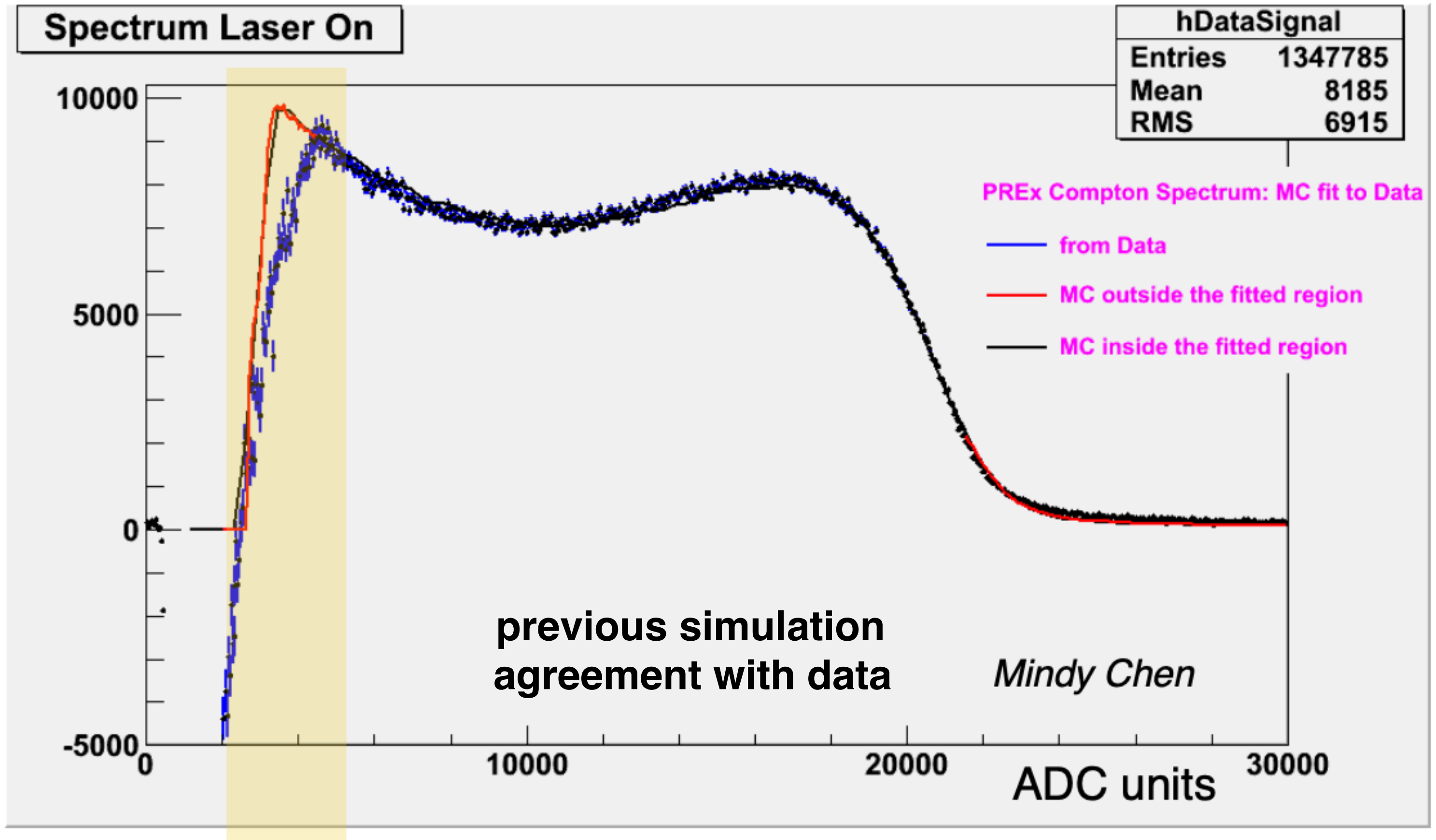


	HAPPEX-II (achieved)	Qweak (achieved)	MOLLER (required)
size asymmetry (quoted)	—	$< 10^{-4}$	$< 10^{-5}$

- Due to the finite size of the beam, off-axis elements will lead to a coupling between position and angle in the PC
    - producing an asymmetry in the spot size of the beam
- In this case as well the RTP is significantly better than the KD*P

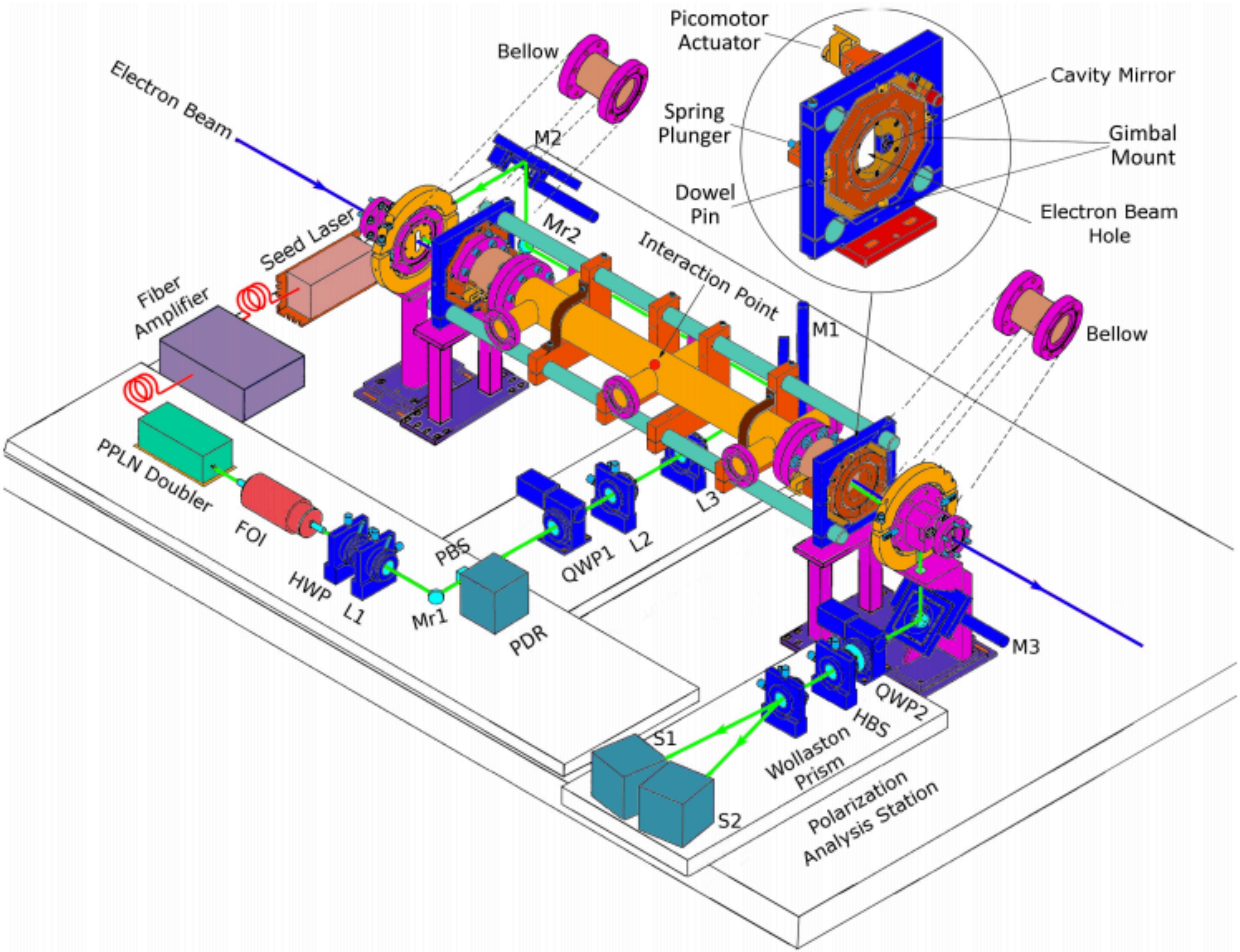
Detector system





- The single crystal Gd_2SiO_5 is 6cm in radius and 15 cm in length
  - no fluorescence and provides high light yield
- It has been used before for PREX1 and should be well understood
- Linearity tests are crucial towards our final systematic goal
- Simulation is being developed by Amali

Compton laser system: basic components



https://hallaweb.jlab.org/parity/prex/theses/AbdurahimRakhamThesis.pdf