Introduction to the HAPPEX Experiment

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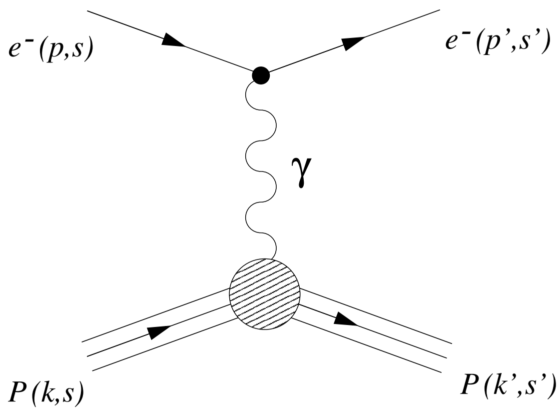
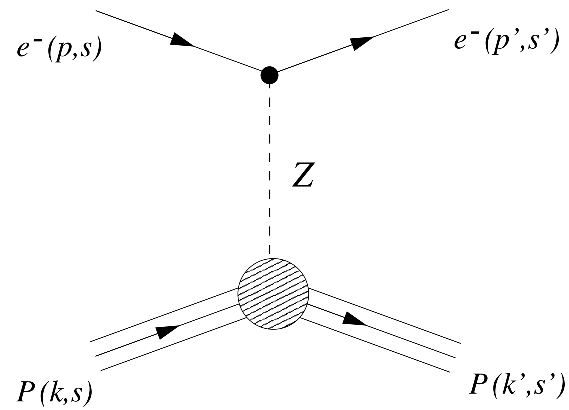
Overview

- Introduction - motivation
- Precision
- Count rate
- Integration
- Acceptance/HRS
- Corrections for False Asymmtries
- False Asymmetries - Beam
- Senstivities -> Criteria
- Beam Monitoring
- Beam Monitoring Precision
- Beam Modulation
- Lumi monitor
- Controlling beam false asymmetries
- Polarization
- Q^2 measurement - low current
- differences from G0

Parity-Violation as a Probe of Nucleon Structure





$$\left\{ A_0 = \frac{-G_F Q^2}{\sqrt{2}\pi\alpha} \right\}$$

$$A^{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

$$= A_0 \frac{\epsilon G_E^{p\gamma} G_E^{pZ} + \tau G_M^{p\gamma} G_M^{pZ} - \frac{1}{2}\left(1 - 4\sin^2\theta_W\right)\epsilon' G_M^{p\gamma} G_A^{pZ}}{\epsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}$$

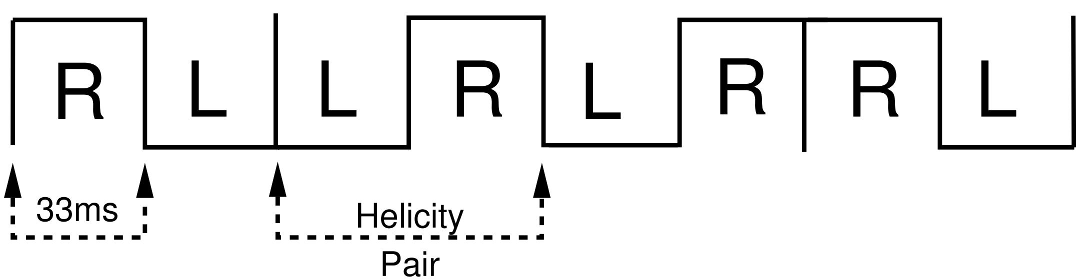
Assuming Isospin Symmetry

$$G_{E,M}^{pZ} = \frac{1}{4}\left(G_{E,M}^{p\gamma} - G_{E,M}^{n\gamma}\right) - \sin^2\theta_W G_{E,M}^{p\gamma} - \frac{1}{4} G_{E,M}^{s}$$

HAPPEX Precision

	Asymmetry	Relative Error	Precision
HAPPEX II	1.2×10^{-6}	5%	60 ppb
HAPPEX ^{4}He	8×10^{-6}	3%	240 ppb
P-REx	5×10^{-7}	3%	15 ppb

Fast Helicity Reversal



$$A_{det} = \frac{D_R - D_L}{D_R + D_L}$$

Precision Measurement of Small Asymmetries

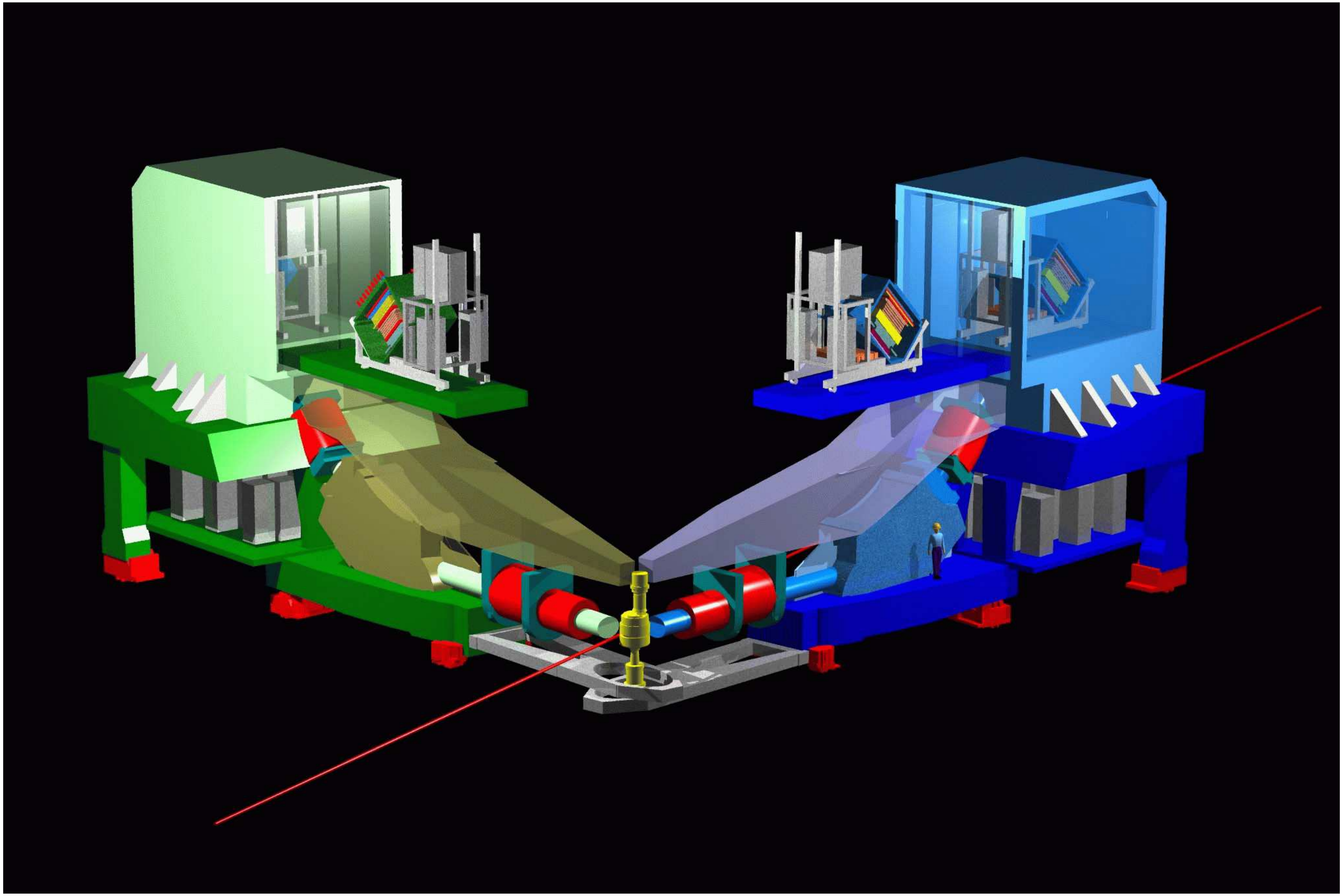
High Statistical Precision

- 1 part per million $\rightarrow 10^{12}$ detected electrons
- 5% precision $\rightarrow$ 400 times more
- Individual counting? at 1 MHz DAQ rate = 12.6 years!

Solutions:

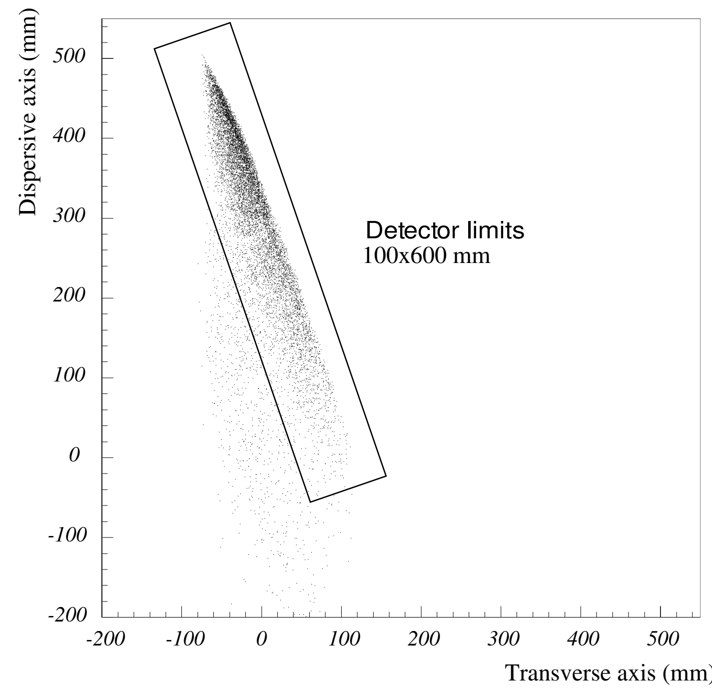
- Fast Counting
  - Fast scalers for counting individual pulses
  - Allows particle ID or background suppression
  - Counting rate up to few MHz
  - Sensitive to deadtime and low energy backgrounds
- Analog Integration
  - No way to exclude background, once detected.
  - Unlimited rate
  - Sensitive to linearity and electronics noise

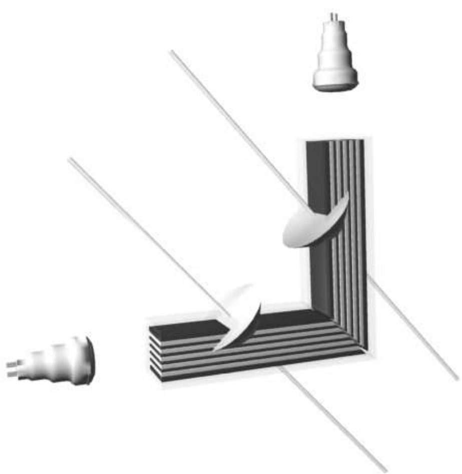
Hall A High Resolution Spectrometers



HAPPEX Approach

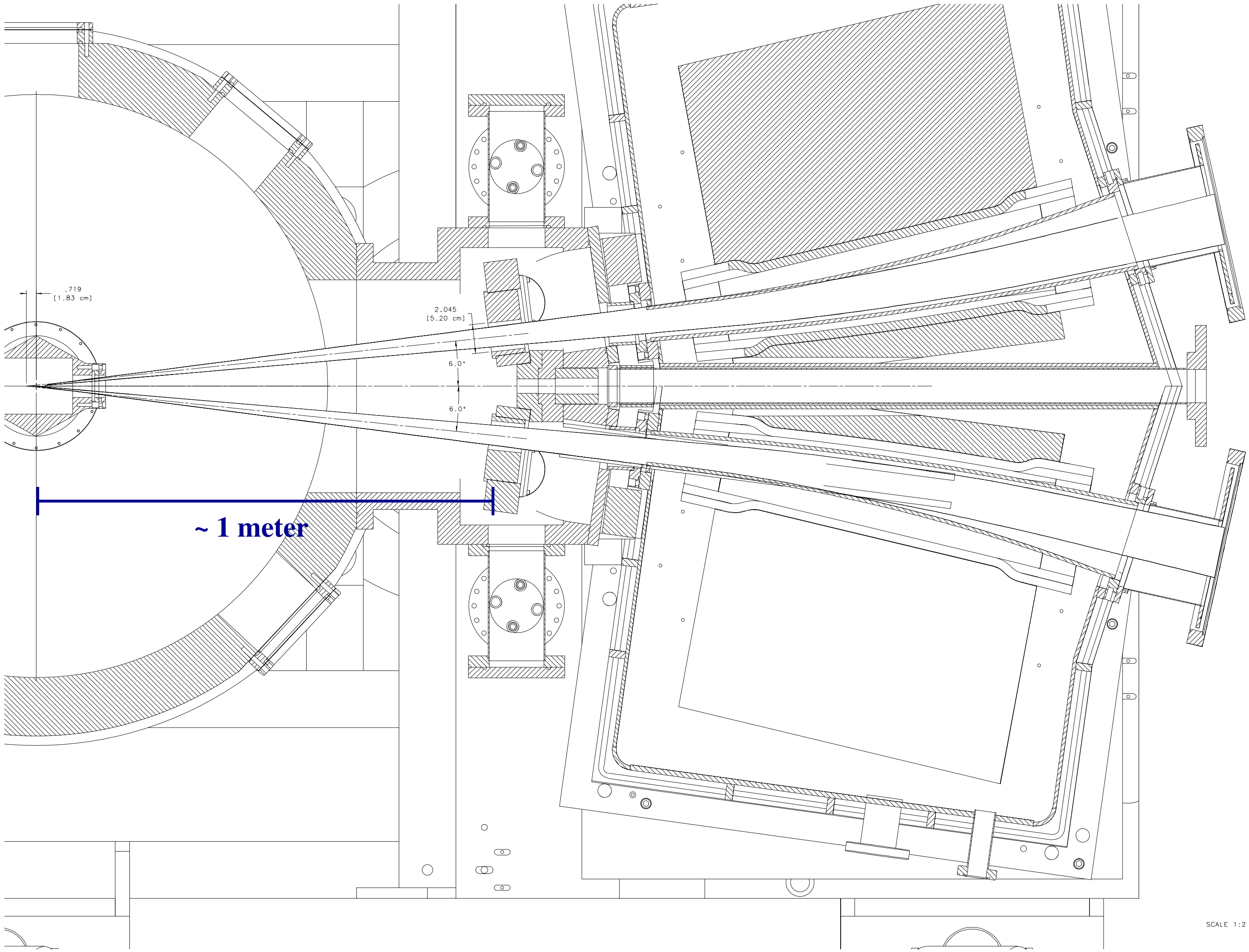
- 12 meter HRS dispersion kills hard and soft background
- No rate limit, no deadtime correction





- Cerenkov calorimeter detector kills soft background
- Requires high linearity
- Requires low electronics noise
- Sensitive to electronics pickup

Hall A Septum Magnets



Correcting the Raw Asymmetry

$$A_{det} = \frac{D_R - D_L}{D_R + D_L} \qquad D \propto \frac{d\sigma(\theta, E)}{d\Omega} \Delta\Omega \cdot Q$$

$$A_{\text{LR}} = A_{\text{det}} - A_Q + \alpha A_E + \sum_i \beta_i \Delta x_i$$

Each correction introduces systematic error

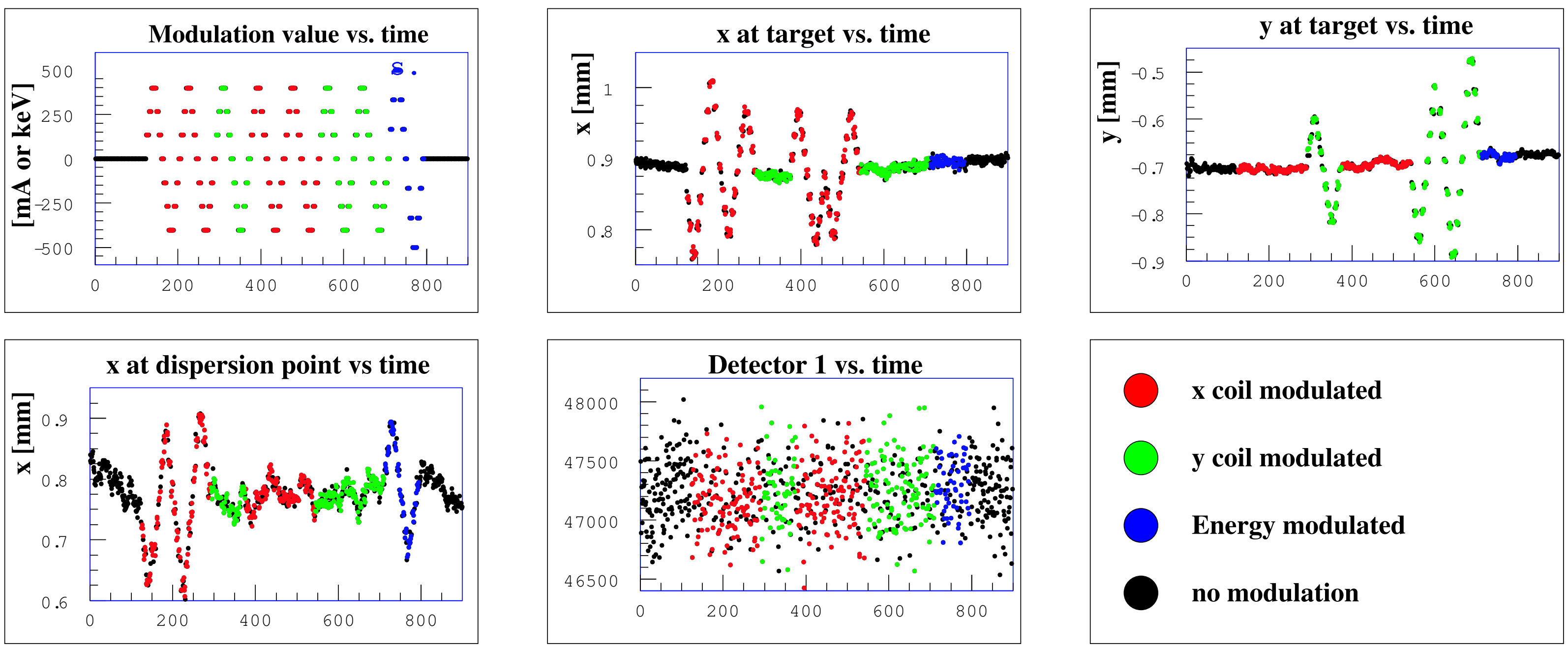
Goal: total systematic error less than 50 ppb

- Precise measurements of $\frac{D_R}{Q_R}$, $\frac{D_R}{Q_R}$, A_E, Δx_i
- Measurements of α, β_i

Measurement of Sensitivities to Beam Parameters

$$A_{\text{physics}} = A_{\text{det}} - A_Q + \alpha A_E + \sum_i \beta_i \Delta x_i \qquad \beta_i = \frac{\partial D}{\partial x_i}$$

- Beam sensitivities measured using "Beam Modulation" method



Measurement of Sensitivities to Beam Parameters

$$A_{\text{physics}} = A_{\text{det}} - A_Q + \alpha A_E + \sum_i \beta_i \Delta x_i$$

Expected: $\alpha_E \sim 4\,\frac{\text{ppb}}{\text{ppb}}$ $\beta_x \sim 40\,\frac{\text{ppb}}{\text{nm}}$ $\beta_{x\prime} \sim 40\,\frac{\text{ppb}}{\text{nrad}}$

- Beam sensitivities measured using Beam Modulation method

$$\beta_i = \frac{\partial D}{\partial x_i}$$

- Intrinsic beam motion can be used (Regression) unless beam is “Too Good”

$$\beta_i = \frac{\partial A}{\partial \Delta x_i}$$

Requirements for Beam False Asymmetries

Goal: < 10 ppb systematic error per correction

- Assume 3% linearity: $\langle A_Q \rangle < 0.6$ ppm
- Assume 10% uncertainty in β_x, Δ_x
  $\beta_x \sim 40\,\frac{\text{ppb}}{\text{nm}} \rightarrow \langle \Delta x \rangle < 2$ nm
- Assume 10% uncertainty in α_E, A_E
  $\alpha_E \sim 4\,\frac{\text{ppb}}{\text{ppb}} \rightarrow \langle A_E \rangle < 13$ ppb

Simple rule: expect 10-15% error in any correction, so each correction should be smaller than size of statistical error (50 ppb).

Beam Current Measurement Precision

Goal: 1% measurement of beam current

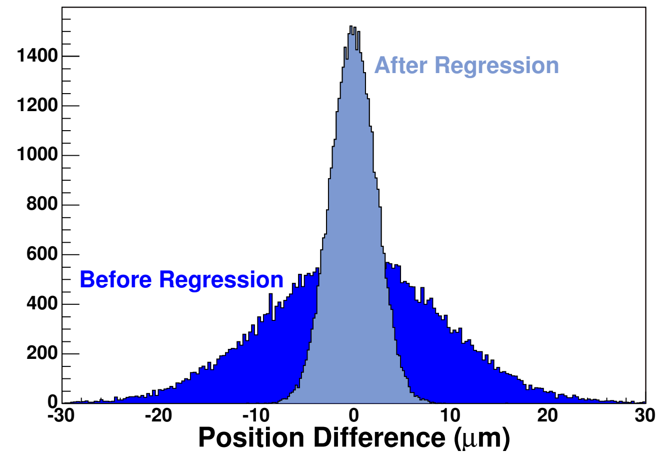
- Beam Current Monitor resolution: Compare A_Q measurements from 2 or more BCMs
  - Non-zero mean represents systematic error (Helicity-correlated or non-linearity)
  - Width reflects resolution/non-linearity of each monitor
- Detector (PMT) linearity is limiting factor to A_Q correction

Beam Position Measurement Precision

Goal: 10% measurement of position difference

Beam Position Monitor resolution:

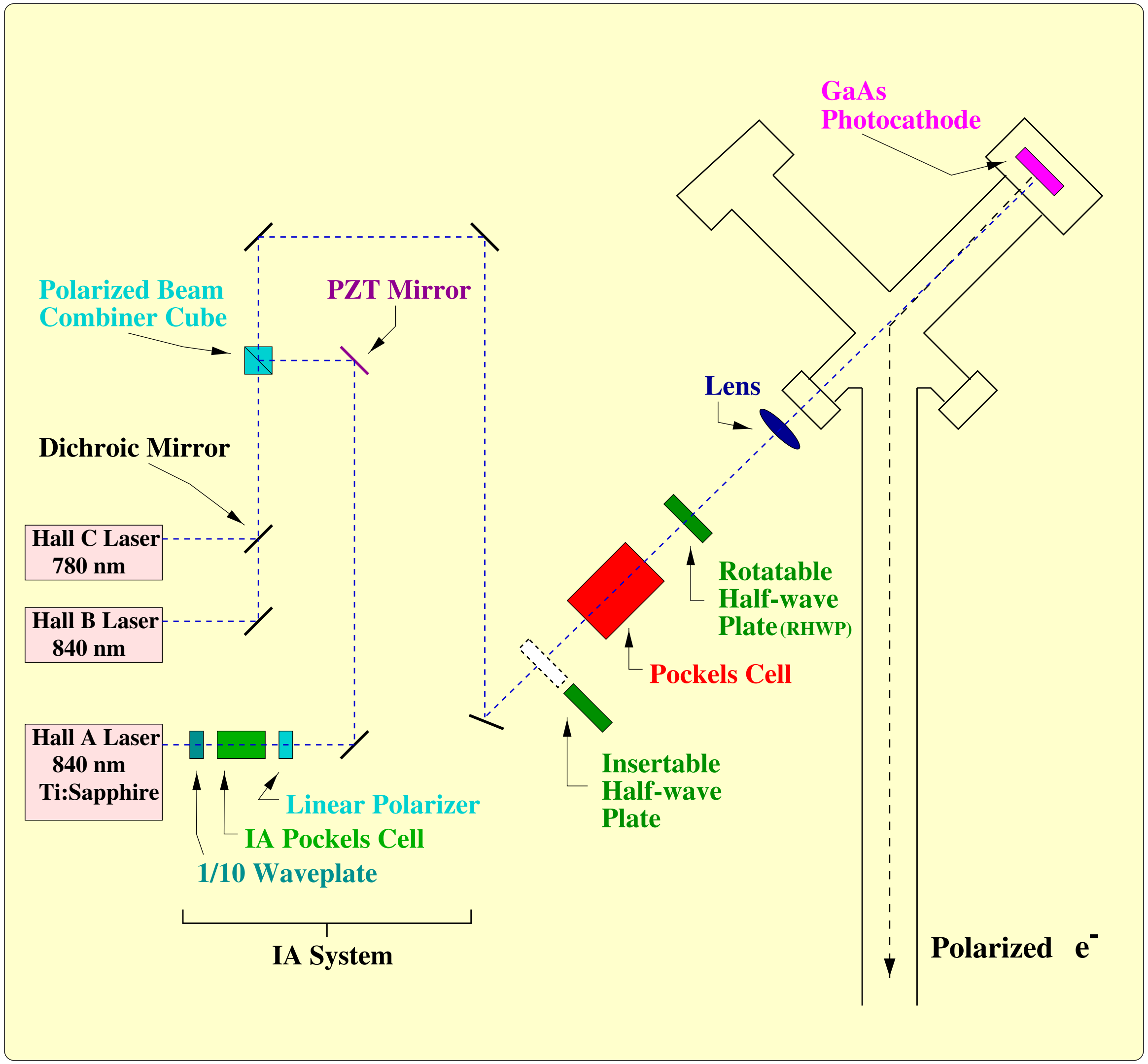
- $\langle \Delta x \rangle$ <2 nm $\rightarrow \sigma_{\langle \Delta x \rangle} <$ 0.2 nm.
- To have a shot, the resolution must be better than 1.2 μm per pair.



- Minimal coverage, stripline BPMs only
- Resolution estimated by regressing position differences using other BPMs.
- Care to avoid subtle systematic errors, for example, coupling of charge asymmetry with position measurement.
- Long-promised cavity monitors will provide redundancy, independent method, improved resolution

Minimizing Corrections through Careful Configuratio

Passive: careful source configuration



- Active feedback on A_Q
- Position feedback if necessary.

Slow Reversals

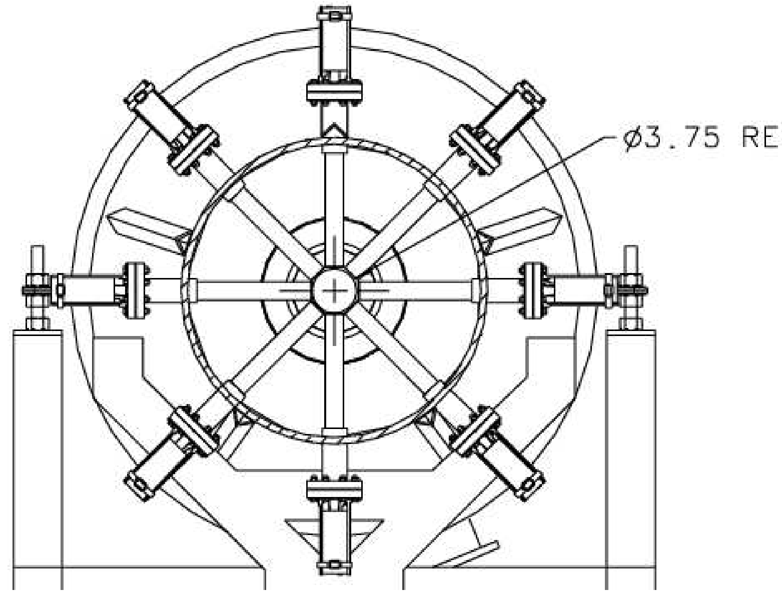
Halfwave Plate:

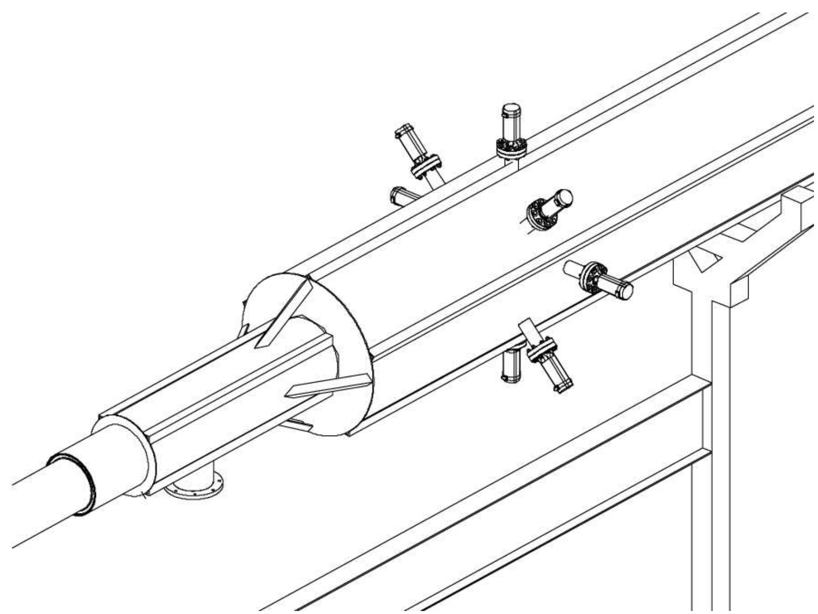
- reverses helicity of laser light relative to Pockels cell voltage, while all other aspects of configuration remain the same
- Cancellation of
  - electronics pickup
  - Pockels cell “Steering”
  - Most sources of A_Q, some higher order effects?

Position difference reversals:

- Phase Trombone
- Wein filter rotation (ruled out)

Luminosity Monitor





Small-angle Lumi

- $0.5°$ Cerenkov detector
- Rate > 1000 MHz
  $\Longrightarrow$ width ~ 100 ppm
- Expected asymmetry 30 ppb
- $10\times$ more sensitive to beam parameters

Polarization Measurement

$$A^{PV} = PA_{LR}$$

Ultimate relative precision is proportional
to relative precision of polarization measurement

- Compton Polarimeter
  - Expected error near 2%
  - Requires very clean beam: 100 Hz / μA at 3mm
  - Requires Fast Feedback
- Moller Polarimeter used as cross-check on Compton

Q^2 Measurement

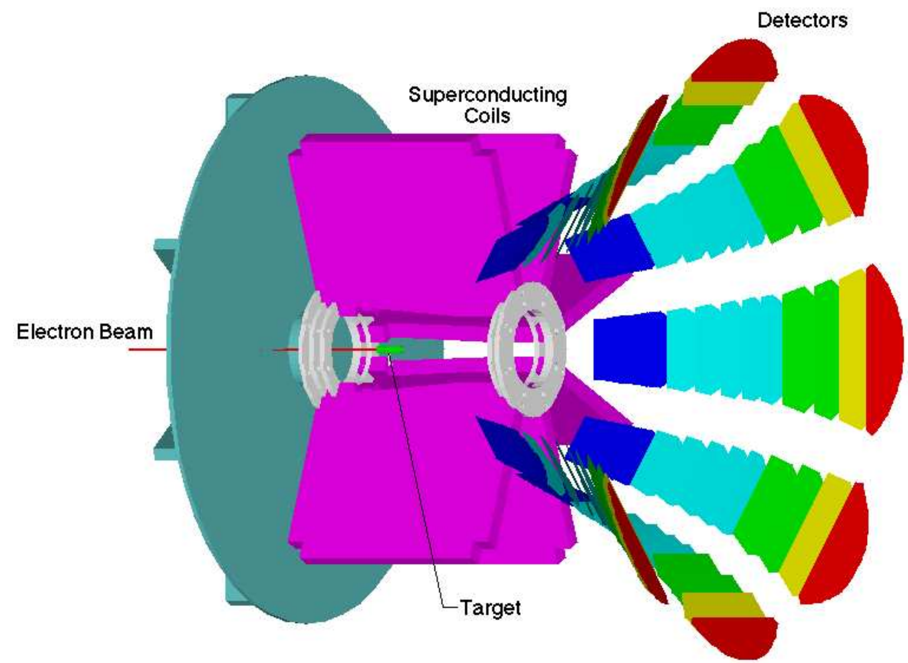
$$A^{PV} \propto Q^2 \times \text{[physics]}$$

Goal: 1% measurement of mean Q^2

- Spectrometer calibration
- Spectrometer "pointing"
  - Elastic scattering with various nuclei
  - Cross-check with precise survey
- Q^2 distribution
  - Must be measured with production target
  - Rate-limit to drift chambers requires low current
  - 50-100 nA is required, with beam conditions matching production(?)
  - High-rate cross check: measure position profile in focal plane with integrating "scanner" detector.

Comparison to G0

- $5° < \theta < 15°$,
  $0.16 < Q^2 < 0.95$ (GeV/c)^2
- Fast Counting
  - Scintillator detectors
  - TOF to exclude background



- Resistant to beam position
  - Recoil proton (not forward scattered e^-)
  - Azimuthal symmetry