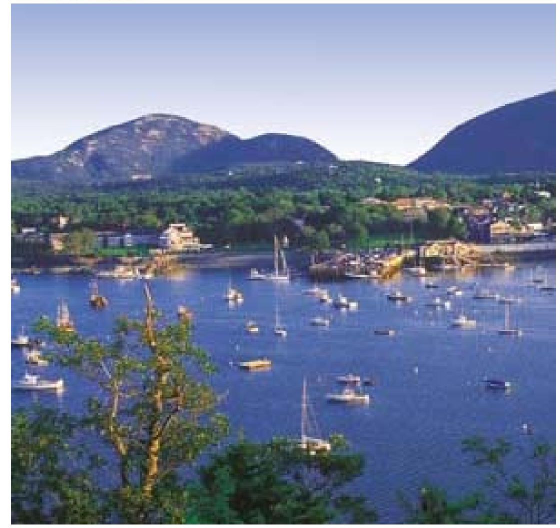
Overview of Technical Challenges in Parity-Violating Electron Scattering Experiments

Mark Pitt* Virginia Tech

PAVI09: 4th International Workshop "From Parity Violation to Hadronic Structure and more…"
Bar Harbor, Maine June 22-26, 2009

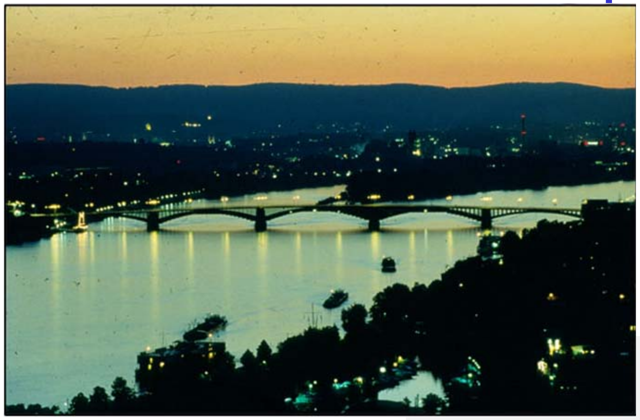


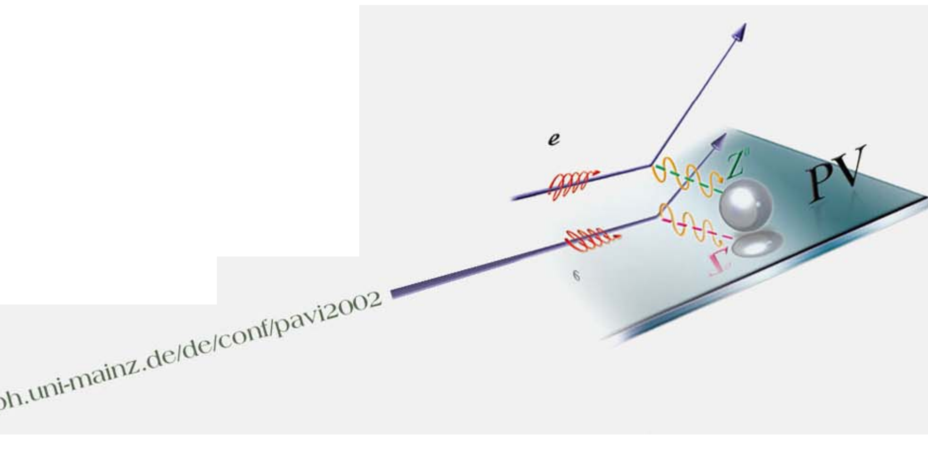
From PAVI02 first circular: "The smallness of the asymmetries to measure has also triggered many technical developments which will be addressed."
→ Coverage of the technical developments in PV electron scattering experiments has always been a part of PAVI workshops.

Thanks to David Armstrong, Roger Carlini, Gordon Cates, Yu-Chiu Chao, Jurgen Diefenbach, Dave Gaskell, Joe Grames, Paul King, Krishna Kumar, Jianglai Liu, Frank Maas, Dave Mack, Bob Michaels, John Musson, Kaz Nakahara, Kent Paschke, Matt Poelker, Greg Smith for slide materials

* Work partially supported by the National Science Foundation

Technical Development Talks at PAVI02, Mainz, Germany



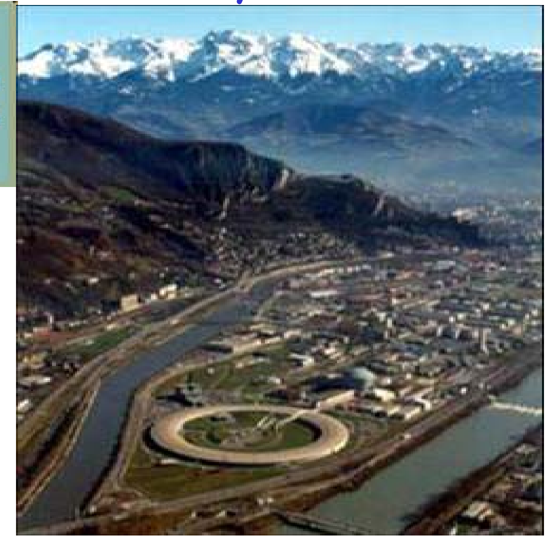


11 talks:

Polarimeter I	E. Burtin, CEA Saclay
Polarimeter II	J. Grames, Jefferson Lab
Polarimeter III	B.Collin, IPN Orsay
Source I	K.Aulenbacher, IfK Mainz
Source II	M. Baylac, Jefferson Lab
Source III	B. Humensky, U. Virginia
Source IV	M. Farkhondeh, MIT Bates
Detector I	J. Martin, Caltech
Detector II	R. Kothe, IfK Mainz
Detector III	D. Marchand, IPN Orsay
Detector IV	K. Grimm, ISN Grenoble

Technical Development Talks at PAVI04, Grenoble, France

International Workshop on
Parity Violation and Hadronic Structure
Laboratoire de Physique subatomique et de Cosmologie
Grenoble (France), 8-11 june 2004



13 talks

- "Stabilization System of the Laser System of the A4 Compton Backscattering Polarimeter" Jurgen Diefenbach – University of Mainz
- "Performance of the G0 Superconducting Magnet System" Steven Williamson – University of Illinois
- "The Transmission Compton Polarimeter of the A4 Experiment" Christoph Weinrich – University of Mainz
- "The Qweak Tracking System" Klaus Grimm – College of William and Mary
- "Redesign of the A4 Calorimeter for the Measurement at Backward Angles" Boris Glaser – University of Mainz
- "Progress Report on the A4 Compton Backscattering Polarimeter" Yoshio Imai – University of Mainz
- "G^0 Beam Quality and Multiple Linear Regression Corrections" Kazutaka Nakahara – University of Illinois
- "Moller Polarimetry with Atomic Hydrogen Targets" Eugene Chudakov – Jefferson Lab
- "Overview of Laser Systematics" Gordon Cates – University of Virginia
- "A Bin-per-Bin Dead-Time Control Technique for Time-of-Flight Measurements in the G^0 Experiment: The Differential Buddy" Louis Bimbot – IPN Orsay
- "Beam Optics for Electron Scattering Parity-Violation Experments" Douglas Beck – University of Illinois
- "Cherenkov Counter for the G^0 Backward Angle Measurements" Benoit Guillon – LPSC Grenoble
- "Electron Beam Line Design of A4 Compton Backscattering Polarimeter" Jeong Lee – University of Mainz

Technical Development Talks at PAVI06, Milos Island, Greece

International Workshop

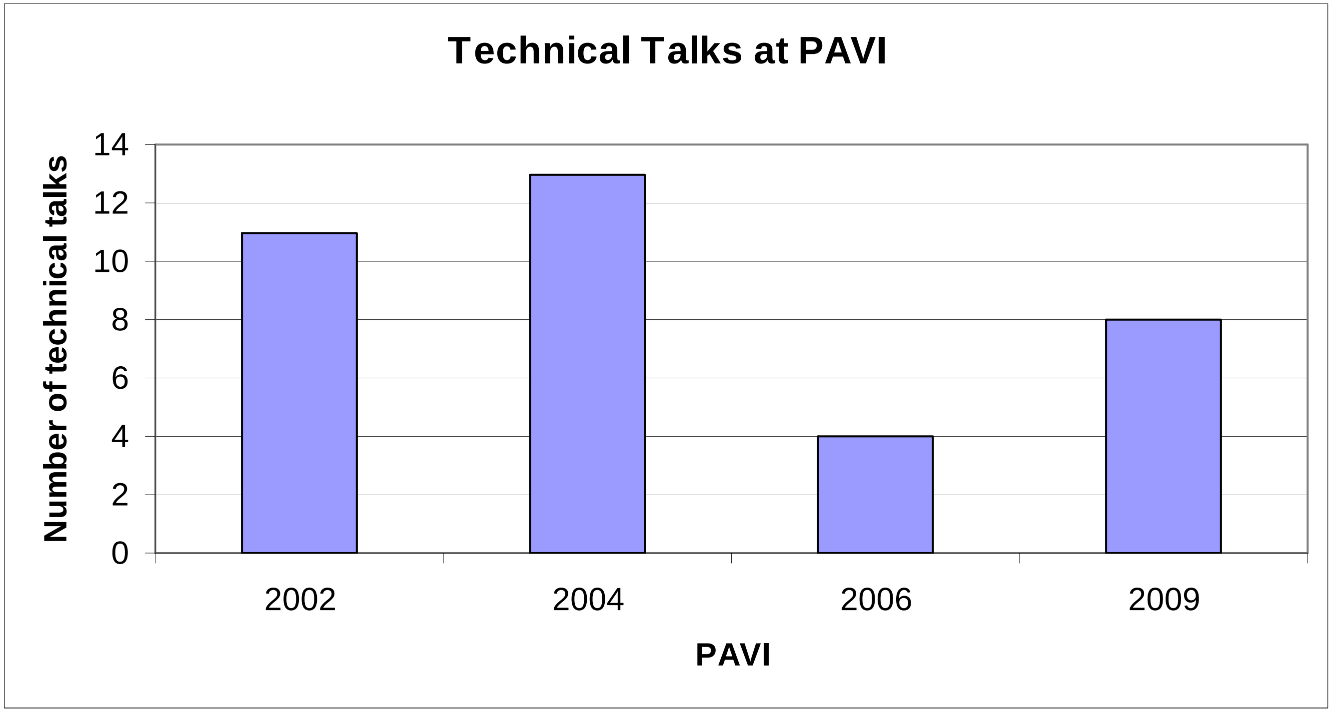
From Parity Violation to Hadronic Structure and more... (Part III)

Milos Conference Center George Eliopoulos
16-20 May 2006
Milos Island, Greece

4 talks

- "Laser Compton Polarimetry at JLab and MAMI" – A Status Report
  Jurgen Diefenbach – University of Mainz
- "New Methods for Precision Moller Polarimetry"
  Dave Mack – Jefferson Lab
- "Special Requirements to Polarized Sources during Parity Violation Experiments"
  Kurt Aulenbacher – University of Mainz
- " Controlling Helicity-Correlated Asymmetries in a Polarized Electron Beam"
  Kent Paschke – University of Massachusetts

Summary of Technical Development Talks at PAVI



Technical Requirement Drivers

$$A_{meas} = P_e(1-f)A_{phys}(Q^2) + f\,A_{back} + A_{false}$$

Statistics:

- Small counting statistics error (Γ_{count}) (need 10^{13} - 10^{14} events): → $\Gamma_{count} \propto \frac{1}{\sqrt{N}}$
  - reliable high polarization, high current polarized source
  - high power cyrogenic LH_2/LD_2 targets
  - large acceptance high count rate detectors/electronics

While minimizing contributions of random noise from

$$\Gamma_{stat} = \sqrt{\Gamma^2_{count} + \Gamma^2_{electronics} + \Gamma^2_{target}}$$

- target density fluctuations (Γ_{target})
- electronics noise (in integrating mode) ($\Gamma_{electronics}$)

Systematics:

- Minimize helicity-correlated beam properties (A_{false})
- Capability to isolate elastic scattering from other background processes (dilution factor f, background asymmetry A_{back})
- High precision electron beam polarimetry (P_e)
- Precision Q^2 determination ($A_{phys} \propto Q^2$)

SLAC E122 Experiment – Pioneering PV e-N Experiment

Charles Prescott and collaborators:

"Finally, parity-violation in the neutral currents was discovered at the expected level in electron-nucleon scattering at SLAC in 1978, and after that most physicists took it for granted that the electroweak theory is essentially correct."

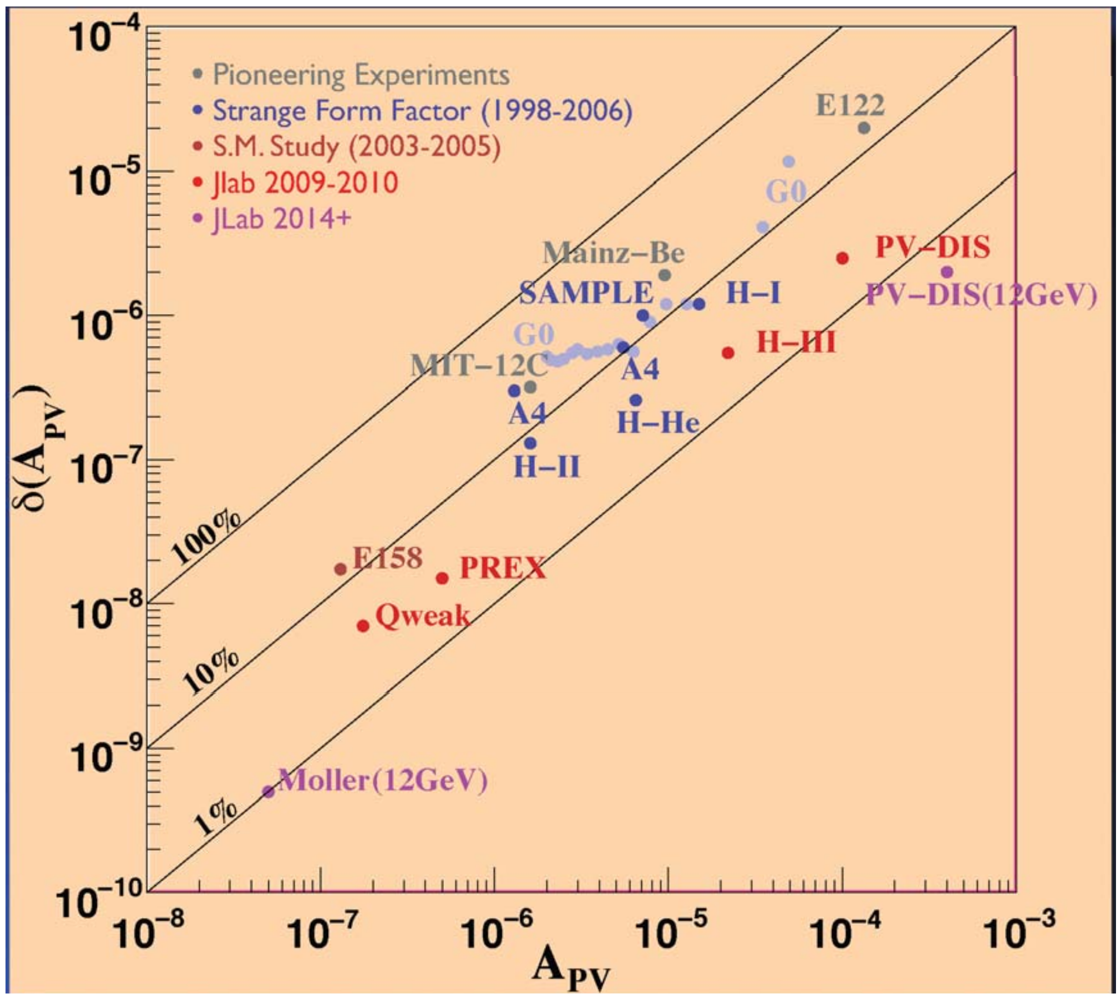
Steven Weinberg
"The Making of the Standard Model"
on the occasion of the CERN
30th anniversary celebration of discovery
of neutral currents AND
20th anniversary celebration of
discovery of W/Z bosons
hep-ph/0401010

- Accurate measurement and control of beam properties
  (applied corrections procedure for helicity-correlated beam properties)

Precision of Parity-Violating $\vec{e}$-N and $\vec{e}$-e Experiments: Past, Present, and Future

Technical progress over three decades since E122 has lead to smaller measured asymmetries and smaller absolute and fractional errors on the asymmetries.

Statistical errors:
- higher beam currents
- higher polarization
- denser targets

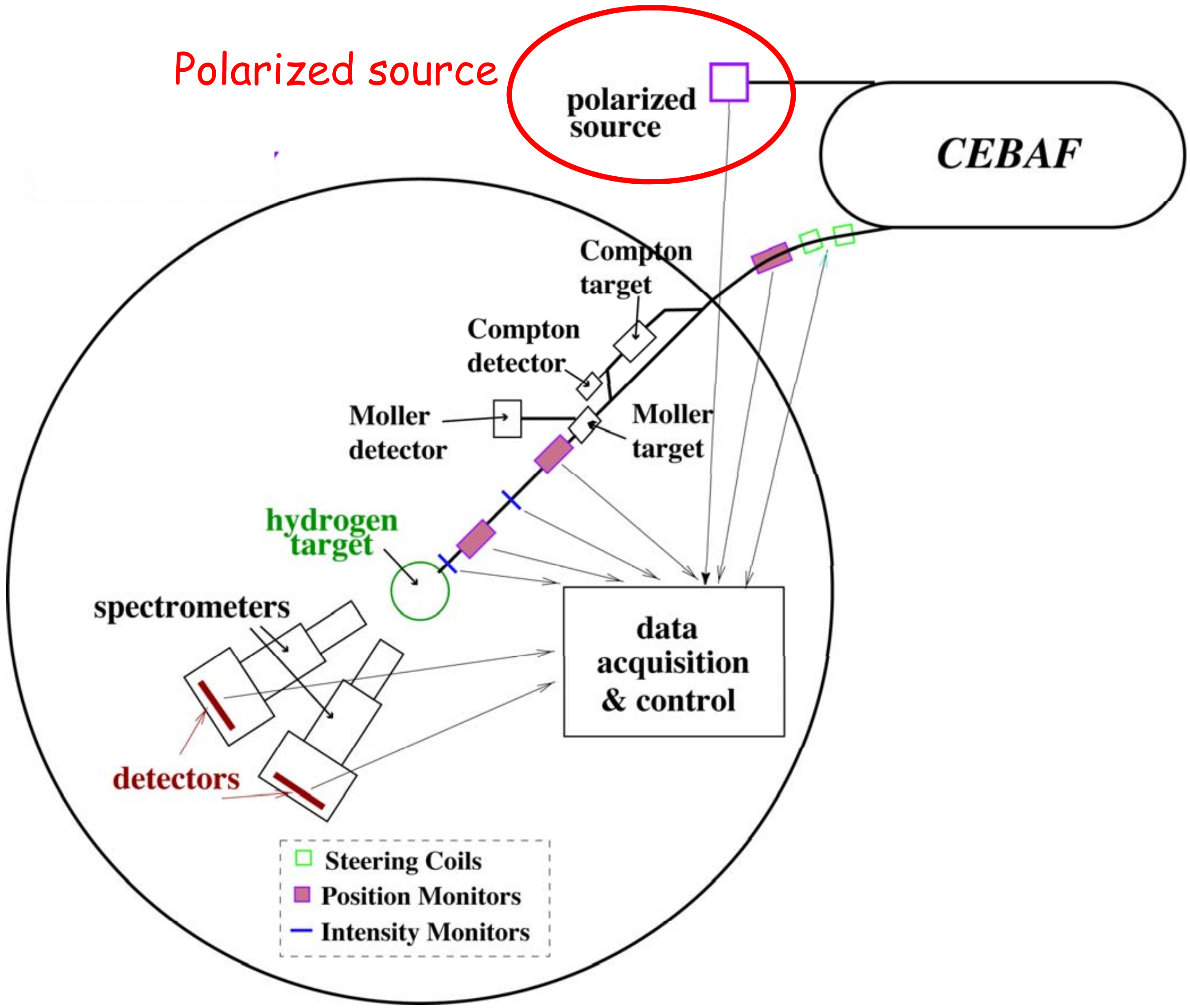


Normalization systematic errors:
- polarimetry
- Q^2 measurements

Figure from K. Paschke

"Additive" systematic errors: improved control of helicity correlated beam properties

"Modern" Overview of Parity-Violating Electron Experiment



Basic layout is the same as E122; we will use this as our basic roadmap to the technical developments. Examples will be drawn from many labs (SLAC, JLab, MAMI) and experiments.

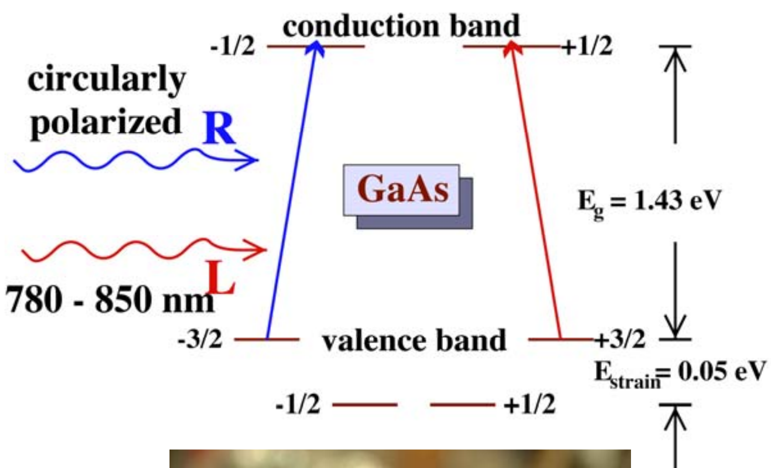
Polarized Electron Sources

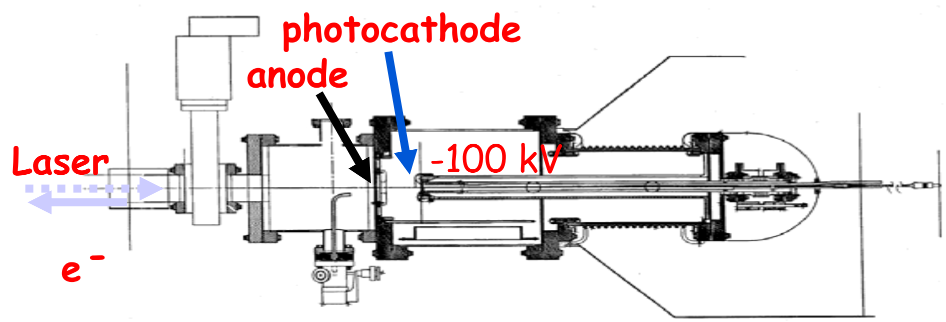
Polarized electron sources are based on photoemission of electrons from GaAs; circularly polarized incident light leads to polarized electrons

→ "Bulk" GaAs; theoretical maximum P_e = 50%; typical ~ 40%

→ "Strained" GaAs; theoretical maximum P_e = 100%; typical ~ 70-85%

Challenges: maintaining high quantum efficiency and lifetime
→ requires proper preparation UHV/EHV conditions





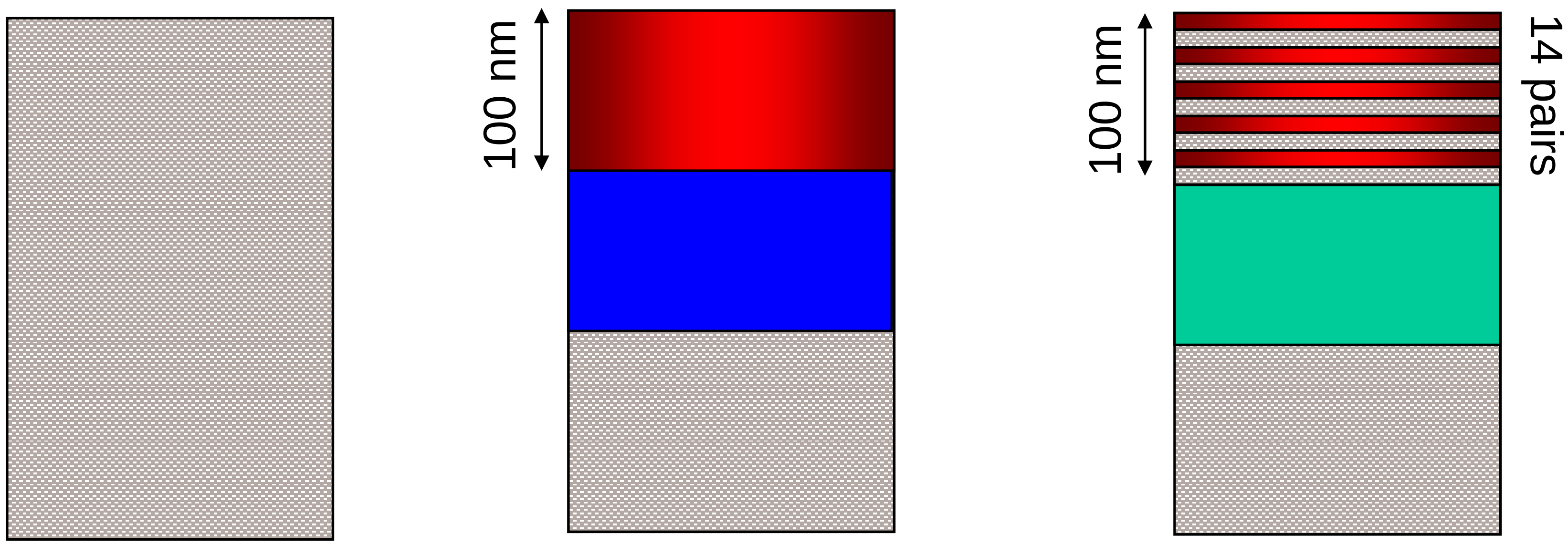
Polarized source overview talk: Kurt Aulenbacher

Evolution of Photocathode Materials

Bulk GaAs

Strained GaAs:
GaAs on GaAsP

Superlattice GaAs:
Layers of GaAs on GaAsP



High QE ~ 10%
Pol ~ 35%

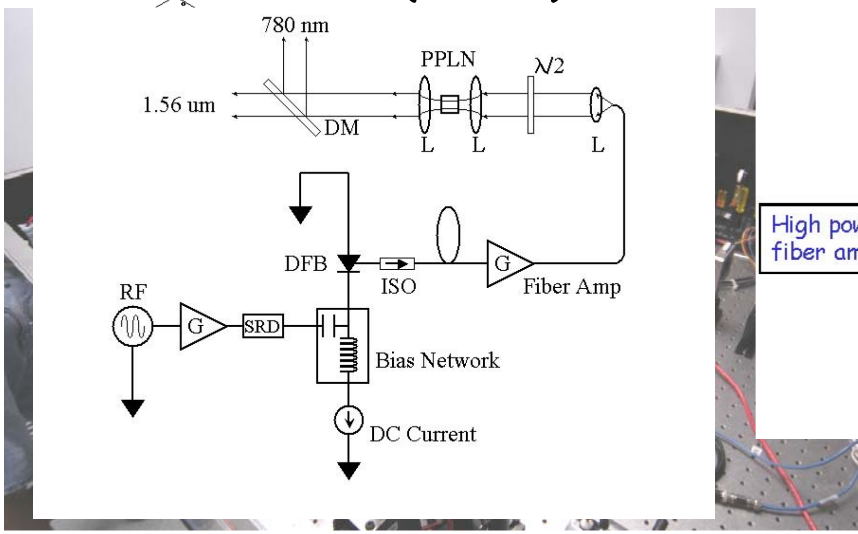
"conventional" material
QE ~ 0.15%
Pol ~ 75%
@ 850 nm

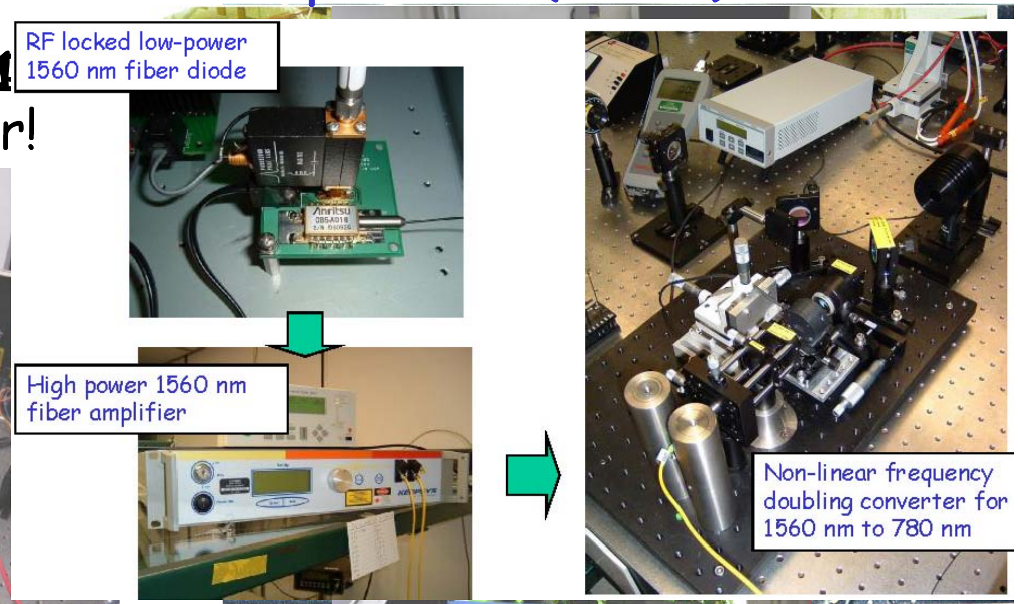
No strain relaxation
QE ~ 0.8%
Pol ~ 85%
@ 780 nm

Superlattice reference; T. Maruyama *et al*, Appl. Phys. Lett. **85**, 2640 (2004)

Other Polarized Source Developments (JLab)

Lasers: (overlapping text) (2007) - CEBAF ... fast laser! (2004) (2000)

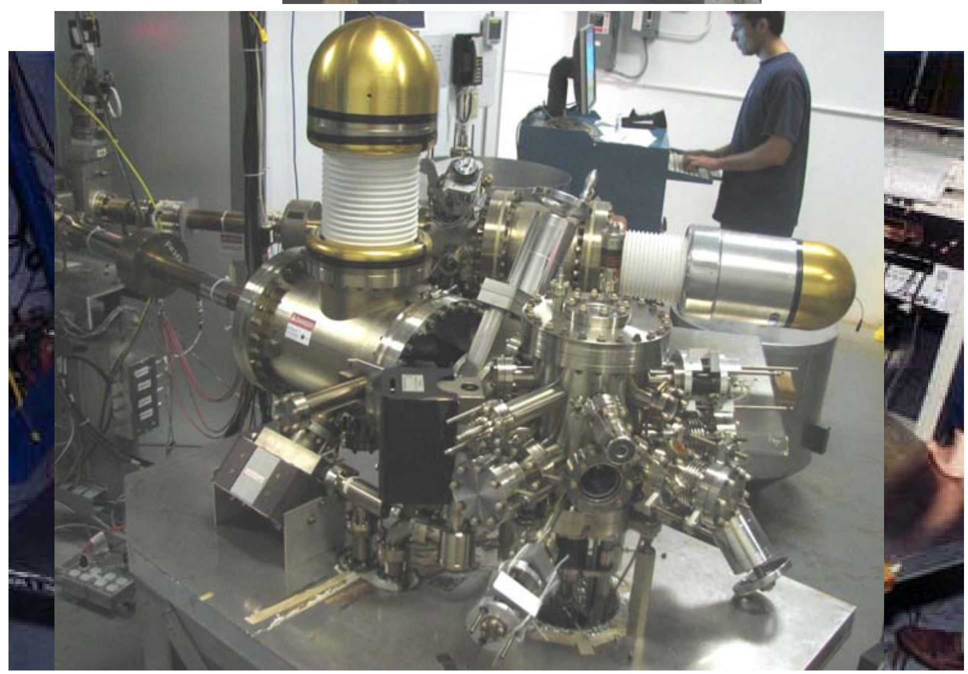




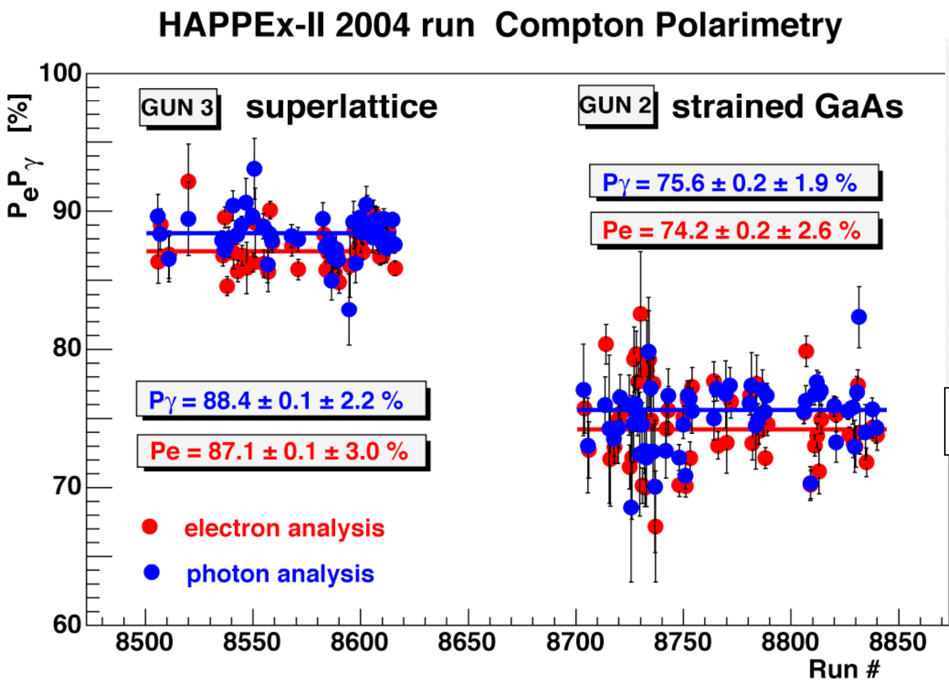
J. Hansknecht and M. Poelker, PRSTAB. **9**, 063501 (2006)

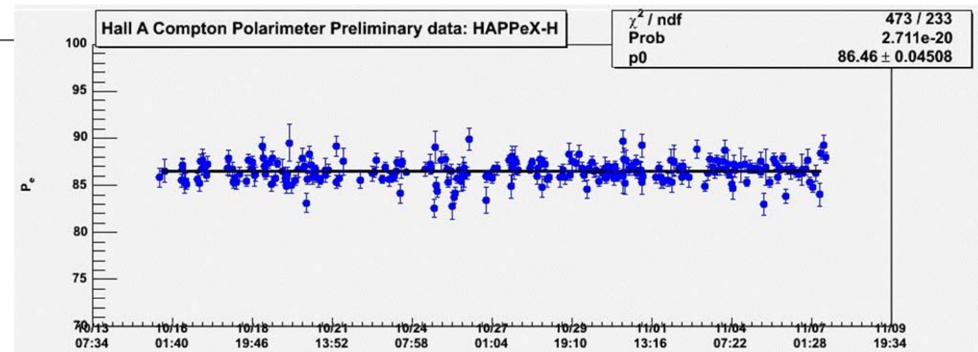
Polarized guns:
Previously used single cathode ("vent/bake") guns
-since 2007 load-locked system

Currently working on increasing high voltage of guns (100 kV → 200 kV) (partly for ILC development)



JLab Polarized Source Performance for Parity Experiments





Oct 13 ← QE dropped by factor of 2 → Nov 9

Superlattice – very stable polarization
- no apparent correlation with QE

	Experiment	Current, beam polarization
	HAPPEx I (1998)	95 μA @ 37%
	HAPPEx I (1999)	40 μA @ 70%
	G^0 forward (2003)	40 μA @ 74%
	HAPPEx II (2004)	
	G^0 backward	20-60 μA @ 85%
Upcoming:	HAPPEx III/PREx	100 uA @ 85%
	Qweak	150-180 uA @ 85%

This is the statistics part of polarized sources – what about systematics?
Parity experiments lead to additional ~~headaches~~ technical challenges here.

Helicity Correlated Beam Properties: False Asymmetry Corrections

$$A_{meas} = A_{phys} + \sum_{i=1}^{N} \frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

$\Delta P = P_+ - P_-$

Y = Detector yield

(P = beam parameter
~energy, position, angle, intensity)

Example: $\frac{1}{2Y}\left(\frac{\partial Y}{\partial x}\right) \sim 1.0\ \% / \mathrm{mm}\,,\ \Delta x = 100\ \mathrm{nm}$

$$A_{\mathrm{false}} = \frac{1}{2Y}\left(\frac{\partial Y}{\partial x}\right)\Delta x \sim 10^{-6} = 1\ \mathrm{ppm}$$

Typical goals for run-averaged beam properties

Intensity: $A_I = \frac{I_+ - I_-}{I_+ + I_-} < 1\ \mathrm{ppm}$

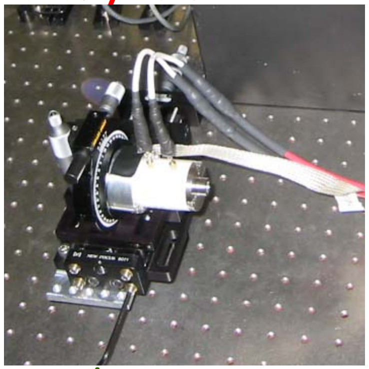
Position: $\Delta x, \Delta y < 2 - 20\ \mathrm{nm}$

$\Delta P = P_+ - P_-$ → keep small with feedback and careful setup

$\frac{1}{2Y}\left(\frac{\partial Y}{\partial P}\right)$ → keep small with symmetrical detector setup

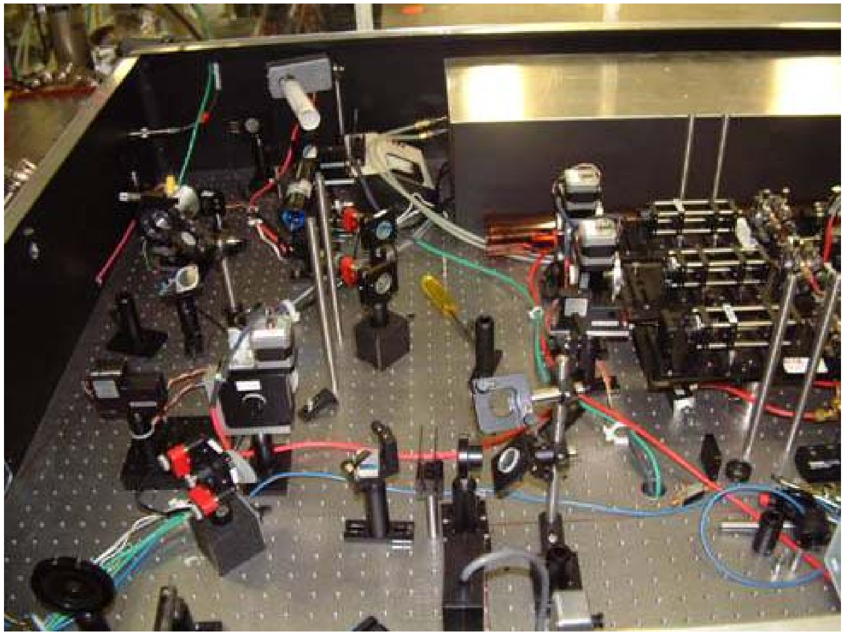
Polarized Source Systematics

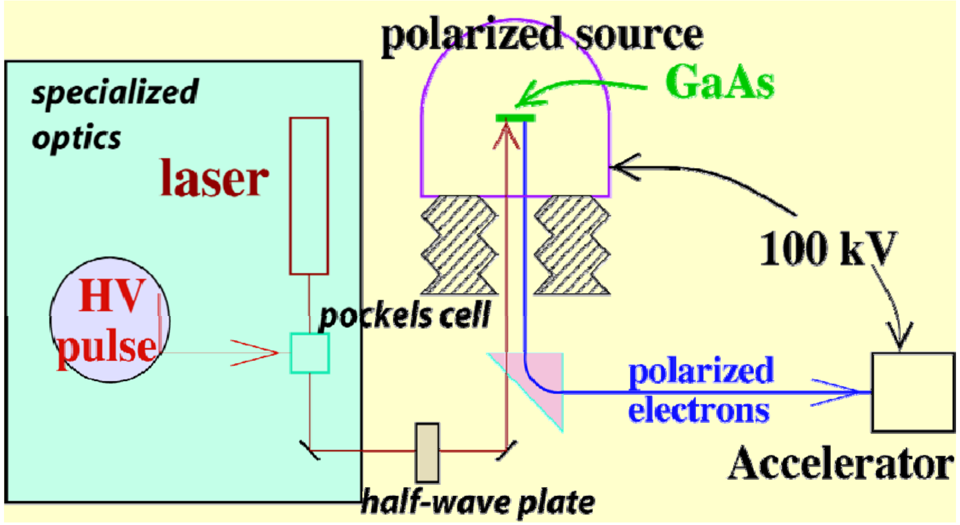
The heart of the parity experiments is the Pockels cell – electro-optic crystal used as a quarter-wave plate to produce circularly polarized light



Positive HV (~ 2500 V) → RCP light → positive helicity electrons
Negative HV (~ -2500 V) → LCP light → negative helicity electrons
Change between these two states at ~ 30 – 120 Hz rates

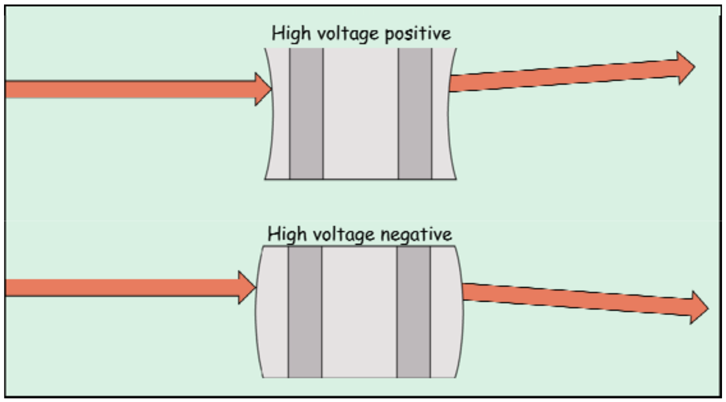
→ideally no other property of the laser beam changes under this reversal
In practice:
→ Laser beam gets helicity-correlated position and angular differences
→ Deviations from pure circular polarization lead to helicity-correlated intensity, position and angle differences



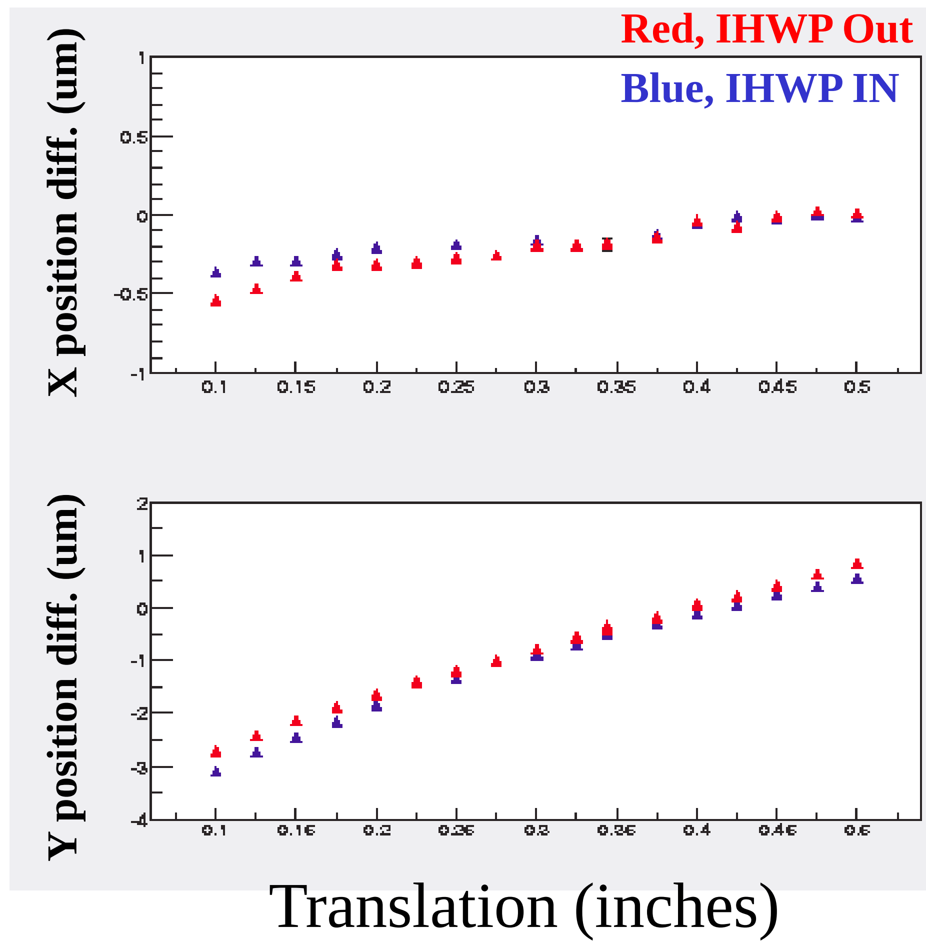


Example of Helicity-Correlated Pockels Cell Effect

Pockels Cell acts as active lens due to piezoelectric effect

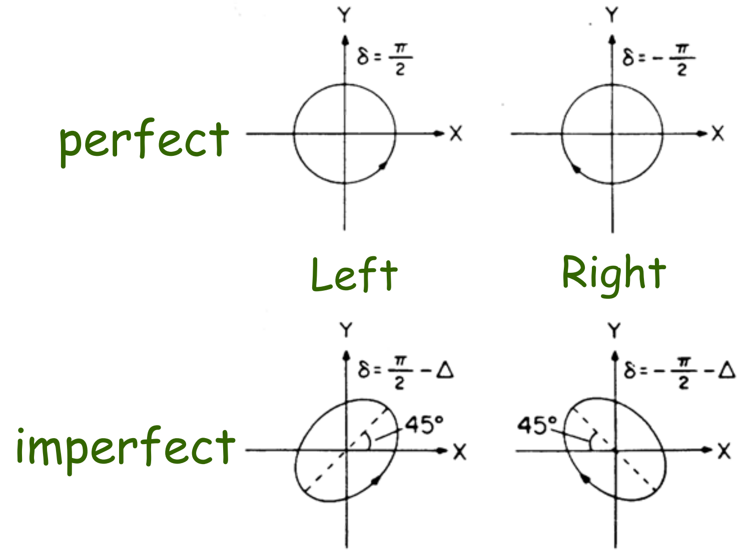


Study effects using segmented photodiode in laser lab to look at helicity-correlated position shifts of laser beam



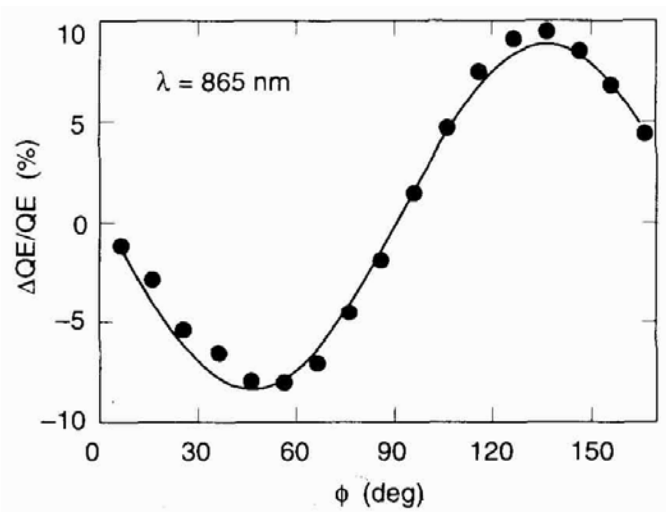
Pockels Cell – Effects from Imperfect Circular Polarization

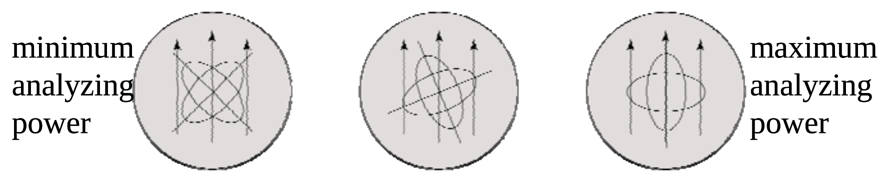
The dominant effects arise from imperfect circular polarization.
L/R states have small orthogonal linear components →
optical elements transport differently
→intensity differences
("PITA" effect – polarization induced transport asymmetry)

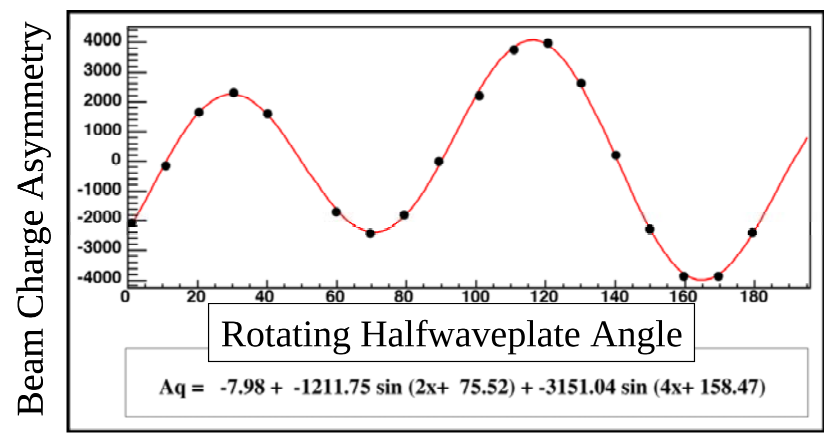


Worse: Quantum efficiency of strained GaAs crystals varies with linear polarization direction!

→ Leads to large large helicity-correlated laser intensity (and position) differences





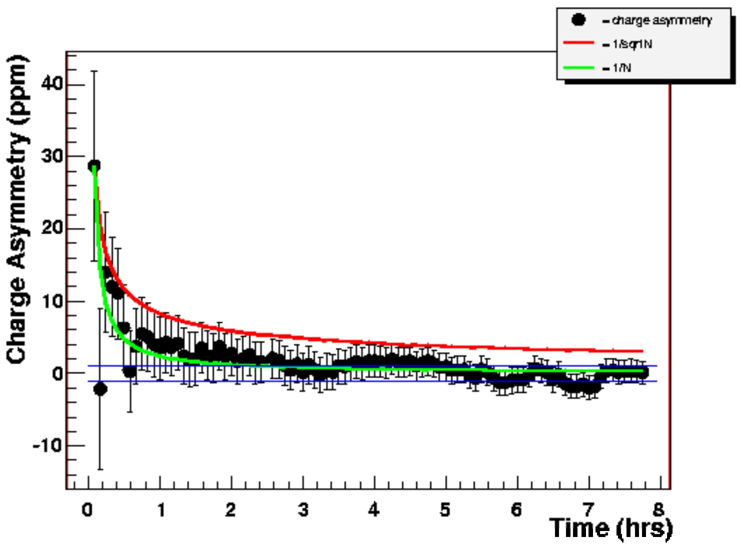


Control of Helicity-Correlated Beam Properties with Feedback

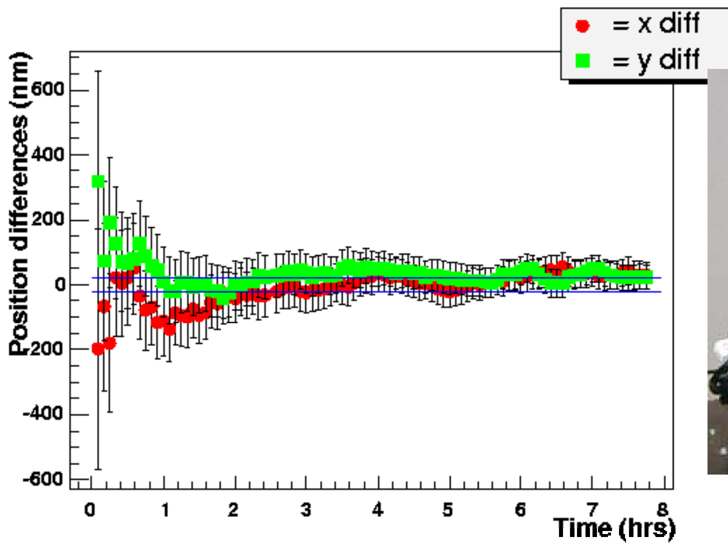
One strategy for reducing the helicity-correlated effects is to use feedback:

- accurately measure helicity-correlated intensity and position/angle differences in real time in the experimental hall
- Correct by applying helicity-correlated signals to optical devices on the polarized source laser table

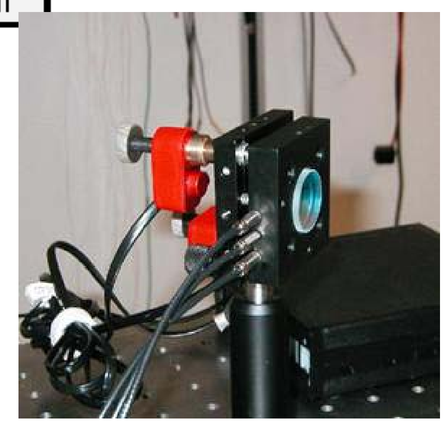
Example of feedback technique from G^0 forward angle run



Intensity asymmetry: control with Pockels cell/polarizer based "intensity throttle"

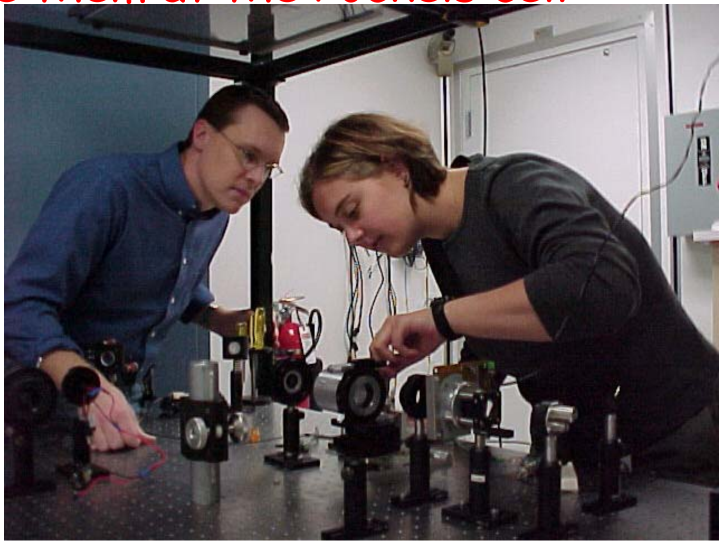


Position differences: control with mirror in piezoelectric mount



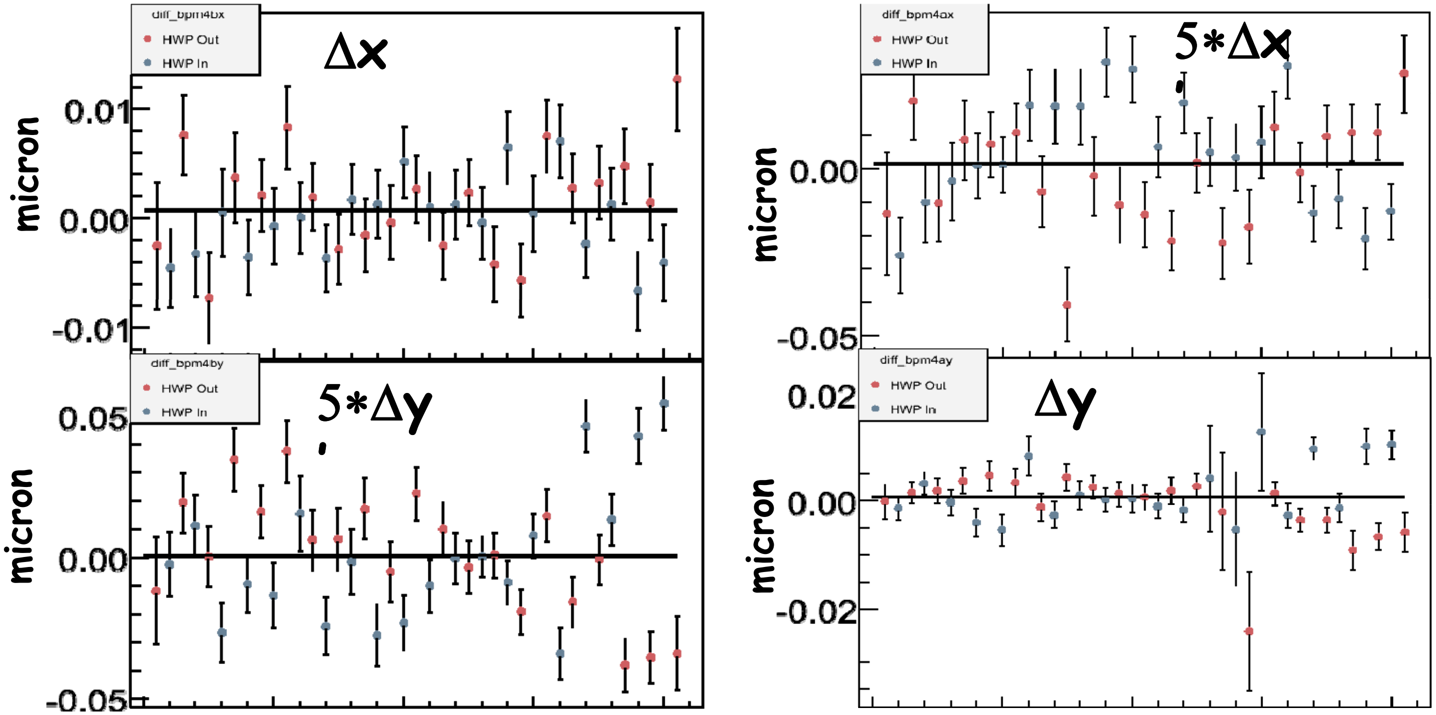
Reduce Helicity-Correlated Effects with Careful Setup

HAPPEx collaboration has done significant work on understanding the origins of these effects and developing techniques to minimize them at the Pockels cell (see Gordon Cates talk)

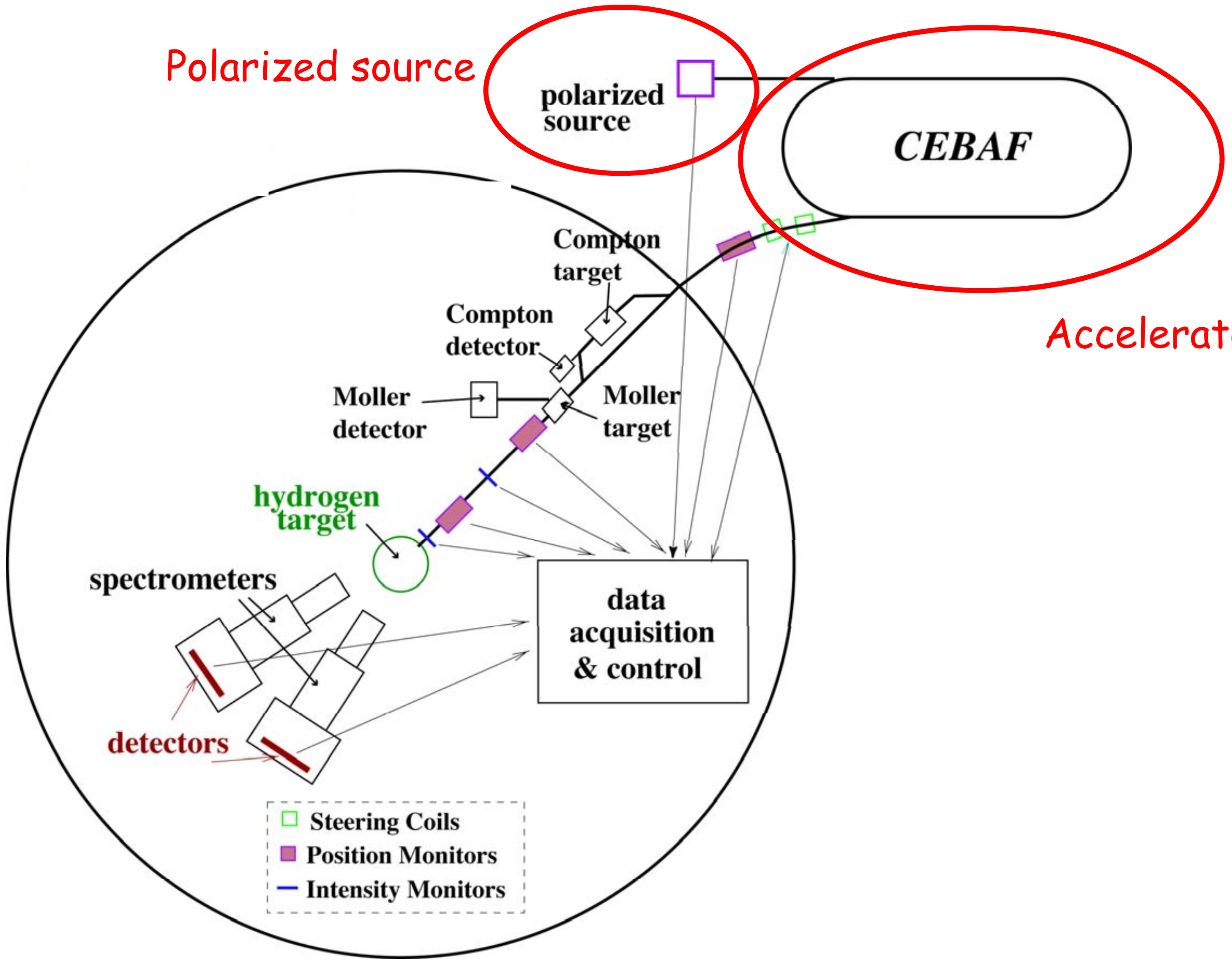


Using techniques based on these studies impressive results were achieved in HAPPEx II (2005)

Run Averaged:
Energy: -0.25 ppb
X Target: 1 nm
X Angle: 2 nm
Y Target : 1 nm
Y Angle: <1 nm



"Modern" Overview of Parity-Violating Electron Experiment



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Accelerator Beam Transport for Parity Experiments

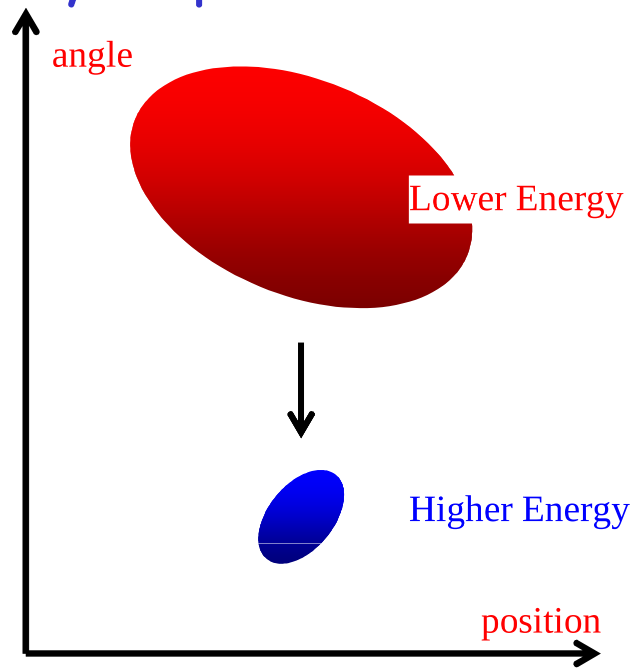
Linear beam optics in a perfectly tuned machine can lead to reduction in position differences from the injector to the experimental hall.

$$x, x' \propto \sqrt{\frac{p_0}{p}}$$

"adiabatic damping"

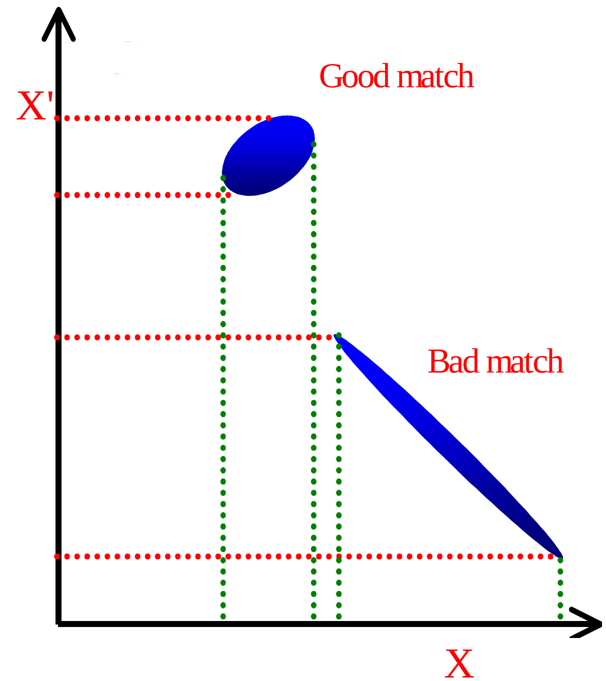
From 100 keV injection energy to 3 GeV at target, one expects helicity-correlated position differences to get smaller

$$\sqrt{\frac{3\,\text{GeV}}{335\,\text{keV}}} \approx 95$$



The ability to achieve this reduction in practice is limited by how close the tune of the accelerator is to the design tune (due to imperfect magnetic elements, coupling between x and y directions, …)

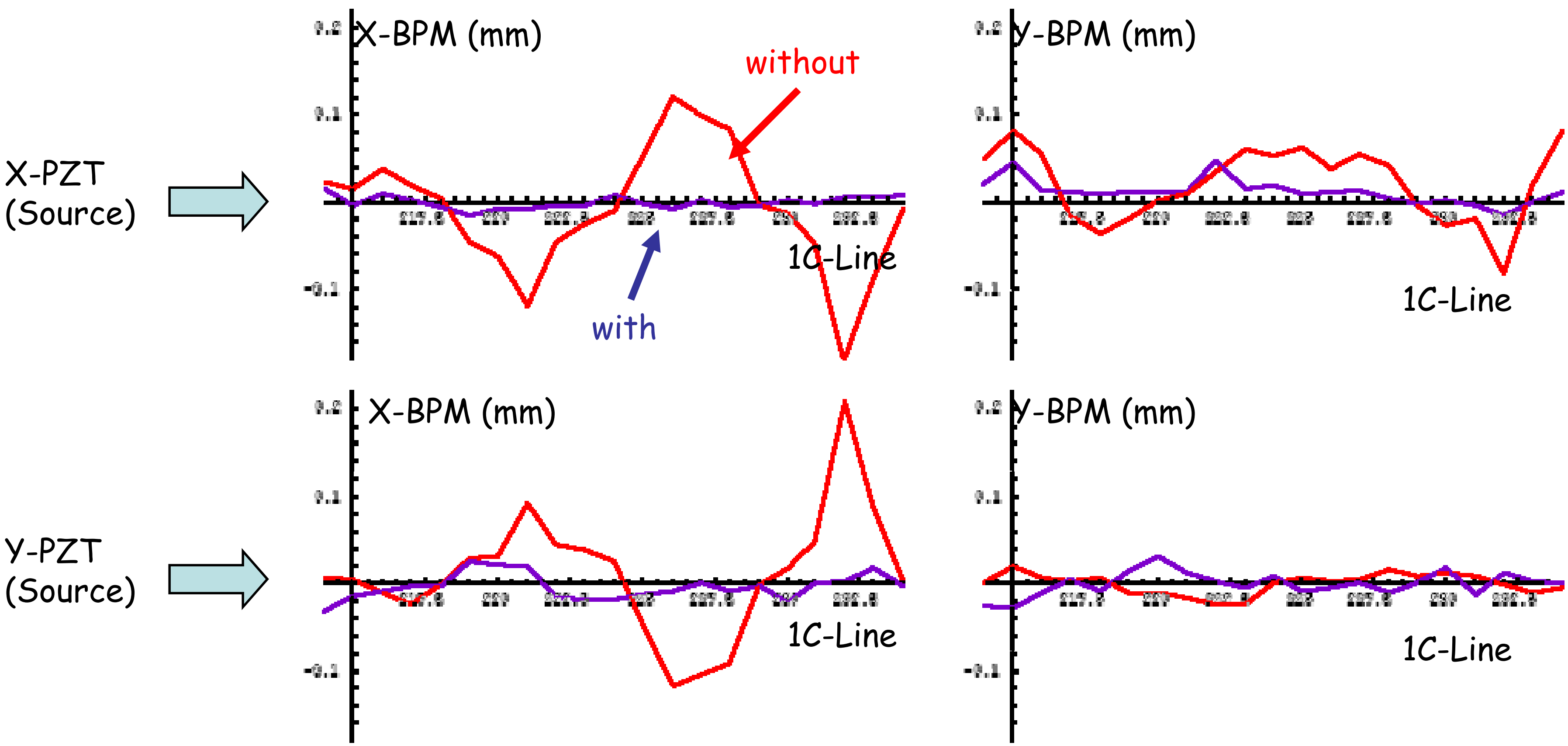
→ a bad match can cause the "ideal" position difference suppression factor to be considerably reduced



Optimizing Accelerator Beam Transport for Parity Experiments

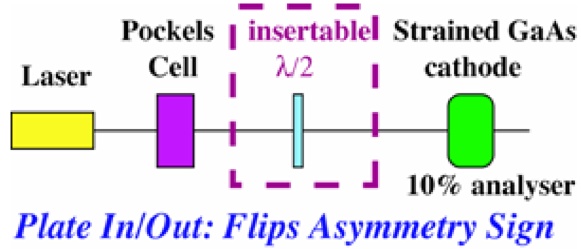
Major work invested to optimizing beam transport (Yu-Chiu Chao)

- "Matching" the beam emittance to the accelerator acceptance realizes damping,
  - Well matched beam => position differences reduced.
  - Poorly matched beam => reduced damping (or even growth).
- Accelerator matching (linacs & arcs) routinely demonstrated.
- Reduction factor of ~ 5-30 observed during HAPPEx-H



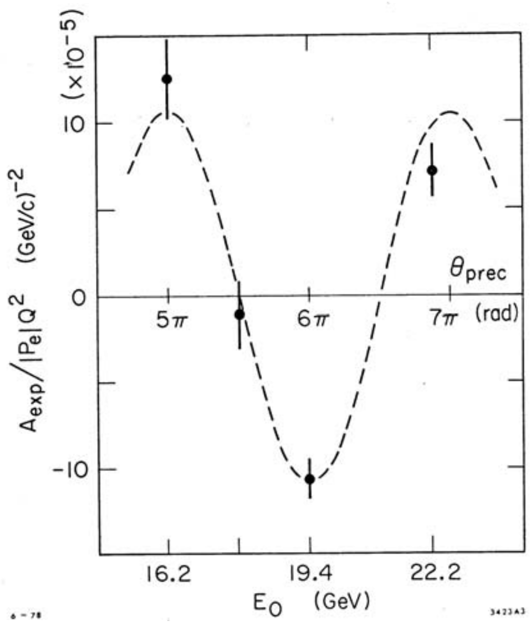
Use the Accelerator for "Slow" Helicity Reversal

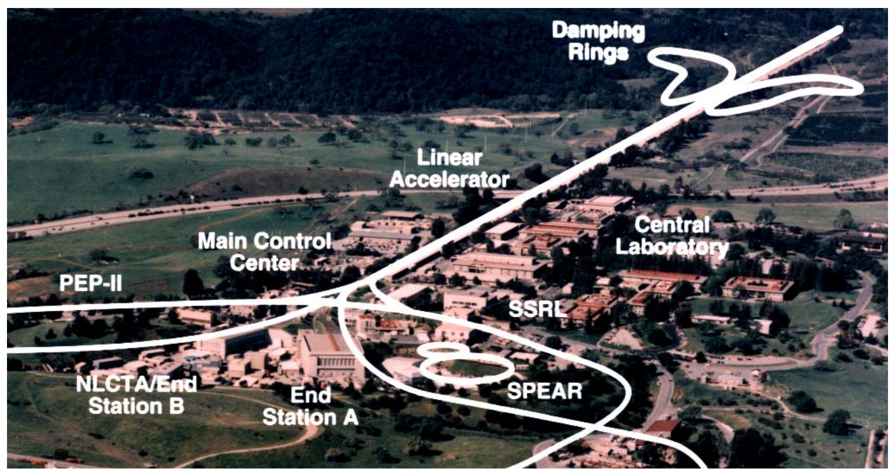
"Slow" helicity reversal often done with an insertable half-wave plate



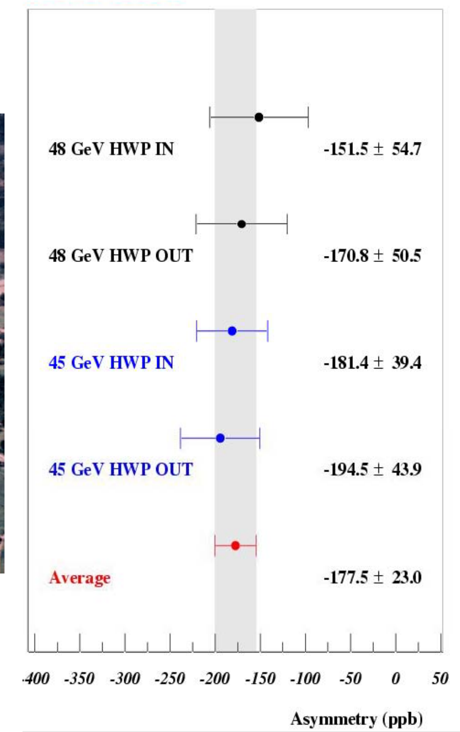
but it can also be done with g-2 spin reversals by changing the accelerator energy

E122





E158



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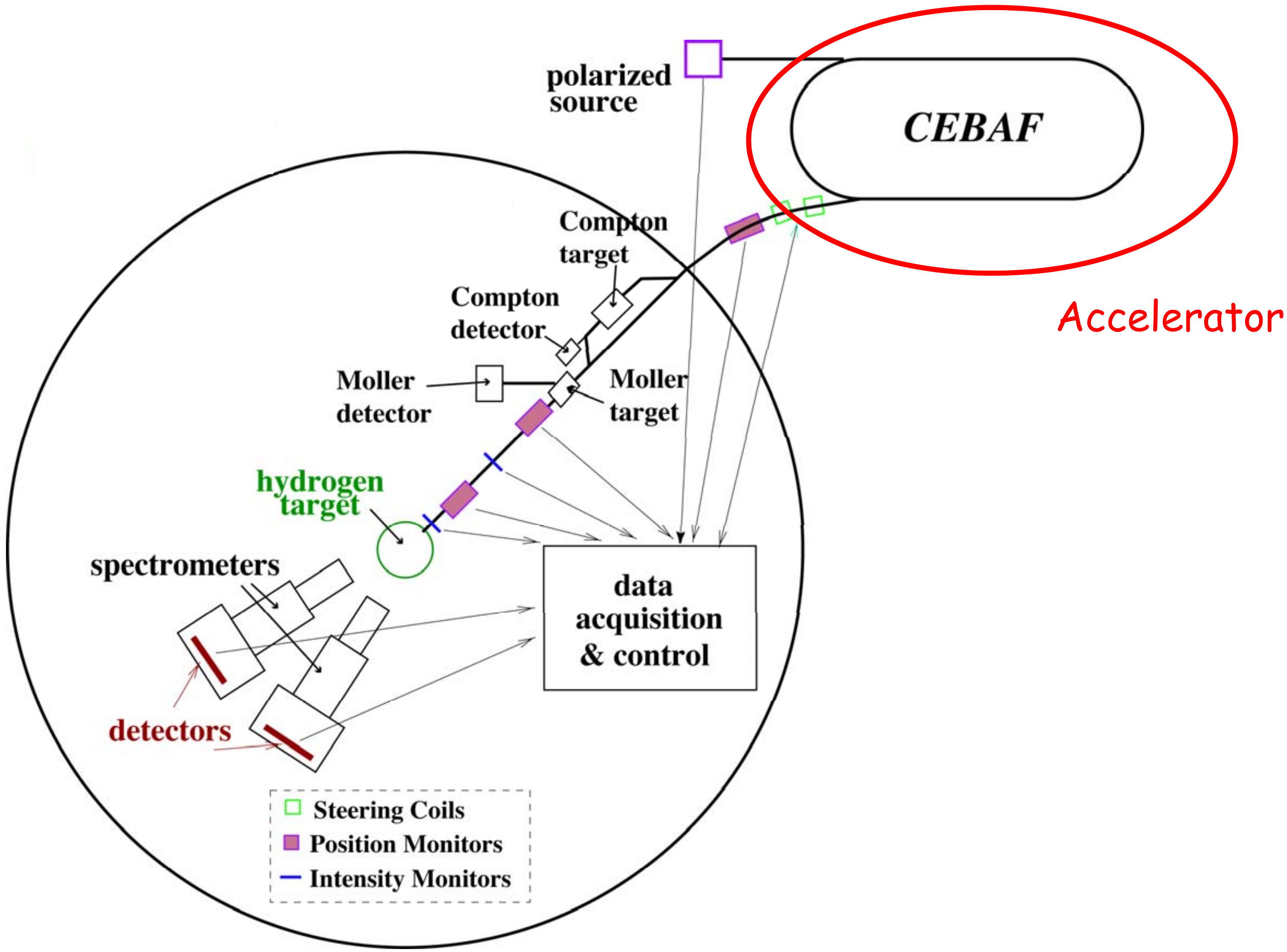

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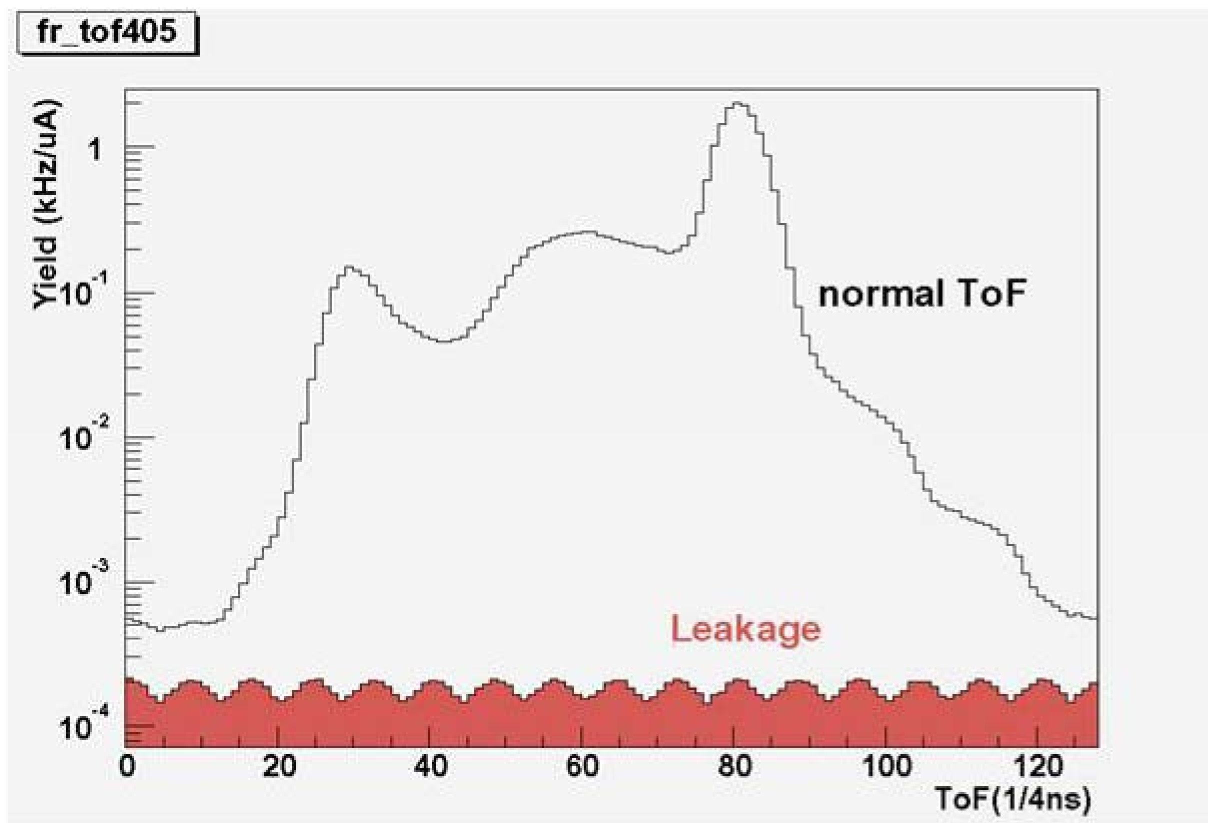
What could go wrong? go wrong? go wrong? go wrong?

During our G^0 run, we observed "leakage beam" from the other two hall's lasers (which had a repetition rate of 2 nsec instead of the 32 nsec G^0 repetition rate.) at the ~ 10^{-3} level

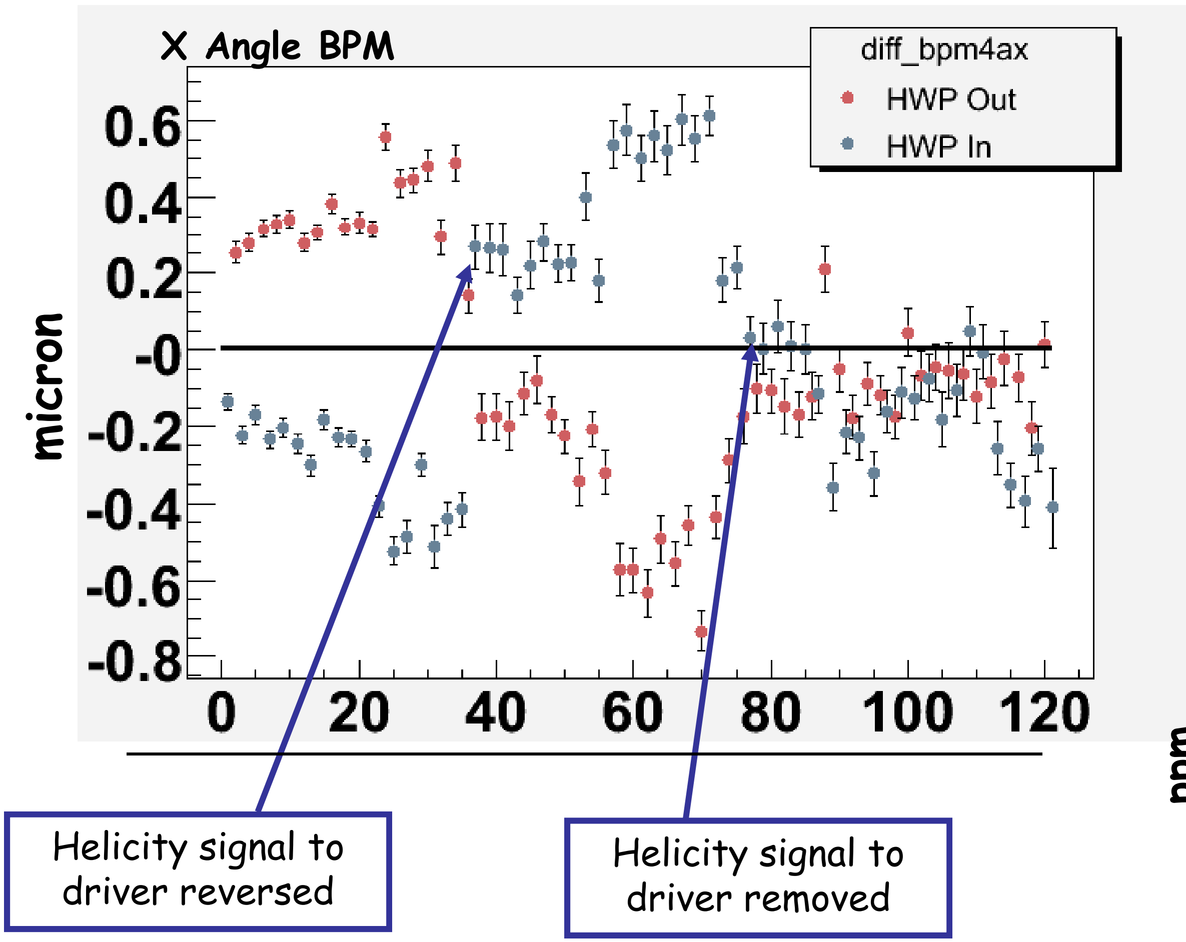
Problem: the leakage beam had ~ 540 ppm charge asymmetry!
Solution: correct using the data in TOF regions where there are few G^0 events. (ultimate correction was small: 0.71 ± .14 ppm).



go wrong? go wrong? go wrong? go wrong?

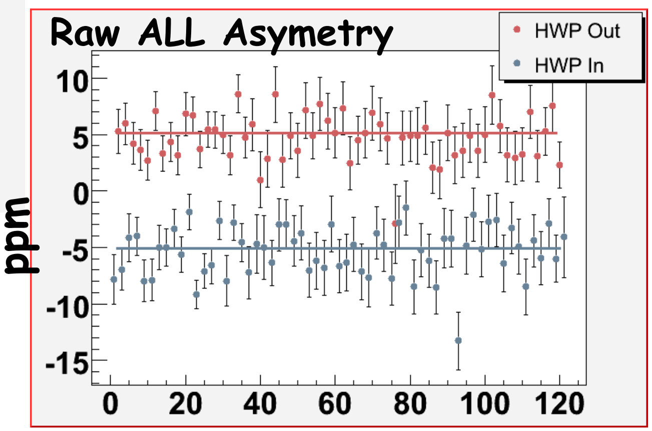
Electronic Cross-Talk of the Helicity Signal

During HAPPEx-He run, abnormally large position differences were observed.



All's well that ends well

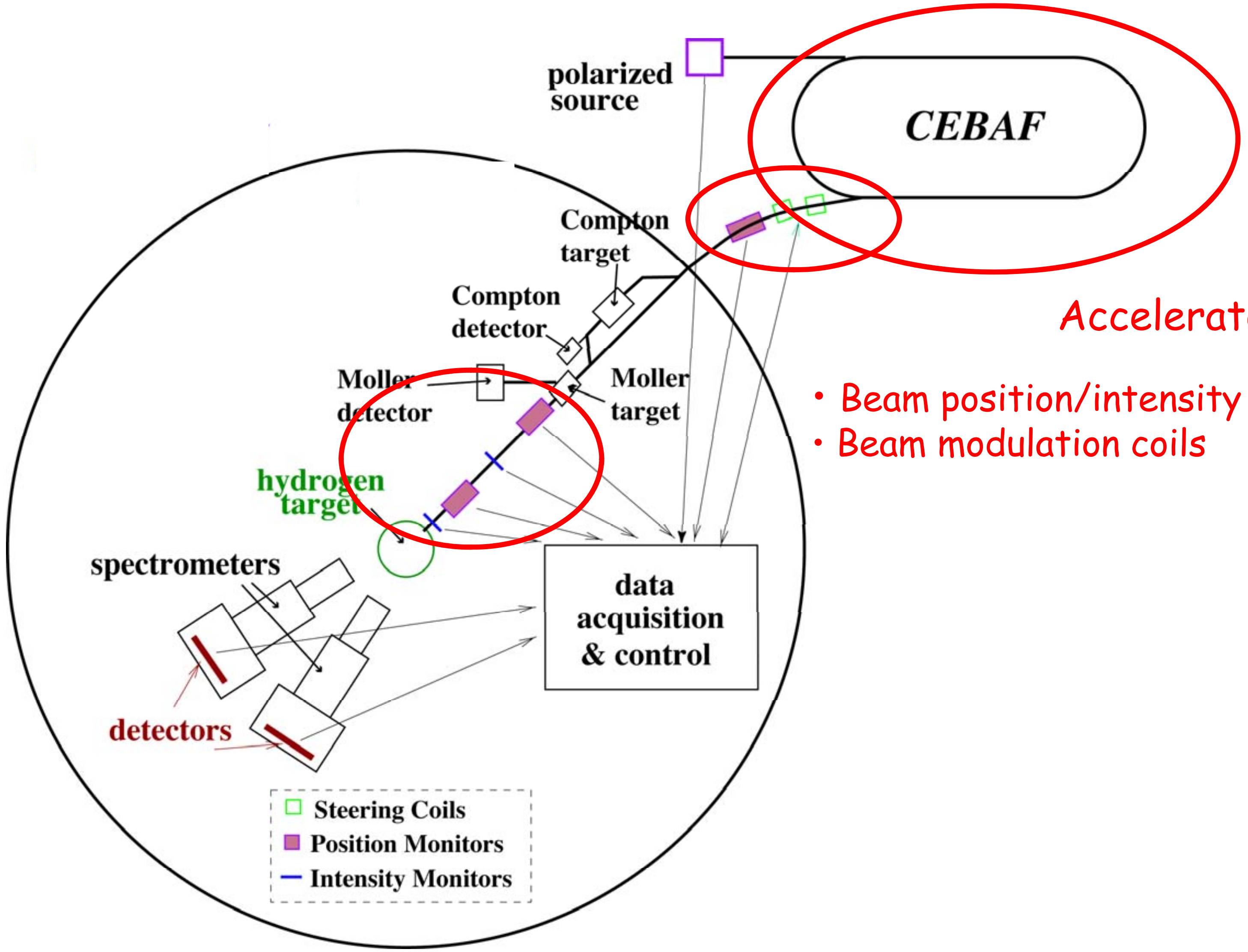
- Problem clearly identified as beam steering from electronic cross-talk
- No helicity-correlated electronics noise in Hall DAQ at < ppb level
- Large position differences ≈cancel in average over both detectors



Problem: Helicity signal deflecting the beam through electronics "pickup"

Large beam deflections even when Pockels cell is off

"Modern" Overview of Parity-Violating Electron Experiment



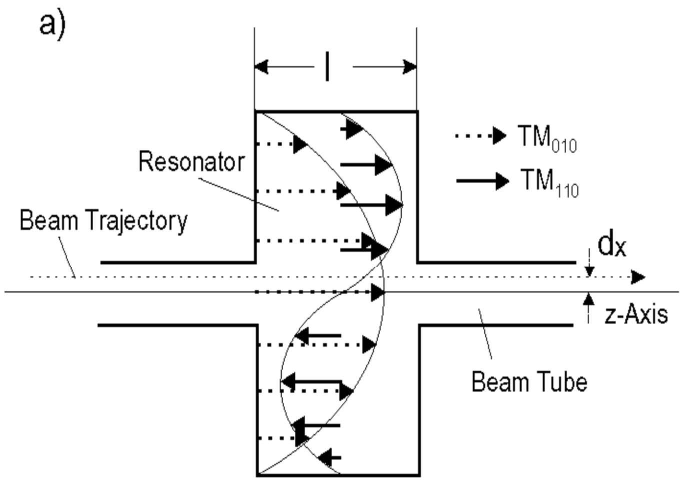
Accelerator

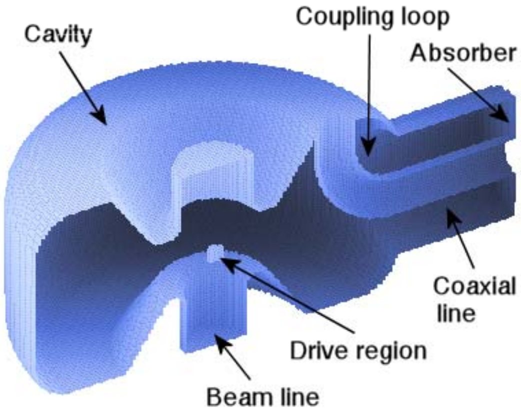
- Beam position/intensity monitors
- Beam modulation coils

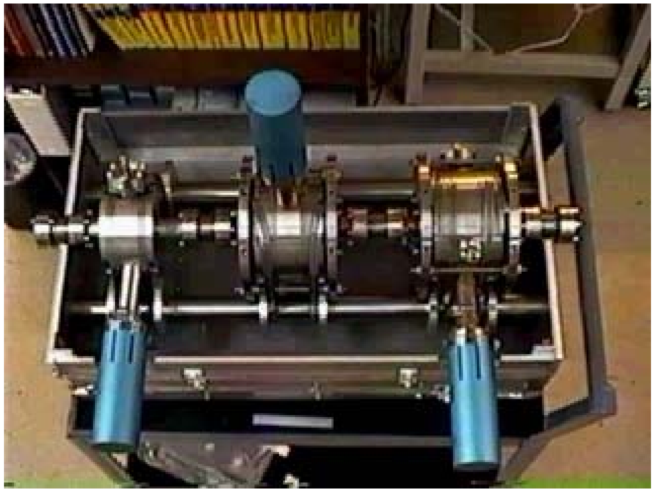
Basic layout is the same as E122; but we will use this as our basic roadmap to the technical developments. Examples will be drawn from many labs (SLAC, JLab, MAMI) and experiments.

Beam Instrumentation – Microwave Cavity Monitors

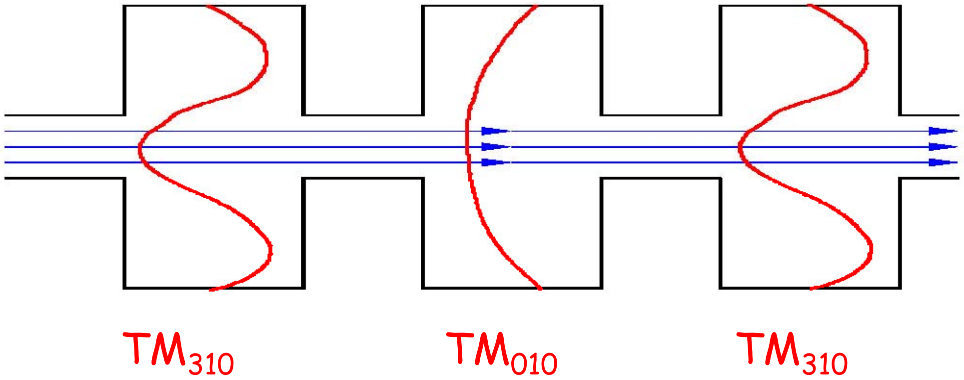
Microwave cavity monitors: used at SLAC and at JLAB at the urging of the parity groups.
Electromagnetic cavity resonant at the accelerator RF (1497 MHz at JLAB).
TM_{010} $\rightarrow$ measure beam intensity
TM_{110} $\rightarrow$ measure beam position





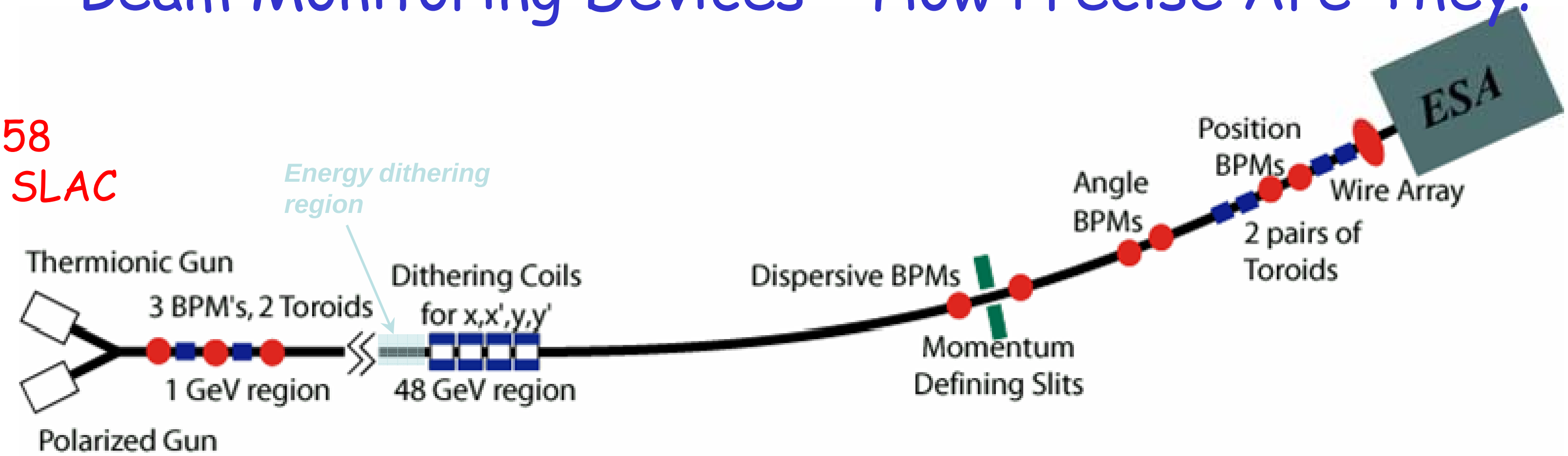


Possible beam spot size monitor for future? (Dave Mack, JLAB, proposal – three cavity scheme based on existing JLAB "pillbox" style cavities)
Upcoming experiments could start to have sensitivity to beam spot size modulations

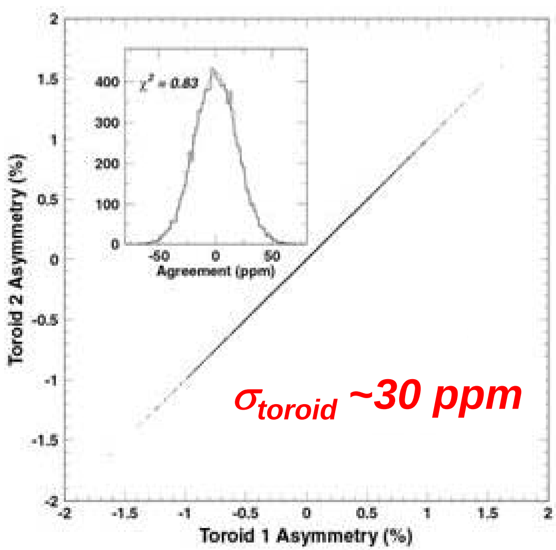


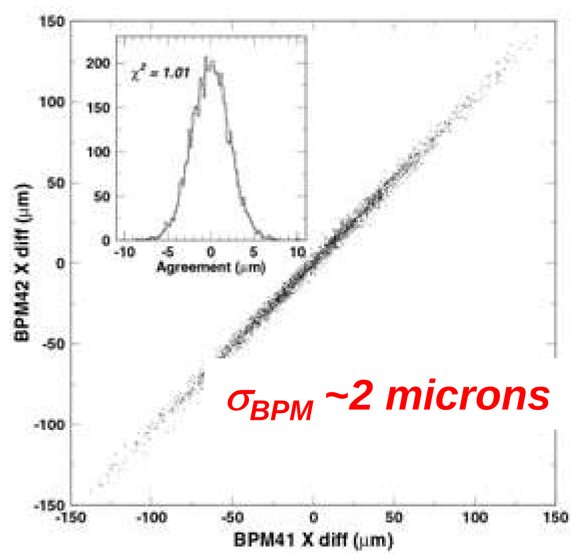
Beam Monitoring Devices – How Precise Are They?

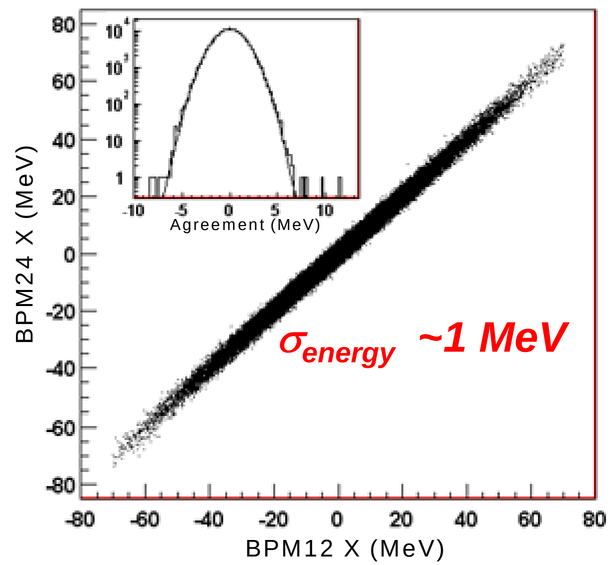
E158
at SLAC



Can compare measurements from neighboring identical devices to separate "beam" noise from intrinsic "beam monitor" noise:
need precise beam property monitoring to minimize helicity-correlated beam property differences and correct for any remaining differences.





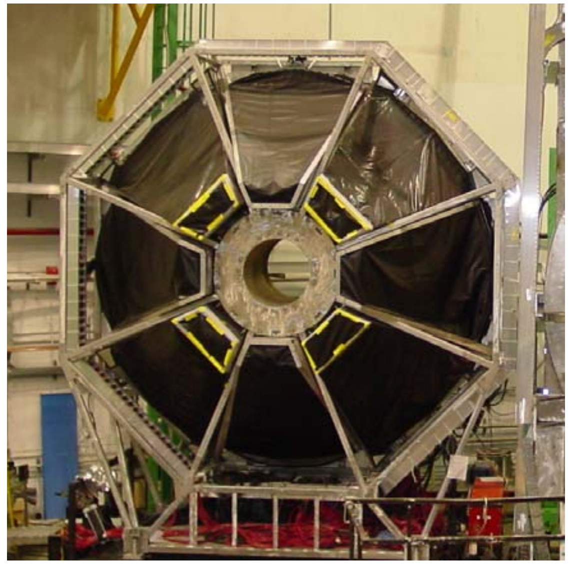


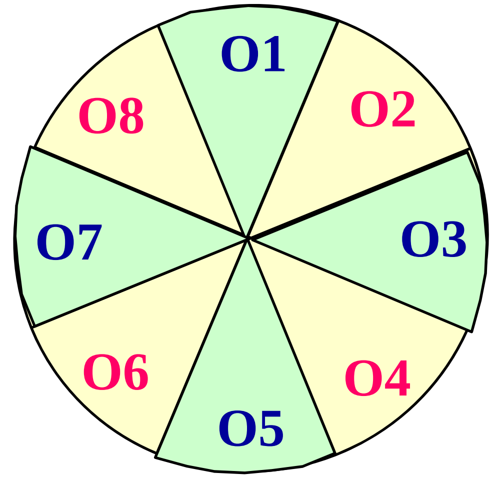
Beam Modulation

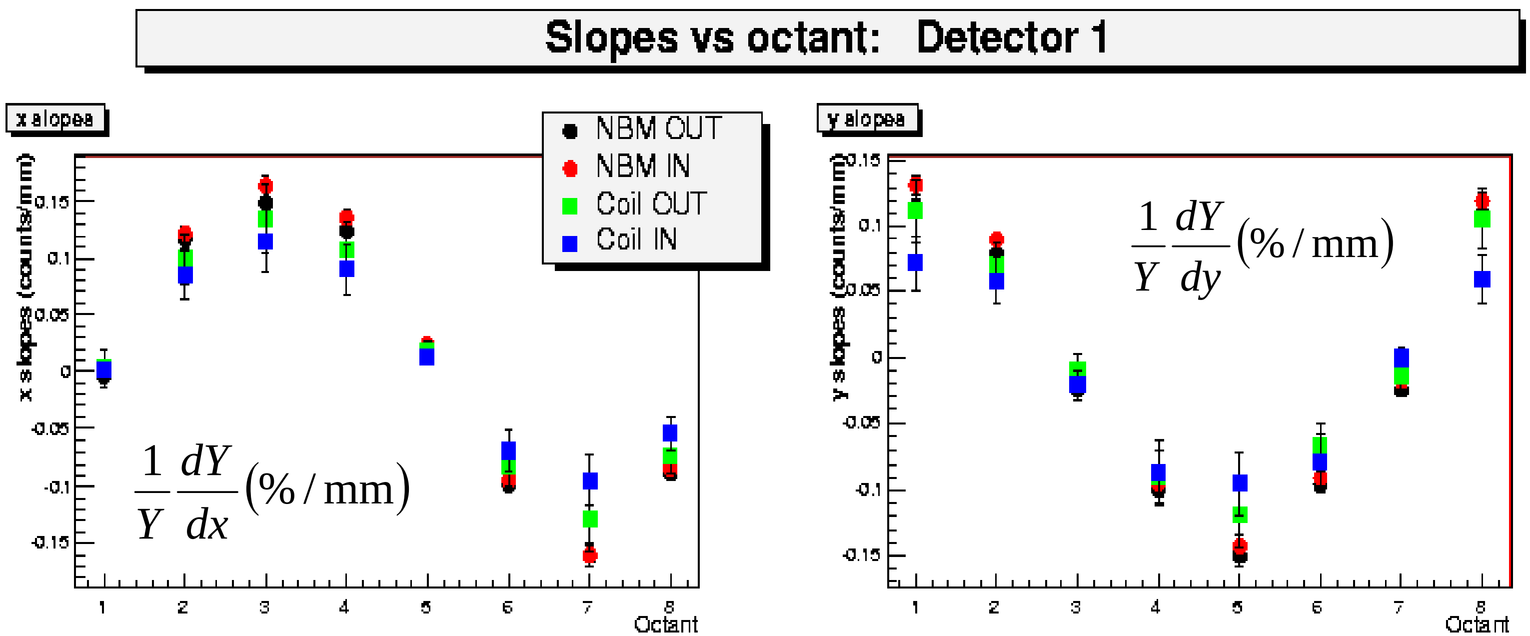
Air-core steering coils are used to rapidly vary the beam position and angle at target in "coil-pulsing scans" to measure the detector response to beam parameter variations

Example from G^0 experiment:

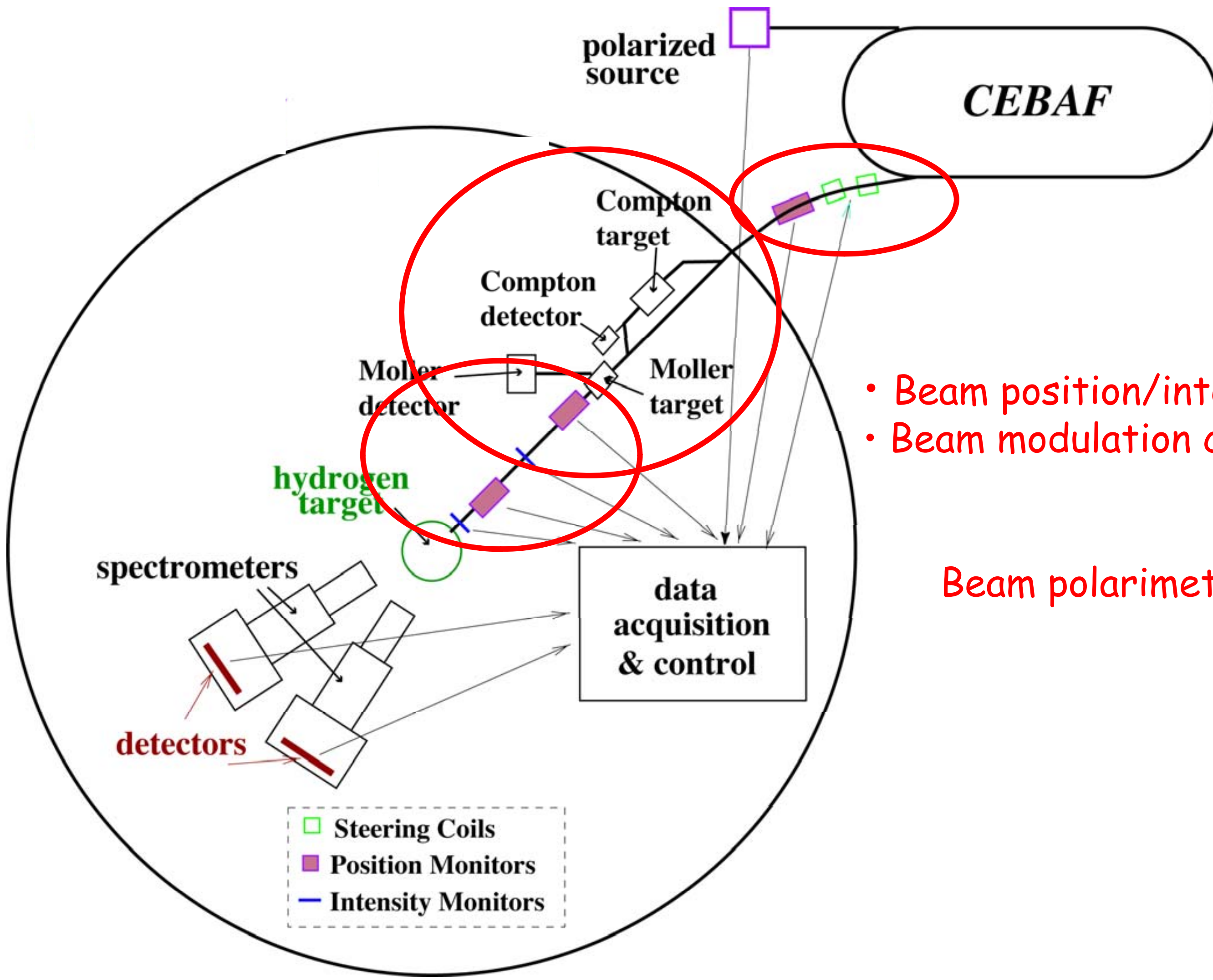
Measured yield slopes







"Modern" Overview of Parity-Violating Electron Experiment



- Beam position/intensity monitors
- Beam modulation coils

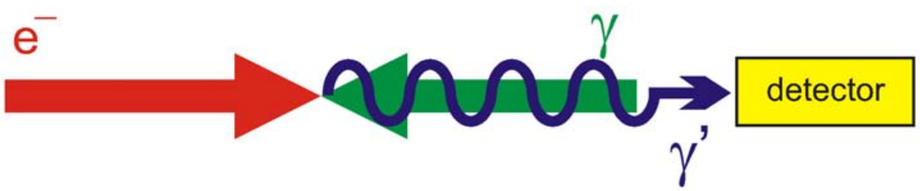
Beam polarimetry

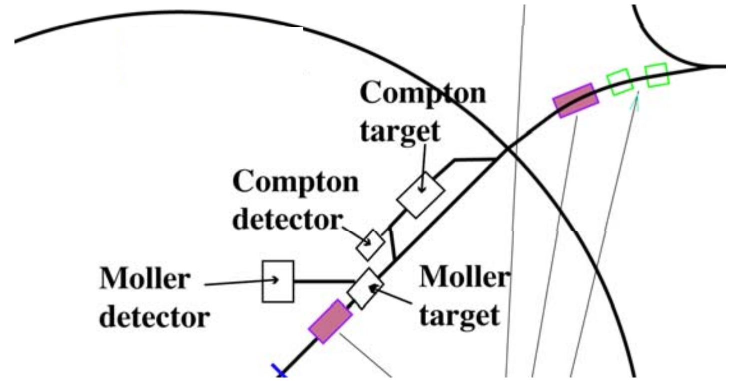
Basic layout is the same as E122; we will use this as our basic roadmap to the technical developments. Examples will be drawn from many labs (SLAC, JLab, MAMI) and experiments.

Electron Beam Polarimetry

Compton backscattering: boost laser photon energy;
can be done non-invasively

$$\vec{e} + \vec{\gamma} \rightarrow e' + \gamma'$$





Moller scattering: scatter polarized electrons from polarized electrons in an iron or iron alloy foil
invasive and only useful at low beam currents; best absolute error

$$\vec{e} + \vec{e} \rightarrow e' + e'$$

In each case, polarization is determined from QED calculated analyzing powers.

For future: Moller polarimetry with atomic hydrogen targets (Chudakov)
$\rightarrow$ would allow for continuous, high current Moller polarimetry

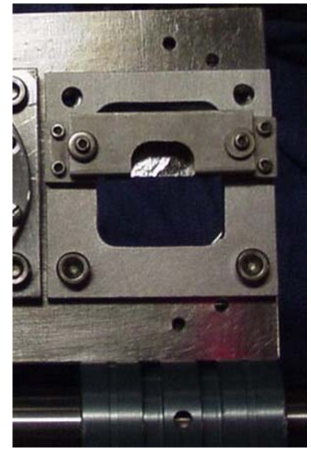
Polarimetry talks: Eugene Chudakov, Jurgen Diefenbach, Wouter Deconinck

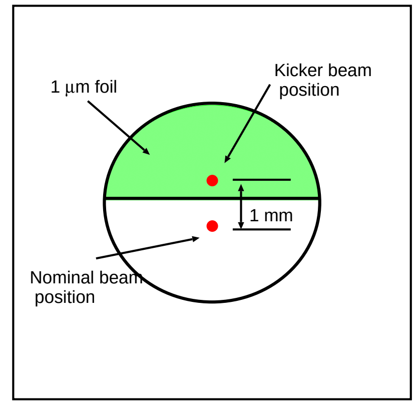
Example – Kicker Magnet for High Current Moller Polarimetry

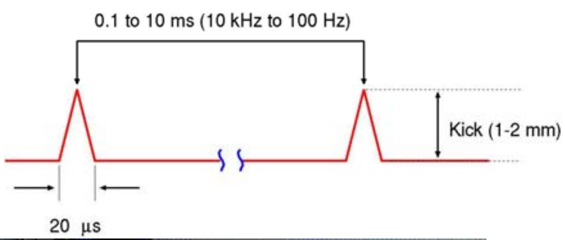
Hall C Moller polarimeter:
Pure iron foil polarized out of plane using 4 T field from solenoid
Limited to ~ 2 μA beam current due to need to keep foil heating effects (and hence target depolarization) low

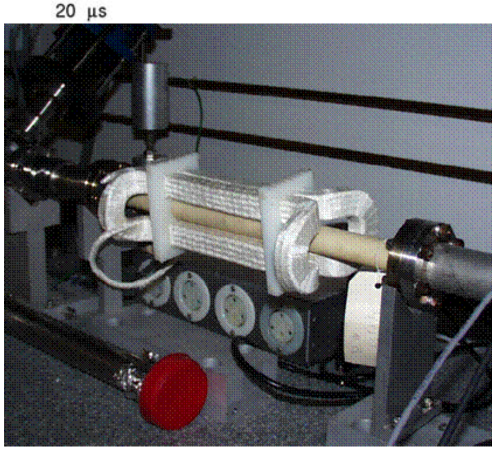
Systematic error on Hall C Moller ~ 0.5%; would be nice to transfer this to higher beam currents

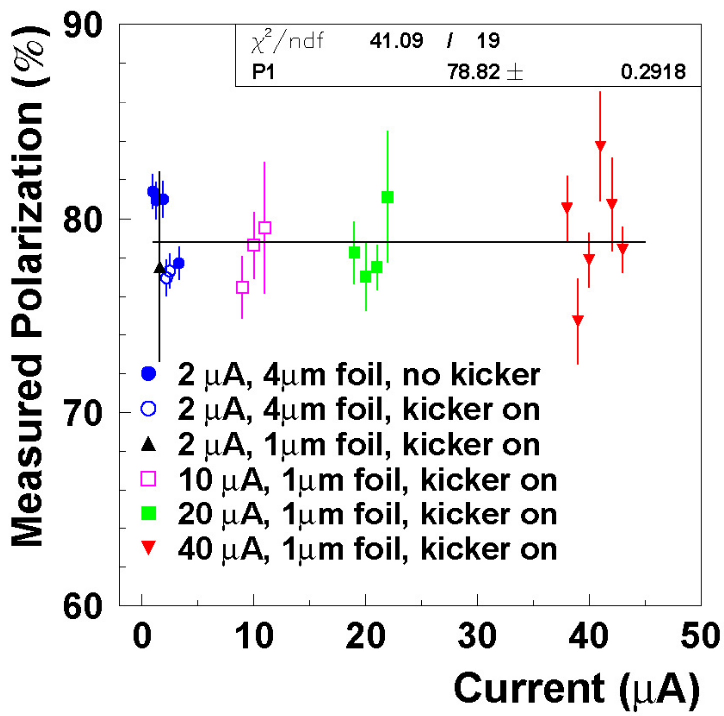
Idea: "kick" the high current beam for short periods onto a Moller foil strip to minimize target heating at high current





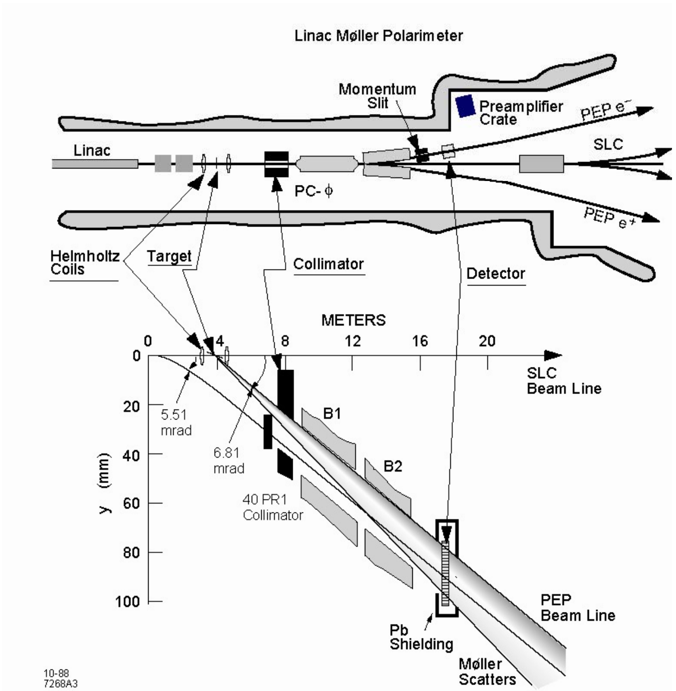


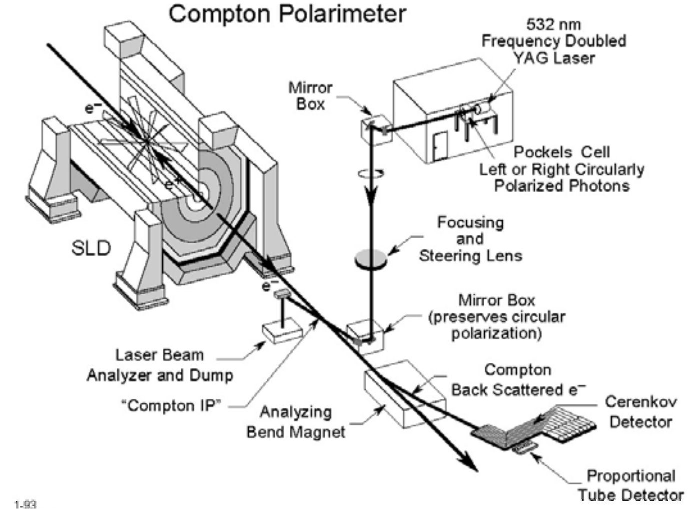




Beam Polarimetry – A Cautionary Tale from SLC

SLC had Compton as primary polarimeter, but could cross compare with Moller polarimeter. (1994)





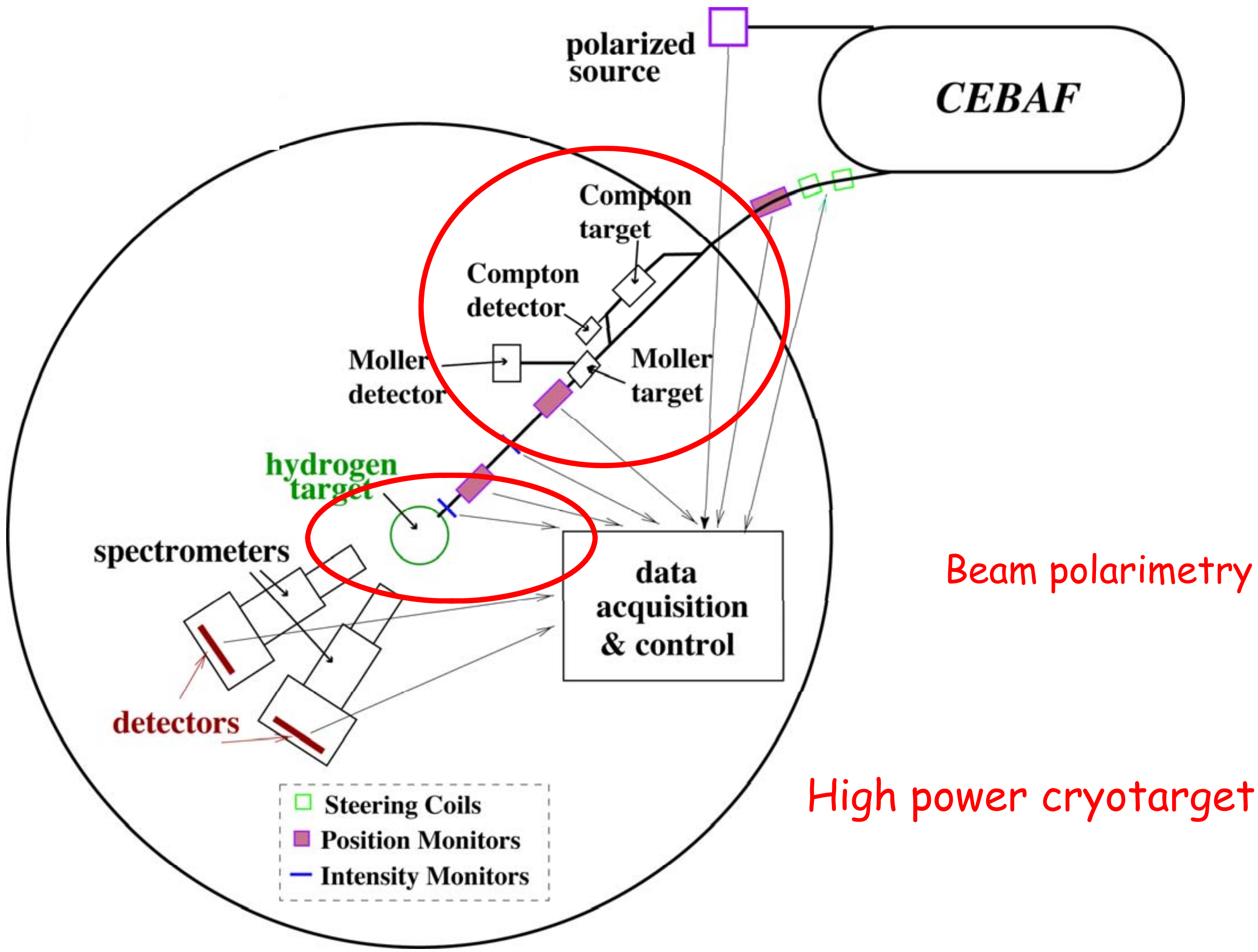
$P_e = 80.0 \pm 0.9 \pm 3.4\%$ $P_e = 65.7 \pm 0.9\%$

$P_e = 69.0 \pm 0.8 \pm 2.9\%$

Levchuk effect: importance of target electron motion effects depends on acceptance (Levchuk NIMA345, 496 (1994))

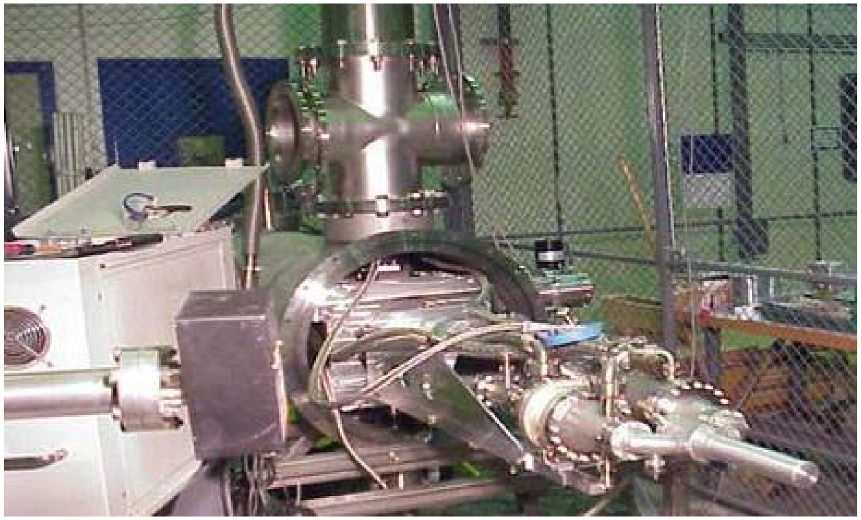
Upcoming experiments (12 GeV Moller) need ~0.4% precision polarimetry: ideally one would have two redundant polarimetry techniques at this level.

"Modern" Overview of Parity-Violating Electron Experiment

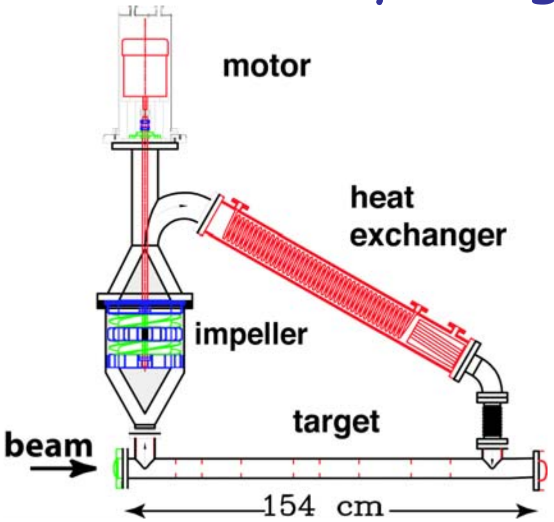


Basic layout is the same as E122; we will use this as our basic roadmap to the technical developments. Examples will be drawn from many labs (SLAC, JLab, MAMI) and experiments.

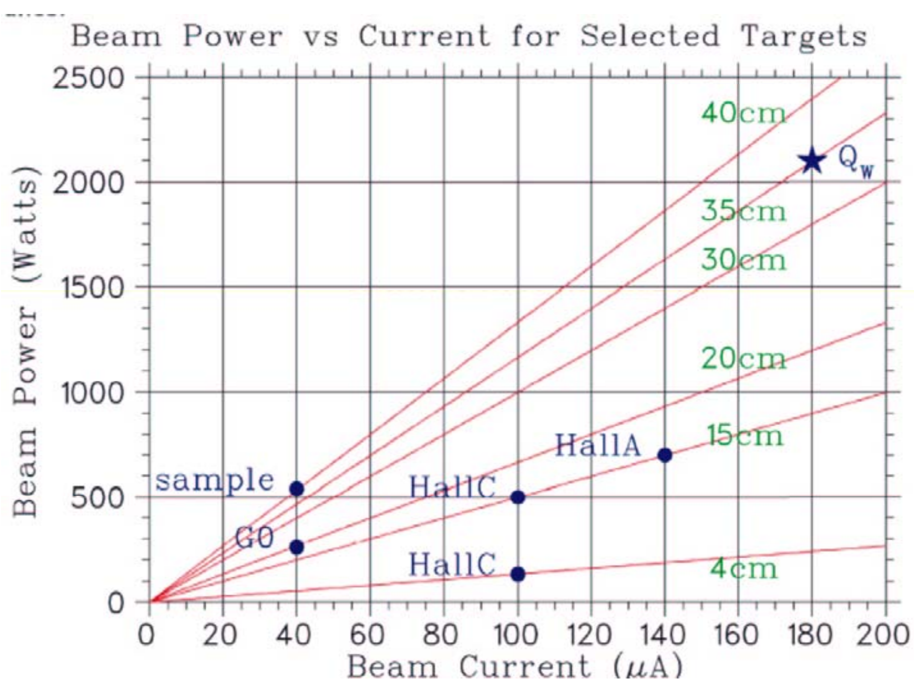
Examples of some High Power Parity Violation Cryotargets



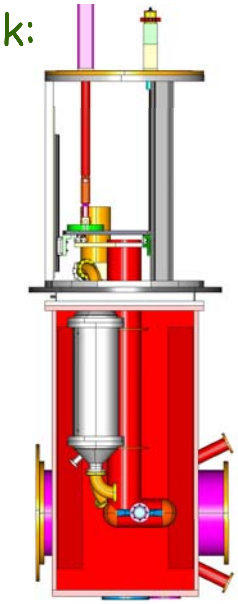
G^0: 20 cm, 500 W @ I=40-60 μA



E158: 150 cm, 700 W @ I=12 μA



Target overview talk:
Greg Smith

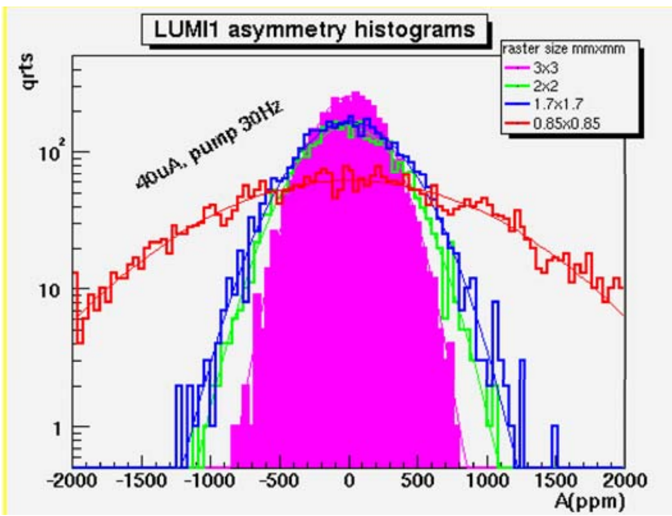


Q_{weak}: 35 cm, 2500 W @ I=180 μA

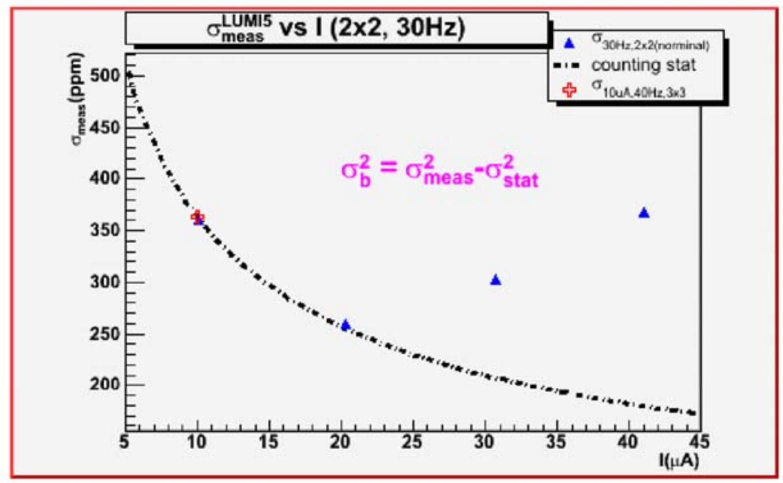
Target Density Fluctuations - "Target Boiling"

$$\Gamma_{stat} = \sqrt{\Gamma_{count}^2 + \Gamma_{electronics}^2 + \Gamma_{target}^2} \quad \text{want } \Gamma_{target} << \Gamma_{count}$$

Example from G^0 target: use "luminosity monitors" (small angle Cerenkov detectors) – smaller Γ_{count} to increase sensitivity to Γ_{targ}



Lumi random fluctuations increase as beam area is decreased at fixed current



Vary beam current – deviation of lumi random fluctuations from 1/sqrt(I) line measures target density fluctuations

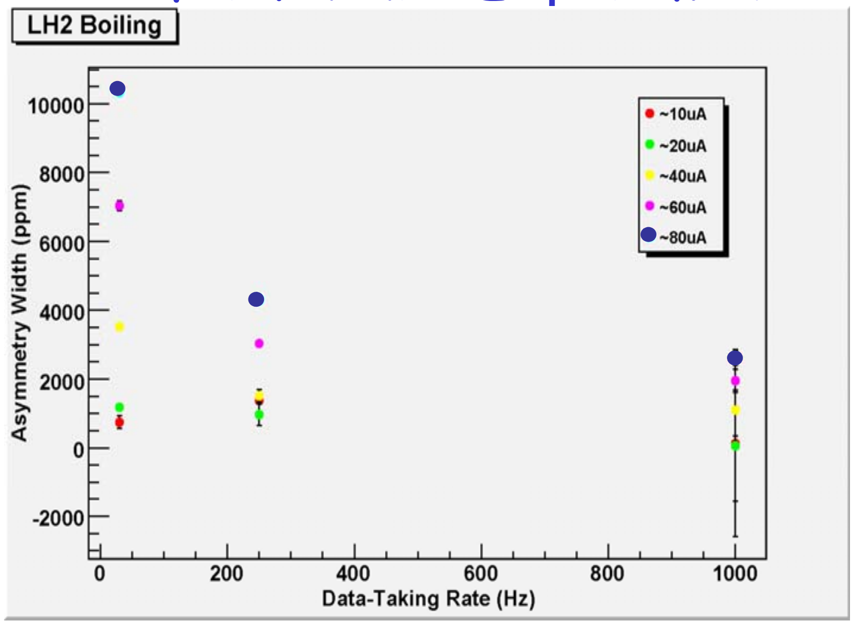
For G^0 target:

Γ_{target} ~ 238 ppm << Γ_{count} ~ 1200 ppm

Target Density Fluctuations – Advantage of Higher Data-Taking Rates for Future Experiments

$$\Gamma_{stat} = \sqrt{\Gamma_{counting}^2 + \Gamma_{target}^2}$$

We can reduce the relative contribution of the density fluctuation term by going to higher data-taking frequencies (increased $\Gamma_{counting}$) assuming Γ_{target} either stays constant or decreases with frequency. The data here indicate that the boiling term drops with frequency as f $^{-0.4}$.

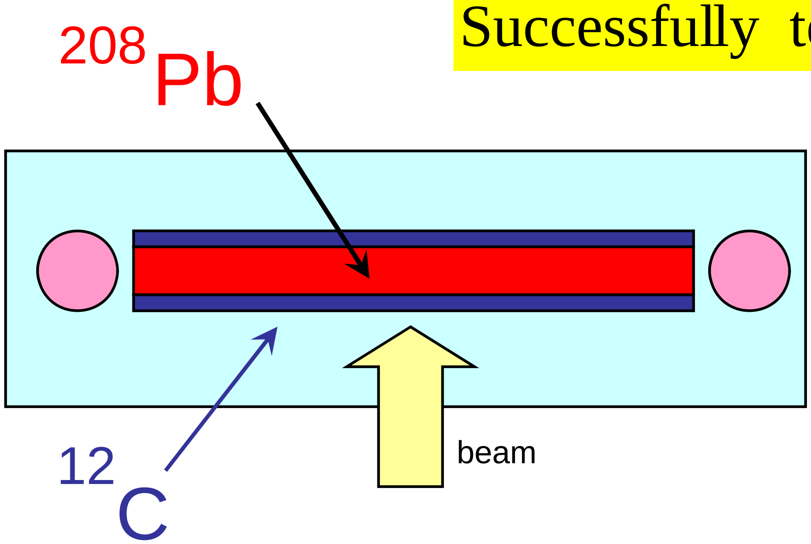


$$\Gamma_{targ} = \Gamma_{30\,Hz}\left(\frac{30\text{ Hz}}{f}\right)^{0.4}$$

	Experiment	Γ_{target}	Γ_{count}
Completed	G^0 (30 Hz)	238 ppm	1200 ppm
	E158 (120 Hz)	<65 ppm	200 ppm
Expected	Qweak (250 Hz)	50 ppm	144 ppm
	12 GeV Moller (2000 Hz)	26 ppm	78 ppm

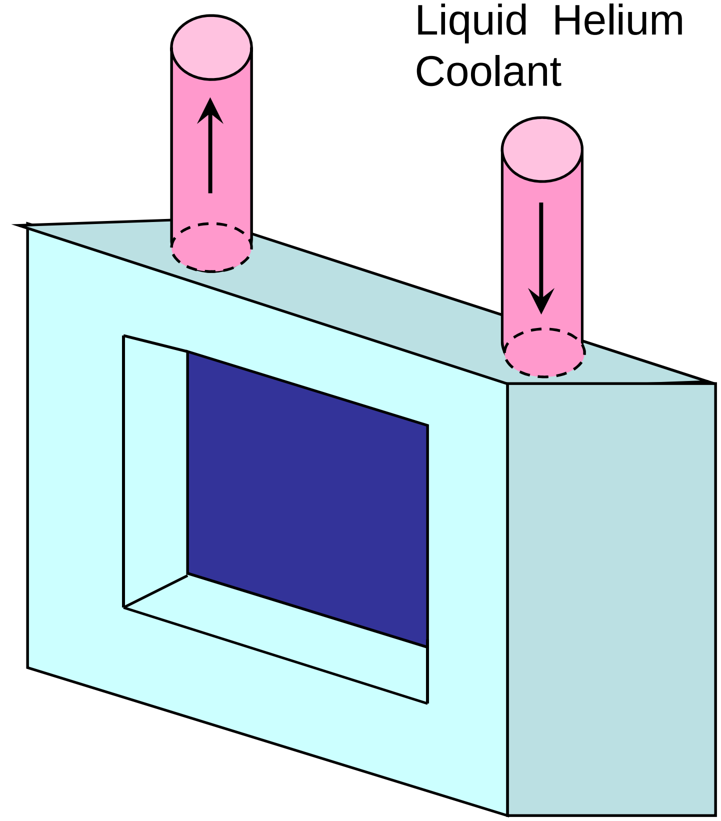
Lead Target for PREX

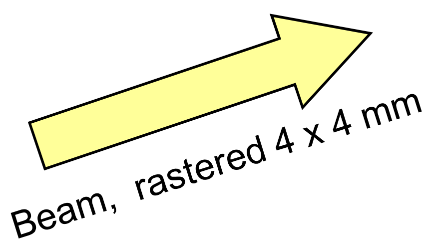
Successfully tested at 80 μA



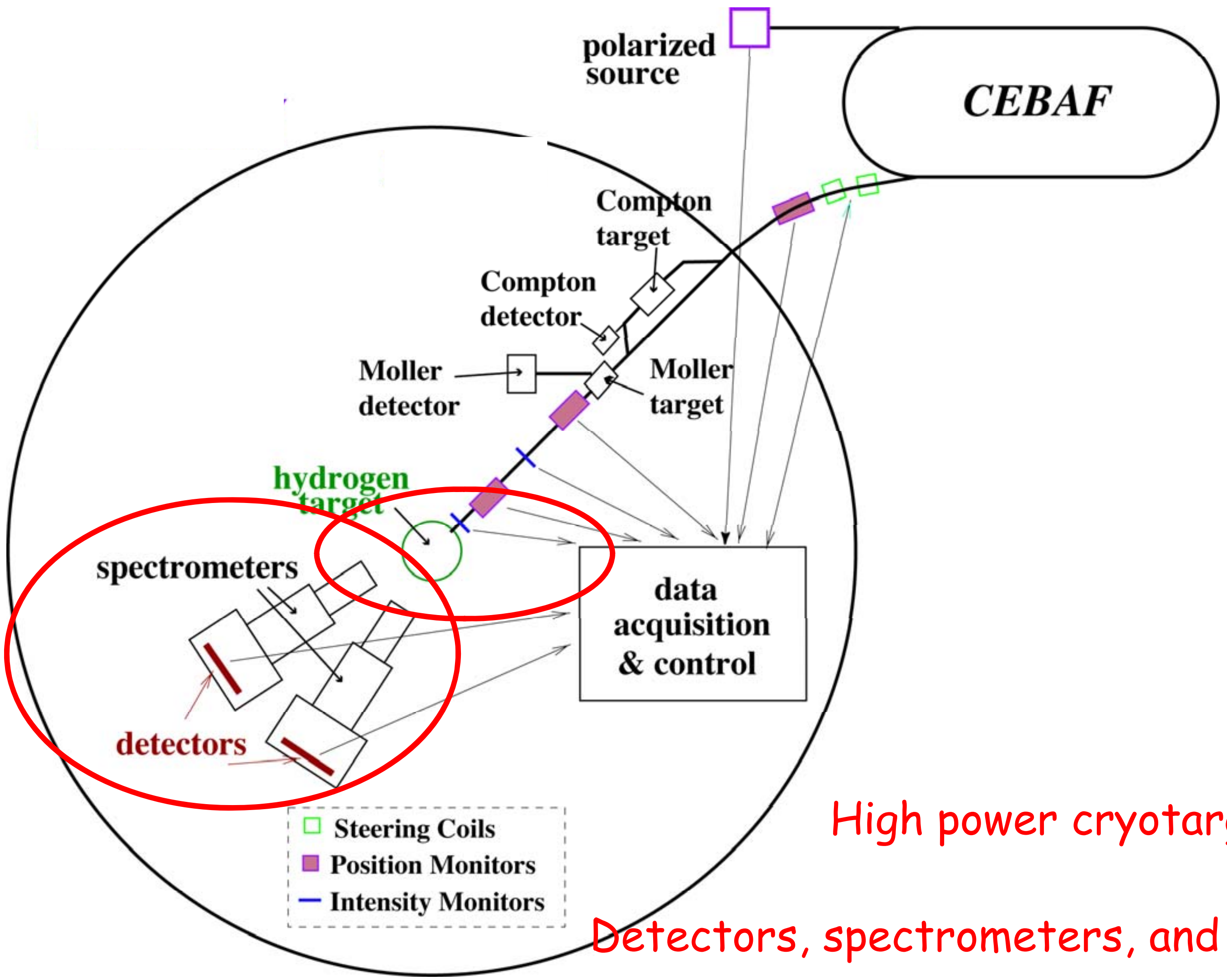
Diamond Backing:

- High Thermal Conductivity
- Negligible Systematics





"Modern" Overview of Parity-Violating Electron Experiment



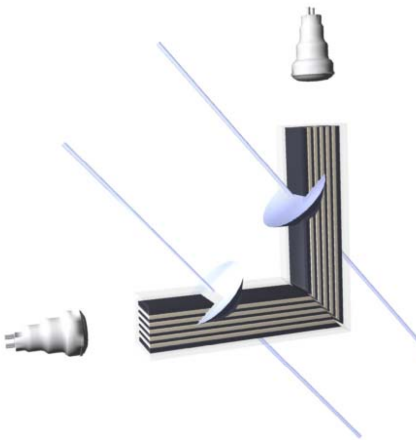
High power cryotarget

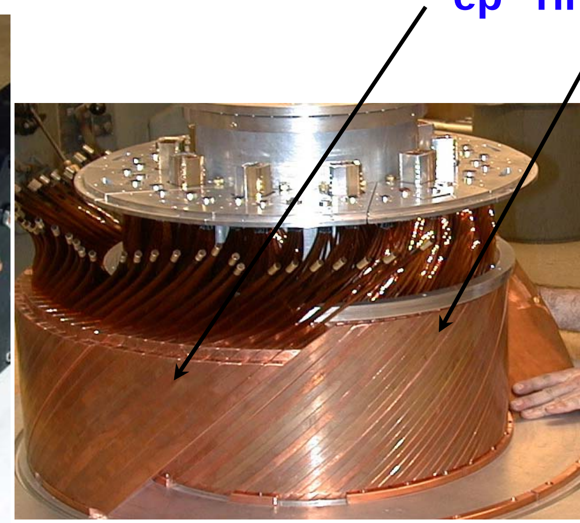
Detectors, spectrometers, and electronics

Basic layout is the same as E122; we will use this as our basic roadmap to the technical developments. Examples will be drawn from many labs (SLAC, JLab, MAMI) and experiments.

Examples of Detector Technologies

HAPPEx:
brass/fused silica
calorimeter



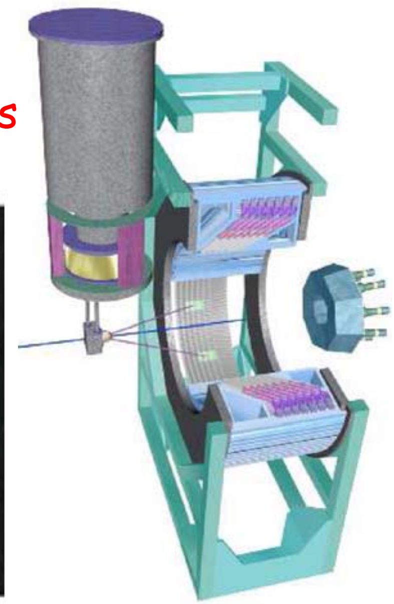


E158:
copper/fused
silica calorimeter;
100 MRad dose

High count rates → radiation hard detector materials essential

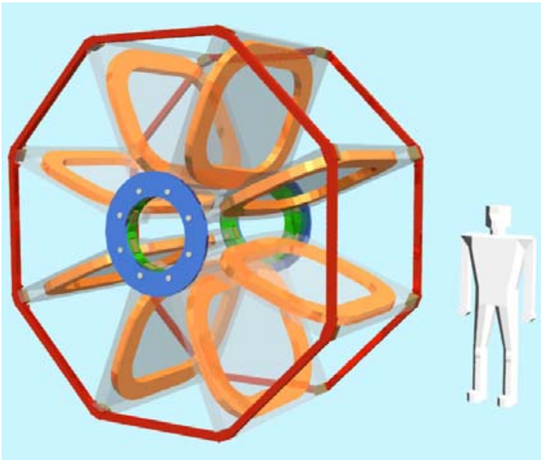
Qweak: Cerenkov detector
made of 1 meter fused silica bars

A4 calorimeter:
array of 1024 PbF_2 crystals

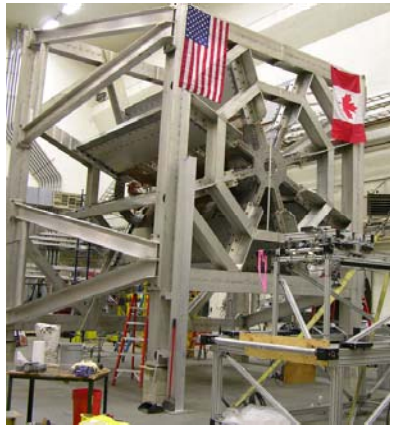


Purpose-built Magnetic Spectrometers

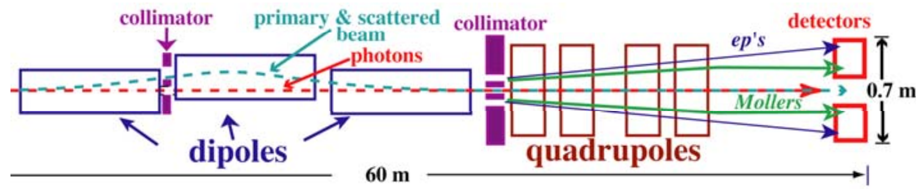
G^0 superconducting toroid



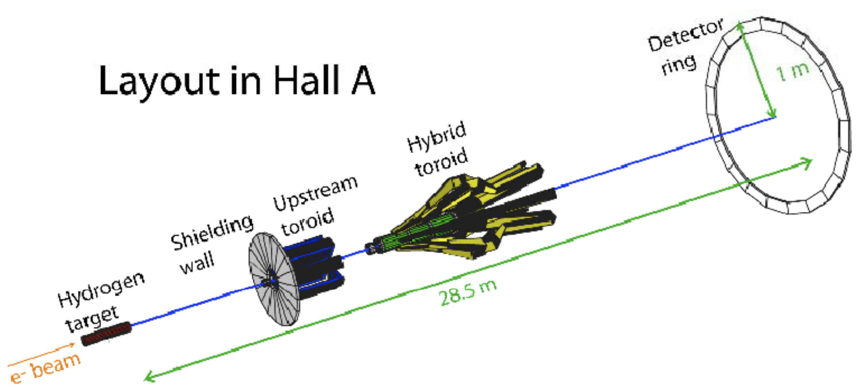
Q_{weak} toroid



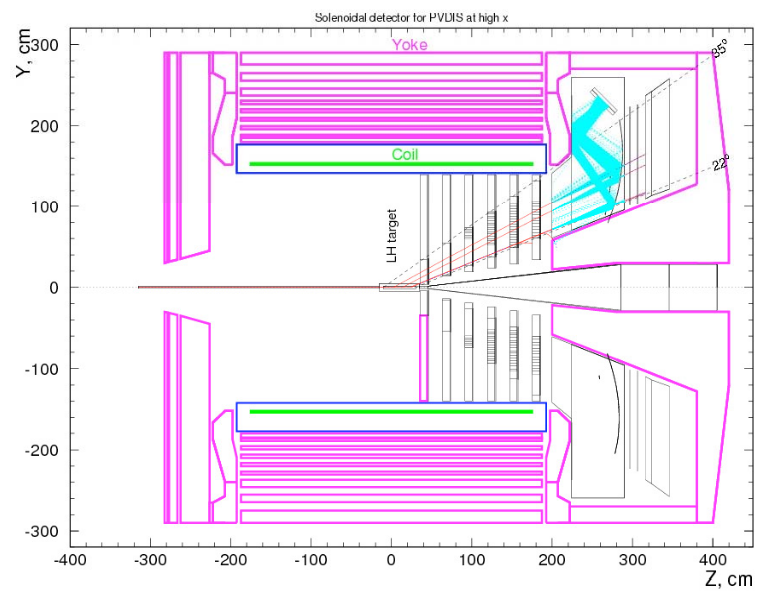
E158 spectrometer: recycled 3 dipoles and 4 quads from 8/20 GeV spectrometers



12 GeV Moller 2 toroid spectrometer concept



12 GeV PVDIS solenoid concept: (recycle magnet from BaBar, CDF, or CLEO II)

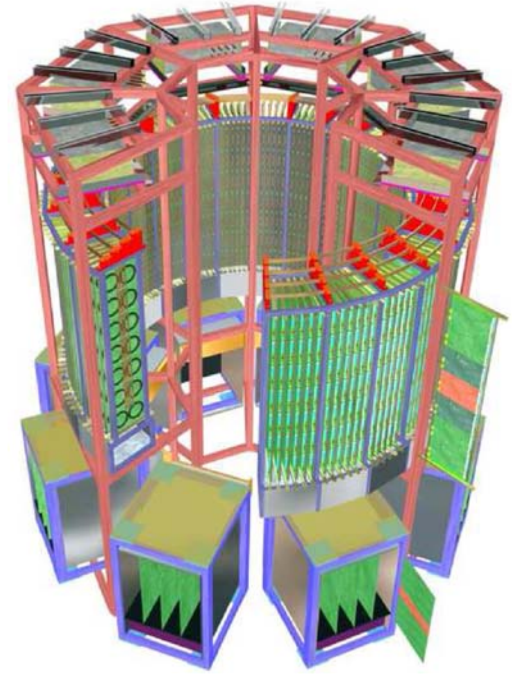


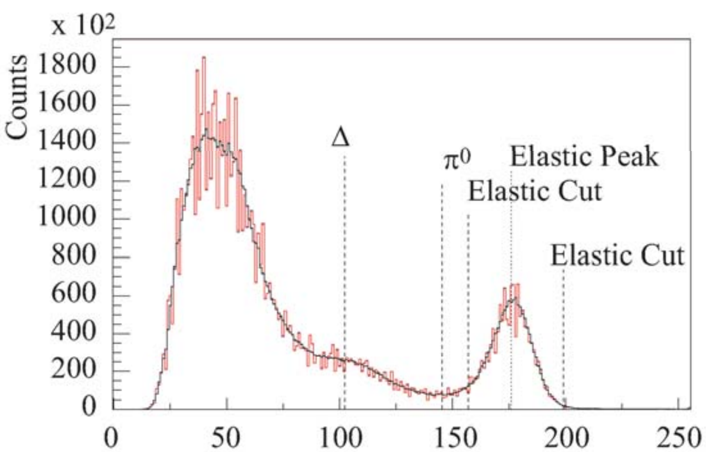
Electronics (Pulse Counting) – A4 Custom Electronics

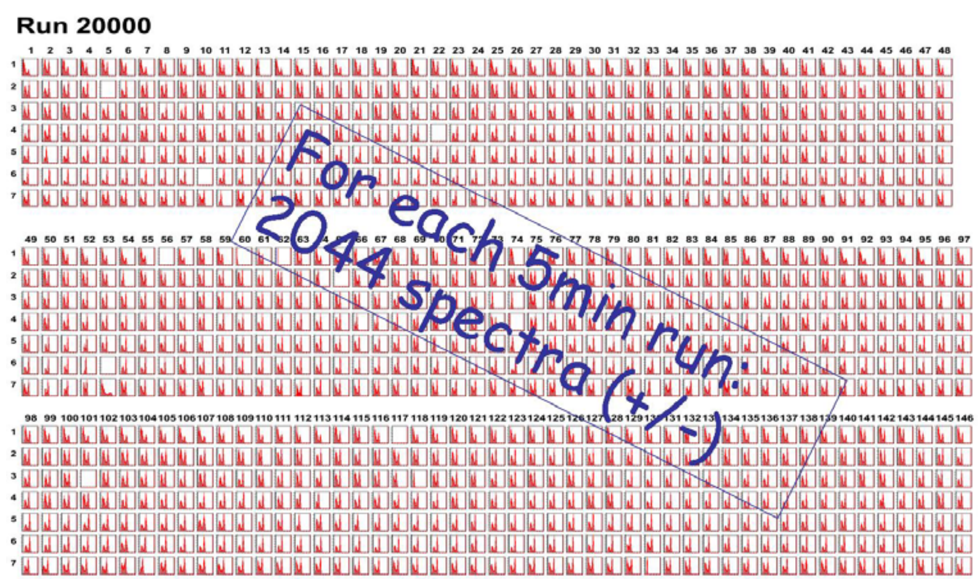
A4: high rates, large (1024) segmentation → energy histogramming

Analog real time event processing/histogramming – sum central crystal and eight neighbors

analogue Real Time Event Processing, analogue Bandwidth ≈ GHz
Network: analog: 8 digital: 24
FIFO pipeline, 50 MHz, Histogramming using PGA
Dual Port Memory in VMEbus, 256 kbyte per Channel
256 Mbyte per 5 Minutes, 20 Frontend CPUs
Experiment Control, Readout and Online-Analysis



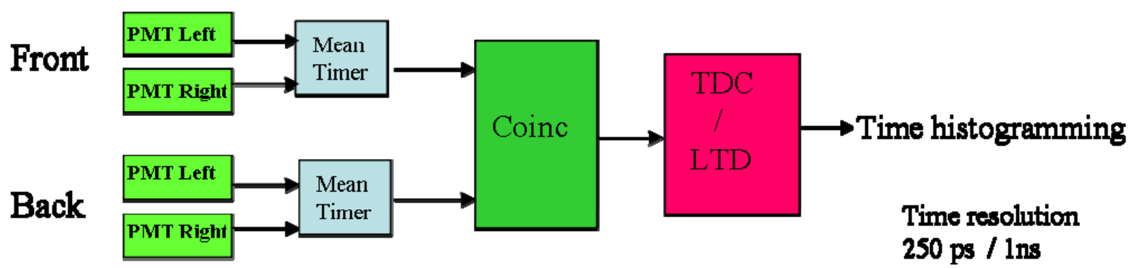


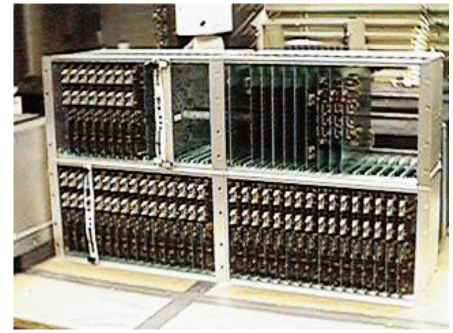


Electronics (Pulse Counting) - G^0 Forward Custom Electronics

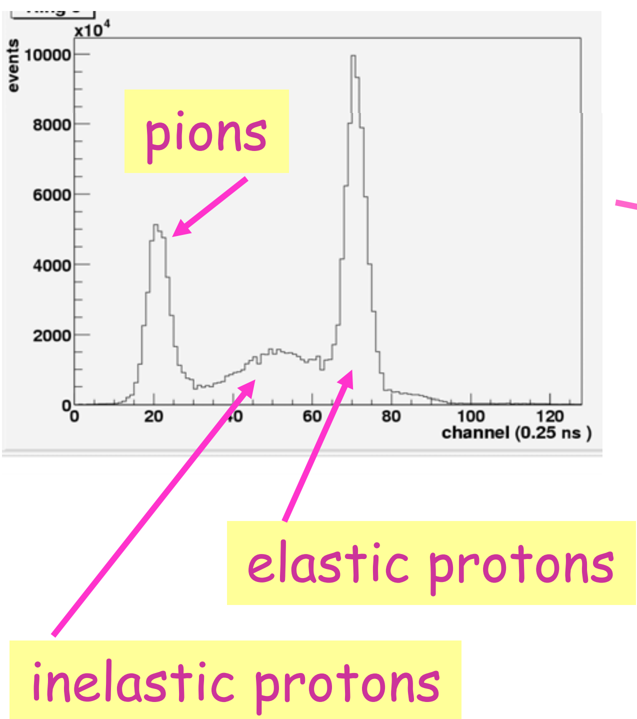
- Custom electronics designed to provide high-rate time-of-flight histogramming
- NA: mean timer → latching time digitizer → scalers (1 ns)
- French: mean timer → flash TDCs (0.25 ns)
- Time histograms read out by DAQ system every 33 msec

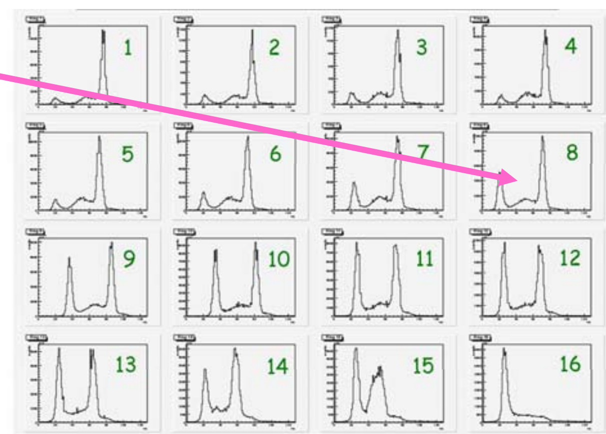
Time of Flight measurement





NA LTD crate (1/2)





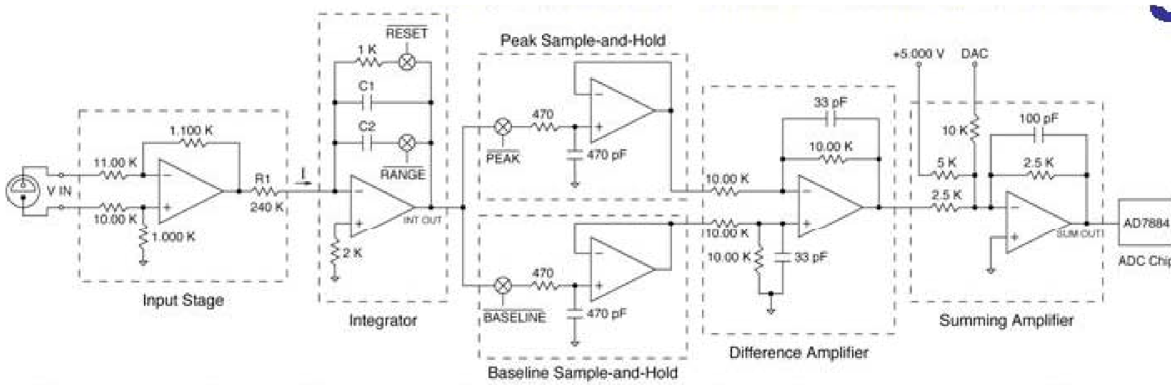
8 x 16 = 108 histograms recorded at 30 Hz

French DMCH16
Module 1/8

Electronics (current mode)

Current mode experiments require low noise amplifiers and high resolution digitization

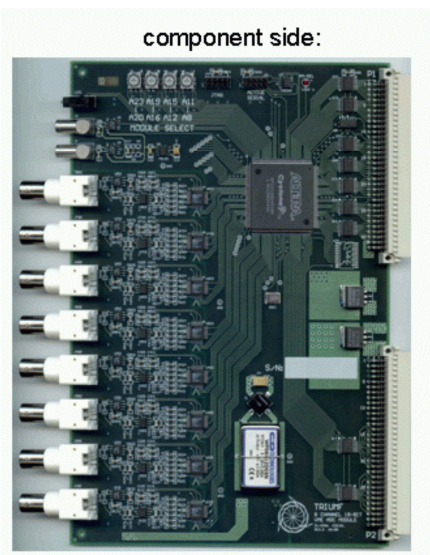
HAPPEx I/II electronics: entire chain on VME module

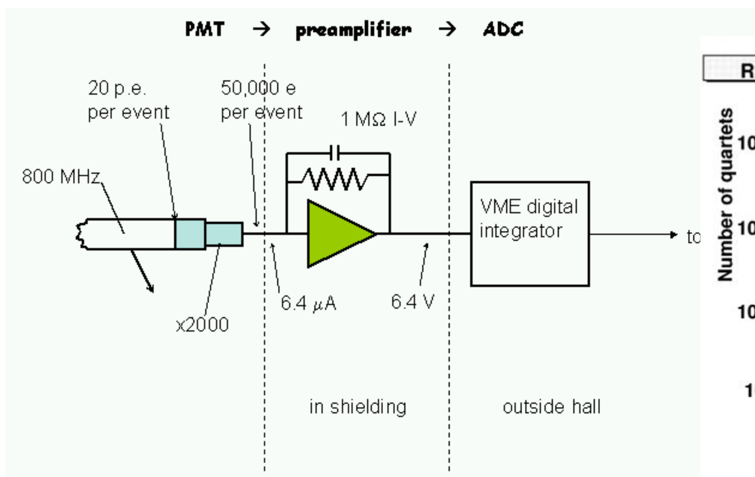


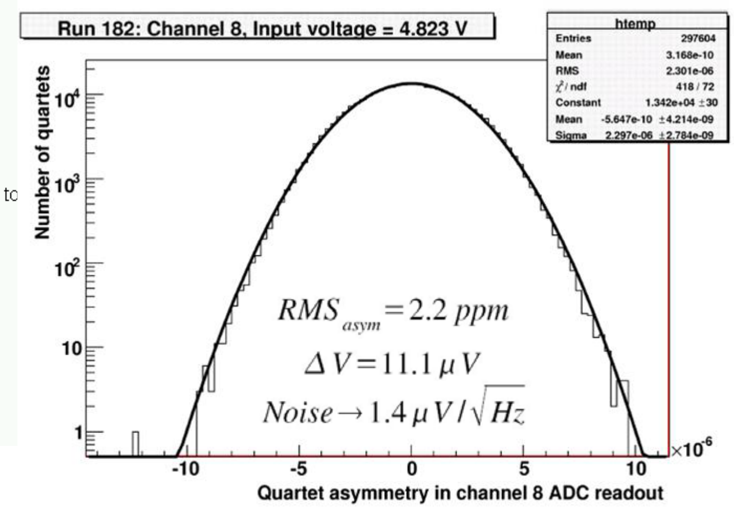
Analog input → integrator → Sample/hold → Difference → ADC chip

HAPPEX
16 bit ADC:
≤ 200 μV noise

Qweak electronics







VME integrator –

18 bit ADC sampling at 500 kHz

FPGA sums 500 samples into one data word

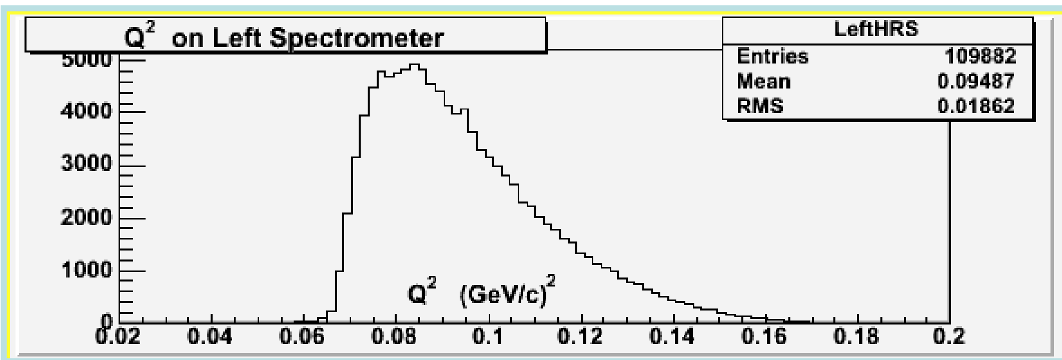
same resolution as a 26 bit ADC

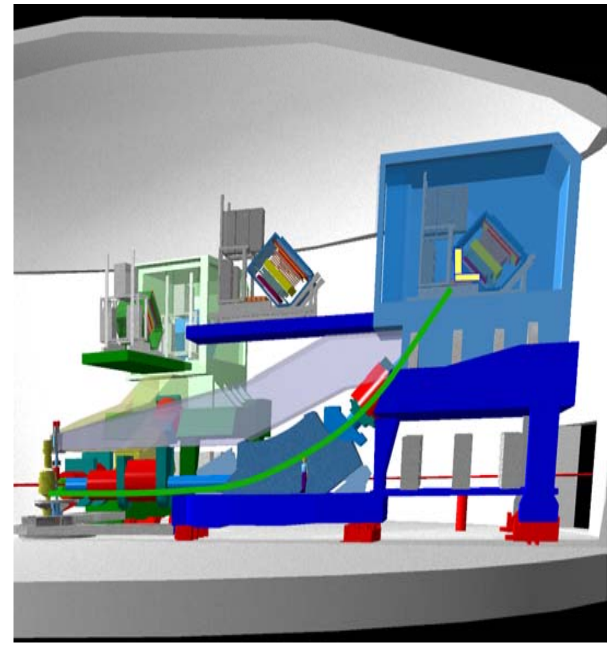
Γ_{elec} ~ 2 ppm << Γ_{count} ~ 144 ppm

Q^2 Measurement

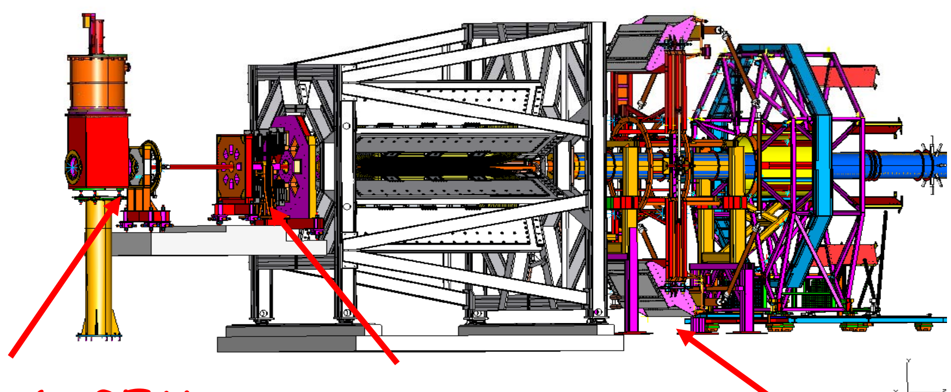
$A \propto Q^2 \rightarrow$ absolute Q^2 measurement needs to be done precisely (to ~1% or better)

HAPPEx: use existing capability of HRS spectrometer





Qweak: Building dedicated system with three sets of tracking devices



Region 1: GEM

Region 2: HDC

Region 3: VDC

Technical Talks at PAVI 2011 or 2012?

Given the experiments that will run or be designed in the next 2-3 years, here are some possible technical development talks you might hear at the next PAVI:

Q_{weak}
- High power (2500 watt) target performance
- Moller polarimetry at high beam currents with kicker magnet
- Cerenkov detector performance
- Tracking system performance

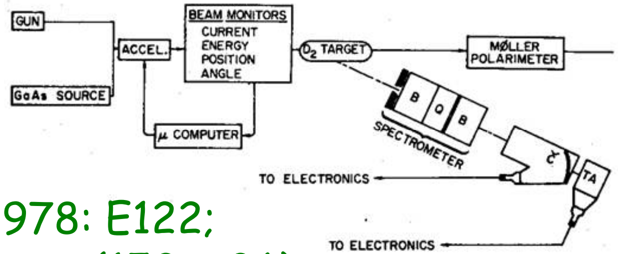
PREX/HAPPExIII
- Wien filter slow spin flip
- Lead target performance

6 GeV PVDIS
- High performance fast pulse counting DAQ

12 GeV Moller
- Novel 2 toroid spectrometer design
- Computational fluid dynamics design of (4600 watt) target

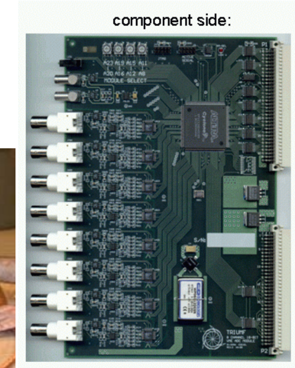
and many others I'm sure I've forgotten.

Summary



1978: E122;
$A = -(152 \pm 26)$ ppm

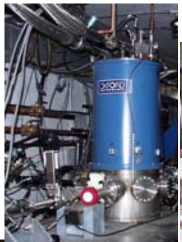
Radiation hard detectors

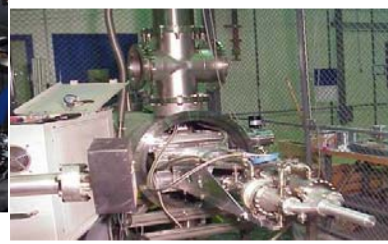


Low noise precision electronics

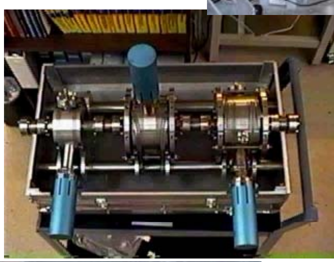
Magnetic Spectrometers

Beam polarimetry





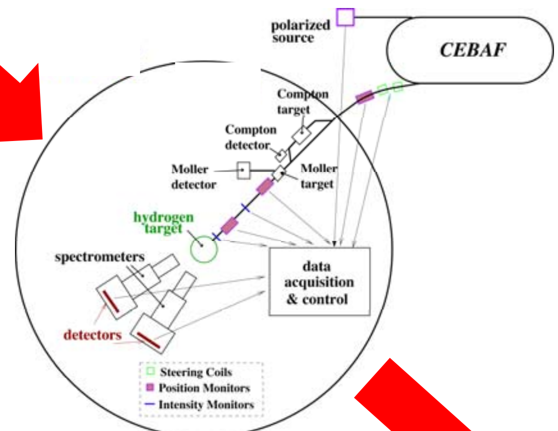
High Power Cryotargets



Beam monitoring/control

Accelerator

Polarized source



2005: E158;
$A = -(131 \pm 17)$ ppb

?

30 years of technical progress: ppm $\rightarrow$ ppb - looking forward to what's next!