The G^0 Experiment: Backangle Running

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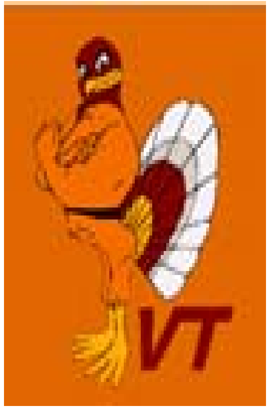
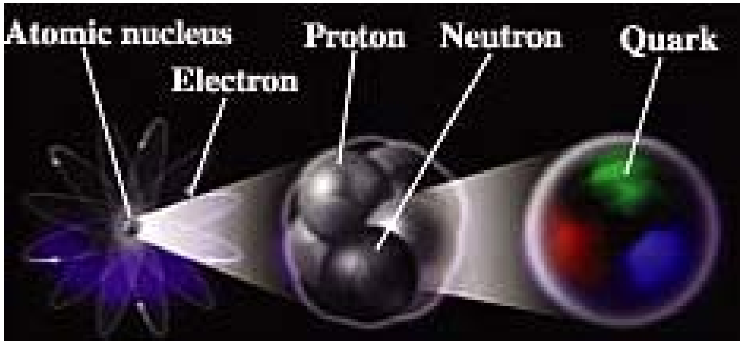


OUTLINE

- The Structure of the Proton and the Goal of the G^0 Experiment
- Parity Violation in Electron-Nucleon Interaction
- The G^0 Experiment
- The Backangle Running
- Controlling the Helicity-Correlated Beam Properties
- Parity Quality of G^0 Beam
- Results

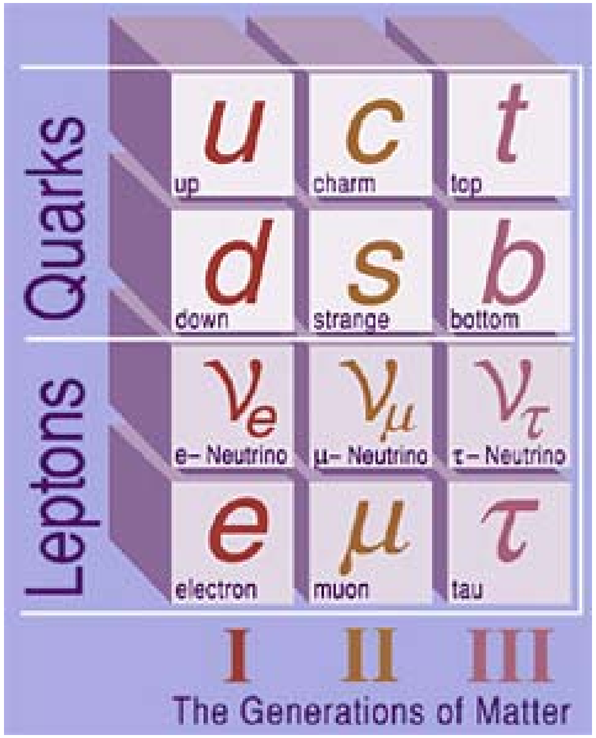
Inside the Nucleon: The Building Blocks of Matter



Meson: quark + antiquark

Baryon: quark + quark + quark

proton: u u d
neutron: u d d
} valence quarks

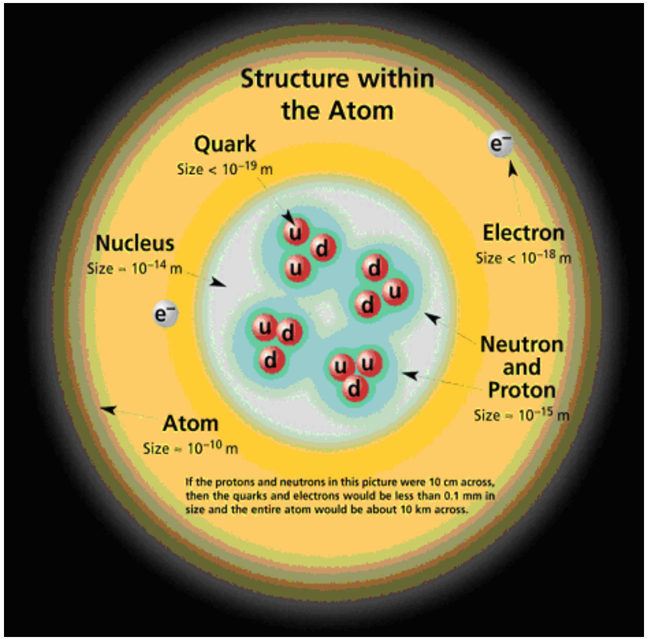


Quarks in More Detail

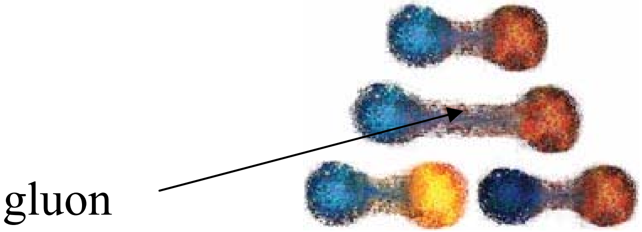
- Mass: range from ~10x electron mass (up quark) to that of a Tungsten atom (top quark) *
- No internal structure (< 10^{-19} m)
- Electric charge:
  +2/3 (u,c,t) and -1/3 (d,s,b)

Proton: $\frac{2}{3} + \frac{2}{3} + (-\frac{1}{3}) = +1$

- No free quarks:



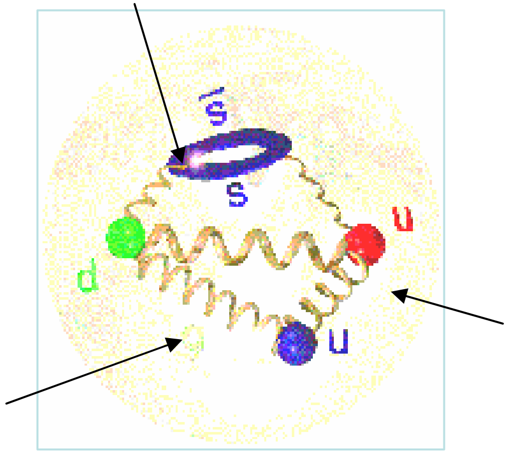
If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.



Quark	Charge (e)	Mass (MeV/c^2)
Up	+2/3	1.5 – 4
Down	-1/3	4 – 8
Strange	-1/3	80 – 130
Charm	+2/3	1150 – 1350
Bottom	-1/3	4100 – 4400
Top	+2/3	171400 ± 2100

* The mass of an electron is 0.5 MeV/c^2 = 9.1×10^{-31} kg

Strange Quarks In Particular



quark and antiquark pair

valence quark

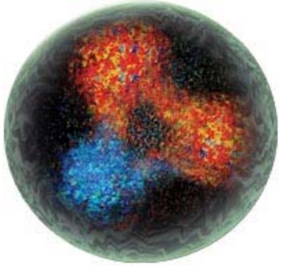
gluon

- Sea of quark and antiquark pairs
  - Made up of Up, Down, and Strange quarks
  - Up & Down quarks in sea difficult to distinguish from valence Up and Down quarks
  - Strange quark provides a unique window

The Goal of the G^0 Experiment

To determine the contribution of the strange quark to the electric and magnetic properties of the proton and neutron.

Quarks move around so the proton has a charge distributed over its size.

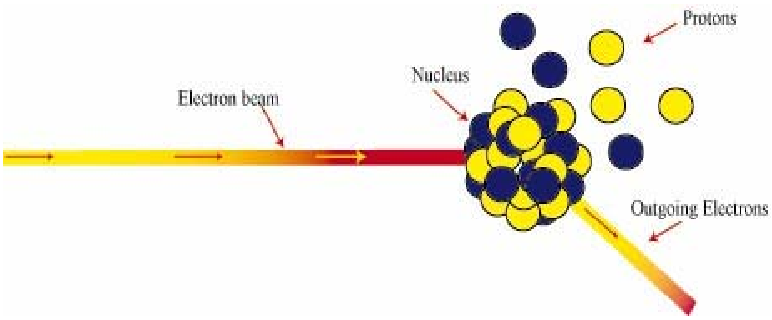


Moving charges → electric current → magnetic field

Quarks and gluons both have spin, leading to a magnetic moment and magnetization distribution.

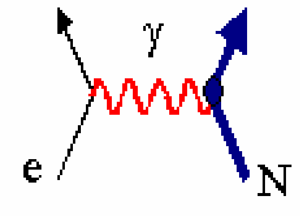
- Form Factors: The most fundamental dynamical quantity for describing the inner properties of a composite particle.
  - Electric (G_E): provides detailed information about the spatial distribution of charges in the particle.
  - Magnetic (G_M): " " " magnetization in the particle.
  - Axial (G_A): " " " spin in the particle.

Electron and Nucleon Interactions

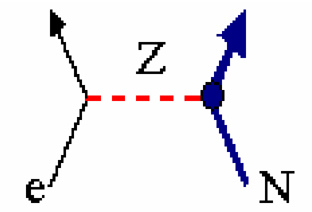


- Why an electron probe?
  - No internal structure
  - Electromagnetic interaction well understood
  - Electrons penetrate deep inside a nucleus

- Electromagnetic Force (binds electrons to nuclei)
  - Carrier particle: photon
  - Parity-conserving

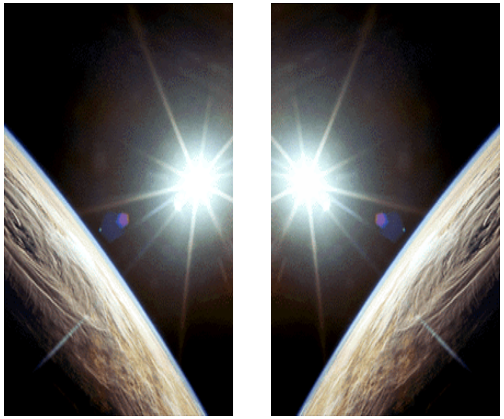


- Weak Force (radioactive decay)
  - Carrier particles: W^+, W^- and Z bosons (particles with integer spin)
  - Z^0 interaction is parity-violating



What is Parity-Violation?

Parity-conservation: strength of particle interaction is same for mirror image



Sun on right

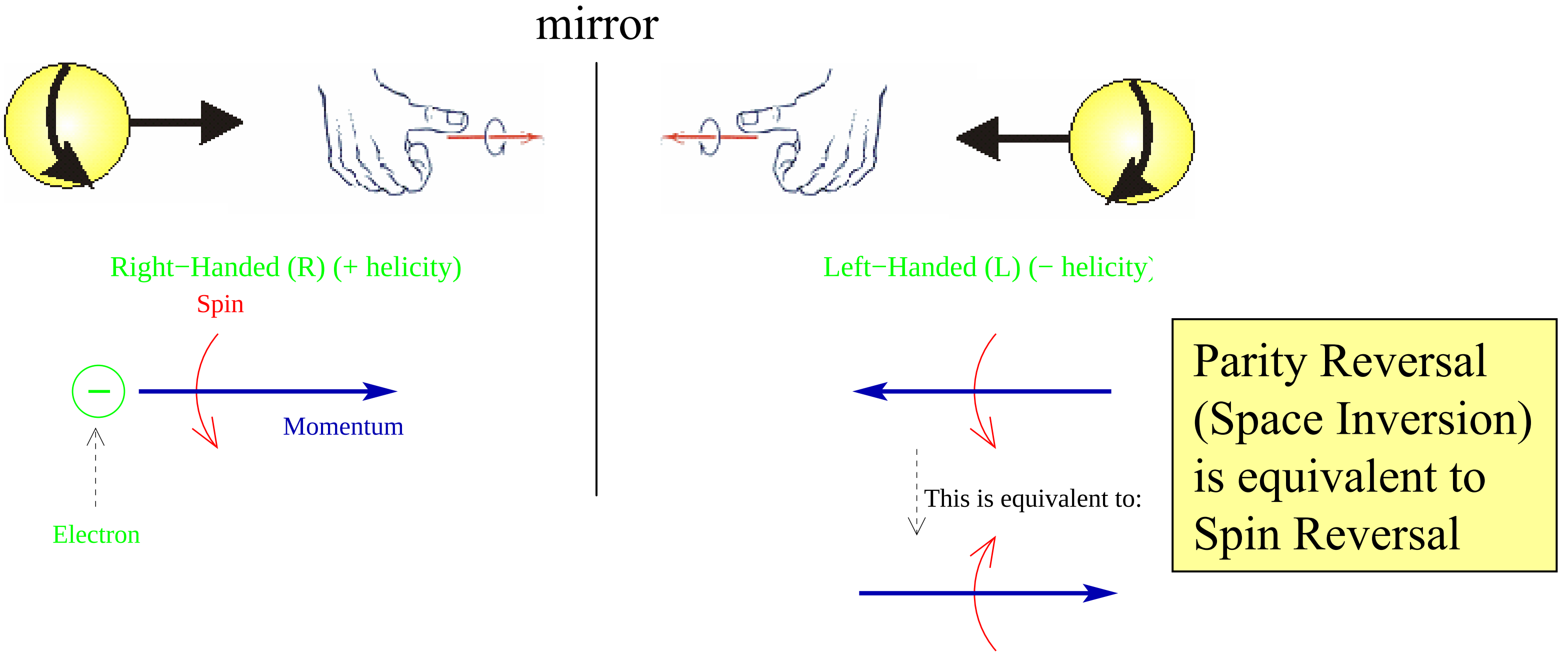
Sun on left

Sun exerts the **same** pull on the earth.

Parity-violation: strength of particle interaction is different for mirror image

The bean family twine to form a right-handed spiral. Left-handed spirals do not exist.

Parity Violation



Parity Reversal
(Space Inversion)
is equivalent to
Spin Reversal

Electromagnetic force is parity-conserving.
Electrons' helicity will not affect the number of electrons scattered.

Weak force is parity-violating.
Electrons' helicity will affect the number of electrons scattered.

A_{meas} The relative difference in these counting rates tells us how big the weak interaction piece is.

Electron and Proton Interactions Revisited

Amplitude of electron-proton interaction $\boxed{M = M^{\gamma} + M^{Z}}$

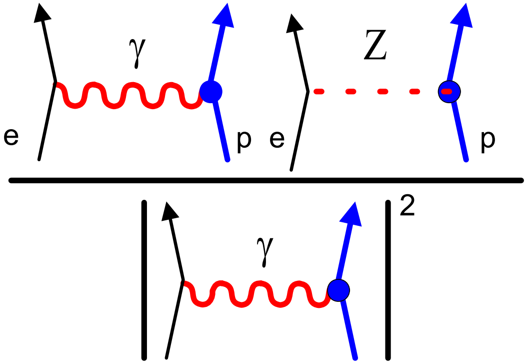
Probability: $\boxed{\left|M^2\right| = \left|M_\gamma^2\right| + 2\,\mathrm{Re}\left[\left(M_\gamma\right)^* \left(M_z\right)\right] + \left|M_z^2\right|}$

Cross sections:

$\boxed{\sigma_R \propto \left|M_\gamma + M_z\right|_R^2}$ $\boxed{\sigma_L \propto \left|M_\gamma + M_z\right|_L^2}$

Asymmetry:

$$\boxed{A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{\left|M_\gamma + M_z\right|_R^2 - \left|M_\gamma + M_z\right|_L^2}{\left|M_\gamma + M_z\right|_R^2 + \left|M_\gamma + M_z\right|_L^2} = 2\frac{M_\gamma^* M_z}{\left|M_\gamma\right|^2}}$$



Parity-Violating Electron Scattering

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right]\frac{A_E + A_M + A_A}{2\sigma_u}$$

1 equation
3 unknowns

$$A_E = \varepsilon(\theta) G_E^Z(Q^2) G_E^\gamma(Q^2)$$

$$A_M = \tau(Q^2) G_M^Z(Q^2) G_M^\gamma(Q^2)$$

$$A_A = -(1 - 4\sin^2\theta_W)\varepsilon' G_A^e(Q^2) G_M^\gamma(Q^2)$$

$$2\sigma_u = \varepsilon\left(G_E^\gamma\right)^2 + \tau\left(G_M^\gamma\right)^2$$

Requires 3 measurements at a given Q^2:
Forward angle e + p (elastic)
Backward angle e + p (elastic)
Backward angle e + d (quasi-elastic)

Probes same hadronic flavor structure, with different couplings:

$$G_{E/M}^\gamma = \frac{2}{3}G_{E/M}^u - \frac{1}{3}G_{E/M}^d - \frac{1}{3}G_{E/M}^s$$

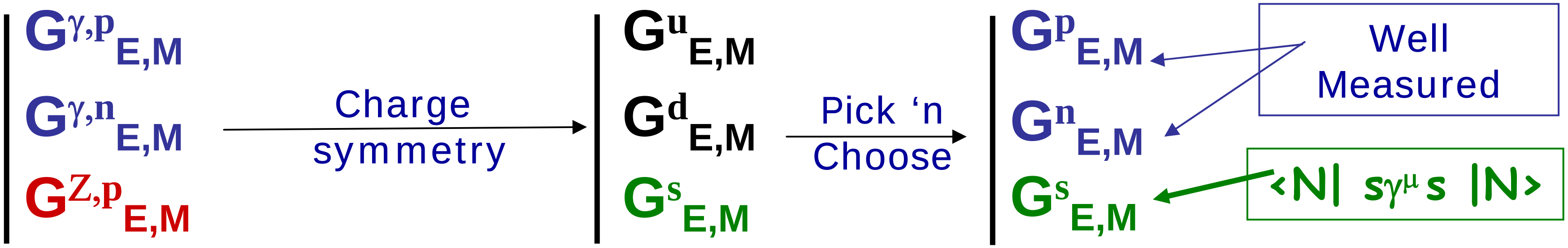
$$G_{E/M}^Z = \left(1 - \frac{8}{3}\sin^2\theta_W\right)G_{E/M}^u - \left(1 - \frac{4}{3}\sin^2\theta_W\right)G_{E/M}^d - \left(1 - \frac{4}{3}\sin^2\theta_W\right)G_{E/M}^s$$

Strange Quark Form Factors

Neglecting trivial breaking due to Coulomb force, one expects the neutron to be an isospin rotation of the proton:

$$G_{E/M}^{p,u} = G_{E/M}^{n,d}, \qquad G_{E/M}^{p,d} = G_{E/M}^{n,u}, \qquad G_{E/M}^{p,s} = G_{E/M}^{n,s}$$

$$G_{E/M}^{\gamma,p} = \frac{2}{3}G_{E/M}^{u} - \frac{1}{3}G_{E/M}^{d} - \frac{1}{3}G_{E/M}^{s} \longrightarrow G_{E/M}^{\gamma,n} = \frac{2}{3}G_{E/M}^{d} - \frac{1}{3}G_{E/M}^{u} - \frac{1}{3}G_{E/M}^{s}$$



$G^{\gamma,p}_{E,M}$

$G^{\gamma,n}_{E,M}$

$G^{Z,p}_{E,M}$

Charge symmetry

$G^{u}_{E,M}$

$G^{d}_{E,M}$

$G^{s}_{E,M}$

Pick 'n Choose

$G^{p}_{E,M}$

$G^{n}_{E,M}$

$G^{s}_{E,M}$

Well Measured

$\langle N|\ s\gamma^{\mu} s\ |N\rangle$

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A_0 + \eta_E G_E^s + \eta_M G_M^s + \eta_A G_A^{eN}$$

“Rosenbluth” type of Separation

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A_0 + \eta_E \, G_E^s + \eta_M \, G_M^s + \eta_A \, G_A^{eN}$$

Vary both the targets (LH_2, LD_2, ^4He) and the kinematics

World data at $Q^2 \sim 0.1\ (GeV/c)^2$

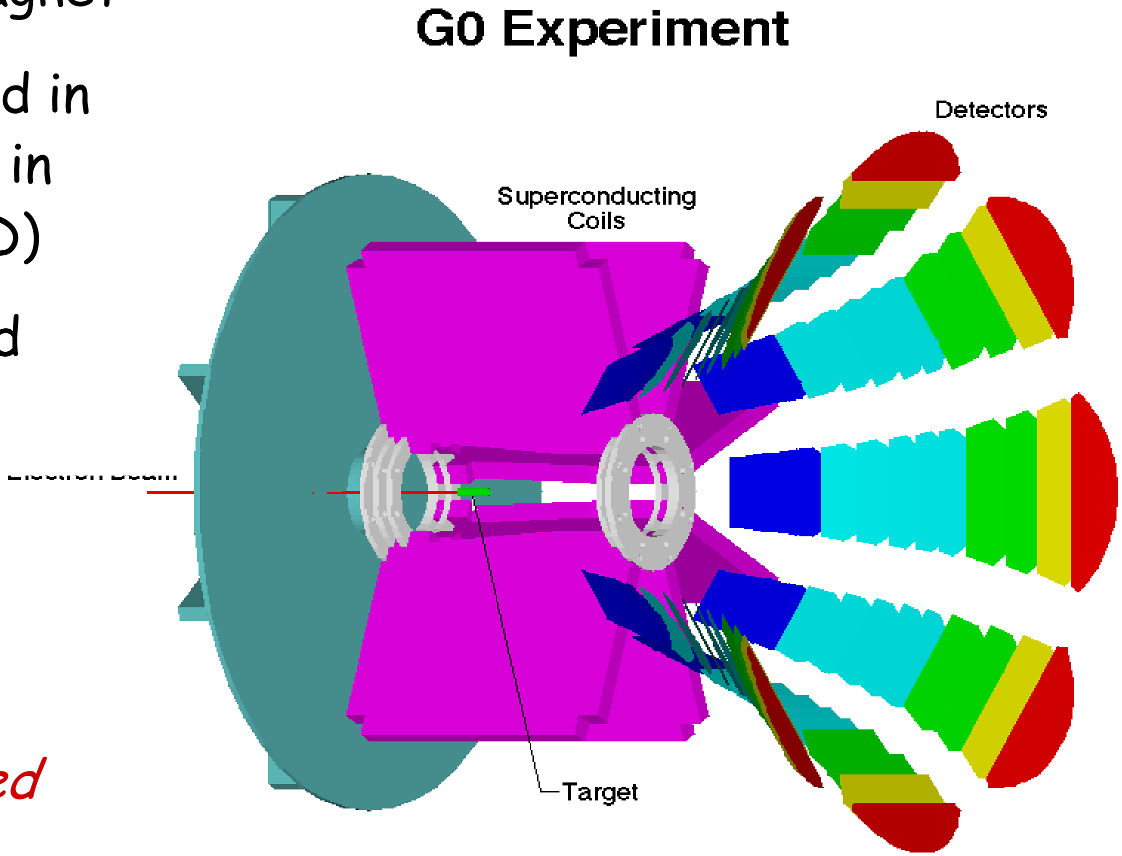
Exp	Target	E_{beam} (GeV)	Θ_e (deg)	A_o (ppm)	η_E (ppm)	η_M (ppm)	η_A (ppm)
SAMPLE	LD_2	0.2	150	-7	1.6	0.8	1.8
SAMPLE	LH_2	0.2	150	-6	2.1	3.5	1.6
HAPPEx	^4He	3	6	7	20.0	0	0
PVA4	LH_2	0.6	35	-2	10.1	1.0	0.3
G^0	LH_2	3	6	-2	12.0	1.2	0.1

The G^0 Experiment

- Forward and backward angle parity-violating e-p elastic and e-d (quasi-elastic) in JLab Hall C

G_E^s , G_M^s and G_A^e separated over range $Q^2 \sim 0.1-1.0\ (\mathrm{GeV/c})^2$

- Superconducting toroidal magnet
- Scattered particles detected in segmented scintillator arrays in spectrometer focal plane (FPD)
- Custom electronics count and process scattered particles (proton at forward angle and electrons at backward angle)



- *Forward angle run completed*
- *Backward angle → March 06 - February 07*

What does G^0 mean?

When this experiment was proposed 12 years ago, people were interested in this combination of form factors, so it was named G^0

Charge (magnetization) form factor of the proton associated with Z^0 interaction

$$G_{E/M}^{0,p} = 4\left[\left(\frac{1}{2} - \sin^2\theta_W\right)G_{E/M}^{p,\gamma} - G_{E/M}^{p,Z}\right]$$

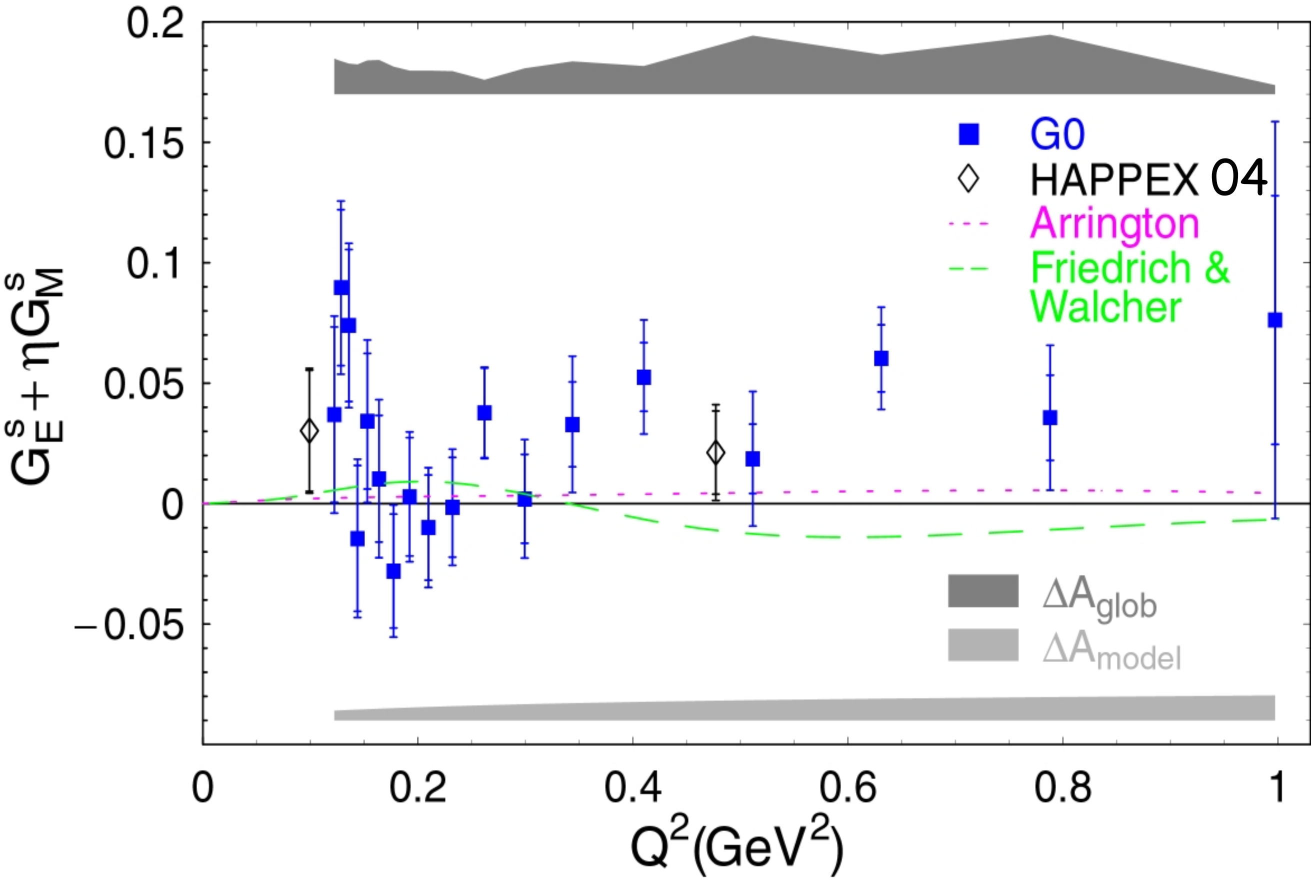
Charge (magnetization) form factor of the proton associated with γ exchange

G^0 Forward Angle Results

$$G_E^s + \eta G_M^s = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2}\,\frac{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}}{\varepsilon G_E^p\left(1+R_V^{(0)}\right)}\left(A_{phys} - A_{NVS}\right)$$

- Use the anapole contribution computed Zhu et al.

Examining full data set,
probability that
$G_E^s+\eta G_M^s \neq 0$
is 89%

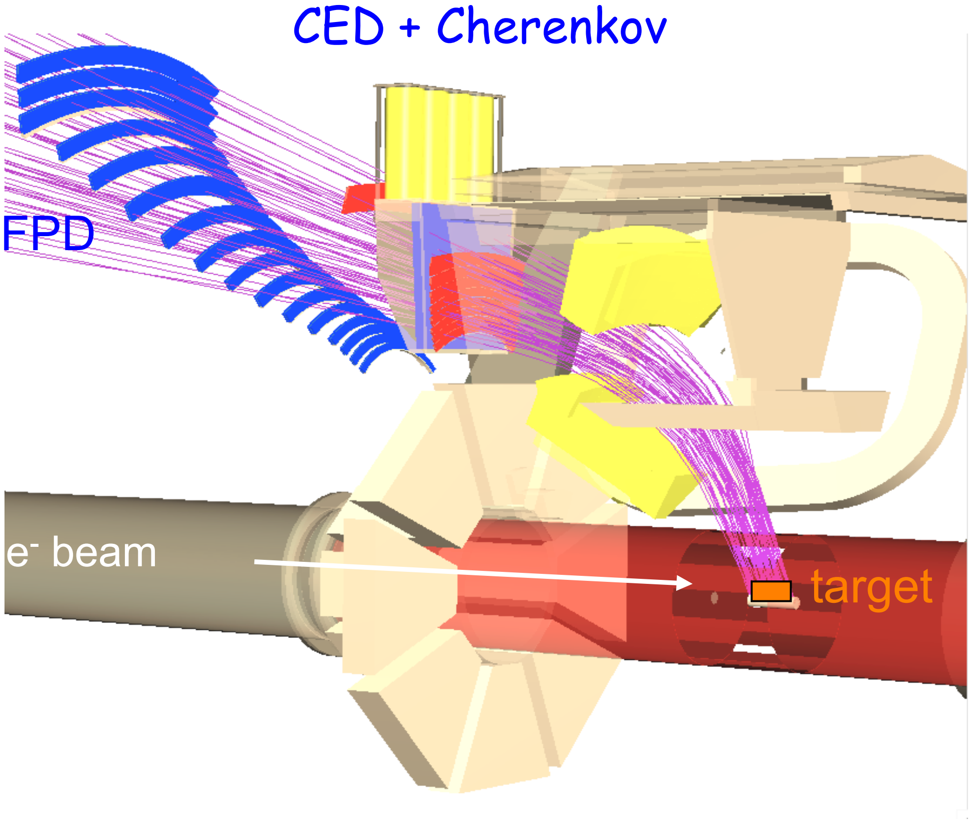


D.S. Armstrong et al,
PRL 95 (2005) 092001

G^0 Backward Angle

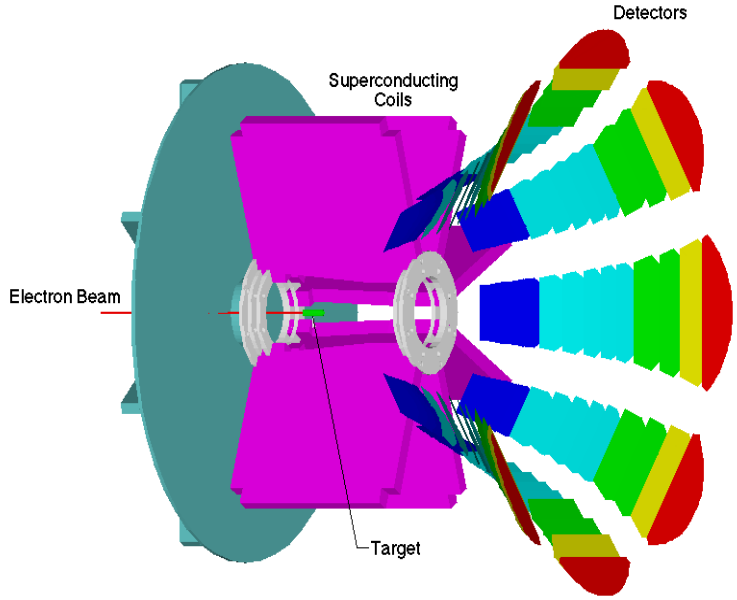
- Electron detection: $\theta = 108°$
- Both LH_2 and LD_2 targets
- Add Cryostat Exit Detectors (CED) to define electron trajectory
- Aerogel Cherenkov detector for π/e separation ($p_\pi < 380$ MeV/c)

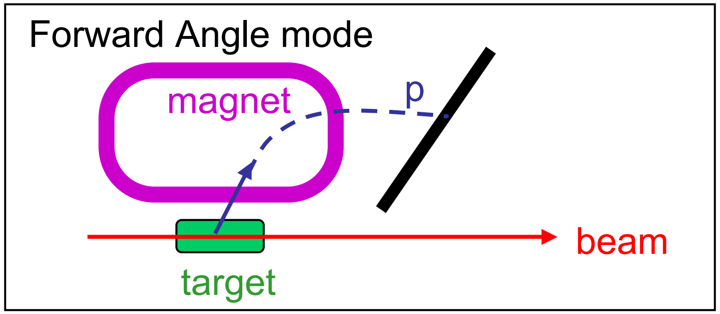
E_e (MeV)	Q^2 $(GeV/c)^2$
362	0.23
686	0.62

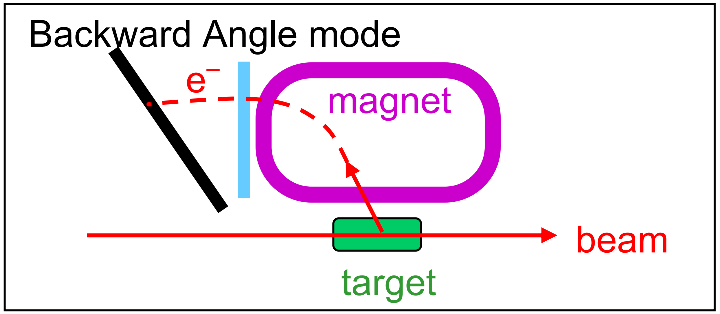


Common Q^2 with HAPPEX-III and PVA4 (both at forward angles)

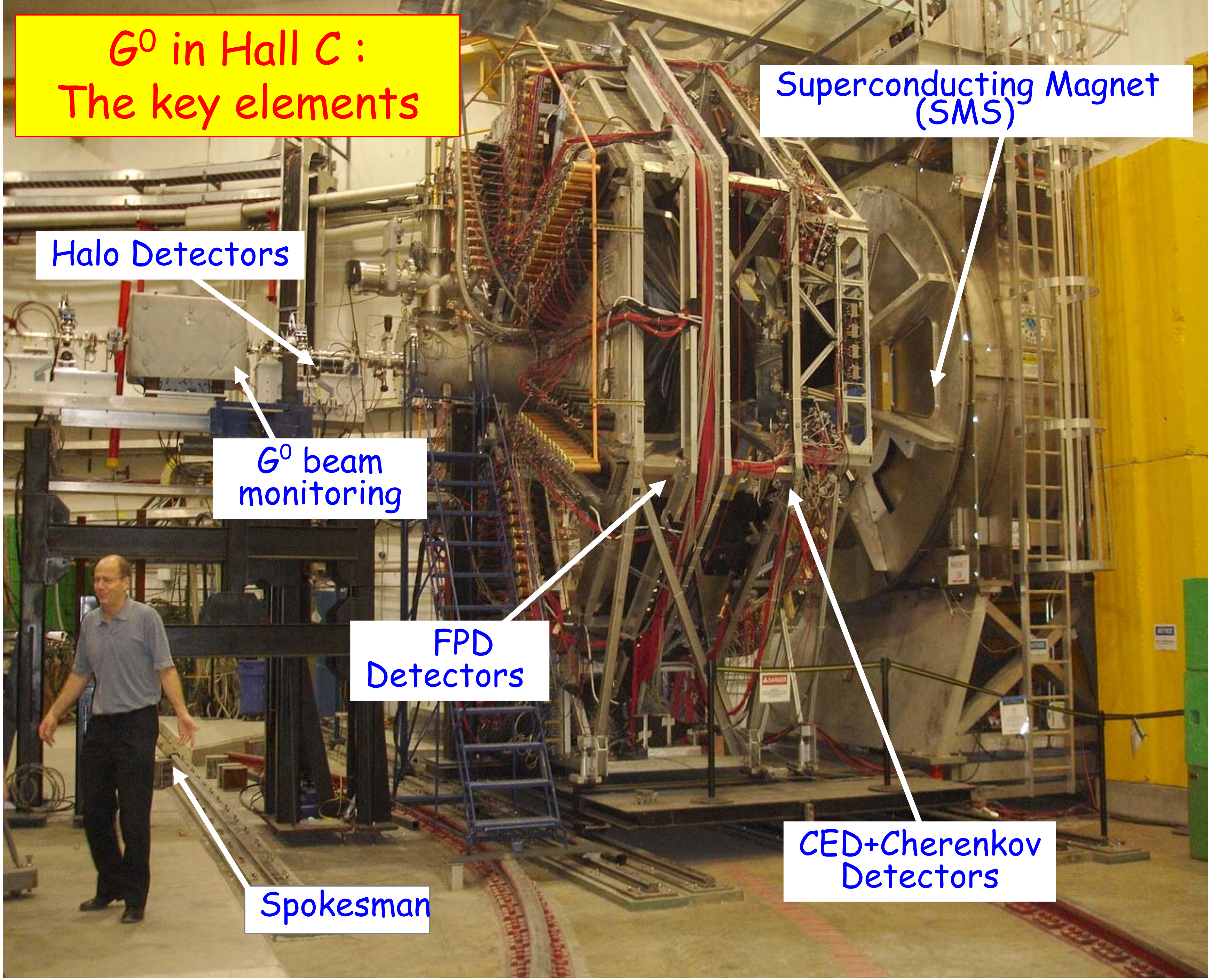
Experiment Schematic




Forward Angle mode


Backward Angle mode

G^0 in Hall C : The key elements



Superconducting Magnet (SMS)

Halo Detectors

G^0 beam monitoring

FPD Detectors

CED+Cherenkov Detectors

Spokesman

G^0 Backangle Run

- March 15 – May 1 (687 MeV):
  - 200 hours LH_2, 50 hours LD_2 (at 10 μA)
  - 80 hours "parity quality" data w/ LH_2 at 60 μA
- May 15 – May 18 (362 MeV):
  - first look at LD_2 at low beam current

High singles rates in the Cherenkov Detector PM tubes from neutrons. Change borosilicate window PM tubes to quartz window PM tubes.

  - outstanding beam delivery
- July 19 – Sept 1 (362 MeV): Production data w/ LH_2 at 60 μA
- Sept 22 – Nov 1 (687 MeV): Production data w/ LH_2 at 60 μA

- Nov 1 – Dec 22 (687 MeV): Production data w/ LD_2 at 60 μA
- Jan 5 – Feb 18 (362 MeV): Production data w/ LD_2 at 60 μA

Great Beam at very low energy, THANKS!

Basic Principles of Parity-Violation Experiments

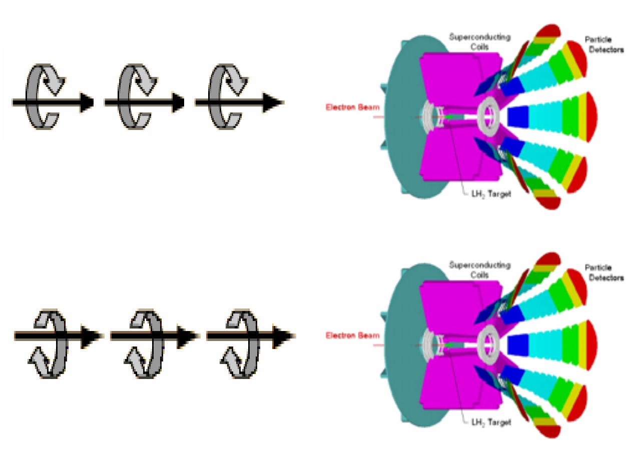
- How do we carry out parity-violation experiment?
  - We scatter longitudinally polarized electrons off un-polarized protons within a hydrogen target
  - We reverse the helicity of the electron beam and measure the relative difference in detected signal:

$$\boxed{A_{meas} = \frac{Y^{+}_{meas} - Y^{-}_{meas}}{Y^{+}_{meas} + Y^{-}_{meas}}}$$

$$\boxed{Y_{meas} = \frac{r}{Q}}$$

← measured rate

← beam charge

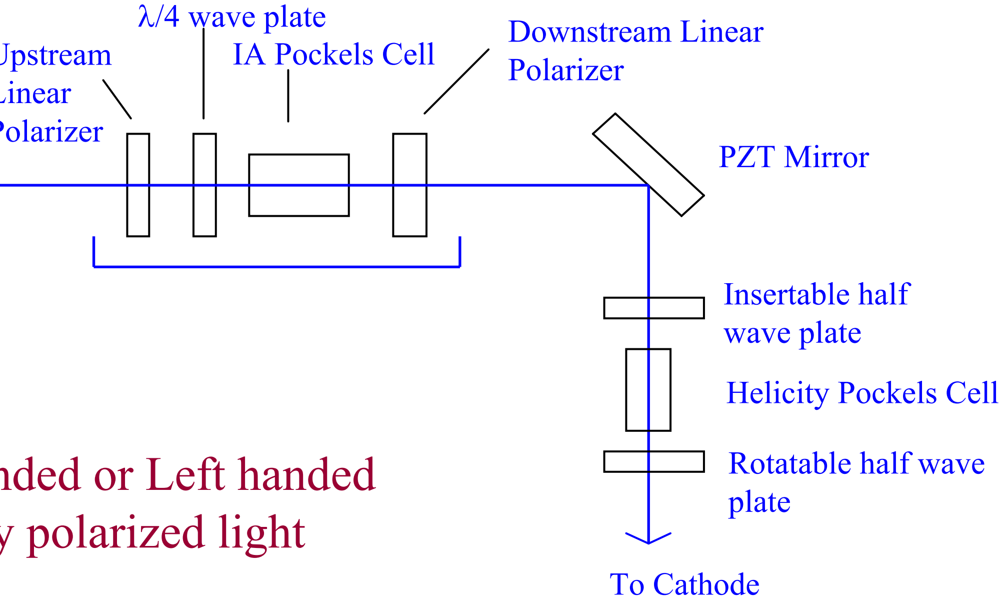


- Here's the catch:
  - The experimental asymmetry is very small (1-50 ppm). *
  - The challenge is controlling the false asymmetries.

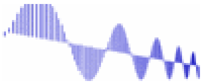
* Four drops of ink in a 55-gallon barrel of water would produce an "ink concentration" of 1 ppm.

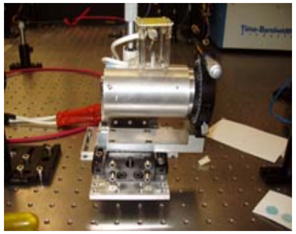
The Polarized Electron Source

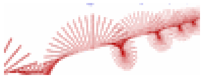
G0
Laser



λ/4 wave plate
Upstream
Linear
Polarizer
IA Pockels Cell
Downstream Linear
Polarizer
PZT Mirror
Insertable half
wave plate
Helicity Pockels Cell
Rotatable half wave
plate
To Cathode





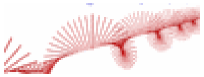


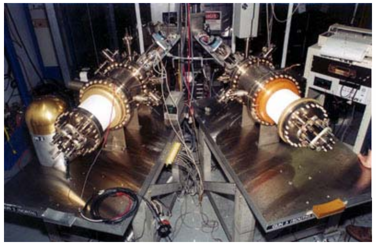
Linearly
polarized light

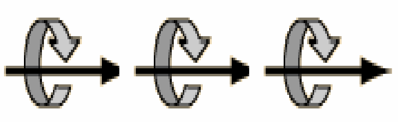
Right-handed or Left handed
Circularly polarized light

Q: How do you reverse the helicity of the electron beam?
A: By reversing the Pockels Cell (PC) voltage

Helicity Reversal

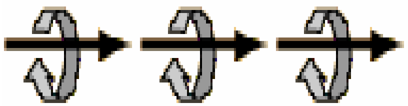






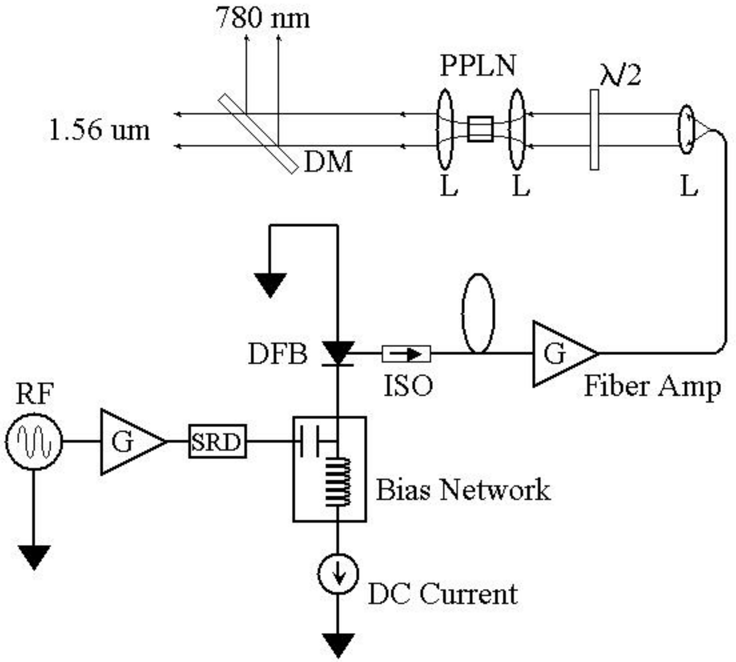
Right-handed electron

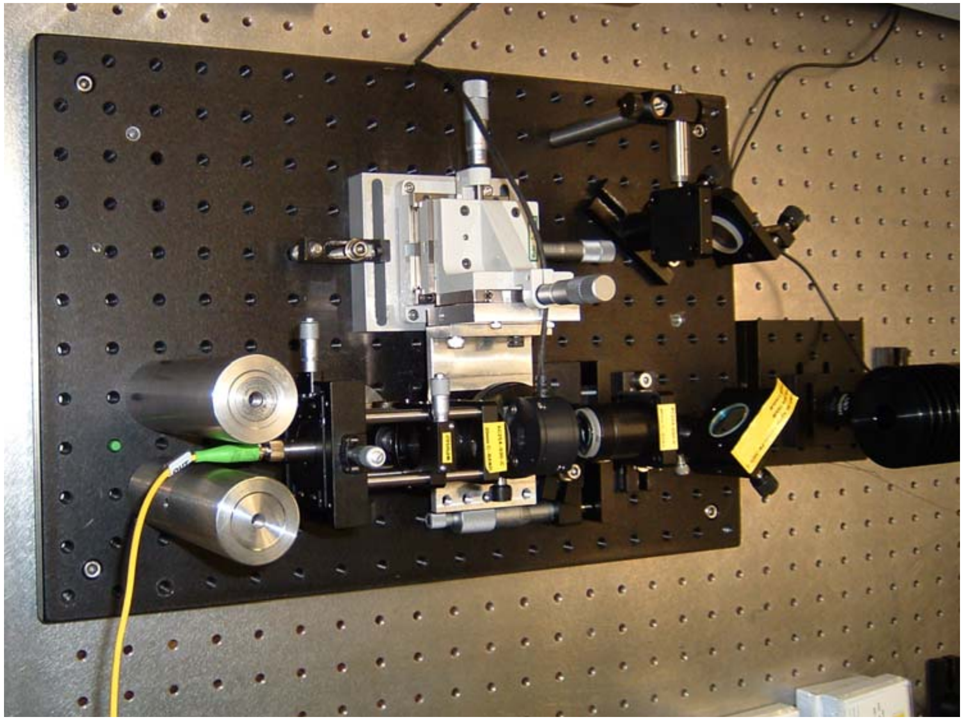
OR



Left-handed electron

New Fiber-Based Laser





- Uses 1560 nm seed laser and amplifier commonly used in the telecommunications industry
- Electrical gain-switching avoids phase lock problems experienced with earlier optically mode locked systems
- Second harmonic generation device yields some 780 nm light from the 1560 nm light
- 780 nm is at polarization peak (P ~ 85%) for super-lattice GaAs

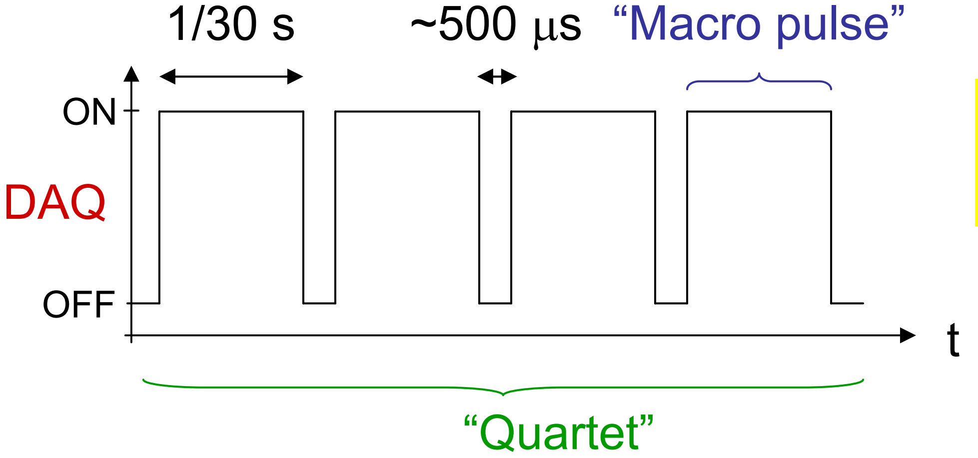
J. Hansknecht and M. Poelker (Phys. Rev. ST-AB 9, 063501)

Helicity Pattern

Frequency of PC helicity flip is 30 Hz
1 mps = 33.33 ms

700 hours / 33.33 ms ~ 75,000,000 times

2*(1/60 Hz) = 33.33 ms



DAQ OFF while PC is reversing HV

G0 Helicity: + - - + or - + + - (random)

"Pair"

Happex Helicity: + - or - + (random)

The Imperfect World

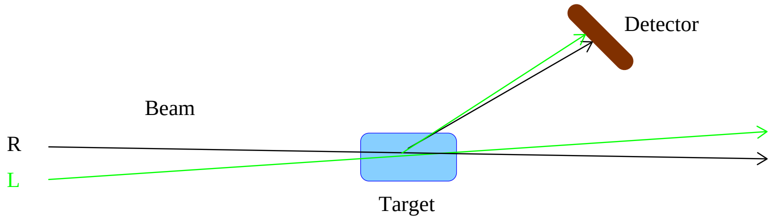
$$A_{meas}=\frac{Y^{+}_{meas}-Y^{-}_{meas}}{Y^{+}_{meas}+Y^{-}_{meas}}$$

If Y^+ or Y^- changes because of anything other than the spin physics of the interaction, it is a false asymmetries:

No beam property other than the beam helicity should change when the beam helicity reverses sign.

But beam properties do change:

- Charge
- Position and Angle on target
- Energy



Anything that changes with helicity reversal is said to be

Helicity-correlated

How Do You Define Changes in Beam Charge and Position?

- Charge asymmetry: When the average current of the electron beam corresponding to one helicity state is different from the other state

$$\boxed{A_I = \frac{I_+ - I_-}{I_+ + I_-}}$$

We measure charge asymmetry of order 1-50 ppm

- Position difference: When the average position of the electron beam corresponding to one helicity state is different from the other state

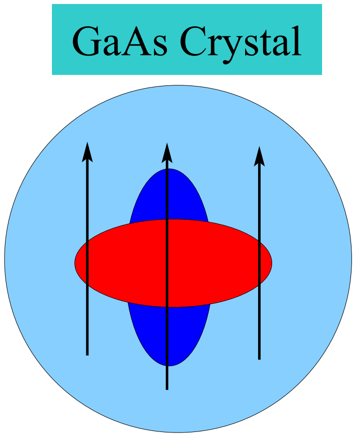
$$\boxed{\begin{gathered}\Delta_x = x_+ - x_- \\ \Delta_y = y_+ - y_-\end{gathered}}$$

We measure position differences of order 1-40 nm *

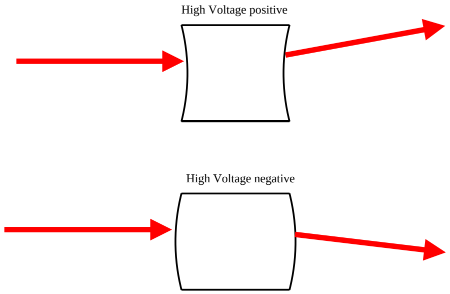
* 1 nm is one-billionth of a meter. The width of human hair is 50,000 nanometers.

Where Do Helicity-Correlated Beam Properties Come From?

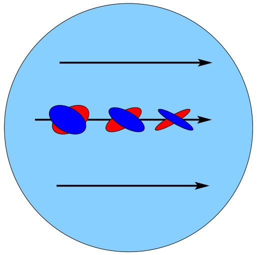
- Residual linear polarization in the laser beam
  - In GaAs crystal, there is a preferred axis
  - QE is higher for light polarized along that axis
  - Induces helicity-correlated charge asymmetry

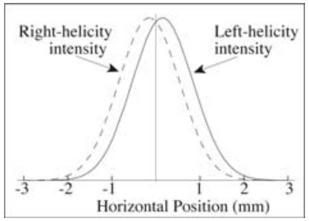


- Steering
  - PC alternately pulsed to + and – high voltages to change from right to left circularly polarized light and vice-versa
  - PC behaves alternately as converging and diverging lens
  - If beam is off-center, it can be steered
  - Induces helicity-correlated position differences



- Phase Gradient (Intrinsic birefringence gradient) in the Pockels cell
  - Linear polarization varies across the laser spot
  - Induces helicity-correlated position differences



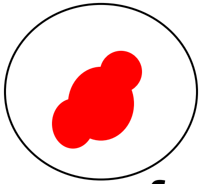


- Beam loading in rf Cavities
  - Induces helicity-correlated energy difference

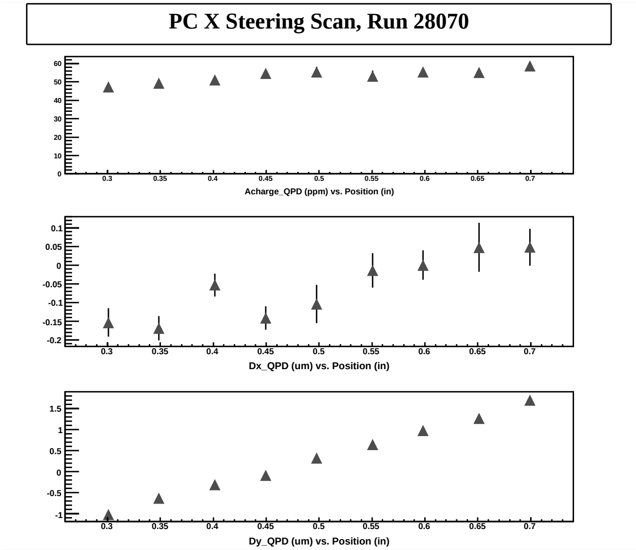
Experimental Techniques to Reduce Helicity-Correlated Beam Properties

1. Careful Setup Procedures for the Pockels Cell:

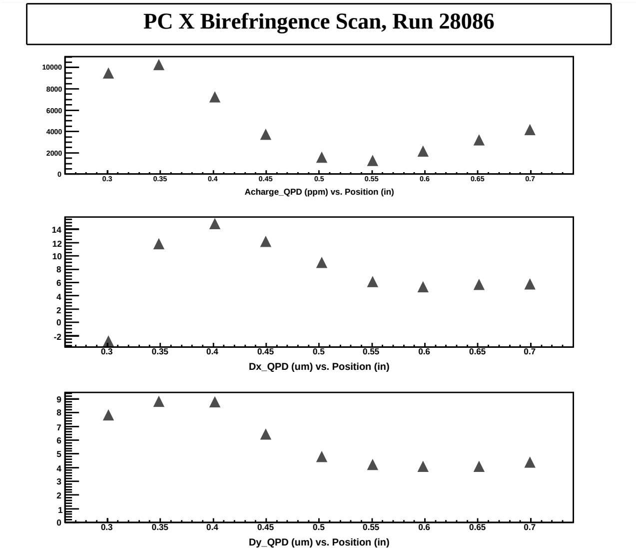
- Check laser spot in front of PC (1mm diameter)



- Align PC to give high degree of circular polarization (> 99.9%)
  - Adjust PC roll, pitch, and yaw
  - Adjust PC high voltages
- Minimize position differences
  - Steering Scan: translate PC in x and y to find the center of the cell
  - Phase Gradient (Birefringence) Scan: translate PC in x and y with Linear Polarizer downstream



PC X Steering Scan, Run 28070

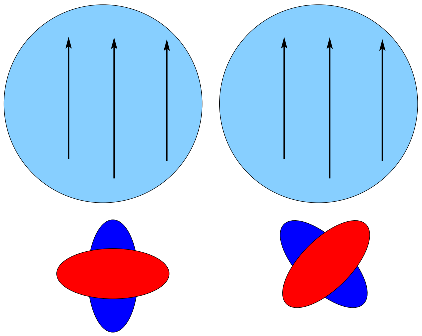


PC X Birefringence Scan, Run 28086

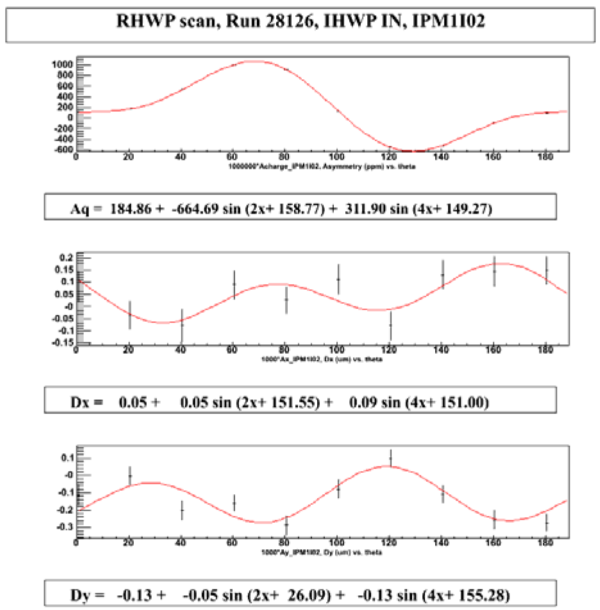
2. More work on the laser table:

- Check for electronic cross talk (PC OFF): must measure 0 for both charge asymmetry and position differences

- Use the rotating half wave plate (RHWP) (rotates the residual linear polarization) to minimize charge asymmetry and position differences



- PC High Voltage (PITA) Scan: Adjust HV to reduce charge asymmetry

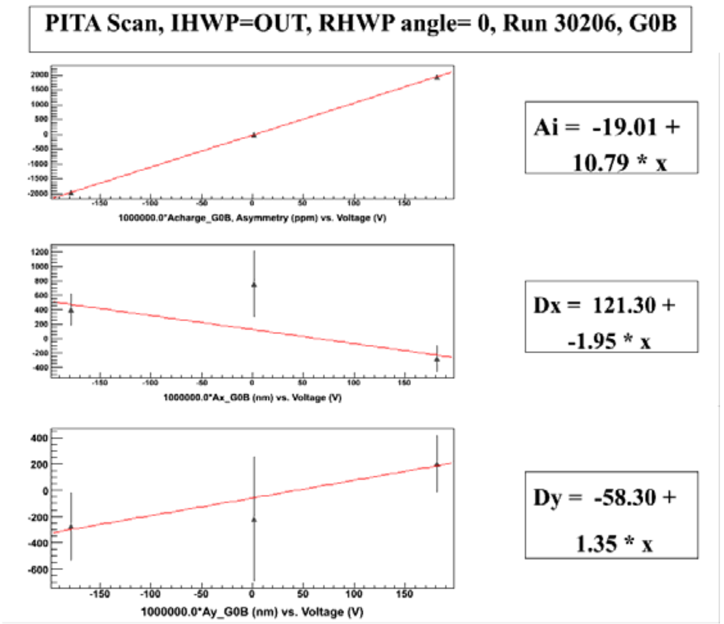


RHWP scan, Run 28126, IHWP IN, IPM1I02

Aq = 184.86 + -664.69 sin (2x+ 158.77) + 311.90 sin (4x+ 149.27)

Dx = 0.05 + 0.05 sin (2x+ 151.55) + 0.09 sin (4x+ 151.00)

Dy = -0.13 + -0.05 sin (2x+ 26.09) + -0.13 sin (4x+ 155.28)

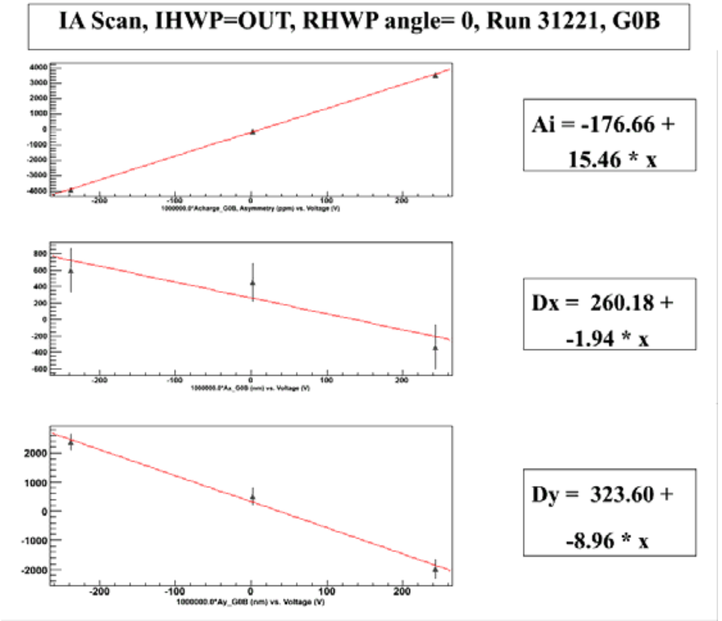


PITA Scan, IHWP=OUT, RHWP angle= 0, Run 30206, G0B

Ai = -19.01 + 10.79 * x

Dx = 121.30 + -1.95 * x

Dy = -58.30 + 1.35 * x



- Further reduction in charge asymmetry by using the IA (intensity attenuator):

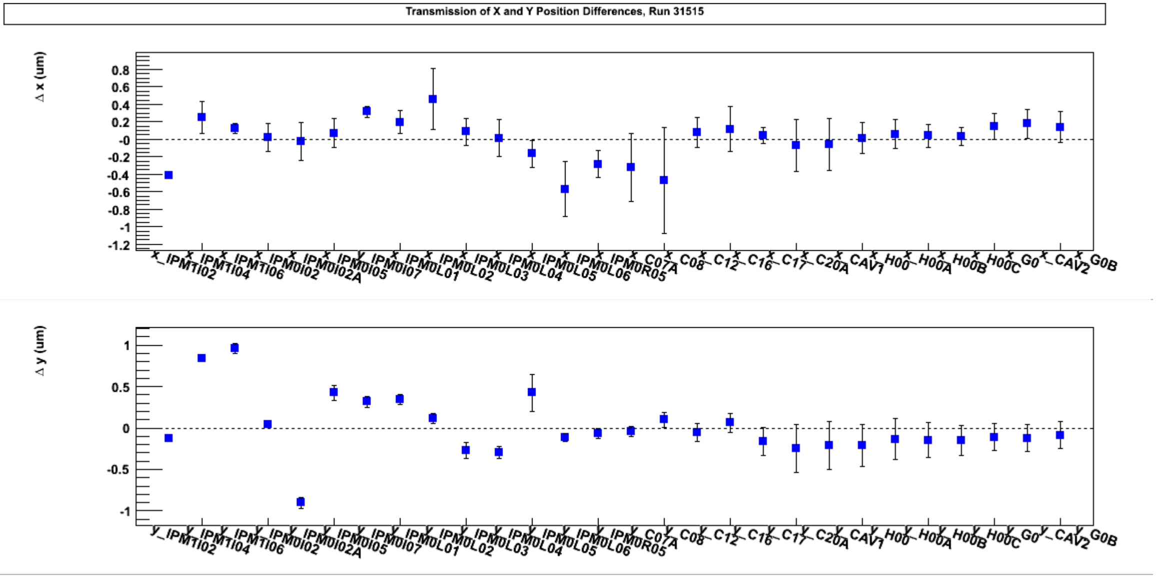
  Charge Feedback

- Use the insertable half-wave plate (IHWP): reverses the sign of the physics asymmetry.

  Electronic cross talk and PC steering do not change sign thus cancel by using IHWP

3. Taking care of the Electron Beam:

- Use special accelerator techniques to achieve “Adiabatic Damping”



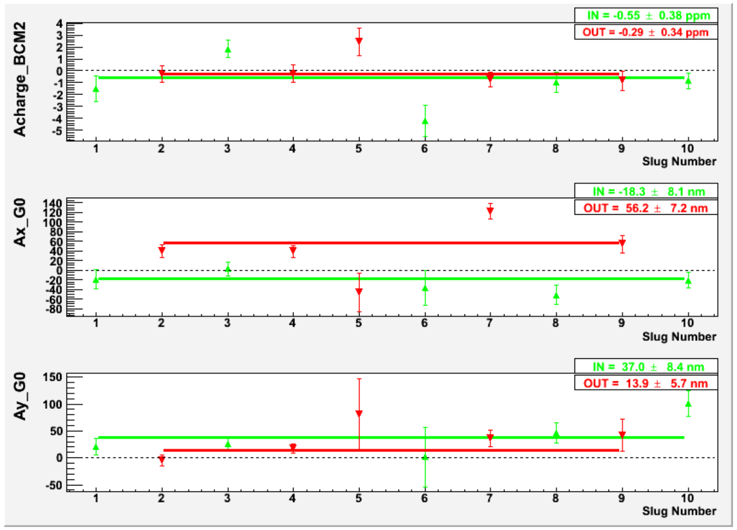
- Use the Helicity Magnets in the 5 MeV region to reduce position differences:

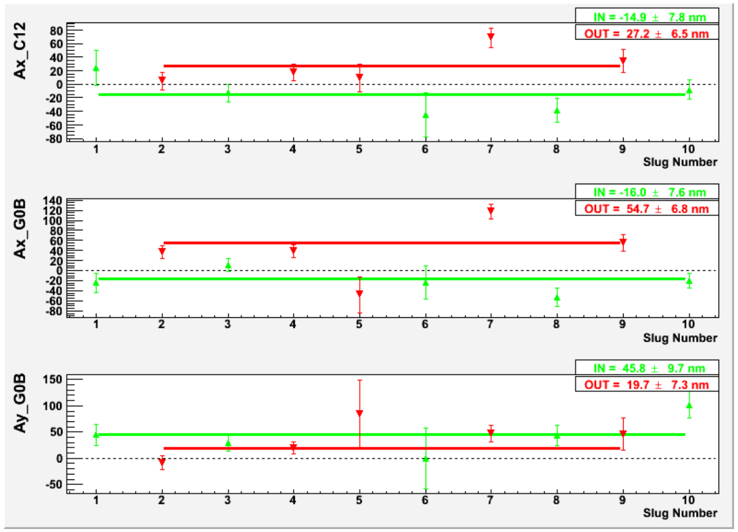
  Position Feedback

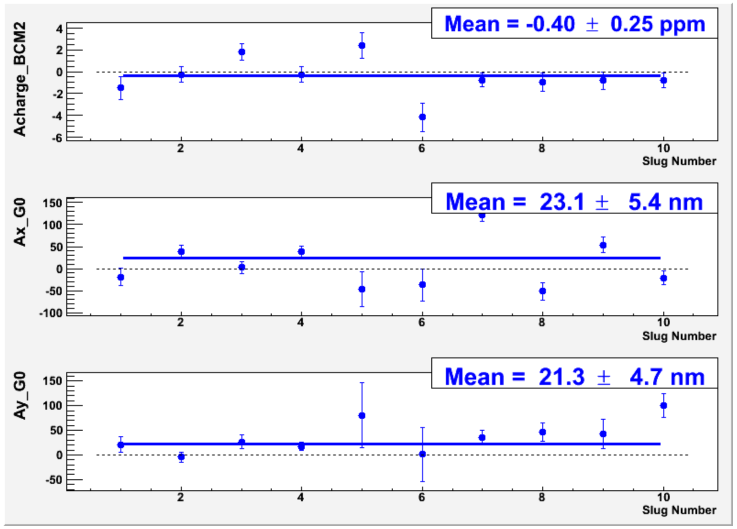
- Change the beam energy slightly such that the polarization rotation in the machine is different by 180 degrees (not done at JLab yet)

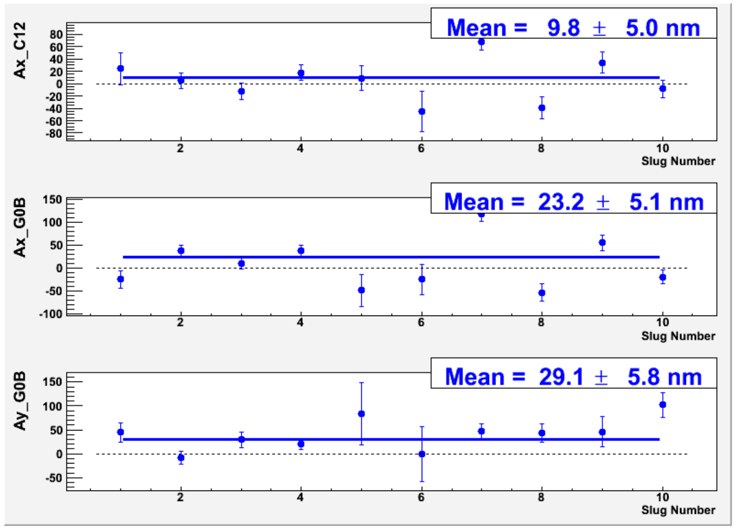
Beam Parity-Quality at 687 MeV

Beam Parameter	**Achieved (IN-OUT)**	**“Specs”**
Charge asymmetry	-0.4 ± 0.25 ppm	2 ppm
x position difference	24 ± 5 nm	40 nm
y position difference	20 ± 5 nm	40 nm
x angle difference	-1 ± 2 nrad	4 nrad
y angle difference	-4 ± 2 nrad	4 nrad
Energy difference	2 ± 1 eV	34 eV
Beam halo (outside 6 mm)	$< 0.3 \times 10^{-6}$	10^{-6}

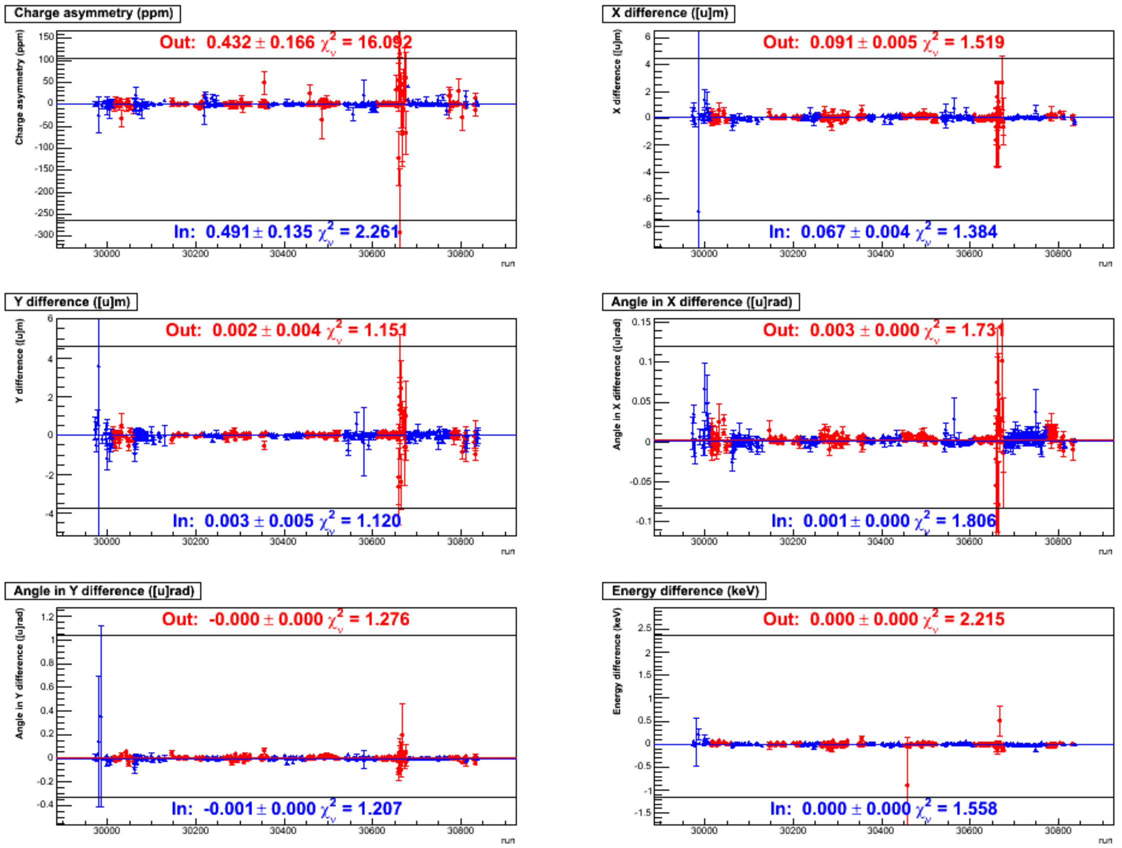

IN = -0.55 ± 0.38 ppm
OUT = -0.29 ± 0.34 ppm
Acharge_BCM2
IN = -18.3 ± 8.1 nm
OUT = 56.2 ± 7.2 nm
Ax_G0
IN = 37.0 ± 8.4 nm
OUT = 13.9 ± 5.7 nm
Ay_G0
1 2 3 4 5 6 7 8 9 10
Slug Number


IN = -14.9 ± 7.8 nm
OUT = 27.2 ± 6.5 nm
Ax_C12
IN = -16.0 ± 7.6 nm
OUT = 54.7 ± 6.8 nm
Ax_G0B
IN = 45.8 ± 9.7 nm
OUT = 19.7 ± 7.3 nm
Ay_G0B
1 2 3 4 5 6 7 8 9 10
Slug Number


Mean = -0.40 ± 0.25 ppm
Acharge_BCM2
Mean = 23.1 ± 5.4 nm
Ax_G0
Mean = 21.3 ± 4.7 nm
Ay_G0
2 4 6 8 10
Slug Number


Mean = 9.8 ± 5.0 nm
Ax_C12
Mean = 23.2 ± 5.1 nm
Ax_G0B
Mean = 29.1 ± 5.8 nm
Ay_G0B
2 4 6 8 10
Slug Number

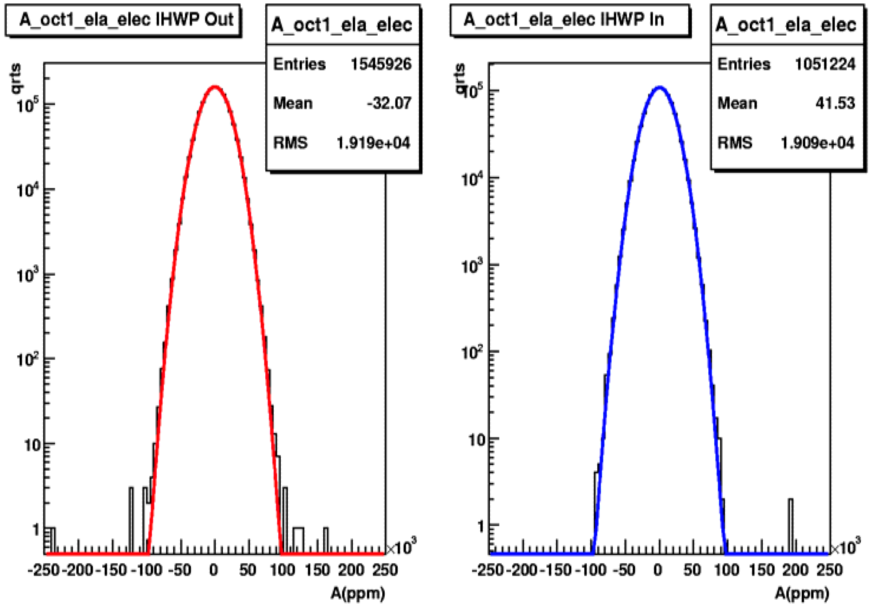
Beam Parity-Quality at 362 MeV

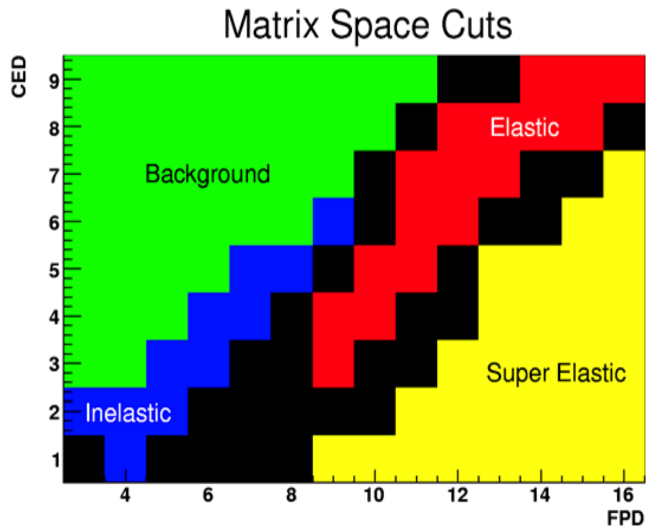


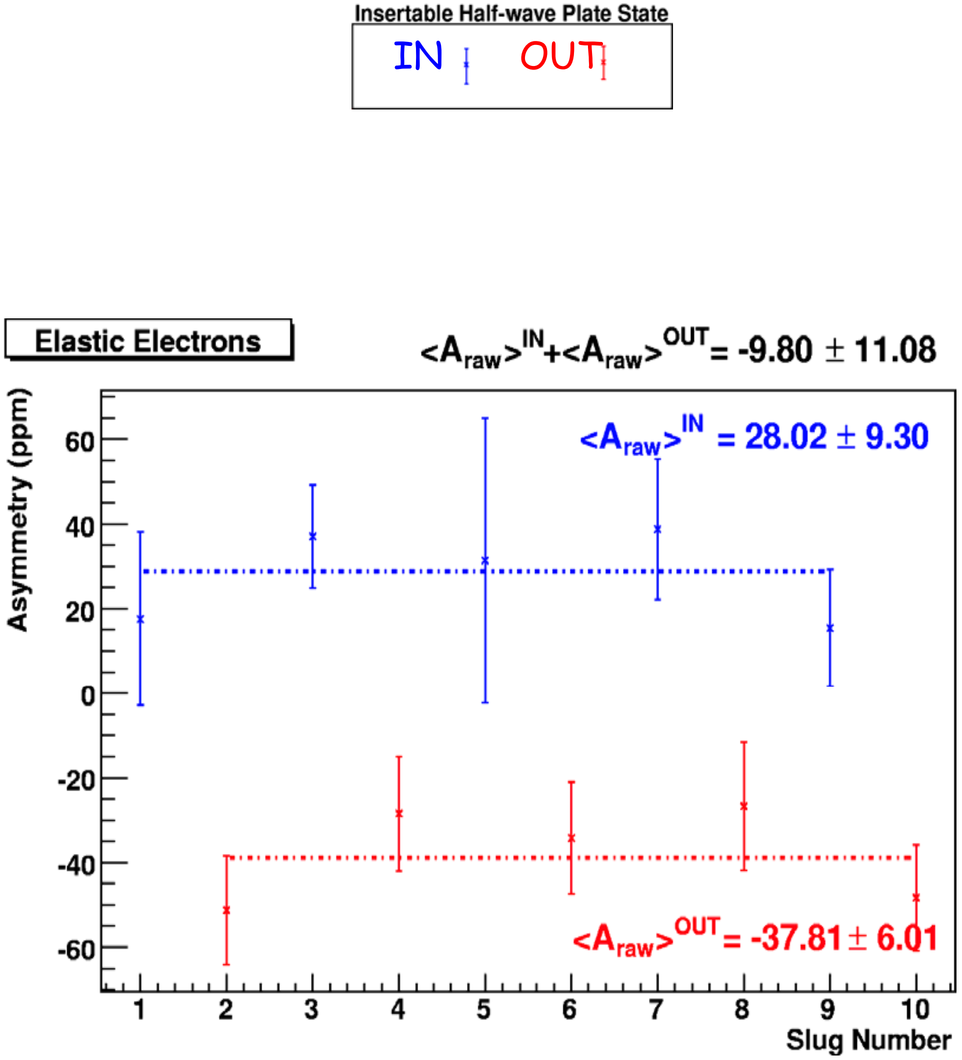
IHWP Cancellation

Beam Param.	Achieved in G^0 (IN-OUT)	Specs
Charge asym.	0.03 ± 0.12 ppm	2 ppm
x position diff.	-12 ± 4 nm	40 nm
y position diff.	1 ± 4 nm	40 nm

Physics Asymmetry : LH_2 at 687 MeV

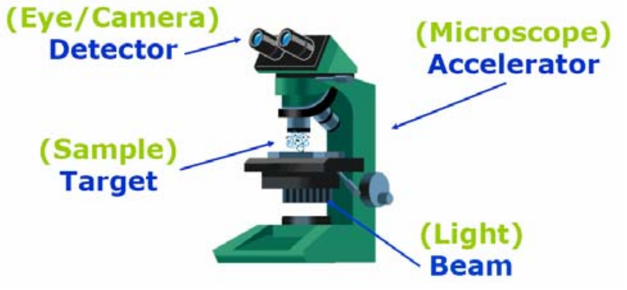


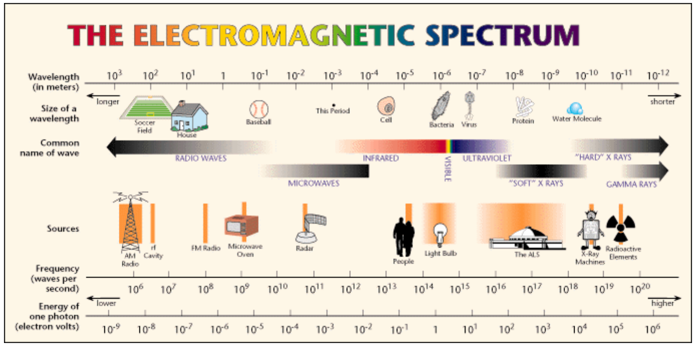




THE END

Looking at Small Dimensions





The smallest detail we are able to see when we look is about as small as the size of the wavelength of light we use.

Wavelength of visible light $\lambda \approx 5 \times 10^{-7}$ m

	Size (m)	Optical microscope
Living organism	10^{-6}	works
Atom	10^{-10}	does not work
Nucleus	10^{-14}	does not work
proton	10^{-16}	does not work

Conclusion: To look in detail into the interior of atoms and nuclei, a particle is needed whose wavelength is comparable to nuclear dimensions.

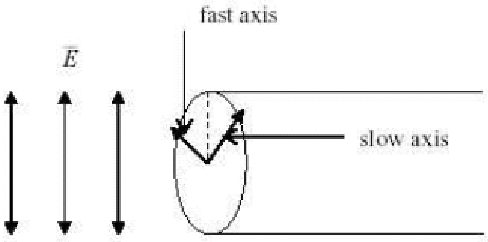
$$E = pc = \frac{h}{\lambda} c$$

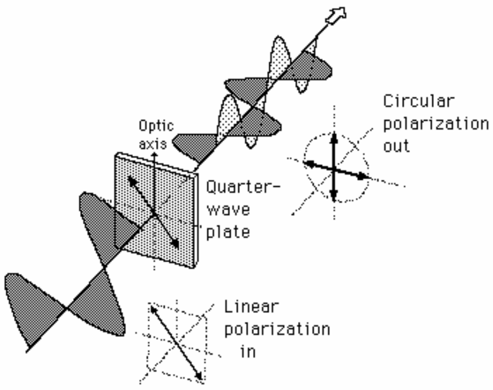
	Energy (eV) *	λ (m)	
Electrons	10,000	10^{-10}	Size of atom
Electrons	100,000,000	10^{-14}	Size of nucleus
Electrons	10,000,000,000	10^{-16}	Size of proton

* In a TV, each electron has an energy of about 20,000 eV.

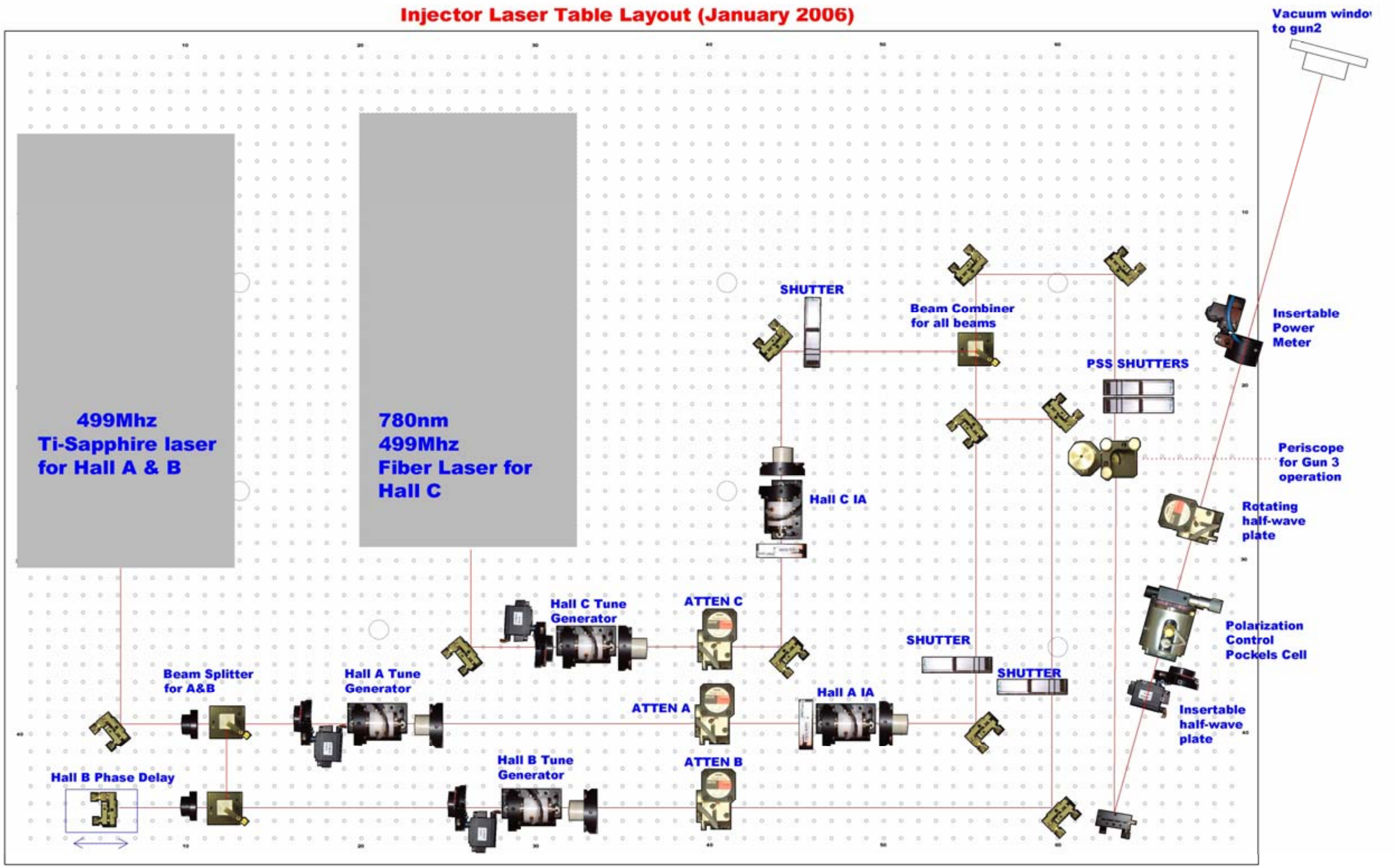
What is a Pockels Cell (PC)?

- Voltage-controlled birefringent crystal
- Applied voltage → electric field → 2 orthogonal rays of light with different velocities → retards phase of 1 component → changes polarization of emerging beam
- Converts linearly polarized light into circularly polarized light (acts as a ¼ wave plate)





Injector Laser Table Layout (January 2006)



Pockels Cell Installation
September 12, 2006

- What did we accomplish?
  - Characterized Intensity Asymmetry (IA) Cell: λ/4, 16°
    - Measured dependence of intensity asymmetry on voltage : 22.27 ppm/V
  - Aligned Pockels Cell (PC)
    - Degree of linear polarization = 3.62%
    - Degree of circular polarization = 99.93%
    - Minimized x and y position differences.

Pockels Cell Installation
September 12, 2006

Steering (LP OUT)	IHWP IN	IHWP OUT	Goal
Δx	0.0023 ± 0.032 μm	-0.064 ± 0.023 μm	< 0.1 μm
Δy	0.24 ± 0.030 μm	-0.24 ± 0.020 μm	< 0.1 μm
Δcharge	6.35 ± 3.41 ppm	-8.13 ± 3.72 ppm	

Birefringence (LP IN)	IHWP IN	IHWP OUT	Goal
Δx	-11.04 ± 0.021 μm	8.22 ± 0.016 μm	< 6 μm
Δy	1.868 ± 0.013 μm	2.06 ± 0.013 μm	< 6 μm
Δcharge	-2169 ± 89 ppm	3601 ± 86 ppm	

Electrical Pickup	PC OFF
Δx	-0.003636 ± 0.004735 μm
Δy	-0.001241 ± 0.003138 μm
Δcharge	0.9439 ± 0.9773 ppm

w/ photocathode 3X larger in injector

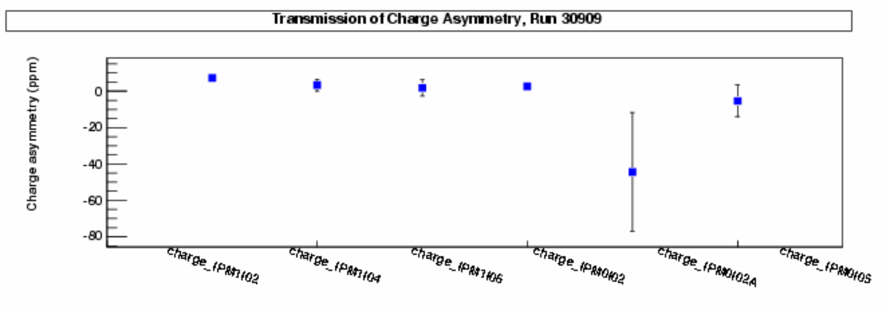
w/ photocathode 20X smaller in injector

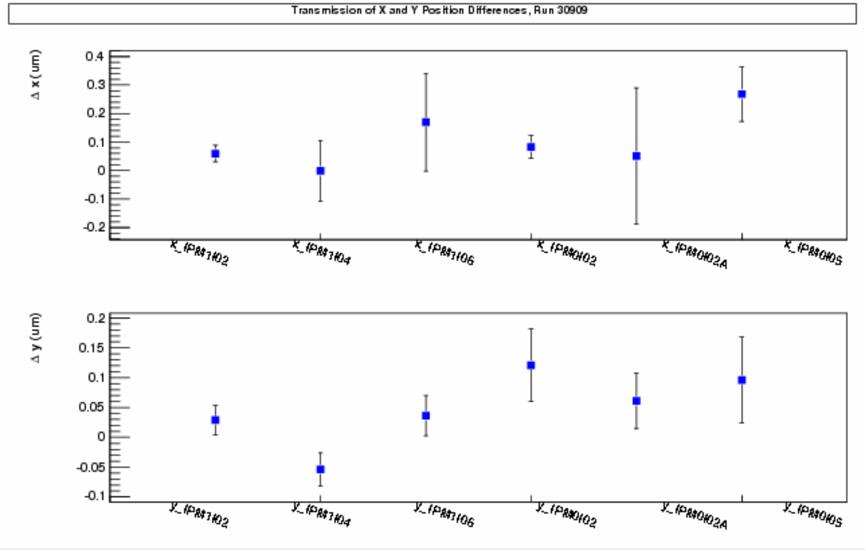
Injector	1I02
Δx	< 0.3 μm
Δy	< 0.3 μm
Δcharge	

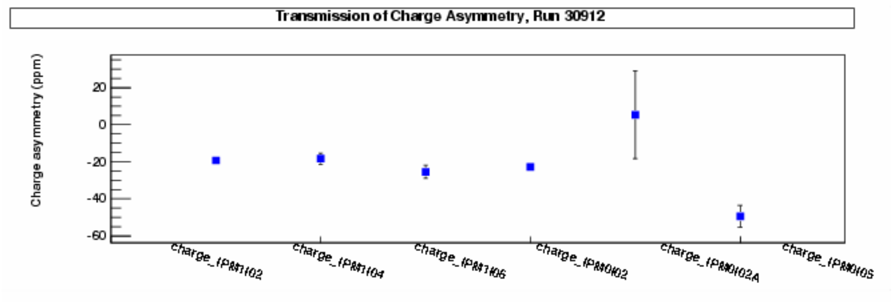
Electron Beam Studies
September 14, 2006

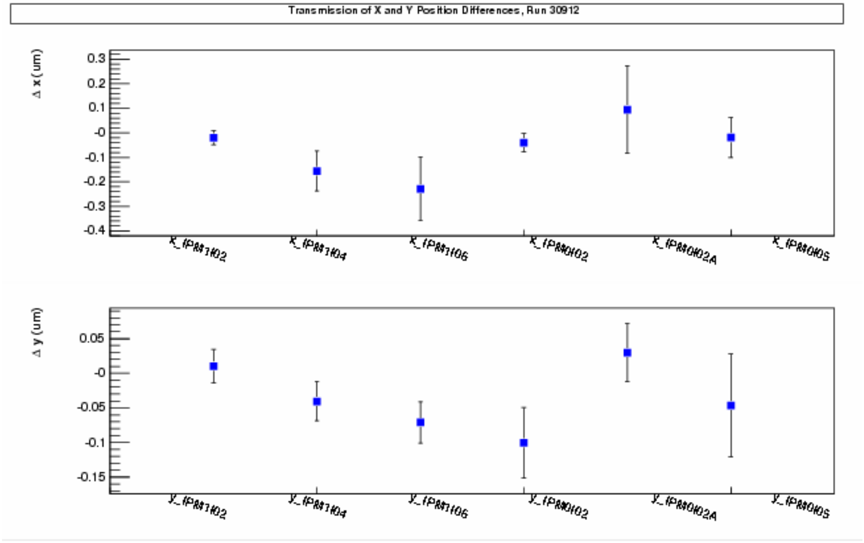
IHWP = OUT
RHWP = 0°
-10 ppm/V

IHWP = IN
RHWP = 0°
-11 ppm/V

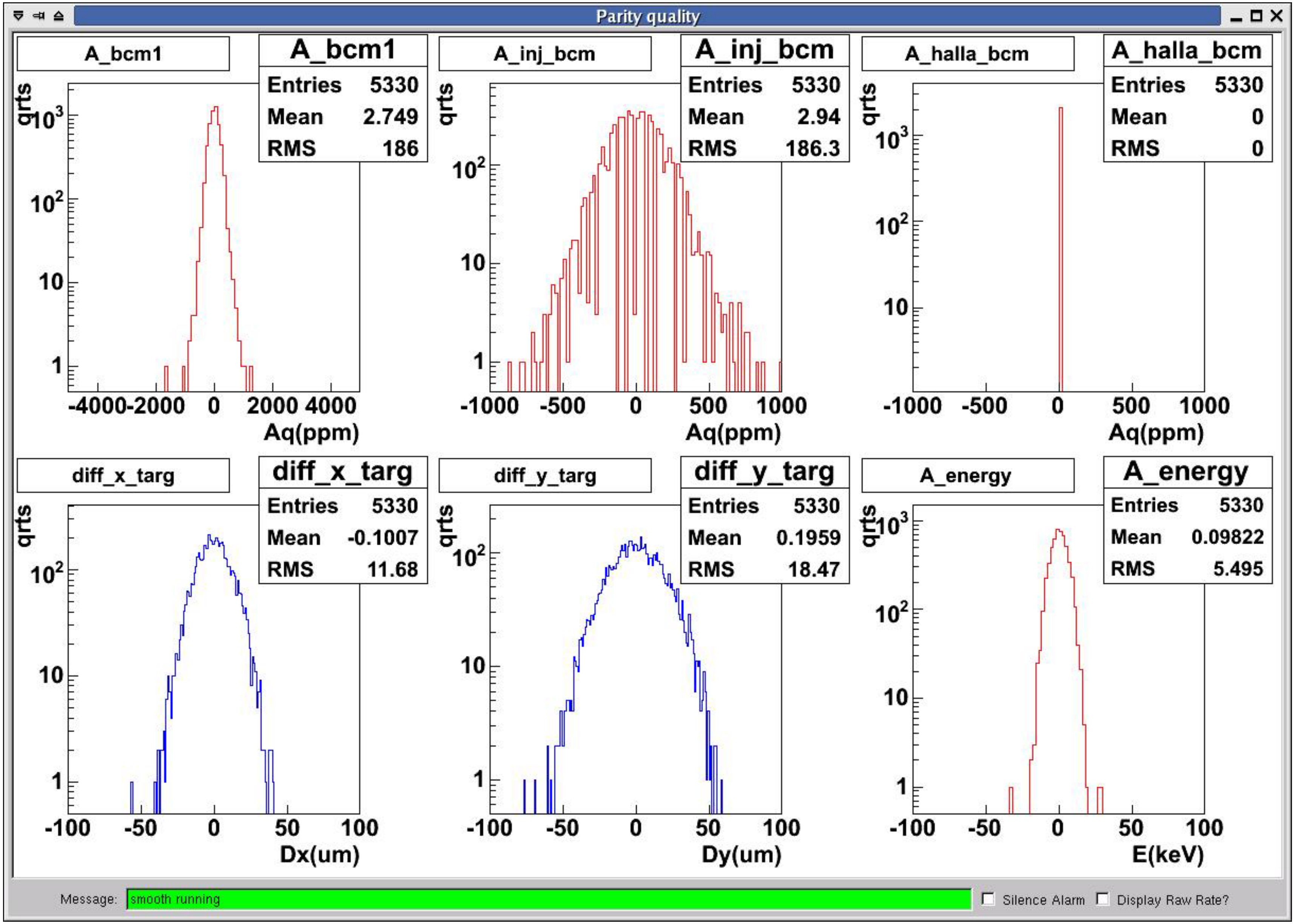

Transmission of Charge Asymmetry, Run 30909


Transmission of X and Y Position Differences, Run 30909


Transmission of Charge Asymmetry, Run 30912


Transmission of X and Y Position Differences, Run 30912

Detectors



```
A_bcm1
Entries     5330
Mean       2.749
RMS          186
```

```
A_inj_bcm
Entries     5330
Mean        2.94
RMS        186.3
```

```
A_halla_bcm
Entries     5330
Mean           0
RMS            0
```

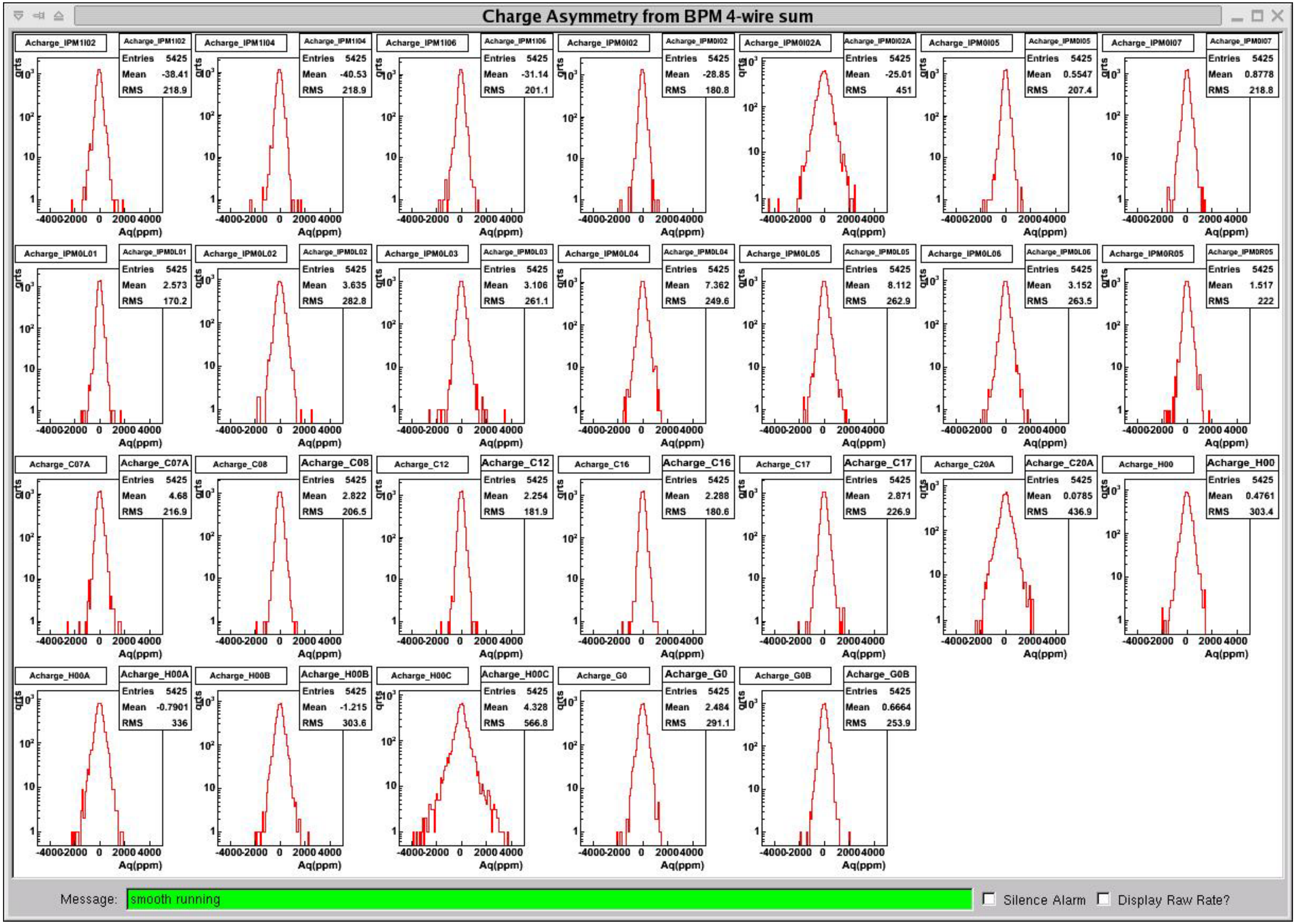
```
diff_x_targ
Entries     5330
Mean     -0.1007
RMS        11.68
```

```
diff_y_targ
Entries     5330
Mean      0.1959
RMS        18.47
```

```
A_energy
Entries     5330
Mean     0.09822
RMS        5.495
```

Message: smooth running

☐ Silence Alarm ☐ Display Raw Rate?



Acharge_IPM1I02
Entries 5425
Mean -38.41
RMS 218.9

Acharge_IPM1I04
Entries 5425
Mean -40.53
RMS 218.9

Acharge_IPM1I06
Entries 5425
Mean -31.14
RMS 201.1

Acharge_IPM0I02
Entries 5425
Mean -28.85
RMS 180.8

Acharge_IPM0I02A
Entries 5425
Mean -25.01
RMS 451

Acharge_IPM0I05
Entries 5425
Mean 0.5547
RMS 207.4

Acharge_IPM0I07
Entries 5425
Mean 0.8778
RMS 218.8

Acharge_IPM0L01
Entries 5425
Mean 2.573
RMS 170.2

Acharge_IPM0L02
Entries 5425
Mean 3.635
RMS 282.8

Acharge_IPM0L03
Entries 5425
Mean 3.106
RMS 261.1

Acharge_IPM0L04
Entries 5425
Mean 7.362
RMS 249.6

Acharge_IPM0L05
Entries 5425
Mean 8.112
RMS 262.9

Acharge_IPM0L06
Entries 5425
Mean 3.152
RMS 263.5

Acharge_IPM0R05
Entries 5425
Mean 1.517
RMS 222

Acharge_C07A
Entries 5425
Mean 4.68
RMS 216.9

Acharge_C08
Entries 5425
Mean 2.822
RMS 206.5

Acharge_C12
Entries 5425
Mean 2.254
RMS 181.9

Acharge_C16
Entries 5425
Mean 2.288
RMS 180.6

Acharge_C17
Entries 5425
Mean 2.871
RMS 226.9

Acharge_C20A
Entries 5425
Mean 0.0785
RMS 436.9

Acharge_H00
Entries 5425
Mean 0.4761
RMS 303.4

Acharge_H00A
Entries 5425
Mean -0.7901
RMS 336

Acharge_H00B
Entries 5425
Mean -1.215
RMS 303.6

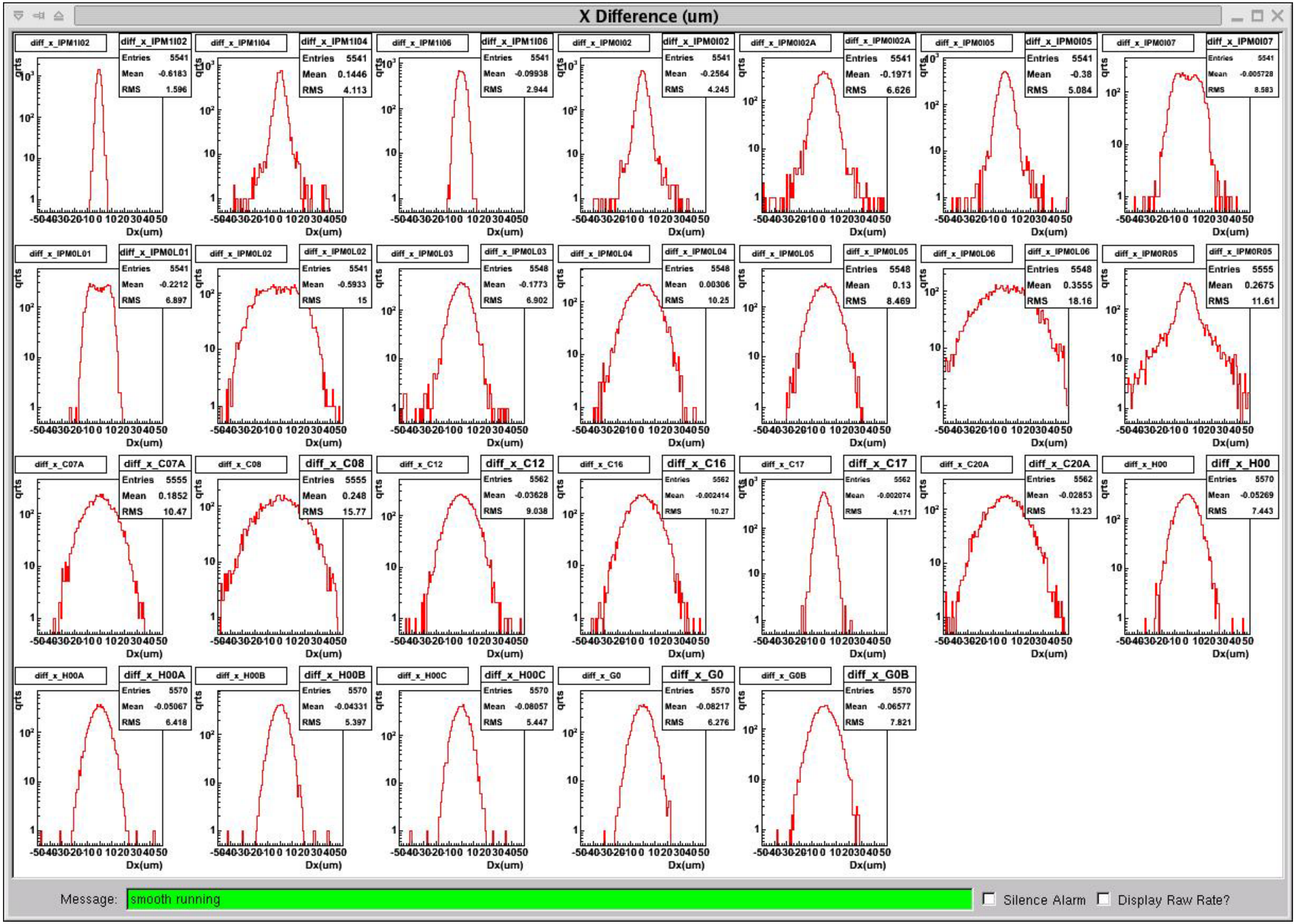
Acharge_H00C
Entries 5425
Mean 4.328
RMS 566.8

Acharge_G0
Entries 5425
Mean 2.484
RMS 291.1

Acharge_G0B
Entries 5425
Mean 0.6664
RMS 253.9

Message: smooth running

☐ Silence Alarm ☐ Display Raw Rate?



X Difference (um)

diff_x_IPM1I02
Entries 5541
Mean -0.6183
RMS 1.596

diff_x_IPM1I04
Entries 5541
Mean 0.1446
RMS 4.113

diff_x_IPM1I06
Entries 5541
Mean -0.09938
RMS 2.944

diff_x_IPM0I02
Entries 5541
Mean -0.2564
RMS 4.245

diff_x_IPM0I02A
Entries 5541
Mean -0.1971
RMS 6.626

diff_x_IPM0I05
Entries 5541
Mean -0.38
RMS 5.084

diff_x_IPM0I07
Entries 5541
Mean -0.005728
RMS 8.583

diff_x_IPM0L01
Entries 5541
Mean -0.2212
RMS 6.897

diff_x_IPM0L02
Entries 5541
Mean -0.5933
RMS 15

diff_x_IPM0L03
Entries 5548
Mean -0.1773
RMS 6.902

diff_x_IPM0L04
Entries 5548
Mean 0.00306
RMS 10.25

diff_x_IPM0L05
Entries 5548
Mean 0.13
RMS 8.469

diff_x_IPM0L06
Entries 5548
Mean 0.3555
RMS 18.16

diff_x_IPM0R05
Entries 5555
Mean 0.2675
RMS 11.61

diff_x_C07A
Entries 5555
Mean 0.1852
RMS 10.47

diff_x_C08
Entries 5555
Mean 0.248
RMS 15.77

diff_x_C12
Entries 5562
Mean -0.03628
RMS 9.038

diff_x_C16
Entries 5562
Mean -0.002414
RMS 10.27

diff_x_C17
Entries 5562
Mean -0.002074
RMS 4.171

diff_x_C20A
Entries 5562
Mean -0.02853
RMS 13.23

diff_x_H00
Entries 5570
Mean -0.05269
RMS 7.443

diff_x_H00A
Entries 5570
Mean -0.05067
RMS 6.418

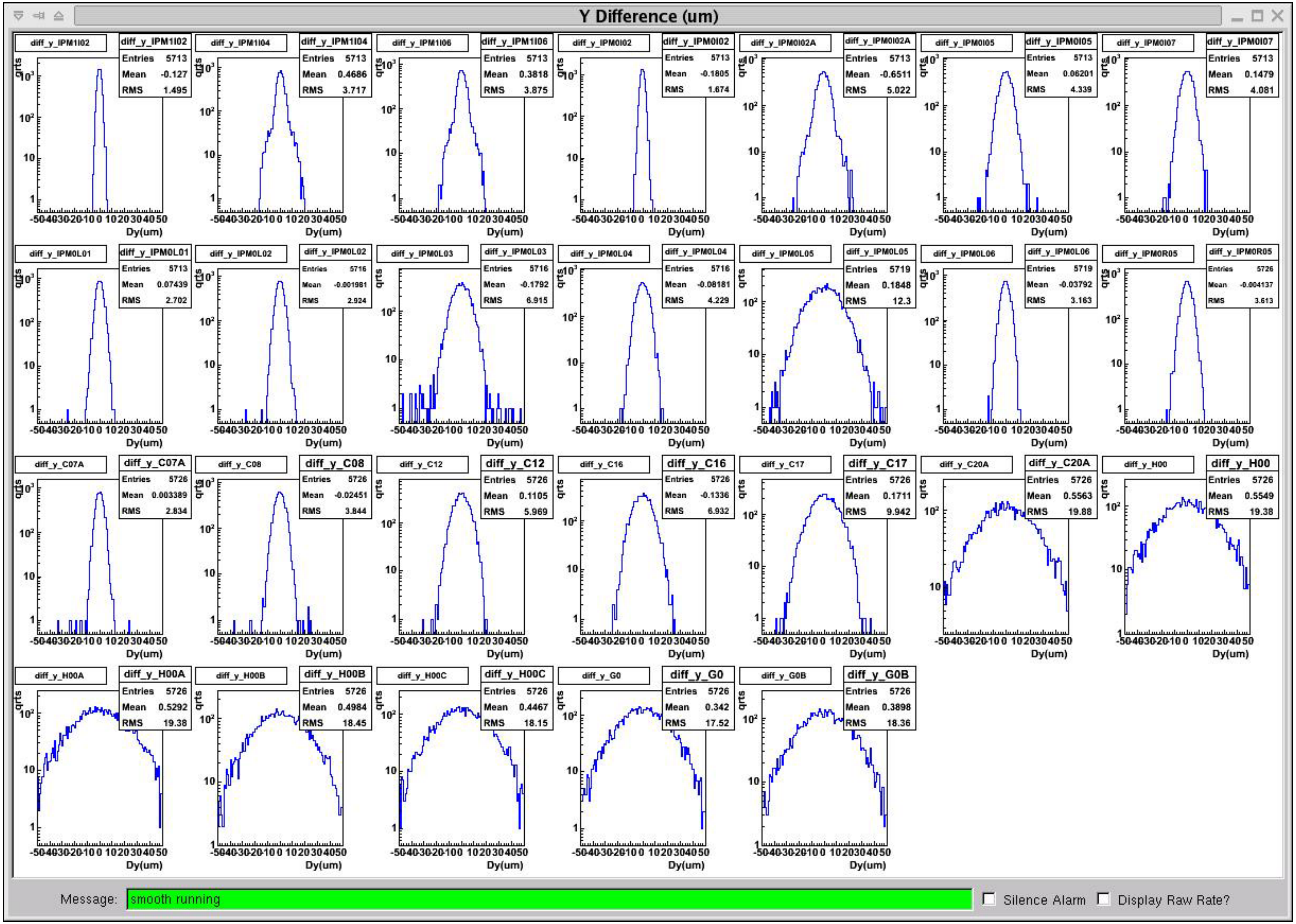
diff_x_H00B
Entries 5570
Mean -0.04331
RMS 5.397

diff_x_H00C
Entries 5570
Mean -0.08057
RMS 5.447

diff_x_G0
Entries 5570
Mean -0.08217
RMS 6.276

diff_x_G0B
Entries 5570
Mean -0.06577
RMS 7.821

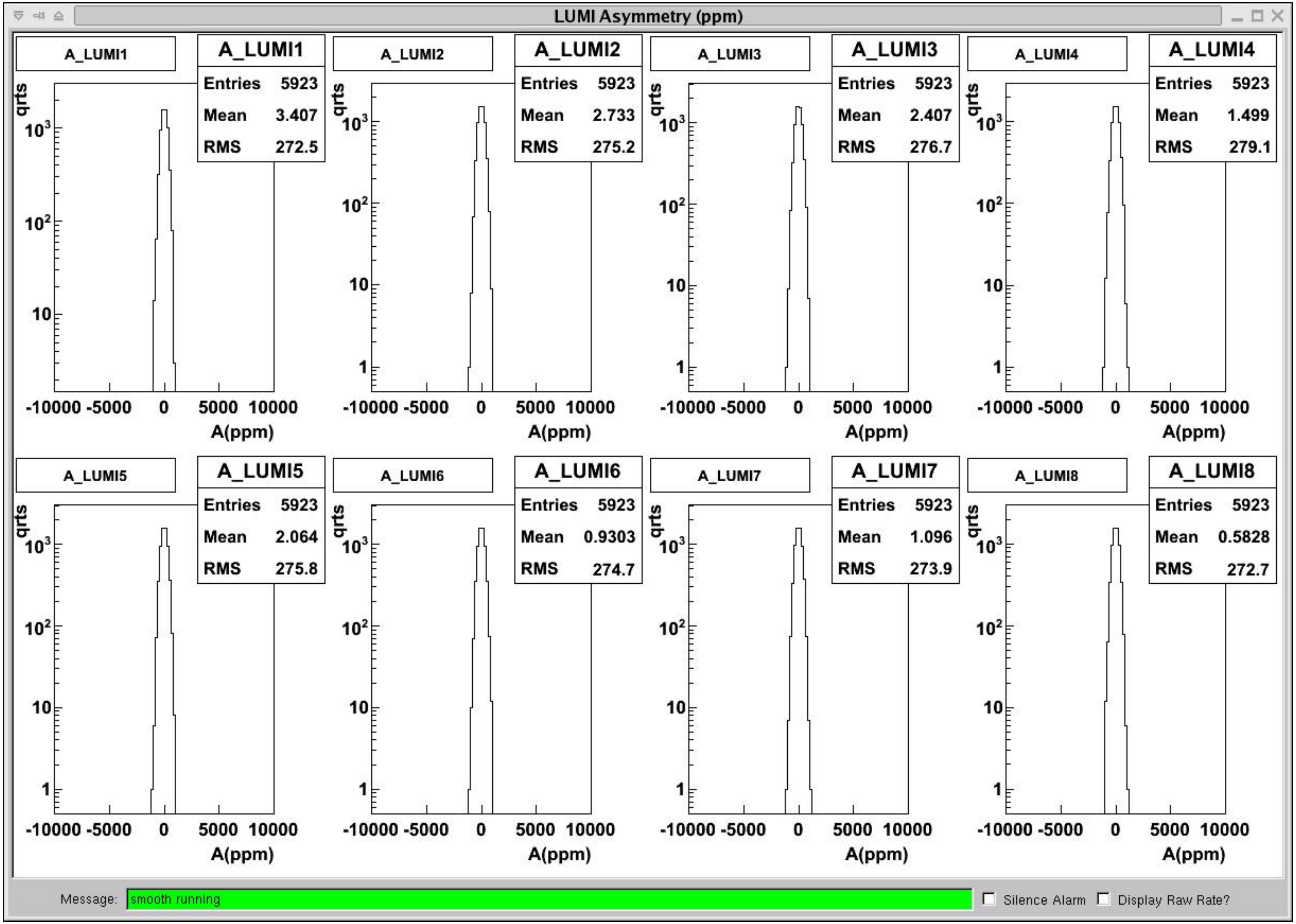
Message: smooth running
]



```
diff_y_IPM1I02
Entries    5713
Mean     -0.127
RMS       1.495

diff_y_IPM1I04
Entries    5713
Mean     0.4686
RMS       3.717

diff_y_IPM1I06
Entries    5713
Mean     0.3818
RMS       3.875

diff_y_IPM0I02
Entries    5713
Mean    -0.1805
RMS       1.674

diff_y_IPM0I02A
Entries    5713
Mean    -0.6511
RMS       5.022

diff_y_IPM0I05
Entries    5713
Mean    0.06201
RMS       4.339

diff_y_IPM0I07
Entries    5713
Mean     0.1479
RMS       4.081

diff_y_IPM0L01
Entries    5713
Mean    0.07439
RMS       2.702

diff_y_IPM0L02
Entries    5716
Mean  -0.001981
RMS       2.924

diff_y_IPM0L03
Entries    5716
Mean    -0.1792
RMS       6.915

diff_y_IPM0L04
Entries    5716
Mean   -0.08181
RMS       4.229

diff_y_IPM0L05
Entries    5719
Mean     0.1848
RMS        12.3

diff_y_IPM0L06
Entries    5719
Mean   -0.03792
RMS       3.163

diff_y_IPM0R05
Entries    5726
Mean  -0.004137
RMS       3.613

diff_y_C07A
Entries    5726
Mean   0.003389
RMS       2.834

diff_y_C08
Entries    5726
Mean   -0.02451
RMS       3.844

diff_y_C12
Entries    5726
Mean     0.1105
RMS       5.969

diff_y_C16
Entries    5726
Mean    -0.1336
RMS       6.932

diff_y_C17
Entries    5726
Mean     0.1711
RMS       9.942

diff_y_C20A
Entries    5726
Mean     0.5563
RMS       19.88

diff_y_H00
Entries    5726
Mean     0.5549
RMS       19.38

diff_y_H00A
Entries    5726
Mean     0.5292
RMS       19.38

diff_y_H00B
Entries    5726
Mean     0.4984
RMS       18.45

diff_y_H00C
Entries    5726
Mean     0.4467
RMS       18.15

diff_y_G0
Entries    5726
Mean      0.342
RMS       17.52

diff_y_G0B
Entries    5726
Mean     0.3898
RMS       18.36
```

Message: smooth running

☐ Silence Alarm ☐ Display Raw Rate?



A_LUMI1
Entries 5923
Mean 3.407
RMS 272.5

A_LUMI2
Entries 5923
Mean 2.733
RMS 275.2

A_LUMI3
Entries 5923
Mean 2.407
RMS 276.7

A_LUMI4
Entries 5923
Mean 1.499
RMS 279.1

A_LUMI5
Entries 5923
Mean 2.064
RMS 275.8

A_LUMI6
Entries 5923
Mean 0.9303
RMS 274.7

A_LUMI7
Entries 5923
Mean 1.096
RMS 273.9

A_LUMI8
Entries 5923
Mean 0.5828
RMS 272.7

Message: smooth running

☐ Silence Alarm ☐ Display Raw Rate?