Monitoring of the Beam Time-Structure in Hall B

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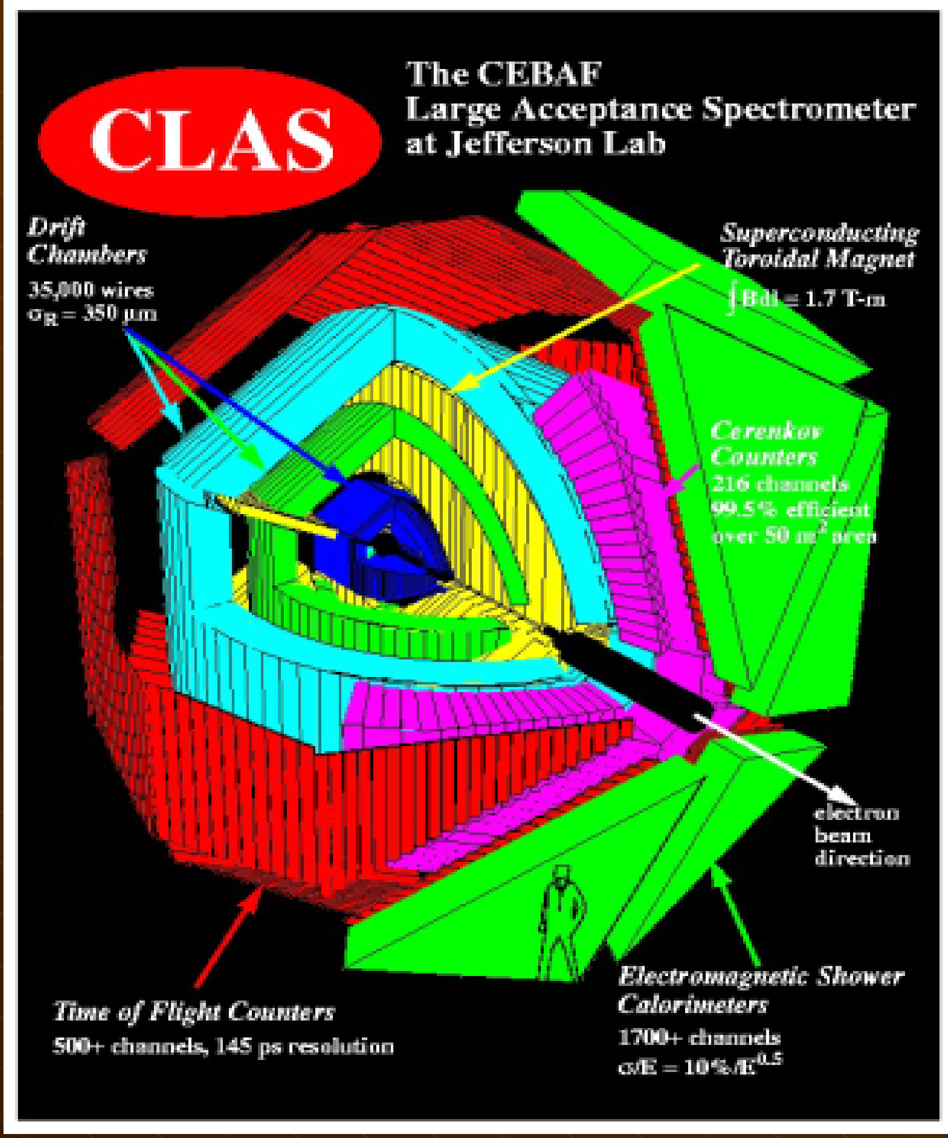
Topics of Discussion

- The science behind the CLAS experiments
- Charged particle identification in CLAS (PID)
- Why do we need to monitor RF structure?
- Existing “*Sixty Hz*” application
- Utilization of *CAEN V775* TDC
- EPICS interface
- Results
- Conclusions

CLAS Detector in Hall B

- Nearly 4π coverage in the laboratory frame.
- Superconducting toroidal magnet dividing CLAS into six sectors.
- Electromagnetic calorimeter for neutral particle detection and triggering on electrons.
- Drift Chambers for charged particle momentum reconstruction with 0.1% resolution.
- Scintillator counters for time-of-flight particle Identification.
- Cherenkov counters for electron-pion separation.
- CLAS is an exceptional tool for detecting multiparticle final states.



Experimental Program with CLAS

- Electron-nucleon Deep Inelastic Scattering (DIS)
  - ✓ Inclusive DIS to study parton distributions
  - ✓ Exclusive processes to study GPDs
- Baryon spectroscopy
  - ✓ Missing states predicted by quark models
  - ✓ Transition form factors
  - ✓ Search for pentaquarks
- Study of the nuclear matter
  - ✓ Short range correlations in the nuclei
  - ✓ Modification of the nucleon structure in the nuclei
  - ✓ Search for Color Transparency effects

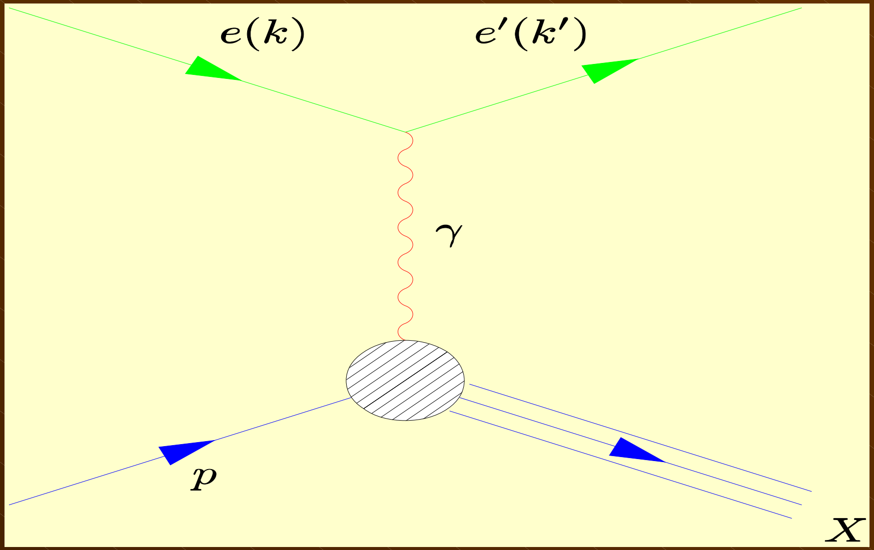
Terminology for *ep* Scattering

- 4-momentum transfer Q^2

$$-Q^2 = (k - k')^2 = (E - E')^2 - (p - p')^2$$

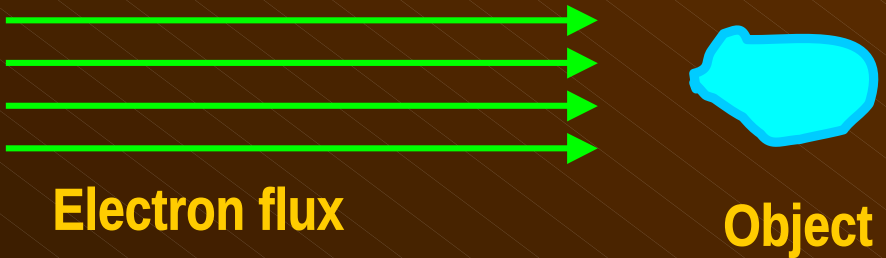
- Hadronic mass W

$$W^2 = M_p^2 + 2M_p(E - E') - 2Q^2$$



- Cross Section

$$\frac{d\sigma(Q^2, W)}{dQ^2\ dW} = \frac{dN_{det}(Q^2, W)}{dQ^2\ dW\ L}$$

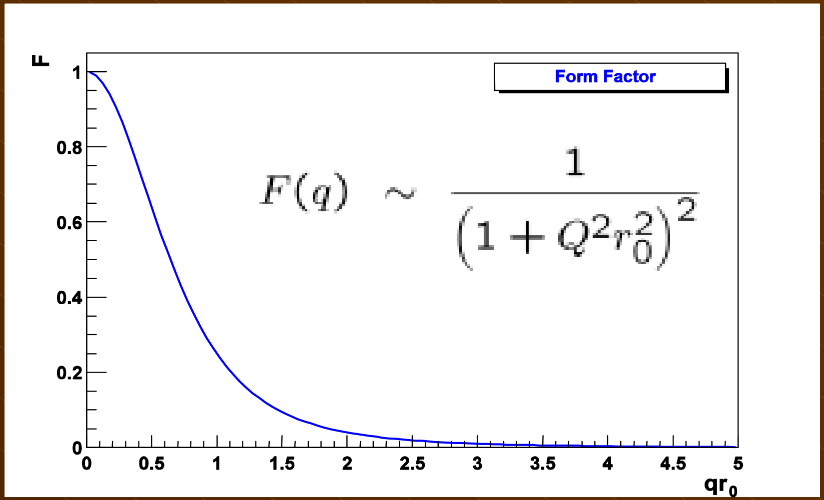


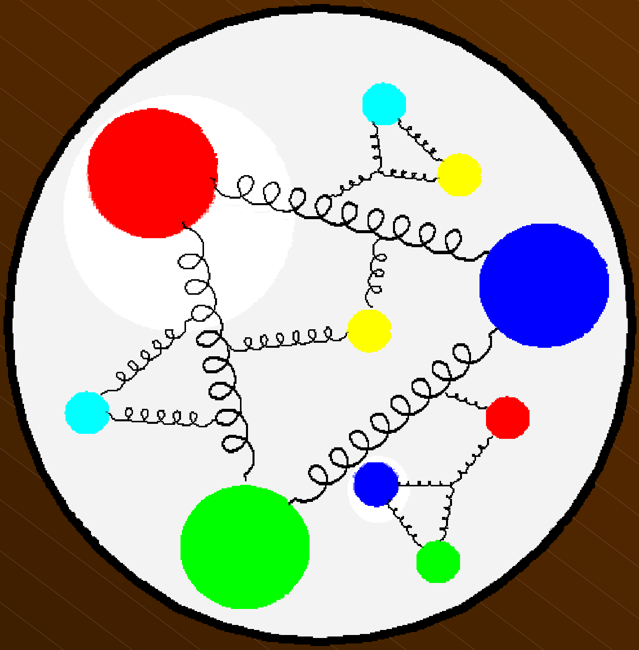
Some More Terminology

- Isospin is introduced to describe proton and neutron (later u- and d-quarks) as two different “polarization” states of one particle
- Multipole amplitudes: Similar to classical EM, the full amplitude can be decomposed in multipoles E_0, M_0, S_1, E_1, M_1 etc … (amplitudes too)
- Photocoupling amplitudes $A_{1/2}$, $A_{3/2}$, $S_{1/2}$ for an excited state give the probability (and the phase) of exciting such a state from proton and photon with specified combined helicity.

Form Factors

- 4-D analogue of Fourier transform for the spatial distribution of an object in 3-D.
- A good comparison point between theory and experiments.
- Q^2 dependent form factors can also be defined for transition from one state to another.
- Transition form factors are related to the internal structure of both initial and the final states.





Δ-resonance (or $P_{33}(1232)$)

- The most prominent peak seen in *ep* scattering at low Q^2 *(J=3/2, I=3/2).*
- At $Q^2 \sim 0$ the Constituent Quark Models (CQM) predict:

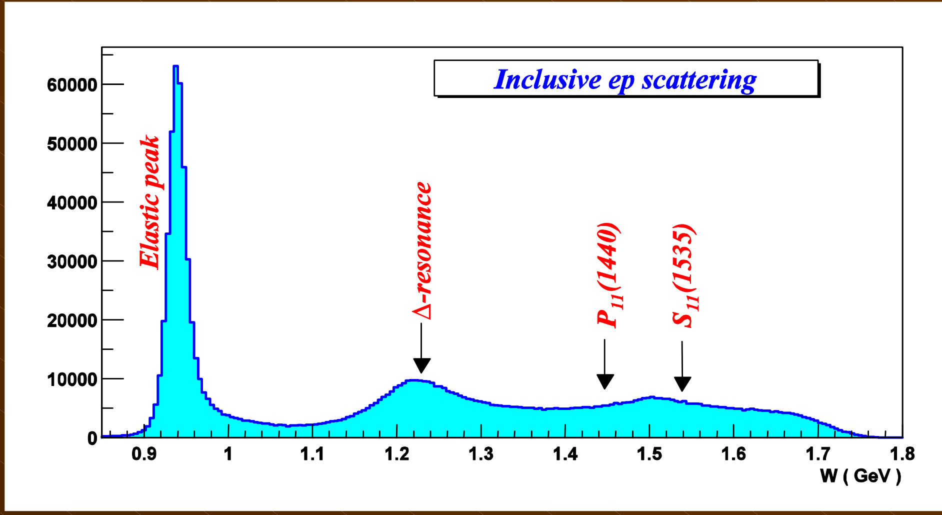
$$R_{EM} \equiv \frac{E_2}{M_1} \sim 0$$

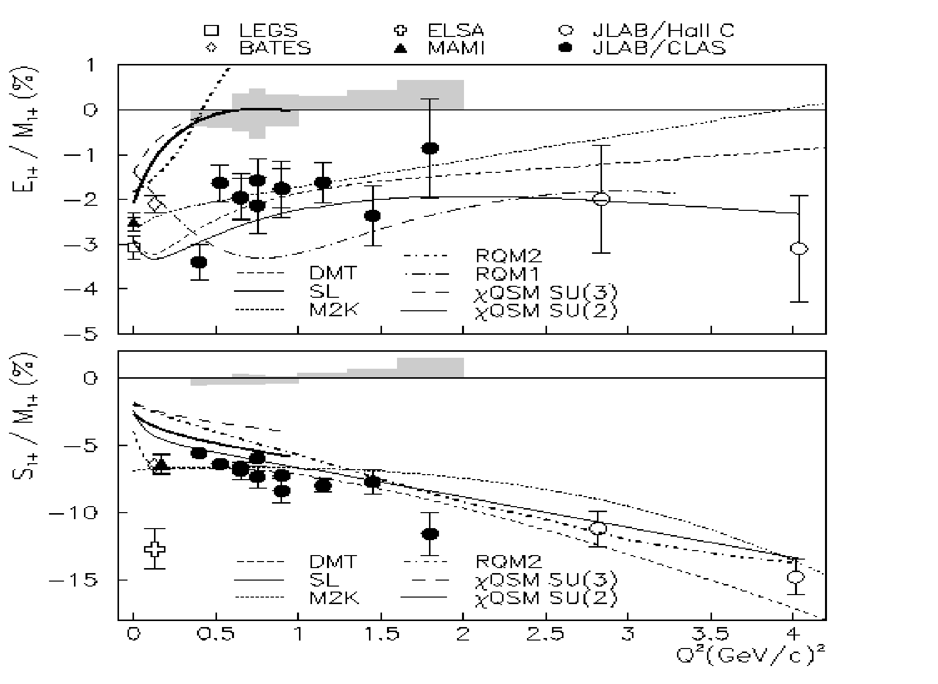
- At $Q^2 \to \infty$ perturbative Quantum Chromodynamics (pQCD) predicts:

$$R_{EM} = 1$$

- A transition to the asymptotic regime is expected at some intermediate value of Q^2.

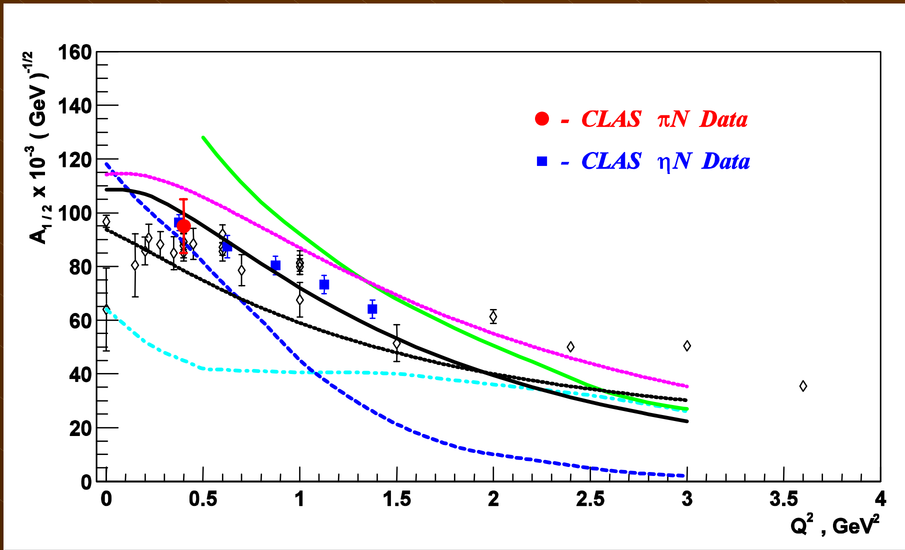
- *No Transition to the asymptotic regime have been seen yet*
- *Data at low Q^2 favor models incorporating pion cloud.*



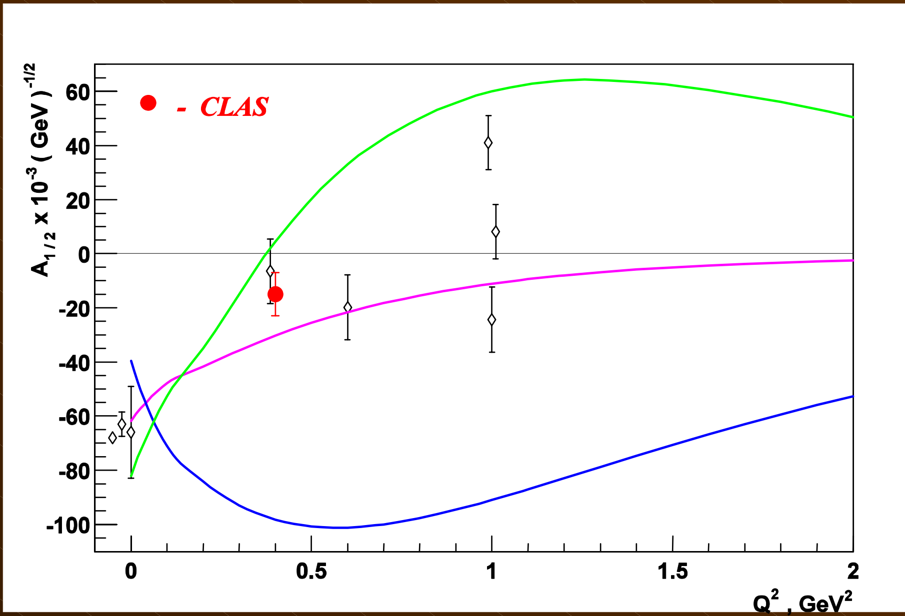


$S_{11}(1535)$ and $P_{11}(1440)$ states

- The $A_{1/2}$ amplitude of $S_{11}(1535)$ indicates very slow Q^2 fall-off not explained by CQM.
- CLAS measured both in πN and ηN decay channels. The results from the two channels agree.



- Roper resonance (or $P_{11}(1440)$) has lower mass than one naturally would expect from CQM.
- It was suggested that $P_{11}(1440)$ can also be a hybrid state **|Q³G>**, a hard core surrounded by a vector meson cloud, or even a pentaquark.
- We still need more Q^2 points for $A_{1/2}$ to understand the nature of the Roper resonance.



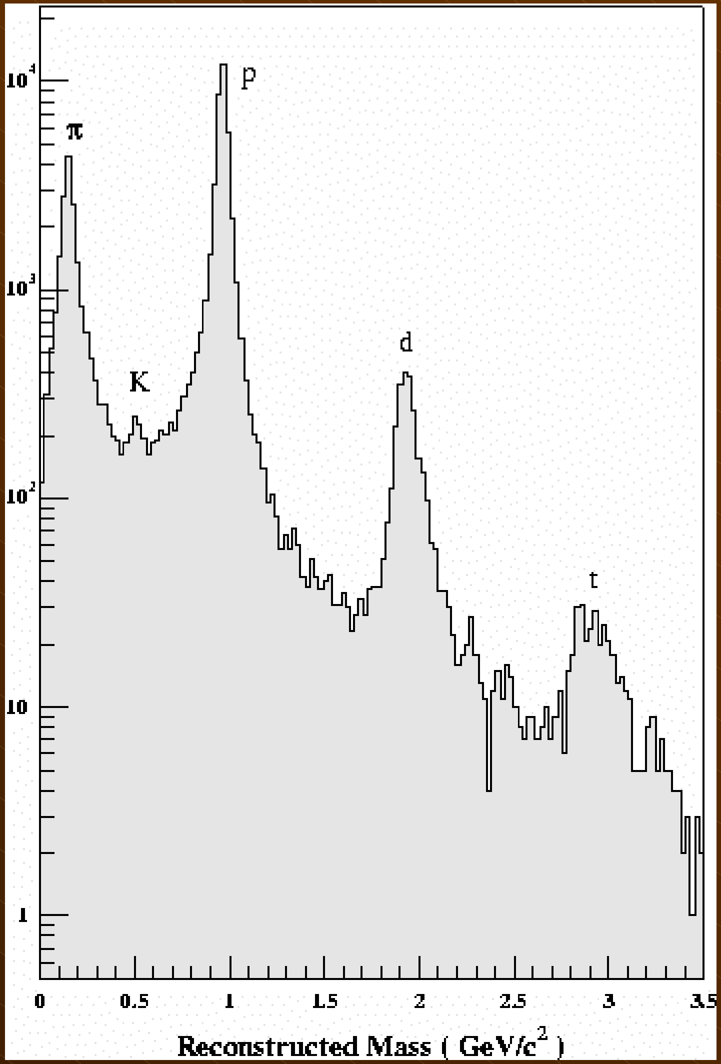
Charged Particle Identification (PID)

- Charged Particle ID is done using the Time-of-Flight (TOF) technique:

$$M = p\sqrt{\left(\frac{T}{L_h}\right)^2 - 1},$$

$$T = T_h - (T_e - L_e)$$

- PID requires momentum for hadron from tracking, and TOF information for the electron and hadron with resolution better than *300 ps* from *288* scintillator counters.
- A procedure is needed to equalize the delays for all *288* TOF channels, which is a very difficult procedure to do using only information from the TOF system.



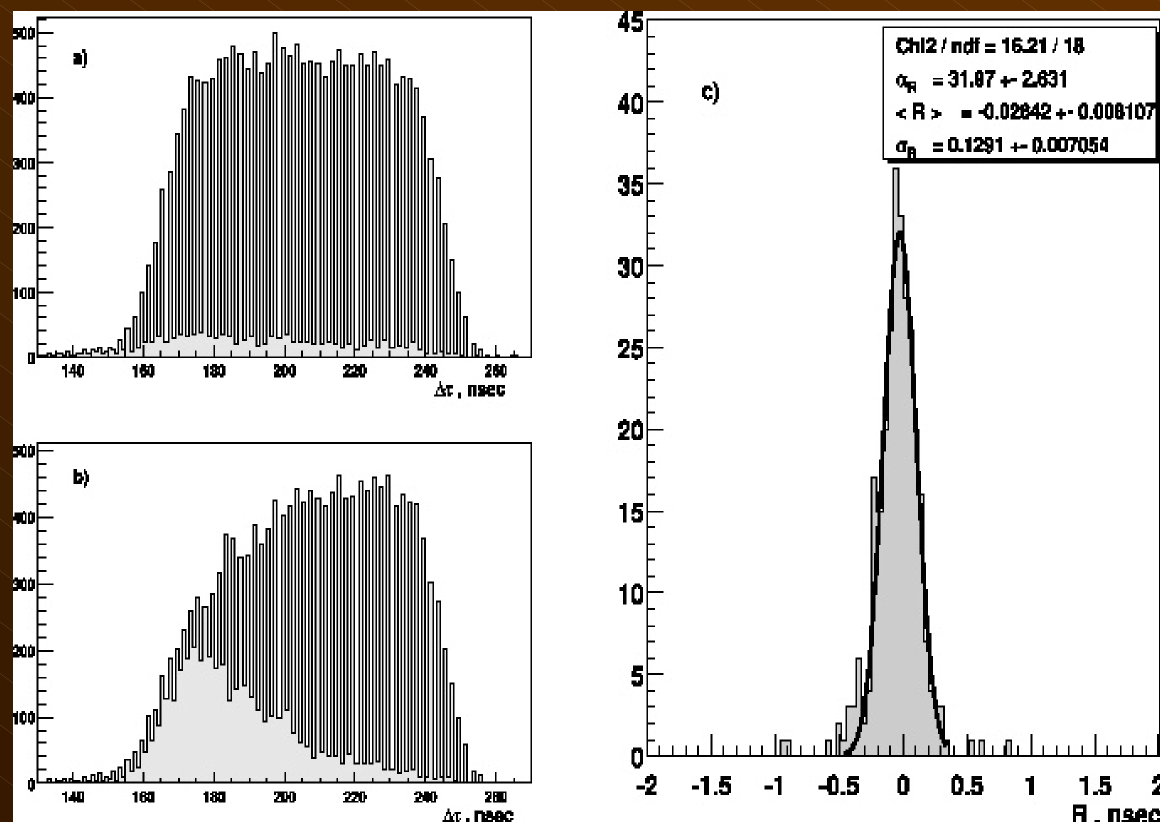
Using the RF structure for PID

Important Note: "The RF signal" here is the *499 MHz* signal from injector (tied to the Hall B electron bunches) pre-scaled by a factor of *40*.

- The *499 MHz* structure of the Hall B beam and "The RF signal" are used for CLAS particle ID
- For each channel calculate :

$$\delta\tau = (T_e - L_e) - T_{RF}$$

and adjust the position of the peak to the same value for all counters.

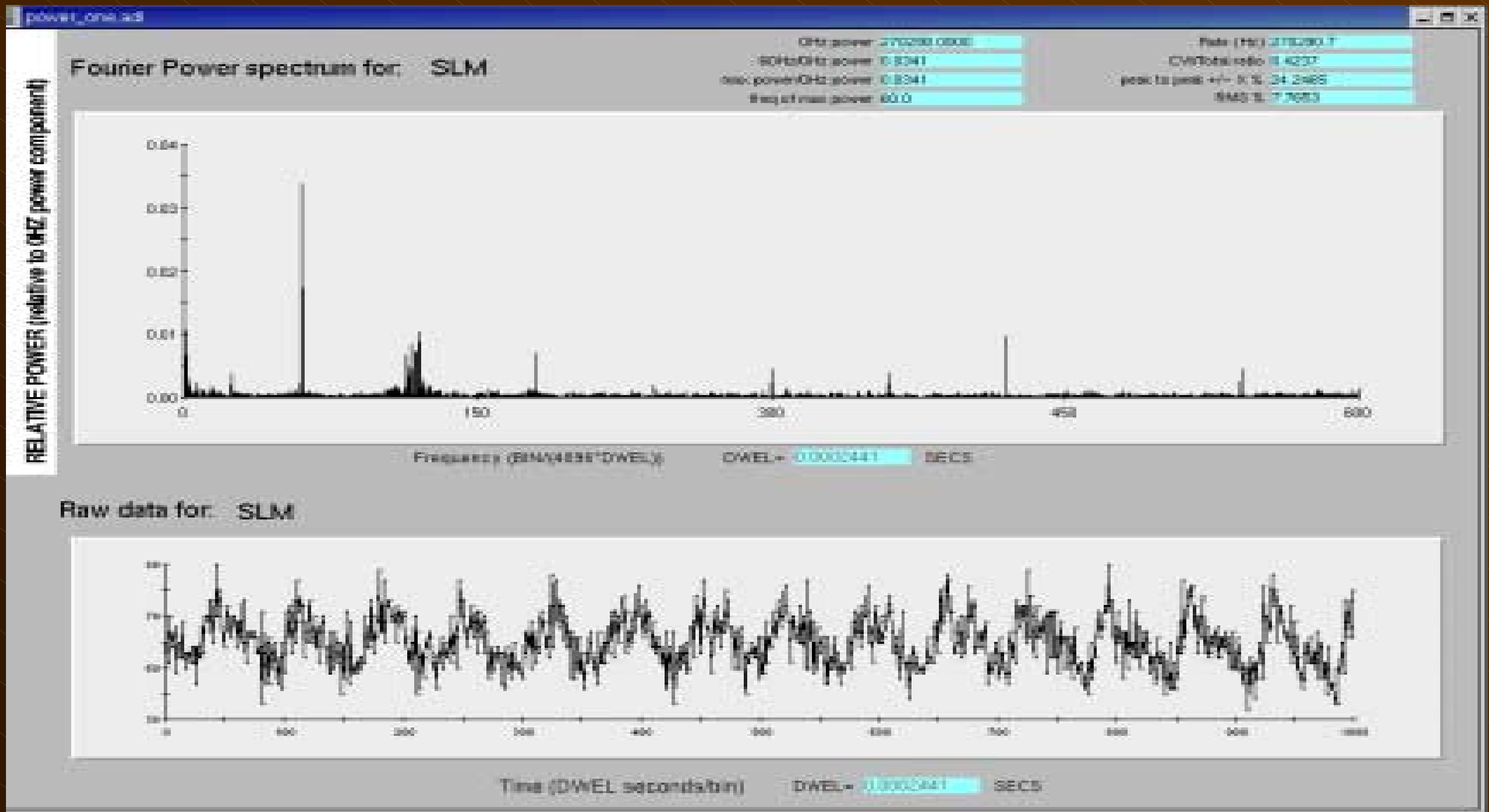


Intermediate Summary

- The time structure of the beam is important for the charge particle ID calibration in CLAS.
- Monitoring of the beam arrival time can be used to provide CLAS calibration groups with early information on phase changes.
- It can also be used to monitor bleed-through of the beam with different time structure.
- These considerations lead the Hall B beam instrumentation group to develop the appropriate diagnostic tools.

The “*Sixty Hz*” Application

- Utilizes SIS3801 VME Multiscaler module.
- Makes “snapshots” of the current each second.
- Can separate frequency components of the beam current in SLM, FCUP and PMTs up to 250 *kHz*.

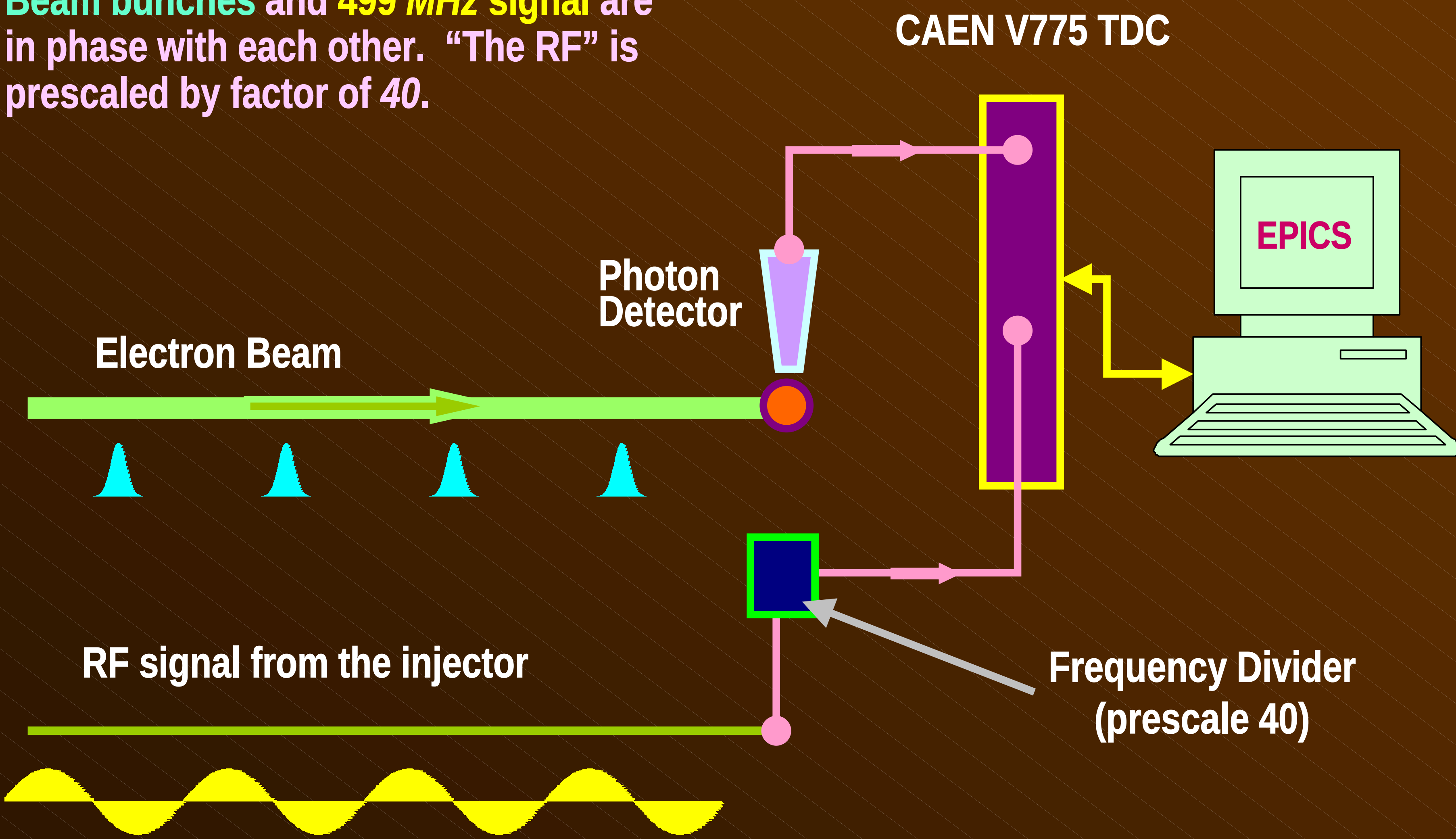


Arrival Time of the Electrons

- Assume that we have an interaction target in the Hall.
- Since the original 499 *MHz* signal is pre-scaled by a factor of *40*, any of "the RF signal" pulses can actually correspond to the electron bunch carrying the electron causing an interaction.
- Measure the time difference between an event and a pulse from "the RF" following the event.
- Typically we should see the ~*2 ns* spaced fence pattern, as we saw in the particle ID.
- If G_0 beam bleed-through is present we may see one of the peaks getting enhanced.

Schematic of the System

Beam bunches and 499 *MHz* signal are in phase with each other. "The RF" is prescaled by factor of *40*.

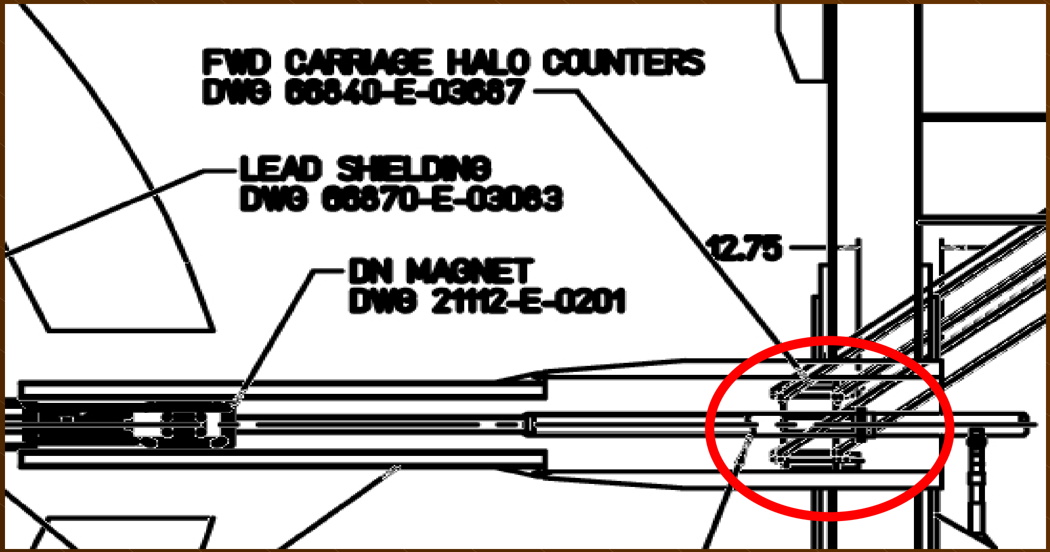


***CAEN V775* TDC Module**

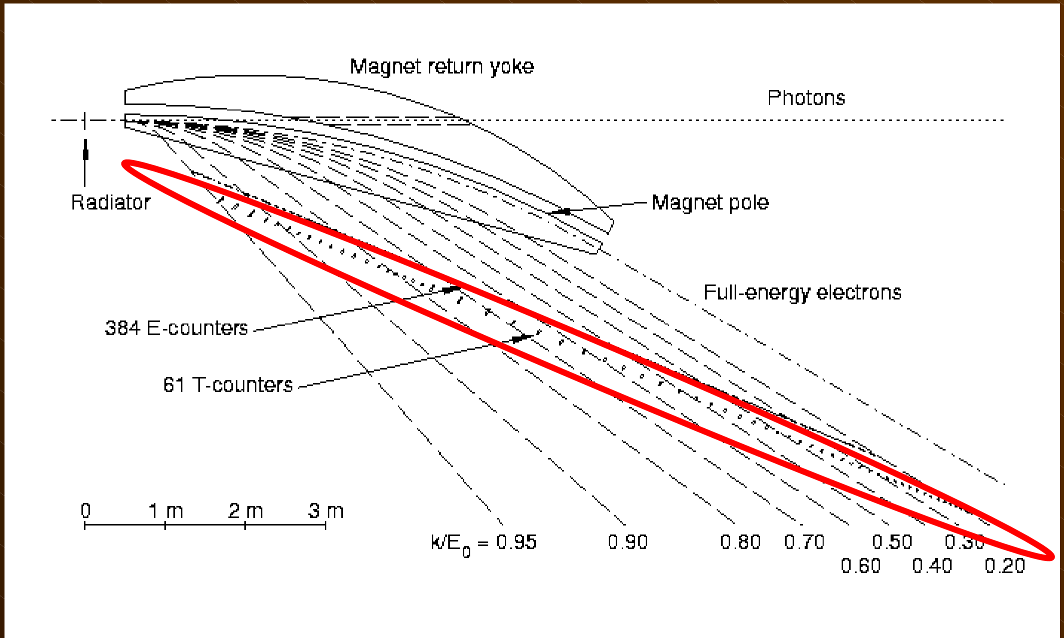
- VME module with a time resolution of *35 ps* with *140 ns* FSR in the high resolution mode.
- Stores data in multi-event buffer *32* events-long.
- Buffer can be read out in interrupt driven mode.
- Such time characteristics will allow for separation of frequencies from *800 kHz* to *14 GHz.*
- *Combined with "Sixty Hz" application we will cover nearly full frequency range.*

Detectors Used for the Study

- "Beam Counter" PMTs, located downstream of the CLAS target. Particles from interactions at CLAS target generate pulses. These counters turned out to be "noisy".

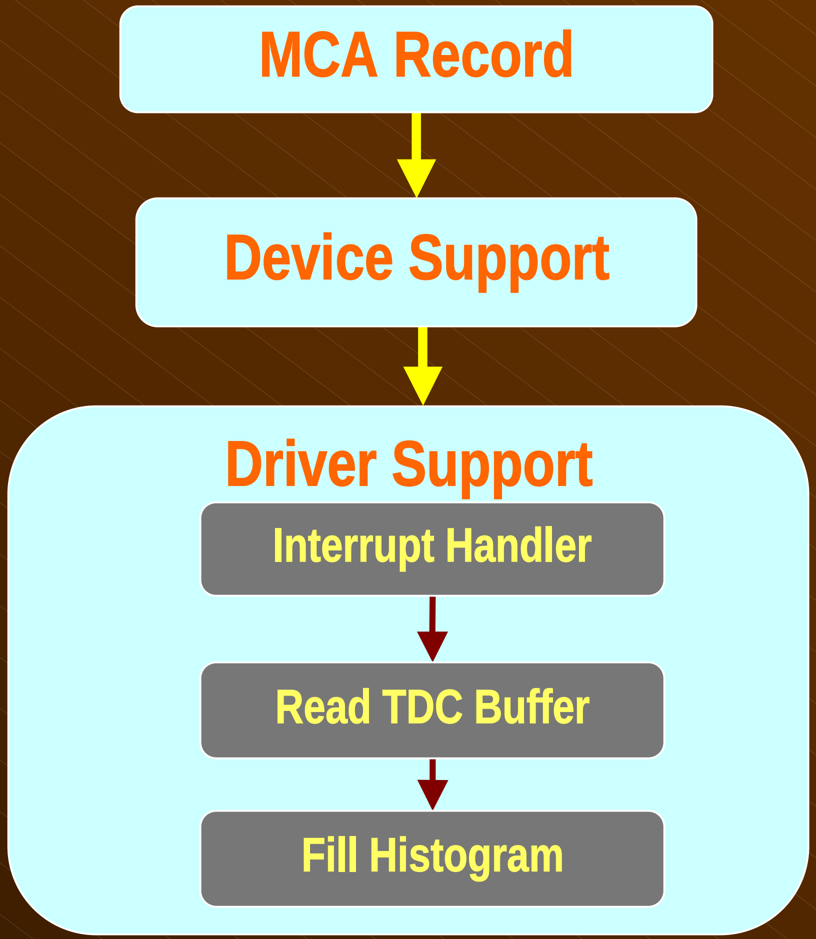


- Tagger T-counters, located in the focal plane of the CLAS tagging system. Electrons, after radiating photons in the radiator, generate pulses in these scintillators. These counters have much less accidental background.

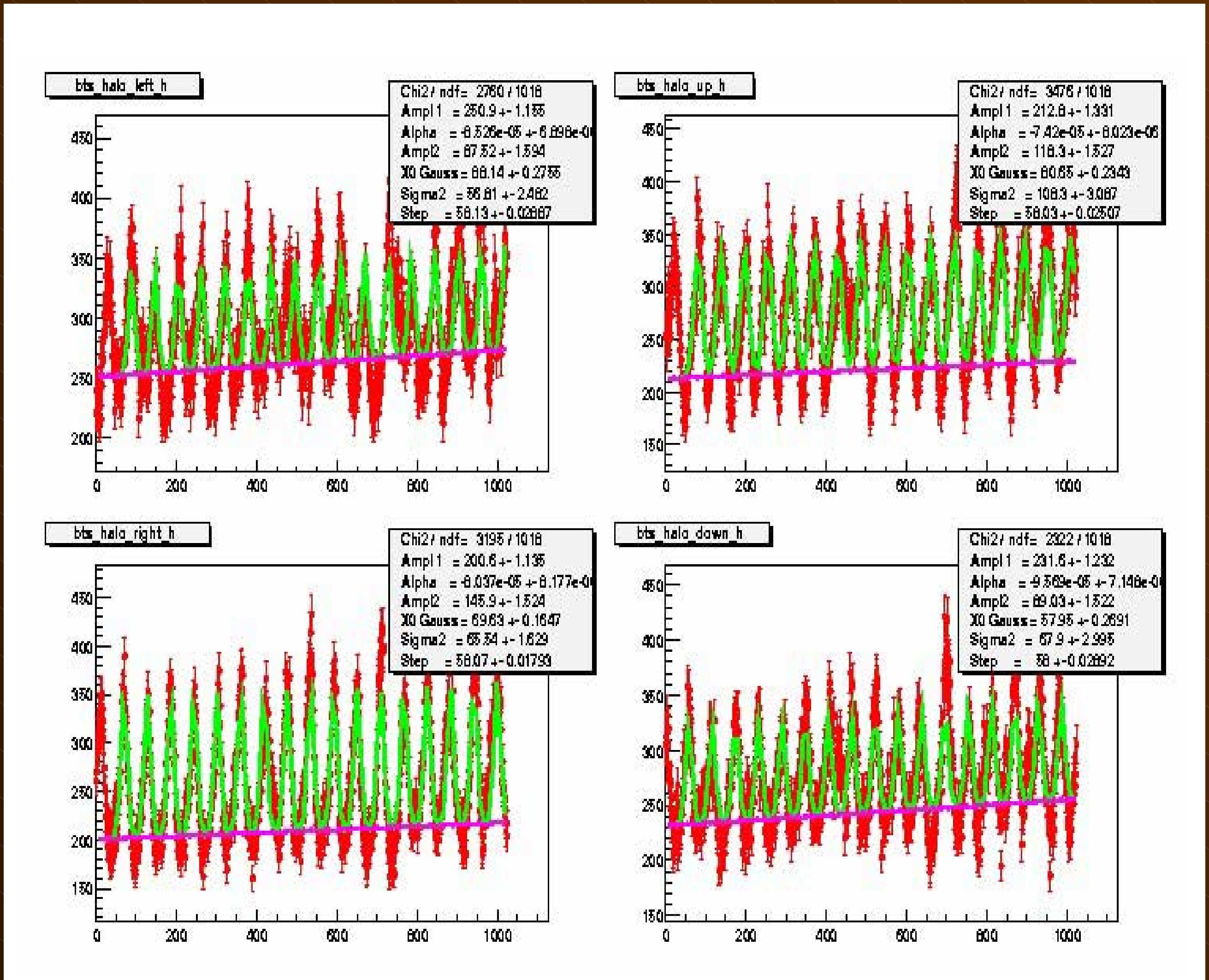


EPICS Interface for TDC V775

- Application runs on VxWorks on PPC 2306 VME controller.
- Utilizes existing **MCA** record, 8192 bin long, with most of the MCA record features functional.
- Uses 1 **MCA** record (i.e. one histogram) per **TDC** channel, measuring the time between two channels with 35 *psec* precision.



Some Data Processing



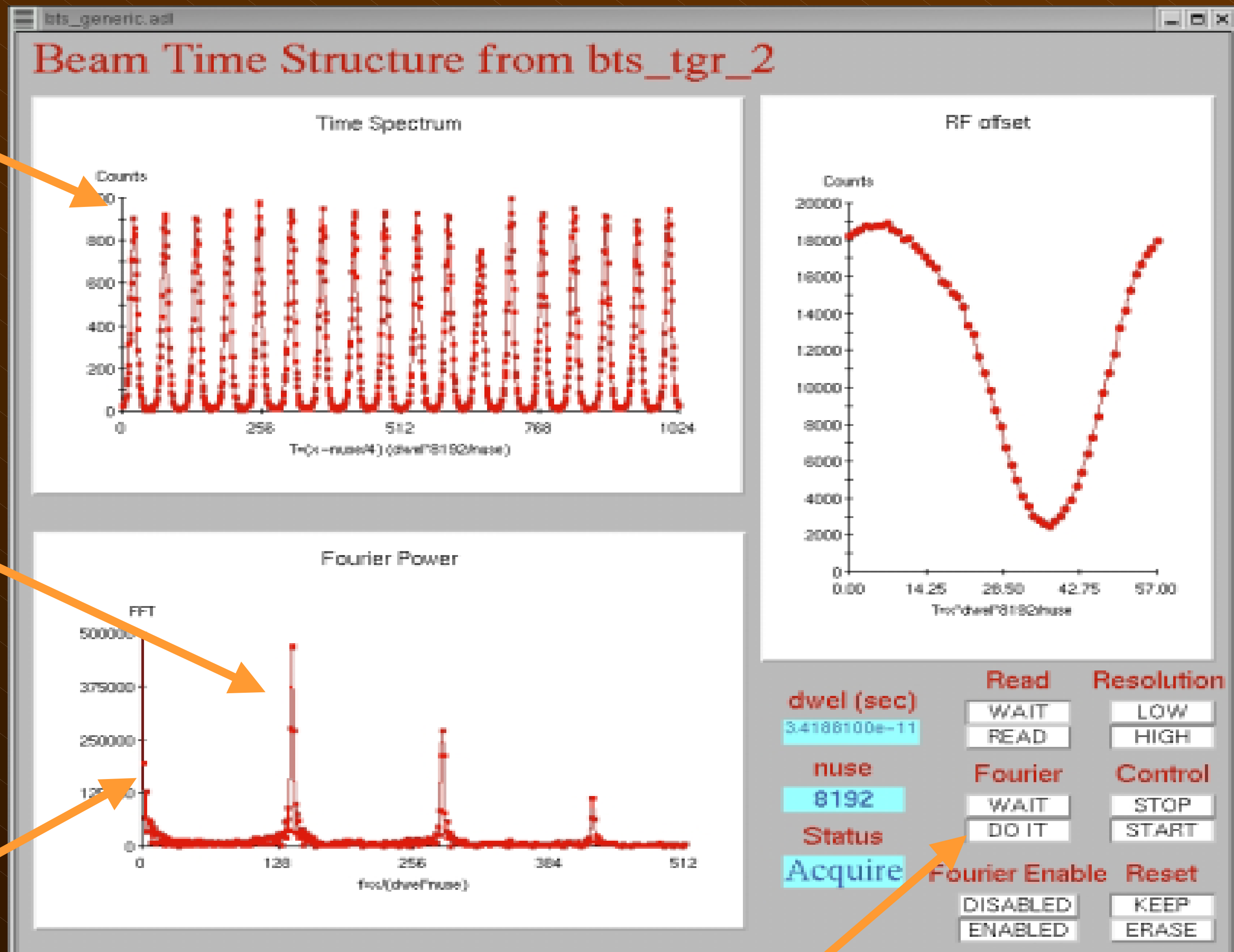
- For some channels there can be substantial accidental background depending on the rate.
- Perform a fit to determine the accidental background and to obtain the phase of the gaussian peaks.
- Perform Fourier transformation on the “cleaned up” time spectrum.

$$f(t) = A\exp(-\alpha t) + \sum_j \exp\left(-\frac{(t-(t_0+j\delta))^2}{2\sigma^2}\right)$$

Online EPICS Screen

Raw Time Spectrum

- Can clearly see **2 ns structure** of the beam
- Can clearly see the ***499 MHz* peak**
- There are other higher frequency peaks due to the gaussian shape of the peaks.



Fourier Transform Spectrum

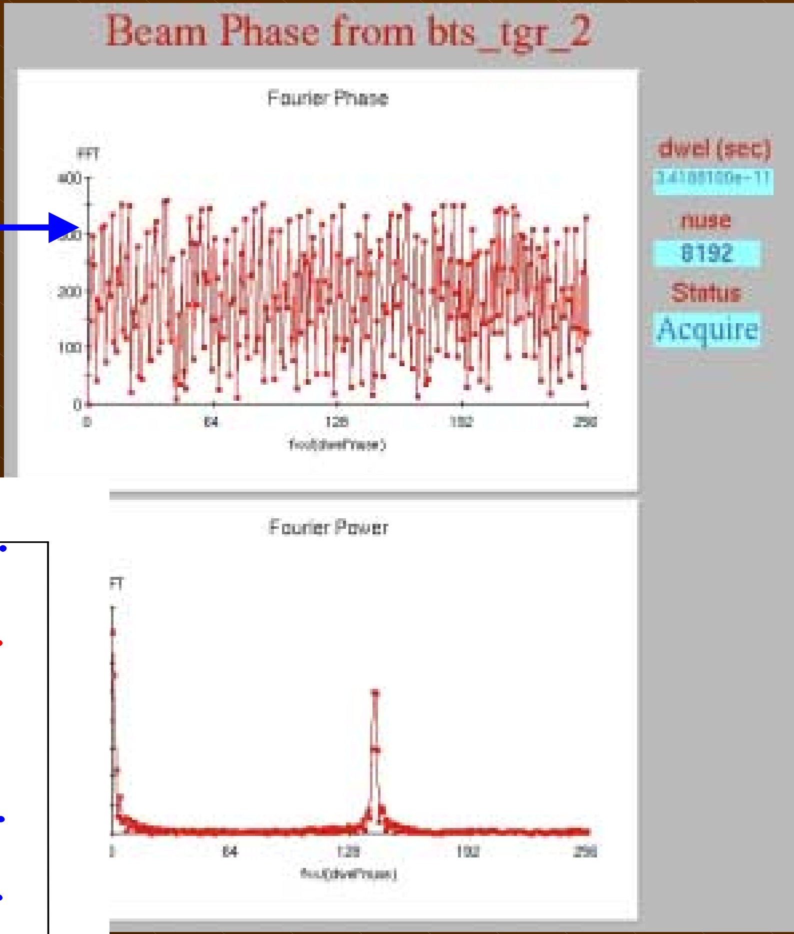
Control Buttons

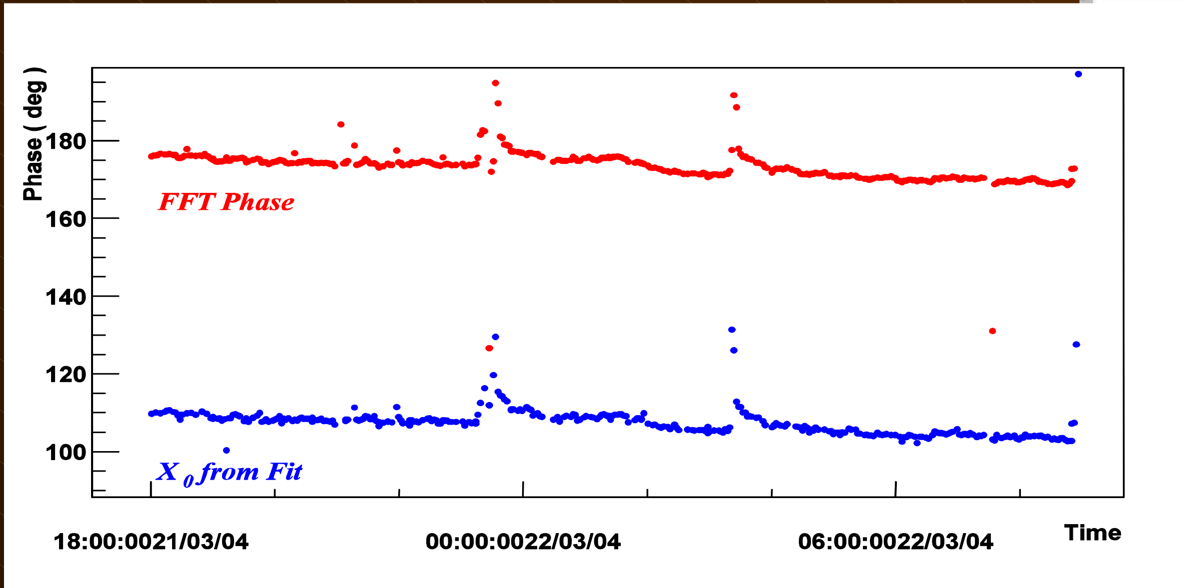
The phase of *499 MHz* component

- We can also extract the phases for each frequency component.

Phase value

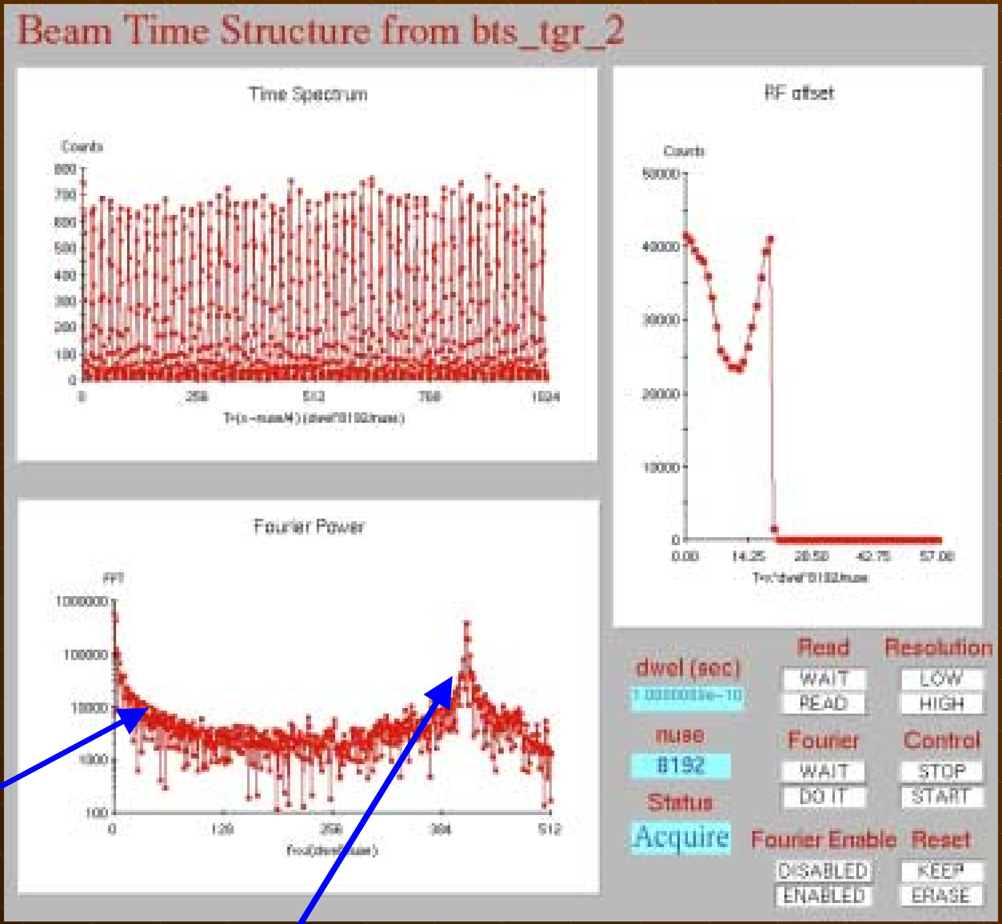
- The *499 MHz* phase is stable in time.





Do We See G_0 Beam in Hall B?

- Running in the low resolution mode should allow us to see G_0 beam with this application.
- There have not been any dedicated tests to observe the G_0 beam in Hall B.
- We have not seen any G_0 beam during recent experimental runs in Hall B.
- We would like to have a test where G_0 beam is sent to Hall B.



No G_0 peak

499 MHz peak

Conclusions

- Charged particle ID is essential for CLAS experiments.
- The RF structure of the beam is used in PID calibration procedure in CLAS.
- An EPICS based application has been created to independently monitor the time structure of the beam.
- Currently we see the beam time structure with ~250 *ps*.
- The phase of the 499 *MHz* component follows the phases from currently used *nA* BPMs.
- A dedicated detector is desirable to be able to monitor the time structure for both electron and photon beams in Hall B.

Thank You!