Decay and Snapback Measurements for Tevatron

August 23 , *2007*

G.V. Velev

Outline

- Introduction
  - Tevatron optimization for Run II
    - A detailed stand-alone measurement program was executed targeting the dynamic effects: 2002 - 2004
    - A new Tevatron correction algorithm at IP has been developed and adopted in 2005
  - The measurements exploited our fast magnetic measurement system based on DSP and ADC
- Sextupole decay and snapback
  - fast decay at the beginning of injection - mean lifetime 0.6 s
  - check of the scaling law (see G. Ambrosio, **L.Bottura** at al., et al.,*IEEE Trans. Appl. Supercond*., Vol. 15, No. 2, June 2005, p. 1217, feed-forward accelerator control
- Dynamic effects in the Main Field
- Dynamic effects in higher order allowed harmonics: b_5 and b_7
- Dynamic effects in the LHC IR LQXB quads
- Conclusion

MTF – Tevatron test stands

12 Tevatron dipoles

TB0295, TB0491,

TB0701, TB0834,

TB1063, TB1065,

TC0710, TC0861,

TC1047, TC1061,

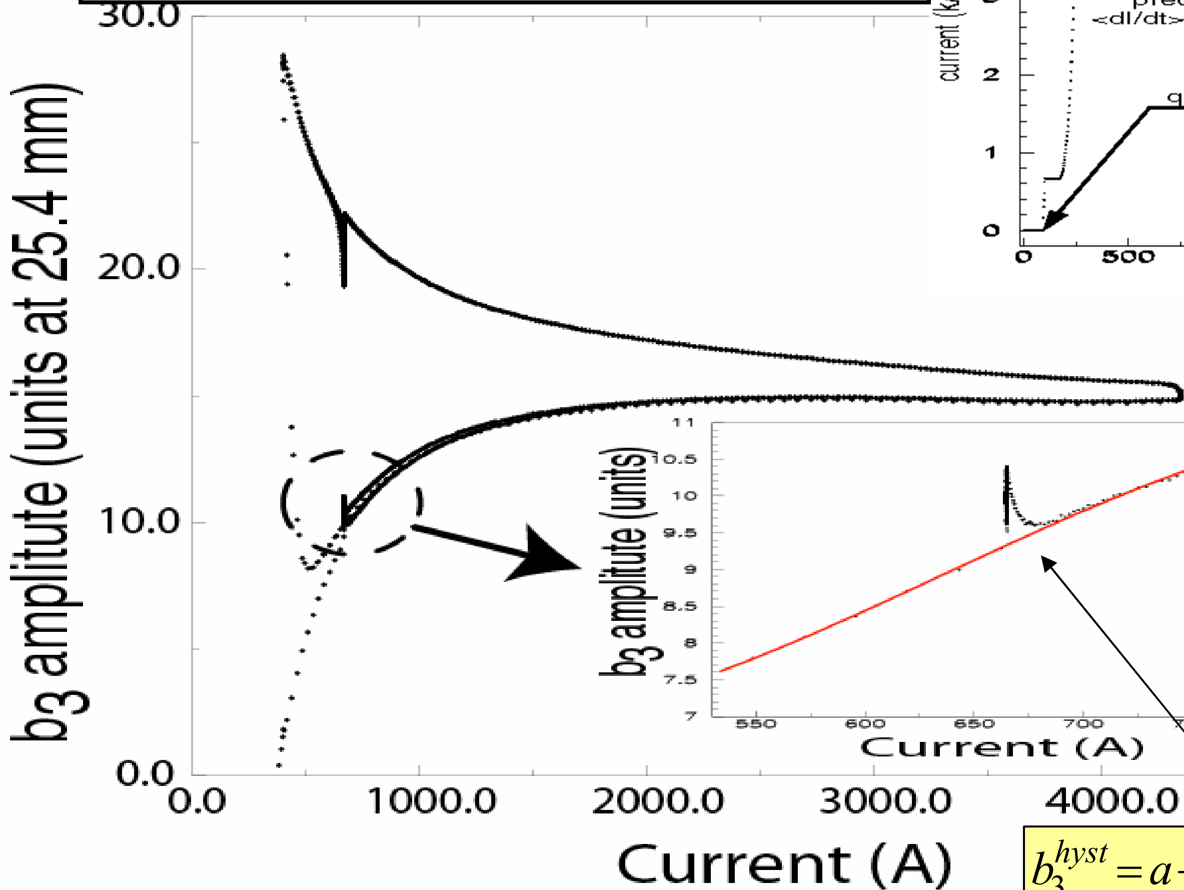
TC1077, TC1206

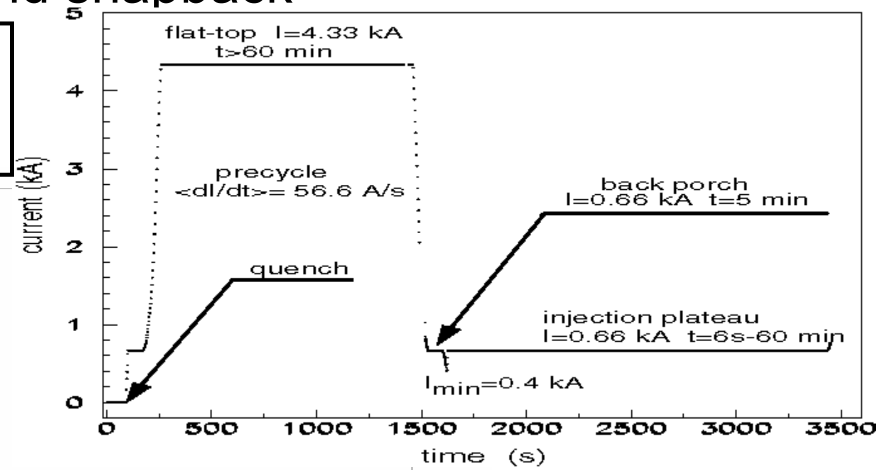
Measurement system

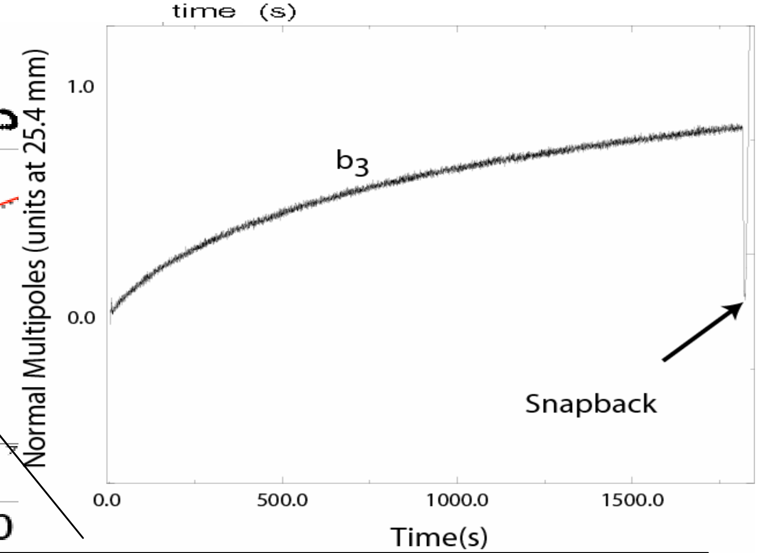
- Specification of the Magnetic Measurement System:
  - The system is based on ADC and Digital Signal Processing (DSP) boards
  - The system should provide the possibility for signal manipulation, including analog bucking, amplifying and attenuation of probe signals
  - To be able to perform measurements up to 10 Hz speed rotation – tested up to 6 Hz ***continuous*** rotation (x 1024 trig.), 3 Hz was used for the reported measurements.
  - Same or better characteristics than PDIs
  - Compatible with the speed of Hall probes
- Summary: fast, continuous with excellent resolution
  - Details: *IEEE Trans. Appl. Supercond.*, Vol. 16, No. 2, June 2006, pp. 1374-1377.

Decay and snapback

Effects discovered during Tevatron commissioning







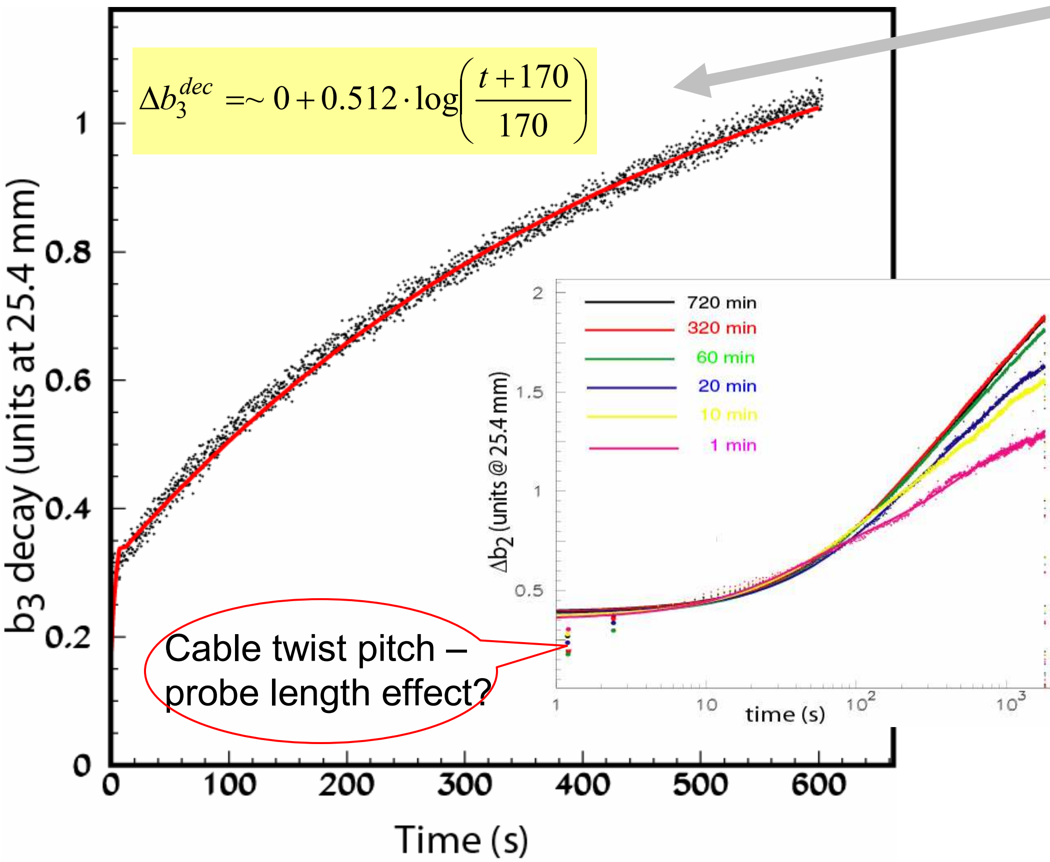
$$b_3^{hyst} = a + b\cdot I + c\cdot I^2 \quad I \in (0.56-0.65, 0.72-0.8kA)$$

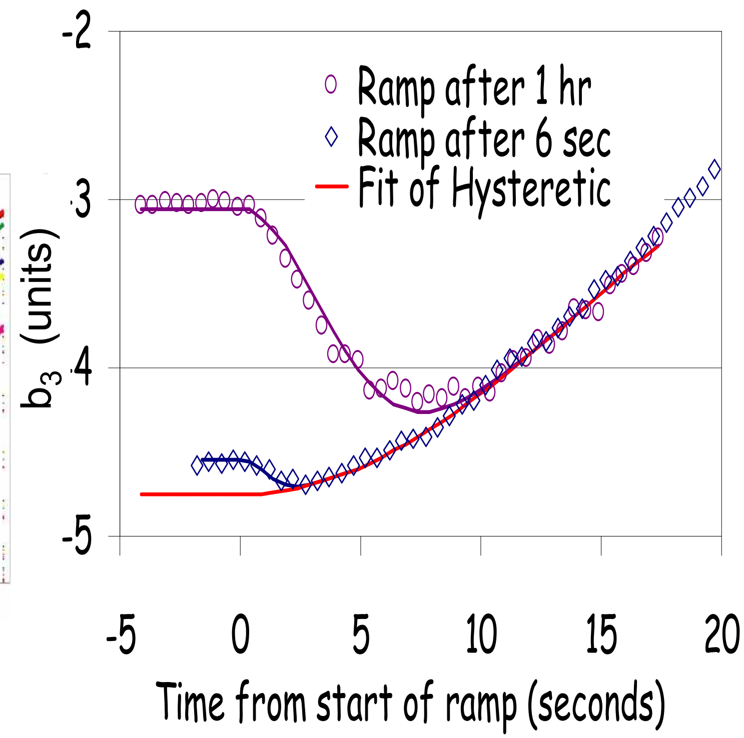
Tevatron Decay

For t =6 s, Δb_3^{dec} ~ 0.02 units.

From beam measurements: Δb_3^{dec} 0.21 units

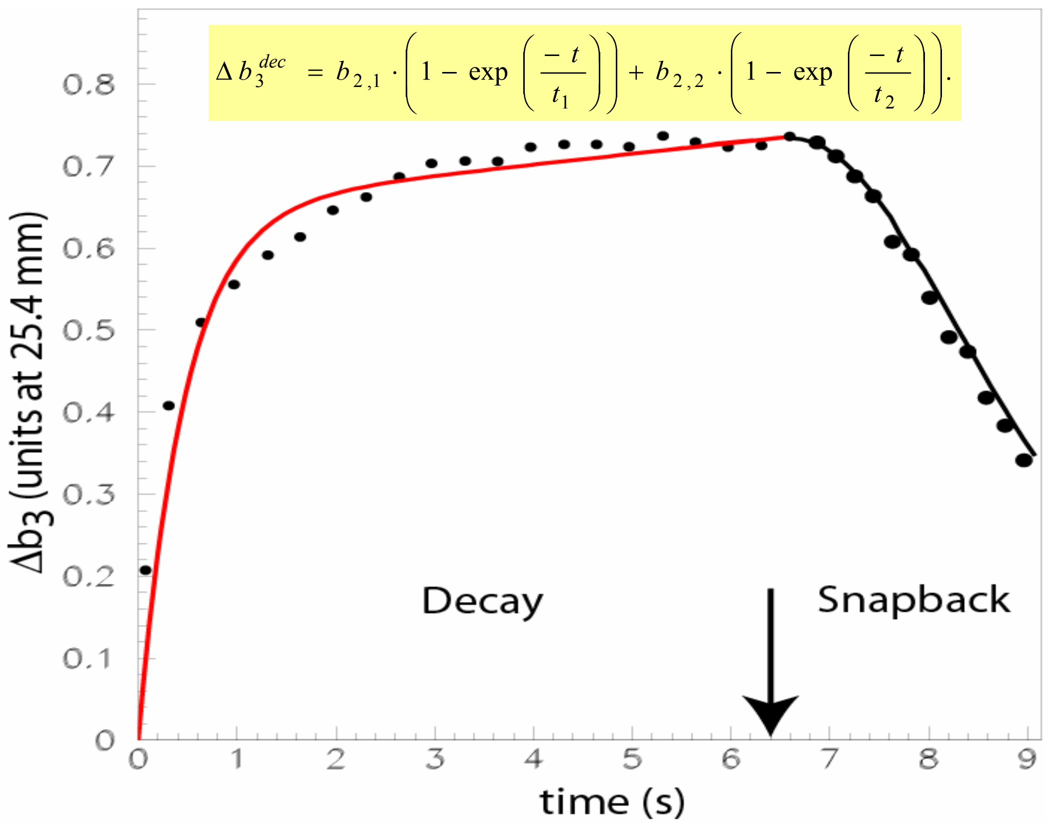
$$\Delta b_3^{dec} = 0.21 + 0.512 \cdot \log\left(\frac{t+170}{170}\right)$$



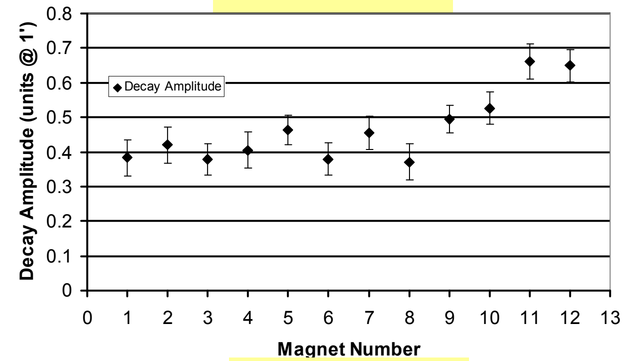


Fast decay at beginning of injection

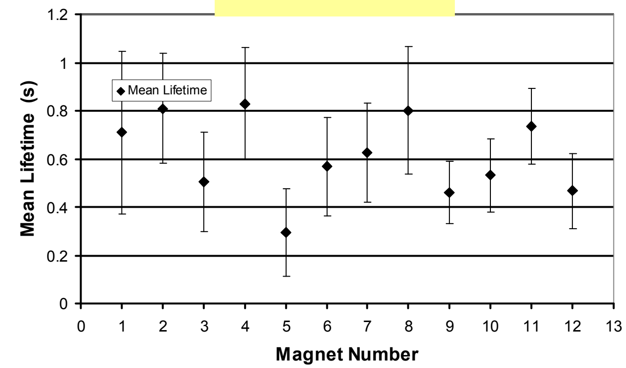
- The data 6 s injection
- The logarithmic function does not work



0.45±0.10



0.61±0.06



For first time measured!

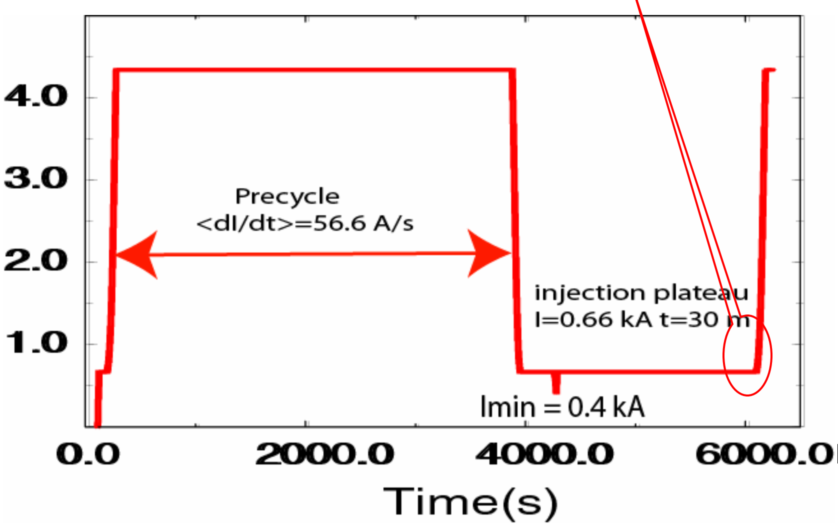
Snapback parameterization

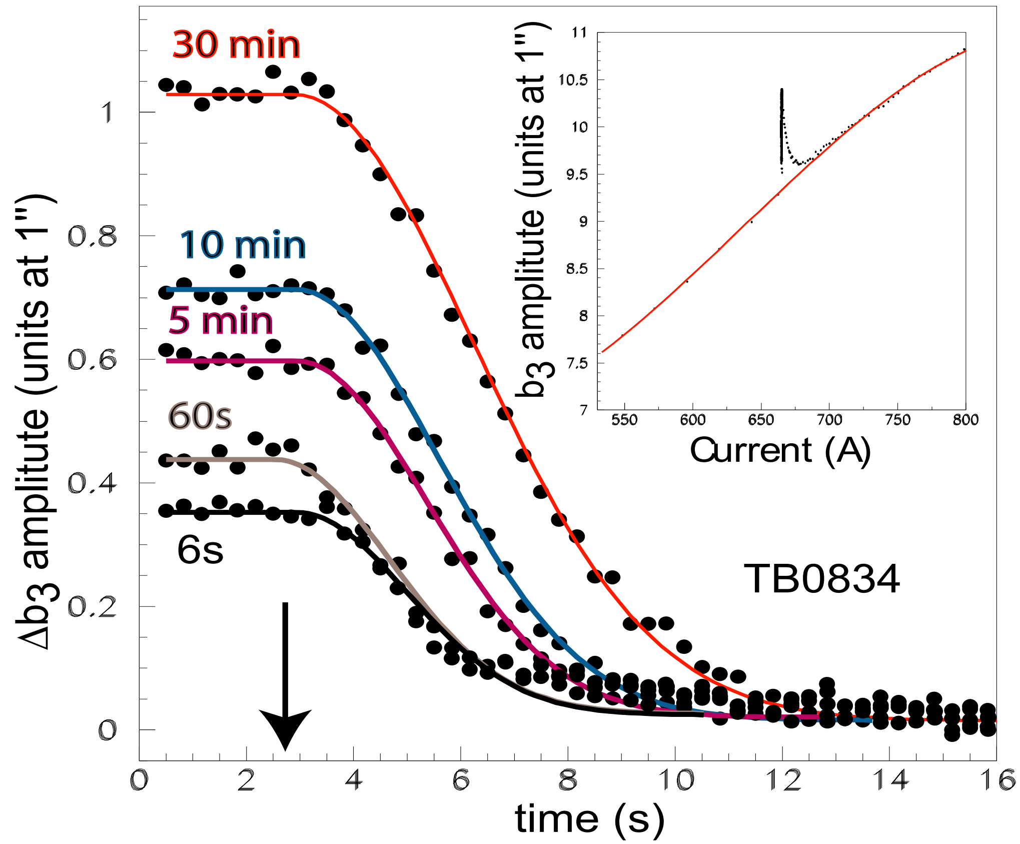
- In Tevatron case:
  - Half Gaussian
  - $\Delta b_3^{sb}(0) \sim t^2$

$$\Delta b_3^{sb}(t) = \Delta b_3^{dec}(t_{inj}^{end}) \cdot \exp\left(\frac{-t^2}{t_{sb}^2}\right)$$

- Scaling law:

$$\Delta b_3^{sb}(0) = \Delta b_3^{dec}(t_{inj}^{end}) \sim \Delta I \sim t_{sb}^2$$

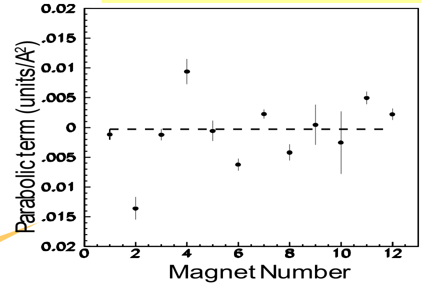




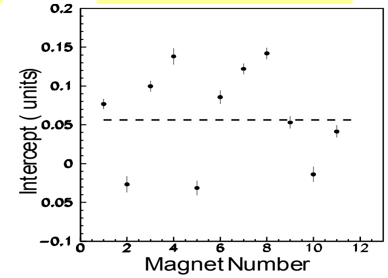
Scaling Law

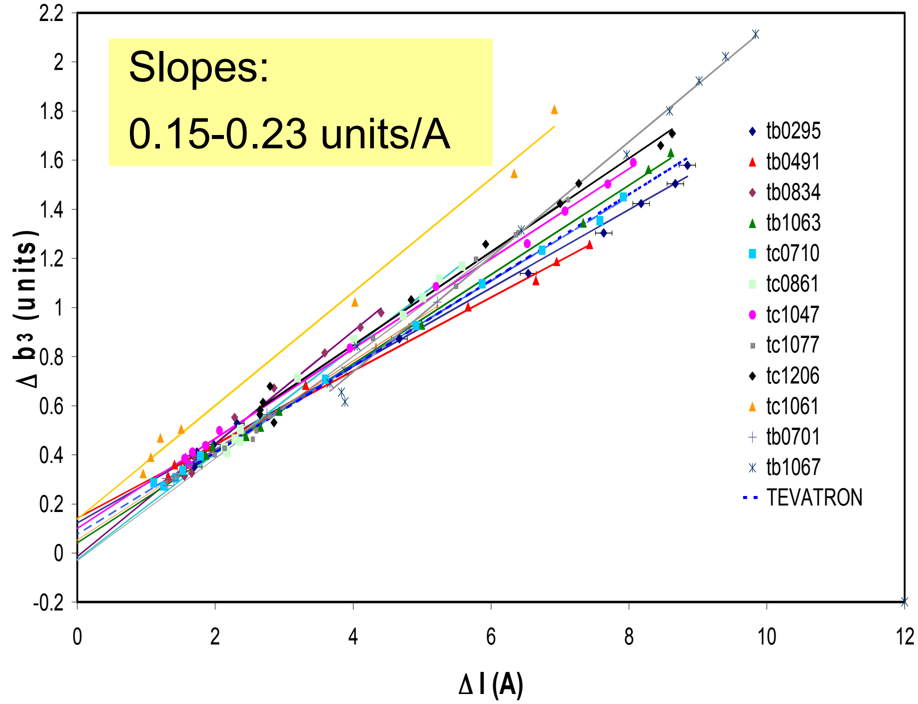
- Scaling law:
  - linear without intercept
  - all the magnets with same design should have the same correlation
- 12 Tevatron dipoles tested with the DSP system.
  - accurate linear dependence for every magnet is observed
  - slopes are close but inconsistent within the error values
  - for an ensemble the linear correlation should be preserved
- Feed-forward version is now implemented in the Tevatron

0.0002±0.0003



0.056±0.002

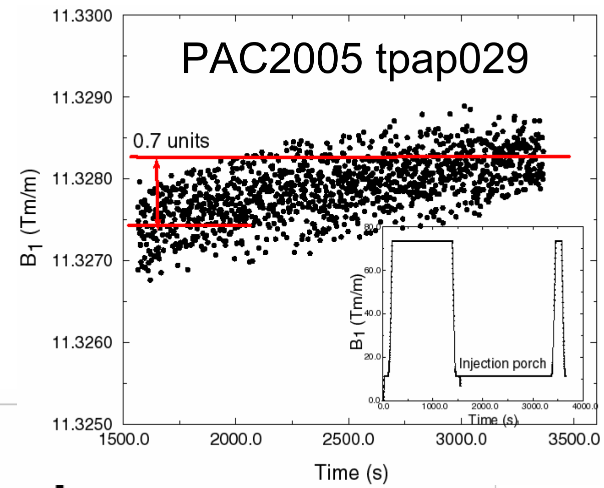


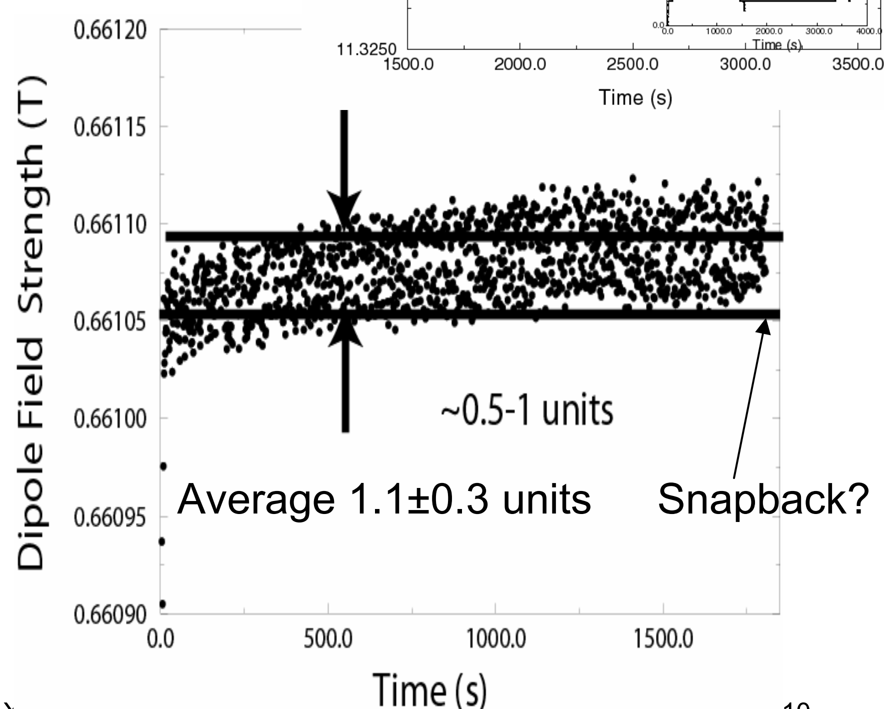


Decay in the main field

- Quadrupole main field – reported at PAC2005
- Observed: 0.7±0.1

- The decay amplitude is in the range of 0.5 to 1.6 units
- Attempts to find the following snapback-type effect were unsuccessful.
- Taking into account the average decay change in the main dipole field of 7.35x10-5 T and the current needed for this change, we estimated that the snapback should occur during a time interval of ~ 0.6 s.



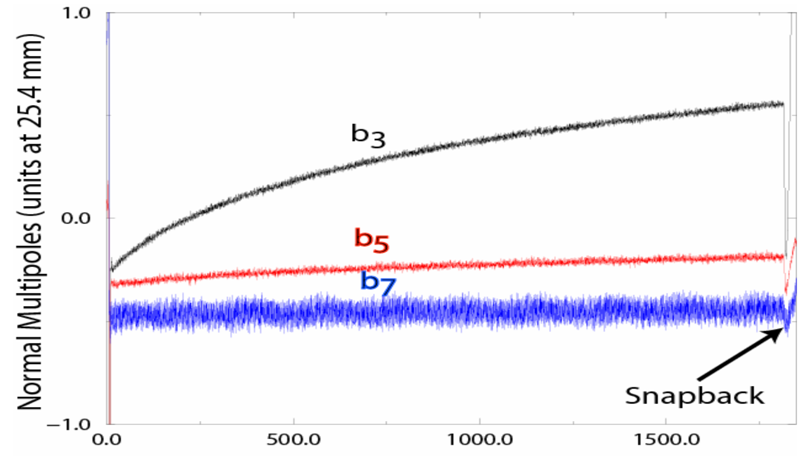


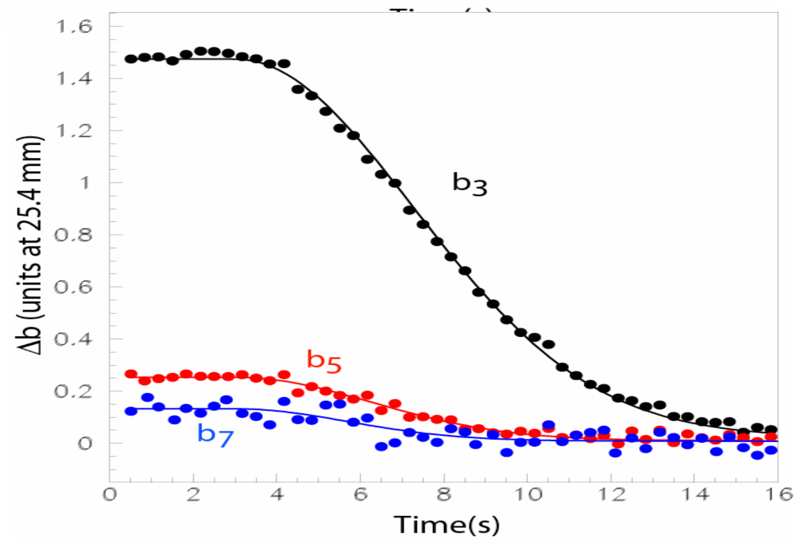
High order harmonics

- Decay in decapole (b_5) and tetradecapole (b_7)
- Results are presented relatively to sextupole decay
- The same sextupole scaling law?

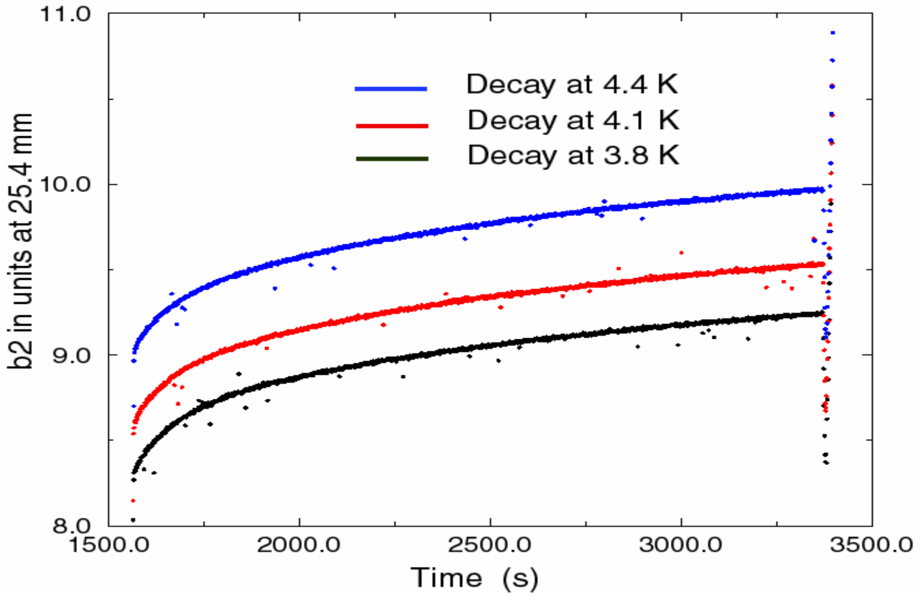
$$\Delta b_k^{sb} / \Delta b_3^{sb} = t_{sb,k}^2 / t_{sb,3}^2, k = 5,7$$

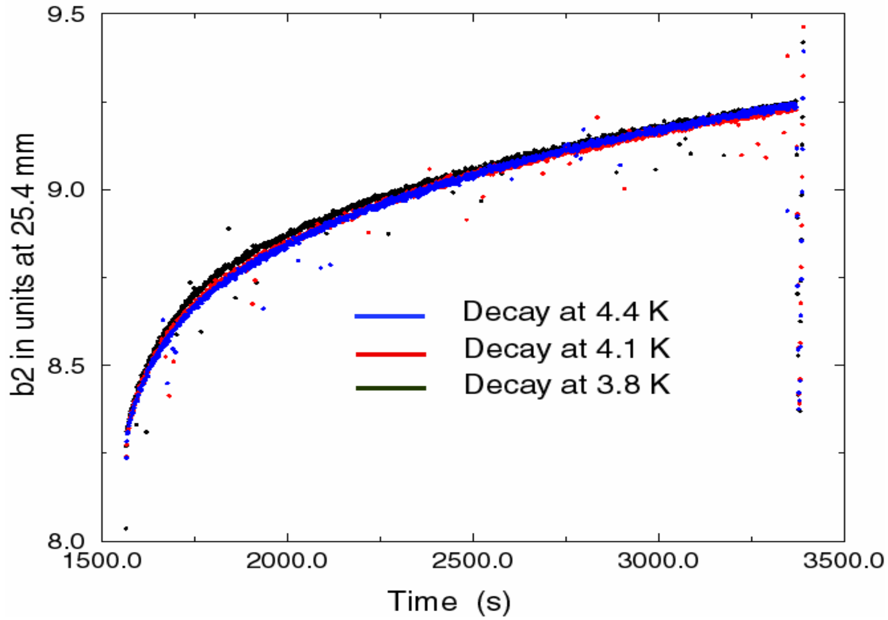
Dipole name	$\Delta b_5^{sb}/\Delta b_3^{sb}$amplitude ratio	$\Delta b_7^{sb}/\Delta b_3^{sb}$ amplitude ratio	$t_{sb,5}/t_{sb,3}$ snapback time ratio	$t_{sb,7}/t_{sb,3}$ snapback time ratio
TB0295	0.11	0.07	0.53	0.94
TB0491	0.20	0.09	0.73	1.11
TB0701	0.22	0.05	0.92	0.43
TB0834	0.27	0.05	1.28	0.71
TB1063	0.14	0.05	0.63	0.35
TB1065	0.18	0.07	0.87	0.78
TC0710	0.17	0.09	0.76	0.63
TC0861	0.22	0.07	1.02	0.14
TC1047	0.22	0.05	0.95	0.67
TC1061	0.19	0.07	0.84	0.60
TC1077	0.19	0.07	0.83	0.73
TC1206	0.16	0.08	0.79	0.95
Average	0.19±0.04	0.07±0.2	0.85±0.19	0.67±0.27



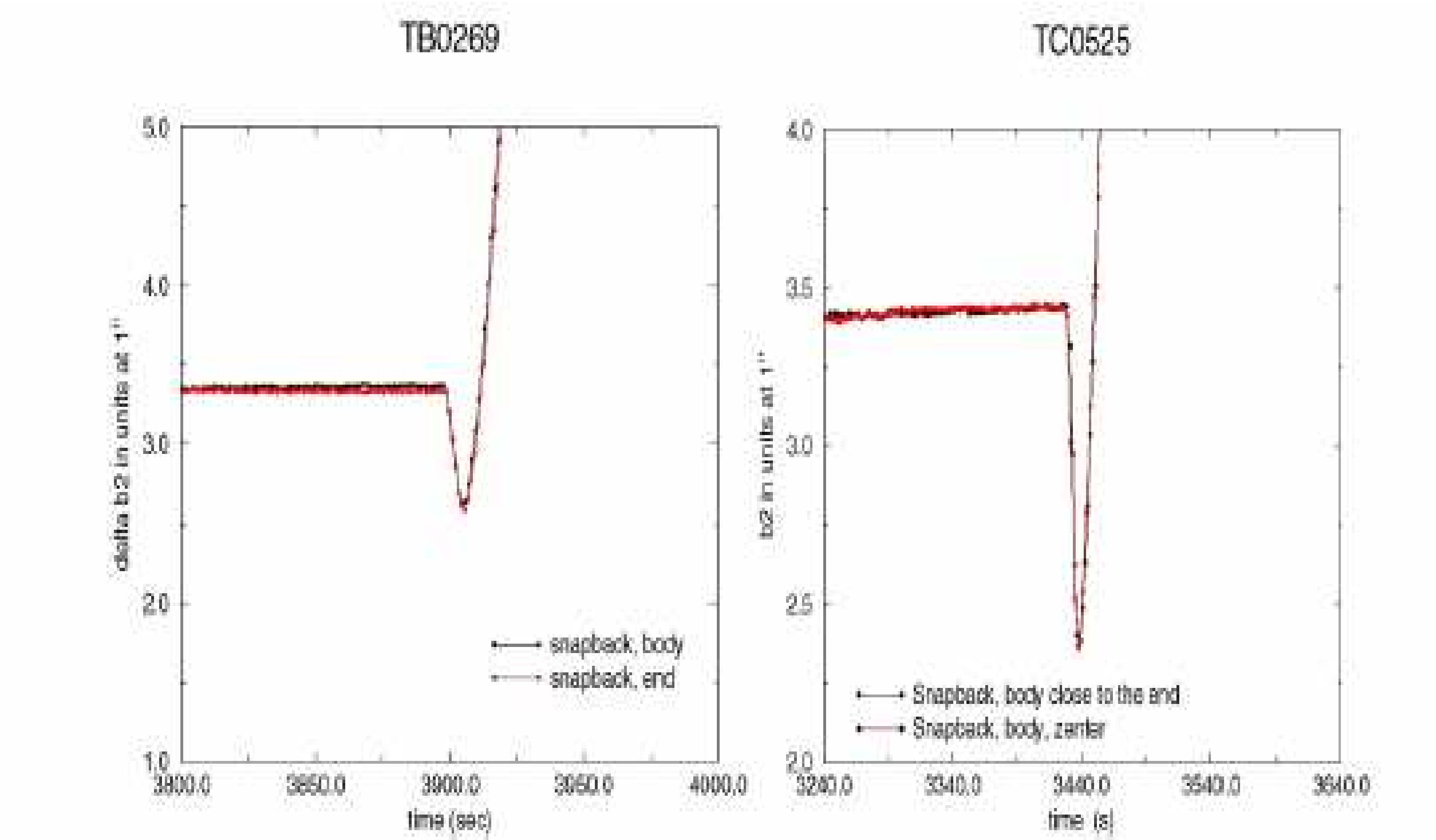


Decay and Snapback: temperature dependence; end vs body

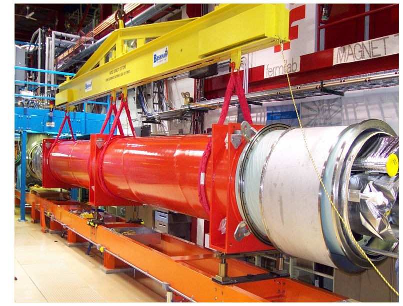




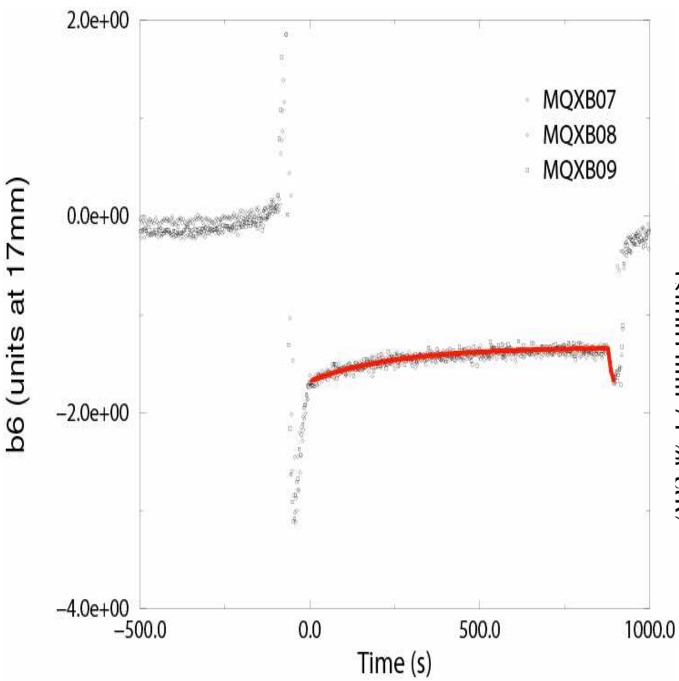
Decay and Snapback: body vs body; end vs body



Dynamic Effects: Decay and snapback



- To characterize this effect in the MQXB quadrupoles, we performed measurements with an accelerator cycle similar to the one used in the LHC arc dipole tests.
  - duration of the inj. plateau is 15 min at 0.67 kA (12.3 T/m).
- Correctors for dodecapole

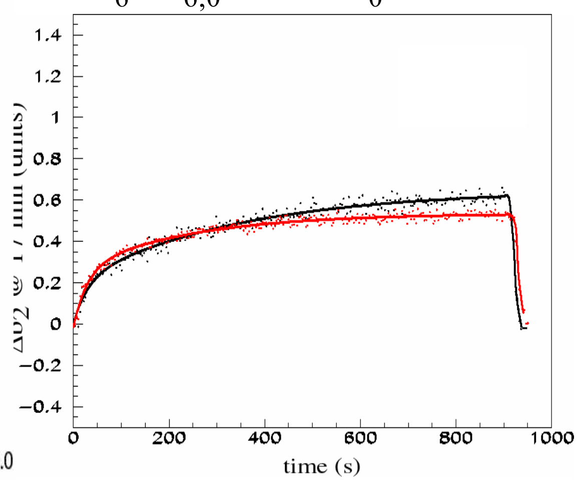


decay

$$\Delta b_6 = b'_{6,0} + b_{6,1} \cdot \log\left(\frac{t+t_s}{t_s}\right).$$

snapback

$$\Delta b_6^S = b_{6,0}^S \cdot \exp(-t^2 / t_0^2),$$



Cold mass	Decay Amplitude* (Units at 17 mm)	Decay Time (s)
MQXB01	0.50	13.3
MQXB02	0.35	8.9
MQXB03	0.50	12.9
MQXB05	0.30	9.8
MQXB06	0.50	13.9
MQXB08	0.26	8.1
MQXB09	0.34	9.5
MQXB10	0.35	9.8
MQXB11	0.33	8.7
MQXB12	0.55	15.3
MQXB13	0.35	9.3
MQXB17	0.54	15.6
MQXB19	0.23	7.6
Average	0.39±0.11	11.0±2.8

* After a subtraction of the underlying hysteresis loop

Conclusions

- Using our fast DSP-based DAQ system, a detailed program of magnetic measurements was performed on a twelve Tevatron dipoles.
- For the first time, the relatively large decay found in Tevatron dipoles after very short injections was measured. We determined its average amplitude and mean lifetime to be 0.45±0.10 units and 0.61±0.06 s respectively.
- In addition, an accurate check of the scaling was performed. For IP durations greater than 6 s, we found the Δb_3^{sb} versus ΔI dependence is linear for the measured magnets; Tevtraon dipoles show close but distinguishably different slopes, varying in the range 0.15-0.23 units/A, and non-zero intercept.
- For the first time we also report on the decay and snapback effects in the main field and allowed harmonics above b3. For the main field in the Tevatron dipoles, we measured average decay amplitude of 1.1±0.3 units after 30 minutes IP. Any attempt to find the following snapback-type effect was unsuccessful.
- The snapback amplitude and time in the b5 and b7 multipoles, after 30 minutes IP. We checked that sextupole scaling law can not be applied directly to Δb_3^{sb} versus ΔI evolution of b5 and b7.
- Independently, that the average ratio of the decay amplitudes was found to be relatively small (e.g. $\Delta b_5^{sb} / \Delta b_3^{sb} = 0.19 \pm 0.04$), the persistent current effects in the decapole may need to be taken into account in future LHC operation.
- A study of dynamics effects was made at the injection plateau current for LHC IR LQXB quads. The decay and snap-back after 15min injection showed an average change in b_6 of ~0.4 units and consistent decay times of ~11 s.

Decay and Snapback Measurements for Tevatron

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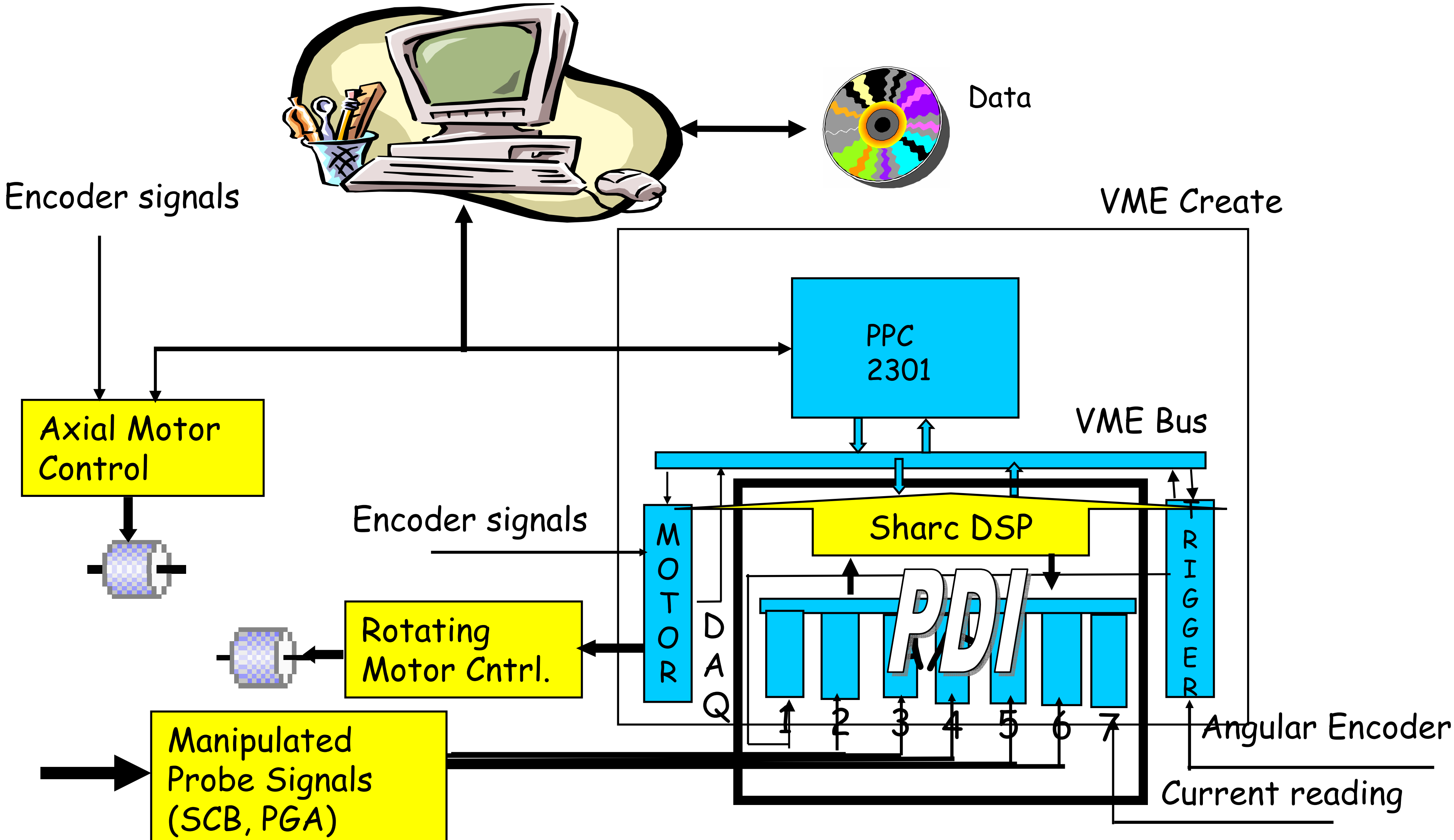
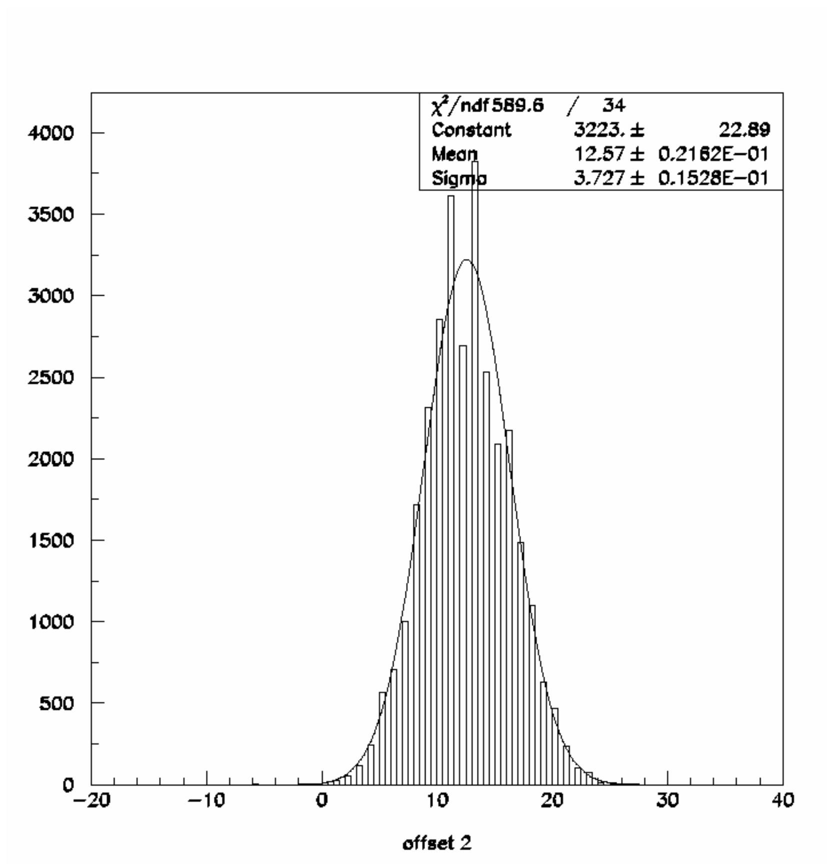
Diagram of the real time measurement system



ADC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Constant 3223. ± 22.89
Mean 12.57 ± 0.2162E−01
Sigma 3.727 ± 0.1528E−01
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3500
3000
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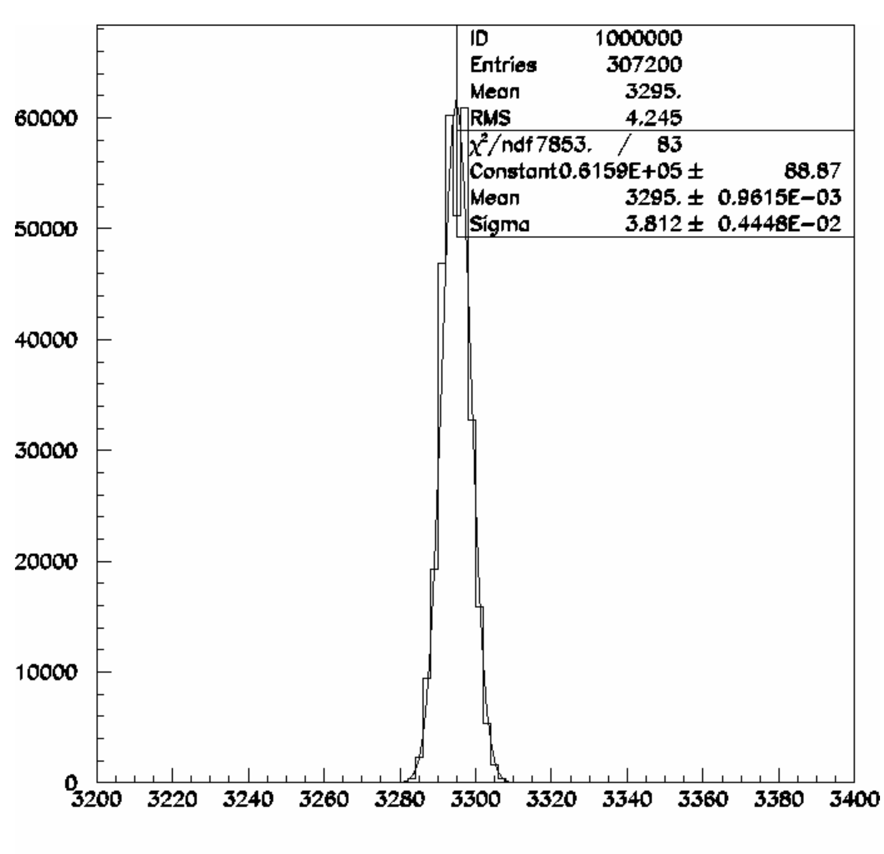
offset 2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Mean 3295. ± 0.9615E−03
Sigma 3.812 ± 0.4448E−02
60000
50000
40000
30000
20000
10000
0
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