Investigation of a little bit of Fast Current Transformer response at HTP

Measurements with Krypton and proton beams
for measurements at the detection limit
and evaluation of new FESA DAQ system

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extrahiert aus *RT+FCT_Analysis2_korr.ppt* und bearbeitet 06.01.2017 H. Reeg

Part III – Proton FCT data

Run 3 – 3E7 particles

- 29. April 2014: Proton, 300 MeV, q=+1, Run 3: 3E7 p
- Attenuator: 0 dB
- Nominal total gain = 45.2 – 3.5 dB (att. insertion loss) = 41.7 dB (gain=121.6)

  Measured gain = 43.5 dB (used in this document)
- **Losses in cable are not considered here (~75 m RG214)**
- 50 extractions from SIS18 were stored for offline analysis (for all runs!)

  (IMPORTANT: The block of cycles is not contiguous! Some cycles are missed, if the DAQ system was still busy to write the output files!)
- Nominal FCT sensitivity S = 4.2 V/A
- Gain = 10**(total gain [dB]/20)

- Current I [A] = $\dfrac{\text{ADC [ch.]} * (\text{ADC\_range [V]} / \text{No\_ADC\_ch. [ch.]})}{\text{Gain} * \text{sensitivity S [V/A]}}$

- Particle numbers are calculated from current integral and proton charge (q=1)

Basic Formulae and Estimates

We start with some basic assumption and calculate the expected peak voltage in units of ADC channels.

- Assume „typical“ triangular bunch shape for each of the 4 „identical“ bunches!
- 300 MeV/u protons travel at v = 0.65 c and have a revolution frequency of 0.9 MHz in SIS18
- At harmonic number h=4, the RF frequency is f_{RF} = 4x0.9 MHz = 3.6 MHz

No. Of particles	N_ion	3,00E+07	
Charge of ions	q_ion	1	
Total charge	**Q_tot**	**4,81E-03**	**nC**
pulse length of 1 bunch	tau_bunch	100	ns
No. Of triangular bunches	n_bunch	4	harmonic number
Charge per bunch	**Q_bunch**	**1,20E-03**	**nC**

Mean current in bunch	**I_mean**	**1,20E-05**	**A**
		0,01	mA
		12,02	µA
Peak current in bunch	**I_peak**	**2,40E-05**	**A**
		0,02	mA
		24,03	µA

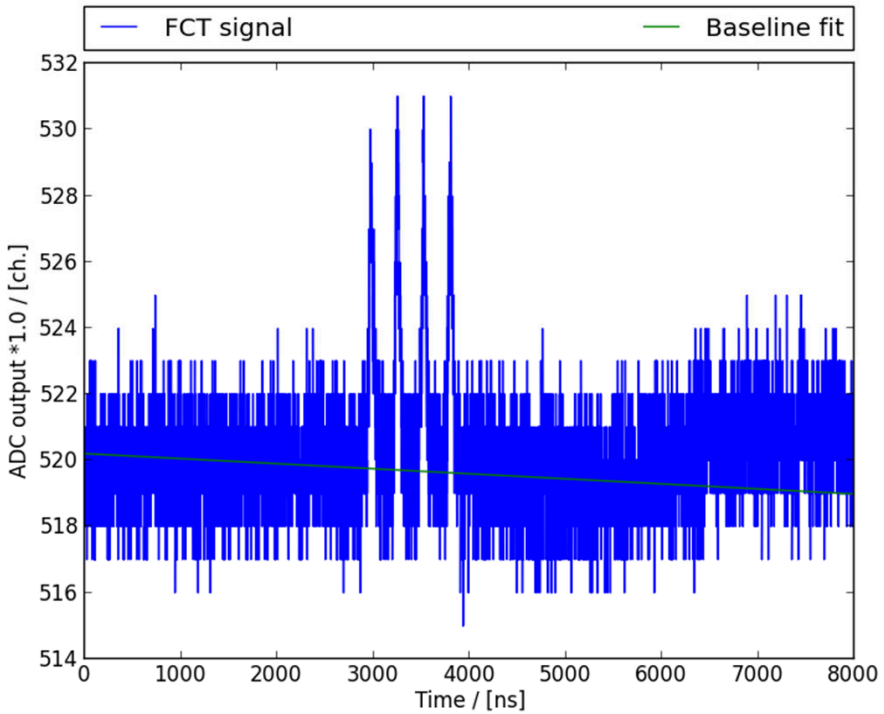
Basic Formulae and Estimates cont.

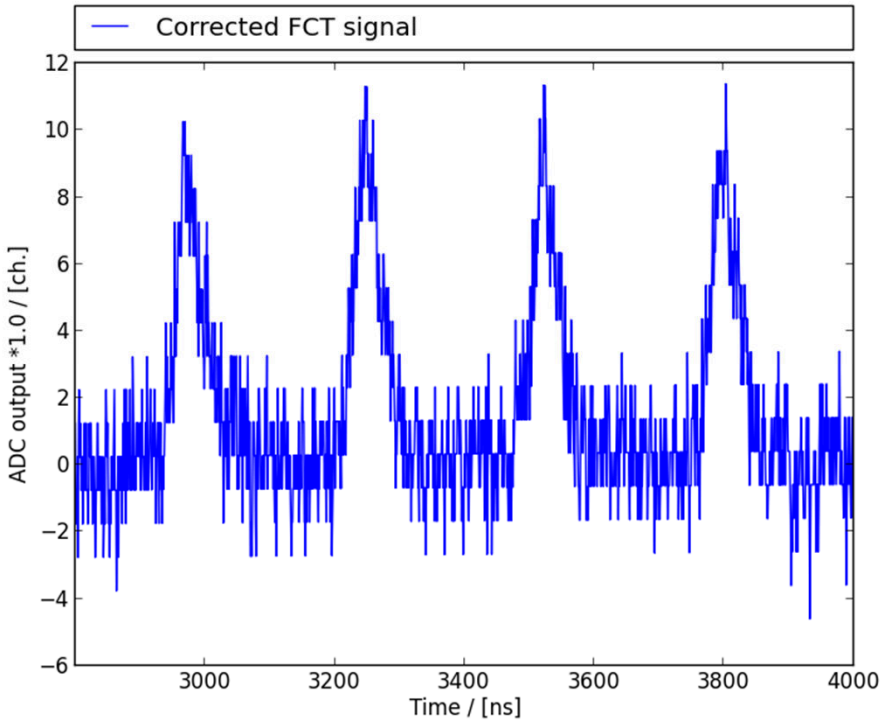
Sensitivity of FCT	S_FCT	4,2	V/A
Mean output voltage	**U_mean**	**5,05E-05**	**V**
		0,05	mV
		50,46	µV
Peak output voltage	**U_peak**	**1,01E-04**	**V**
		0,10	mV
		100,93	µV
Amplifier/attemuator	gain_dB	41,7	dB
	gain	**121,62**	
ADC input range	V_ADC	2	V
Nominal ADC bits	N_bit	10	
No. Of ADC channels	N_ADC	1024	channel
Sensitivity Ch./Volt	S_ADC	512	Ch./V
Sensitivity V/ch.		1,95	mV / ch.
Mean ADC ouput	**U_ADC_mean**	**3,1**	**ch.**
Peak ADC output	**U_ADC_peak**	**6,3**	**ch.**

For 2E9 particles and 16 dB attenuation, one gets U_ADC_peak ~ 66 ch.

Data Analysis I – Baseline Correction

- A block of 10.000 samples is saved for each extraction, with respect to the trigger timing of the extraction kicker that is fed to the DAQ system! Some data are faulty!
- Fit baseline in two regions, one to the left (1600 – 2400) ns and one to the right of beam signal (4160 – 4960) ns. Subtract fit from raw data to yield „corrected FCT signal“.
- Integrate beam pulse in region (2800 – 4000) ns

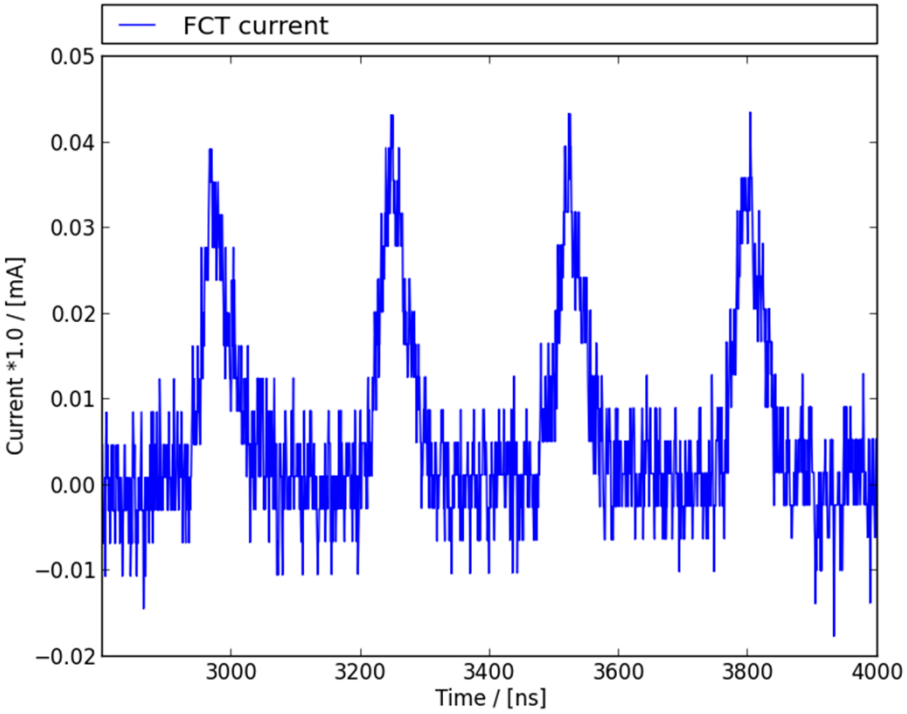


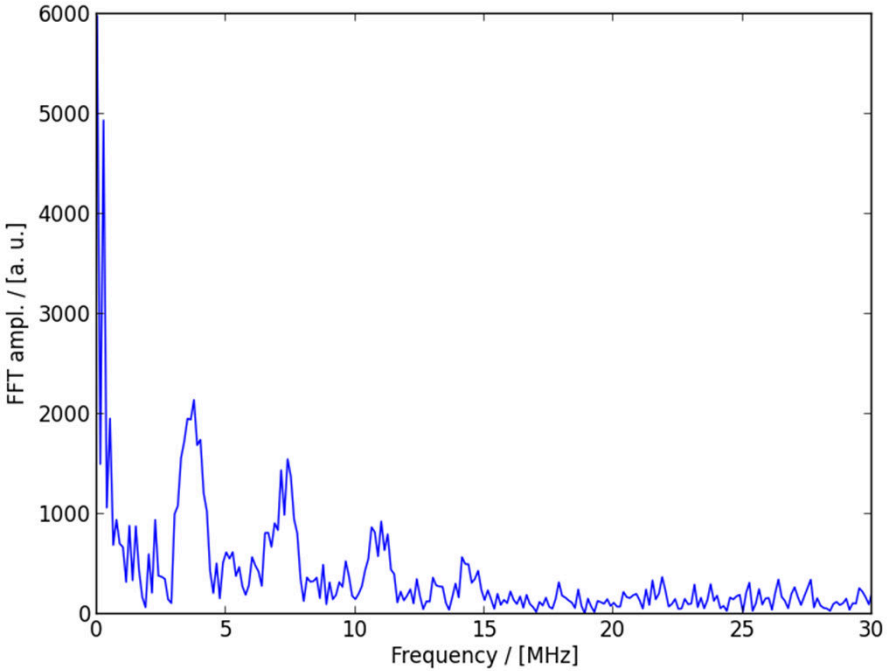


- Raw ADC signal agrees in magnitude with estimate!

Data Analysis II – Conversion to physical unit

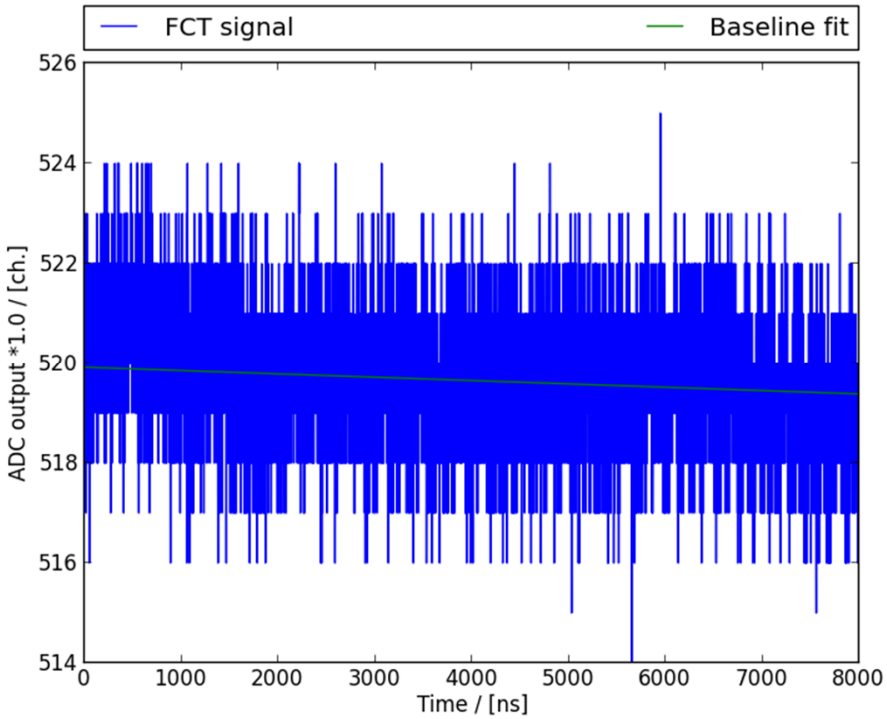
- The corrected FCT signal is scaled to units of ampere via sensitivity of S = 4.2 V/A and ADC sensitivity of 1.95 mV/ch (nominal ADC values).
- The FFT of the corrected FCT signal is calculated and displayed up to 30 MHz. The spectrum shows the total revolution frequency at 3.6 MHz of the bunch train, higher order components, and a peak at frequencies < 1 MHz.

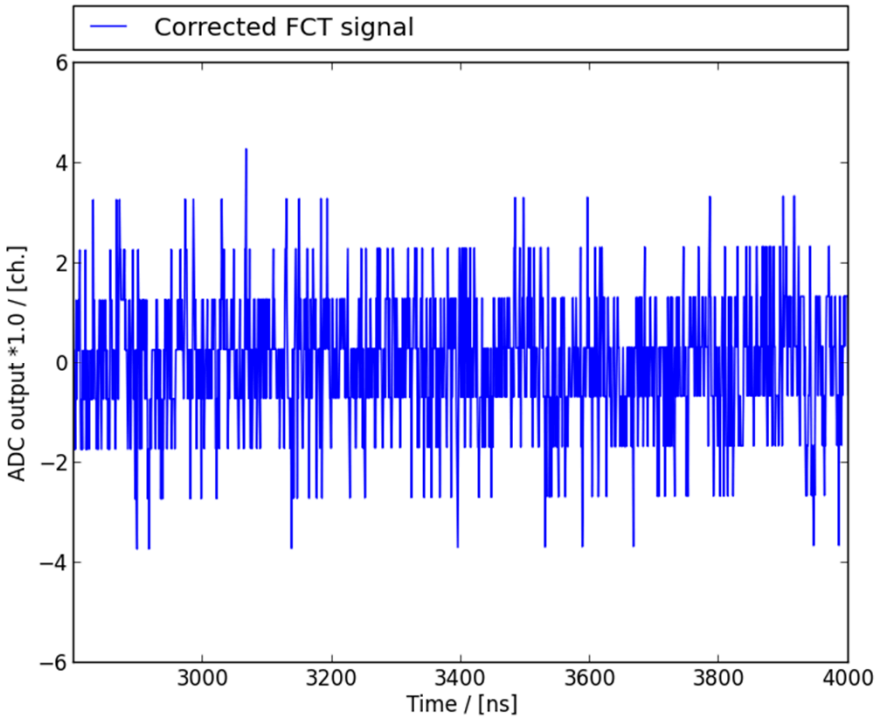




Data Analysis – Conversion to physical unit
„Empty cycle“ or weak beam

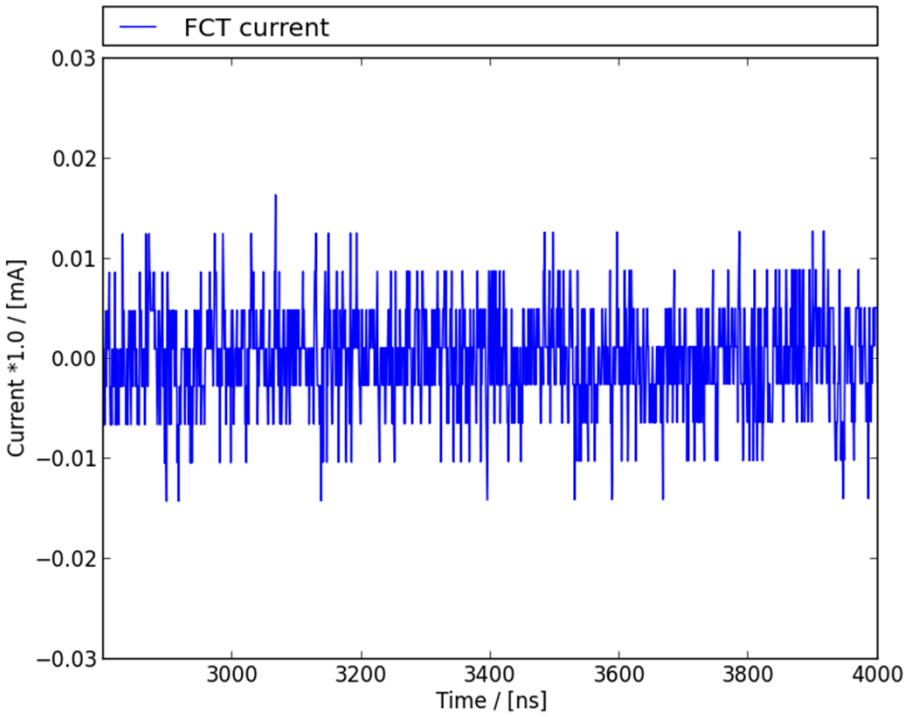
- The „empty“ data set shows a clean baseline of ~8 channels total width

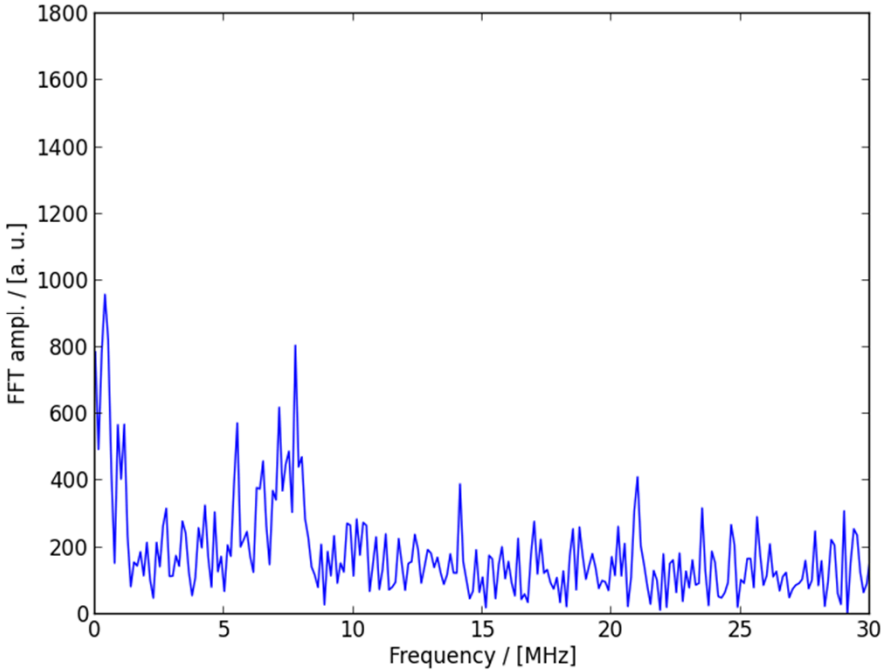




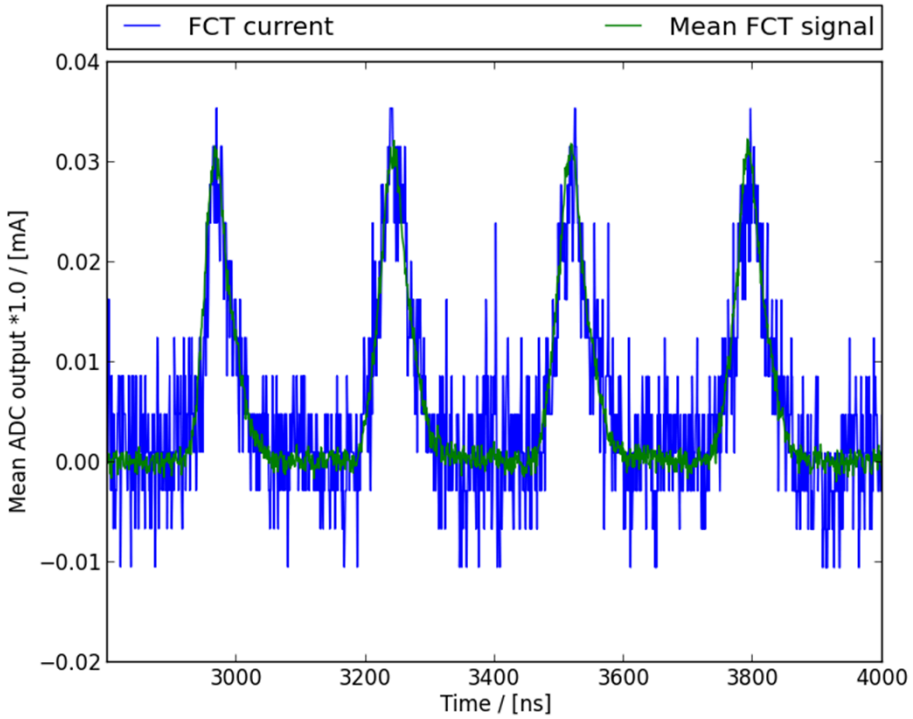
- The total baseline width is ~8 channels (15.6 mV)
- The standard deviation can be estimated to be 1.5 ch. (0.15% FS) = 3 mV

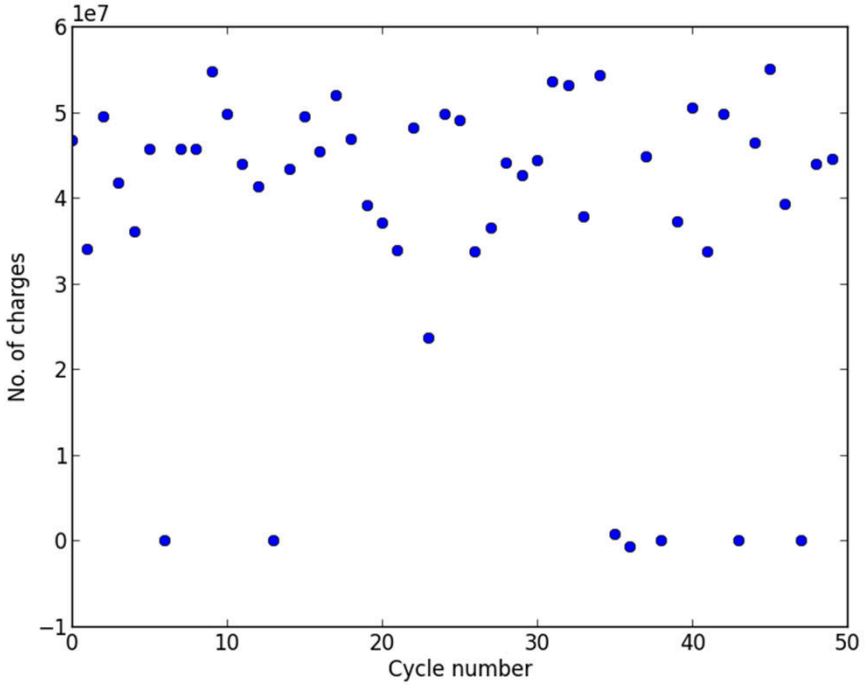
Data Analysis – Conversion to physical unit
„Empty cycle“ or weak beam



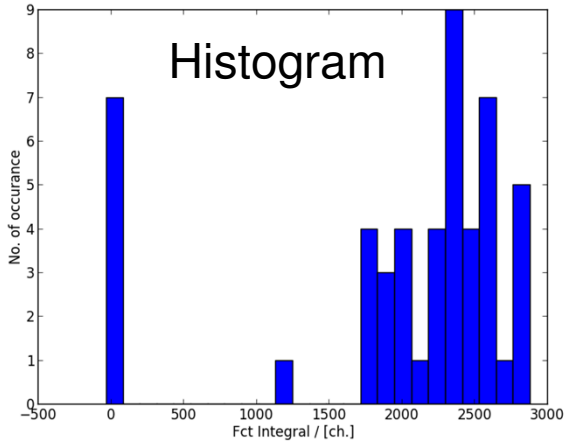


Run 3 – Trend of FCT integral

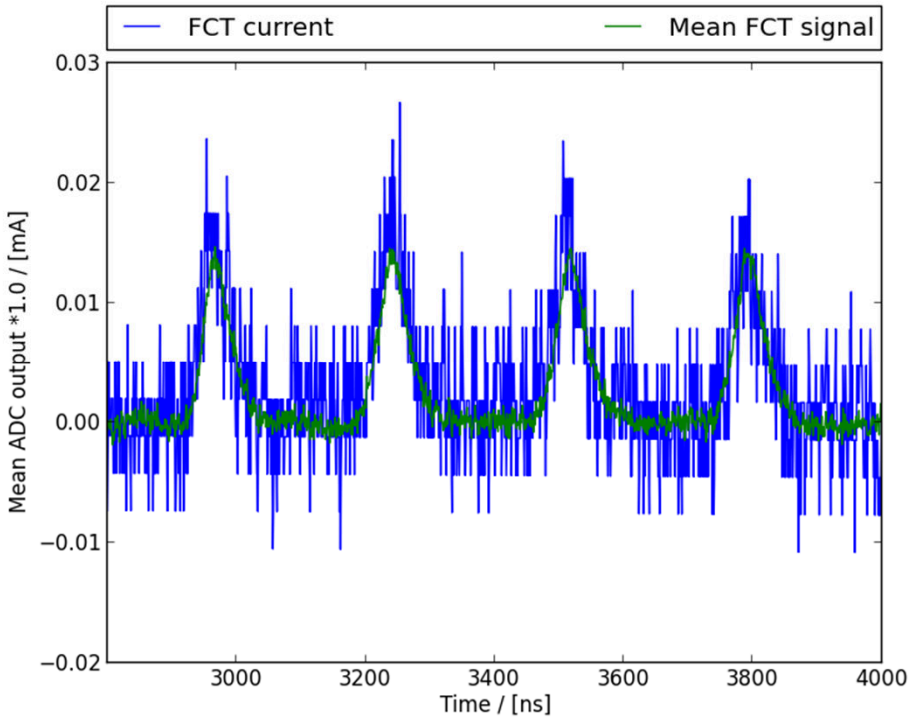


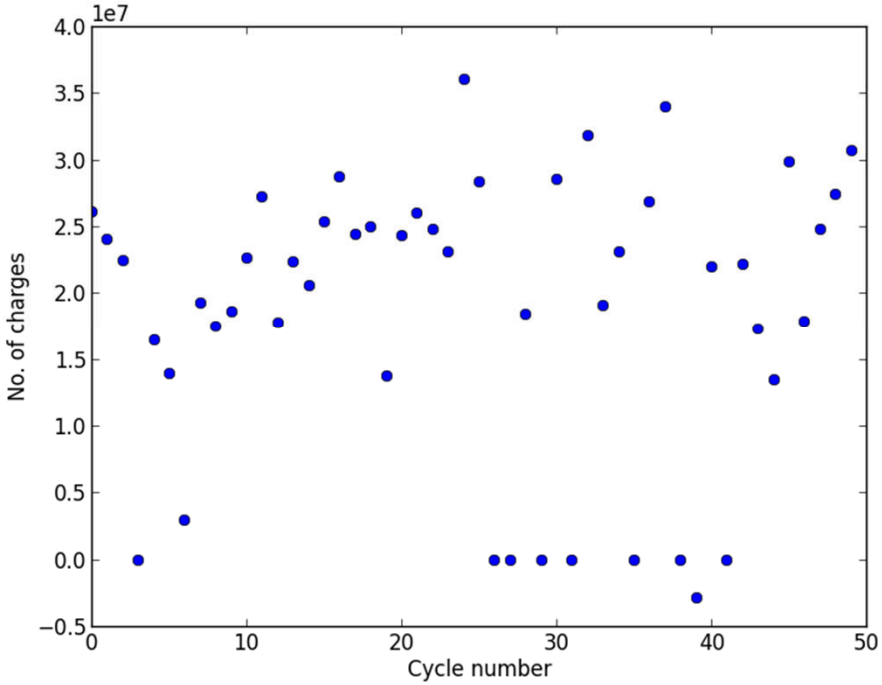


- Nice comparison between mean signal of all data (green) and single signal trace (blue)
- Zero-value in trending plot : Kicker not detected !
- 2 empty cycles at number 35 and 36
- Signal peak ~10-11 channels. Peaks are clearly detected.



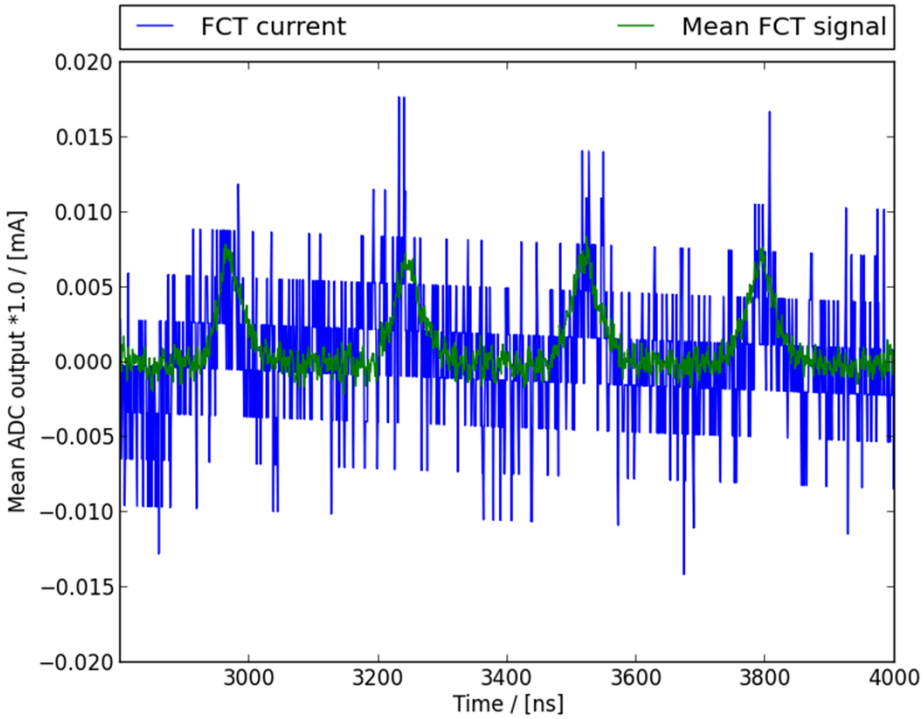
Run 4 – Trend of FCT integral

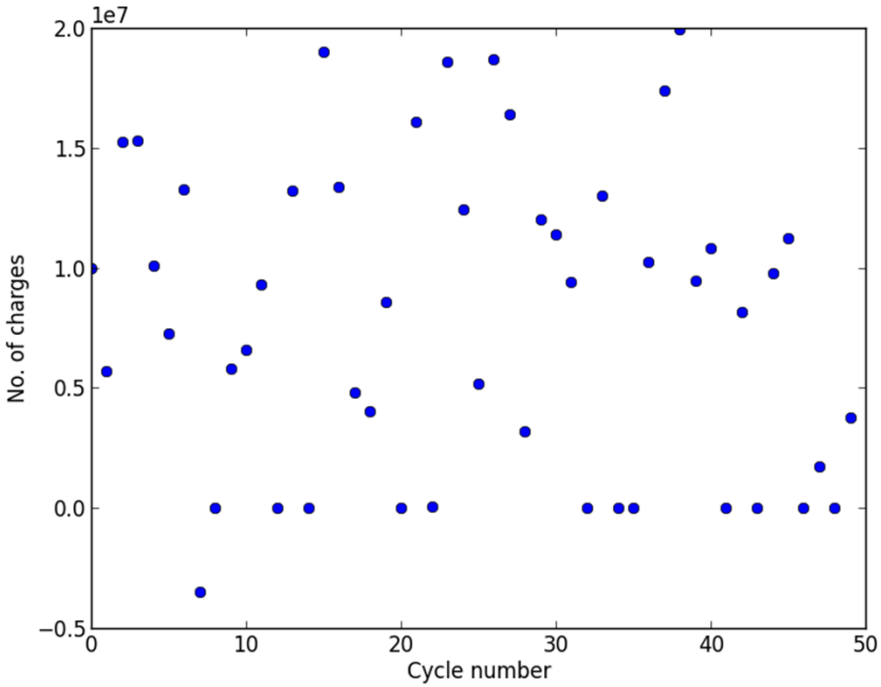




- Zero-value in trending plot: Kicker not detected!
- Weak signal of <8 channels, but peaks are clearly detected.

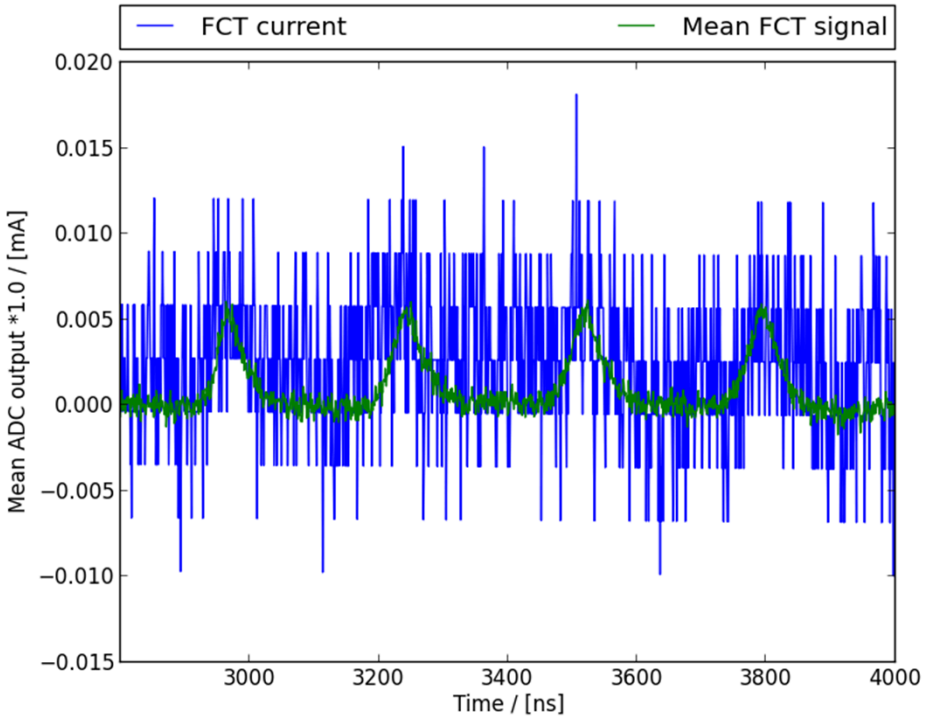
Run 6 – Trend of FCT integral

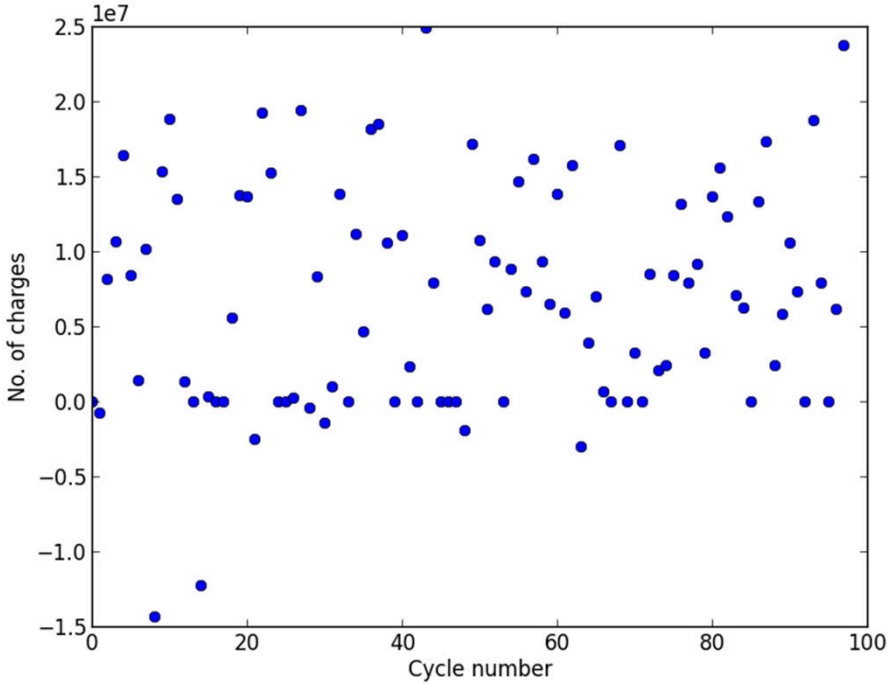




- Zero-value in trending plot: Kicker not detected!
- Extremely weak signal of a few ~5 ADC channels. Peaks are now „thinner“ compared to Run 5.

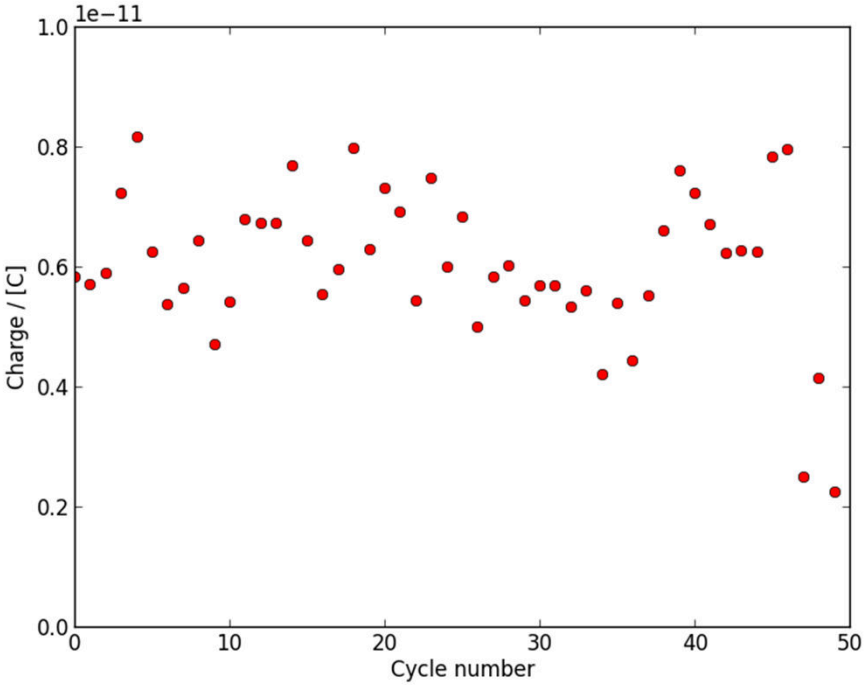
Run 7 – Trend of FCT integral

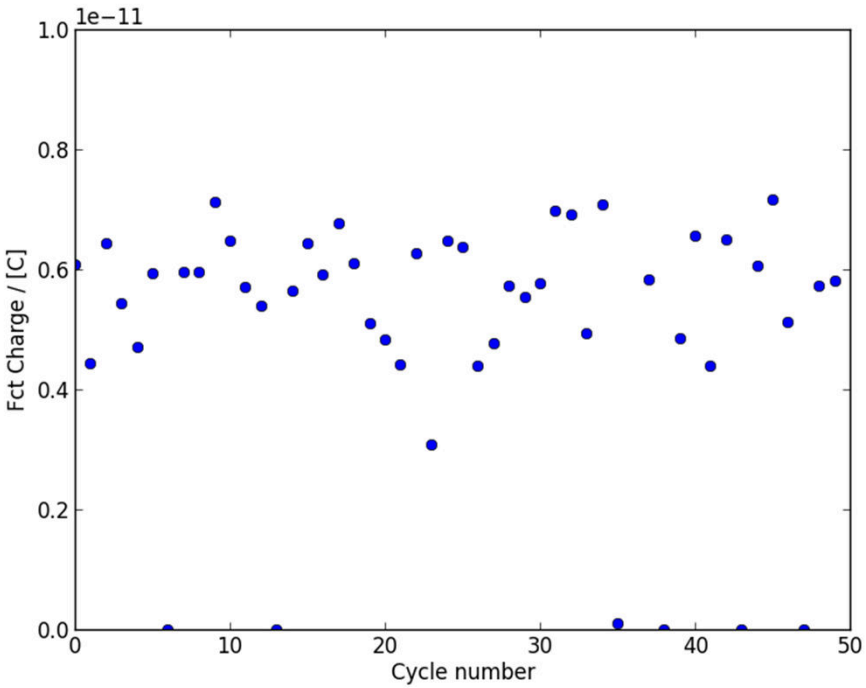




- Zero-value in trending plot : Kicker not detected!
- Extremely weak signal of a few ~5 ADC channels. Large fluctuation in FCT integral.
- Similar signal strength to Run 6.
- **Very nice resolution for mean value down to the few micro-Ampere range!!!**

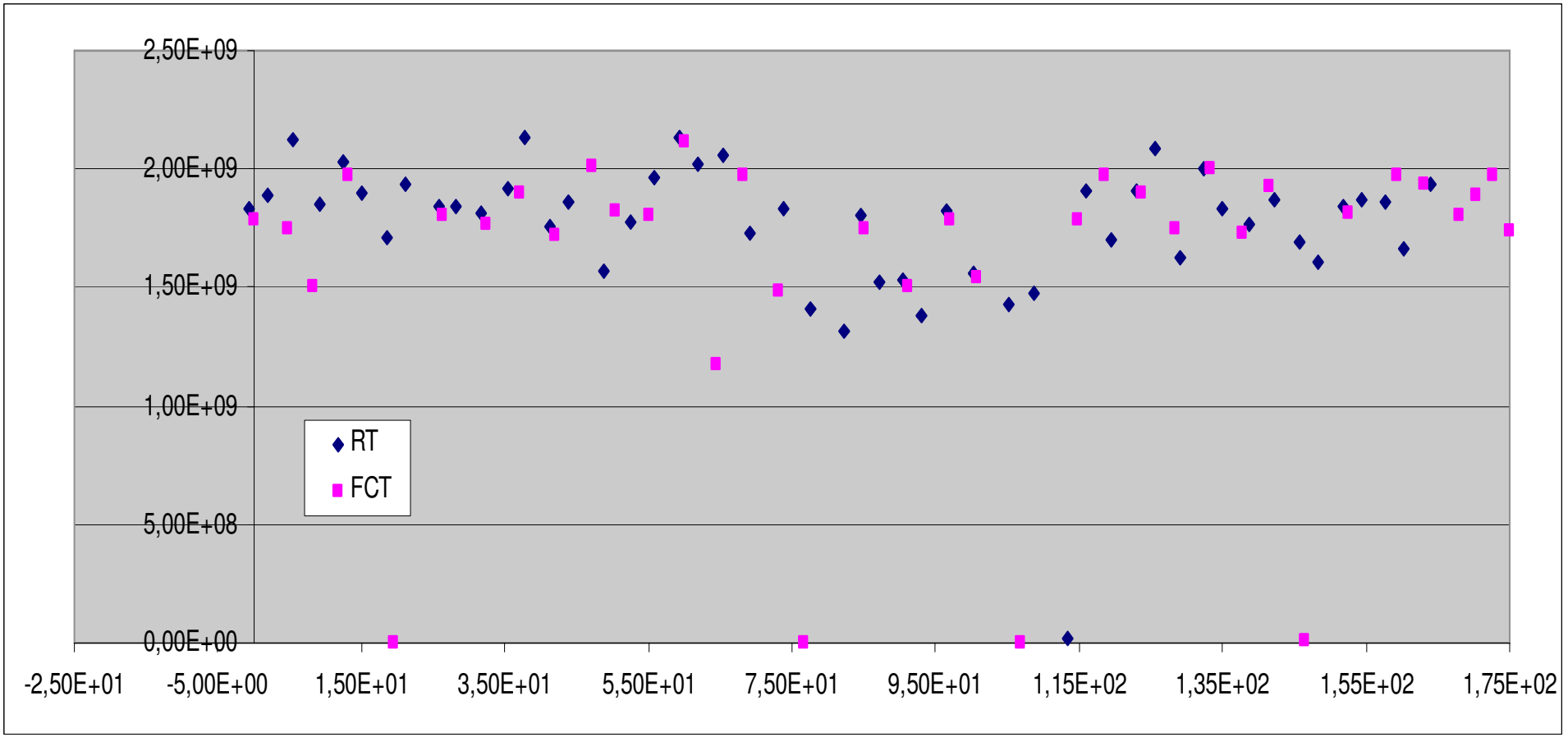
Run 3 – Trend of FCT and RT charges





- Calculated particle numbers do agree to within 10%, if measured gain is used!
- Cable losses in RG214 can shift FCT charge by ~10-15%:
  Attenuation(3.6 MHz, 75 m) = 0,975 dB or factor ~0.89.
- Cycles are not identical due to gaps in DAQ system outputs and asynchronous (manual) start of 2 different DAQ systems for FCT and RT

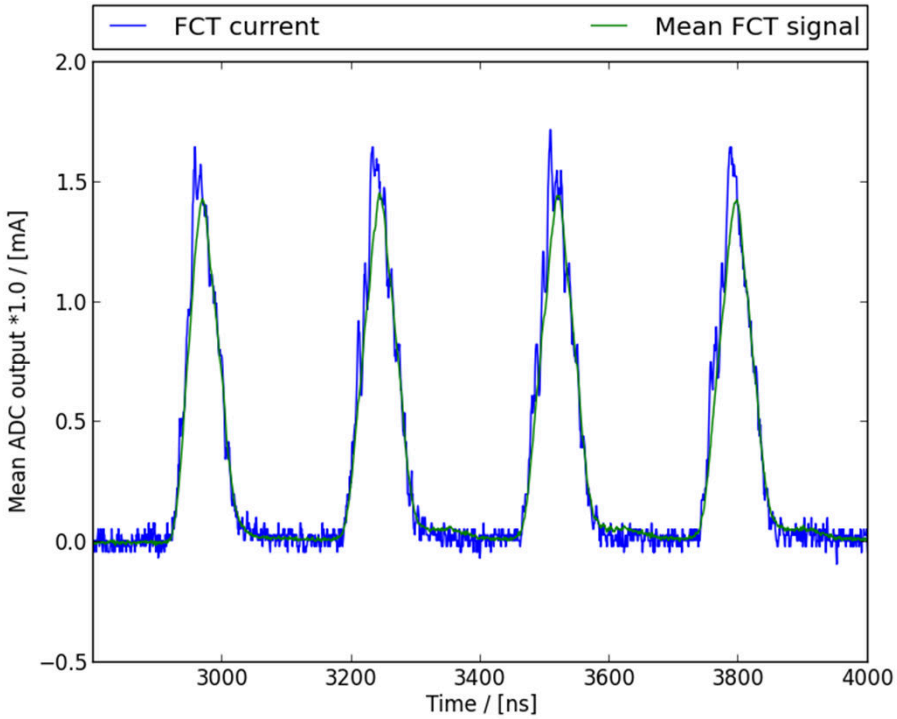
Run 1 – Trend of FCT and RT particle numbers

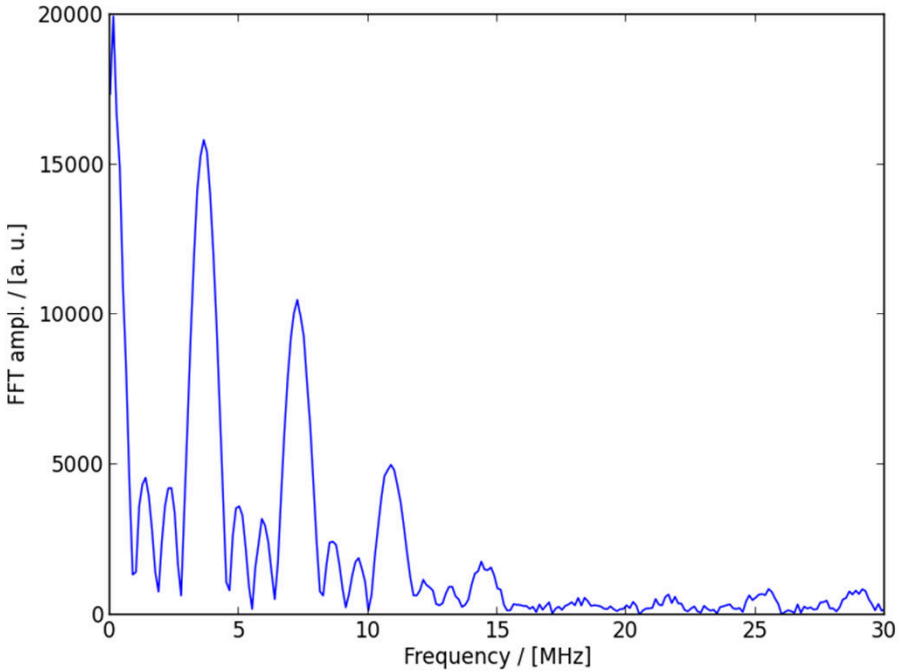


- DAQ systems did not save every single extraction! Asynchronous exports.
- FCT and RT charges agree, only if the time stamp is identical!

Run 1 – 1.5E9 particles, 16 dB attenuation

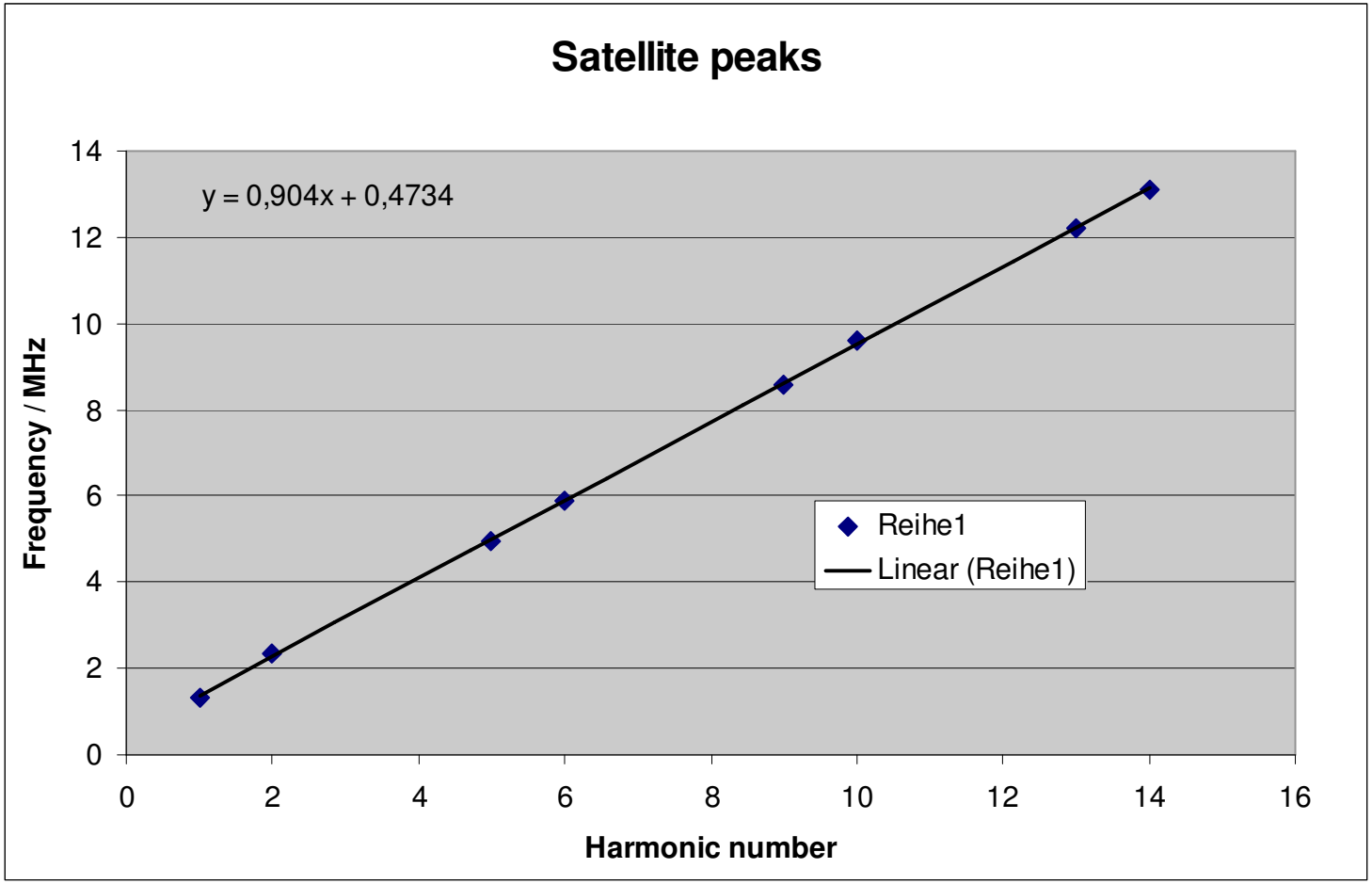
- The attenuator was set to 16 dB (peak value ~ 65 ADC ch.) by accident!
- The FCT data export was started „as is“ as a test in Run1. The signal was not checked online!
- For 2E9 protons the peak current in the bunch is about 1.6 mA.





- Nice comparison between mean signal (green) and single signal trace (blue)
- FFT spectrum shows larger „main peaks“ at multiples of 3.6 MHz (h=4)
  and smaller „satellite peaks“ at multiples of 0.9 MHz (h=1)

Trendline through satellite peaks



- Satellite peak frequencies as function of harmonic number. The gradient of 0.9 MHz corresponds to the revolution frequency of a single bunch at v = 0.65 c
- Gaps correspond to positions of the „main peaks“ (that obscure „satellites“)

Conclusions

- Baseline of Struck ADC very clean. Width of baseline ~8 ch. (of 1024) or 0.15%.
- At a total number of 2E7 protons per bunch (3.2 pC) is clearly detectable.

- Minimum detectable proton number in a single peak is about 5E6 (0.8 pC)
  for a triangular pulse shape of 100 ns total width.

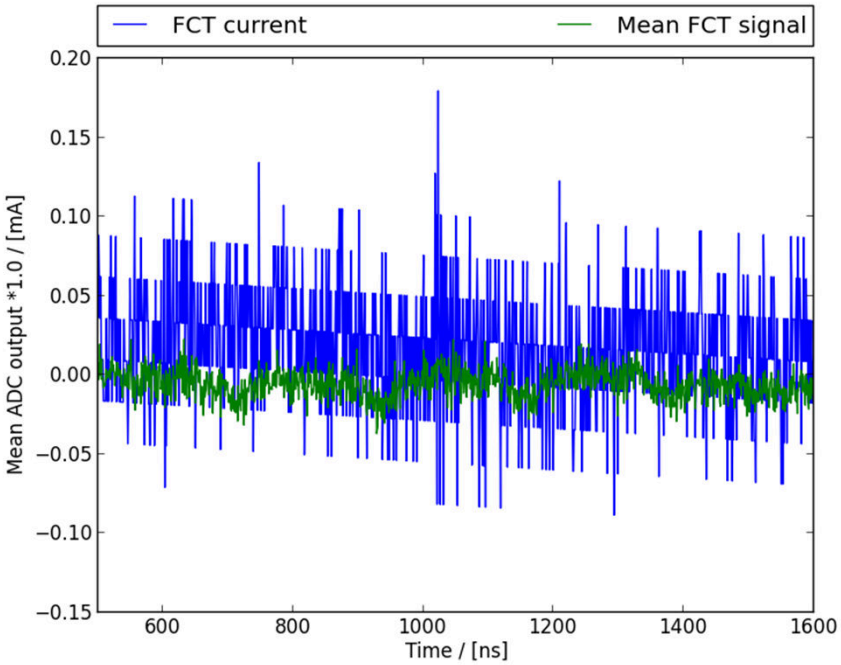
- There is a significant discrepancy (~20-30 %) between particle numbers derived by FCT and RT when the available nominal calibration values are used. This discrepancy is reduced to ~10%, if the measured gain is applied.
- AR will re-check his code for bugs, only if needed and if all calibrations and gain/attenuation values are available! See next item.

- Necessary investigation:
  - The RT calibration should be re-checked locally at HTP and in the AP Container
  - The FCT amp/att unit incl. Transmission line to AP Container should be measured at 3.6 MHz (and higher harmonics) sine waves and some pulsed signals. Inject since wave at amp. input and attenuator input (2 separate measurements). Measurements with pulsed signals inject signal at amp. input.

FCT Measurements
2016

- Xe^{43+}
- 300 MeV/u
- Only 4 of 5 bunches were extracted to the HEST!
- Comparison of Bergoz FCT with old GSI FCT

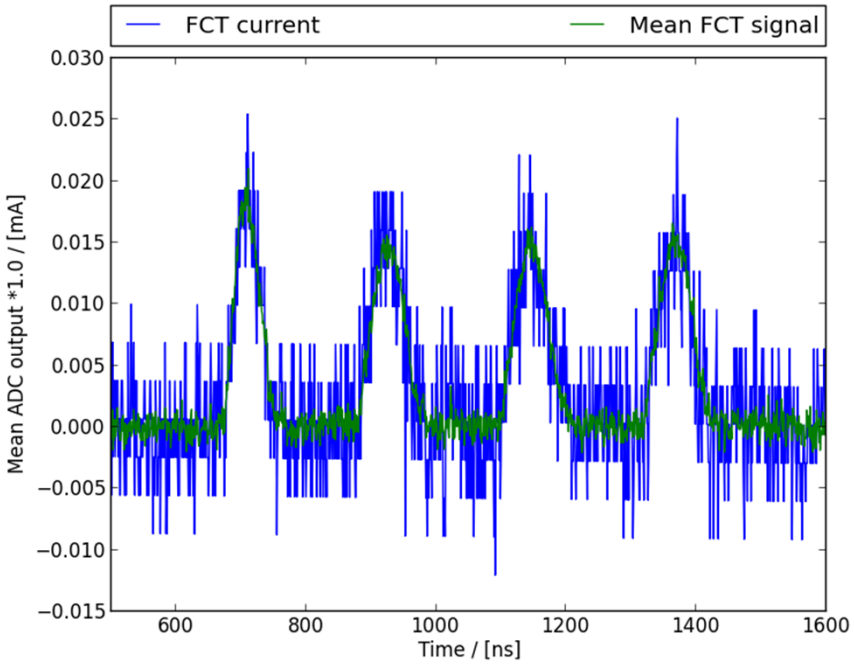
6E5, Xe^{43+} (2.58E7 p, 4 pC)



FAIR FCT: Sensitivity = 0.5 V/A

Att = 0 dB

At best a hint of a signal in the mean signal of 50 extractions (green trace)



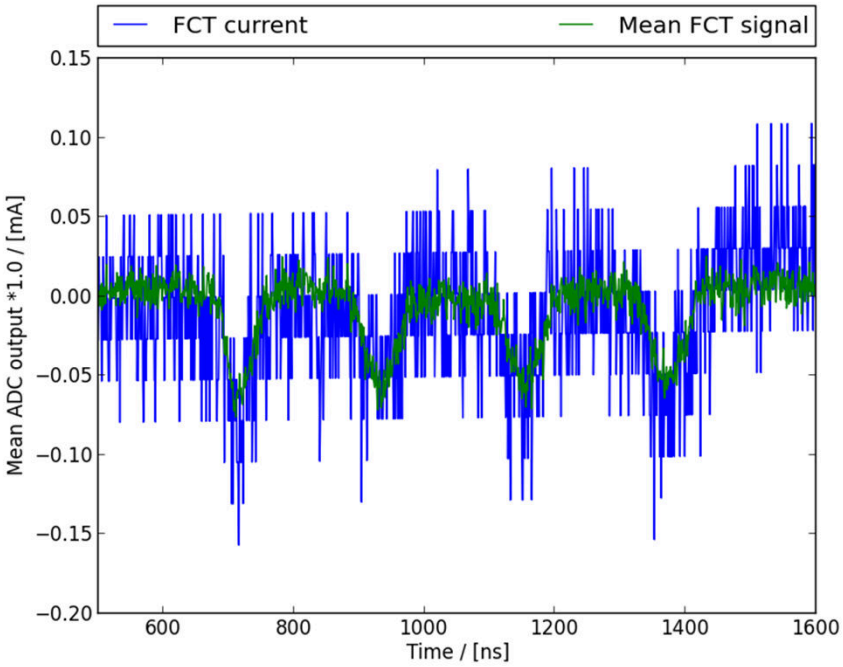
GSI FCT: Sensitivity = 4.2 V/A

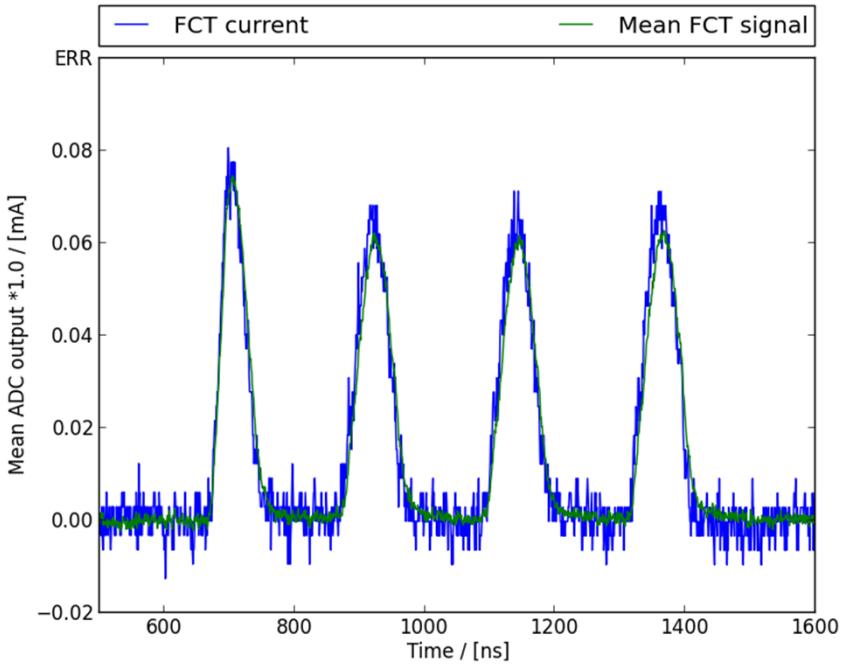
Att = 0 dB

Minimum detectable signal for single bunch of 100 ns full width

~0.5-1.0 pC ~ 3-6 E6 p ~ 5-10 µA peak

2E6, Xe^{43+} (8.6E7 p, 14 pC)





FAIR FCT: Sensitivity = 0.5 V/A

Att = 0 dB

Minimum detectable signal (S/N~2)

for single bunch of 100 ns full width

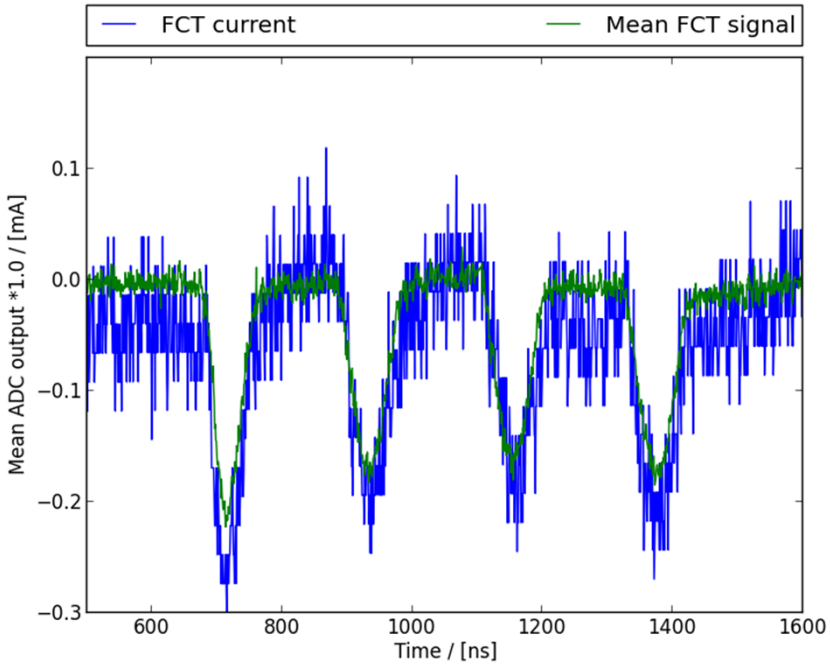
~3.8 pC ~ 2.4E7 p ~ 75 µA peak

GSI FCT: Sensitivity = 4.2 V/A

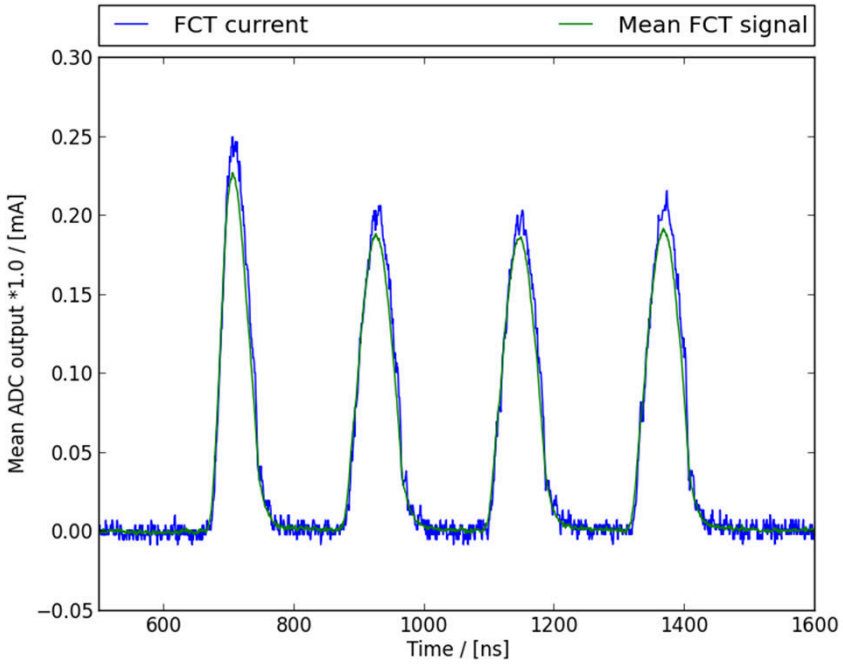
Att = 0 dB

Strong signal (S/N~20)

5E6, Xe^{43+} (2.15E8 p, 34 pC)



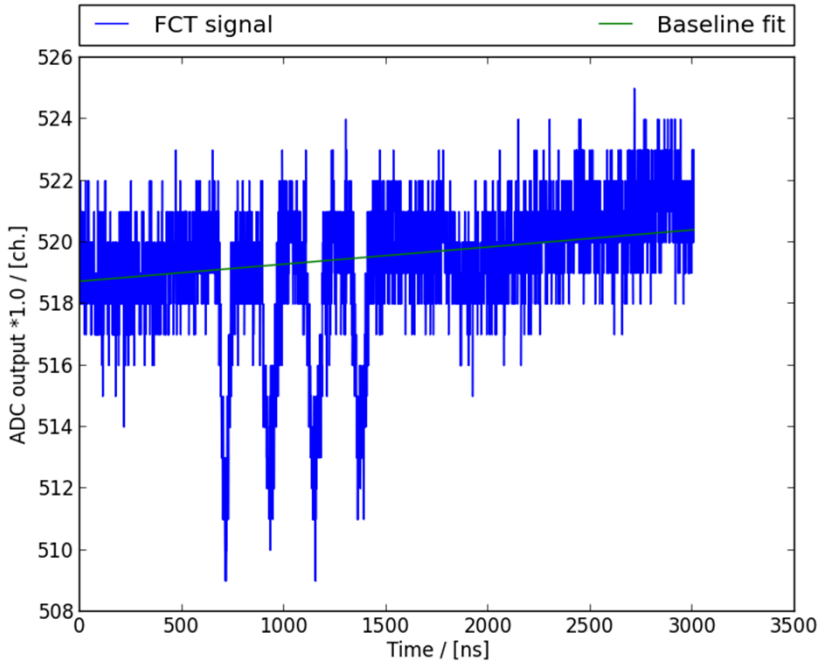
FAIR FCT: Sensitivity = 0.5 V/A
Att = 0 dB
Measureable signal for single bunch of 100 ns full width
~10 pC ~ 6.5E7 p ~ 200 µA peak



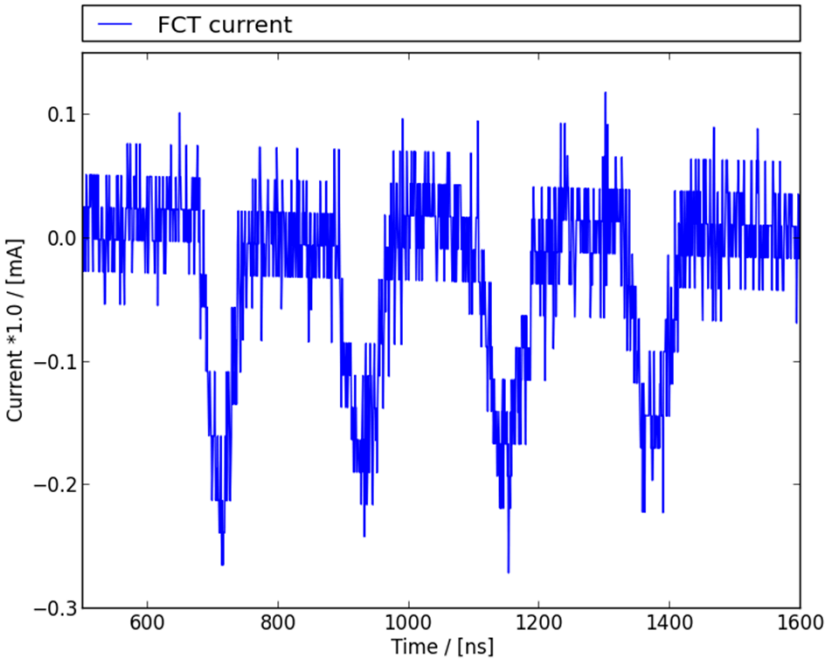
GSI FCT: Sensitivity = 4.2 V/A
Att = 0 dB
Measurable signal for single bunch of 100 ns full width
~1.3 pC ~ 8E6 p ~ 20 µA peak

FAIR FCT (Bergoz LLS)

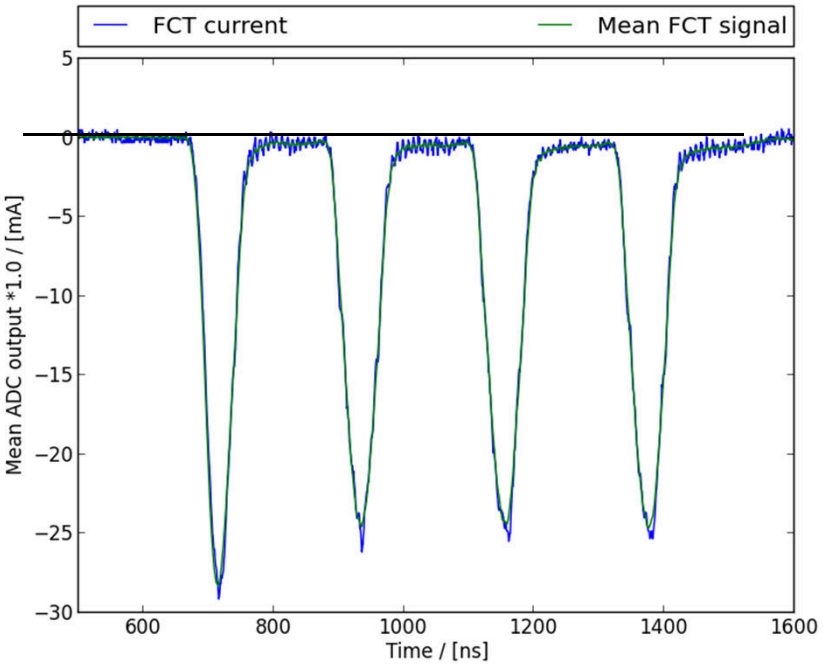
Full signal trace (raw data)



Peak region after baseline subtraction and conversion to physical units (mA)



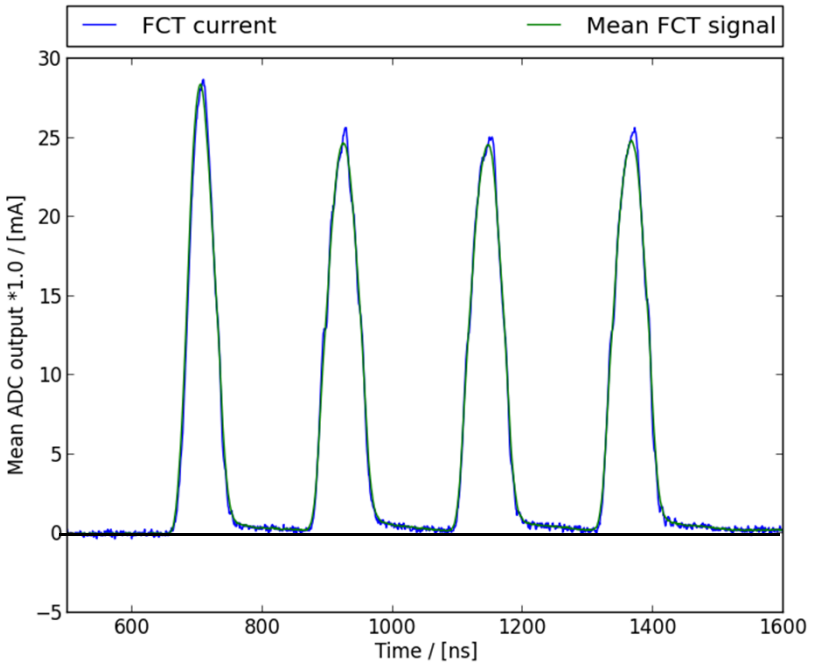
8E8, Xe^{43+} (3.4E10 p, 5.5 nC)



FAIR FCT: Sensitivity = 0.5 V/A

Att = 16 dB

Peak amplitude ~ 25 mA for last bunches



GSI FCT: Sensitivity = 4.2 V/A

Att = 30 dB

Peak amplitude ~ 25 mA for last bunches

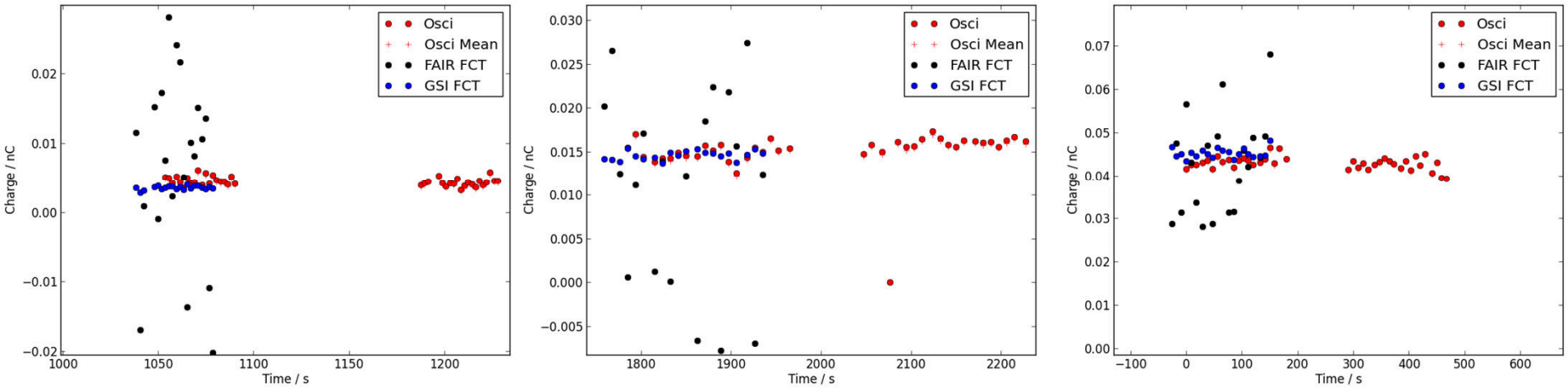
Trenddaten

- Streuung GSI FCT klein, da S=5 V/A
- Dann aber 400 Volt Spitzenspannung bei nominellen FAIR Pulsen!!!

- FAIR FCT hat größere Streuung, da S=0.5 V/A

GSI & FAIR FCT: 0 dB attenuation

Xe^{+43} ions:	6E5	2E6	5E6
Charges [e]:	2.58E7	8.6E7	2.15E8
Charge [pC]:	4.1	13.8	34.4



GSI FCT (4.2 V/A): 4 pulses: Min. charge ~5 pC comparable to RT (3.00E7 [e])

1 pulse : Min. charge ~1.5 pC (~1E7 [e])

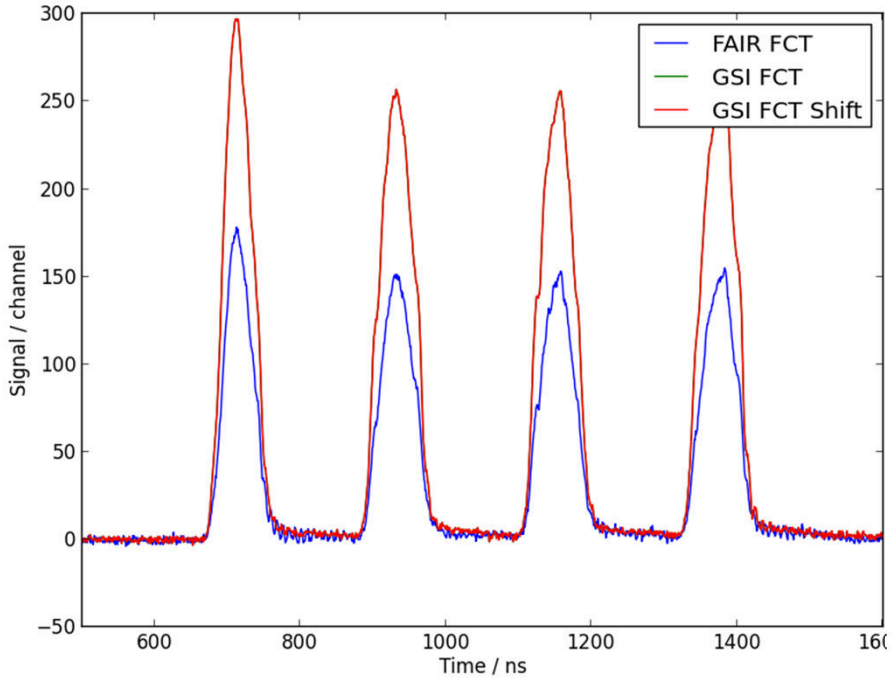
FAIR FCT (0.5 V/A): 4 pulses: Min. charge >50 pC; probably 100 pC (6.25E8 [e])

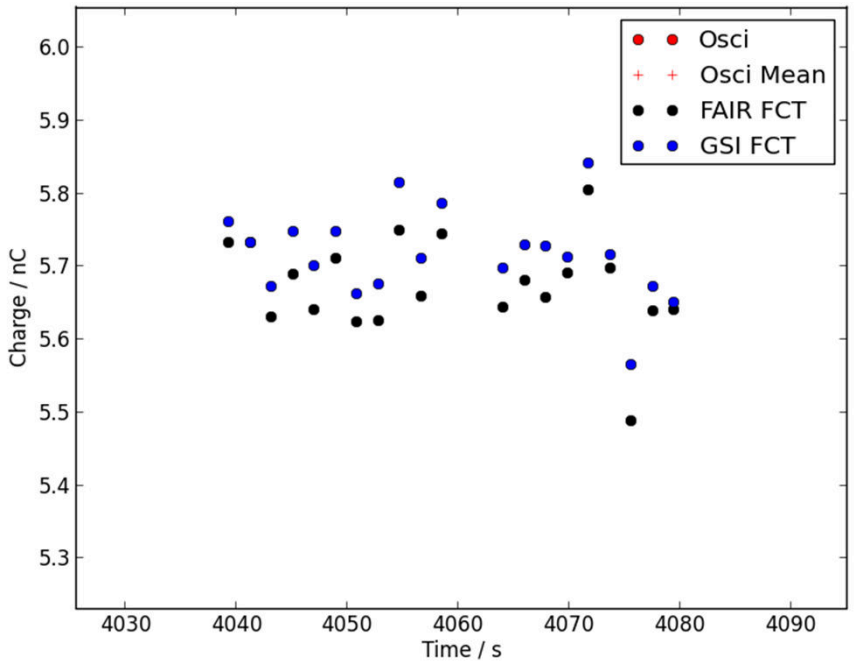
1 pulse: Min. charge ~25 pC (1.5E8 [e])

Xe 8E8
Raw Data

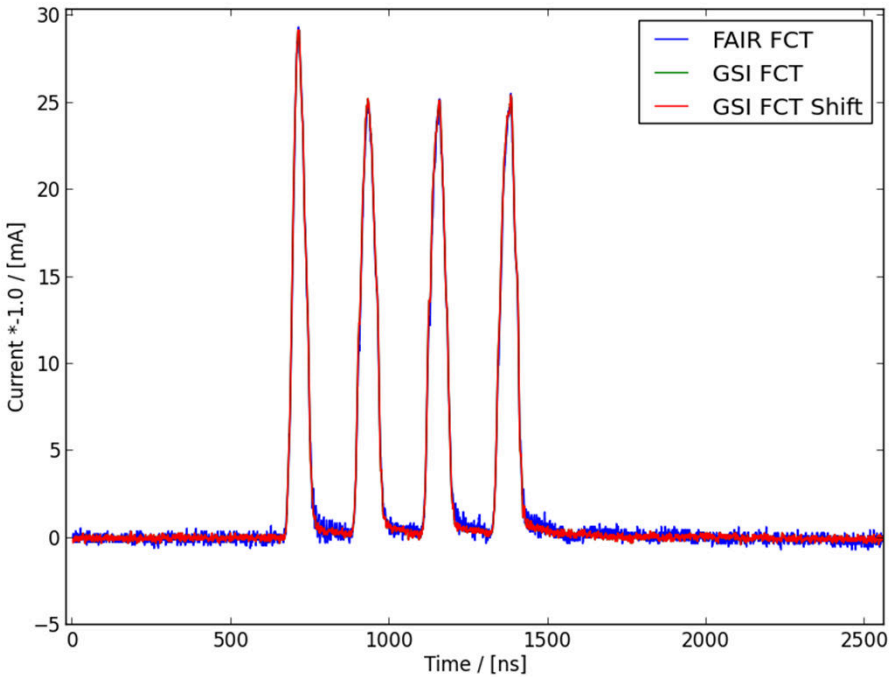
FAIR FCT: 30 dB
GSI FCT: 16 dB

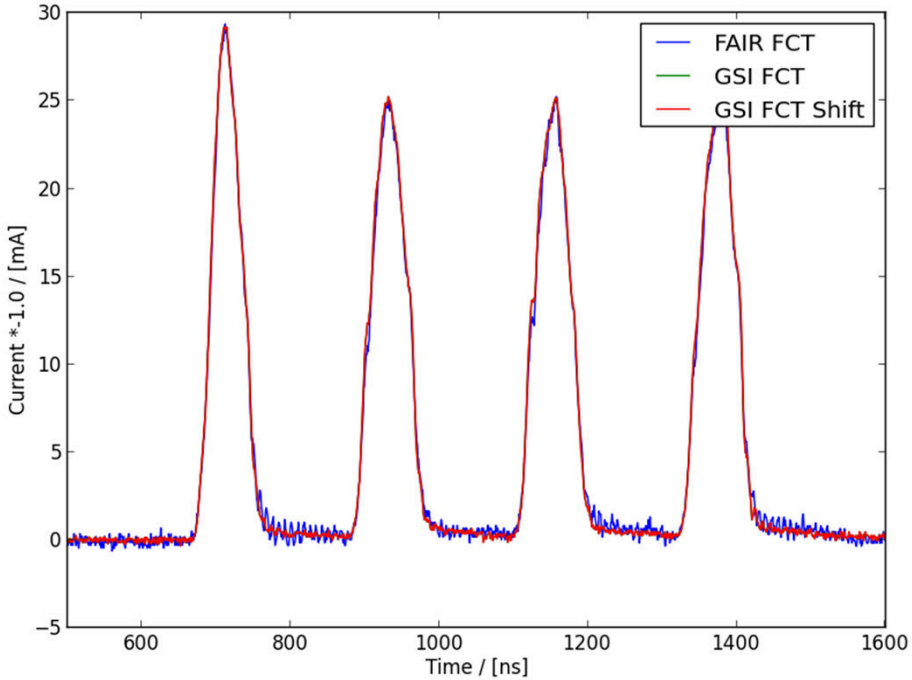
Xe^{+43} ions: 8E8
Charges [e]: 3.4E10
Charge [pC]: 5500

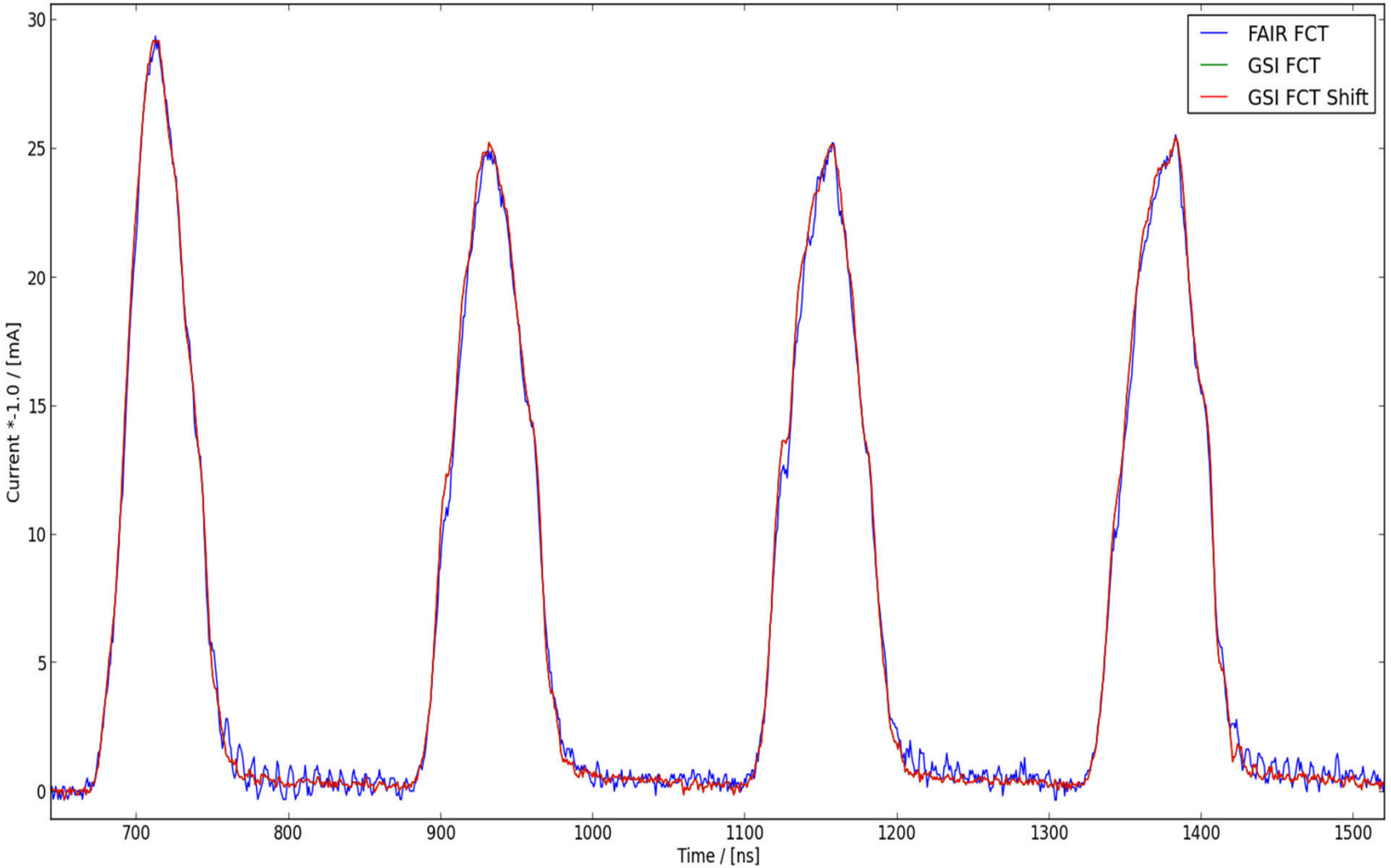




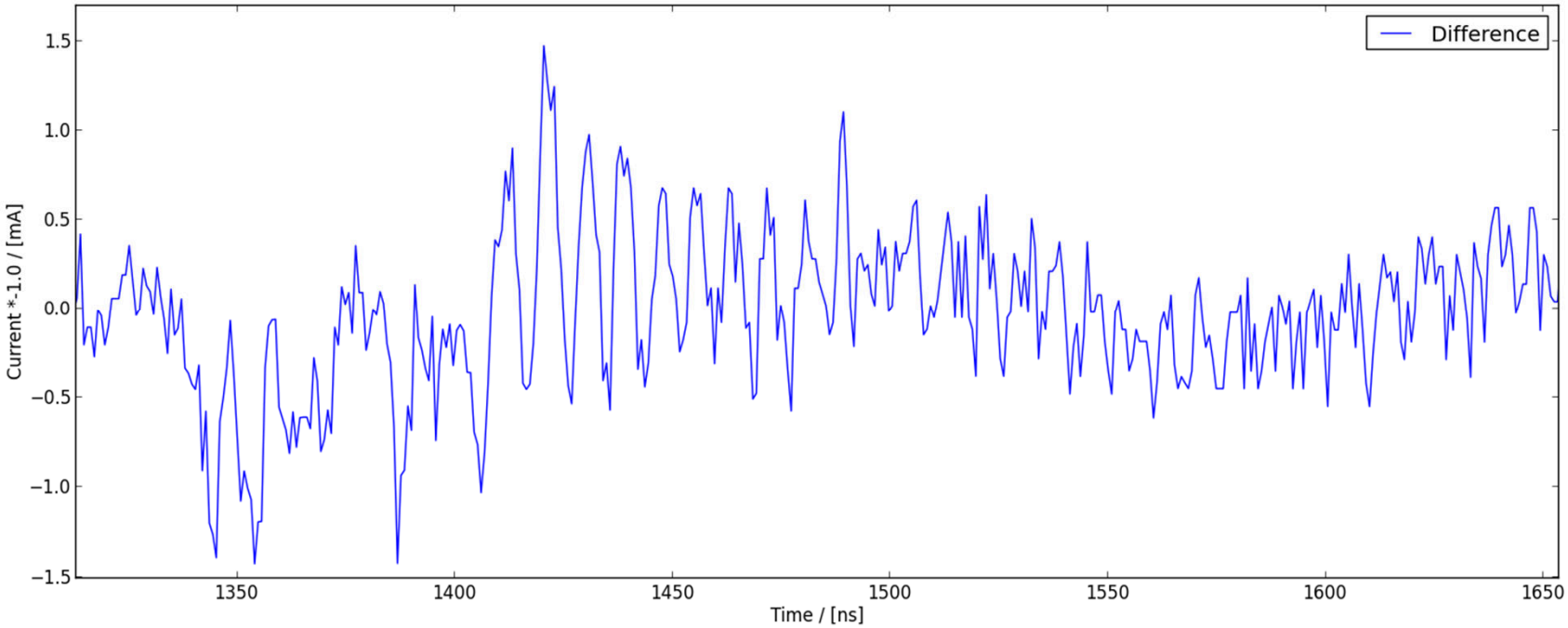
Xe 8E8
Current

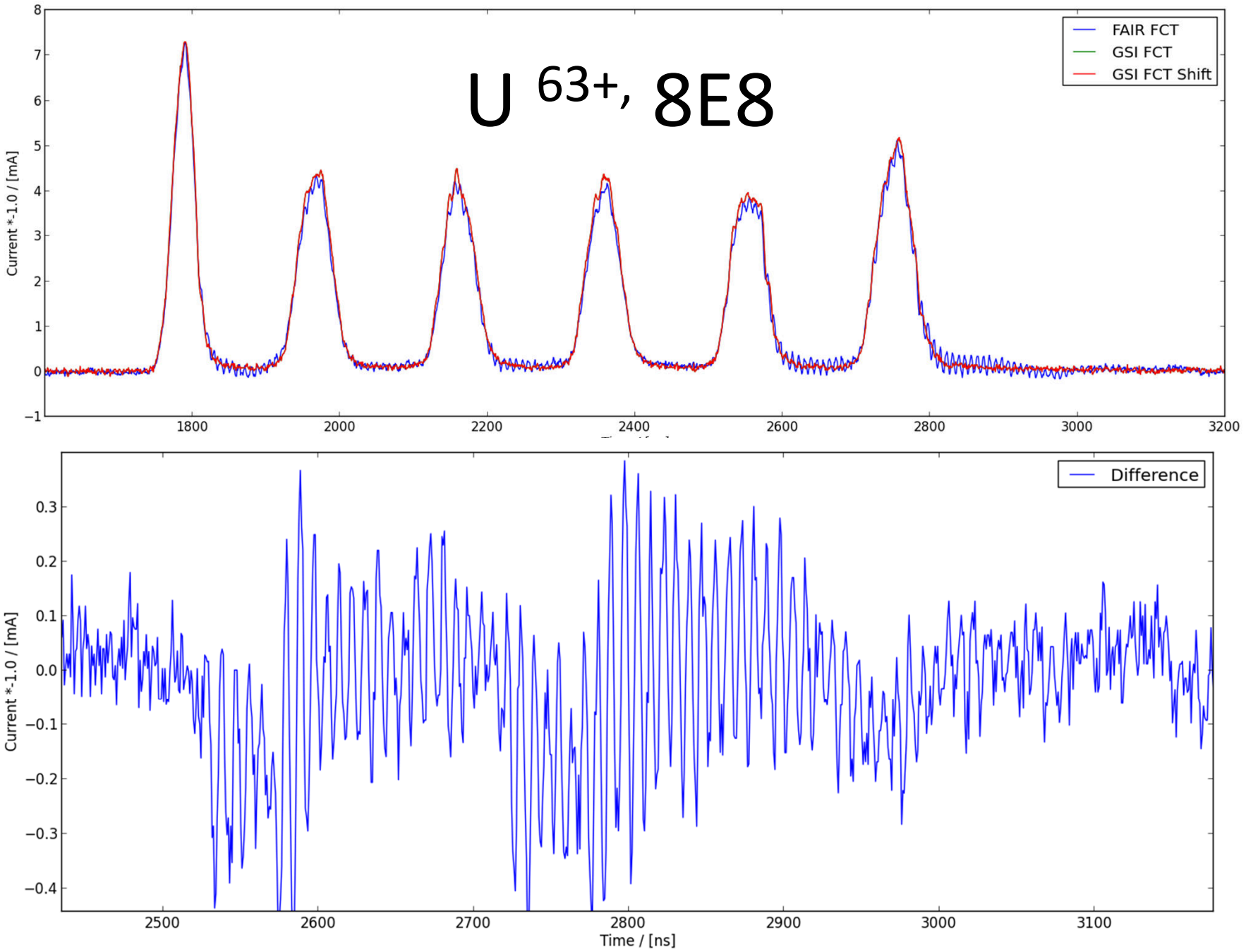





FAIR FCT
GSI FCT
GSI FCT Shift
Current *-1.0 / [mA]
Time / [ns]
30
25
20
15
10
5
0
700
800
900
1000
1100
1200
1300
1400
1500

Difference Signal



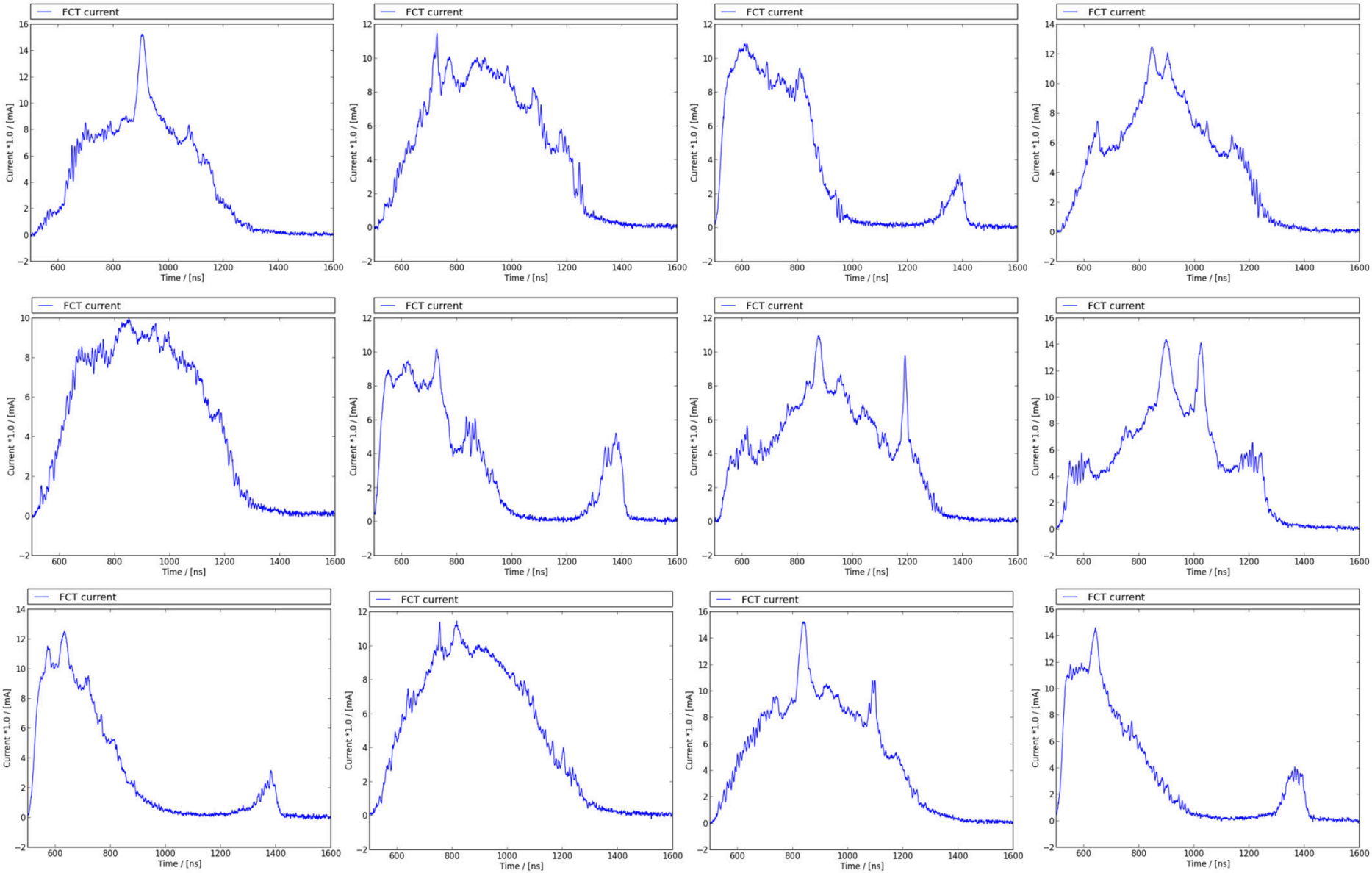

U 63+, 8E8
FAIR FCT
GSI FCT
GSI FCT Shift
Current *-1.0 / [mA]
Difference
Time / [ns]

Open Issues & Conclusions

- Ringing at FAIR FCT (in 2014: GSI FCT, see h=1 data) -> problem in Att/Amplifier unit rather than in FCT sensor ???

  Edit 06.01.2017: recent measurements by Bergoz show strong resonance at ~1.2 GHz for FCT-LLS -> ringing from sensor !
- Check amplifier units: Inject h=1 signal with AFG & monitor output on scope!

Last shift 17th July, h=1

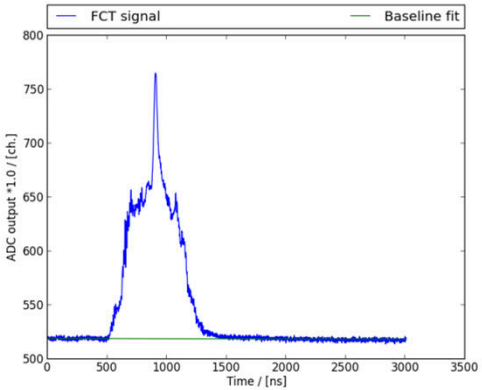


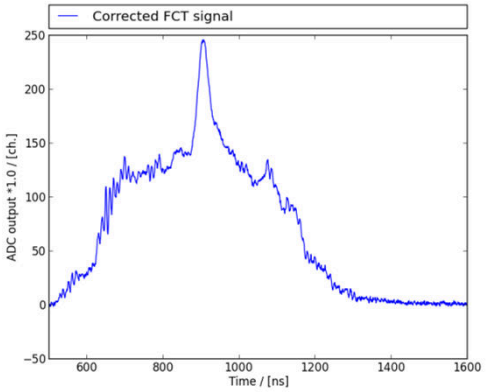
Last shift 17th July (protons, h=1)

Important: Quads on ESR timing -> did not work -> shitty beam !!!!

Longitudinal structure should however not be affected !!!

Same bunch: Full acquisition window and expanded view





Some selected bunches

a shorter bunch (300 ns) and 2 bunches with „spiky“ structures (800 ns)