Chromaticity Measurement via RF Phase Modulation

- ***need for fast chromarticity measurements in the LHC:***
  - head-tail monitor

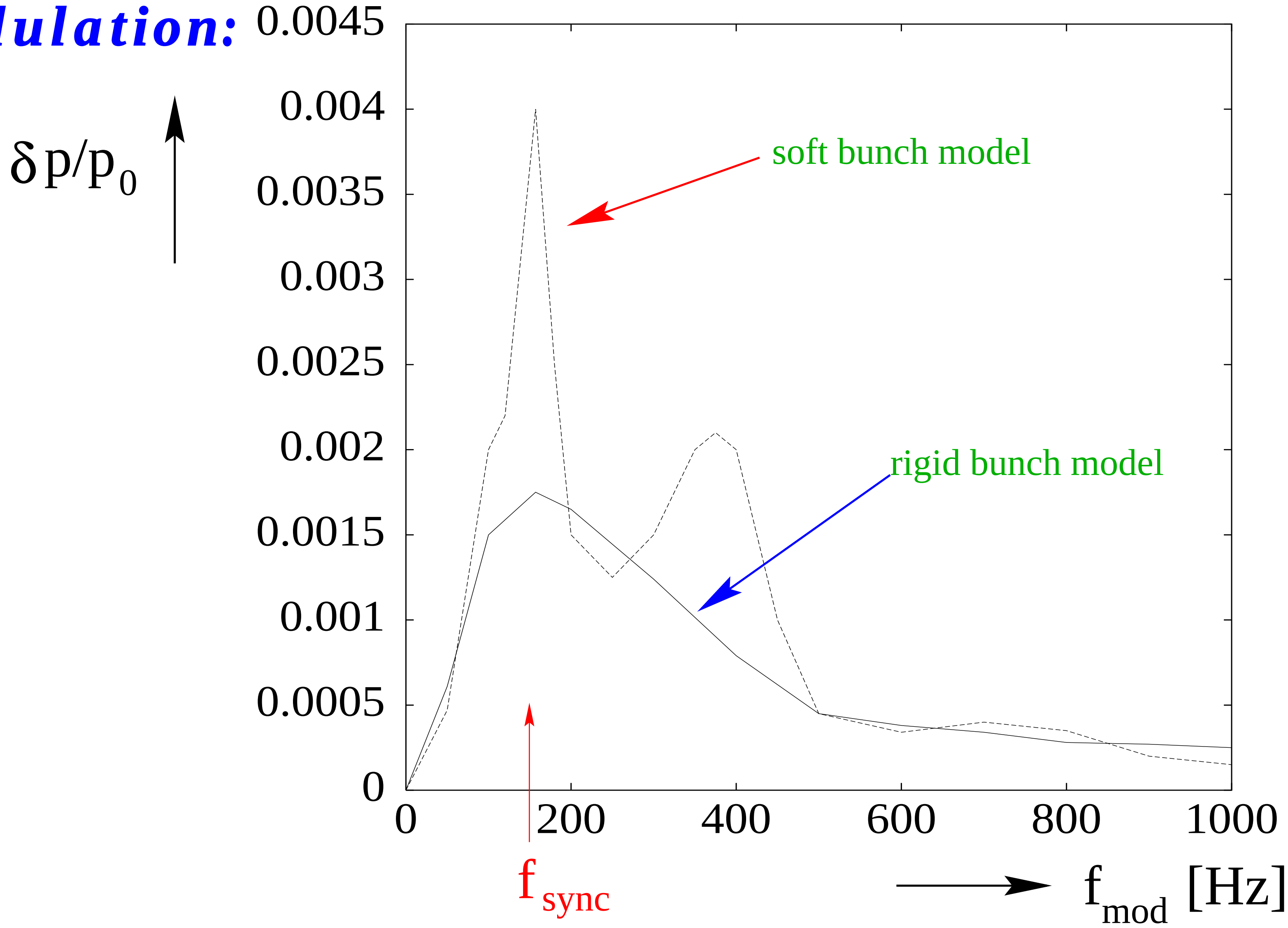
    → fast but destructive

- ***RF phase modulation:***
  - allows fast RF adjustments → > 100Hz
  - small energy variation for fast phase modulation
  - slow phase modulation can interfere with RF phase loop

    → f ≈ 5 fs →(SPS) f ≈ 700Hz <-> 800Hz

Chromaticity Measurement via RF Phase Modulation

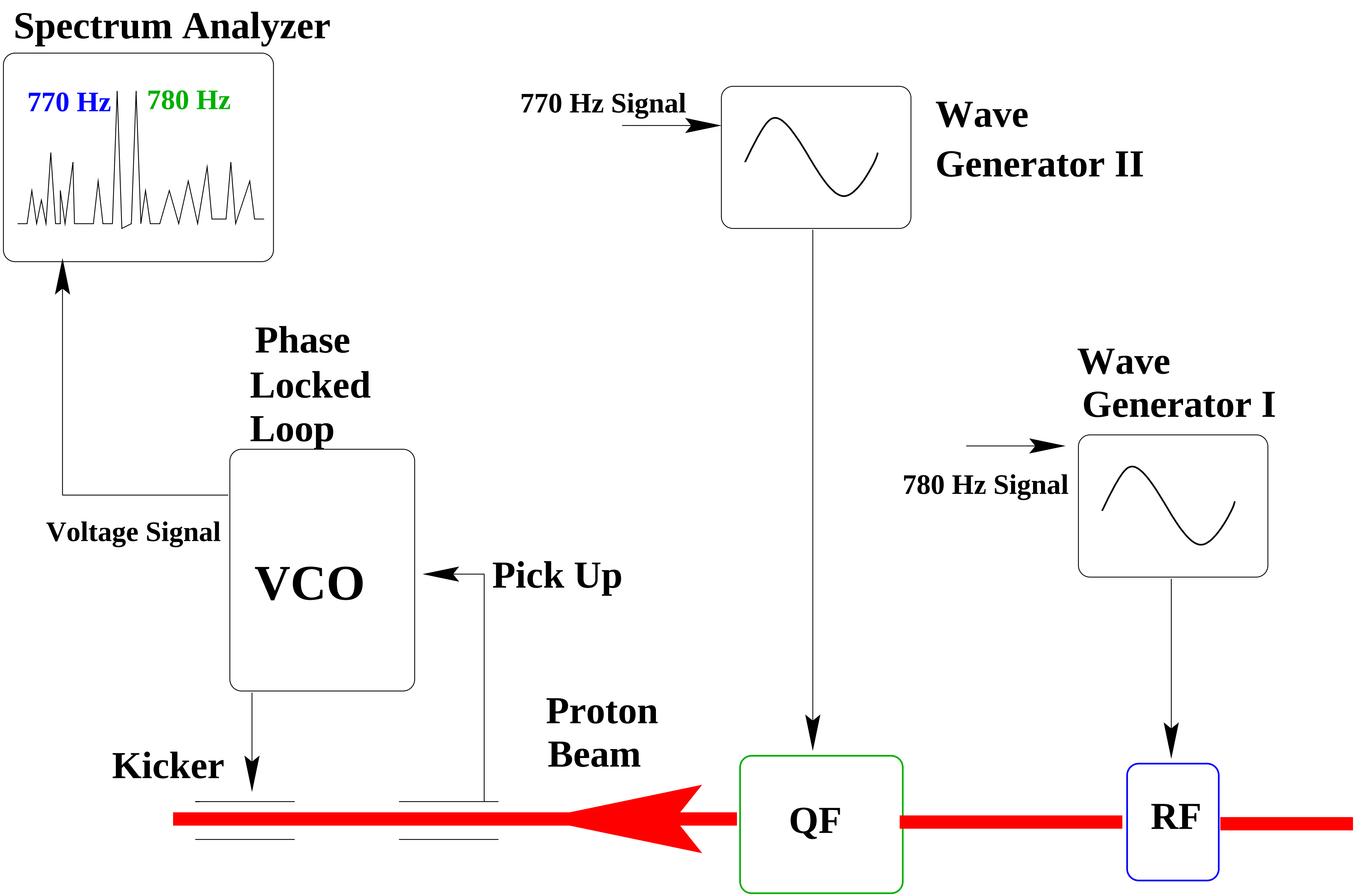
- ***energy modulation:***



Chromaticity Measurement via RF Phase Modulation

- ***energy modulation:*** (Trevor Linnecar)
  - RF phase modulation of 3 degrees (LHC)
    - → energy modulation: $\frac{\Delta E}{E_0} \approx 5 \cdot 10^{-5}$
    - → extra cavity power: 22.5 kW/cavity at injection

      180 kW/cavity at top energy
    - → maximum beam intensity limited by RF power
  - SPS measurements showed neither particle losses nor emittance growth during the RF phase modulation


Spectrum Analyzer
770 Hz
780 Hz
770 Hz Signal
Wave
Generator II
Phase
Locked
Loop
Wave
Generator I
780 Hz Signal
Voltage Signal
VCO
Pick Up
Proton
Beam
Kicker
QF
RF

Measurement Procedure

- adjust RF phase modulation for $\frac{\Delta E}{E_0} \approx 5 \cdot 10^{-5}$

- adjust tune modulation for $\Delta Q = 10^{-4}$

- lock the tune modulation to the RF phase modulation (180^{o})

- adjust tune modulation so that the frequency does not appear

→ $Q' \propto +2$

→ no net tune modulation acting on the beam

Chromaticity Measurement via RF Phase Modulation

- ***first measurements in the SPS 2.10.2001:***

Oliver Bruning, Wolfgang Hofle, Rhodri Jones, Trevor Linnecar

- no PLL -> measurement with transverse excitations and pickup
- single bunch measurement at 26 GeV $N \approx 4.2 \cdot 10^{10}$
- energy modulation: $\frac{\Delta E}{E_0} \approx 1 \cdot 10^{-4}$
- chromaticity variation: $0.0 < \xi < 13.0$

$$\Delta Q = \xi \cdot \frac{\Delta E}{E_0}$$

Chromaticity Measurement via RF Phase Modulation

measurement goals:

- demonstrate that RF phase modulation can produce

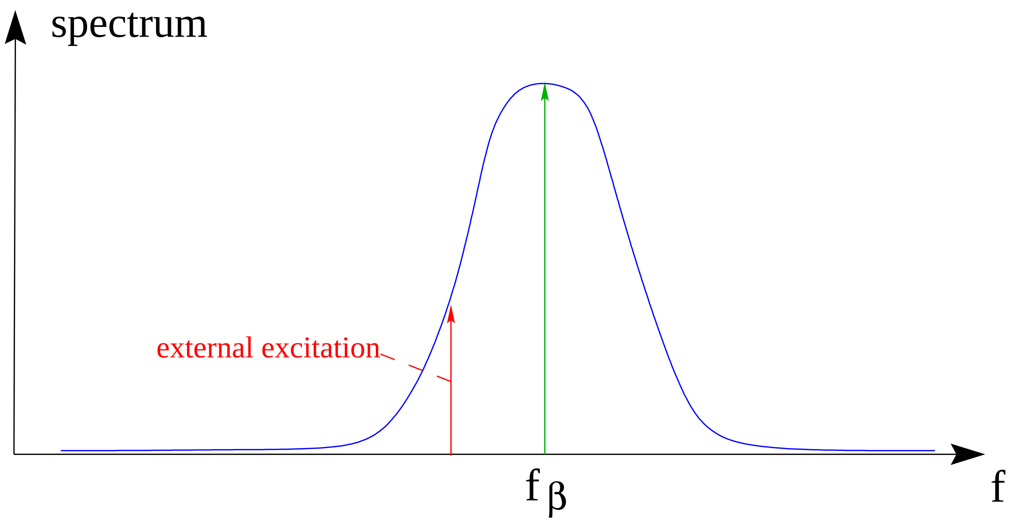
$$\longrightarrow \quad \frac{\Delta E}{E_0} \approx 1 \cdot 10^{-4}$$

- demonstrate that one can detect resulting signal in transverse plane
- demonstrate that phase modulation is non-destructive
- demonstrate that the transverse signal is proportional to ξ

Chromaticity Measurement via RF Phase Modulation

measurement in the vertical plane (no dispersion):

(Herman Schmickler)



- varying the central beam energy changes the position of the distribution in the spectrum for: $\xi \neq 0$

- modulating the central beam energy shows up in the FFT of the beam response: FFT line proportional to ξ

Chromaticity Measurement via RF Phase Modulation

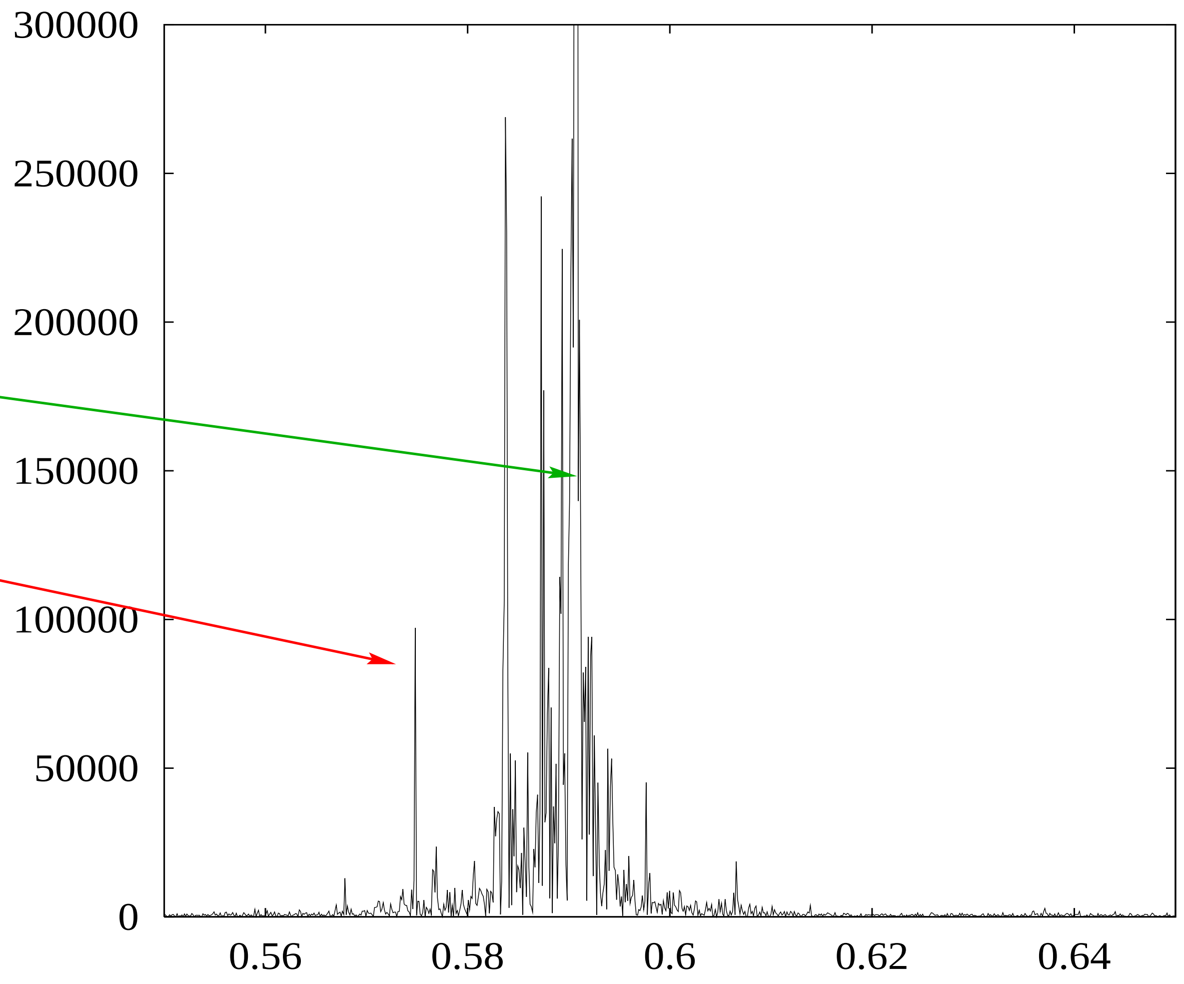
- ***typical spectrum:***

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}\ (Q = 0.59)$

$f_{RF} = 615\text{Hz}\ (Q = 0.576)$

$\xi_v = 13$



Chromaticity Measurement via RF Phase Modulation

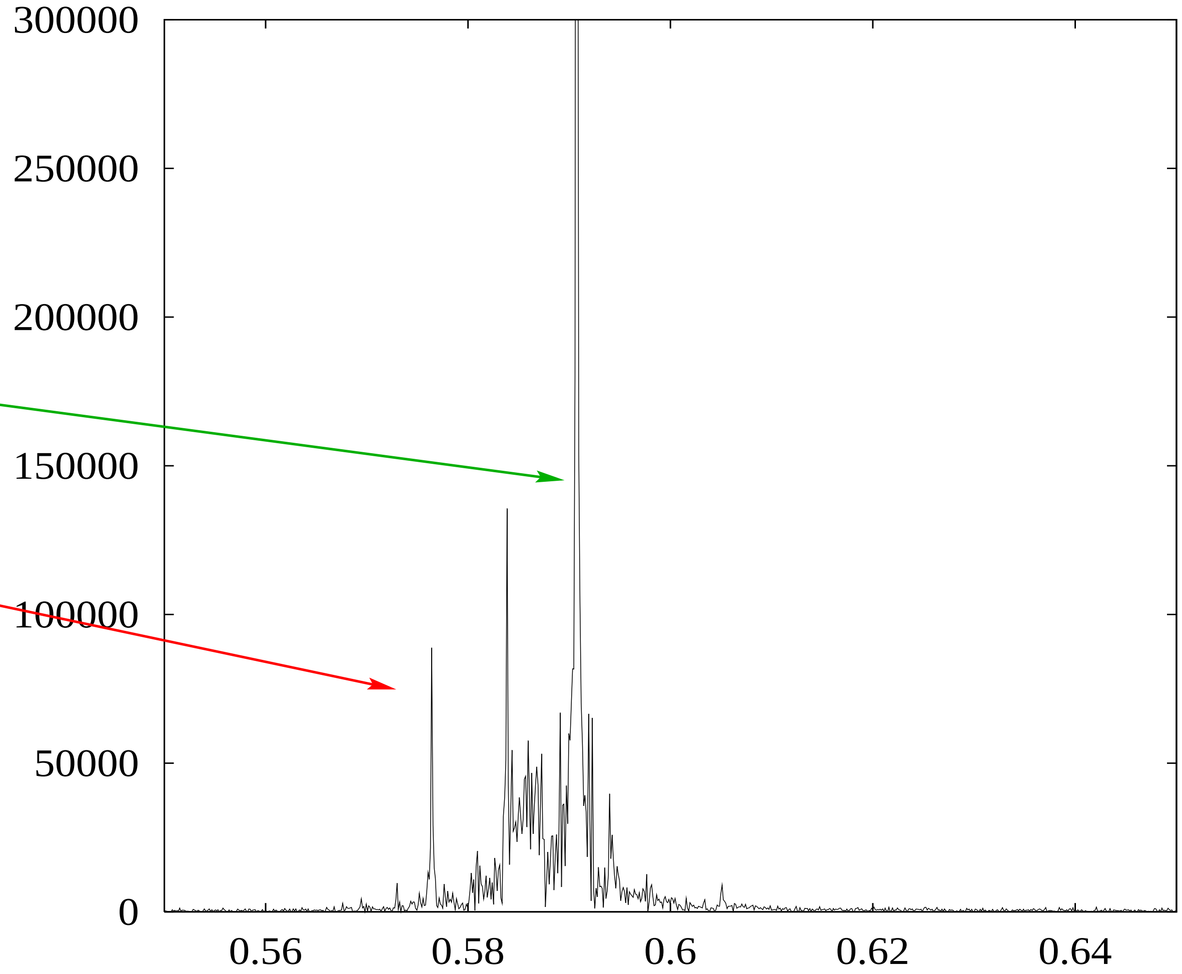
- ***typical spectrum:***

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}$ ($Q = 0.59$)

$f_{RF} = 615\text{Hz}$ ($Q = 0.576$)

$\xi_v = 10$



Chromaticity Measurement via RF Phase Modulation

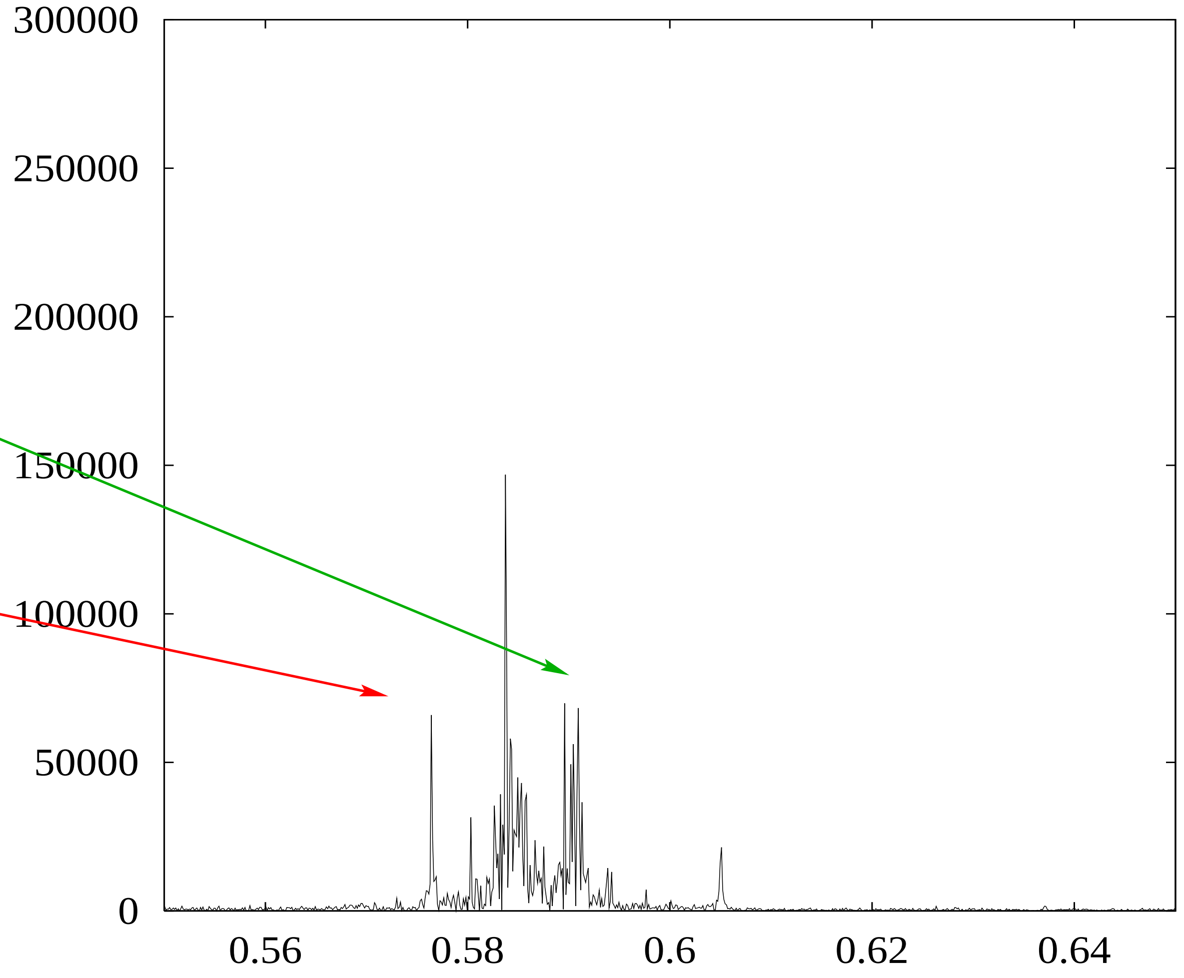
- ***typical spectrum:***

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}\ (Q = 0.59)$

$f_{RF} = 615\text{Hz}\ (Q = 0.576)$

$\xi_v = 7.5$



Chromaticity Measurement via RF Phase Modulation

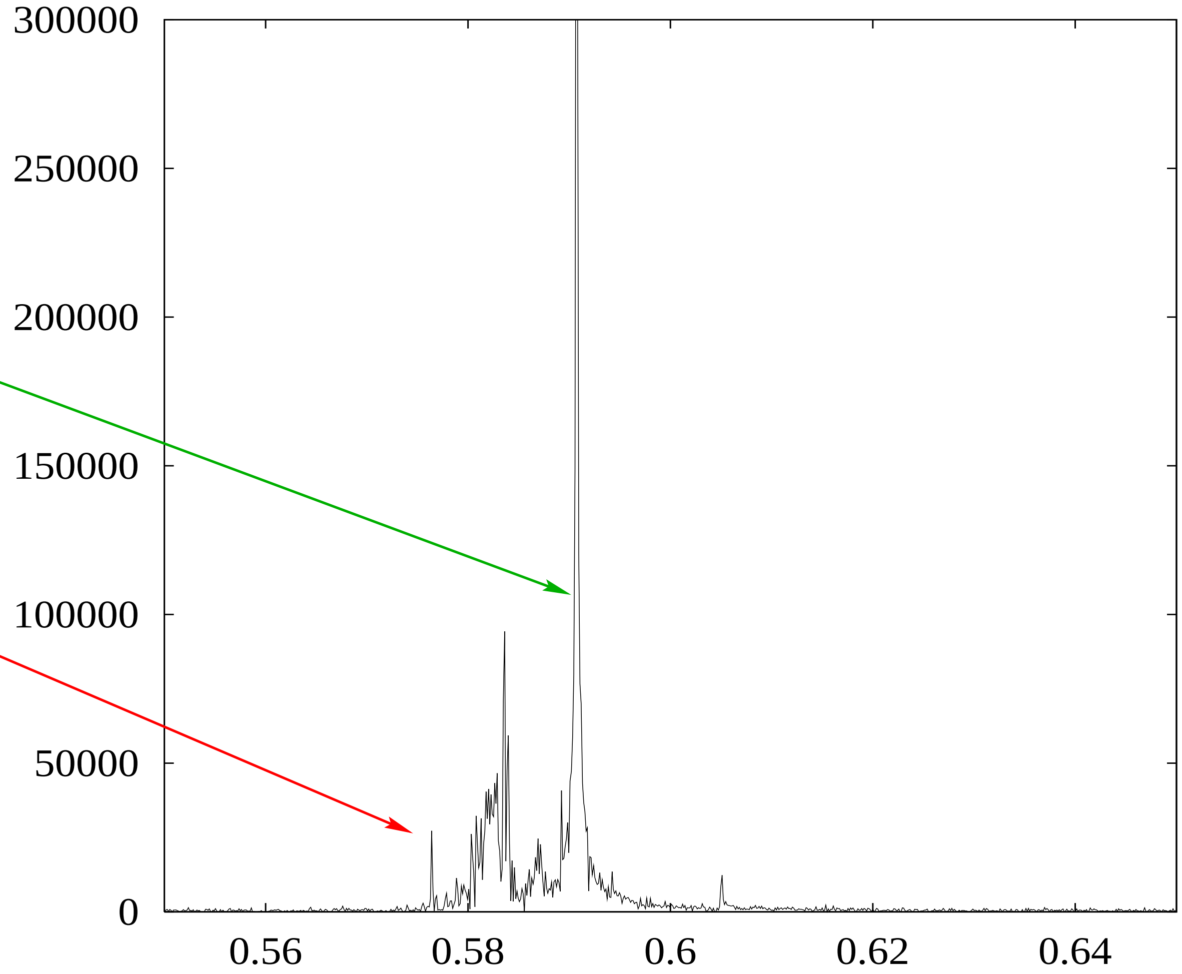
- *typical spectrum:*

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}\ (Q = 0.59)$

$f_{RF} = 615\text{Hz}\ (Q = 0.576)$

$\xi_v = 5$



Chromaticity Measurement via RF Phase Modulation

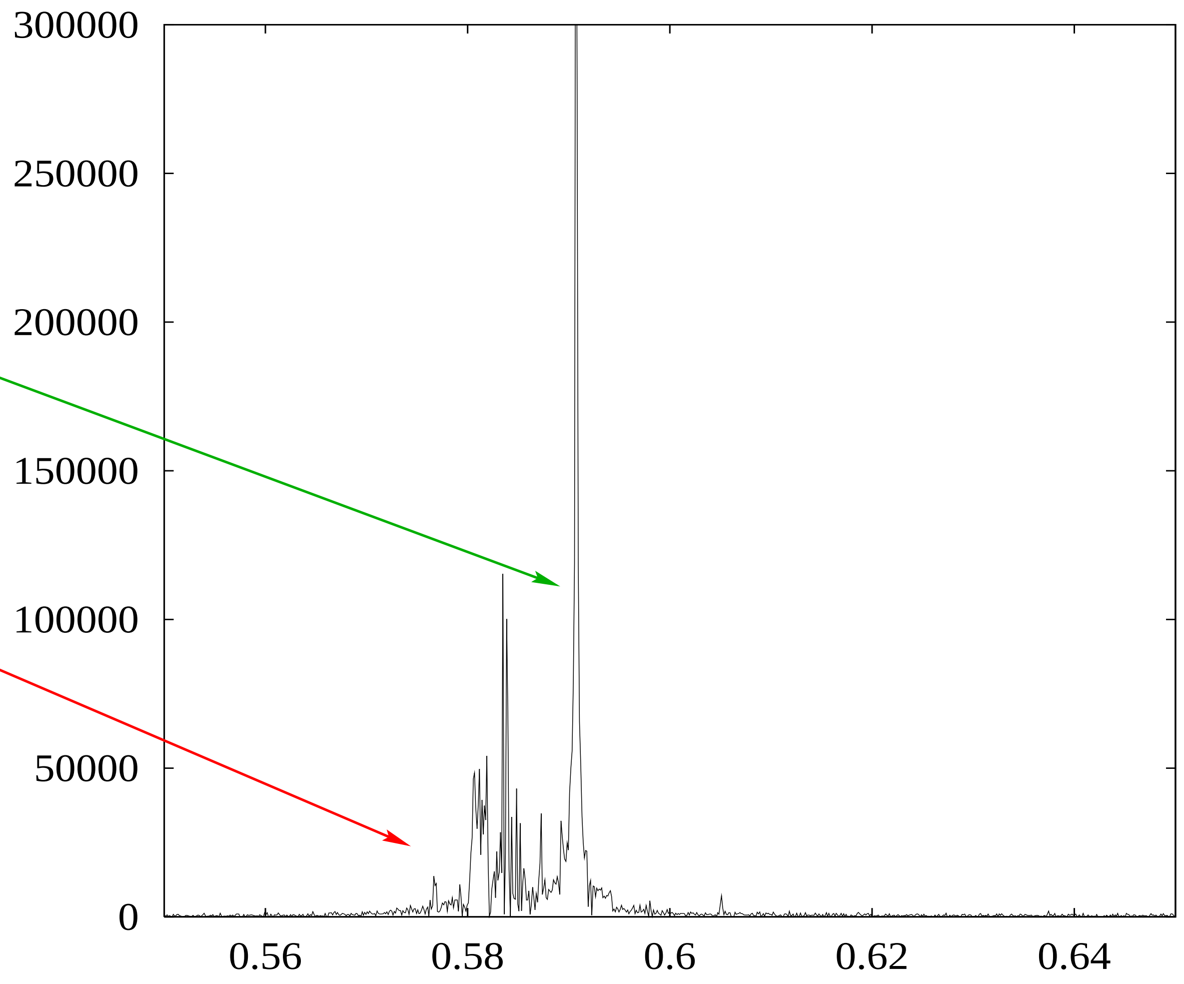
- *typical spectrum:*

$Q_v = 0.59$

$f_{kicker} = 17.74\text{Hz}$ (Q = 0.59)

$f_{RF} = 615\text{Hz}$ (Q = 0.576)

$\xi_v = 2.5$



Chromaticity Measurement via RF Phase Modulation

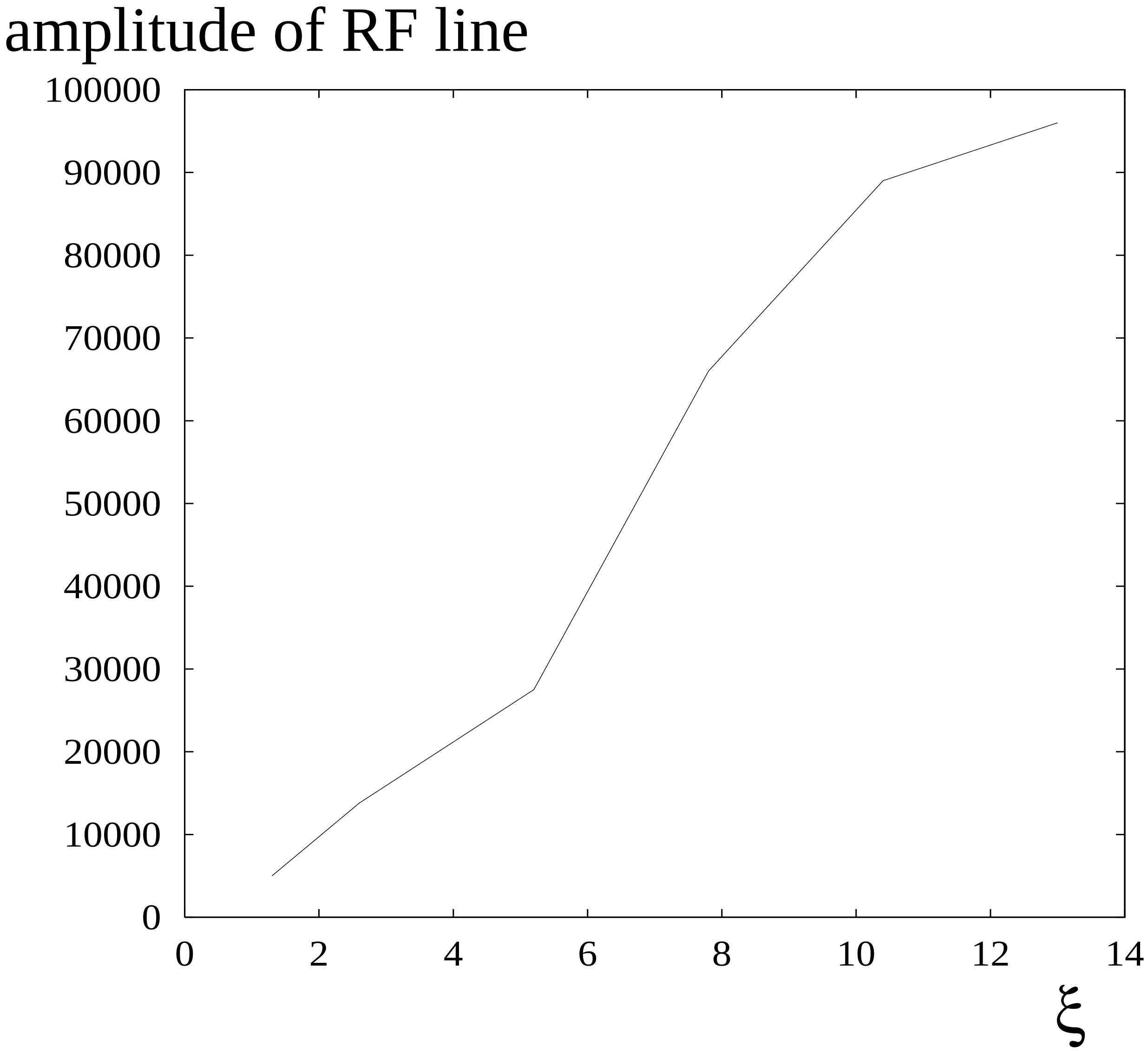
- ***chromaticity scan:***

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}$

$f_{RF} = 615\text{Hz}\ (Q = 0.576)$

$\xi_v = 2.5 \text{ <–> } 13$



Chromaticity Measurement via RF Phase Modulation

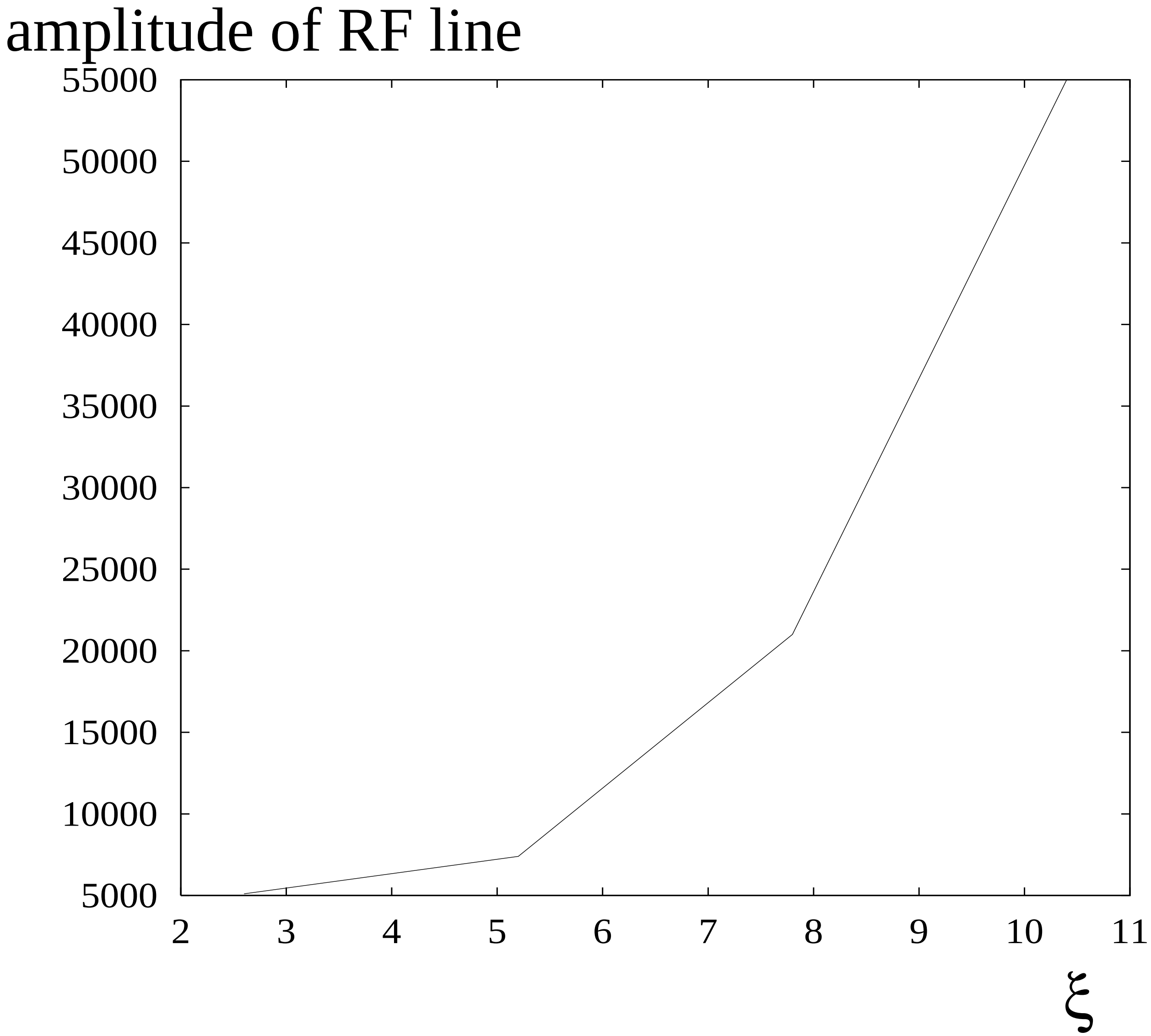
- ***chromaticity scan:***

$Q_v = 0.59$

$f_{kicker} = 17.74\text{kHz}$

$f_{RF} = 780\text{Hz}\ (Q = 0.584)$

$\xi_v = 2.5 <\!\!-\!\!> 13$



Chromaticity Measurement via RF Phase Modulation

- ***chromaticity scan:***

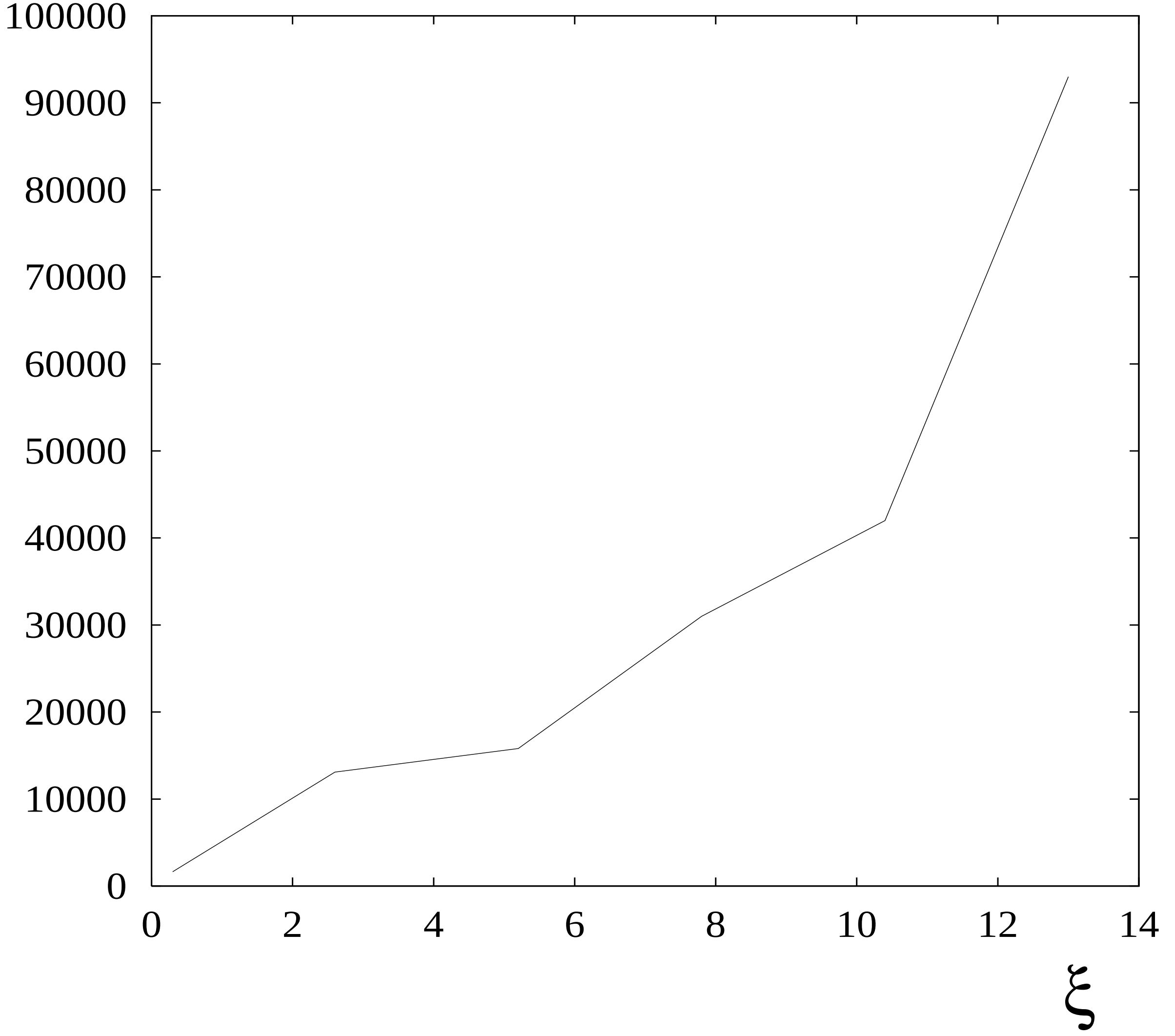
$Q_v = 0.59$

$f_{kicker} = 18.58\text{kHz}$ ($Q = 0.57$)

$f_{RF} = 780\text{Hz}$ ($Q = 0.584$)

$\xi_v = 2.5 <-> 13$

amplitude of RF line



Chromaticity Measurement via RF Phase Modulation

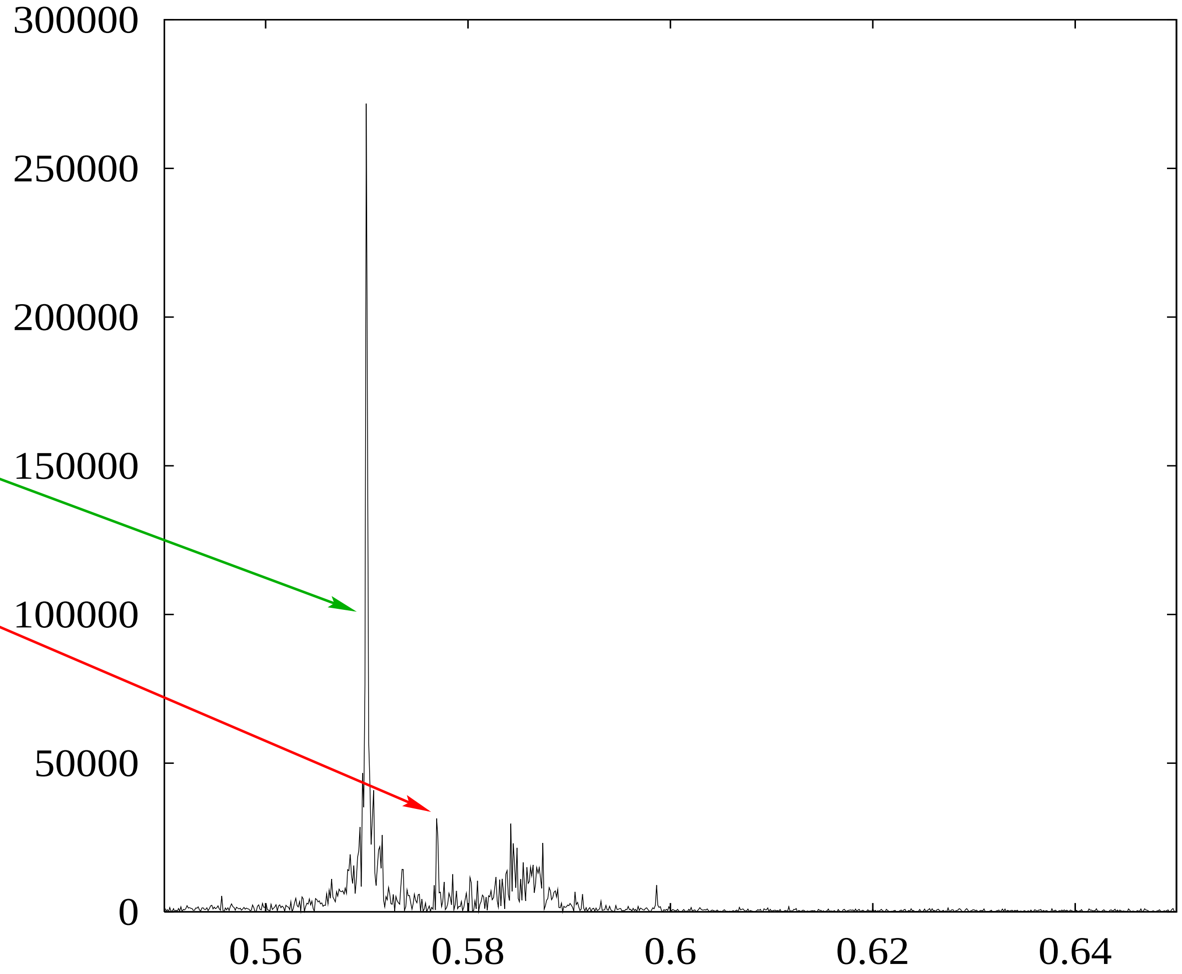
- *typical spectrum:*

$Q_v = 0.59$

$f_{kicker} = 18.62Hz\ (Q = 0.57)$

$f_{RF} = 615Hz\ (Q = 0.576)$

$\xi_v = 7.5$



Measurement Rate

- 500 Hz modulation → 20 turns for the LHC
  - → sample 5 to 10 oscillation periods → 1024 to 2048 turns for the LHC
  - → average over 5 to 10 FFTs → 10000 to 20000 turns for the LHC
  - → measurement at 0.5 Hz to 1 Hz
- sliding window for FFT average → measurement at 1-10 Hz?
- signal to noise ratio at the pickup?
- tune measurement precision $\propto 1/N^2$