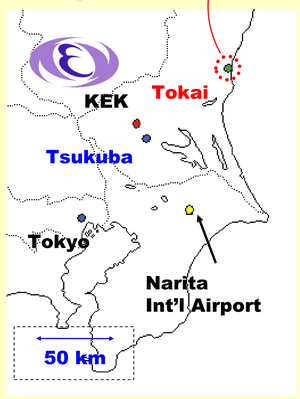
A novel analysis of time evolving betatron tune

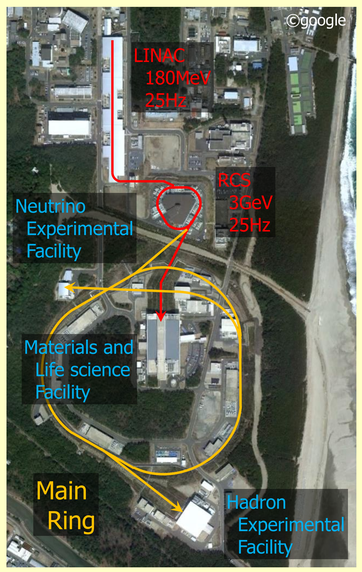
S.YAMADA
High Energy Accelerator Research Organization (KEK) 1-1 Oho, Tsukuba, Ibaraki, 305-0801

Abstract

J-PARC Main Ring (MR) is a high-intensity proton synchrotron and since 2009 delivering beam to the T2K neutrino experiment and hadron experiments. It is essential to measure time variation of betatron tune accurately throughout from beam injection at 3 GeV to extraction at 30 GeV. The tune measurement system of J-PARC MR consist of a stripline-kicker, beam position monitors, and a waveform digitizer. Betatron tune appears as sidebands of harmonics of revolution frequency in the turn-by-turn beam position spectrum. Excellent accuracy of measurement and high immunity against noise were achieved by exploiting a wide-band spectrum covering multiple harmonics.

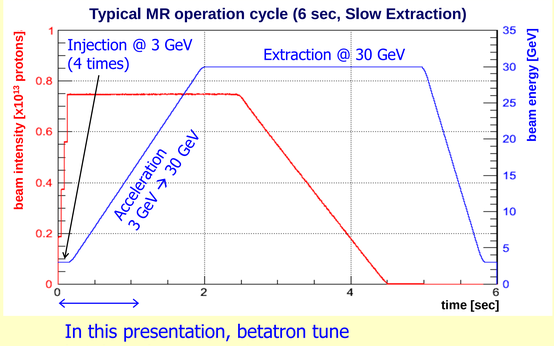
Japan Proton Accelerator Research Complex





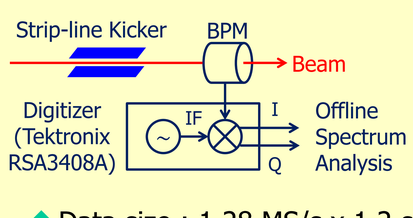
J-PARC Main Ring

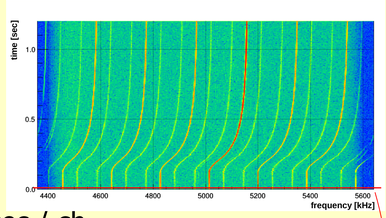
- MW-class High Power Proton Synchrotron
  - Intensity frontier for elementary particle physics
  - Accelerate from 3 GeV to 30 GeV
- Slow Cycle Machine
  - Fast Extraction: 2.48 sec
    247 kW (1.29×10^{14} ppp)
  - Slow Extraction: 6.0 sec
    24 kW (3.0×10^{13} ppp)
- Cycle-by-cycle monitoring is essential
  - Entire cycle, from injection thru extraction, is desirable



In this presentation, betatron tune in this region was analyzed

Betatron Tune Measurement



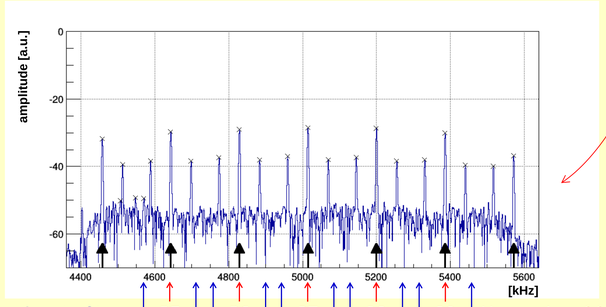


- Data size : 1.28 MS/s x 1.2 sec / ch

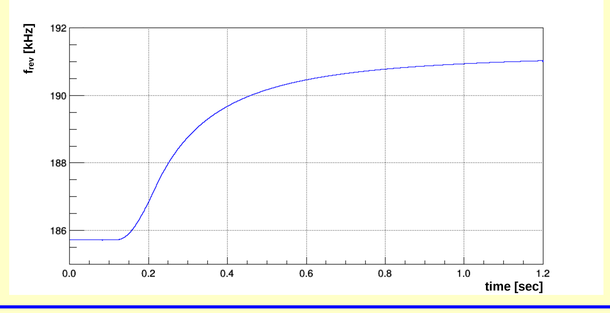
Challenge in Betatron Tune Measurement

- Achieve good resolution both in tune and its time variation
  - $\Delta\nu \approx 0.02$ of tune ramping for Slow Extraction
  - $\Delta\nu \approx 0.02$ of disturbance caused by Magnet Power Supply
    - ≈100Hz, 600Hz, 1800Hz

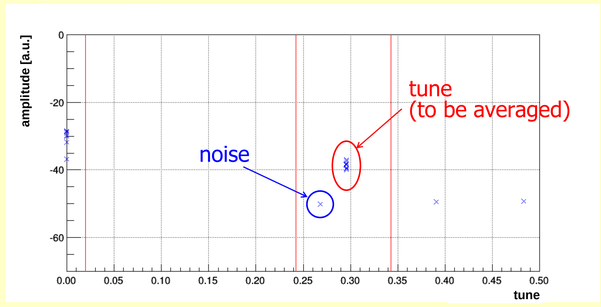
- Short-time FFT spectrum of beam position
  - 1 frame : 1024 samples w/ zero-padding
    512 samples stepping



- Estimate of f_{rev}
  - In each frame, find a combination of line spectra such that they are simple integer ratio
  - f_{rev} found to be the common divisor
    - 185.7 kHz (3 GeV) < f_{rev} < 191.2 kHz (30 GeV)



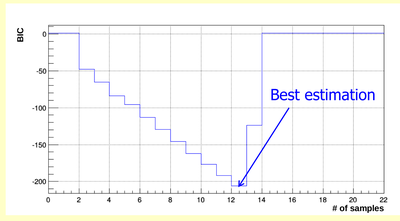
- Extraction of tune
  - In each frame, normalize line spectra by f_{rev}
  - Fractional part represents betatron tune
  - Noise rejection using Bayesian Information Criterion
  - Average to improve resolution



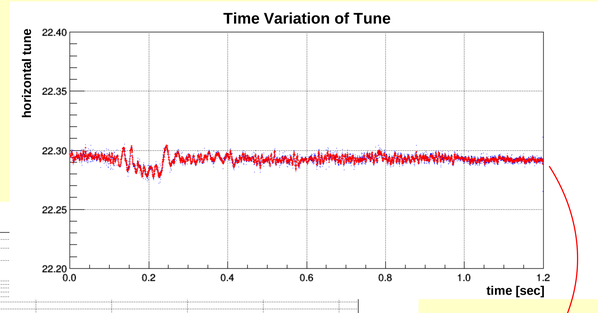
- Bayesian Information Criterion
  - A statistical method for selecting parametric model representing the dataset

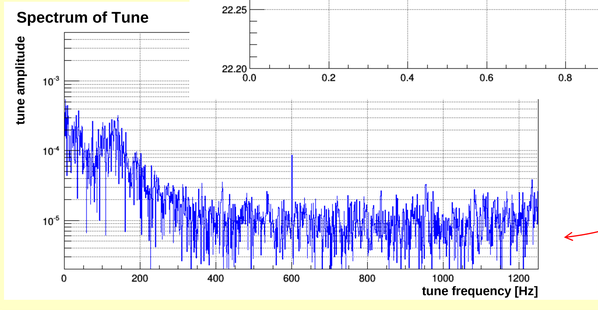
$$BIC = n \ln\left(\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2\right) + k \ln(n)$$

n : number of observations
k : number of free parameters



- Time variation of tune
  - Lay betatron tunes in each frame along time





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