Schottky Measurements at RHIC

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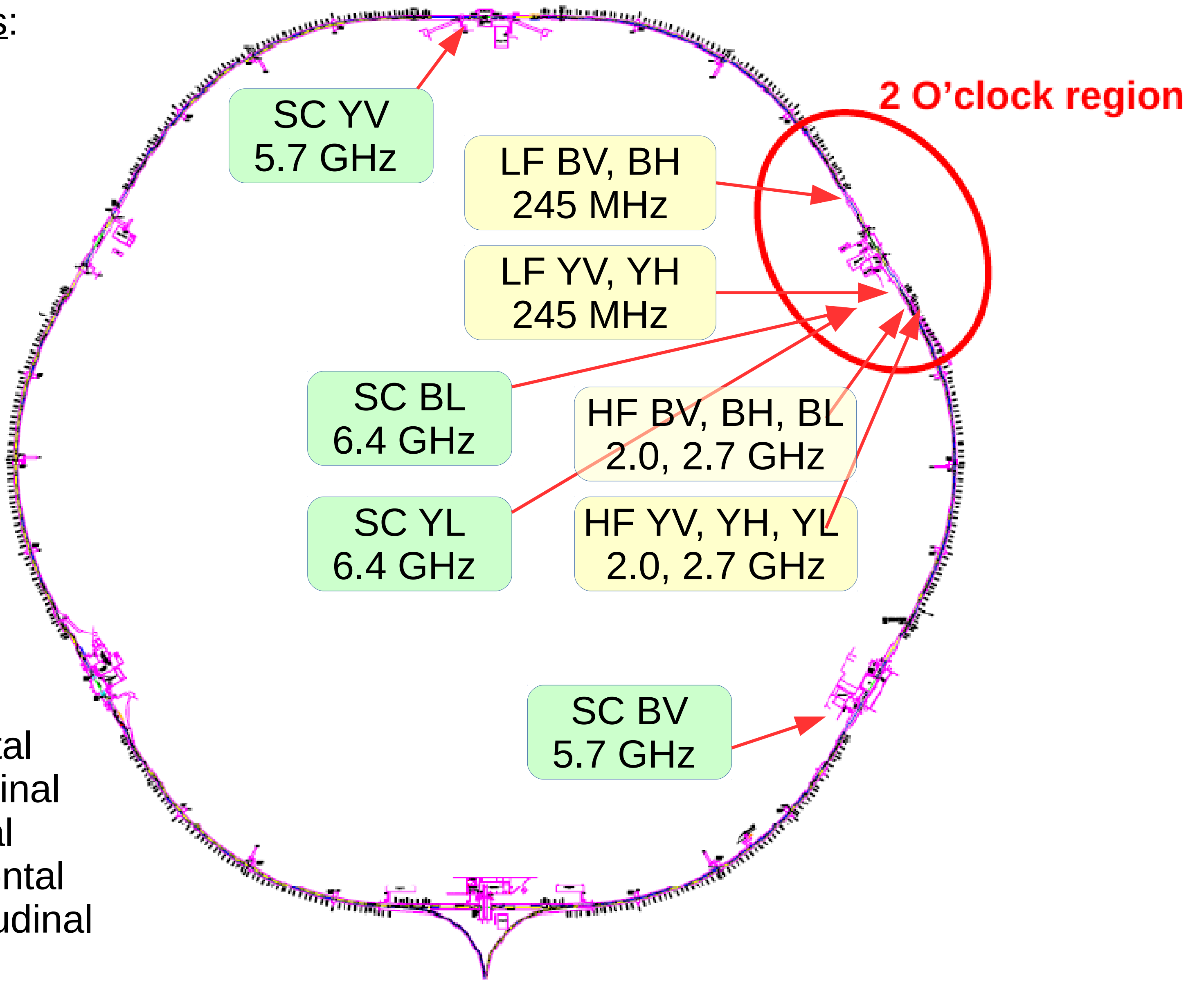
BNL: M. Blaskiewitz, K. Brown, W. Dawson,
C.Degen, R.Lee, M. Kesselman, P. Cameron, J. Cupolo A. Della Penna, R. Schroeder.
LBNL 1998 (HF cavity): W. Barry , J. N. Corlett, D. A. Goldberg, D. Li

Outline

- Schottky installations at RHIC
  - For routine operations:
    High Frequency Schottky (2.0 GHz, Q ~5000).
    Low Frequency Schottky (245 MHz, Q ~100).
  - Schottky pickups for stochastic cooling.
- Signal treatment.
- Extraction of beam parameters.
- Absolute calibration of beam size measurement.
- Analysis:
  - Fit-less.
  - Handling of changing RF during ramp.
- Results

Schottky Cavities at RHIC

Schottky detector systems:
SC: Stochastic cooling
LF: Low Frequency
HF: High Frequency



Beam/axis:
BV: Blue beam, Vertical
BH: Blue beam, Horizontal
BL: Blue beam, Longitudinal
YV: Yellow beam, Vertical
YH: Yellow beam, Horizontal
YL: Yellow beam, Longitudinal

LF Schottky at RHIC

Provides measurable signals for broad range of beam conditions.

Routine measurements:
- **Tune**.
- Beam size/emittance.

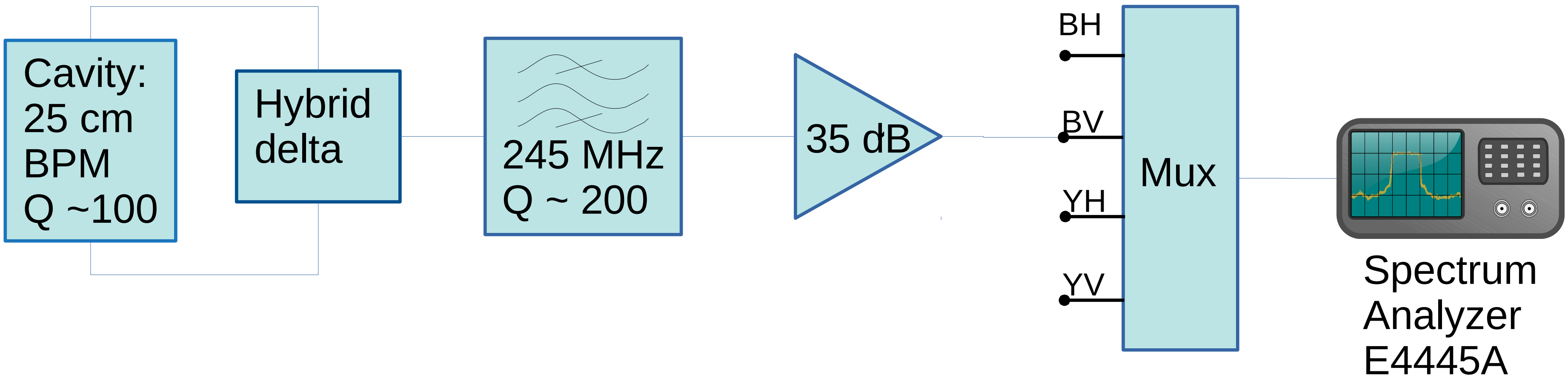
Main usage at RHIC:
- When dp/p is large, I.e. low energy ion runs.
- Reference for other systems.

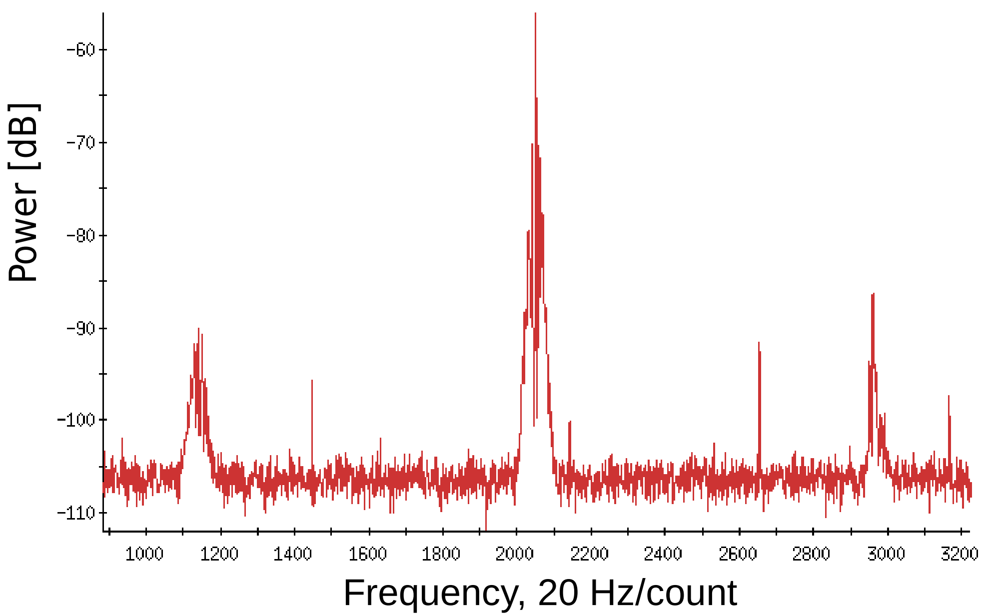
Advantage:
- No downmixing.
- Narrow sidebands.
- Fast filling time.

Disadvantage:
- Low signal/noise
- Long acquisition time

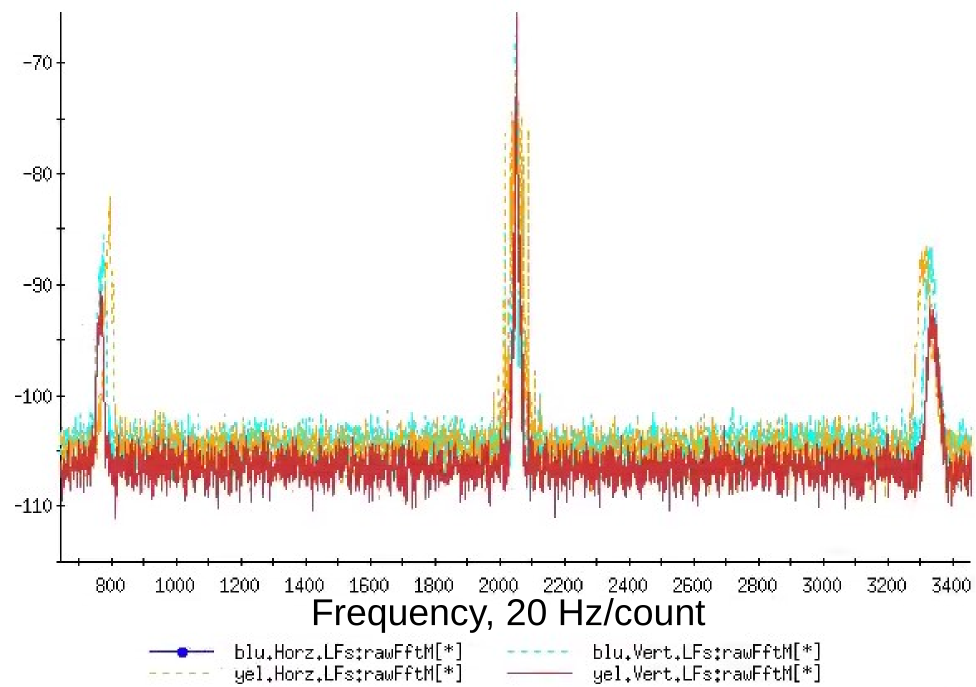
Stub-tuned ¼ wave resonator
- Frequency ~240 MHz (8.5xRF)
- Q ~ 100
- Movable

LF Schottky Signal Treatment





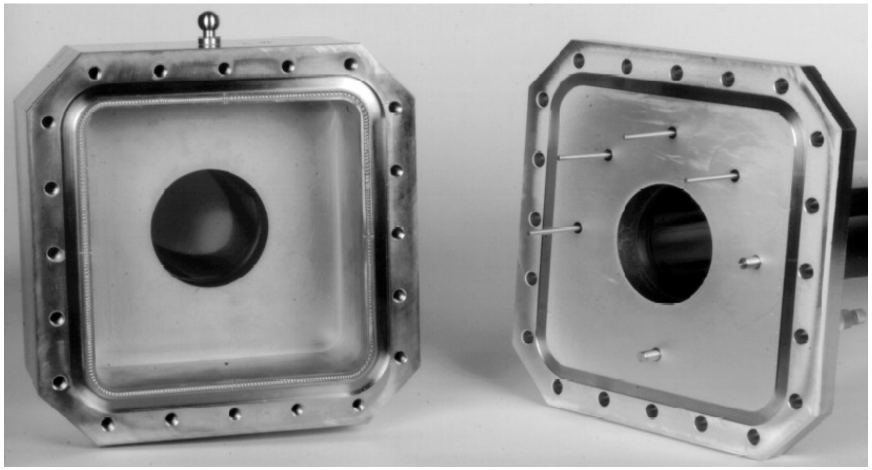
Zirconium beam 100 GeV



Polarized proton beam 250 GeV

High Frequency Schottky

Provides high quality signals for routine measurements.

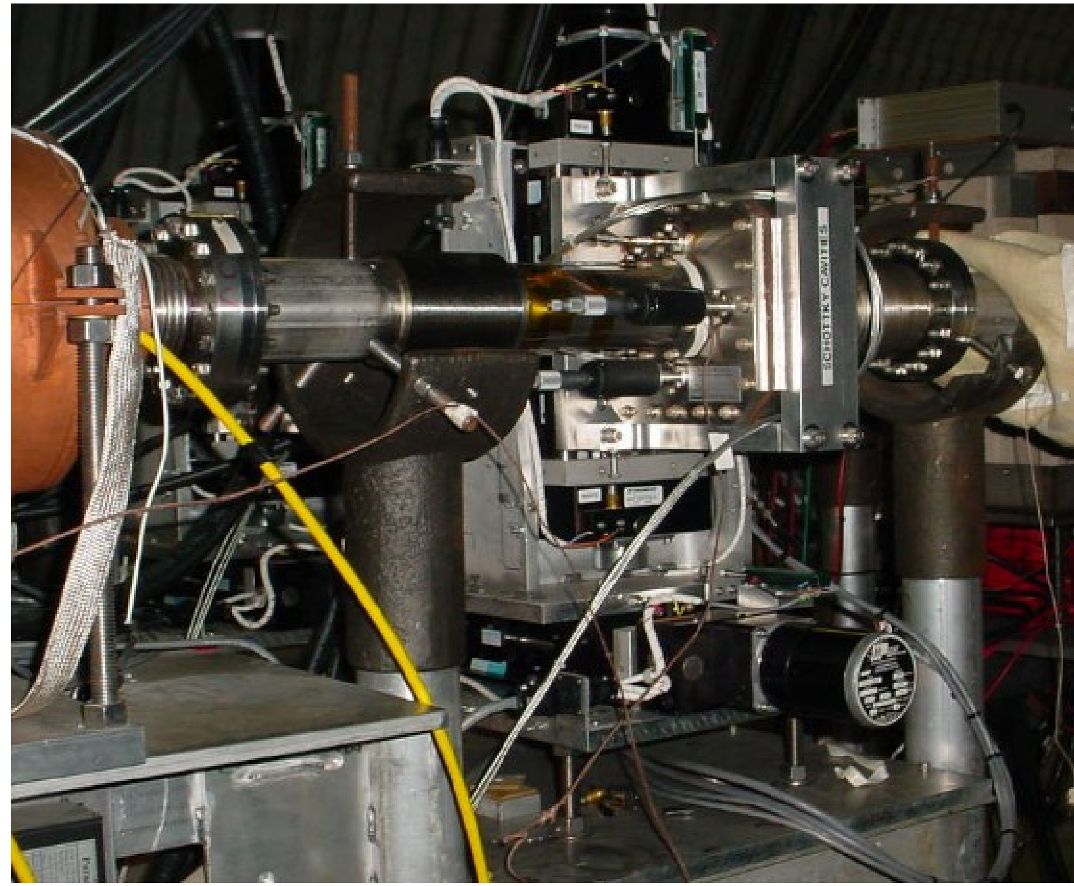


HF Schottky cavity [1]

Q = 4700

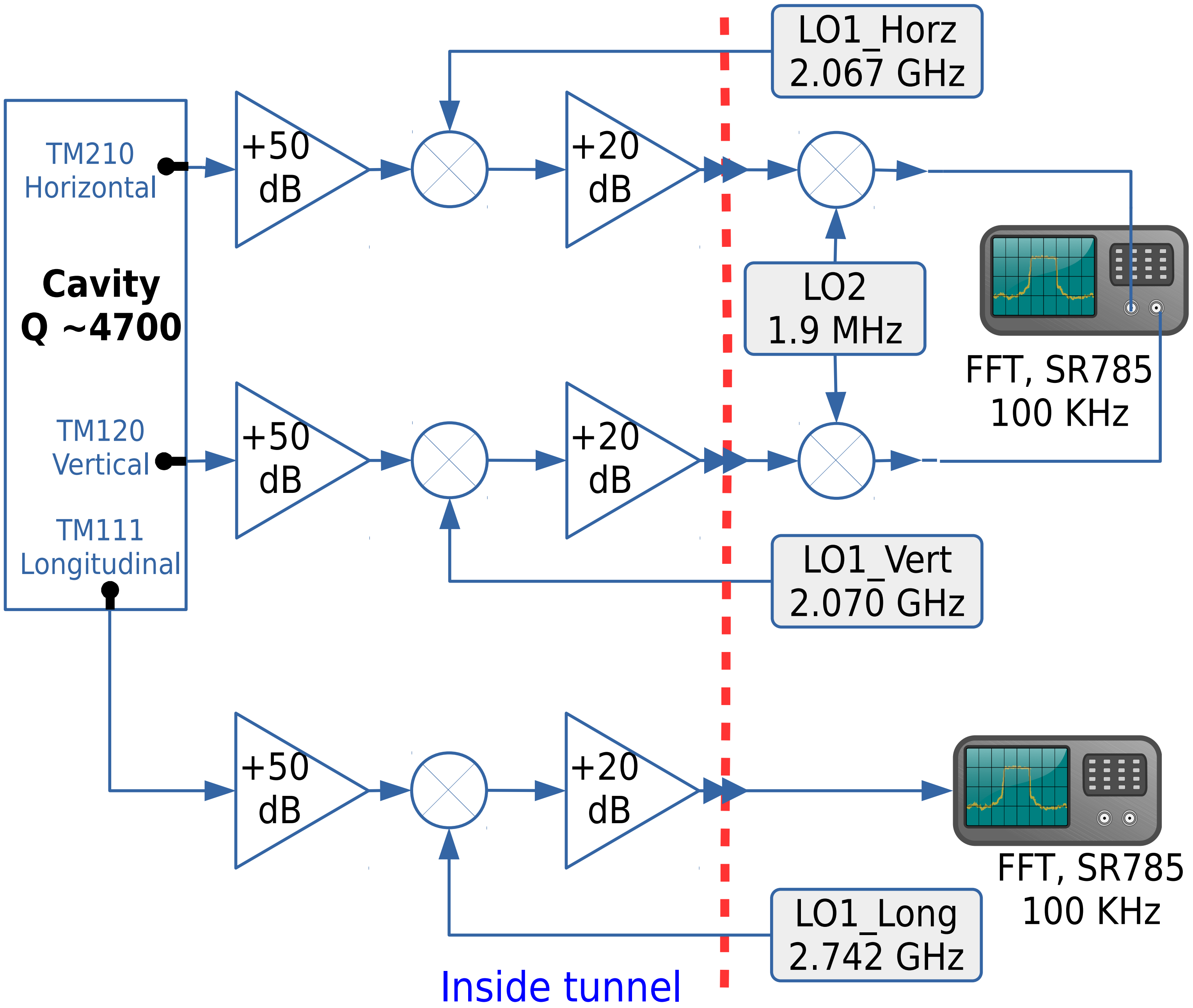
Needle probes for:

- Transverse modes
  TM210 and TM120 at ~ 2.0 GHz
- Longitudinal mode:
  TM111 2.7 GHz

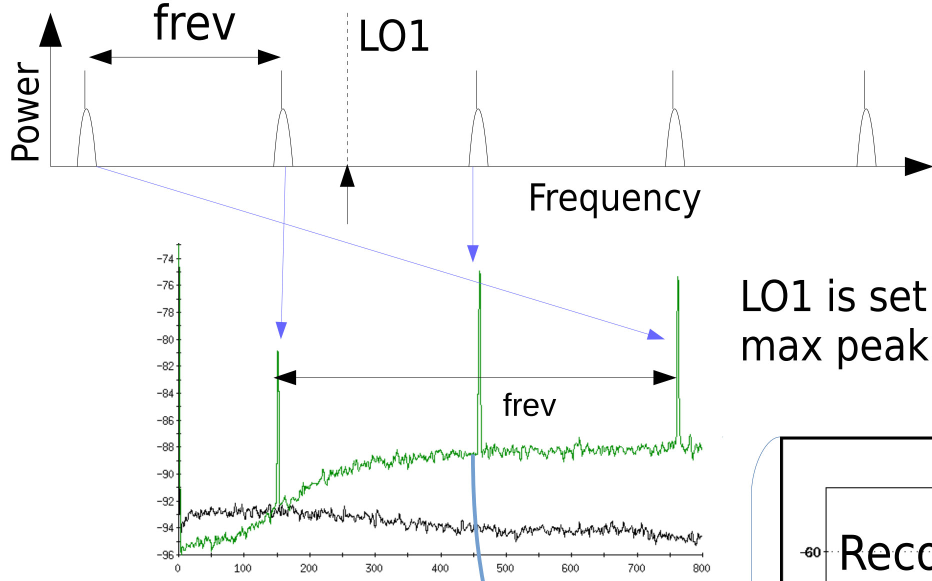


HF Schottky installed on a moving platform at RHIC beamline.

HF Schottky, Signal Treatment



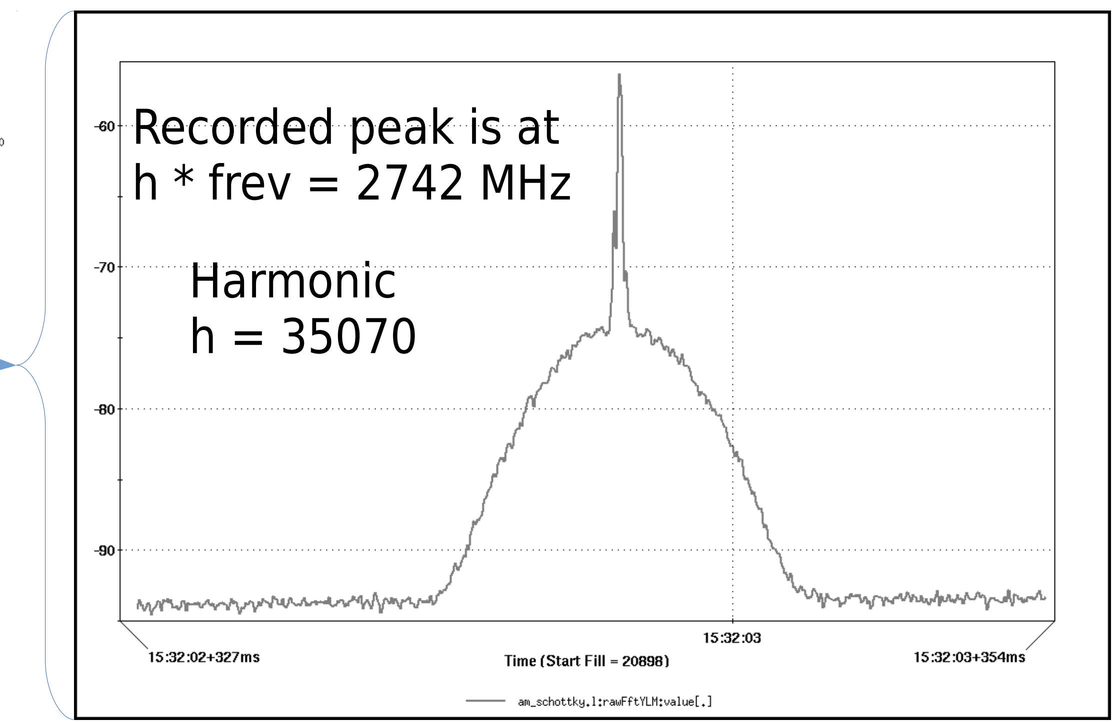
Longitudinal spectrum after mixing



Beam parameters at store:
RF = 28 MHz
frev = RF/360 = 78 KHz

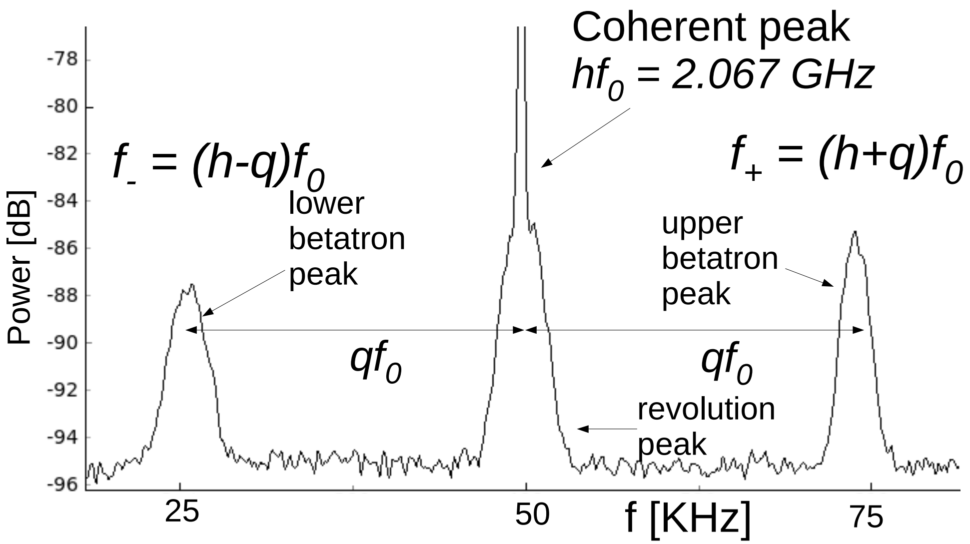
LO1 is set to (h + 0.25)*frev for max peak separation

Downmixing with LO1 complicates arrangement of peaks.



Span 25600 Hz

Beam Parameters from Schottky



The **fractional part q of the tune** is recovered from the positions of betatron peaks: $q=\frac{f_{+}-f_{-}}{2f_{0}}$

Momentum spread: $\frac{dp}{p}=\frac{\Delta f_{0}}{h f_{0}\eta}$

The **chromaticity** ξ is determined from the width asymmetry of the betatron peaks [3]
Here the η is a phase-slip factor of the accelerator.

$$\xi=\eta\left(\frac{\Delta f_{-}-\Delta f_{+}}{\Delta f_{-}+\Delta f_{+}}h-q\right)$$

The RMS of the **beam size σ**, determined from the power of the betatron peaks [3,4].
N is the number of particles, Q is particle charge.

$$P_{+}=P_{-}=\frac{1}{2}f_{0}^{2}Q^{2}N\sigma^{2}$$

Transverse **emittance ε**:
Where β is value of beta function at cavity position

$$\epsilon=\frac{\sigma^{2}}{\beta}$$

For more details see [2,3]

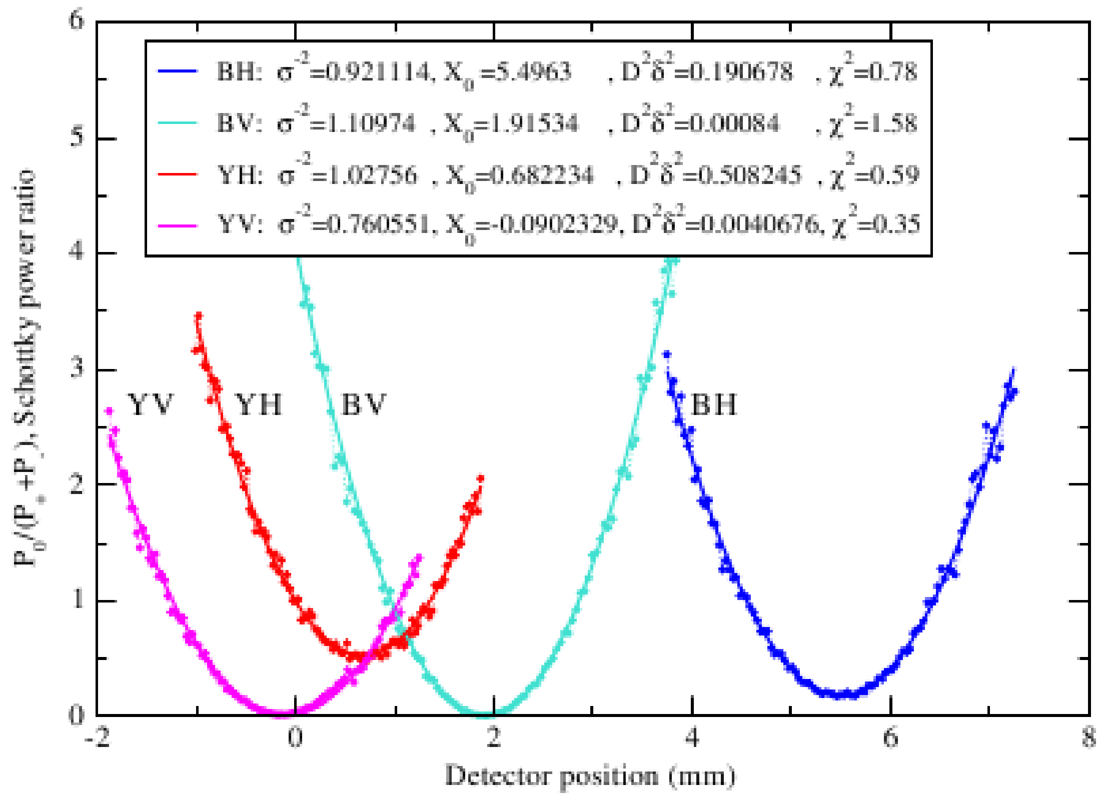
Absolute Calibration of the Beam Size

Ratio of powers in revolution P_0 and betatron lines P_+,P_- as a function of cavity position X:

$$\frac{P_0}{P_+ + P_-} = \frac{1}{\sigma^2}\left[X^2 + D^2\delta^2\right]$$

$$\delta^2 = \frac{\langle (E_k - E_0)\rangle}{(\beta^2 E_0)^2}$$

Where D is lattice momentum dispersion
$\beta = v/c$,
E_0 – energy of the particle on the reference trajectory
E_k is single particle energy



RMS of the beam size:

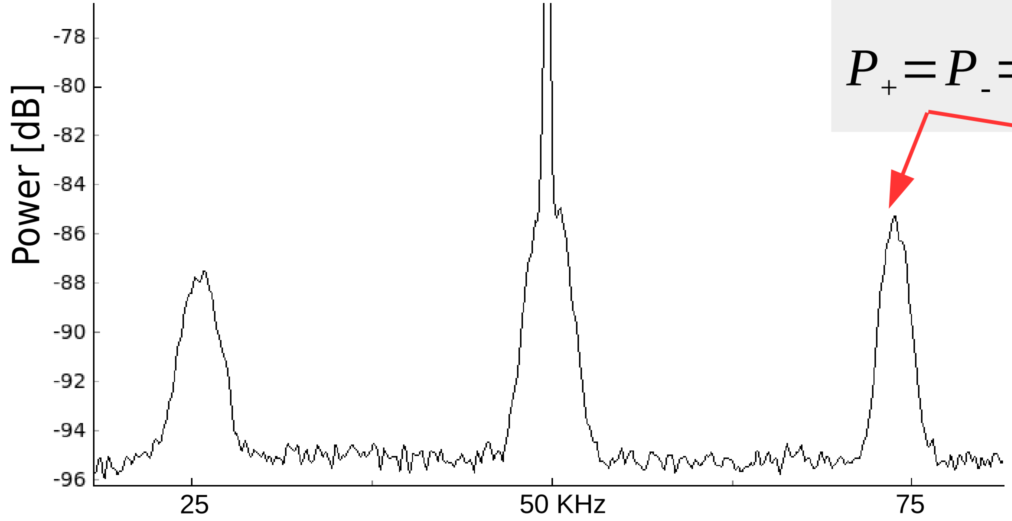
- Fit $P_0/(P_+ + P_-) = a*x^2 + b$
- Beam RMS: σ = sqrt(1/a)

Beam Emittance = σ/β-function

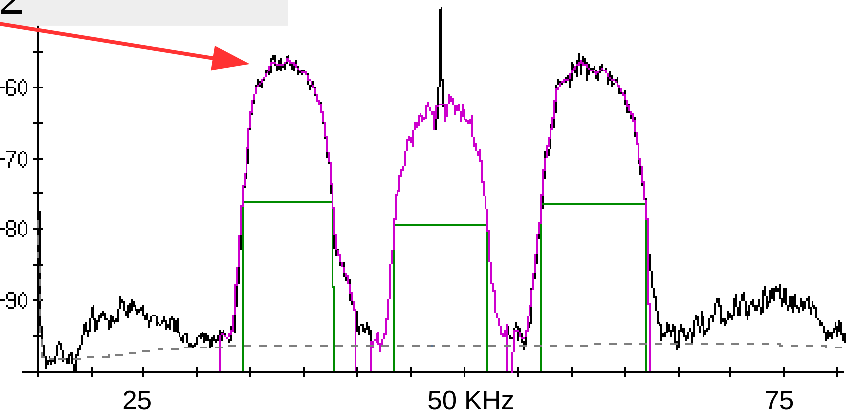
For more details see reference [3]

Transverse Schottky Signals at Top Energy

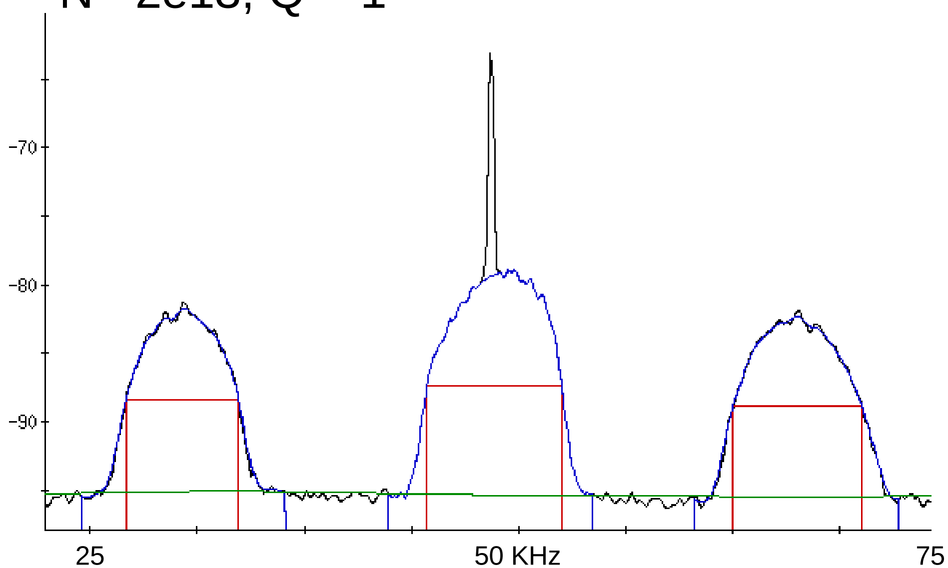
$$P_+ = P_- = \frac{1}{2} f_0^{\,2} Q^2 N \sigma^2$$



Polarized proton beam 250 GeV.
N ~2e13, Q = 1



Gold beam 100 GeV, N ~1e11, Q = 79.



Ruthenium beam 100 GeV
N ~ 1e11, Q = 44

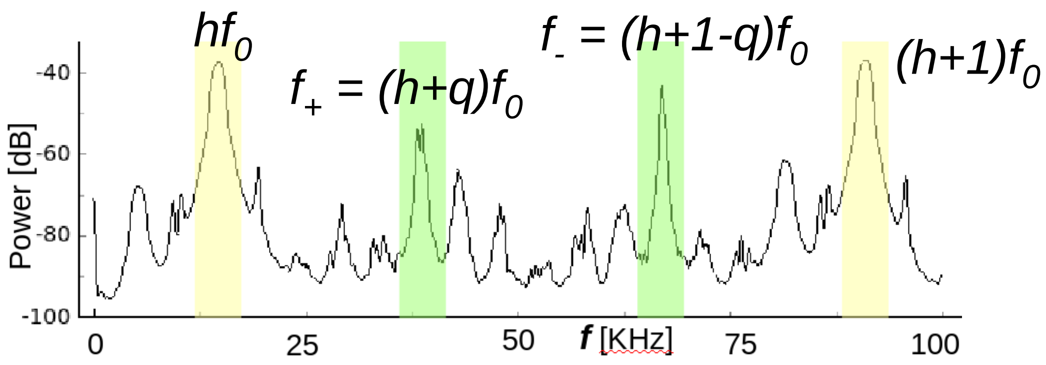
- Signal/Noise in ion runs is 50 higher than in proton runs.
- **Coherent spike**: No definitive explanation has yet been found. It needs to be removed from analysis.
- Peak shapes are not gaussian.
- Noise is not gaussian.

Required estimations:

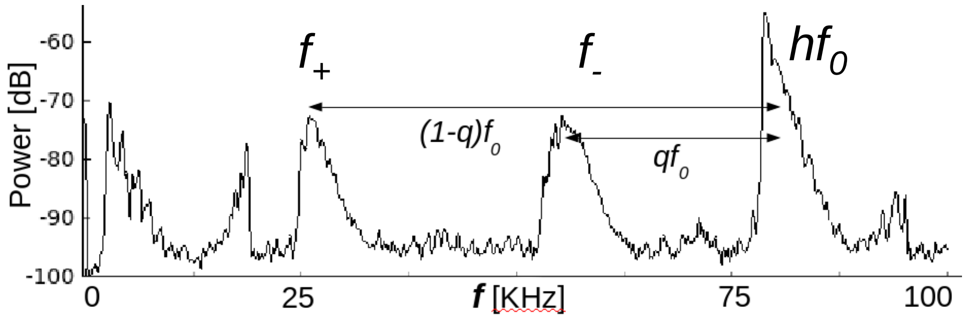
- Peak position
- Peak width
- Peak area

No need for curve fitting

Spectra During Injection and Ramp



Injection



Ramp

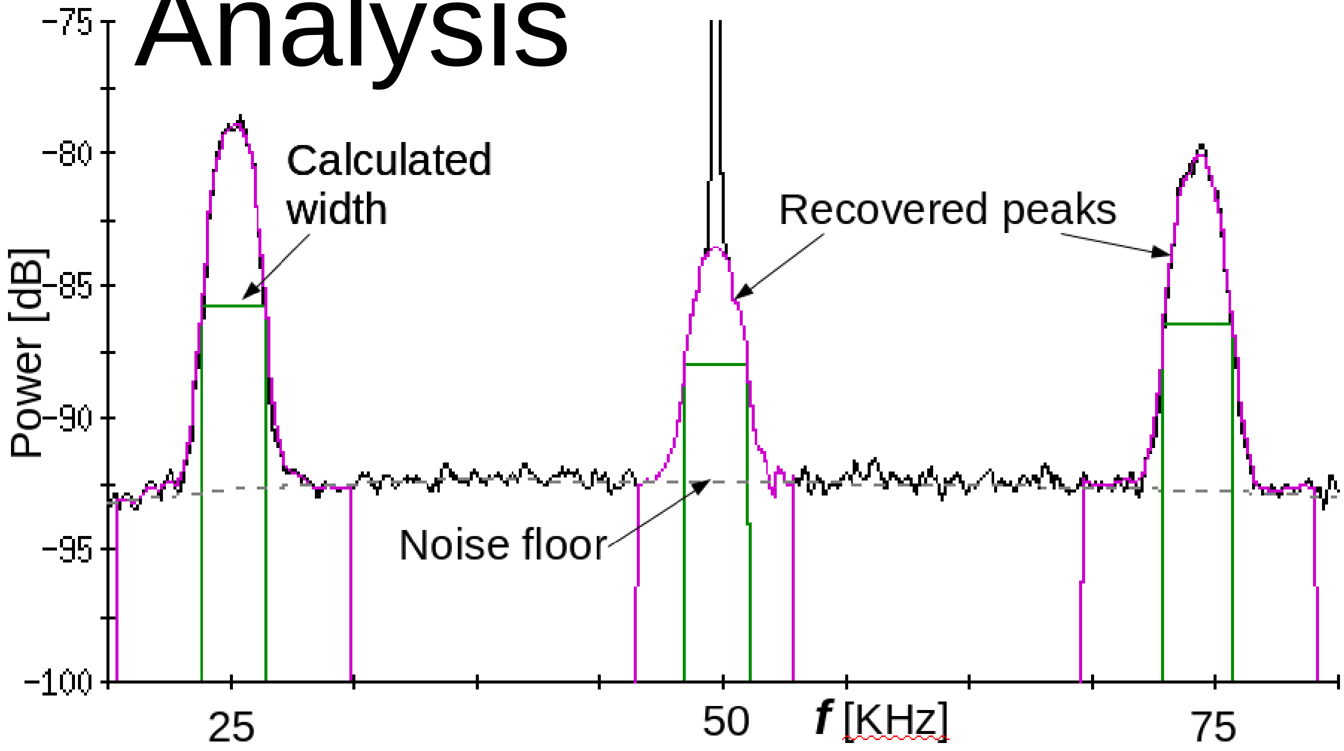
Options to deal with the changing RF:

1. Use RF-locked LO1.
   RF harmonic = 71
2. Use RF instead of LO2. ← Easiest to implement
3. Frequency modulated LO1.
4. Software-adjusted LO1.
5. Online analysis using predicted position of f_0, f_- , f_+

Most precise at top energy. Implemented.

Analysis

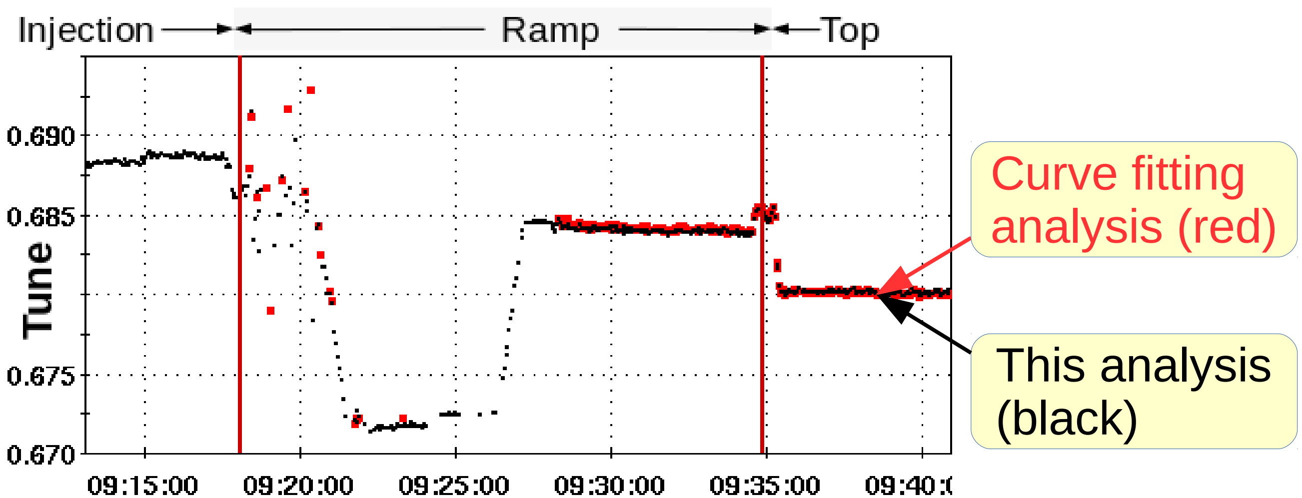
- Analysis is done in linear scale, it is less sensitive to noise.
- Spike removal: replace spike with parabolic approximation of the adjacent Schottky signal.



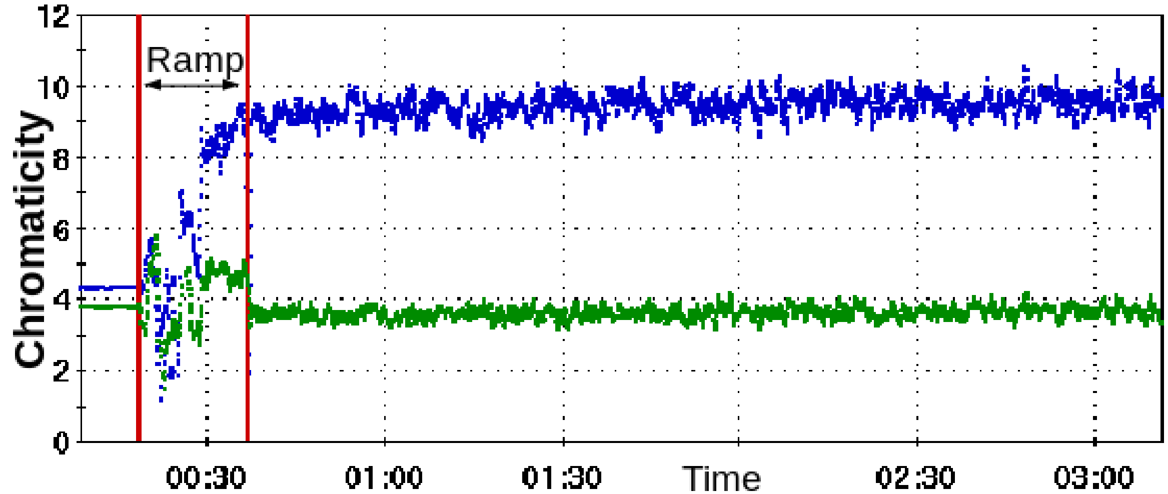
- The **peak widh**:
  - Find the left and right edges of the peak using the crossing points of the filtered data at a half-amplitude level in log scale.
  - The peak width is the difference between the edges.
- The **peak position** is the arithmetic average of edge positions.
- The **peak power** is the sum of the peak points above the noise floor (pink line above the noise floor on next slide).

Calculate the beam parameters according to equations on slide 8.

Results

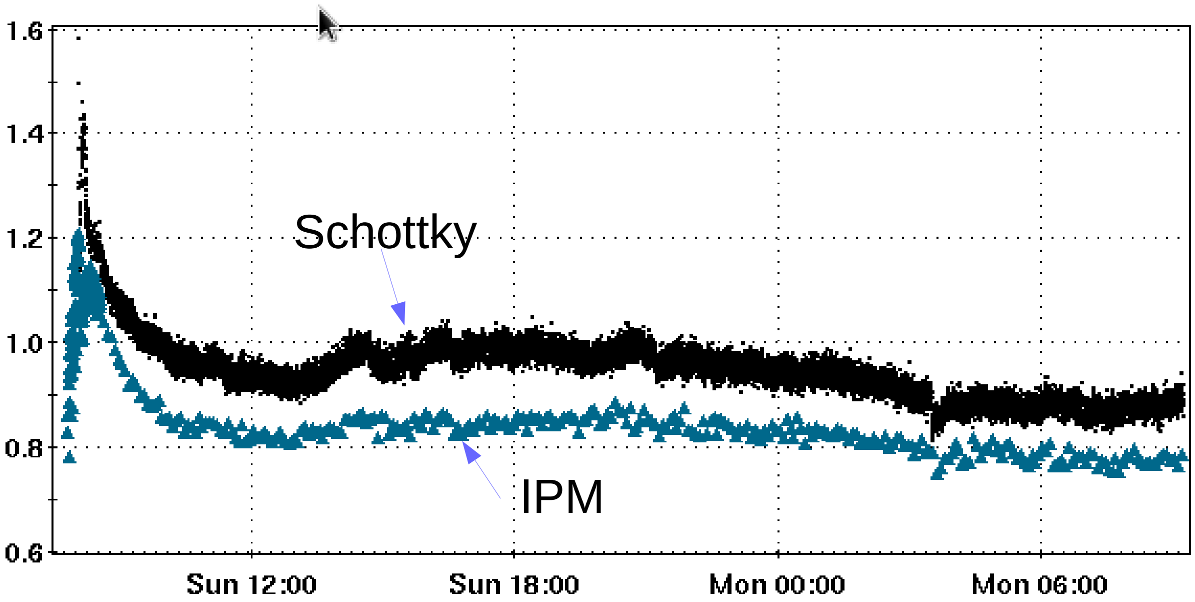


Tune measurement display during 250 GeV protons



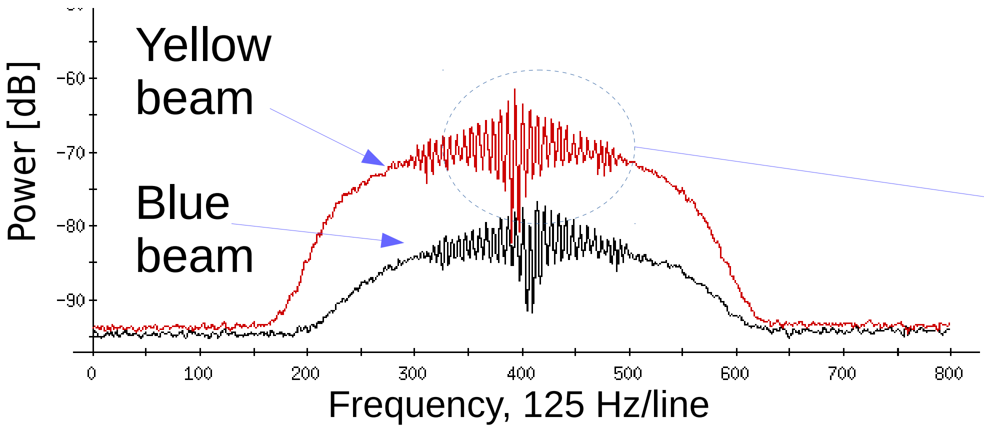
Chromaticity display during 250 GeV protons

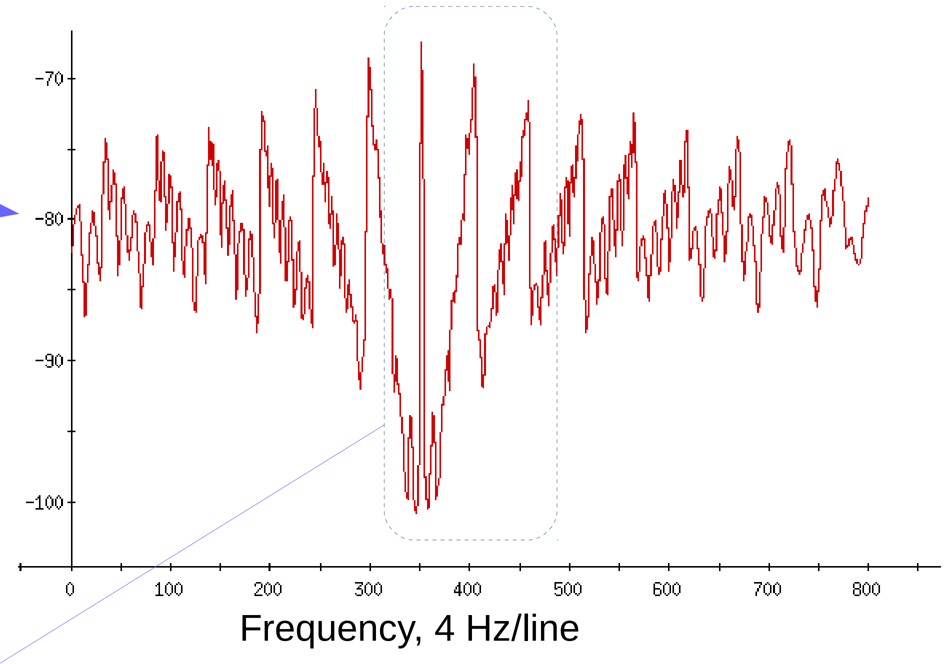
Emittance Measurement



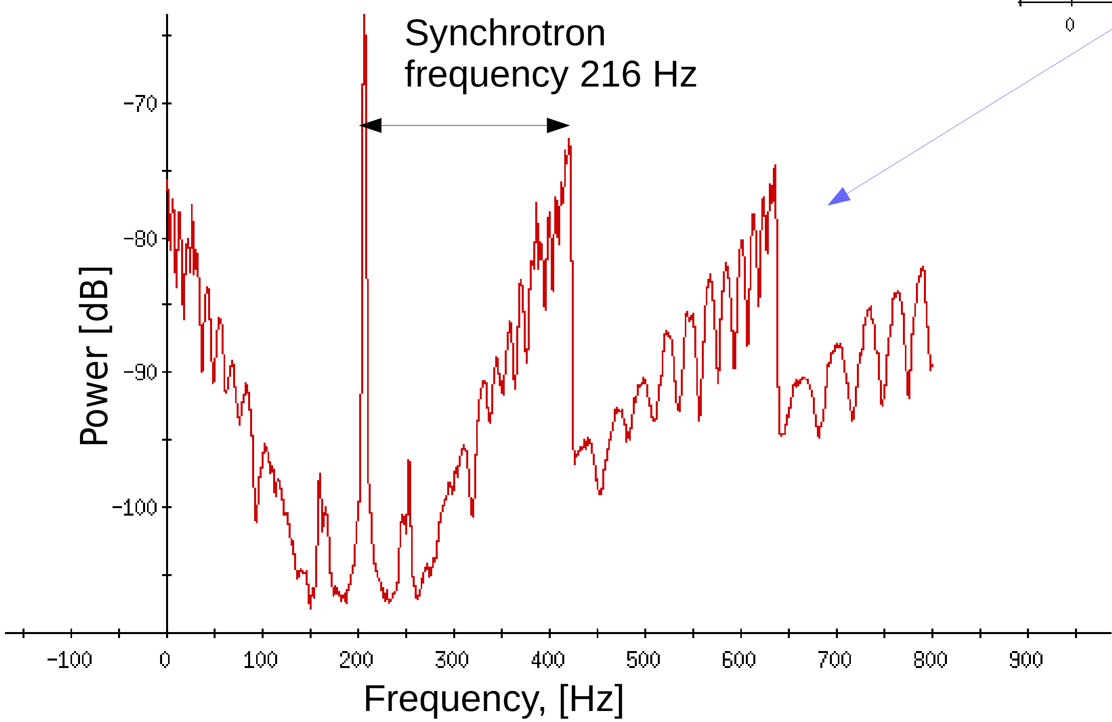
Emittance (blue vertical) measurement for Ru-Ru run, 200 GeV, N = 1e11.
The schottky measurements (black ponts) are consistent with IPM measurements (blue triangles).
The scaling mismatch is due to uncertainty in beta function.

Spectrum of Longitudinal Schottky





Longitudinal Schottky spectra of the 100 GeV Ruthenium beams.



The theory of the fine structure can be found in the paper:
M. Blaskiewicz at al [4].

<u>Analysis</u>.

- Full spectra are recorded, providing spectrogram plots.
- Analysis of the fine structure is work in progress.

Summary

- Schottky systems are continuously operational at RHIC:

(1) Narrow band: (HF Schottky, 2.0 GHz, Q=5000)
(2) Medium band: (LF Schottky, 245 MHz, Q=100)

- Routine measurement of beam tune, chromaticity and emittance provided.
- Developed analysis of transverse Schottky works reliably at injection, ramp, and full energy.

Resolutions:
Using on-board averaging for 128 frames (~2s)

Parameter	Injection	Ramp	Flat Top
Tune	0.1%	0.4%	<0.1%
Chromaticity	2%	N/A	10%
Betatron power, Beam size, Emittance	Inconsistent with IPM		2%
dp/p, revolution peak	N/A	N/A	2%
dp/p, betatron peak	>20%	10%	2%

- Near term plan: try RF-locked downmixing to get quality of tune and chrom at ramp comparable with BBQ.

References

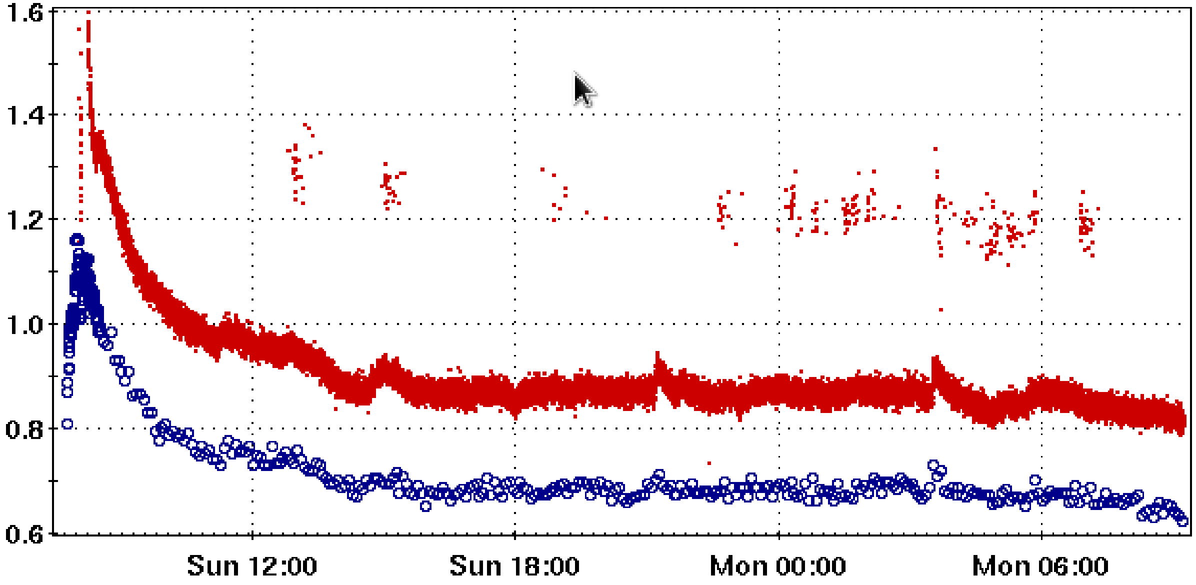
[1] W. Burry et al, Design of a Schottky Signal Detector for Use at RHIC, EPAC98 Stockholm.

[2] D. Boussard, Schottky Noise And Beam Transfer Function Diagnostics, 10.5170/CERN-1995-006.749, CERN, Geneva, 1995

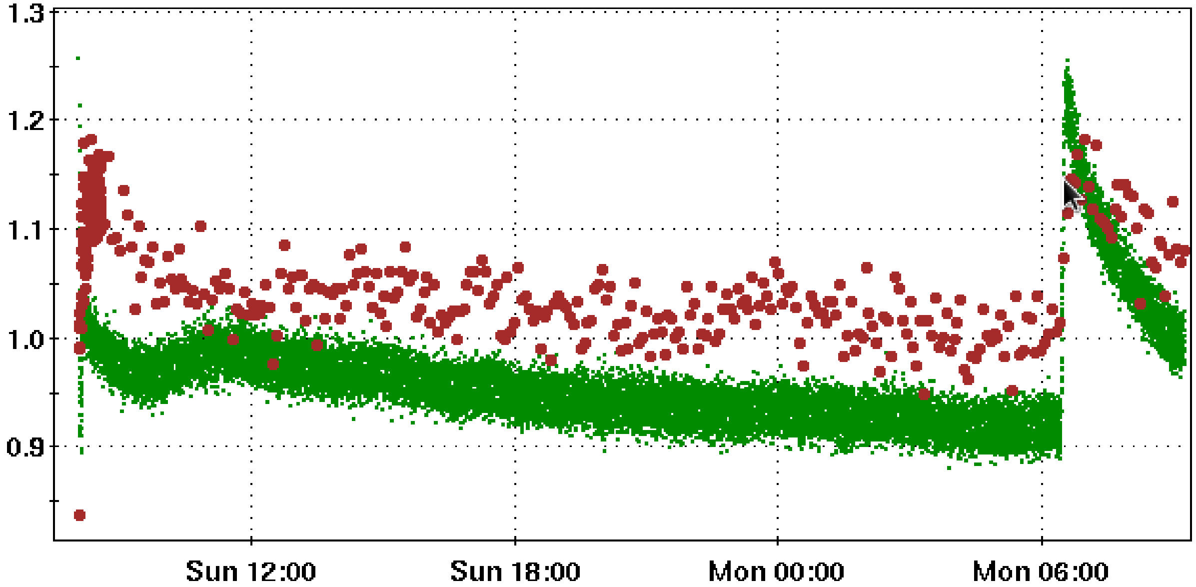
[3] K. A. Brown, M. Blaskiewicz, C. Degen, A. Della Penna in in Phys. Rev. Accelerators and Beams, 12, 012801 (2009)

[4] M. Blaskiewicz, J.M. Brennan, P. Cameron, W. Fischer. LONGITUDINAL IMPEDANCE MEASUREMENT IN RHIC, Proceedings of EPAC 2002, Paris, France

Backup slides

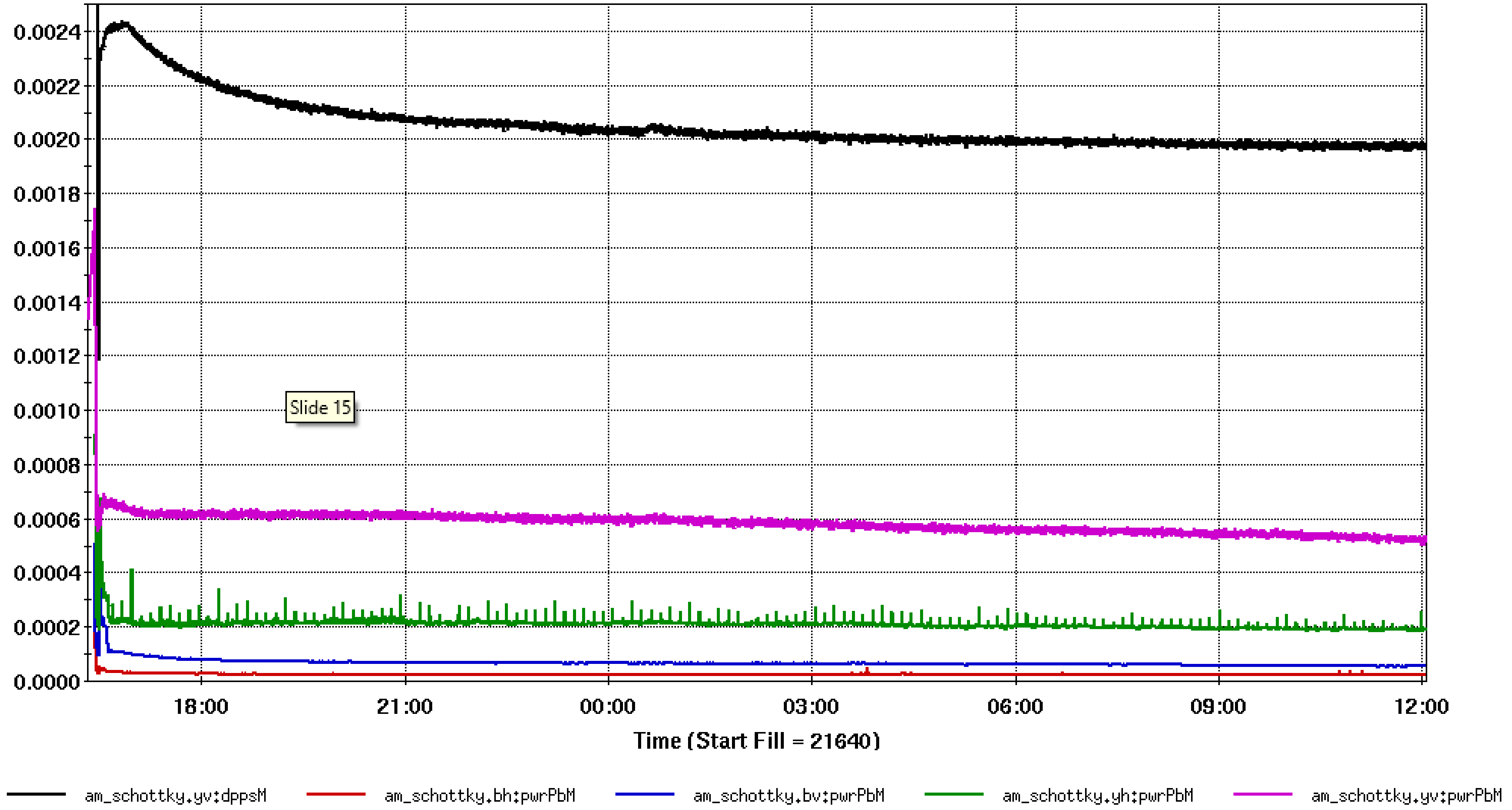


BV emittance, HFs (red) IPM (blue)



YV emittance, HFs (red) IPM (green)

DP/P and PwrPb



HF Cavity Parameters

Table 1: Cavity parameters.

Mode	Parameter	Value
TM_{120}	Frequency	2.071 GHz
	$Q_{unloaded}$	10,000
	$R_\perp T^2/Q$	900 Ω
	$R_\perp T^2$	9 MΩ/m
TM_{210}	Frequency	2.067 GHz
	$Q_{unloaded}$	10,000
	$R_\perp T^2/Q$	900
	$R_\perp T^2$	9 MΩ/m