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Microwave Schottky Beam Diagnostics

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May 2012

IPAC 12

Microwave Schottky Beam Diagnostics

Tevatron Schottky Signals 1992 Bunched Beam Cooling Attemp

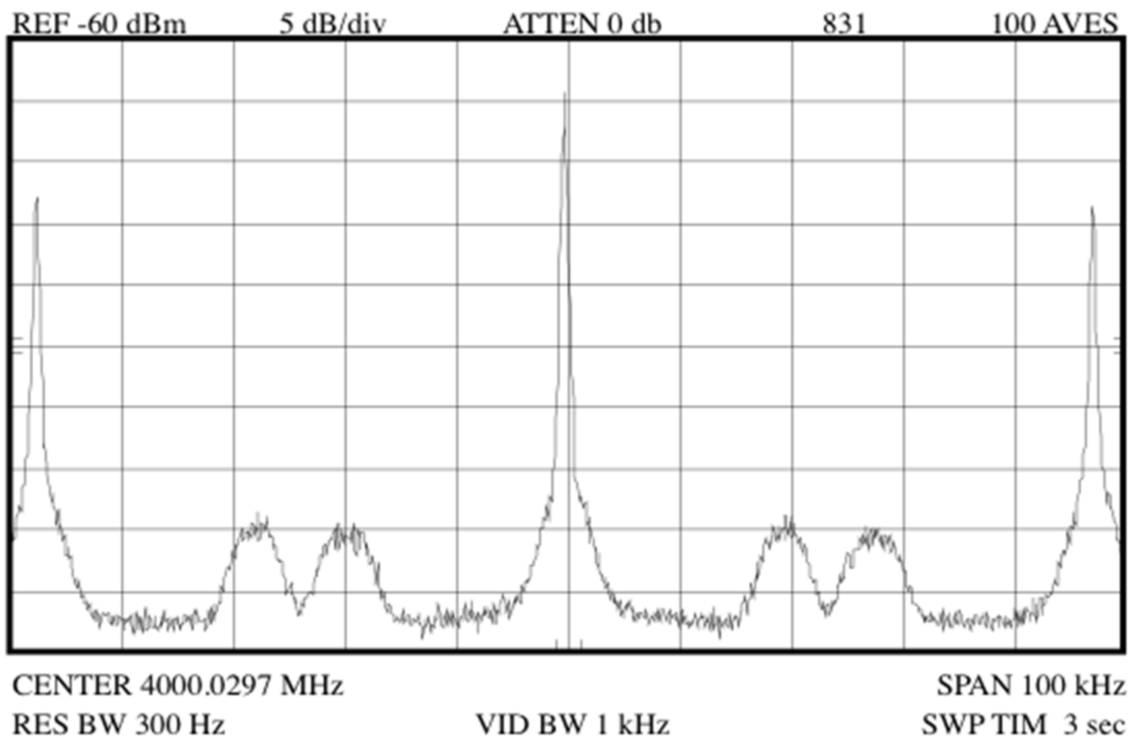

Figure 1: Example of a typical open loop proton vertical power spectrum measured with a spectrum analyzer.

Microwave Schottky Beam Diagnostics

Tune, momentum spread, chromaticity derived from frequency domain

$$\nu = \frac{\Delta f_t}{f_{rev}}$$

$$\frac{\Delta p}{p} = \frac{\Delta f_{low} + \Delta f_{up}}{2 \times \eta \times f_{rev}}$$

$$\xi = \frac{\Delta f_{up} - \Delta f_{low}}{2 \times f_{rev} \times \frac{\Delta p}{p}}$$

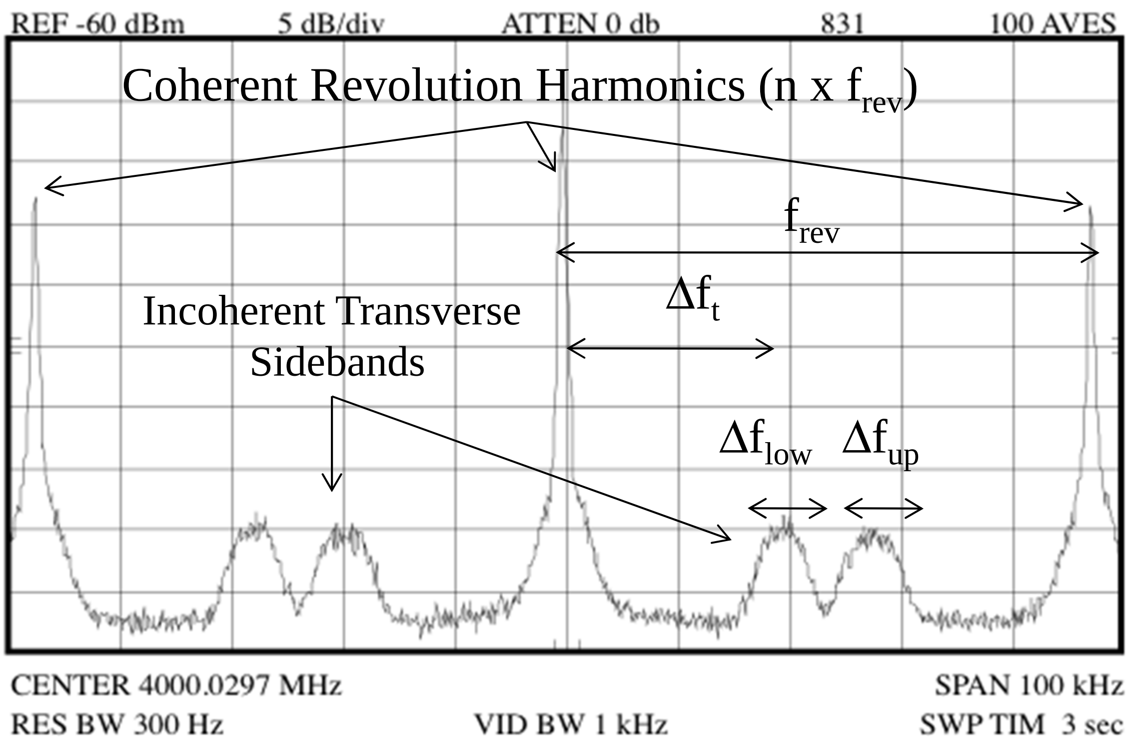

Figure 1: Example of a typical open loop proton vertical power spectrum measured with a spectrum analyzer.

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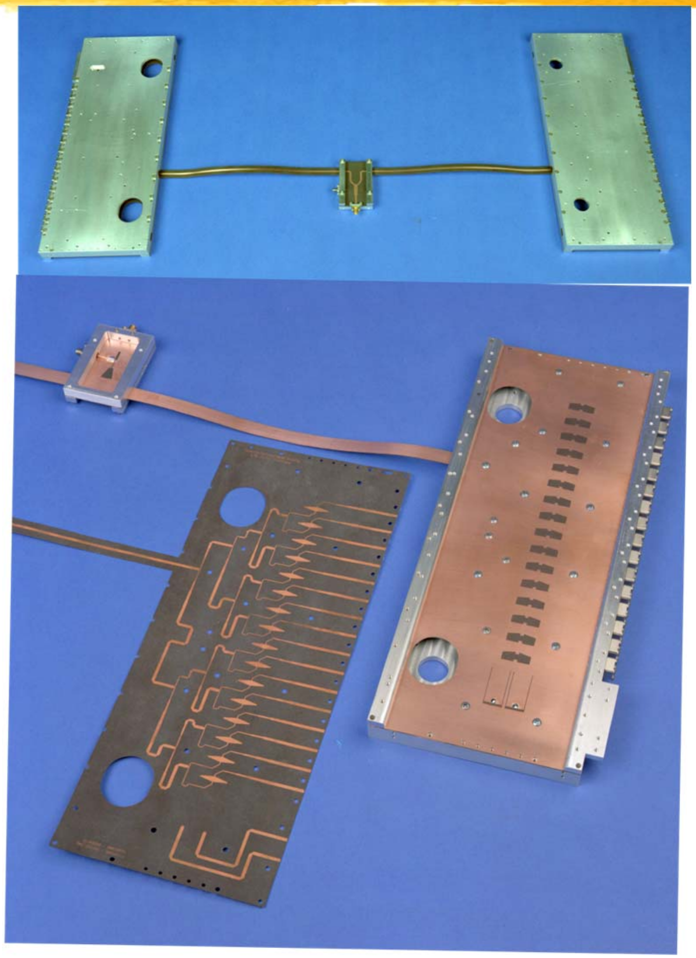
Planar Pickup Arrays

4-8 GHz Planar Loop Pickups
for
Tevatron Bunched Beam
Cooling



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Gating is Essential & Allows Single/Multiple Bunch Monitoring

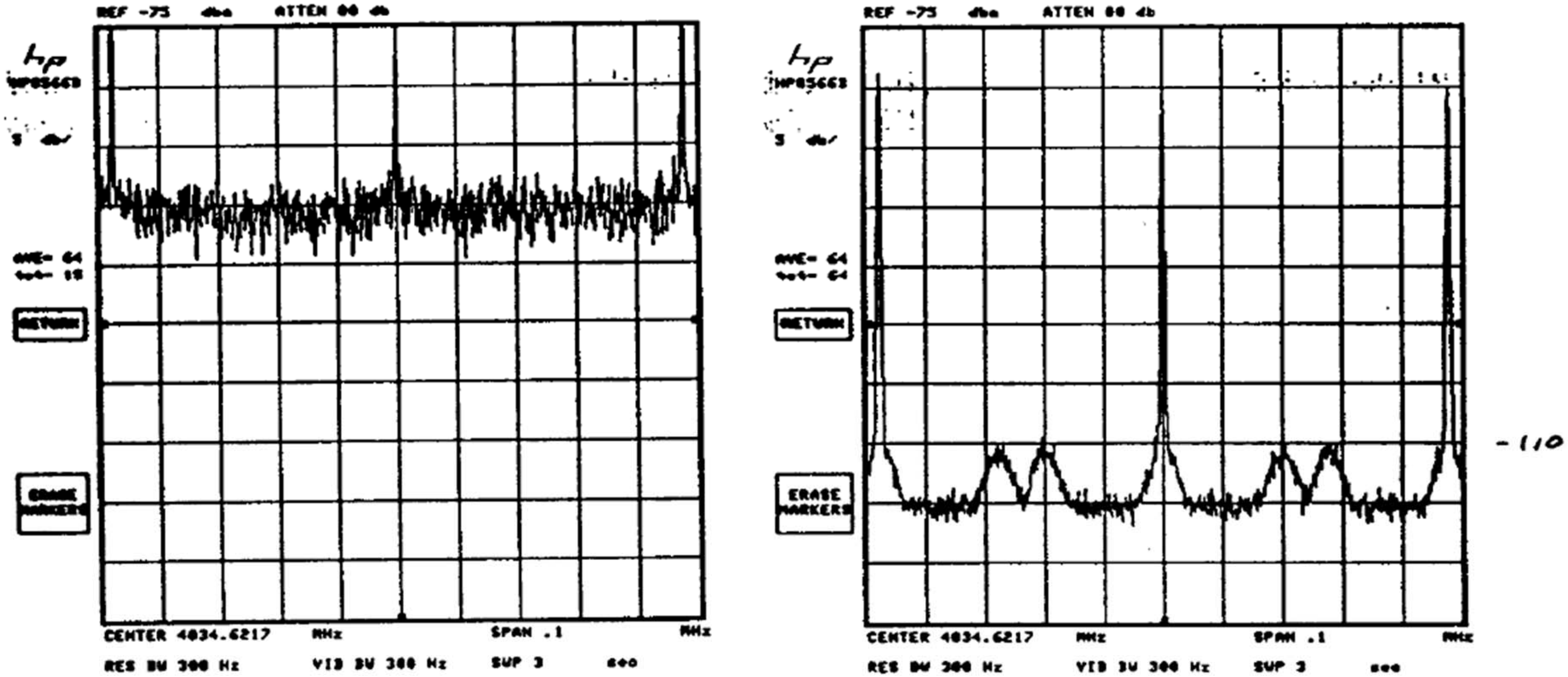

Figure 10. Effect of gating on signal to noise ratio. Left ungated bunched beam cooling signal. Right same signal with gating.

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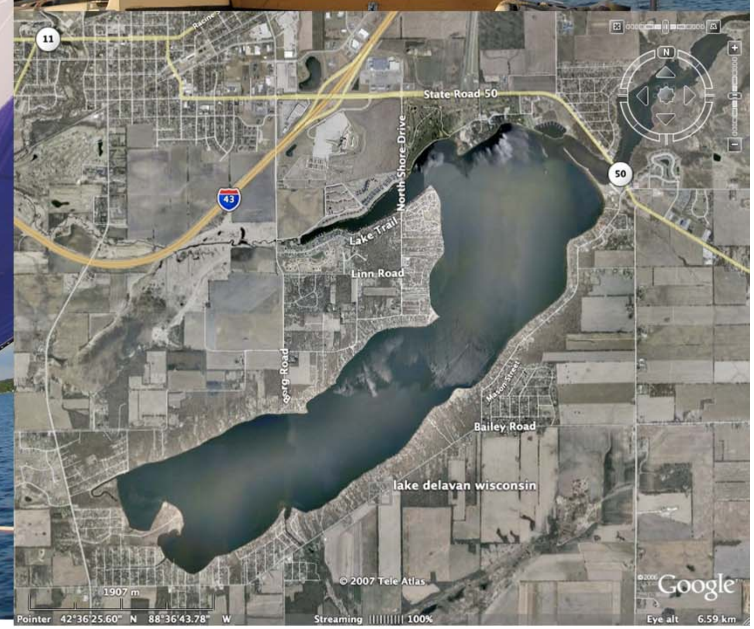

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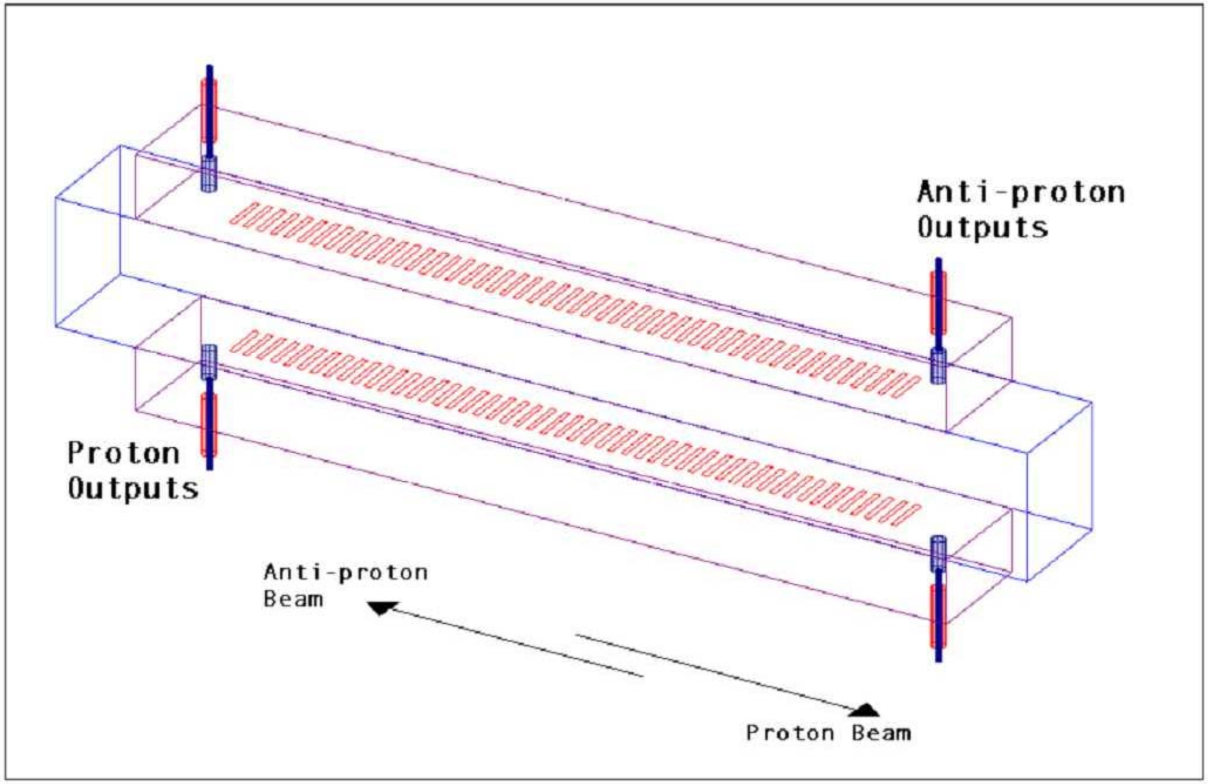
Slotted Waveguide Pickup



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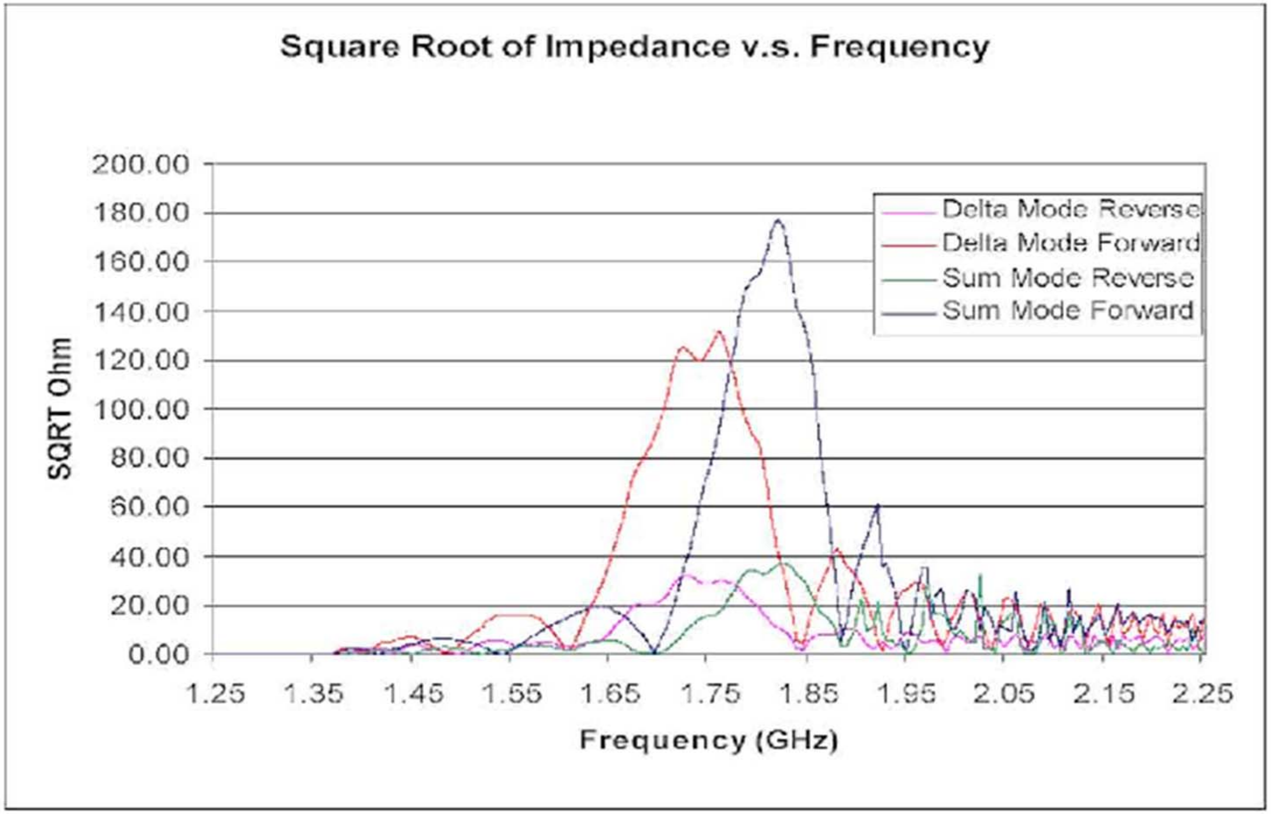
Schottky Pickup Frequency Response



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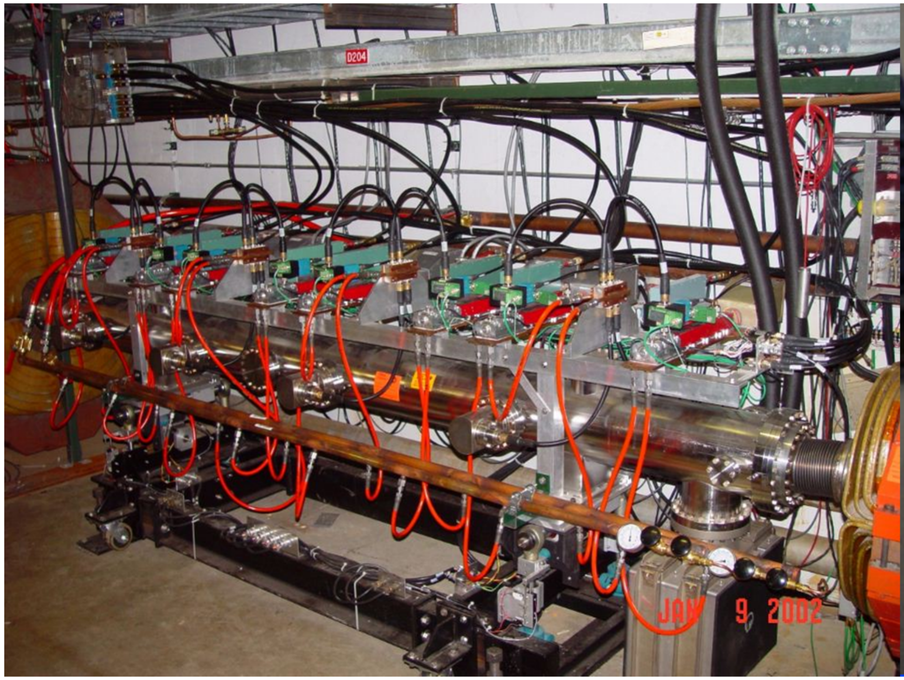

Debuncher Cooling
8 Bands 4-8 GHz
1999

Accumulator Core Cooling
3 Bands 4-8 GHz
2002

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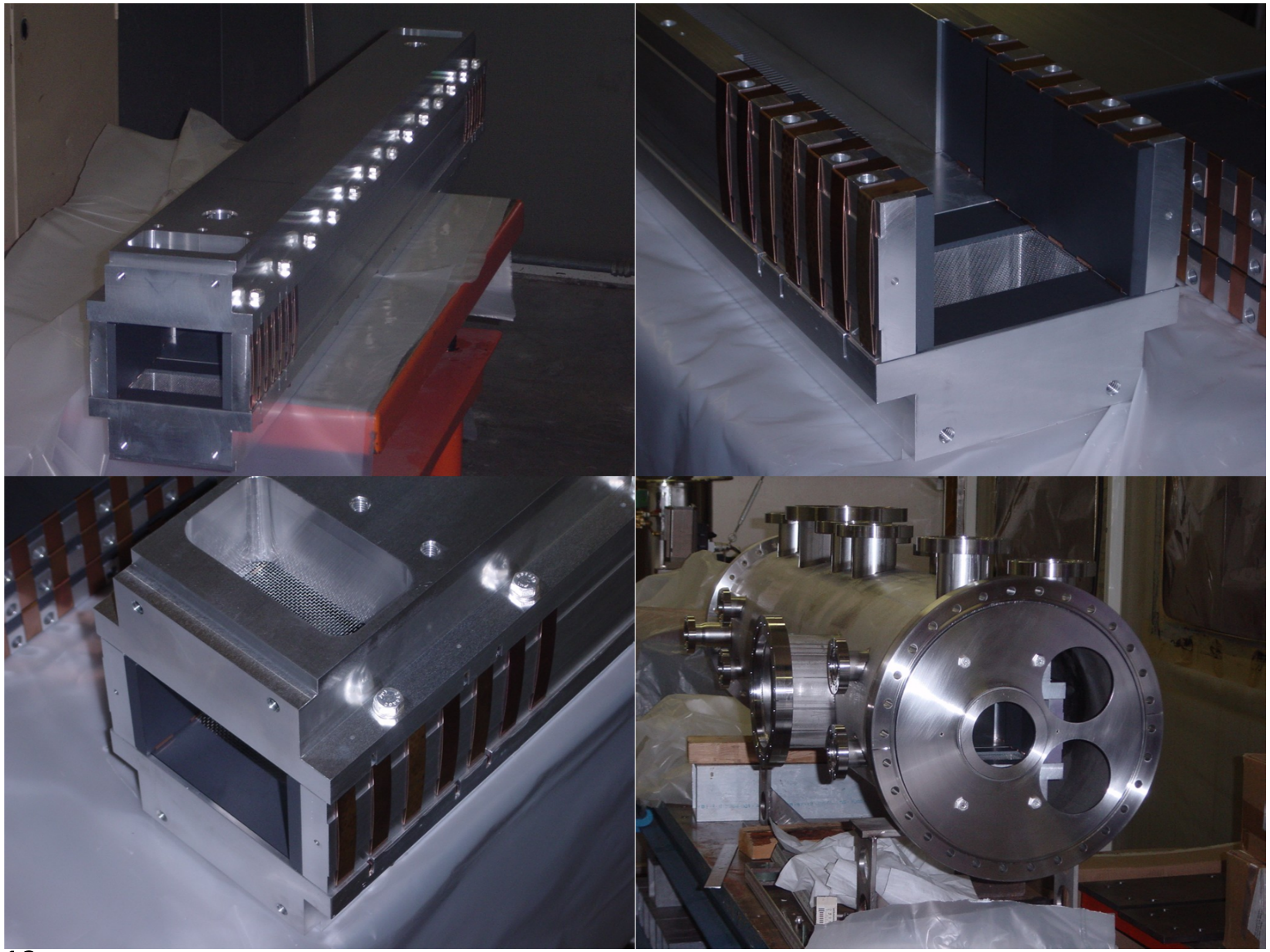
1.7 GHz Array Assembly Summer 2002



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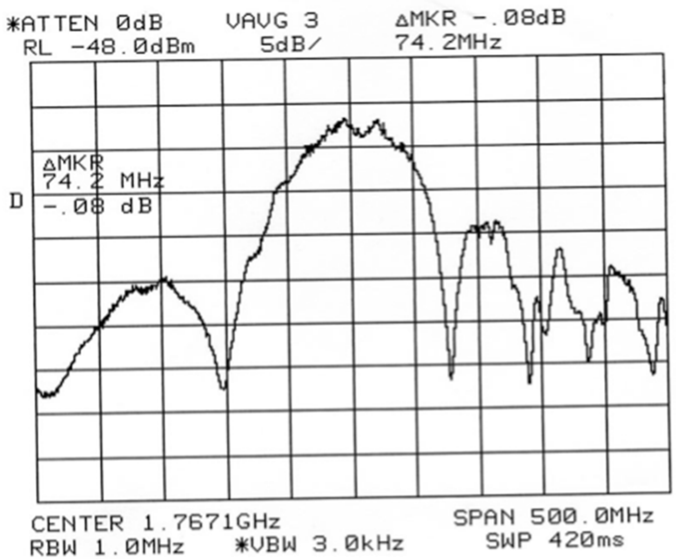
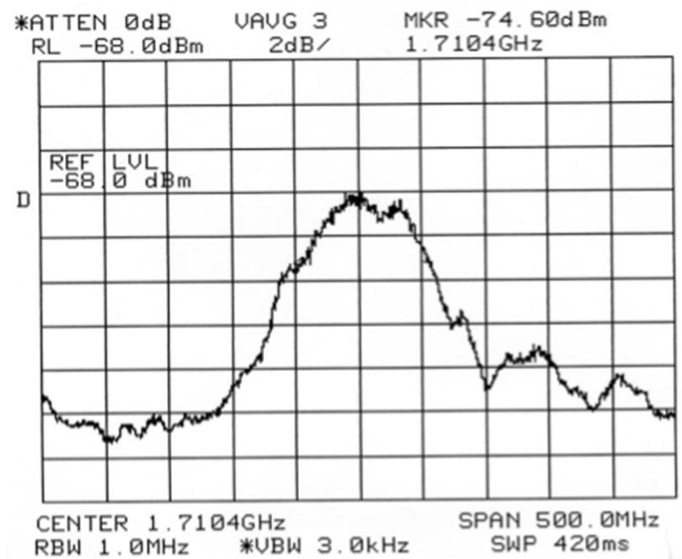
Measured Pickup Sensitivity in Recycler 2003





Sum Mode *Difference Mode*

Directivity Measured at 12-15 dB

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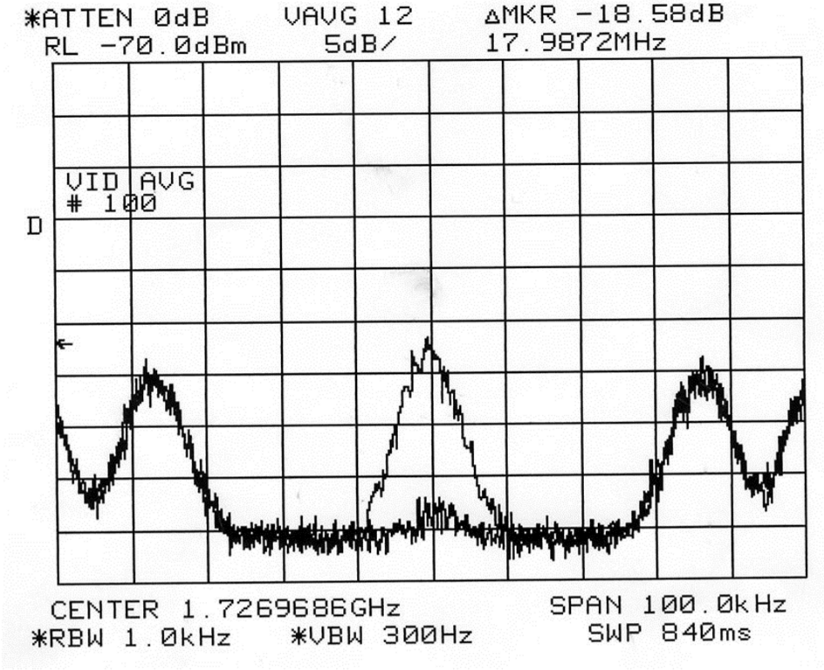
Beam Centering Reduces Common Mode

Not an Option
for the Tevatron
with Protons &
Antiprotons
on Helical Orbits



Recycler Horizontal Pickup 1 x 10^{11} Protons

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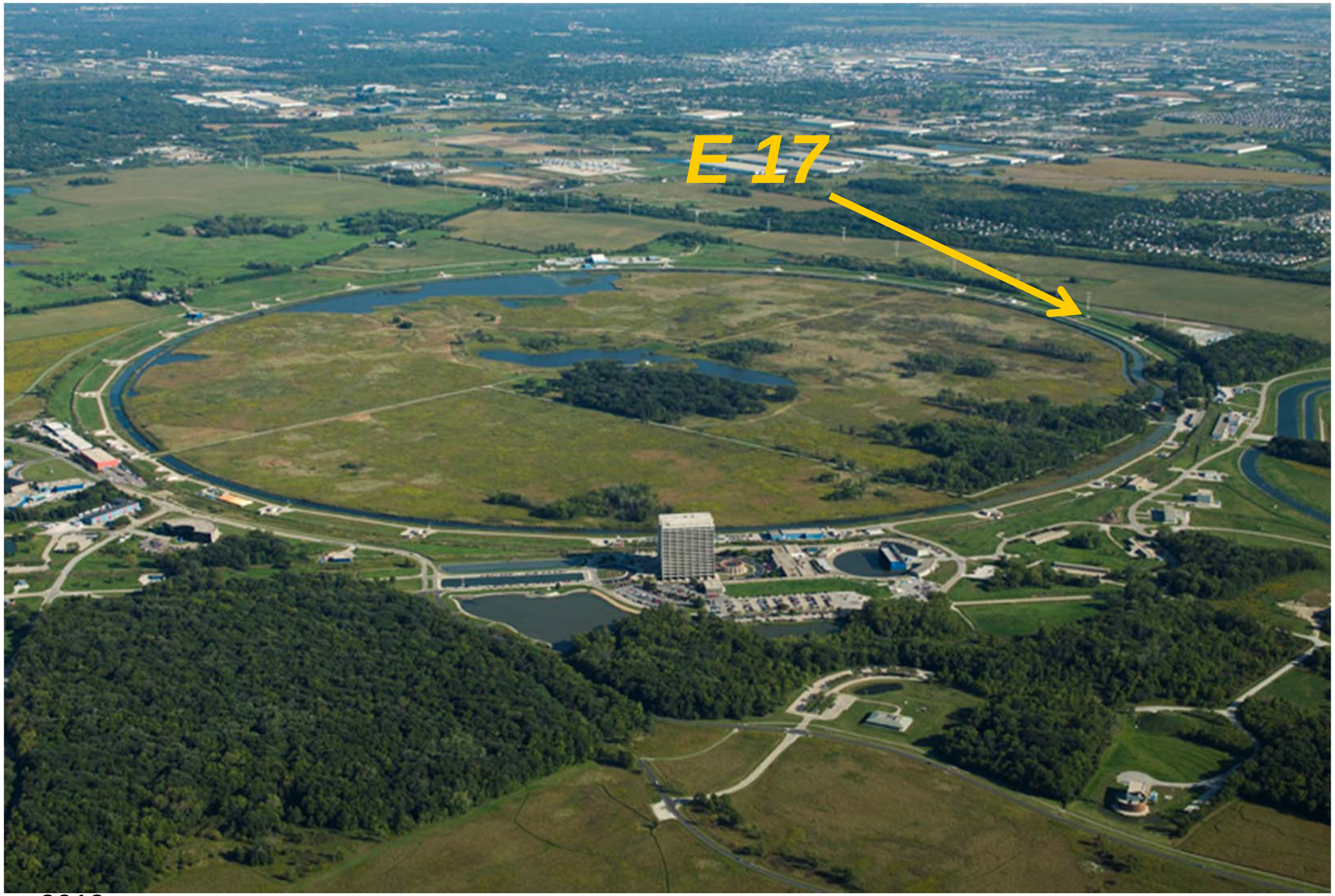
Location of Tevatron Schottky Pickups



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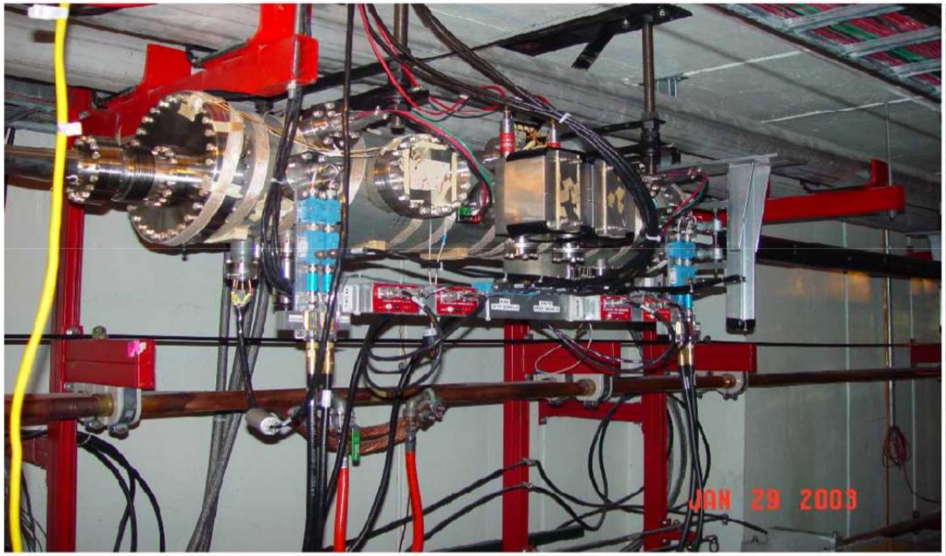
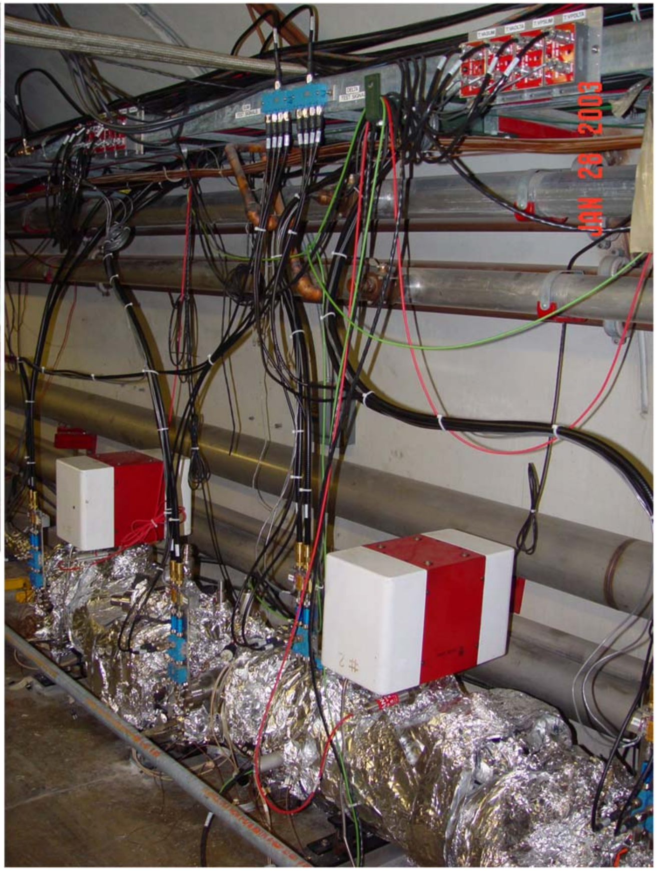
Tevatron Installation





Recycler Installation

January 2003

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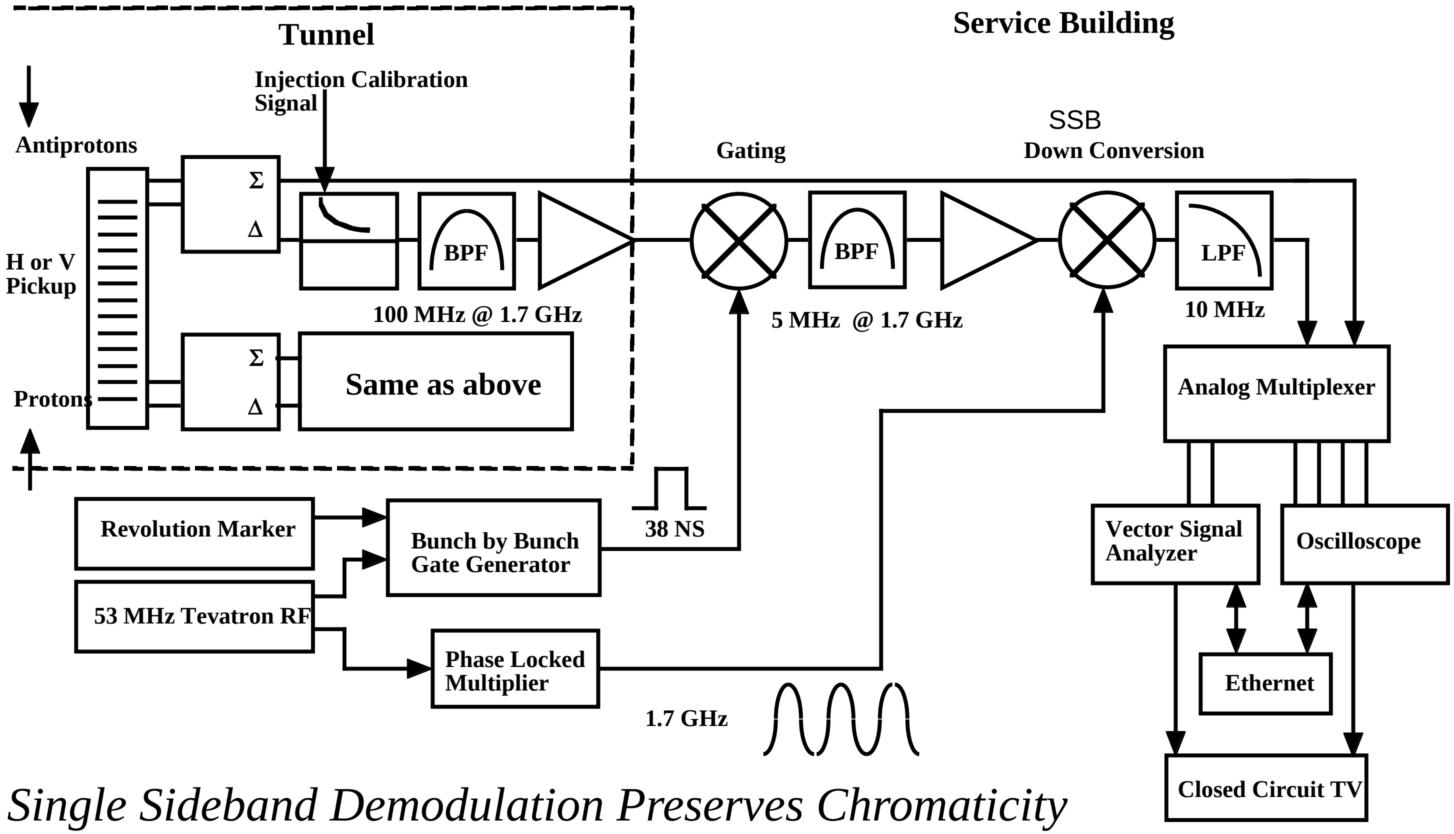
Original Tevatron Schottky Signal Processing



Single Sideband Demodulation Preserves Chromaticity

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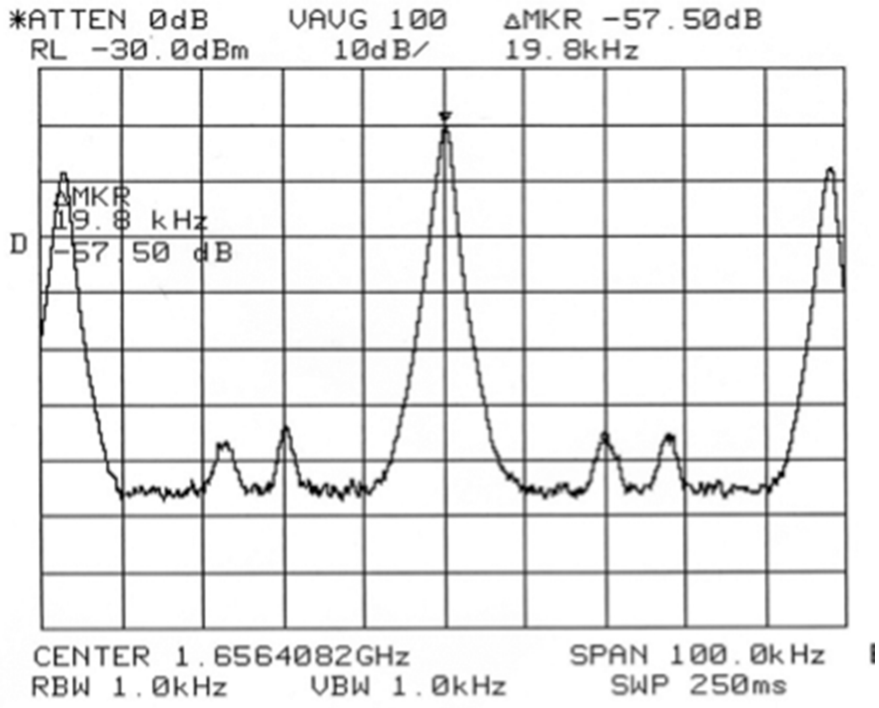
Tevatron Schottky Signal
Large Common Mode Signal Requires High Dynamic Range



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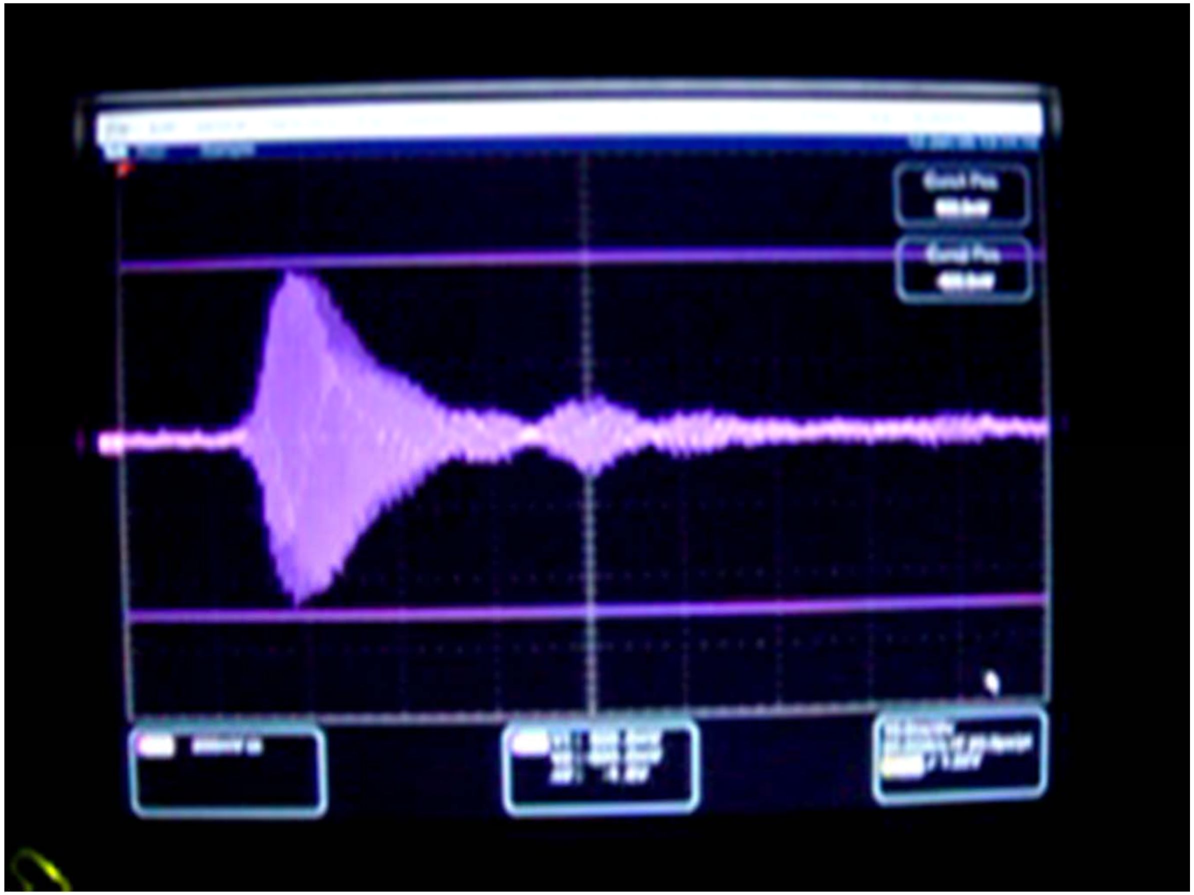
1.7 GHz Tevatron Single Bunch Horizontal Protons



⌘*LARP LHC Collaboration*

- *Propose Schottky system for LHC, Fall 2004*
- *Schottky accepted as part of LARP, Summer 2005*
- *Pickup design complete, plans sent to CERN, construction begins, Spring 2006*
- *Design of analog processing electronics with prototype, Fall 2006*
- *Installation of pickups and processor hardware at CERN, Spring 2007*
- *Installation of control interface hardware at CERN, Spring 2008*
- *Initial commissioning with beam 2009*
- *Turn over operation to CERN 2010*

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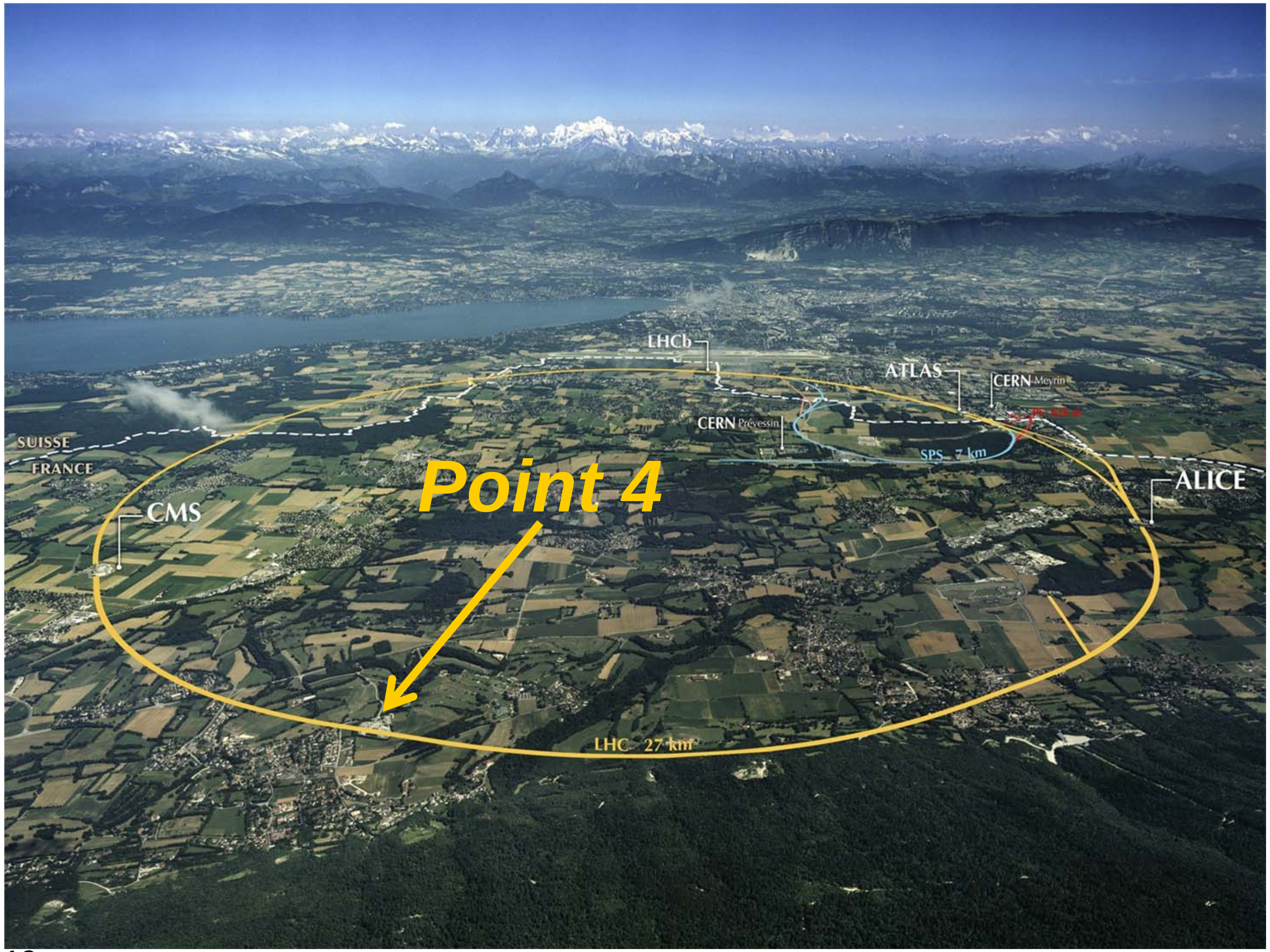
Location of LHC Schottky Pickups



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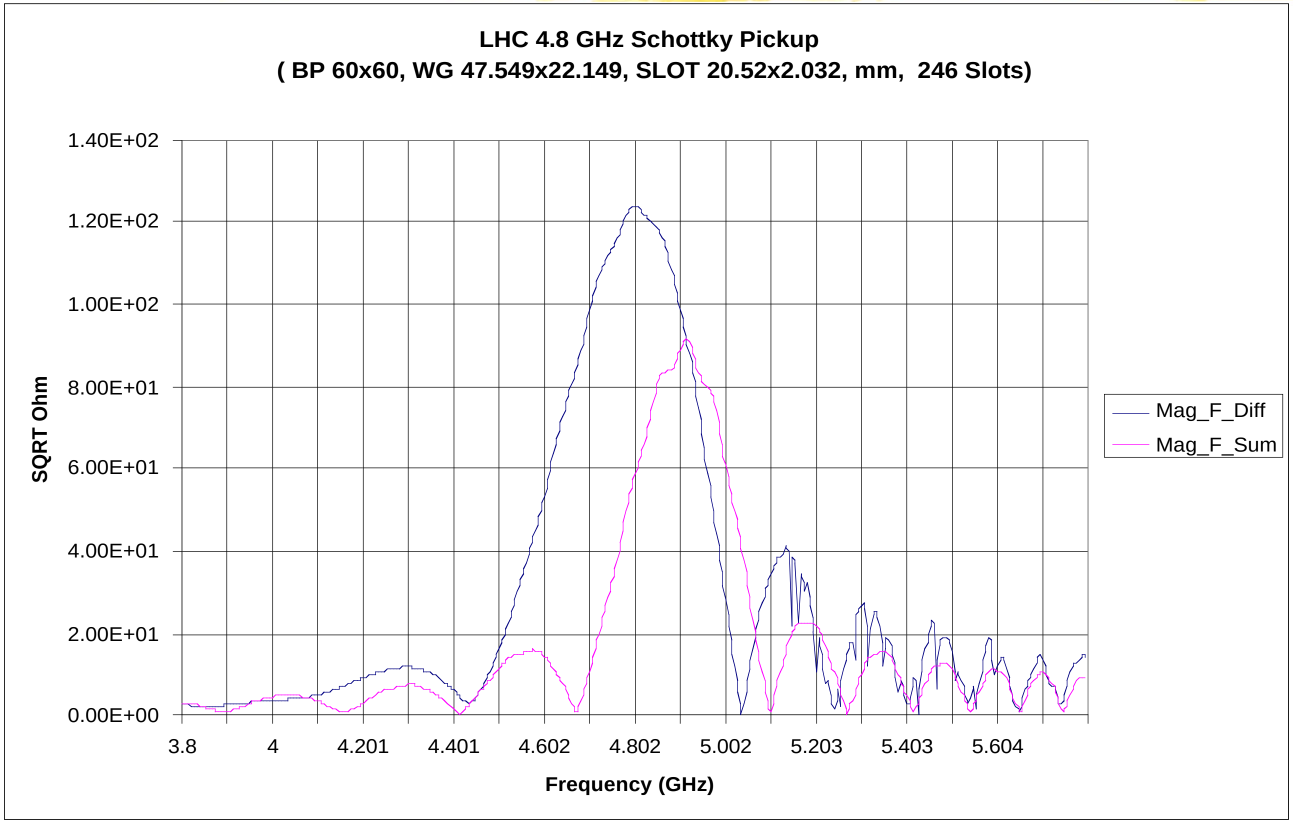

Figure 2. Impedance of LHC Schottky pickup

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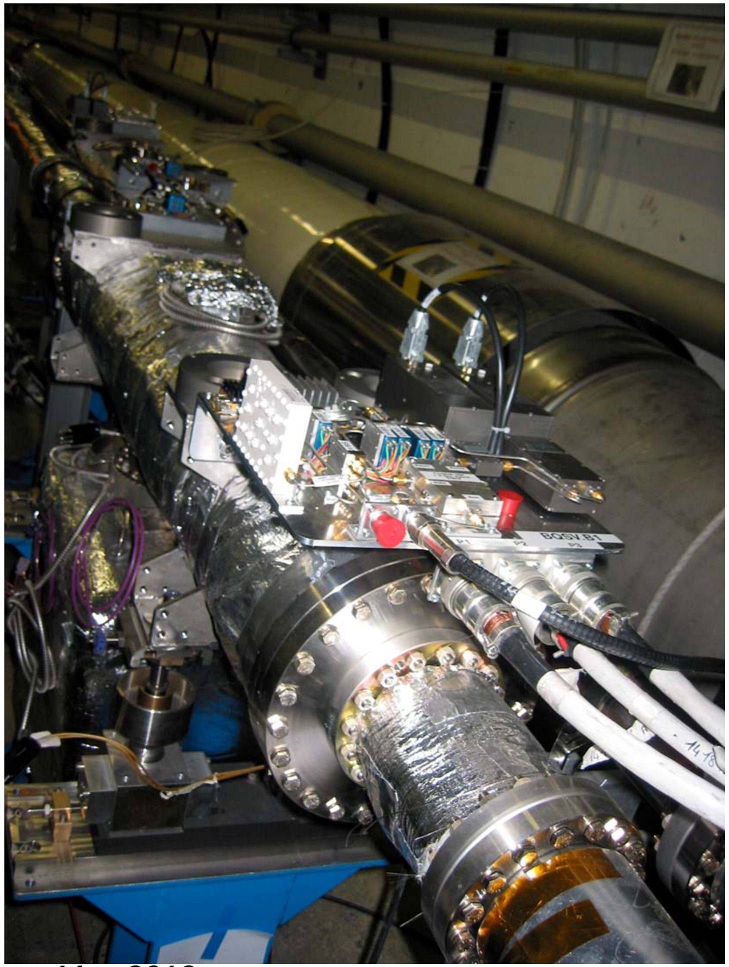
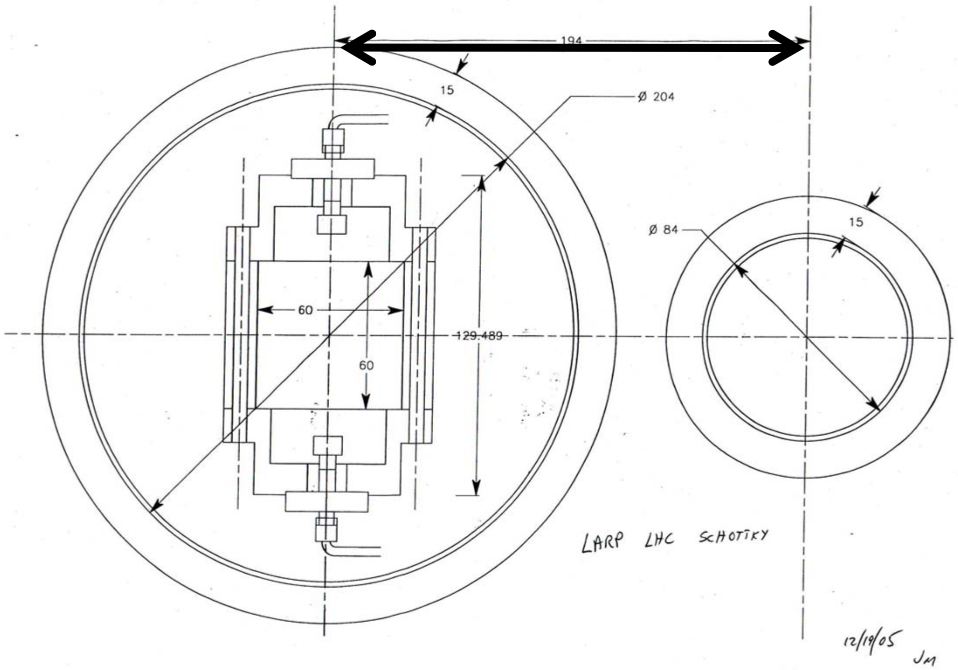
Pickups Assembly
at CERN Autumn 2006

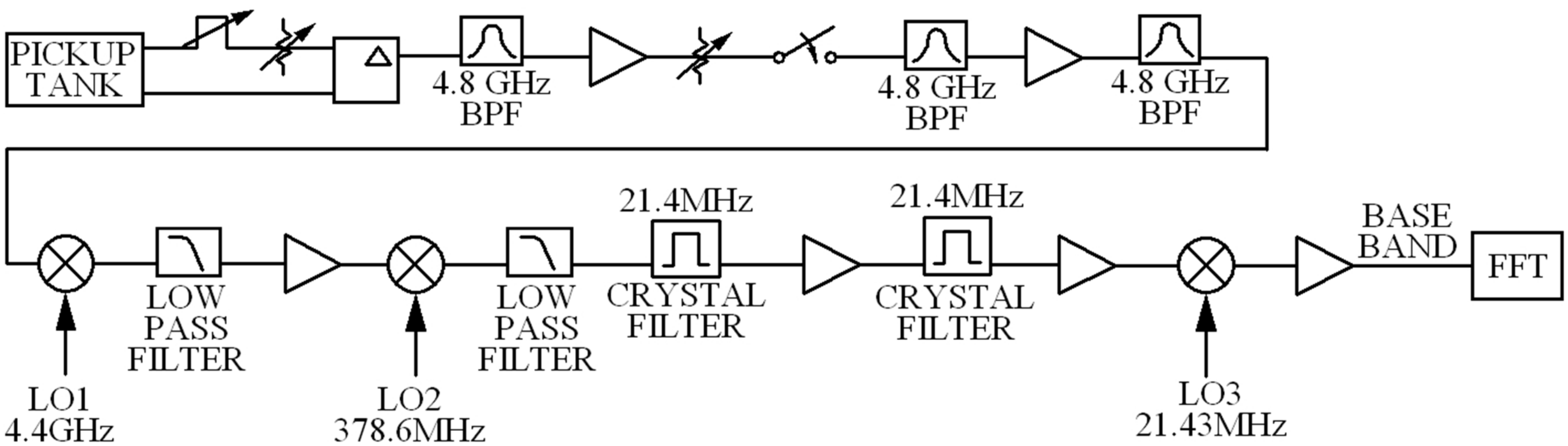
Microwave Schottky Beam Diagnostics



Tight Squeeze
LHC Beam Pipes Separated by 194 millimeters



LHC Schottky Triple Heterodyne Block Diagram



Microwave Schottky Beam Diagnostics

System Noise Analysis

LARP LHC 4.8 GHz Schottky Monitor System Noise and Dynamic Range Analysis

Pilot bunch case 5x10^9 hybrid CMRR 20 dB

Tests of the 1.7 GHz Schottky at the SPS with 10^11 per bunch yielded 5 volts delta and 51 volts sum at the hybrid output
These results are used to estimate the signal level for the 4.8 GHz Schotttky. Hybrid CMRR was 20 dB for the CERN test.

Calculations are done for single revolution lines. The integrated signal power is also calculated so that
monitoring of gain saturation is possible at all stages. Total signal power is adjusted with every change in bandwidth due to a filter.

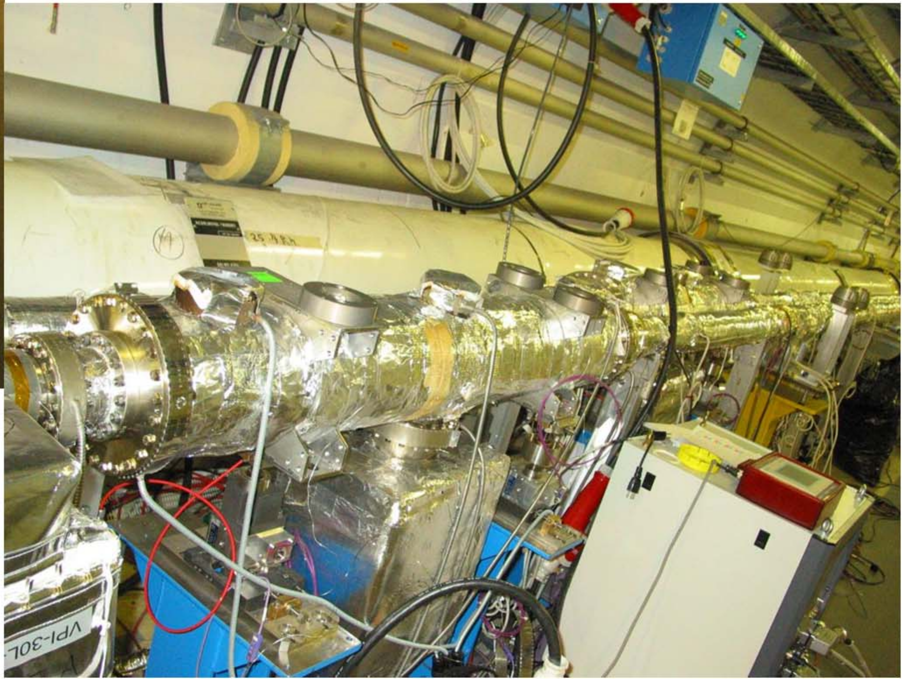
Bold/RED Values are inputs

estimated input sig power	**0**	dBm	cavity filter 3 dB bandwidth	**20**	MHz	effective gain before gate	8128.3	linear	input incoherent schottky SNR for pilot [dB]	injection	-18
Pickup input bandwidth	**200**	MHz	xtal filter 3 dB bandwidth	**15**	KHz		39.1	dB		collision	-25
KTB noise floor @ 290K	**-174**	dBm/Hz	fo revolution	**11**	kHz	gain due to gating	3096.0	linear			
total input KTB noise	-91.0	dBm	pk to pkADC volts	**2.8**	volts		**34.9**	dB			
input noise per rev band	-133.6	dBm	Baseband Gain for peak to ADC	4.9292338	dB						
input incoherent schottky SNR	**-18.0**	dB	gate duty ratio	**2.00E-04**							

	Stage Description	INPUT NF dB	INPUT Gain dB	NF linear	Gain linear	Gain adjacent 2 stages linear	system NF liner	system NF dB	per rev signal dBm	per rev noise dBm	S/N dB	SNR transverse [dB]	total output signal dBm	stage description	
1	PU out	**0.00**	0.00	1.00	1.00	1.00	1.000	0.00	-44.6	-133.6	89.0	**-18.00**	0.0	PU out	
2	hybrid out including losse	**2.00**	-2.00	1.58	0.63	0.63	1.585	2.00	-46.6	-133.6	87.0	-20.00	-2.0	hybrid out including losses from switches and	
3	cavity BPF 20 MHz	**2.00**	-2.00	1.58	0.63	0.40	2.512	4.00	-48.6	-133.6	85.0	-22.00	**-24.0**	cavity BPF 20 I	Cavity filter, Center=4.8 GHz,
4	amp 1	**2.00**	**35.00**	1.58	3162.28	1258.93	3.981	6.00	-13.6	-96.6	83.0	-24.00	11.0	amp 1	Miteq AFSD4-020060-20-27P,
5	7/8" coax loss	**7.00**	-7.00	5.01	0.20	251.19	3.984	6.00	-20.6	-103.6	83.0	-24.00	4.0	7/8" coax loss	
6	gate preampli	**5.00**	**15.00**	3.16	31.62	7943.28	3.993	6.01	-5.6	-88.6	83.0	-24.01	**19.0**	gate preampli	
7	splitter	**3.90**	-3.90	2.45	0.41	3235.94	3.993	6.01	-9.5	-92.5	83.0	-24.01	**15.1**	splitter	to be chosen
8	gate switch	**3.00**	-3.00	2.00	0.50	1621.81	3.993	6.01	-12.5	-95.5	83.0	10.89	12.1	gate switch	
9	cavity BPF 20 MHz 1	**2.00**	-2.00	1.58	0.63	1023.29	3.994	6.01	-14.5	-97.5	83.0	10.89	**10.1**	cavity BPF 20 MHz 1	
10	amp 2	**3.70**	**12.00**	2.34	15.85	16218.10	3.995	6.02	-2.5	-85.5	83.0	10.89	22.1	amp 2	
11	cavity BPF 20 MHz 2	**2.00**	-2.00	1.58	0.63	10232.93	3.995	6.02	-4.5	-87.5	83.0	10.89	**20.1**	cavity BPF 20 MHz 2	
12	amp 3	**3.70**	**12.00**	2.34	15.85	162181.01	3.995	6.02	7.5	-75.5	83.0	10.89	32.1	amp 3	
13	splitter	**3.90**	-3.90	2.45	0.41	66069.34	3.995	6.02	3.6	-79.4	83.0	10.89	28.2	splitter	
14	1st mixer	**5.00**	-5.00	3.16	0.32	20892.96	3.995	6.02	-1.4	-84.4	83.0	10.89	23.2	1st mixer	
15	LPF+split	**4.30**	-4.30	2.69	0.37	7762.47	3.995	6.02	-5.7	-88.7	83.0	10.89	18.9	LPF+split	
16	2nd mixer	**6.00**	-6.00	3.98	0.25	1949.84	3.996	6.02	-11.7	-94.7	83.0	10.89	12.9	2nd mixer	
17	LPF and split	**4.30**	-4.30	2.69	0.37	724.44	3.997	6.02	-16.0	-99.0	83.0	10.89	8.6	LPF and split	
18	gain block	**4.20**	**20.00**	2.63	100.00	72443.60	3.999	6.02	4.0	-79.0	83.0	10.89	28.6	gain block	
19	xtal filter #1	**6.00**	-6.00	3.98	0.25	18197.01	3.999	6.02	-2.0	-85.0	83.0	10.89	-8.6	xtal filter #1	
20	gain block	**4.20**	**20.00**	2.63	100.00	1819700.86	3.999	6.02	18.0	-65.0	83.0	10.89	11.4	gain block	
21		**0.00**	0.00	1.00	1.00	1819700.86	3.999	6.02	18.0	-65.0	83.0	10.89	11.4	0	
22	3rd mixer	**6.00**	-6.00	3.98	0.25	457088.19	3.999	6.02	12.0	-71.0	83.0	10.89	5.4	3rd mixer	
23	LPF	**1.00**	-1.00	1.26	0.79	363078.05	3.999	6.02	11.0	-72.0	83.0	10.89	4.4	LPF	

Microwave Schottky Beam Diagnostics

Pickup tanks installed at Point 4, Spring 2007



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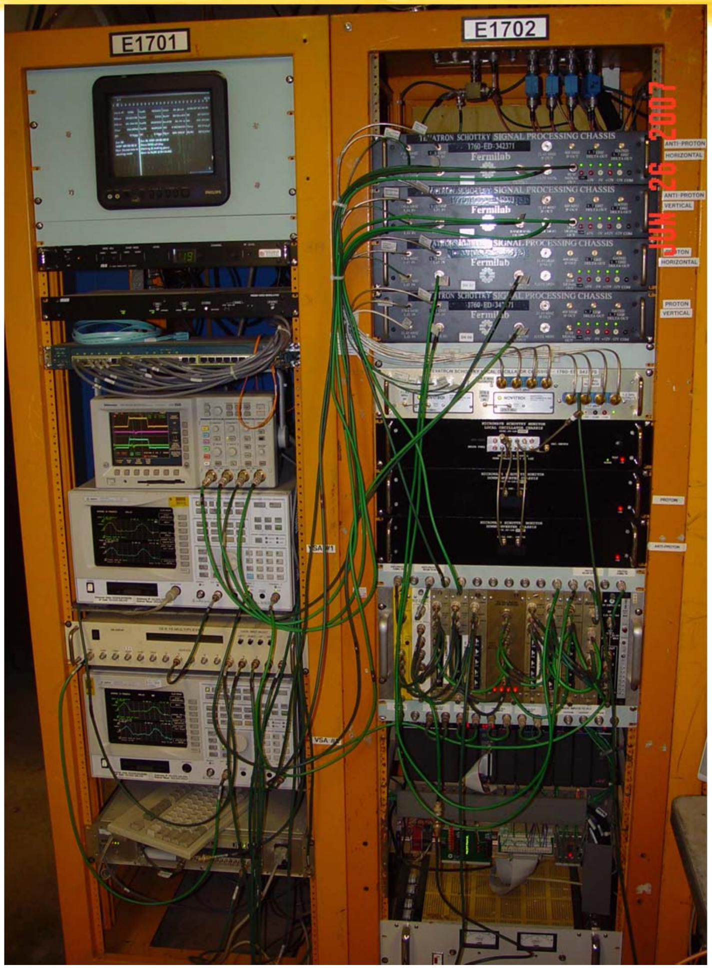
Hardware Test Set UP @ Fermilab

Microwave Schottky Beam Diagnostics



Triple Conversion Electronics Installed in Tevatron at E17 June 2007

Microwave Schottky Beam Diagnostics

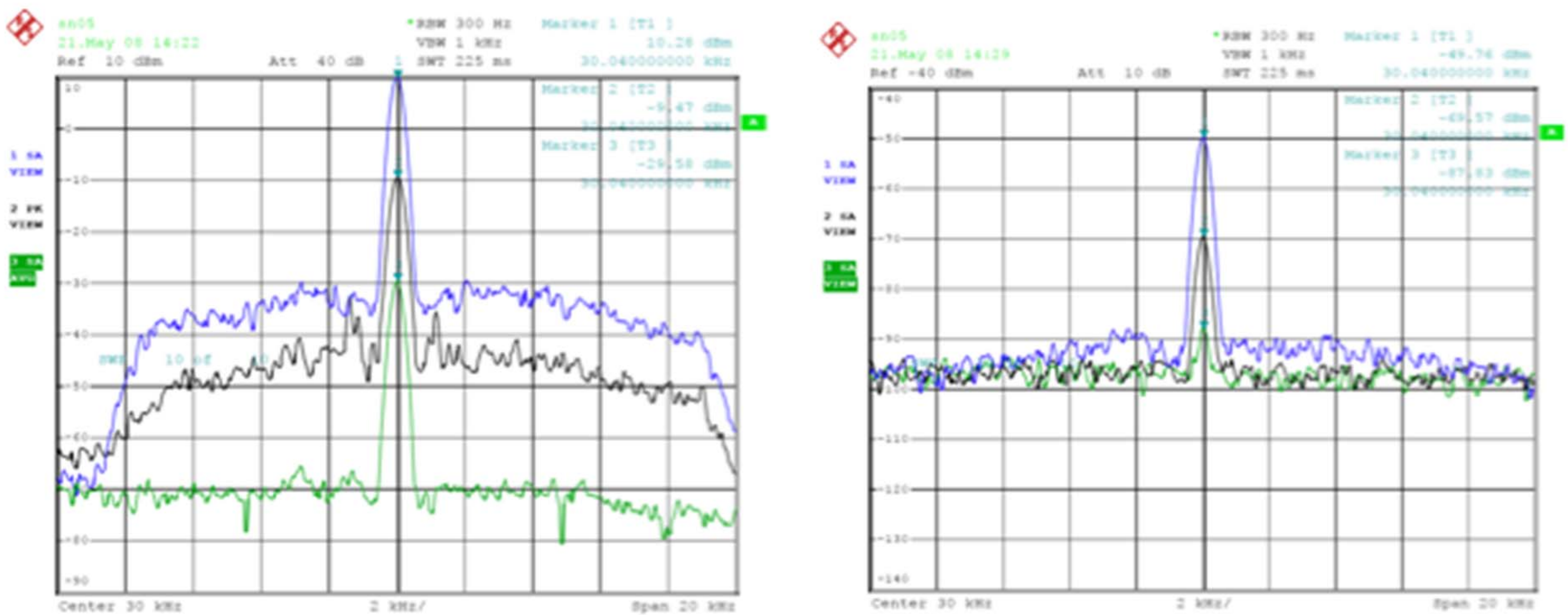
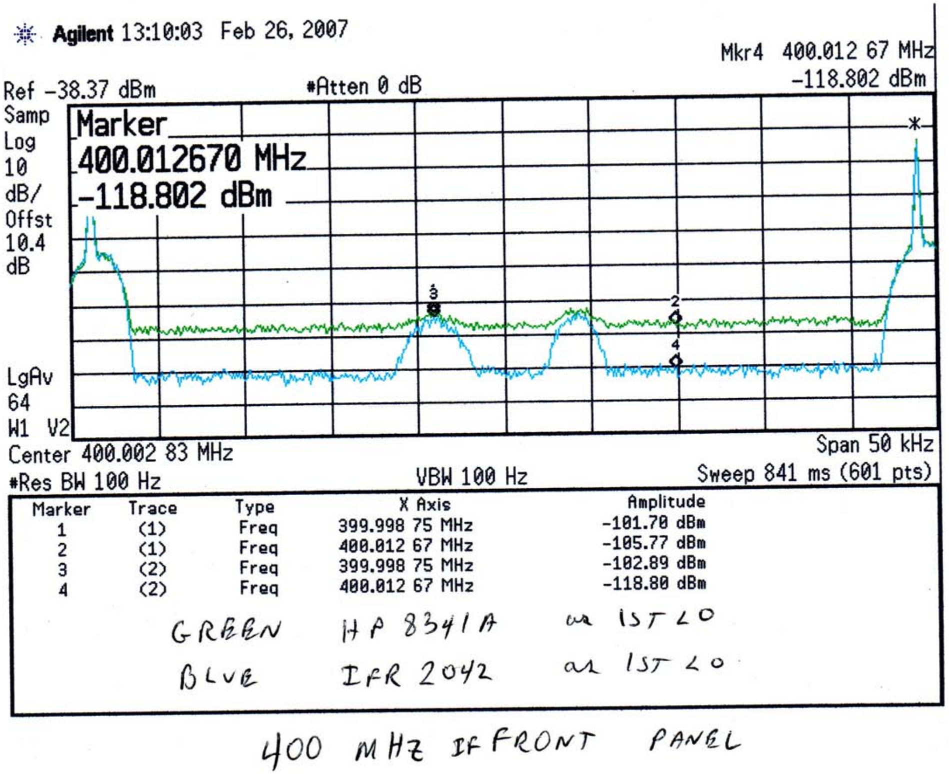


Figure 6. Measured 100 dB instantaneous dynamic range at baseband in Tevatron signal processing electronics utilizing triple down conversion and crystal filters in 20 db steps. Input signal ranges from +10 dBm to -90 dBm. Center frequency 30 KHz, 2 KHz/div, 10 dB/div.

Microwave Schottky Beam Diagnostics

Importance of Low Phase Noise Local Oscillators



Test in the Tevatron - 400 MHz IF

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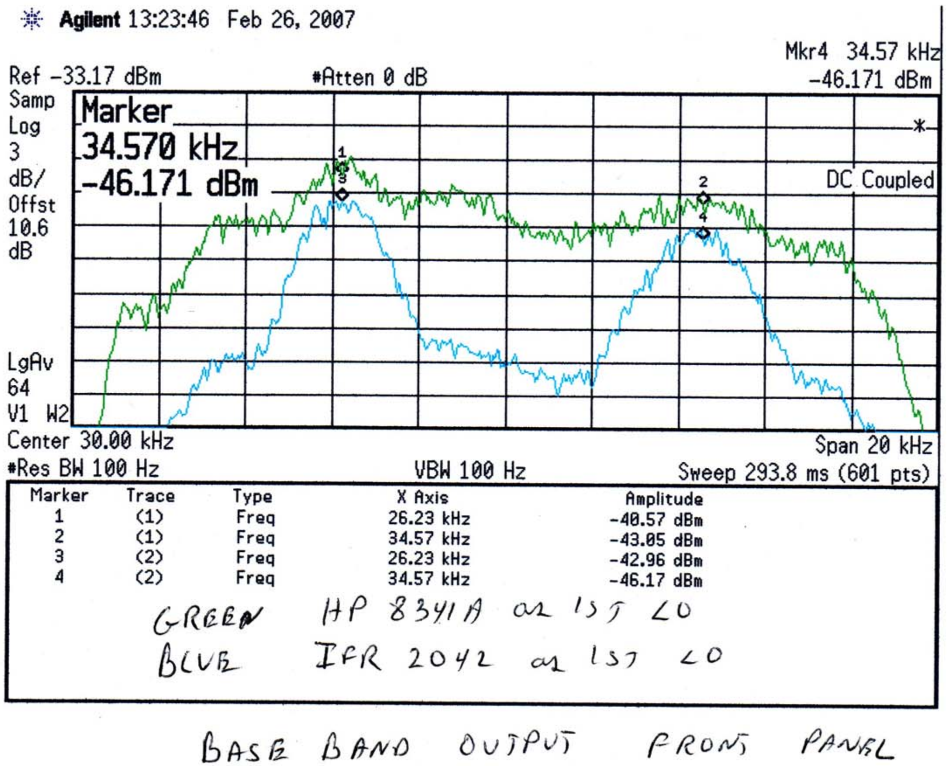
Different Widths of Sidebands allows Chromaticity Measurement



Test in the Tevatron - Baseband output

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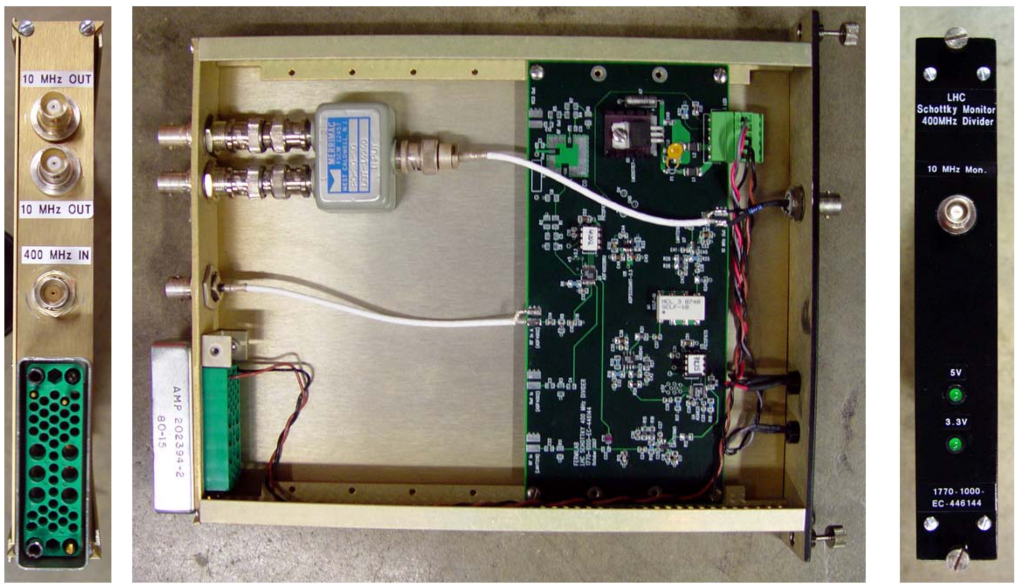
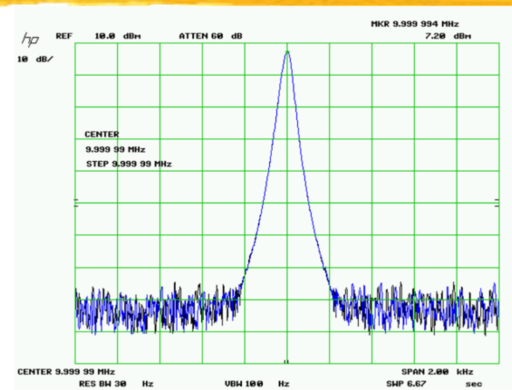
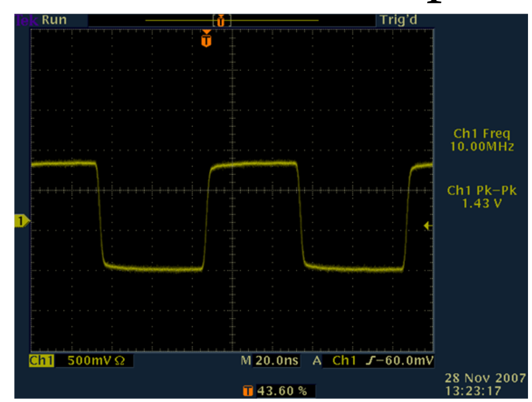
400.78897 MHz RF to 10 MHz Reference Divider for LO sync





10.000 MHz Output



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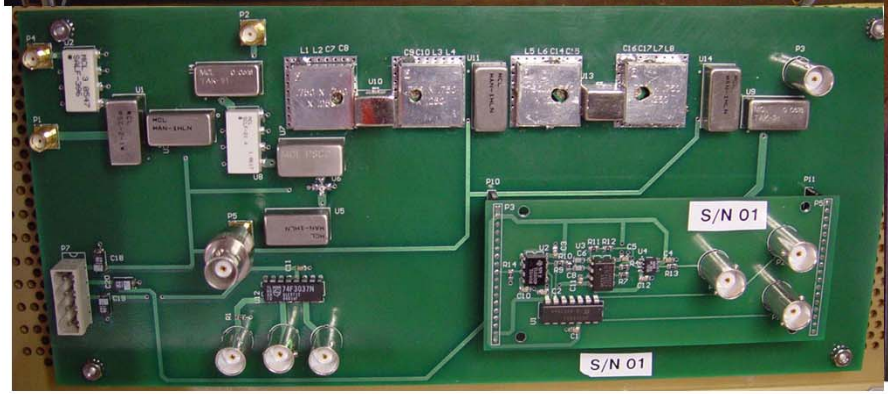
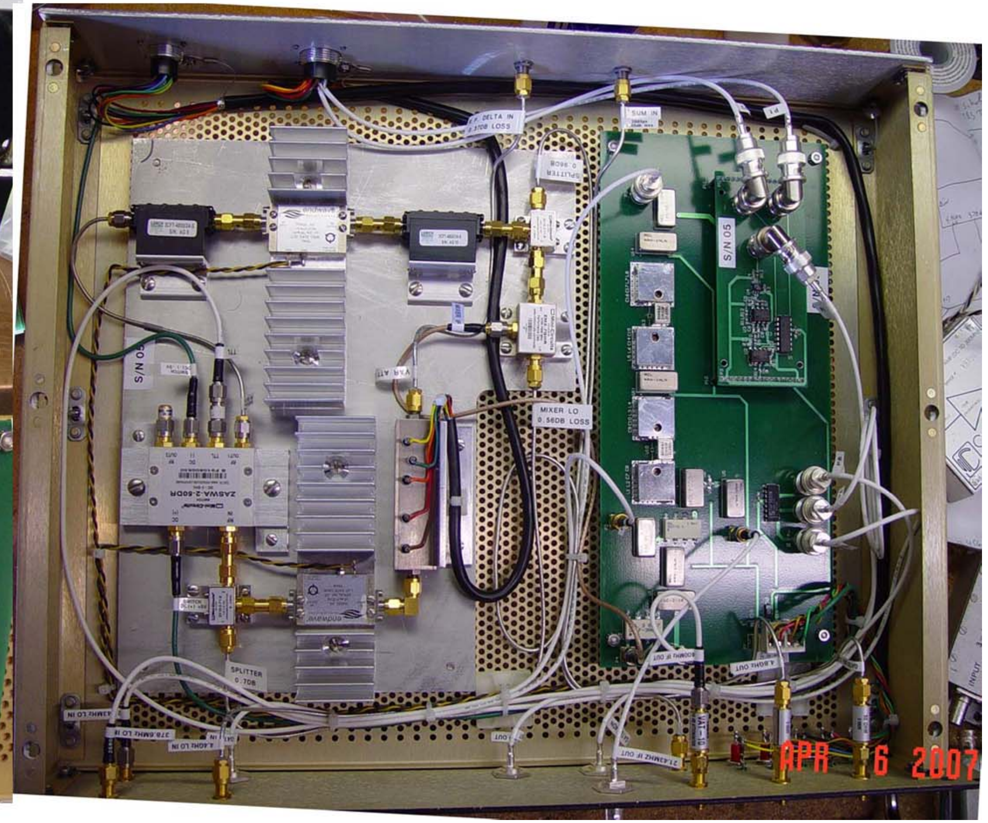
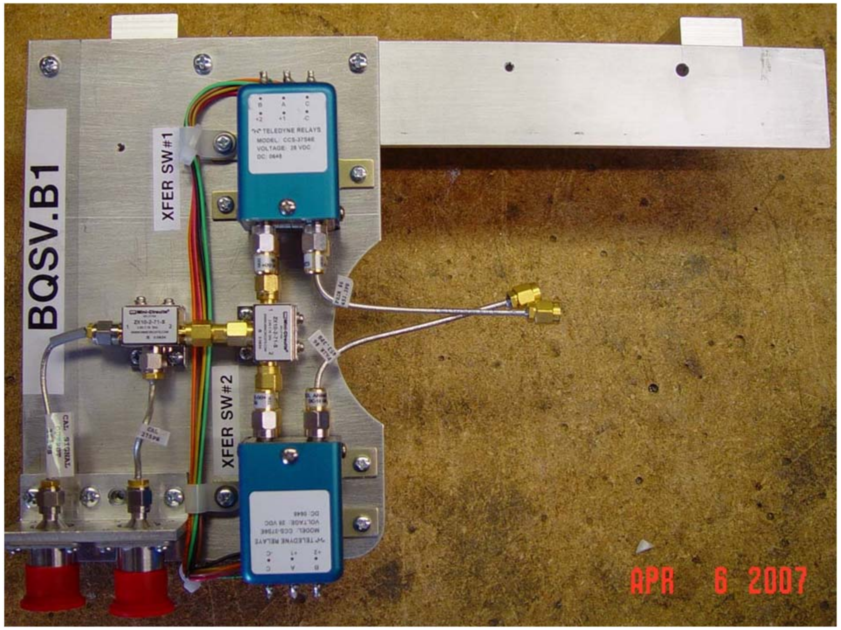


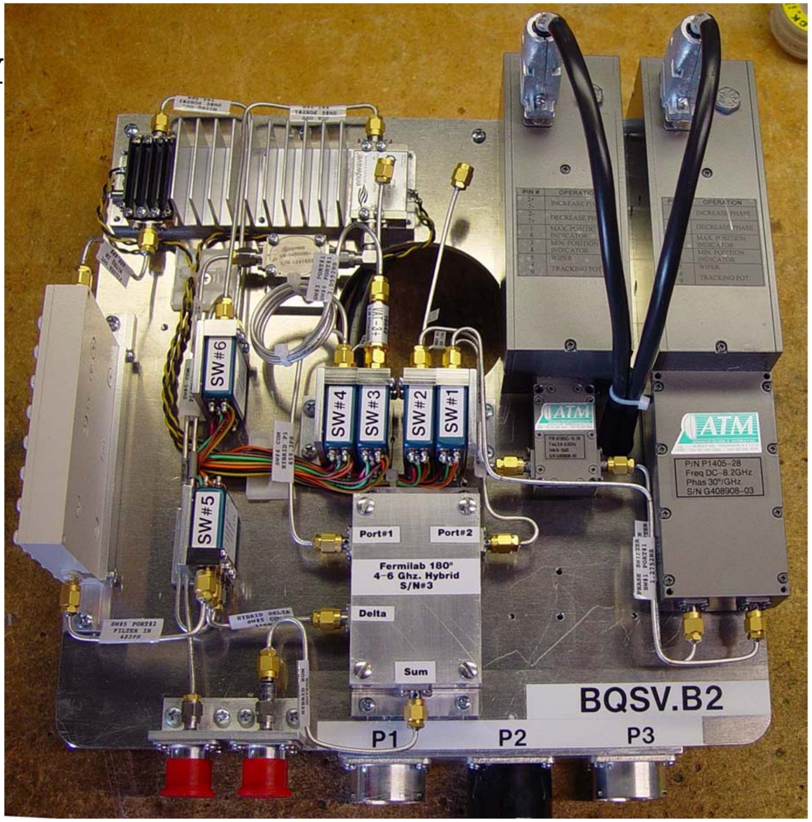
Signal Processing Chassis
Spring 2007



Microwave Schottky Beam Diagnostics

LHC Pickup Plate Hardware
Switches, Variable Attenuator and Phase Shifter allow for Calibration & Common Mode Rejection

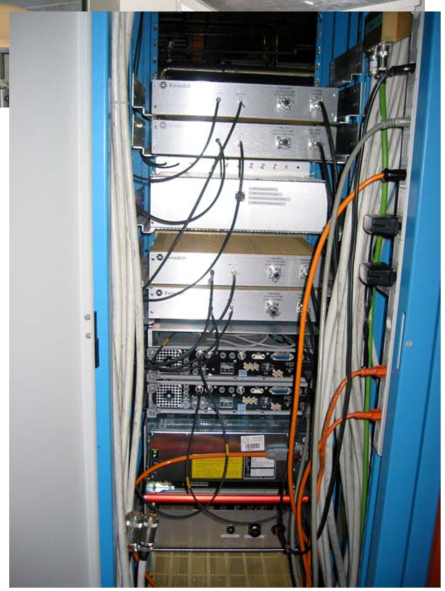




Microwave Schottky Beam Diagnostics

Crated up and on its way to CERN April 2007!

Microwave Schottky Beam Diagnostics



Point 4 Alcove Hardware May 2007

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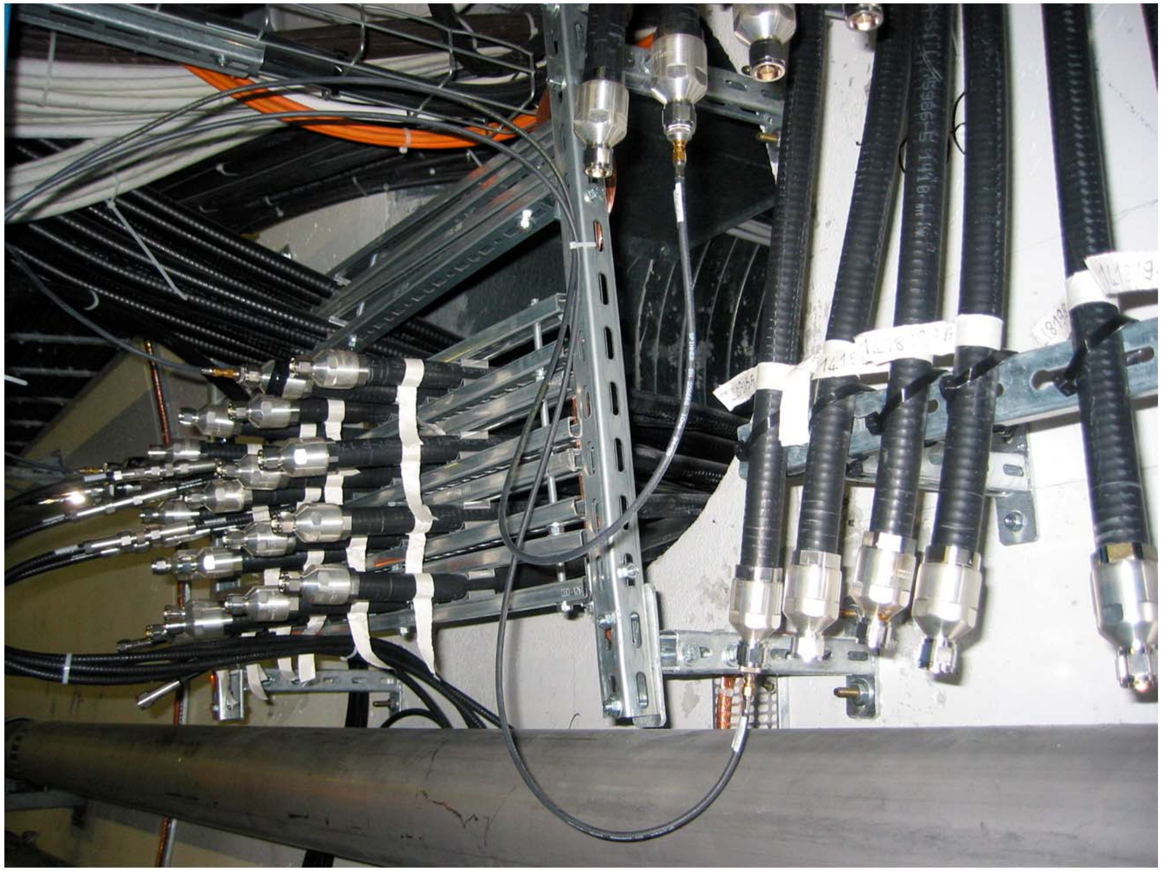
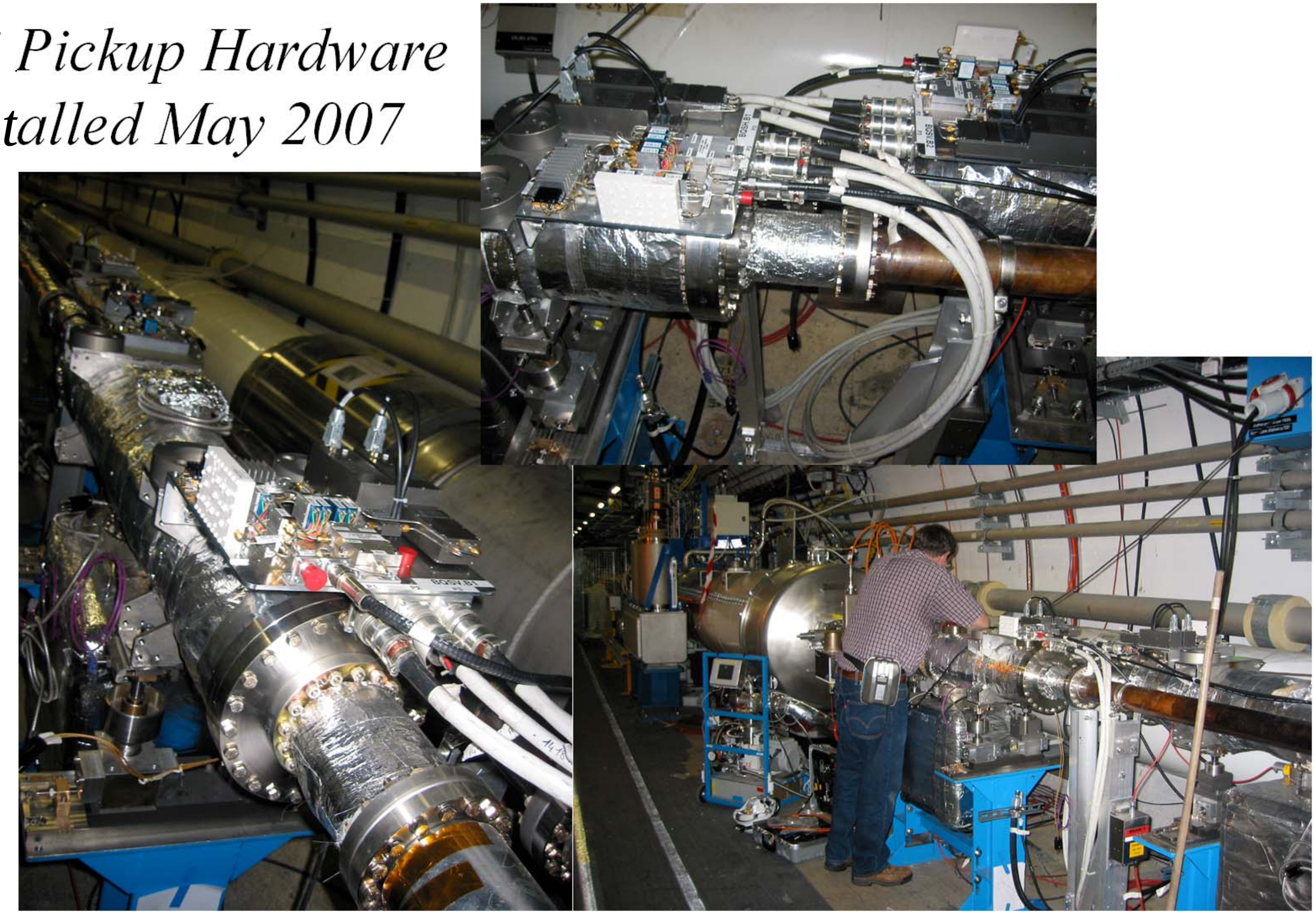
Microwave Schottky Beam Diagnostics

Cable plant alcove point 4



Microwave Schottky Beam Diagnostics

LHC Pickup Hardware Installed May 2007



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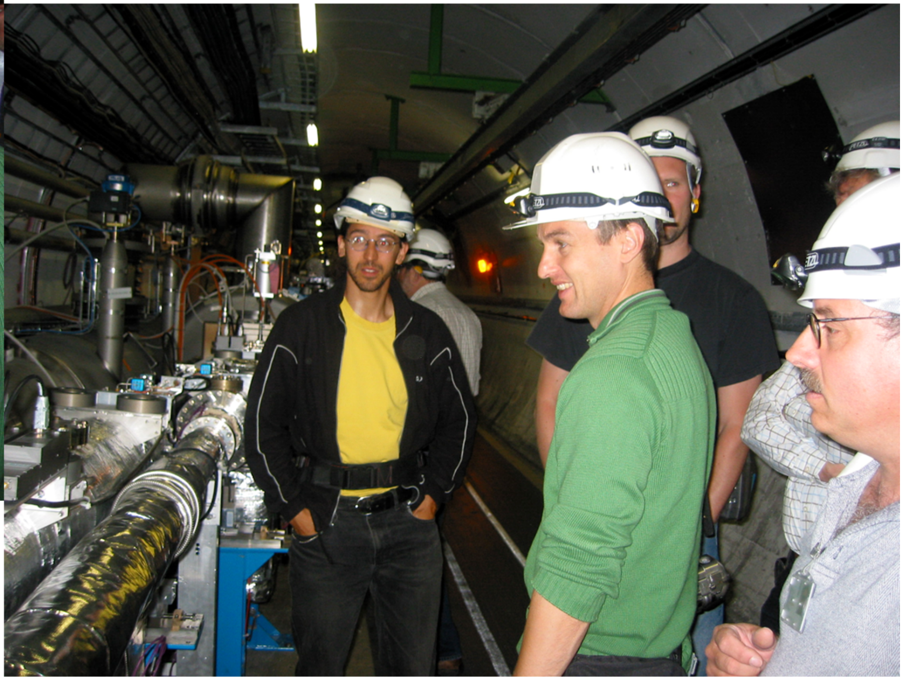
Microwave Schottky Beam Diagnostics

Touring Final Installation
May 2007



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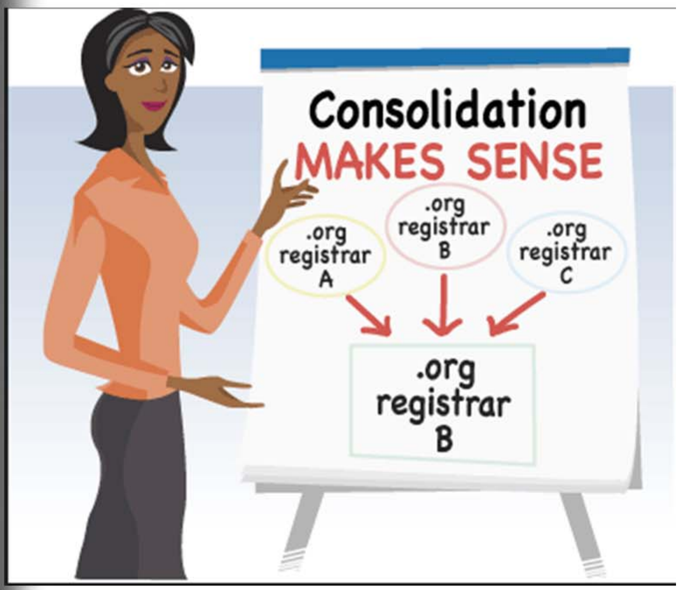
Microwave Schottky Beam Diagnostics



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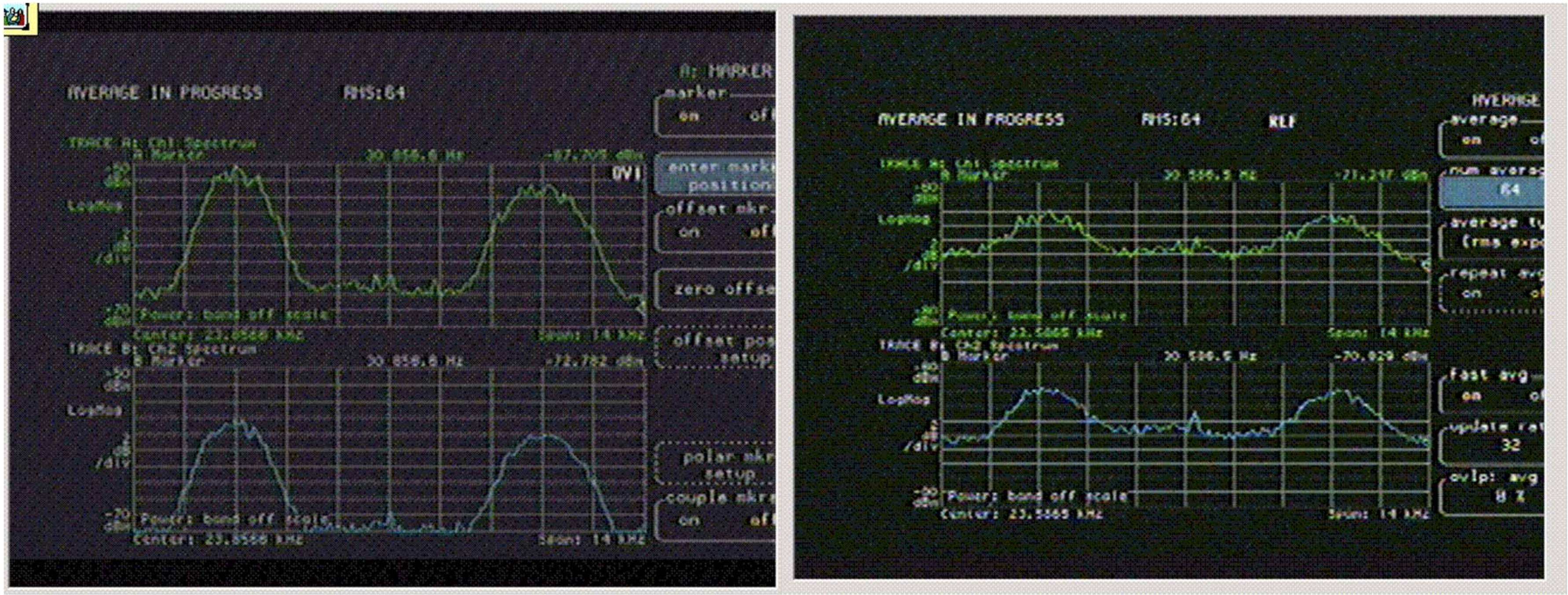
Microwave Schottky Beam Diagnostics

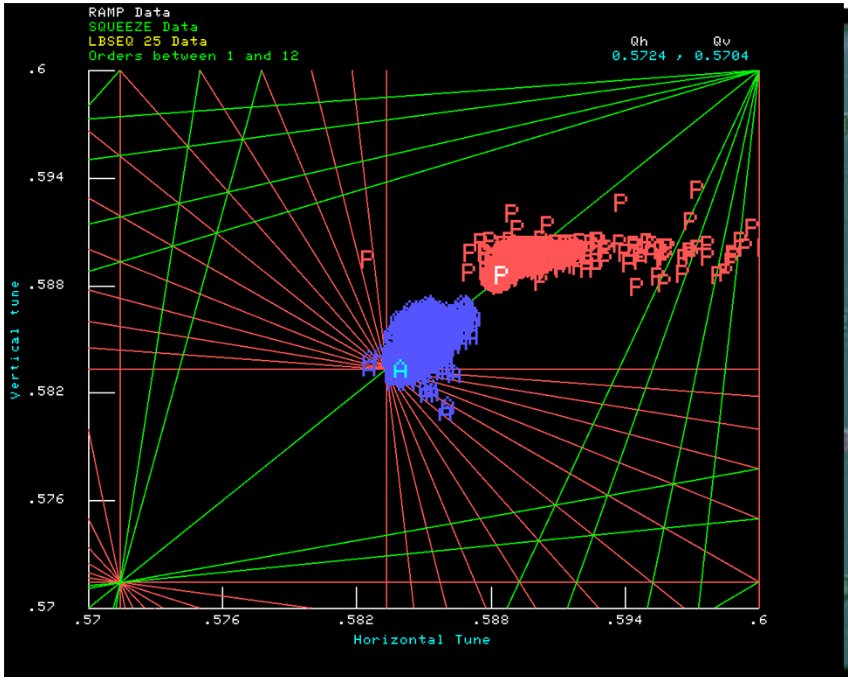
Tevatron Schottky Comfort Displays

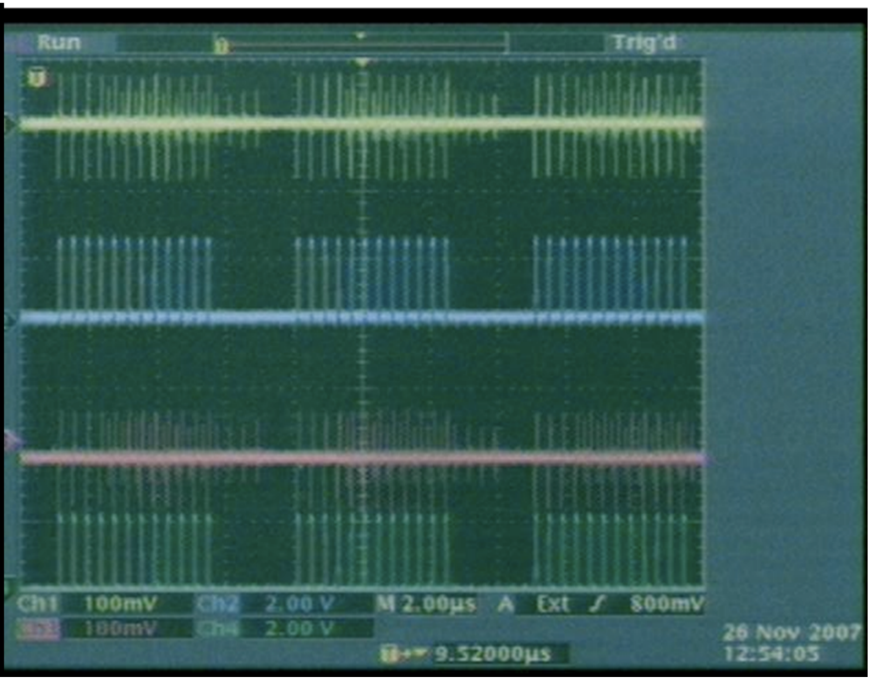


Protons

Antiprotons

Tevatron Tune Plot and Gate Monitor Comfort Displays





Microwave Schottky Beam Diagnostics

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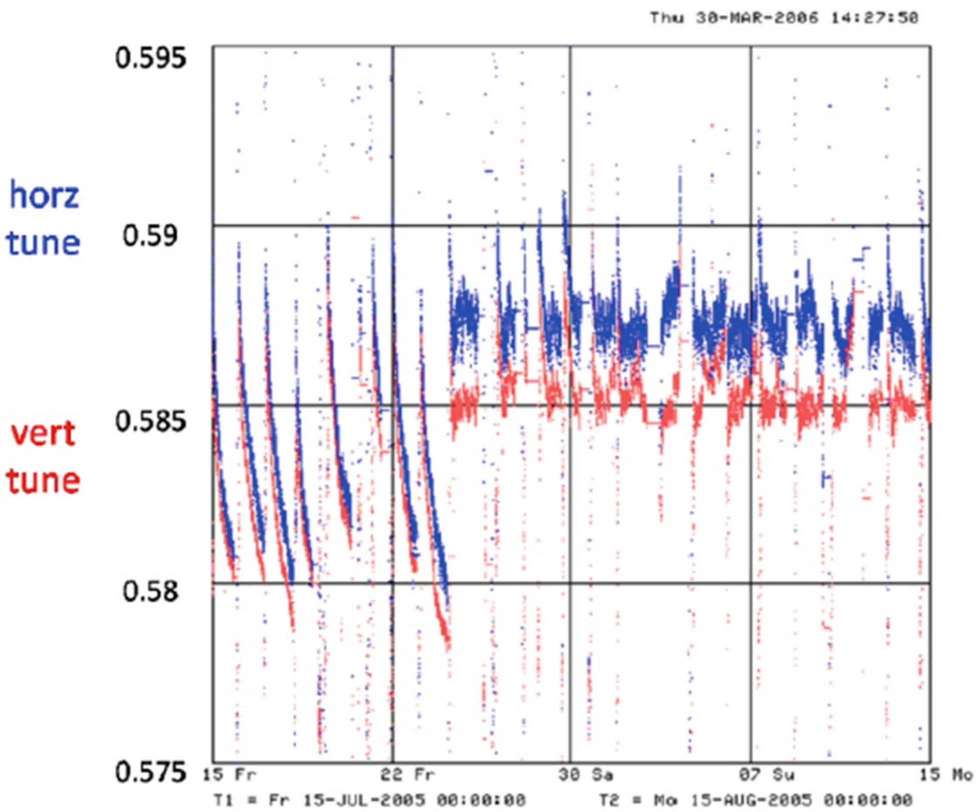
Tevatron Antiproton
Beam-Beam
Tune shift
Before and After
Correction
based on
Schottky Measurement



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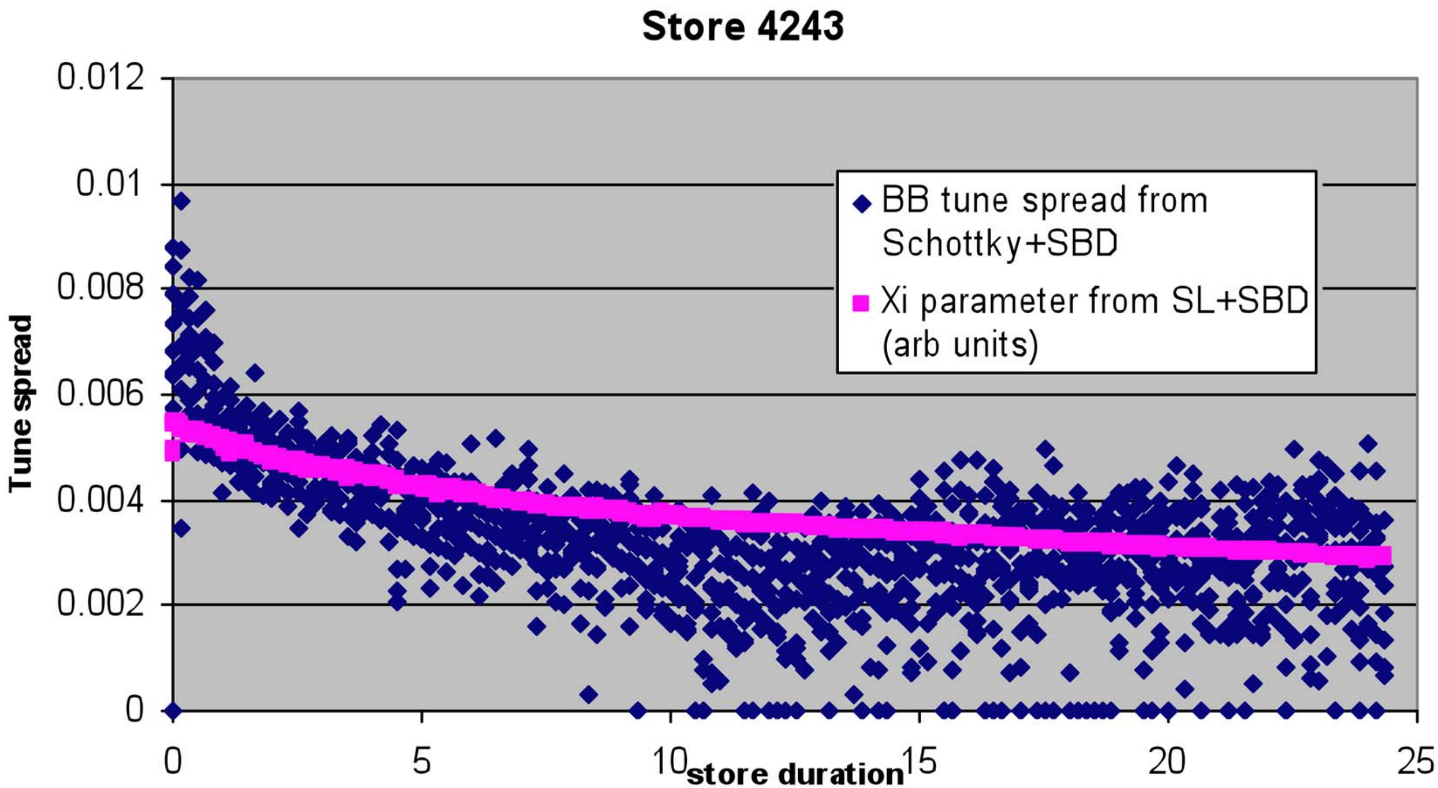
Microwave Schottky Beam Diagnostics

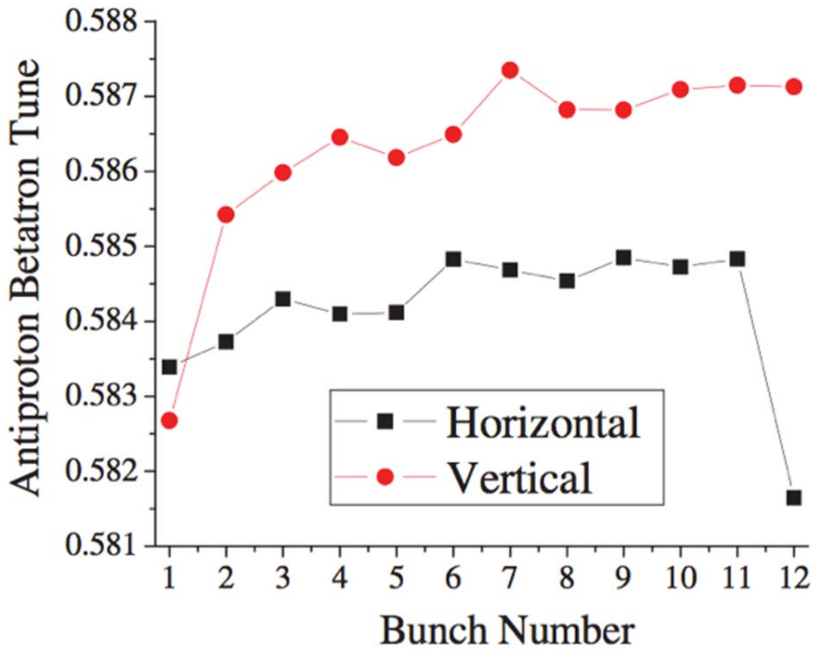
Measured Beam Beam Tevatron Tune Shift

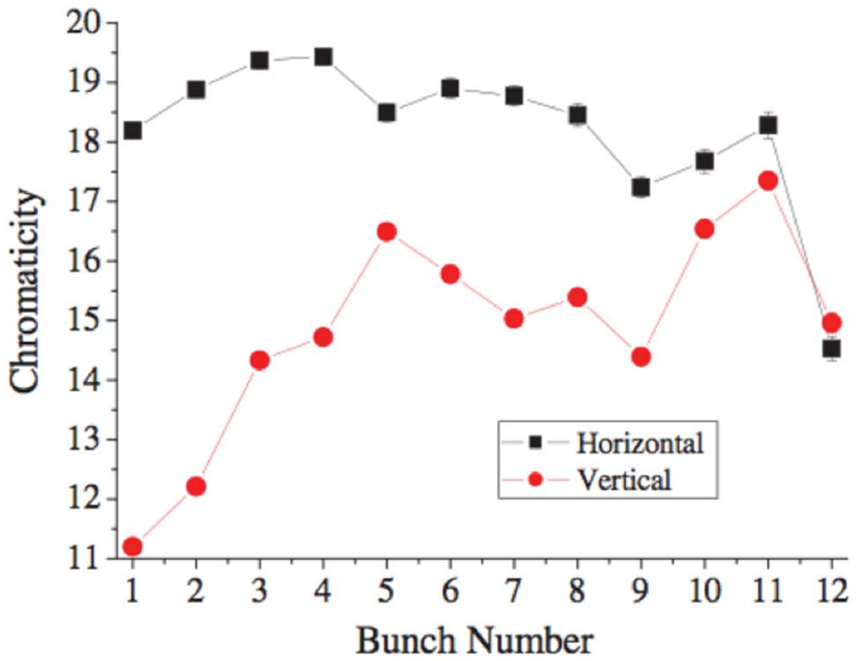


SBD=sampled bunch display
SL=synchrotron light monitor

Microwave Schottky Beam Diagnostics

Tevatron Individual Antiproton Bunch Tunes & Chromaticity





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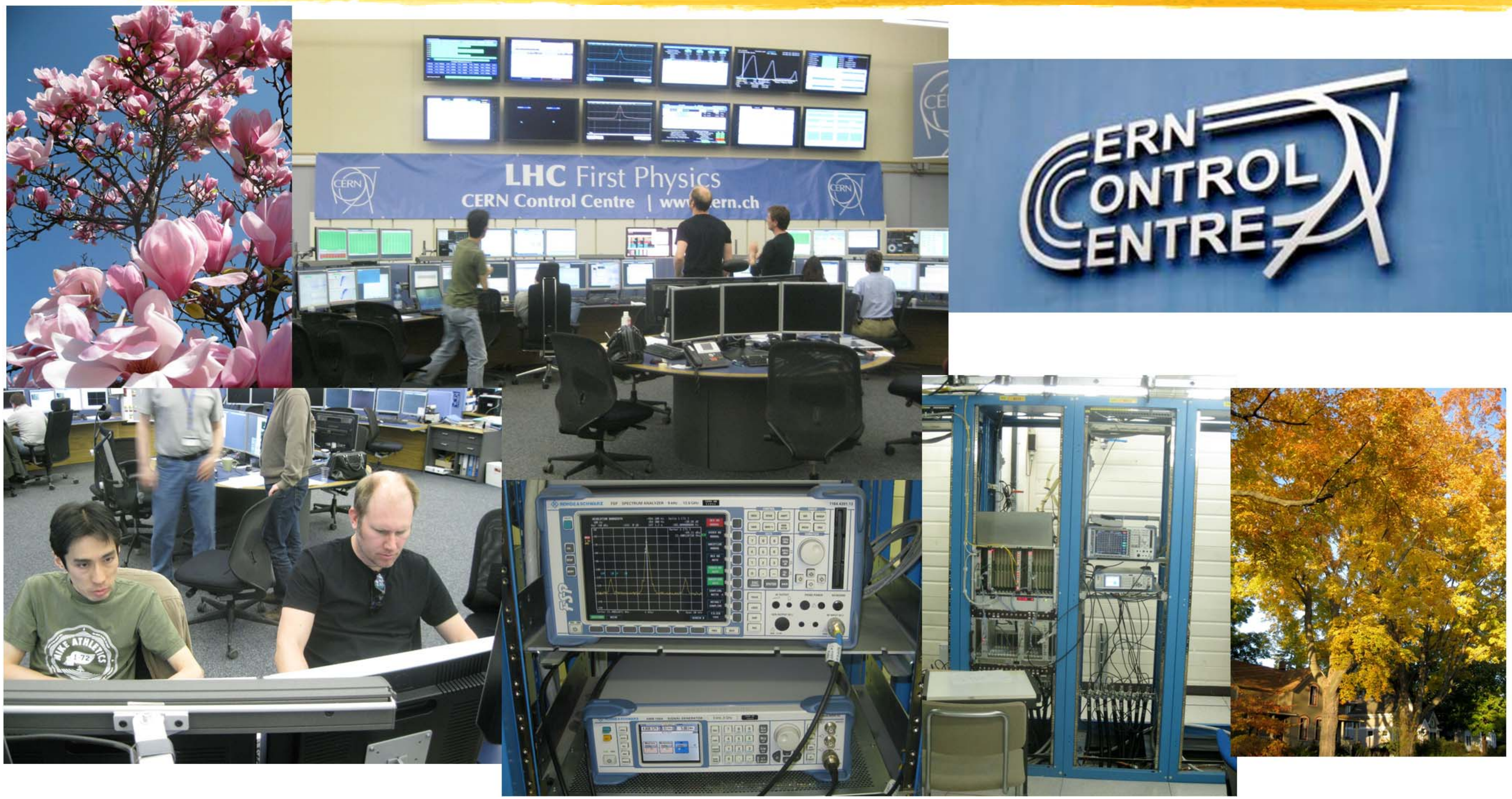
Commissioning Spring and Fall 2010



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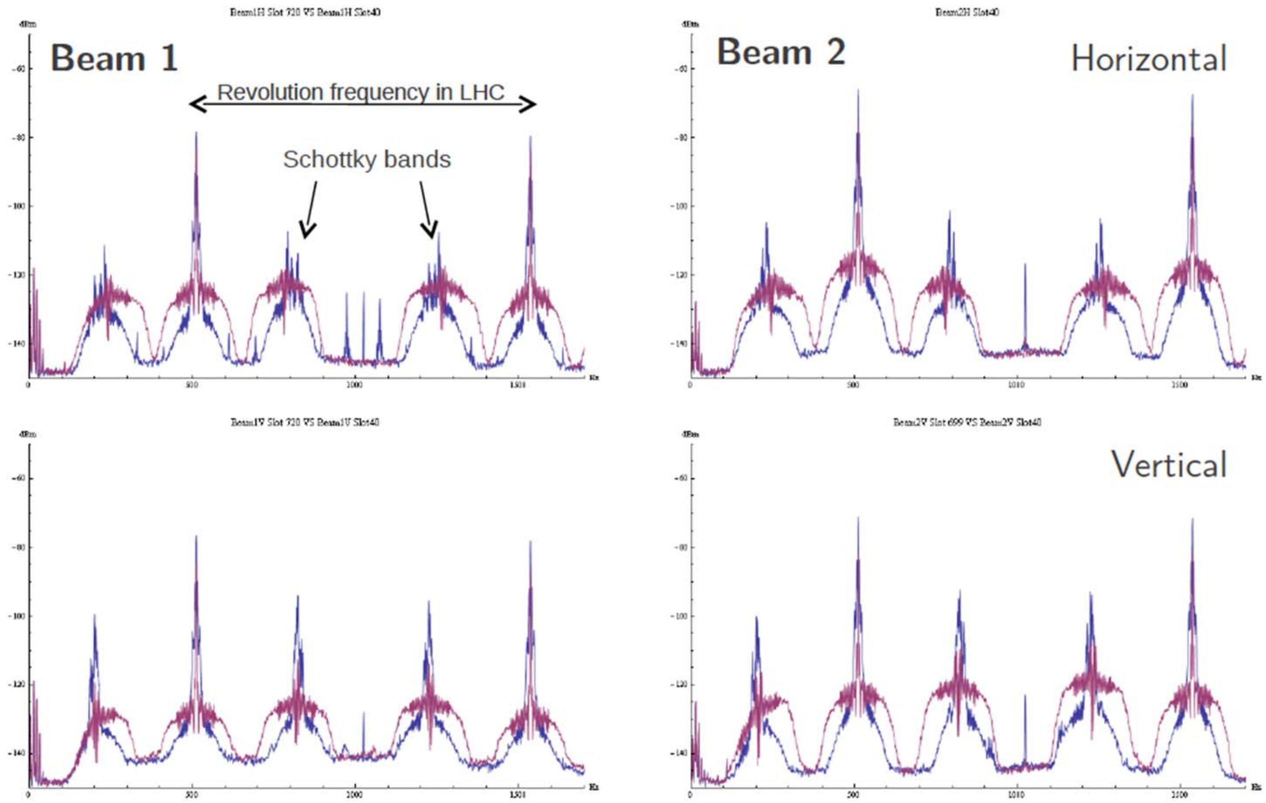
LHC Schottky Comparison Protons and Ions

- Protons
- Ions

Bunch by bunch spectra (stable beams)



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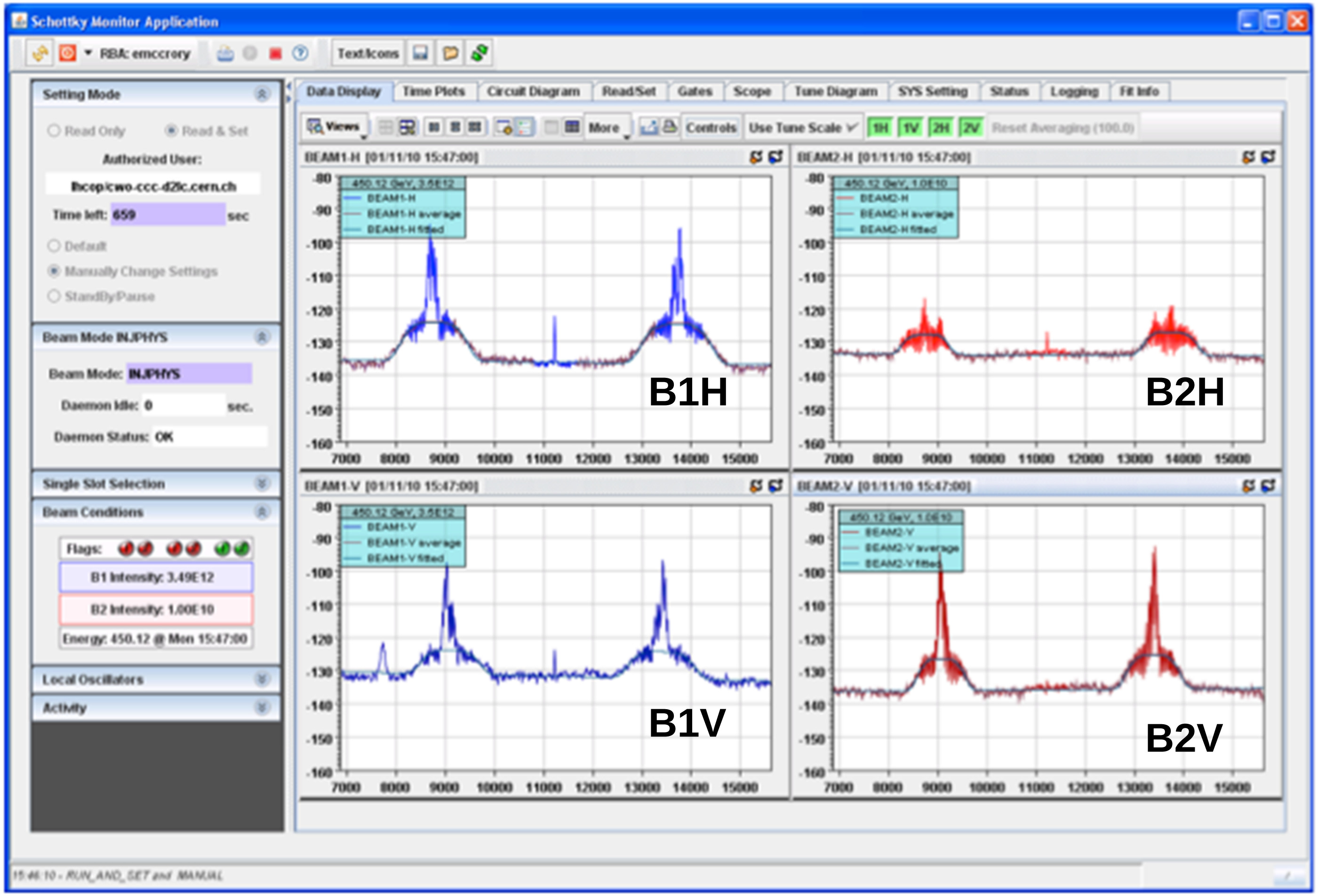
LHC Schottky Protons @ 3.5 TeV



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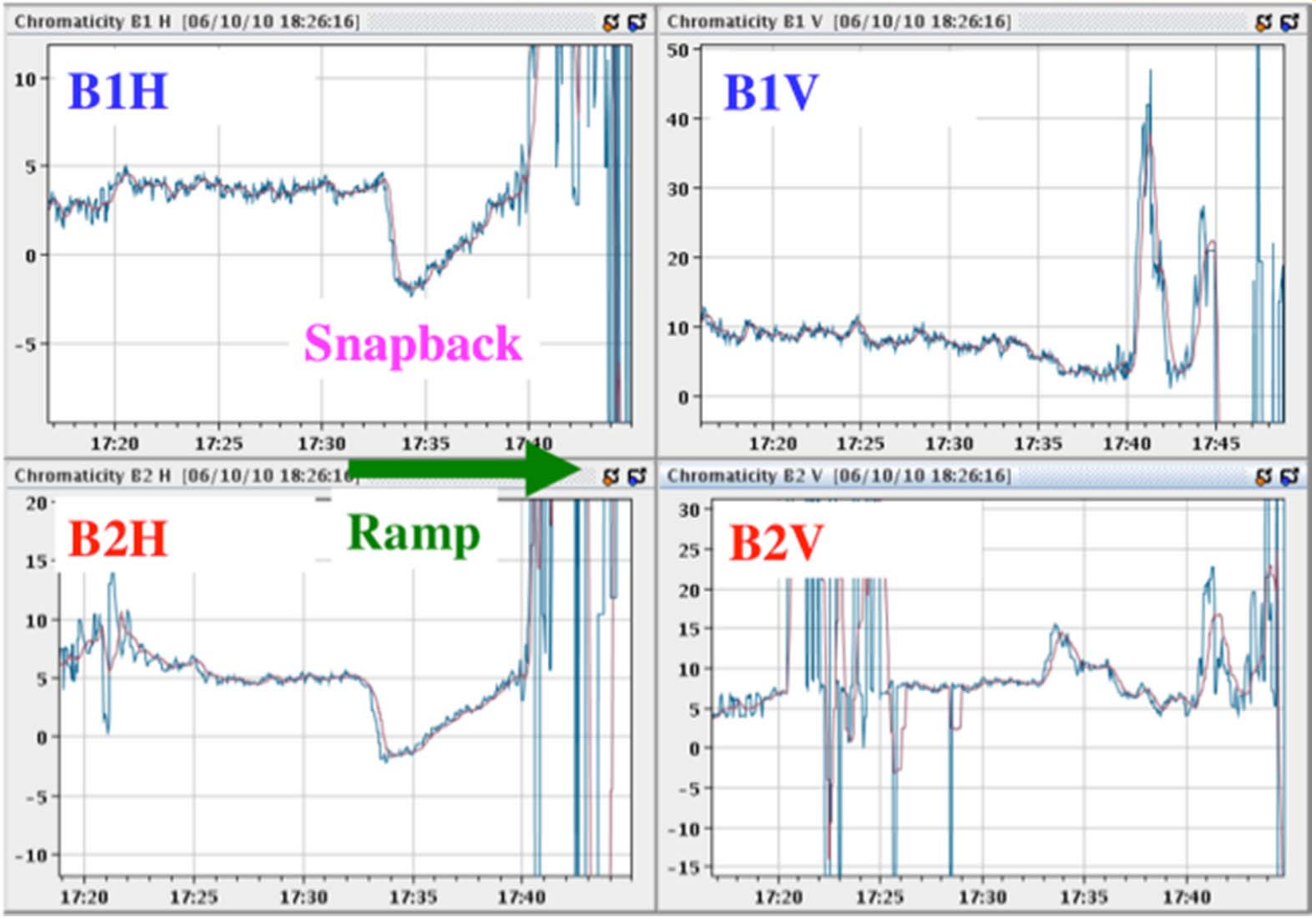
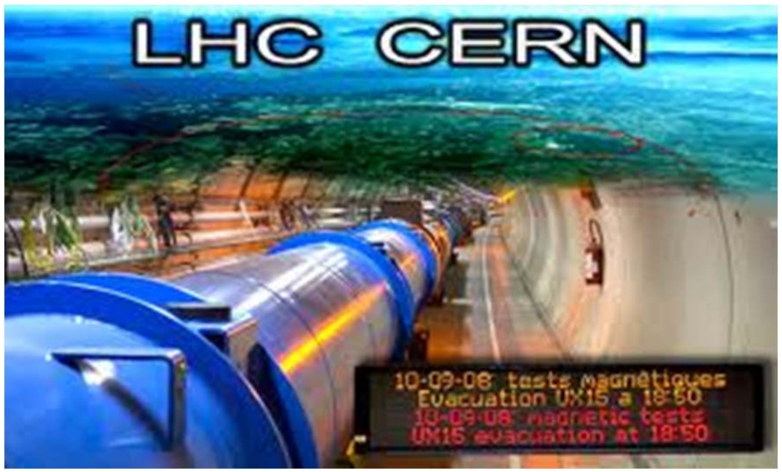
LHC Schottky Chromaticity Injection thru Ramp



Microwave Schottky Beam Diagnostics



⌘Summary

- H & V Pbar Schottky in Recyler 2003-2011
- H & V Proton + Pbar Schottky in Tevatron 2003- 2011
- H & V Proton + Proton Schottky in LHC 2009-Present
- Ability to measure tune, chromaticity, momentum spread
- Gating allows measurment of individual and any combination of bunches
- Emittance can be measured when calibrated
- 100 dB of dynamic range

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Microwave Schottky Beam Diagnostics

Thank You!