Tevatron Tunes Measurements: Status Report on 1.7 GHz and 21.4 Mhz systems, Sept 2004

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Introduction

This talk is a status report on recent work done on the tune fitters. As such, the topics addressed here are a bit disparate, at they reflect detailed issues, some resolved and other not quite yet completely understood. Most of the work done very recently was on the combined analysis of the 21.4 and 1.7 GHz data recorded during stores. The frequency spectrum obtained by these two systems are markedly different. Some differences are straightforward, given the large difference in the harmonic number at which the Schottky detectors operate. Other are not so simple, the phenomenology of the 21.4 MHz is particularly complex. Extracting the exact ``true" betatron tunes from the 21.4 MHz data with excited, large emittance beams –coalesced beams - is difficult.

Introduction: Issues..

A quantitative description of the ``coherent" (non ``Schottky") signals from the 21.4 MHz is difficult. Only semi-quantitative observations will be made. Understanding the frequency response of large emittance beams could become perhaps become relevant if we succeed at correlating the 21.4 MHz signals to the non-luminous beam losses.

A discussion of the proton non-luminous losses (or ``machine" losses) will be the subject of a separate talk. We report solely on the analysis of the 21.4 & 1.7 frequency spectra.

Note: Technical documentation at the Tevatron Tune Fitter can be found at http://www-ad.fnal.gov/tevtune/

Organization of the talk:

1. Are emittance measurements with the 1.7 GHz hopeless?
   1. Acknowledging a simple normalization bug.. Easy to fix
   2. Error modeling uncertainties..
   3. Some success => we do observe a true, genuine "Schottky" signal after all.
2. 21.4 MHz response on uncoalesced, small intensity, small emittance beam (brief) :
   1. Working, reporting data at 1Hz. To ACNET..
   2. Revived the TevChromaticity application..
3. 21.4 MHz with Coalesced beam, during Stores, & 1.7 GHz data.
   1. Observations on spectra from Ramp, Init. Collisions and HEP
   2. Comparison with the 1.7 GHz tunes => mysterious "eigen-frequencies" of the Tev for `coherent" signals..
   3. Yet, the 21.4 Mhz "sees" pbars !! (Once we know where the signal is..)

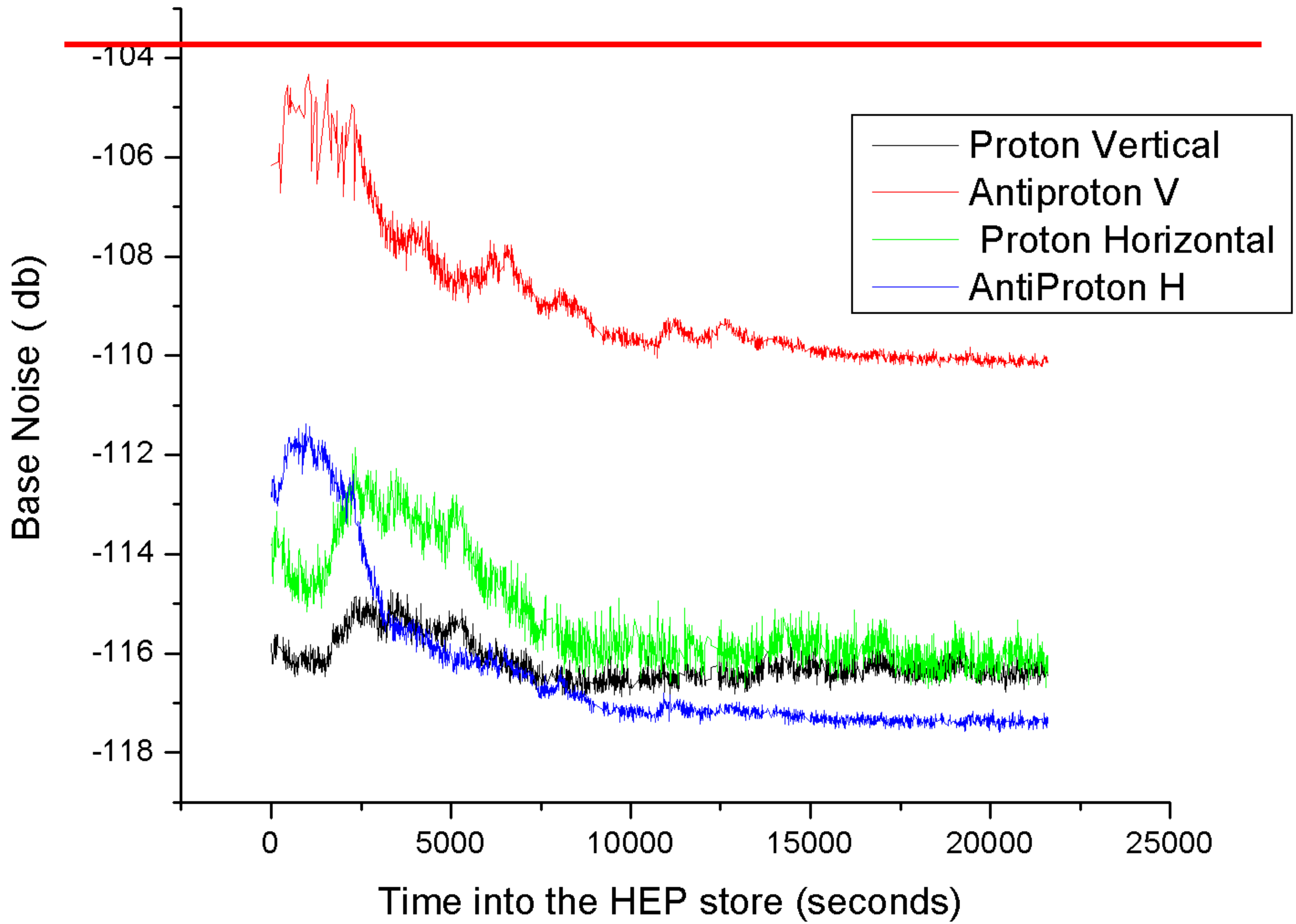
1.7 GHz Emittances bug: Summary

1. Andreas J. and myself noticed a very strong correlation between the noise level and the reported emittance.. After resurrecting the crude simulation class written ~ 1 year ago, and reading the code, identified a bug in output emittance re-normalization after fitting. (forgot to apply it for emittance, but not for noise level!) After correction, most of correlation is gone.
2. What kind of normalization is this? The minimization package, via the calculation of the fit chi-square, requires an estimate of the error for each frequency bin. While converting the VSA spectra, in db, to a linear scale, frequency bin content are re-normaized such that the noise level is ~ 1 unit (arbitrary).
3. Error model: The error on each bin is proportional to the squared root of the content… Easy to do in ROOT! (default).

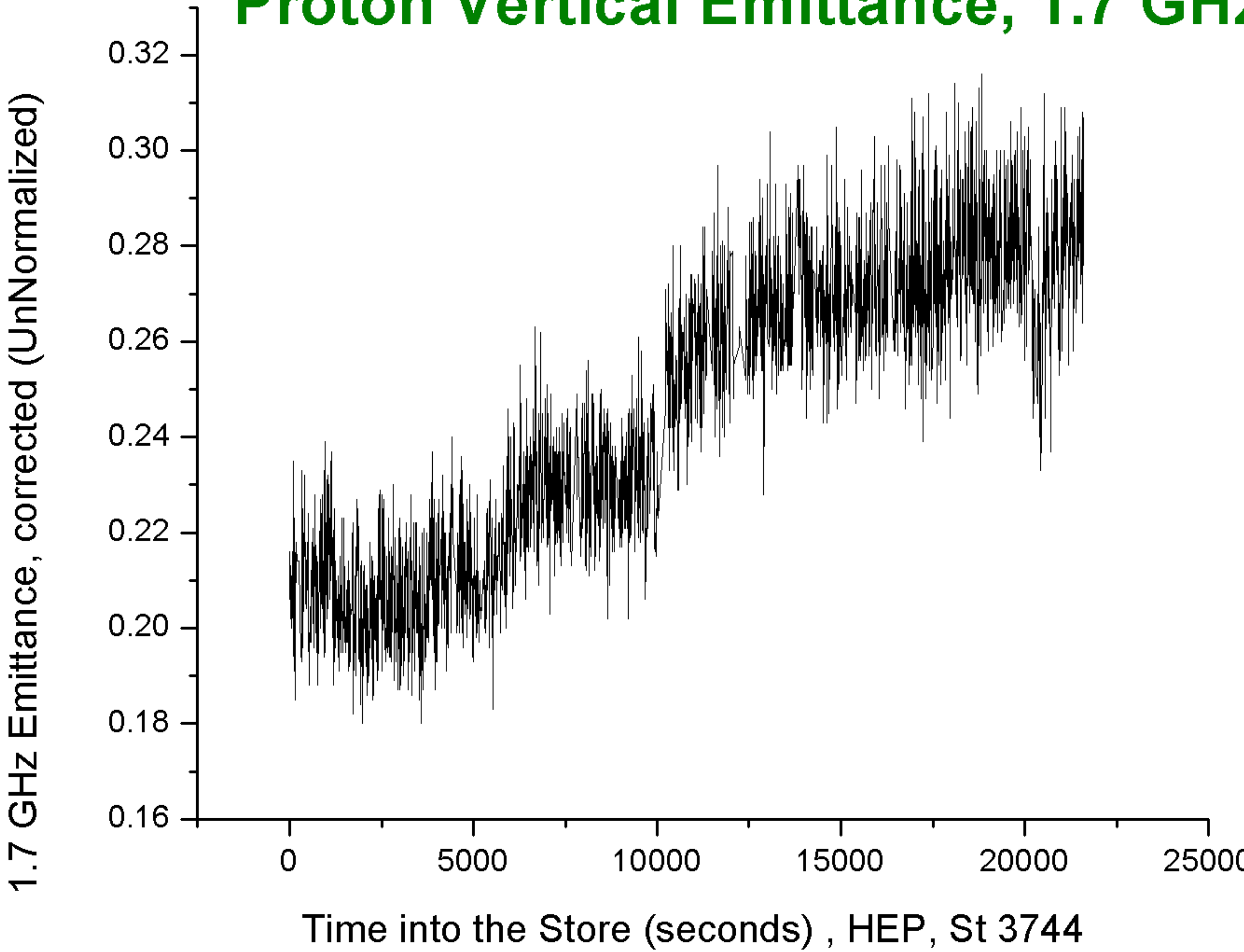
1.7 GHz Emittance Error Model & correction.

1. SQRT(N)?? This is not a statistical sample! Justification for such error model definitely suspicious, but not crazy:
    1. If errors are fixed to a constant, concerns of over-weighting the bins with a high value. If a frequency spike occurs, it will possibly shift the position of the fitted tune
    2. If the errors are proportional to amplitude (fixed relative error), noise level will be down-weighted..
    3. Compromise: somewhere in between a fixed absolute and fixed relative…
    4. Need more study to empirically see what's best!!! Or a more formal approach?
2. Since the Noise Level was data-logged, one can re-construct this normalization constant and fix the emittance data offline.

Baseline Noise vs time, Store 3744



Proton Vertical Emittance, 1.7 GHz



1.7 GHz Emittance Corrections.

The fitted signal strength (T:TULPVE) is

a. corrected for the renormalization error (multiply by the k*10**(T:TULPVN*0.1)), where k is an arbitrary constant.

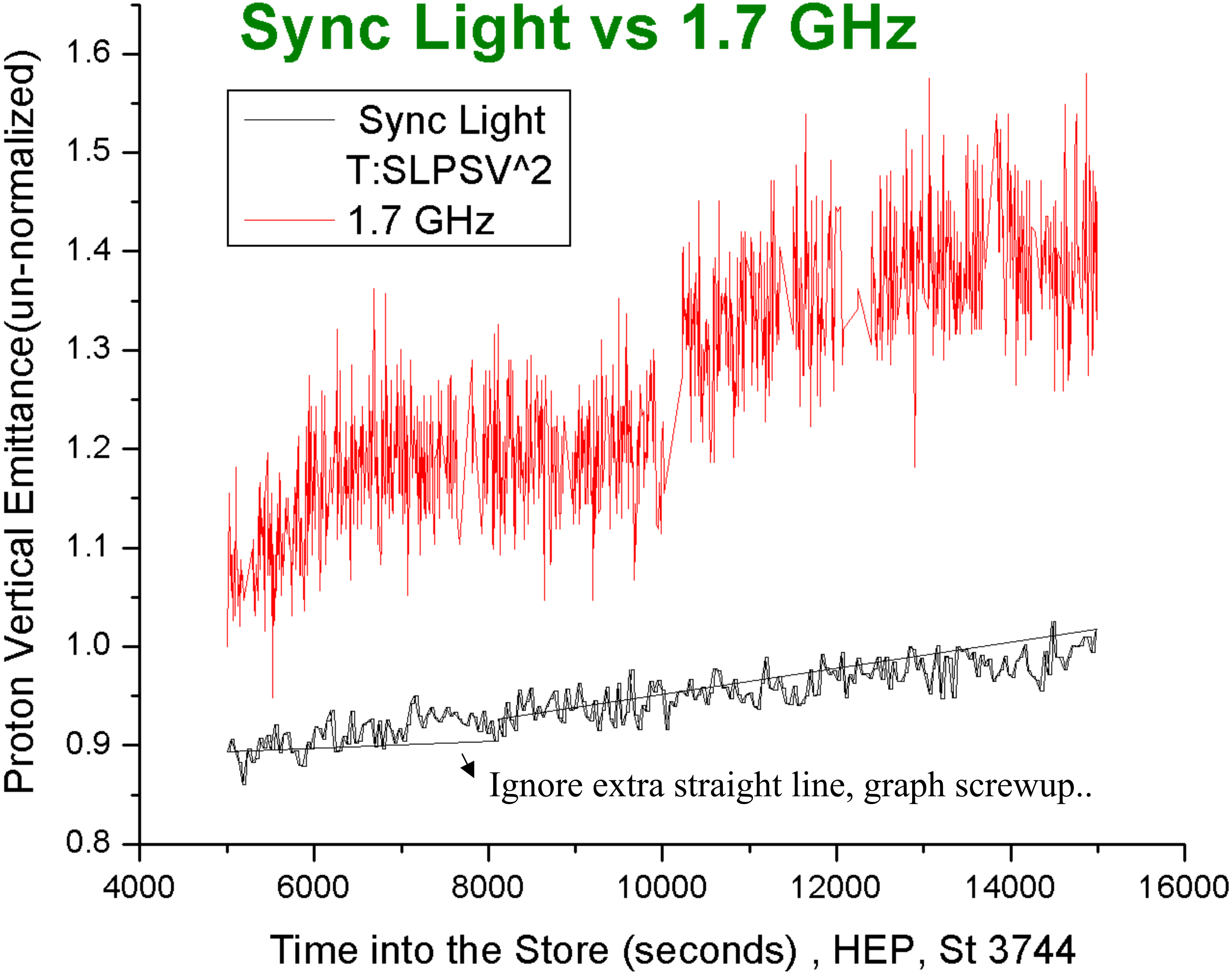
b. divided the square root of the beam intensity (This assumes a pure Schottky noise!)

➔ Obtain a "un-normalized", transverse emittance, but in principle independent of the noise level..

➔ The arbitrary constant k should by independent of time and beams!

- ➔ Proton vs Pbar, at end of store 3744: from flying wire, ratio of emittance Proton/Pbar is 26/19 pi mmrad. For 1.7 GHz data, I got 0.28/0.71 ???????????? (This assumes that the observed signal strength is proportional to the bunch intensity)
- ➔ Vs time.. What's expected? Do we know the answer? And, within a few %?

Proton Vertical Emittance, Sync Light vs 1.7 GHz



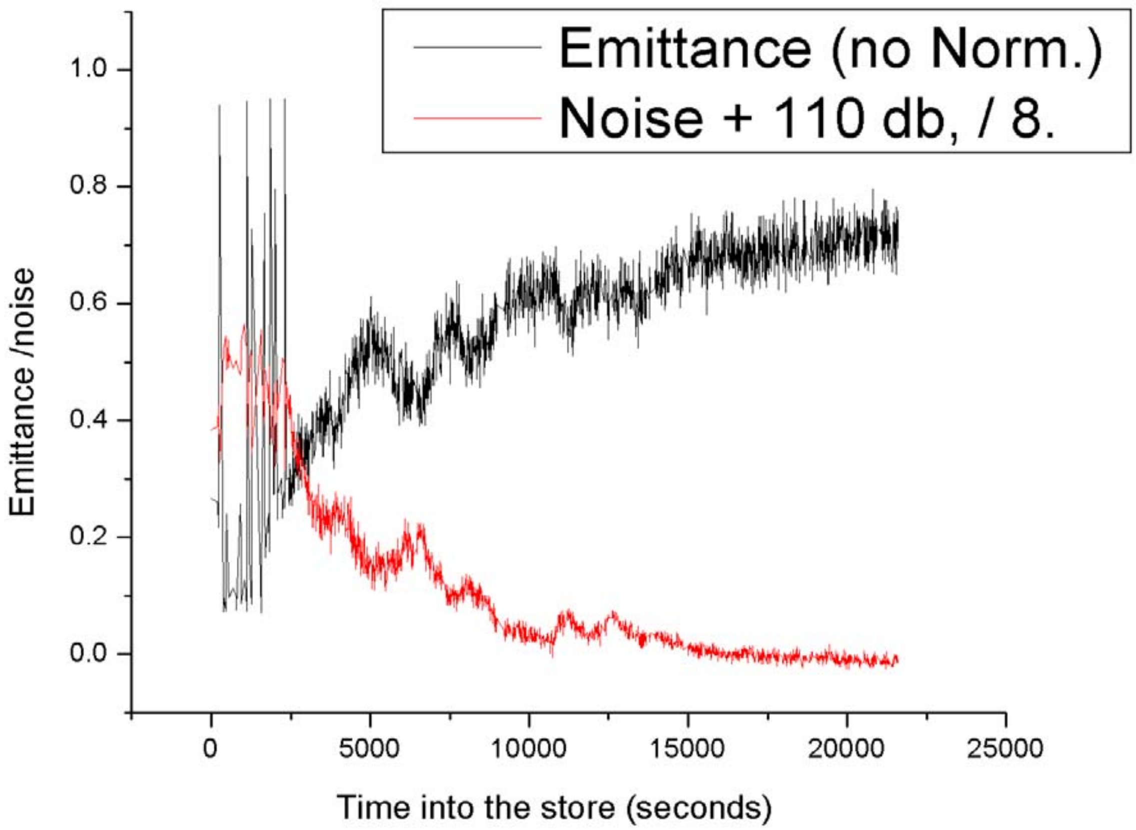
Emittance Growth, Crude..

- No corrections for
  - 1.7 GHz Noise level fluctuation (see next slide)
  - No Sync-light correction for possible light diffusion…
- Linear fit, after $5000 < t < 15{,}000$ seconds (3 hours, after ~ 1.5 hours to let nasty coherent noise fluctuation die away..) got vertical proton emittance growth rate of 10% (relative) per hour, while Sync-light gets 3.8% per hour..

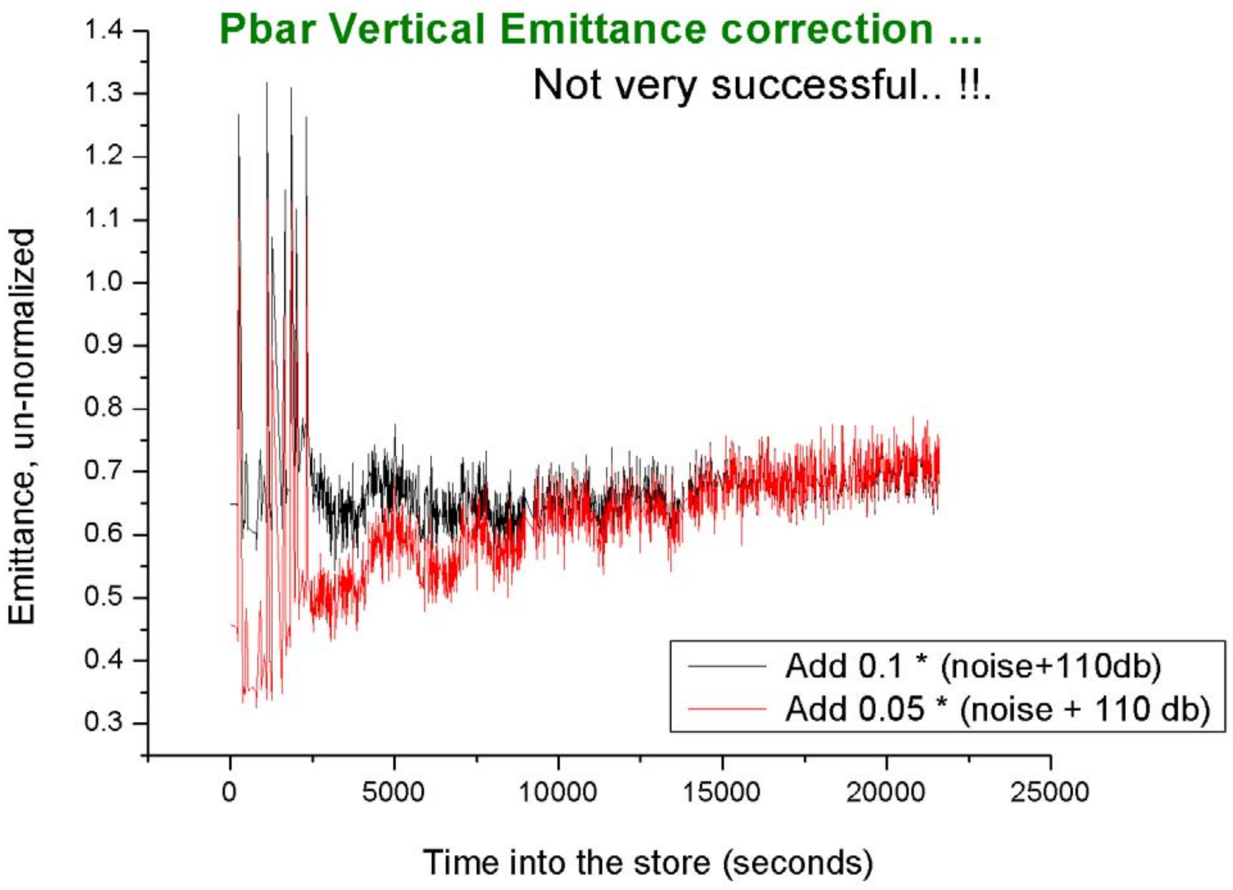
Reaching an accuracy of ~ %/hour is difficult, but interesting: this is the scale of IBS, consistent with observed luminosity lifetime during the store…

Residual Noise – Emittance correlation…

Pbar, Vertical



Attempting to correct, linear correction…



Outlook for 1.7 GHz Emittance

Correction for noise fluctuations still required if one wants to measure ~ few %/hour (relative) emittance growth..

Not easy without careful calibration.. !! Costly: need dedicated beam time as we need to fly the wires…Also, how reproducible such calibration will be ?

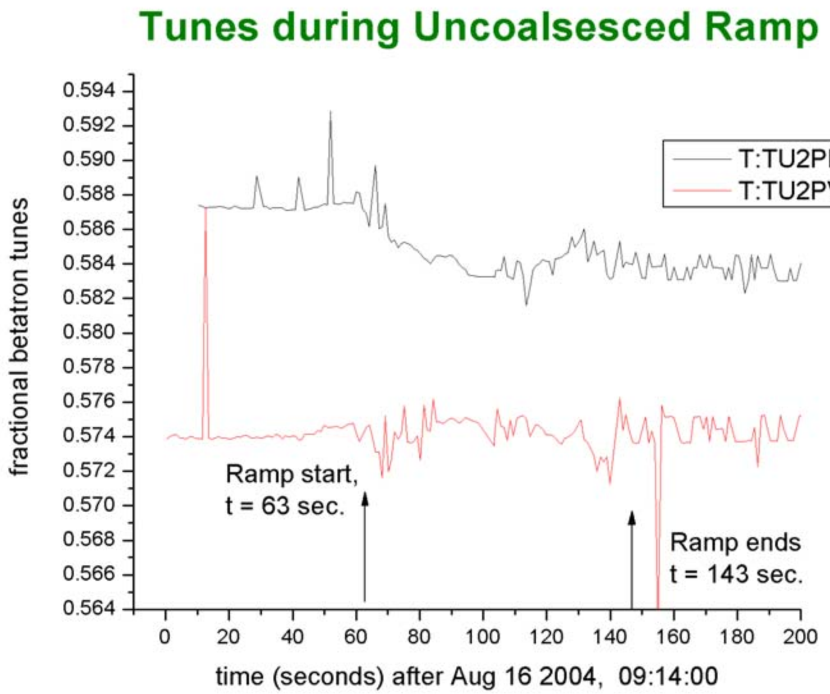
Further hardware improvements ?

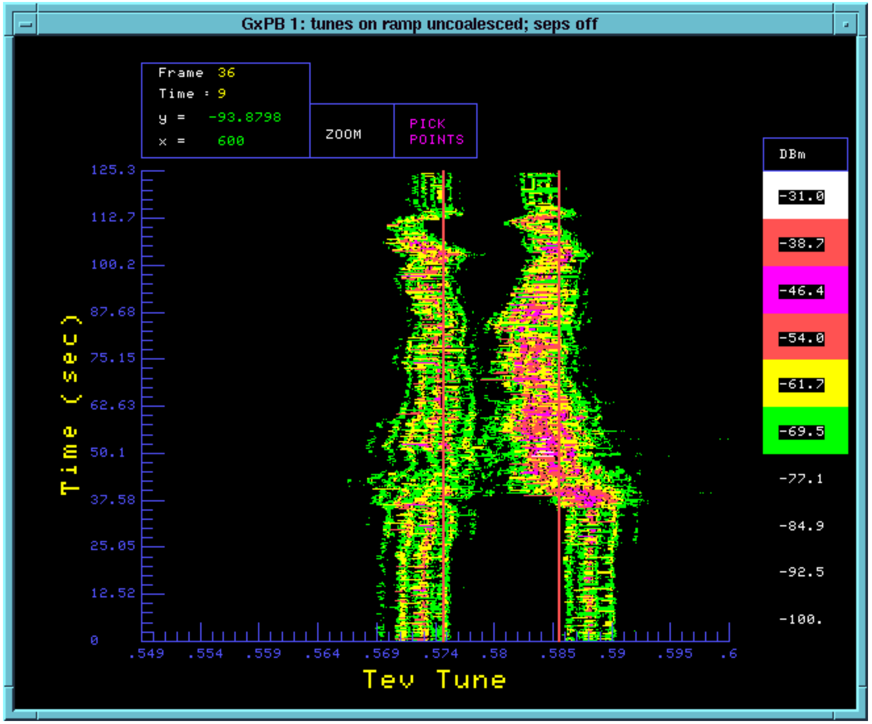
Meanwhile, could definitely study the error modeling business…

I'll save raw spectra and we will refit offline using different error models.

And fix the emittance re-normalization bug online.

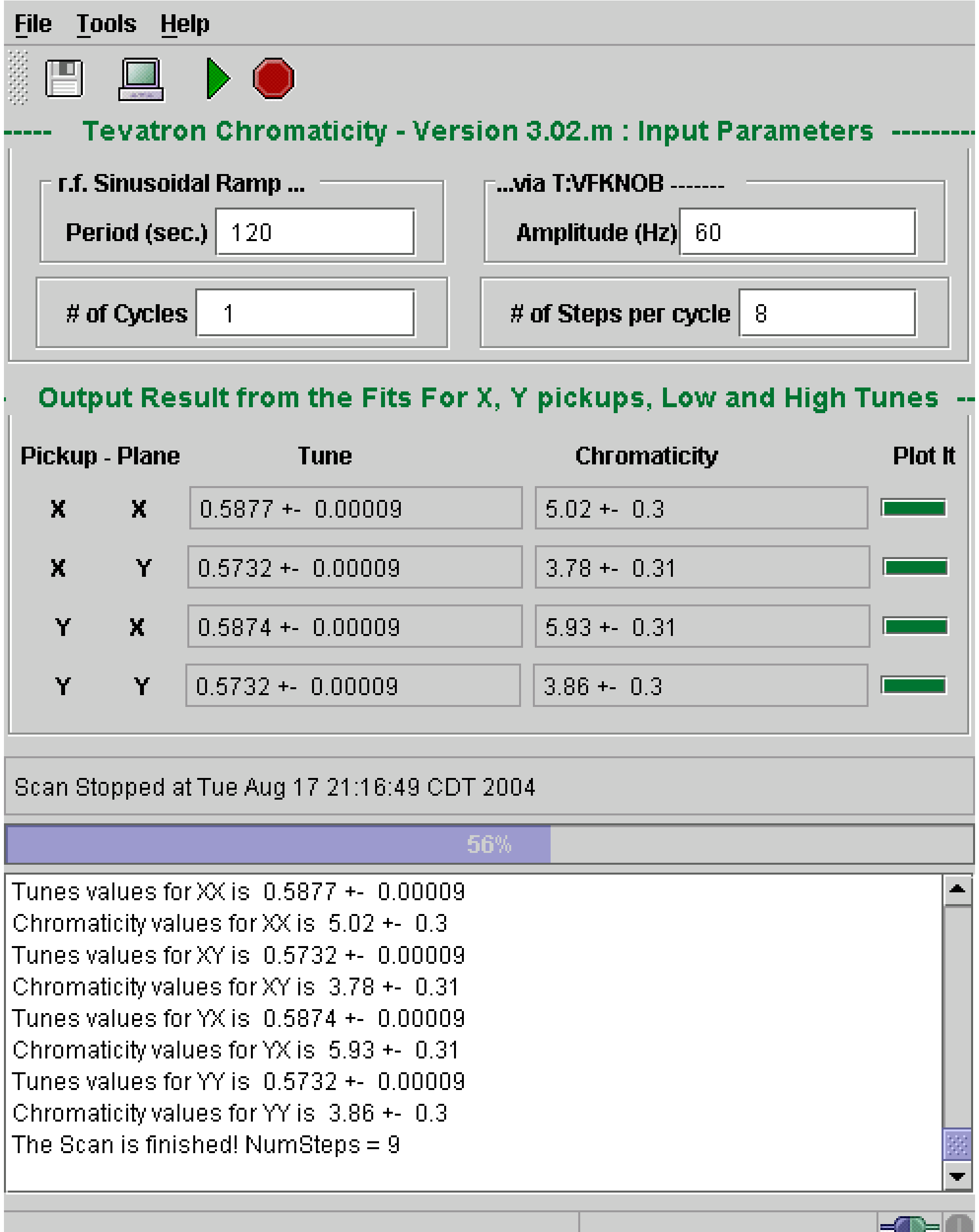
21.4 MHz, Uncoalesced: Status… Running..





Operational, running smoothly during shot-setup and studies..

Works best when V:Tickler is on.. Still provide valuable information when tickler is off. This includes Ramp…



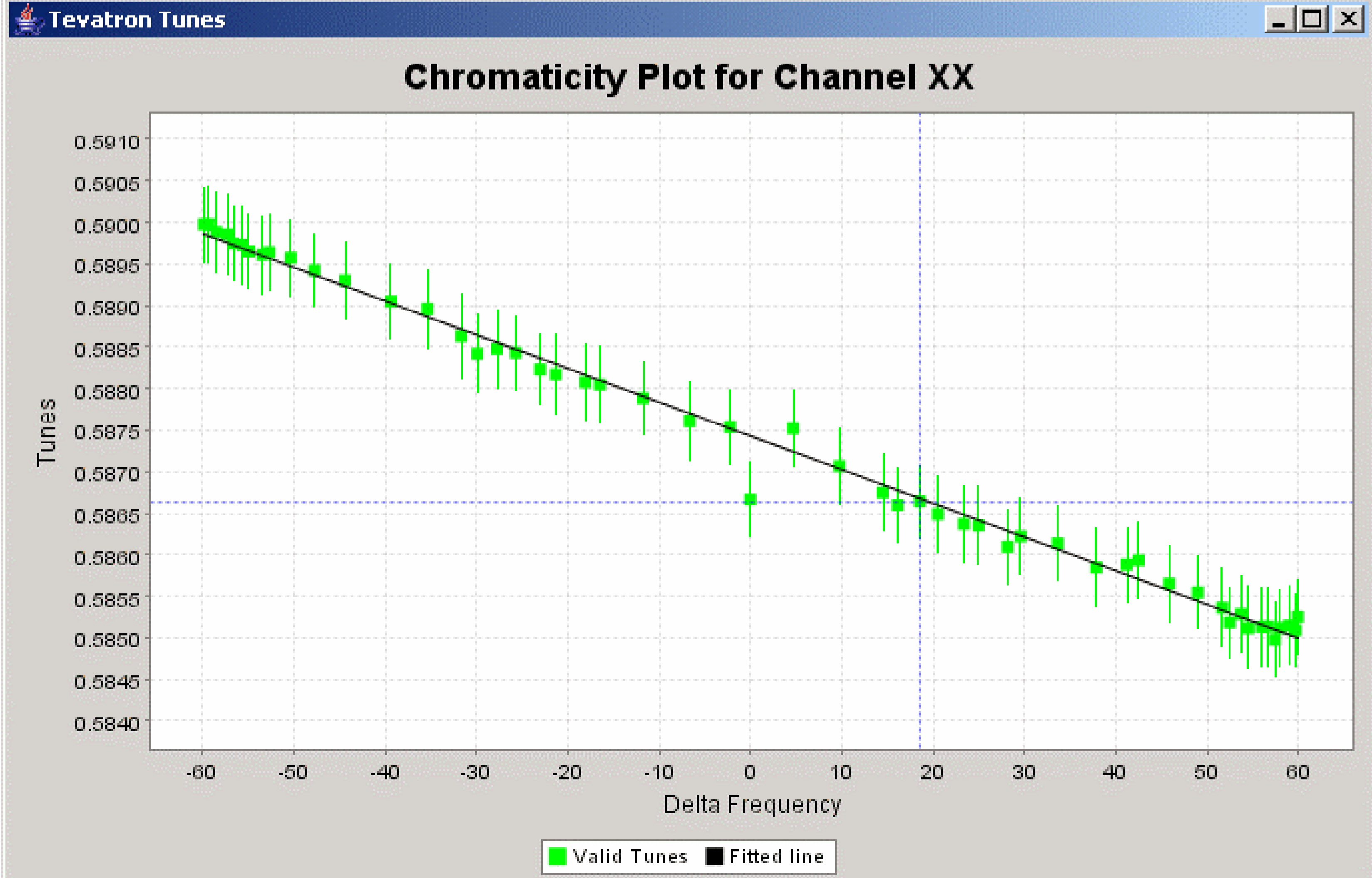
TeVChromaticitiy

Restored and running upon Demand.

Brief User guide:

- Uncoal. Beam 150 in Tev
- Turn V:Tickler On. (optional)
- Separate tunes
- Start TeVChromaticity
- Press green button
- Optionally, change setting to data more data..or at greater dP/P..

- That's it it!



You can also let it run longer, to check reproducibility or drifts.
Note: Error are overestimated.. And no sign of non-linearity over +- 60 Hz

New Coalesced Data, 21.4 MHz

In addition to performing two Gaussian fits, raw spectrum have been saved during Ramp, Squeeze, Init Collision and HEP for the last 3 store of FY04 running. (3739, 3744, 3745)

As seen in the next few plots, this data is very complex. During HEP, it is not surprising that a simple 2 or 3 Gaussian fit gives tunes that not exactly consistent with the 1.7 GHz system, given the messy character of such spectra.

The 21.4 MHz are definitely not “pure Schottky”. Uncoalesced beams at 980 without excitation are barely visible on HP3561 Spectrum Analyzer, and the 100kHz ICS digitizer card sees almost nothing but white noise. For coalesced coasting beams, without excitation (no machine change, no tickler, no collision), we see almost no signal at all. The strength (Relative power per frequency bin, obtained via FFT) depends on various beam excitations mechanism.

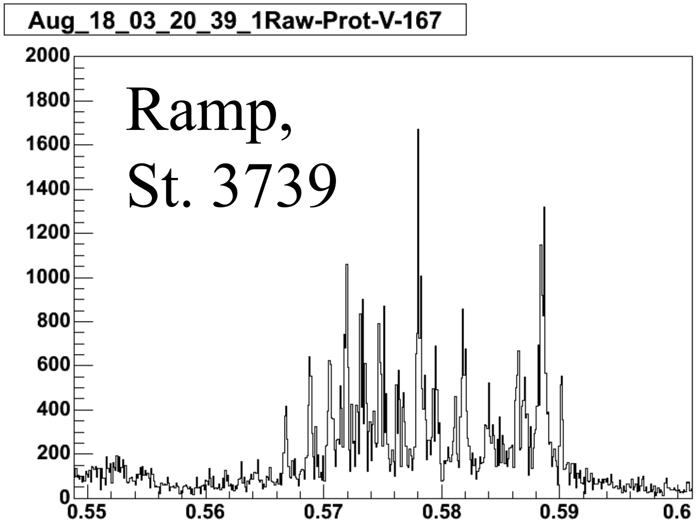
21.4 MHz, Brief Parameters & Methods.

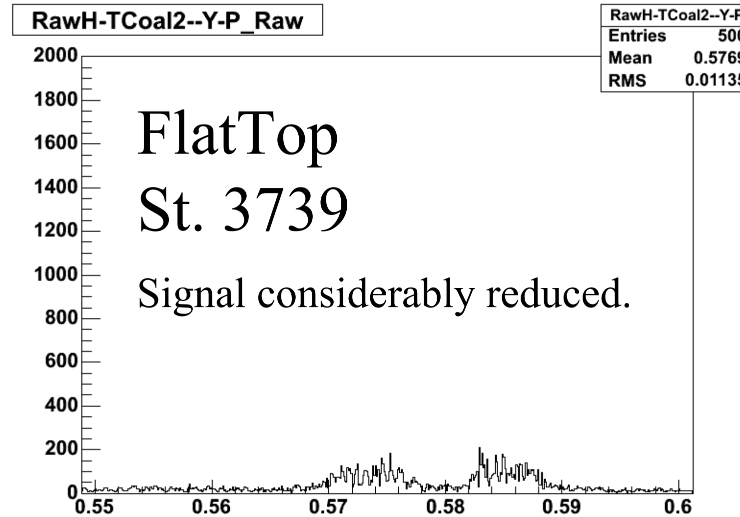
The ICS-110B card digitizes at 100 kHz, 20,000 samples at a time, (corresponding to 0.2 seconds sweeps), concurrently on 4 channels (only proton channels will considered in this analysis)

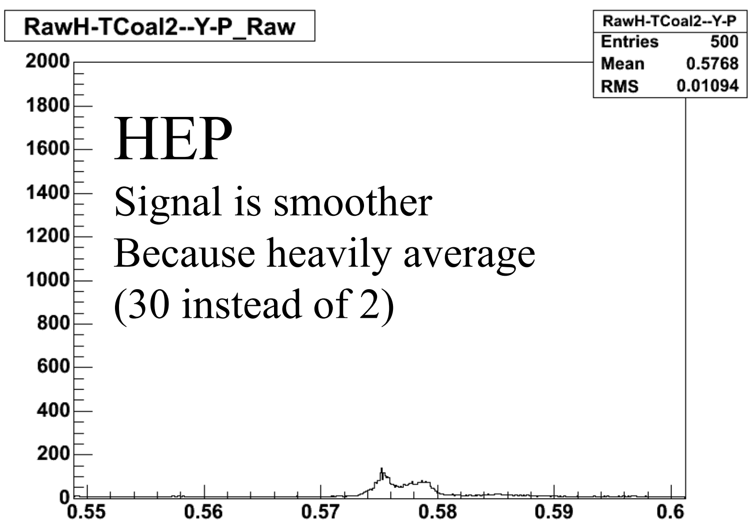
The FFT takes little time, the system delivers frequency spectra at a maximum rate of ~ 4 Hz These are 500 bins wide, the center frequency is set to 27.437 kHz. The frequency bin width is 4 Hz, corresponding to 0.0001048 TeV. Fractional tune units (rev. frequency is 47713, at 150).

Data is transferred to OAC ``tevics" running on node dce03, via ACNET, and from there, to node dce04 for fitting. Spectrum are averaged, we typically do one fit for every two spectrum received. During HEP, we average 30 spectrum before saving to disk, but execute the two-Gaussian fits for every 2 spectrums received. Fitting algorithms are state specifics, range from a simple 2 Gaussian to a search for synchrotron tune over multiple ranges of betatron tune values.

Raw 21.4 MHz Signals, examples..

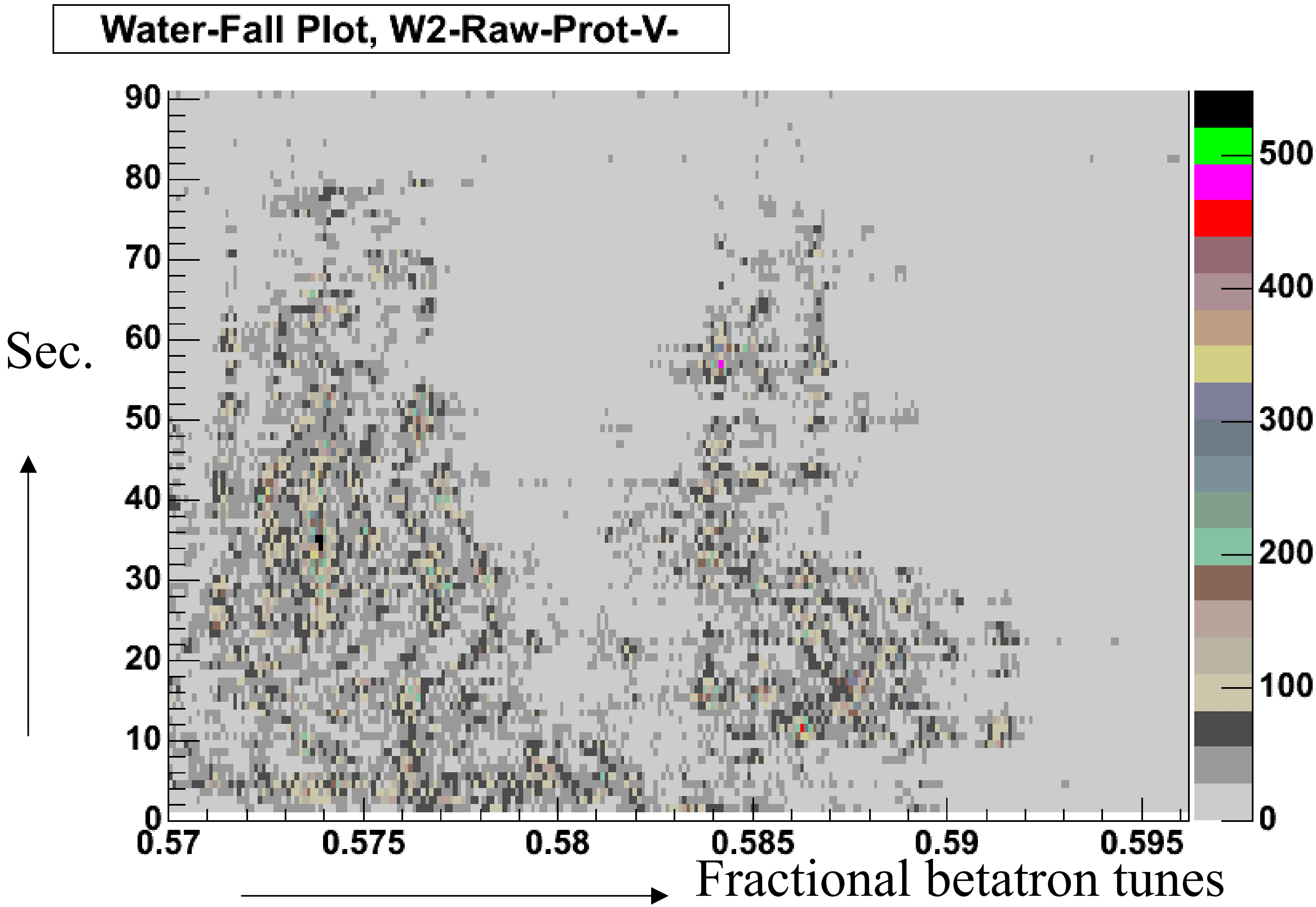






Signal shape and complexity depend on the state of the TeV. Maximum beam excitations occurs on the Ramp. Although feeble, signals during HEP can be analyzed, when properly averaged.

Ramp Raw Data, Vertical, Store 3739



Or Animation Based on 1D plots..
Show Movies

21.4 MHz, Ramp Data, Uncoalesced.

Evidently, we do not see a pure Schottky signal.. Some sort of beam excitation is obvious. Note that the MCRVSA data we record for every ramp is also messy. => not a feature of the digitization process, a beam feature.

Also, why is the beam suddenly quiet when we reach ~750 to 800 GeV? (Also observed in the 1.7 GHz.. Andreas, is this still correct?)

Is this worth studying?

Cons:

Too complicated, we'll never resolve anything with such jittery data…

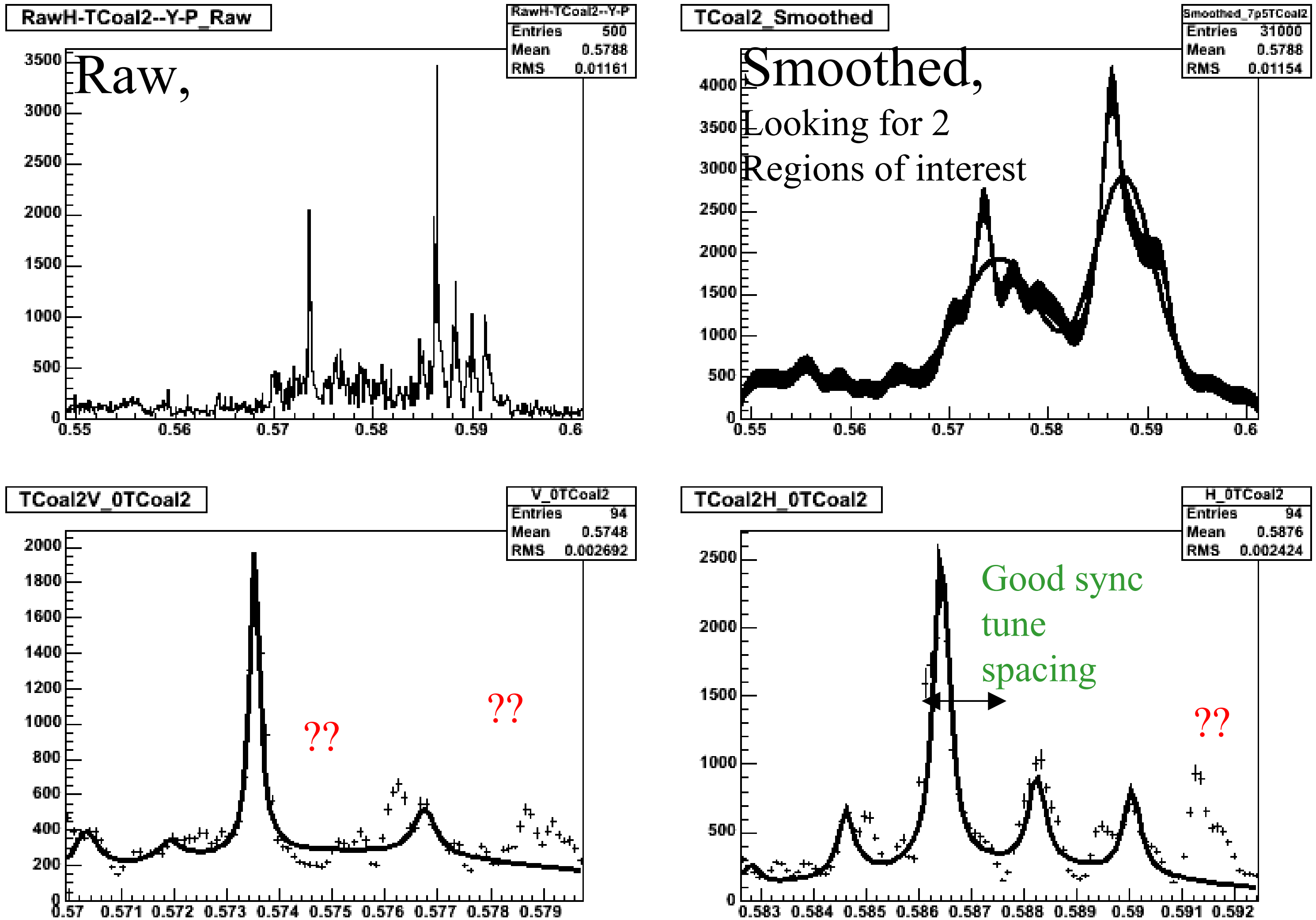
Pros:

We can't afford to to numerous ramp studies with uncoalesced beam…

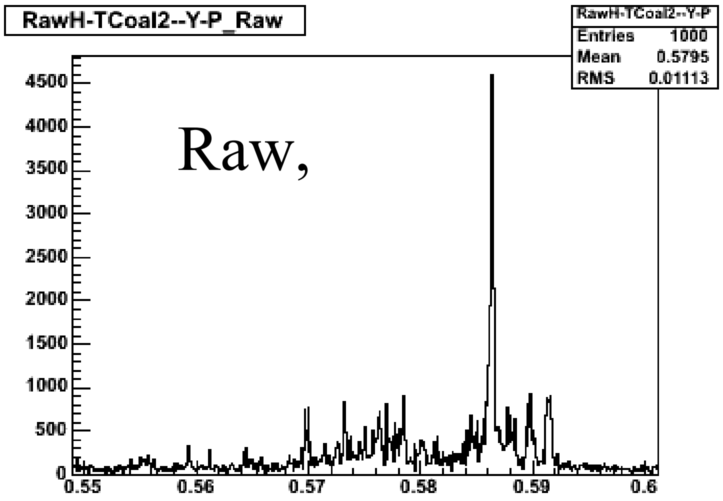
That's data that counts, that is store data!

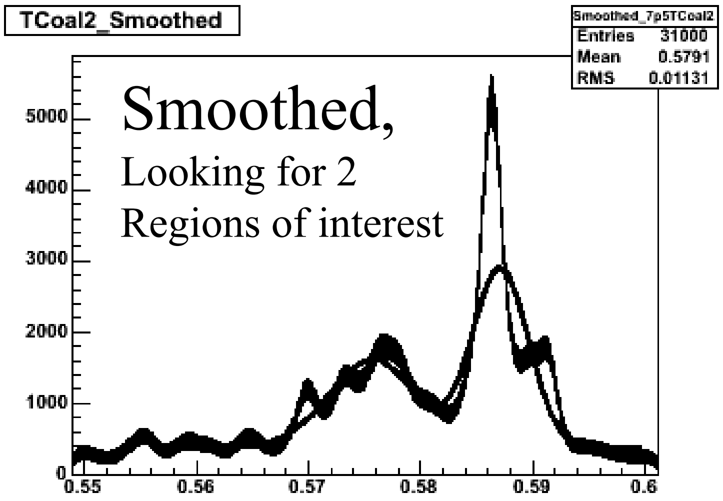
What if such beam excitations play a significant role in the tune tracker C. Y. Tan is building?

Ramp Data, St 3739, Vertical pick-up, hunting for synchrotron Tune..
Same algorithm used for uncoalesced beam



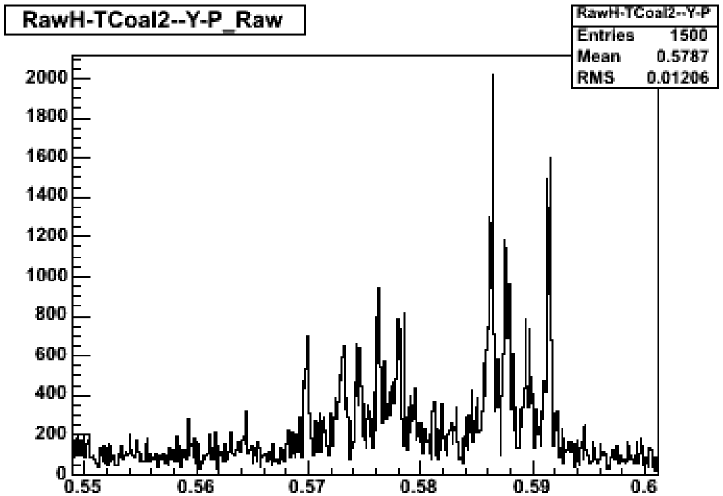
Ramp Data, St 3739, Vertical.. 1 second later.

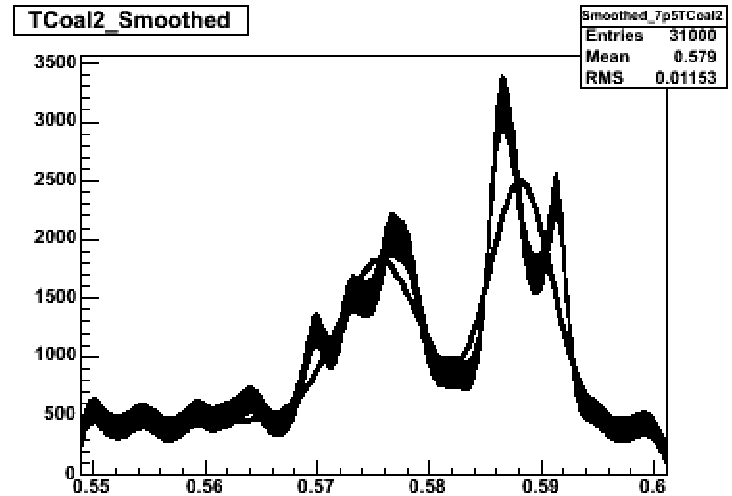




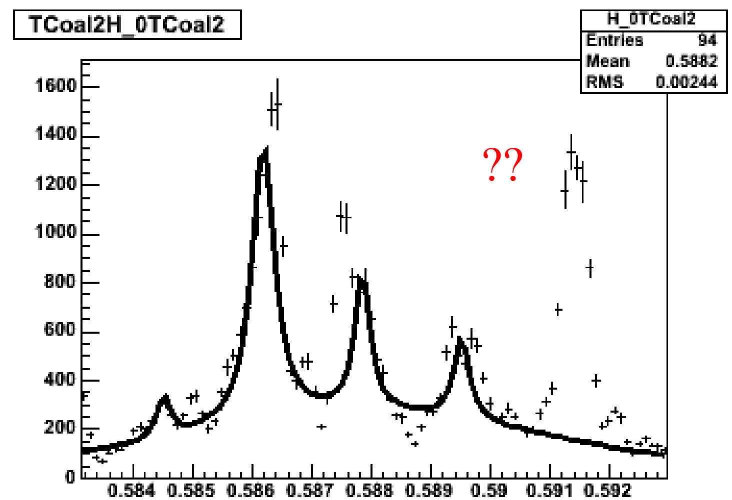
For this sweep, on both plane, no consistent set of 5 Breit-Wigner set of curves was found. (The fit requires a fixed spacing between the spikes, consistent with expected synchrotron tune).

And 0.5 second later..





We got a "synchrotron tune" on the horizontal tune, but, asymetric heights?
What is the peak on the left ?
Is the width consistent.



21.4 MHz, Ramp Data, Other Models?

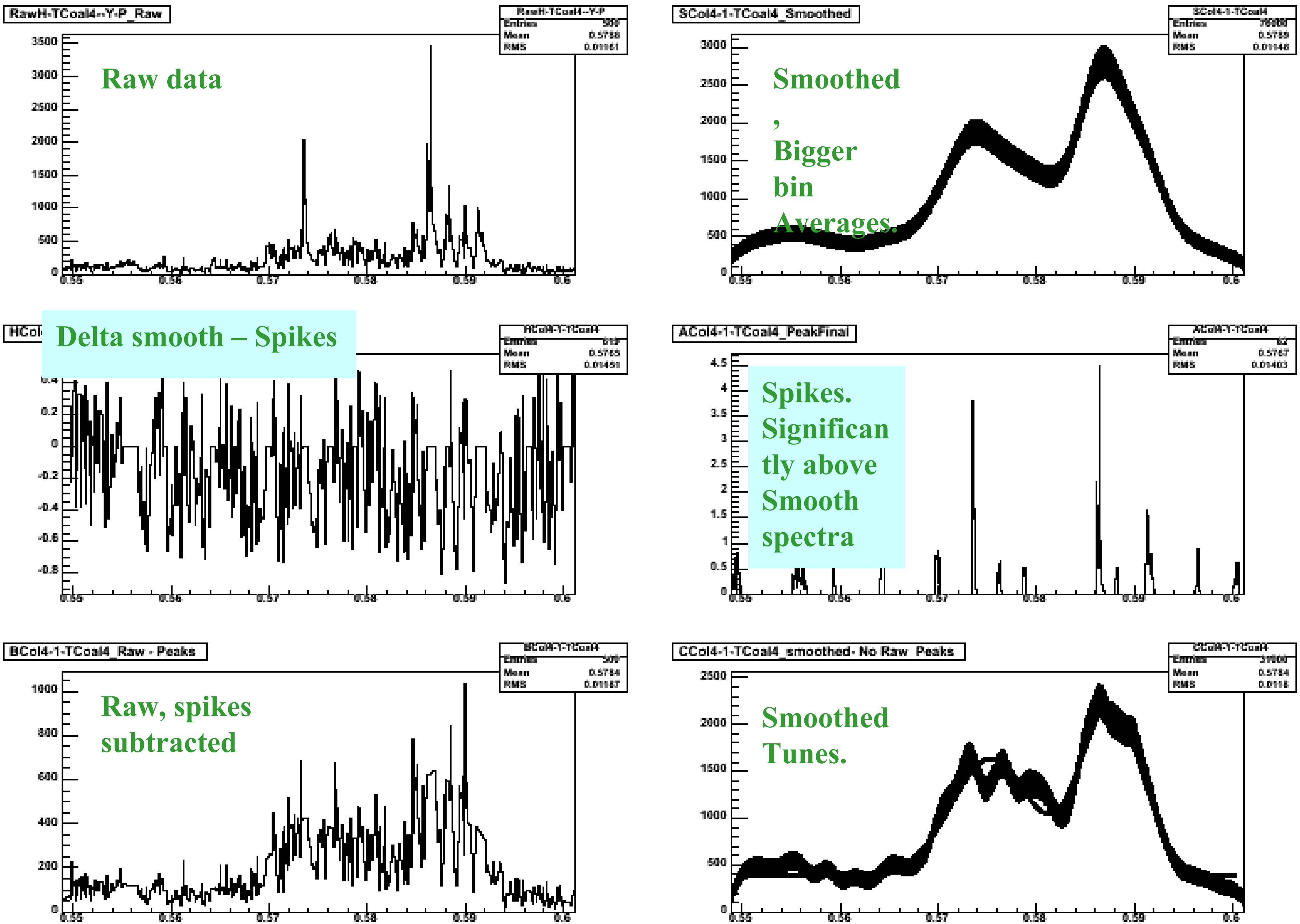
While Synchrotron tune can be accurately measured and compared with expected values (we now the r.f. voltage), that is, for Uncoalesced beams, this model is not very successful for Coalesced beams

Not too surprising: when the longitudinal emittance is large, the synchrotron tune varies from the minimal value (small or negligible longitudinal emittance) to … 0 Hz .. -> not a fixed value!.

Let us start with a strict phenomenological approach of these spikes:

Let us collect these spikes throughout the ramp (or squeeze..), and see if there is a pattern…

New fitting algorithm, step by step.. Smooth, renormalized with respect to Raw and hunt for spikes. Subtract these spikes.


RawH-TCoal4--Y-P_Raw
Raw data
SCol4-1-TCoal4_Smoothed
Smoothed
,
Bigger
bin
Averages.
Delta smooth – Spikes
ACol4-1-TCoal4_PeakFinal
Spikes.
Significan
tly above
Smooth
spectra
BCol4-1-TCoal4_Raw - Peaks
Raw, spikes
subtracted
CCol4-1-TCoal4_smoothed- No Raw_Peaks
Smoothed
Tunes.

Obvious problems with such (naïve) algorithm

Without proper handling of noise, hard to determine what it means.

The number of such spikes is in fact arbitrary.

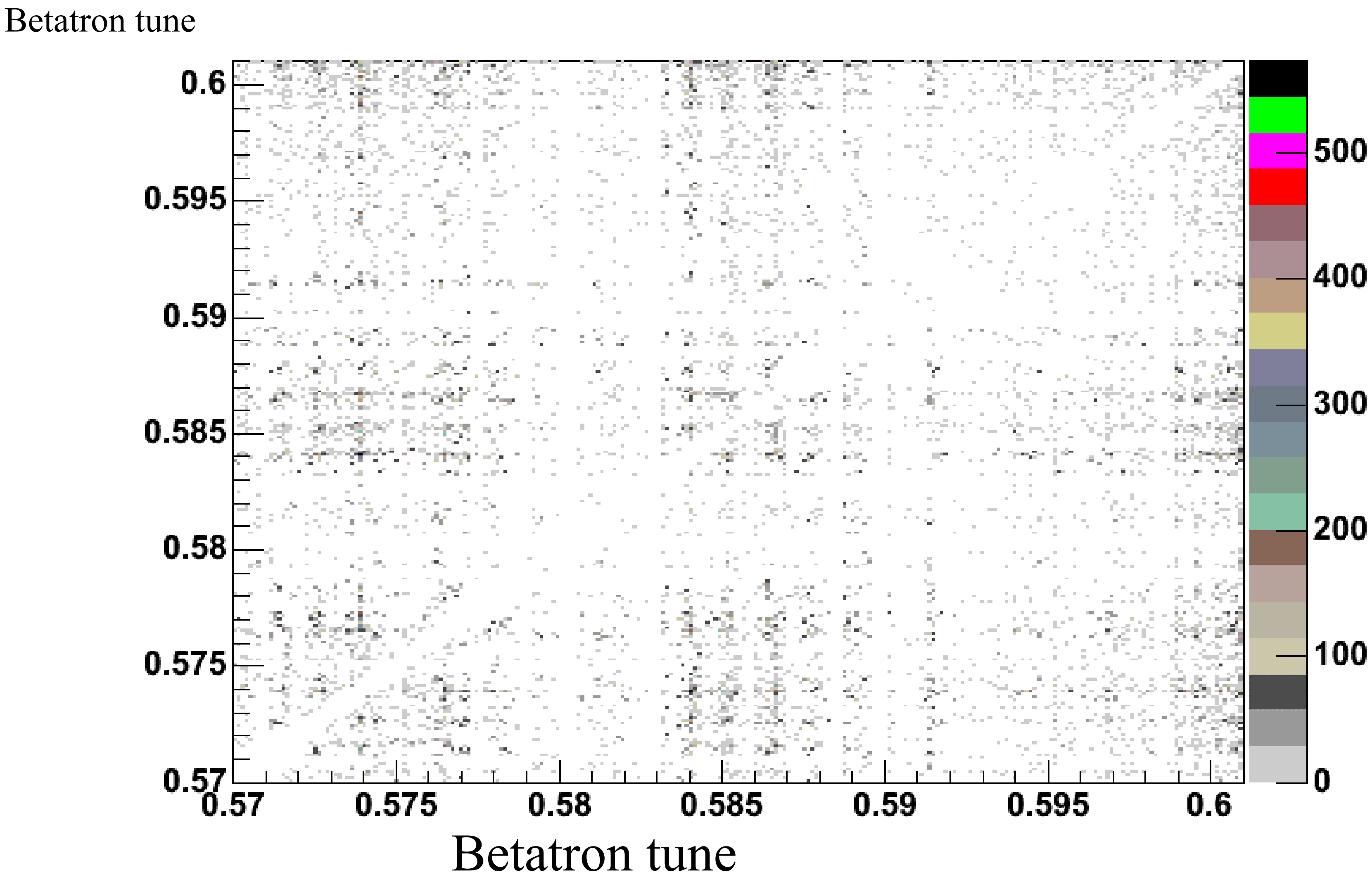
"Eye-ball tuning of smoothing parameters and spike threshold!.

→ Semi-quantitative analysis…

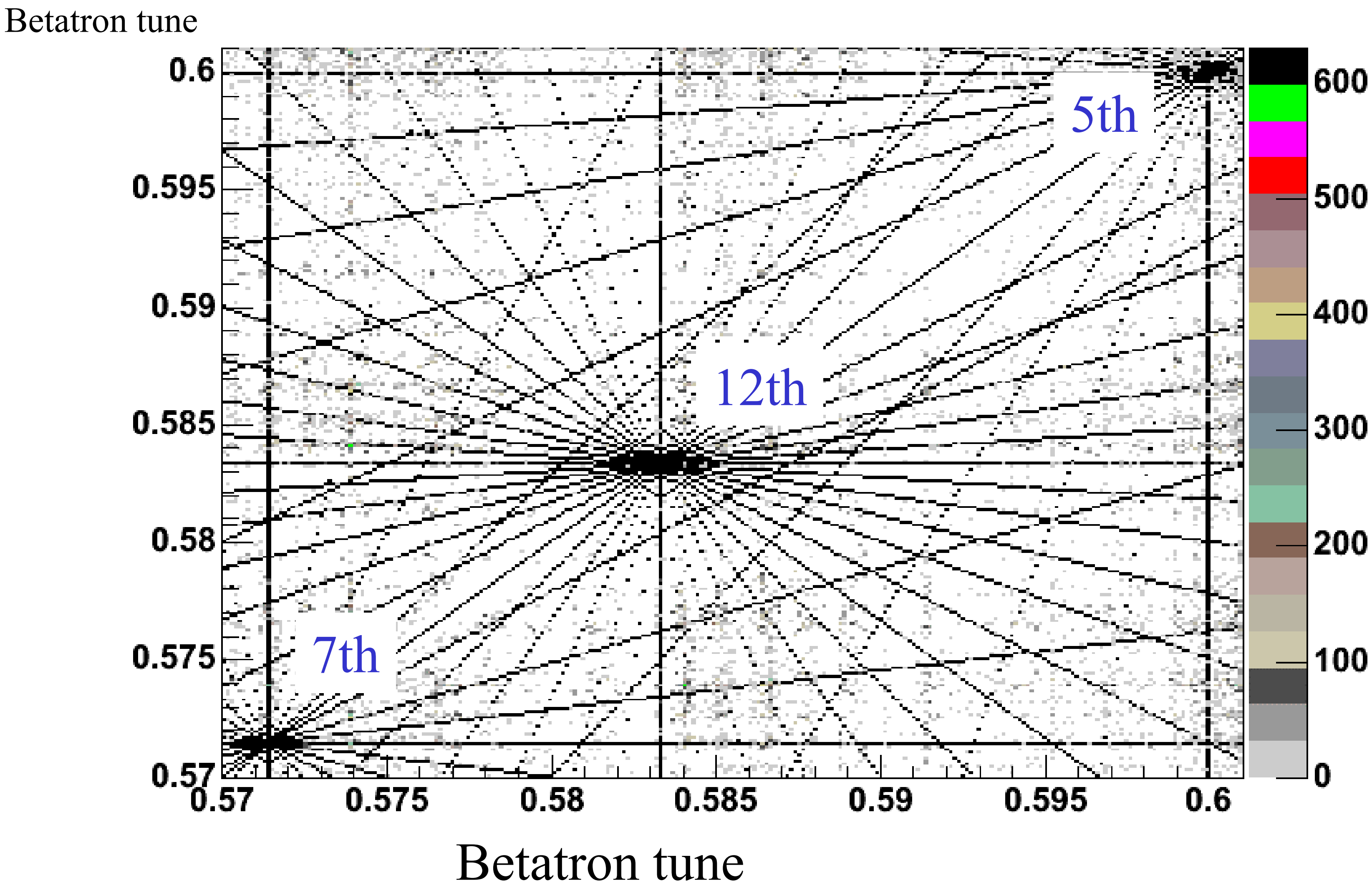
Yet, let us try this purely phenomenological algorithm through the Ramp and look at the distributions of tunes we get..

For each spectrum (average of 2 sweep, ~ 1Hz), we collect the spikes, and enter them in a 2D scatter plot.

Ramp, Store 3739, Vertical Pickup, tune ``spike" distribution.

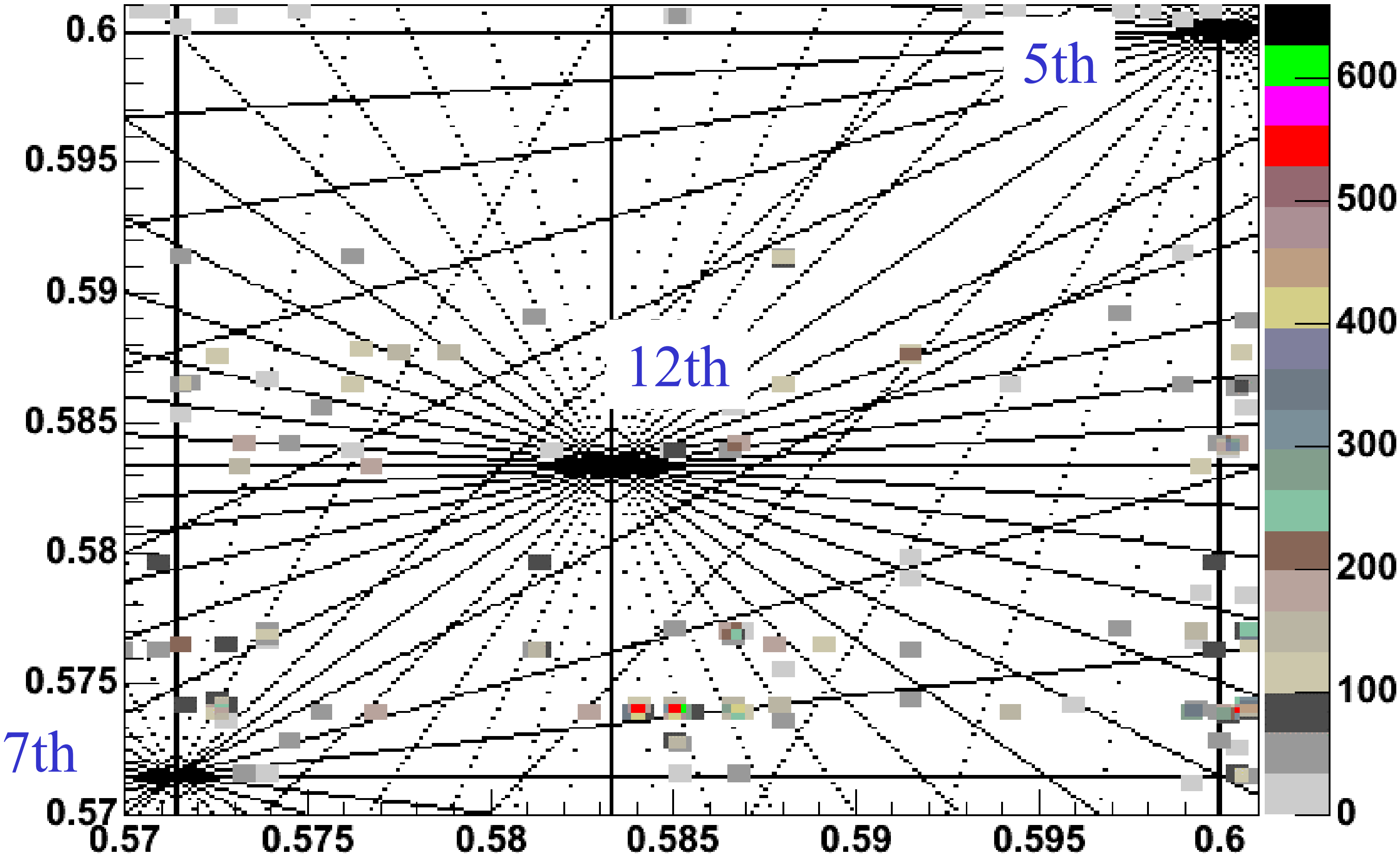


Ramp, Store 3739, Vertical Pickup, tune ``spike” distribution.



Ramp, Store 3739, V&H Pickup, coincidental ``spike" distribution.

Betatron tune

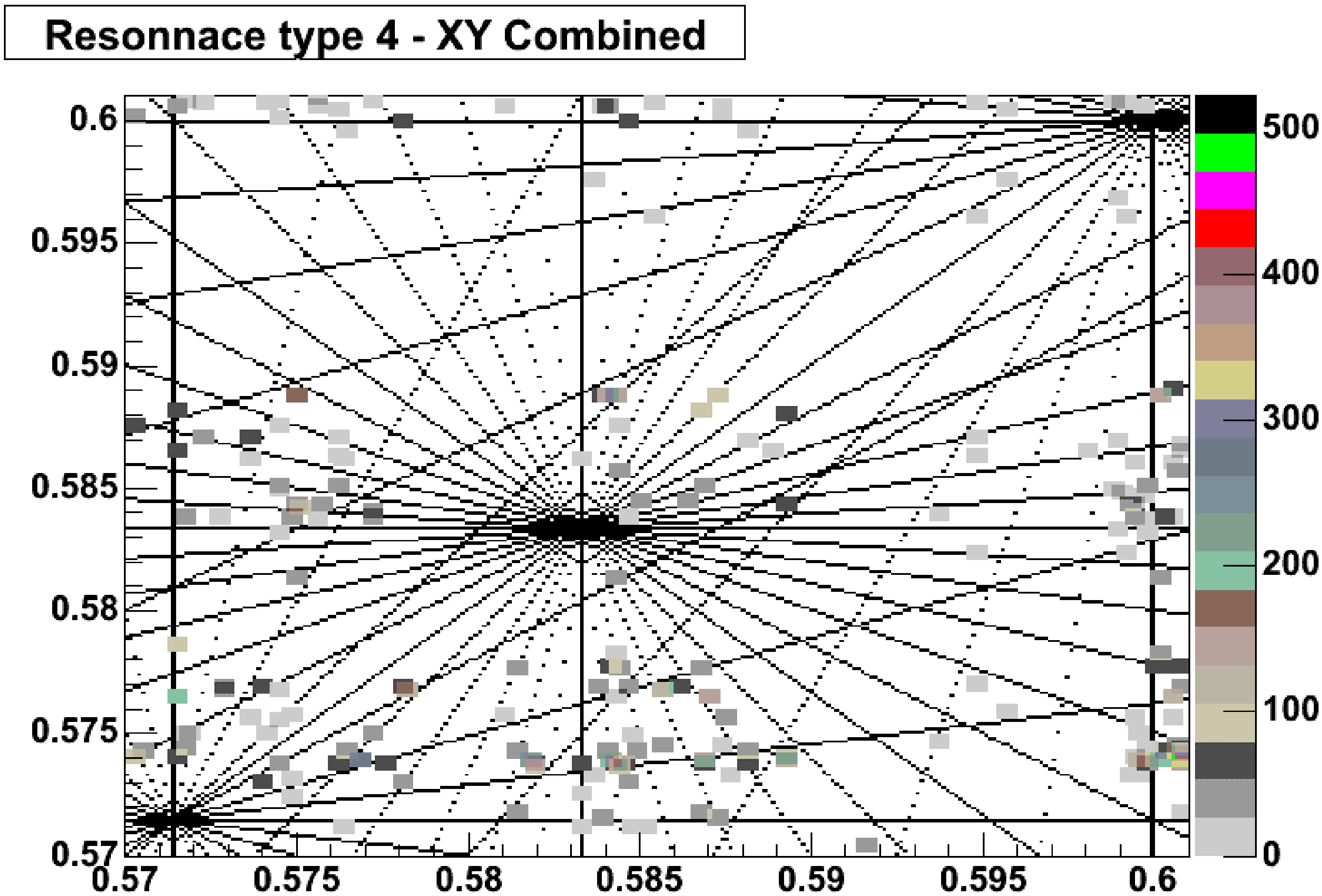


Betatron tune

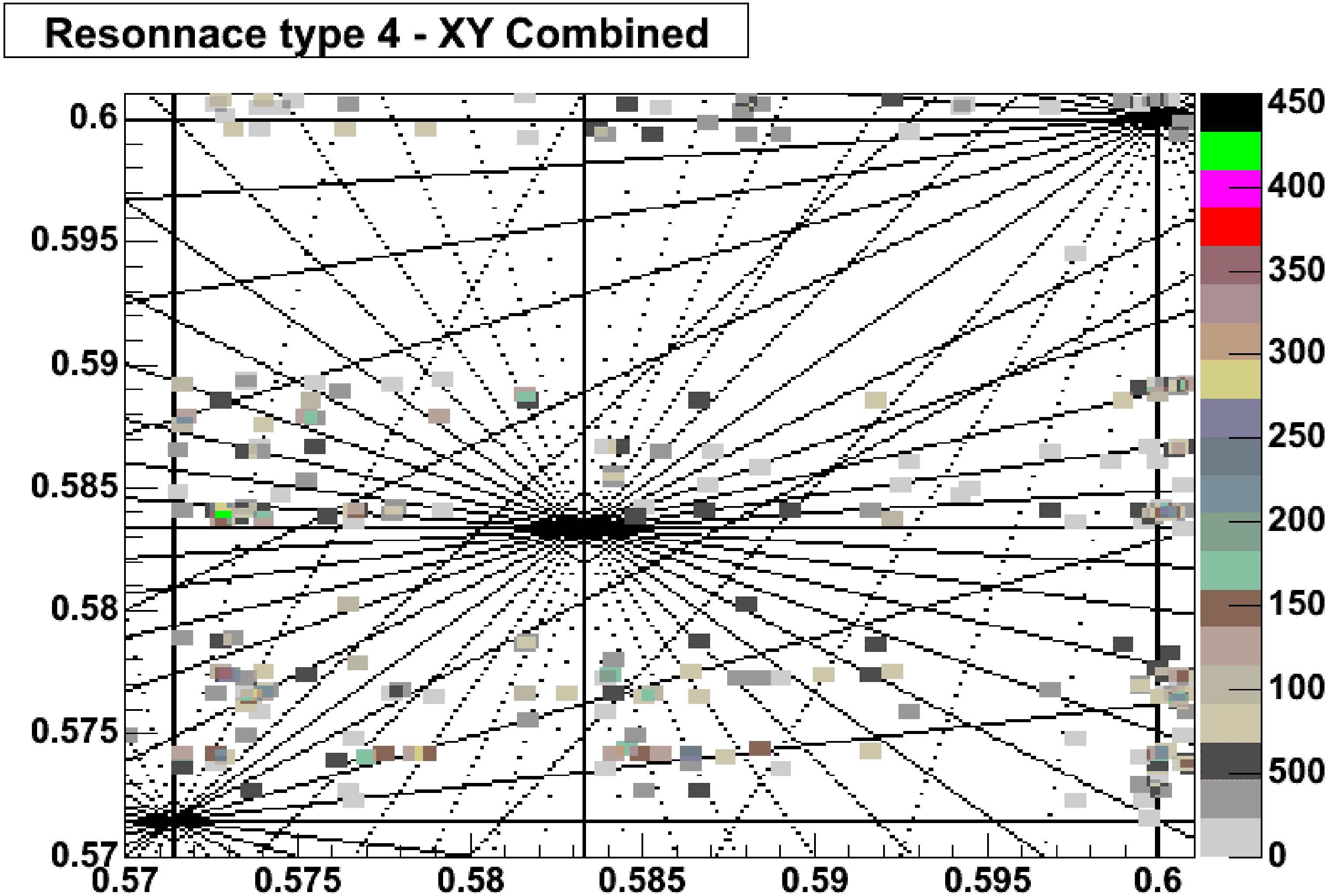
Attempting to match tunes from H&V pickups..

- Tune must agree within 0.0005
- Each entry is weighted by the relative amplitude.
- We see ‘`common” H & V spikes. Or “resonances”.
- Tunes pairs are plotted once, X vs Y position ambiguity is resolved based on relative amplitudes of the spikes. This breaks in symmetry in the previous,
- Tune H > Tune V is indeed consistent with standard TeV setting.
- Far from perfect match between lattice betatron resonance and spike locations (ex: 0.5865, 0.5913 ??)

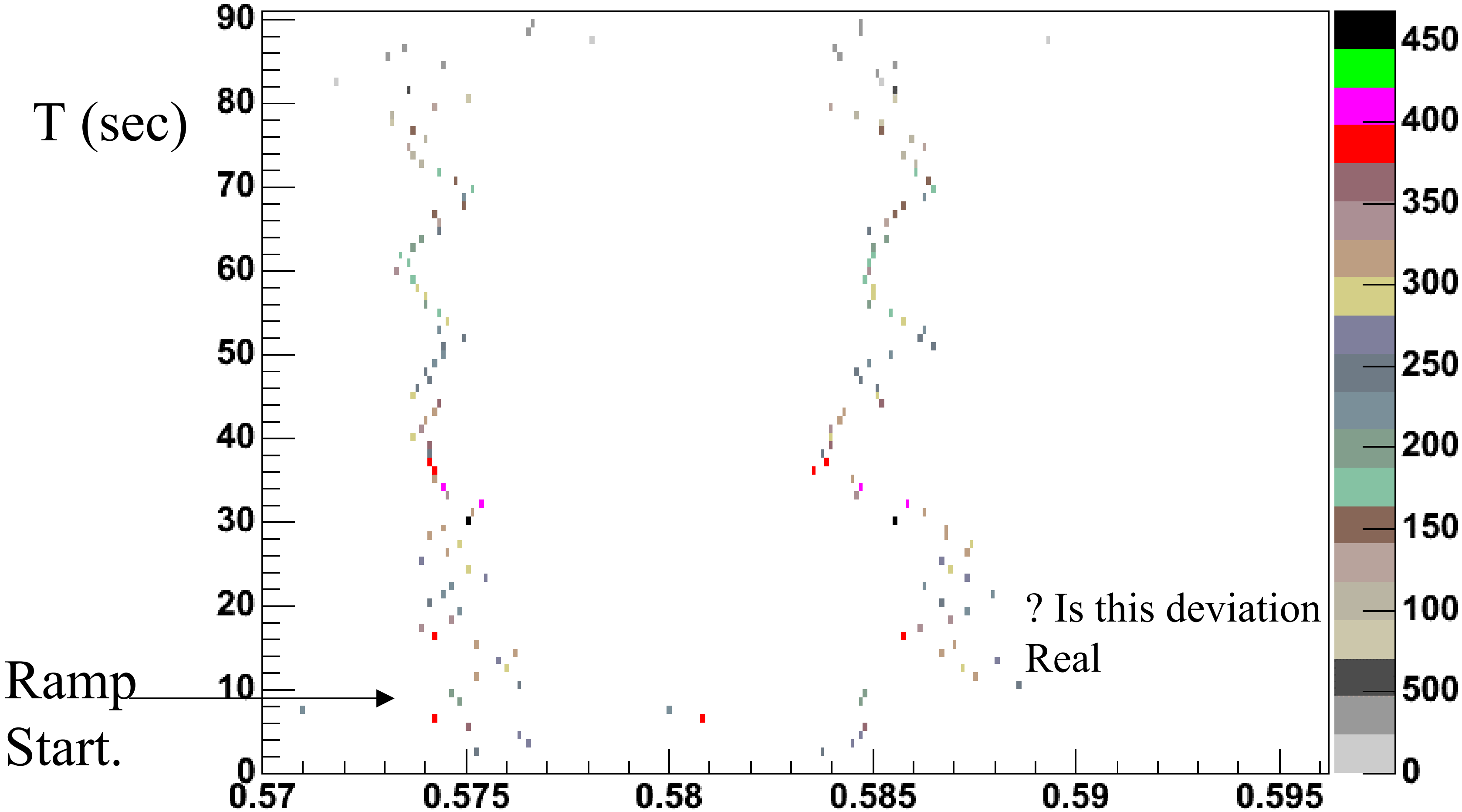
Same, store 3745



Same, store 3744

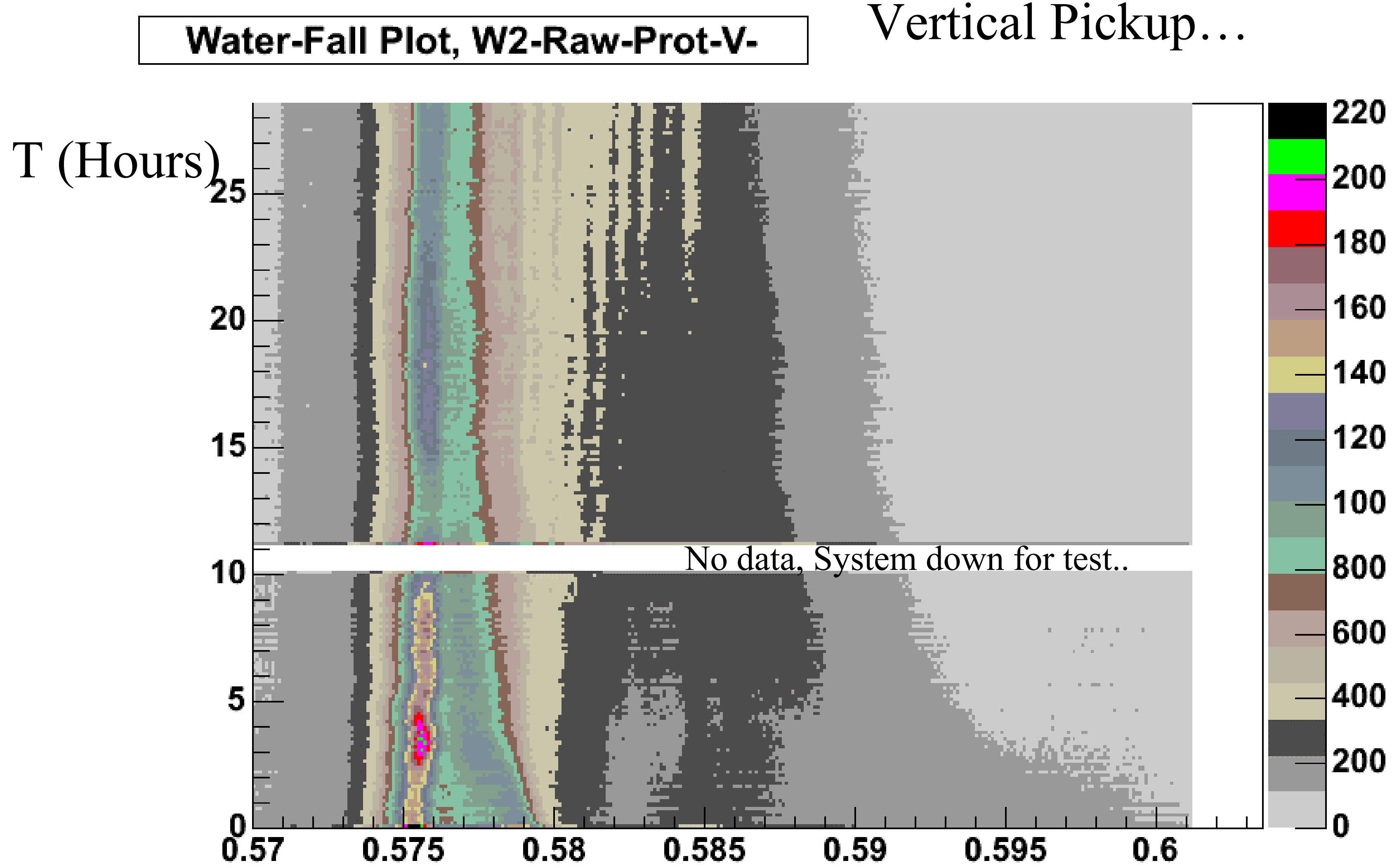


Broad bump tune for Coalesced, Store 3739



Coalesced, HEP, Store 3739, 30 x averaged..

Vertical Pickup…



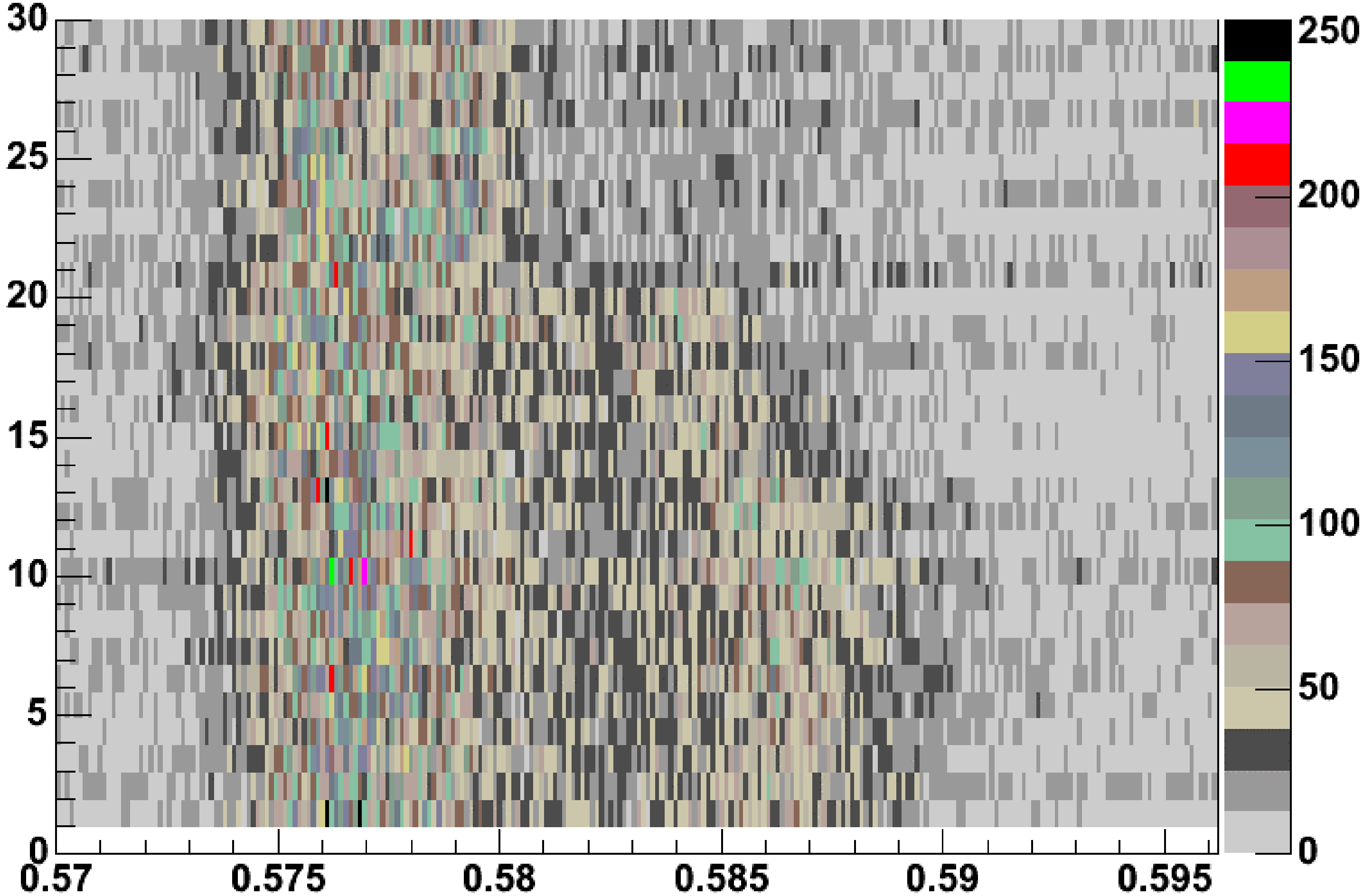
Complex data, once again..

- Spike at ~ 0.575
- Amplitude in some fixed tune are not momotonic..
- Integrated over all tunes, signal strength decreases over time
- Shoulder at 0.579 moves..
- Broad hump at 0.595 disappears after a few hours..

At Initiate Collision… The spike ~ 0.575 appears…

End of Separator Voltage change

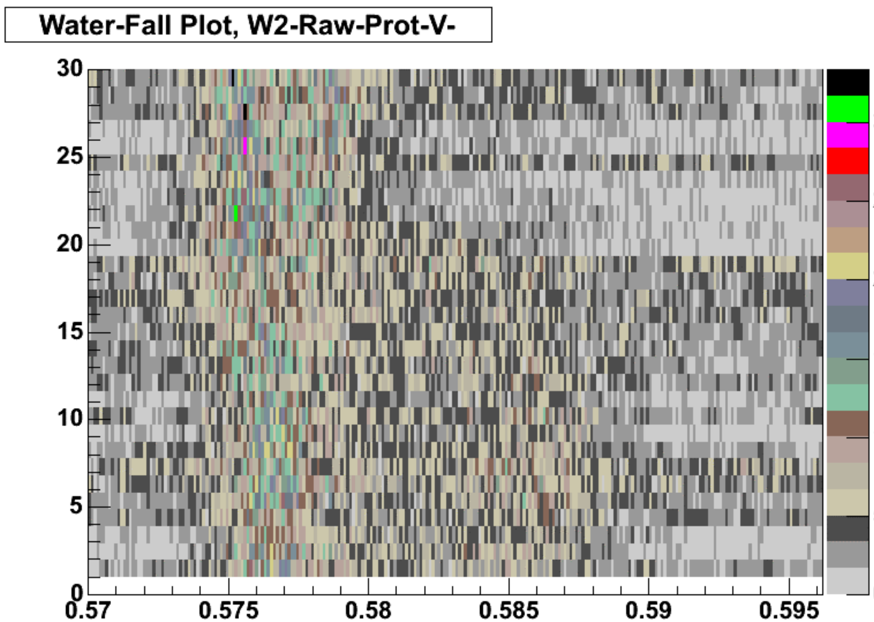
Start of Separator Voltage change

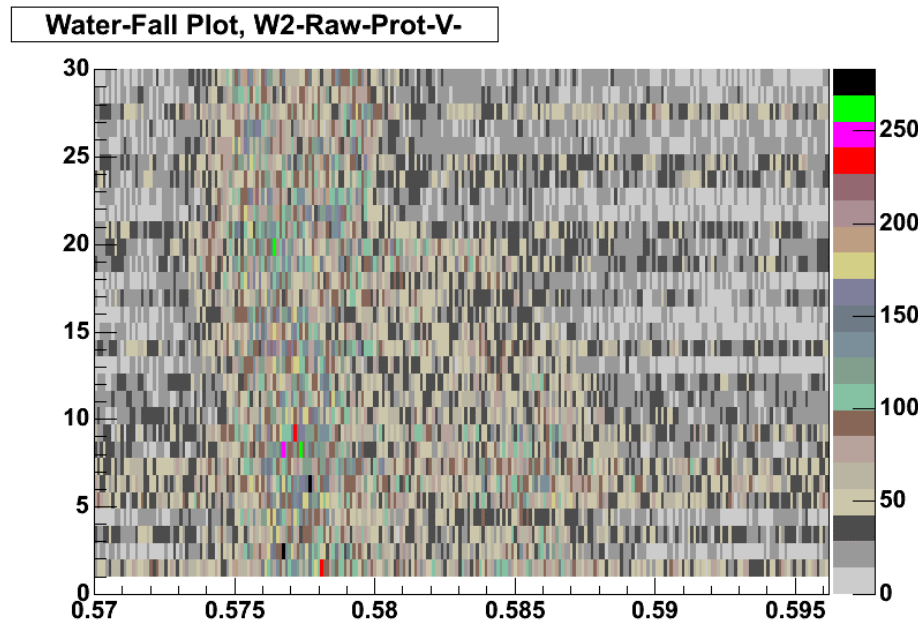


Comments…

- If anything the most prominent tune line at ~0.575 moved a bin down when beam started to collide. They suppose to move upwards, not downwards..
- The broad signals at ~ 0.583 and 0.585 decrease intensity when beam collides…
- Is it reproducible? ***Sort off..!***

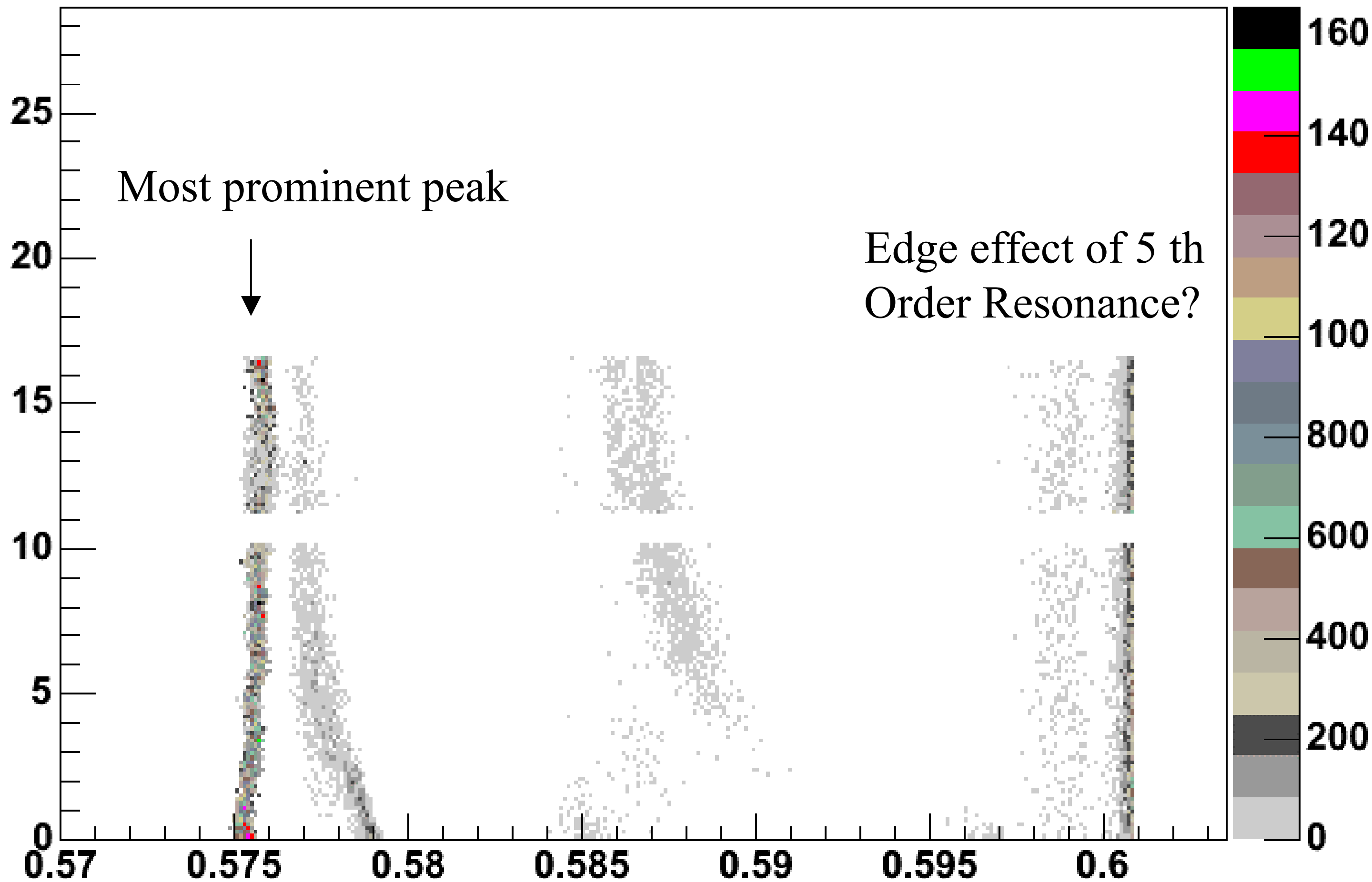
Store 3744…………………………Store 3745



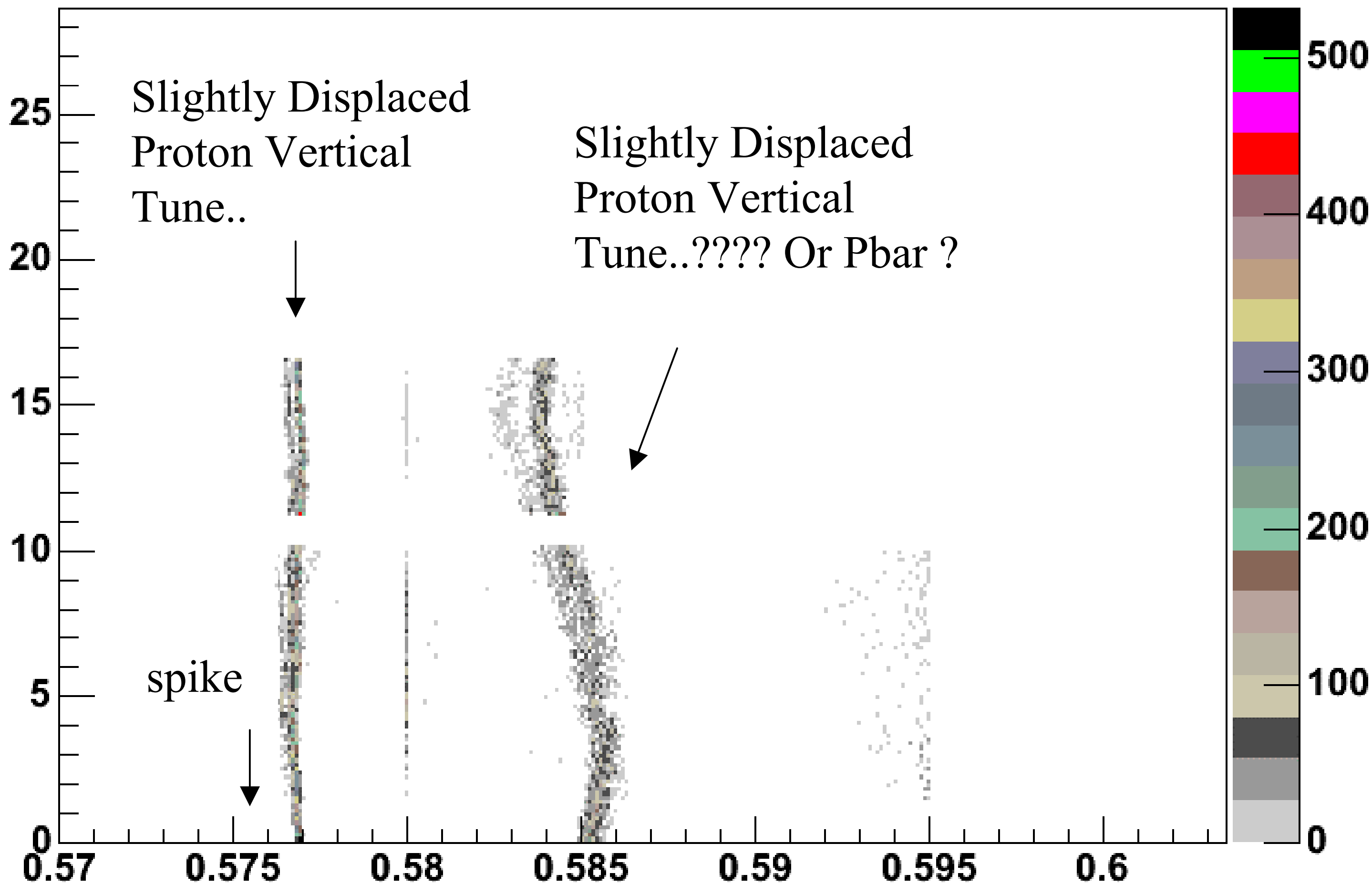


Rough features seems to be confirm. No move upward of the Proton horizontal tune.. May the pbar intensity was to small For these store….

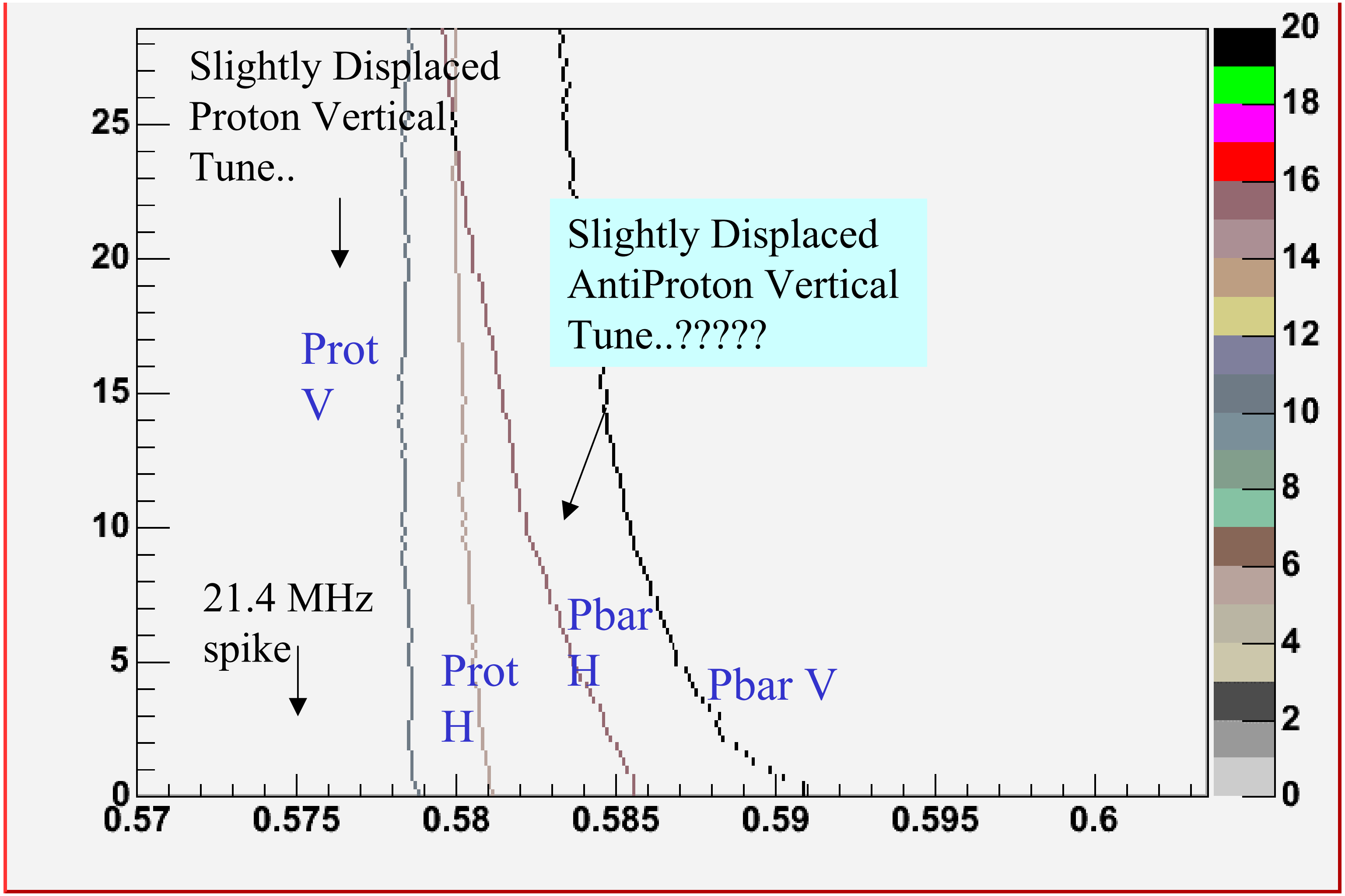
Back to HEP data, store 3739, “spikes/lines” Analysis

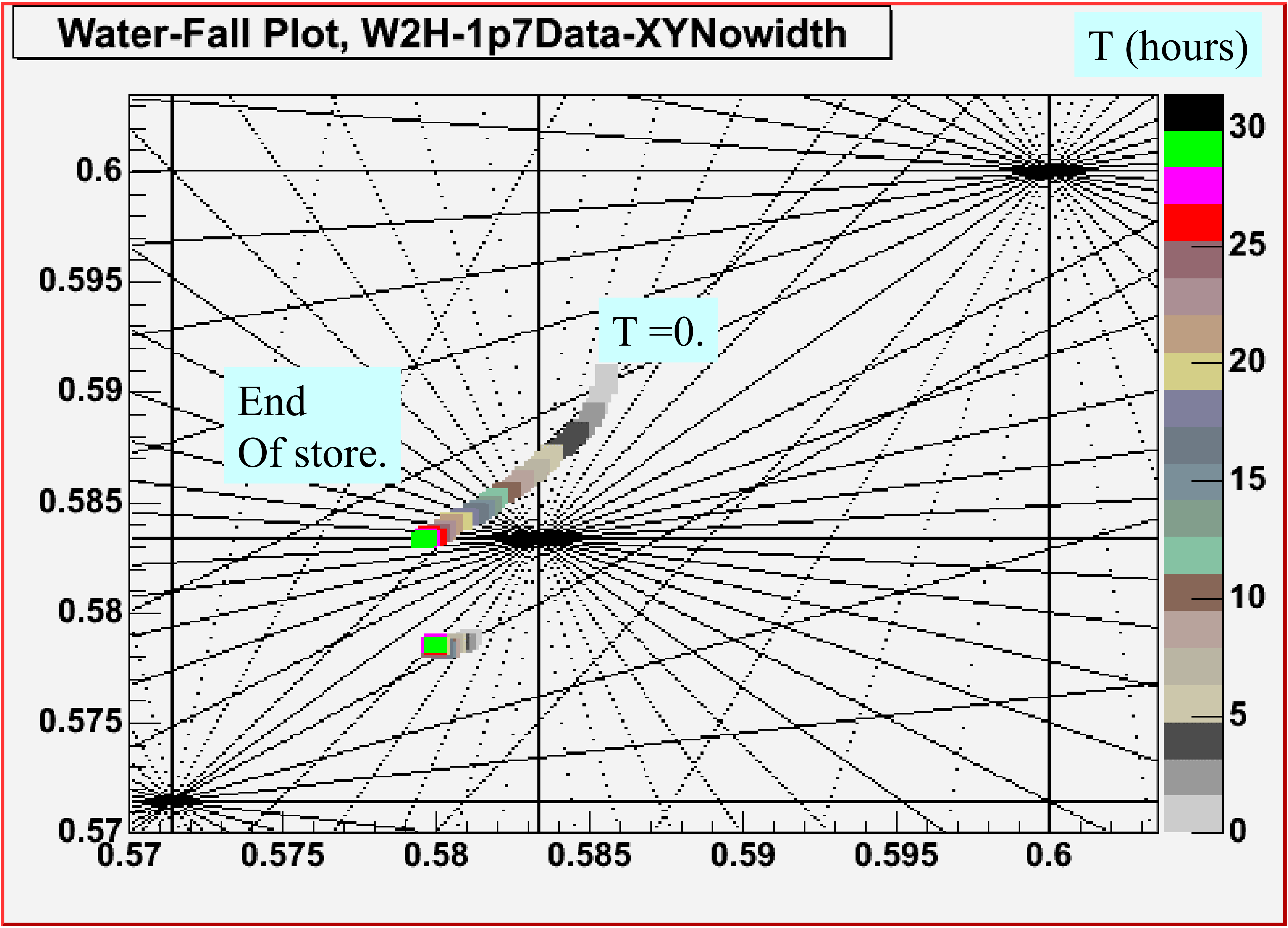


HEP, store 3739, "Broad Tune Results"

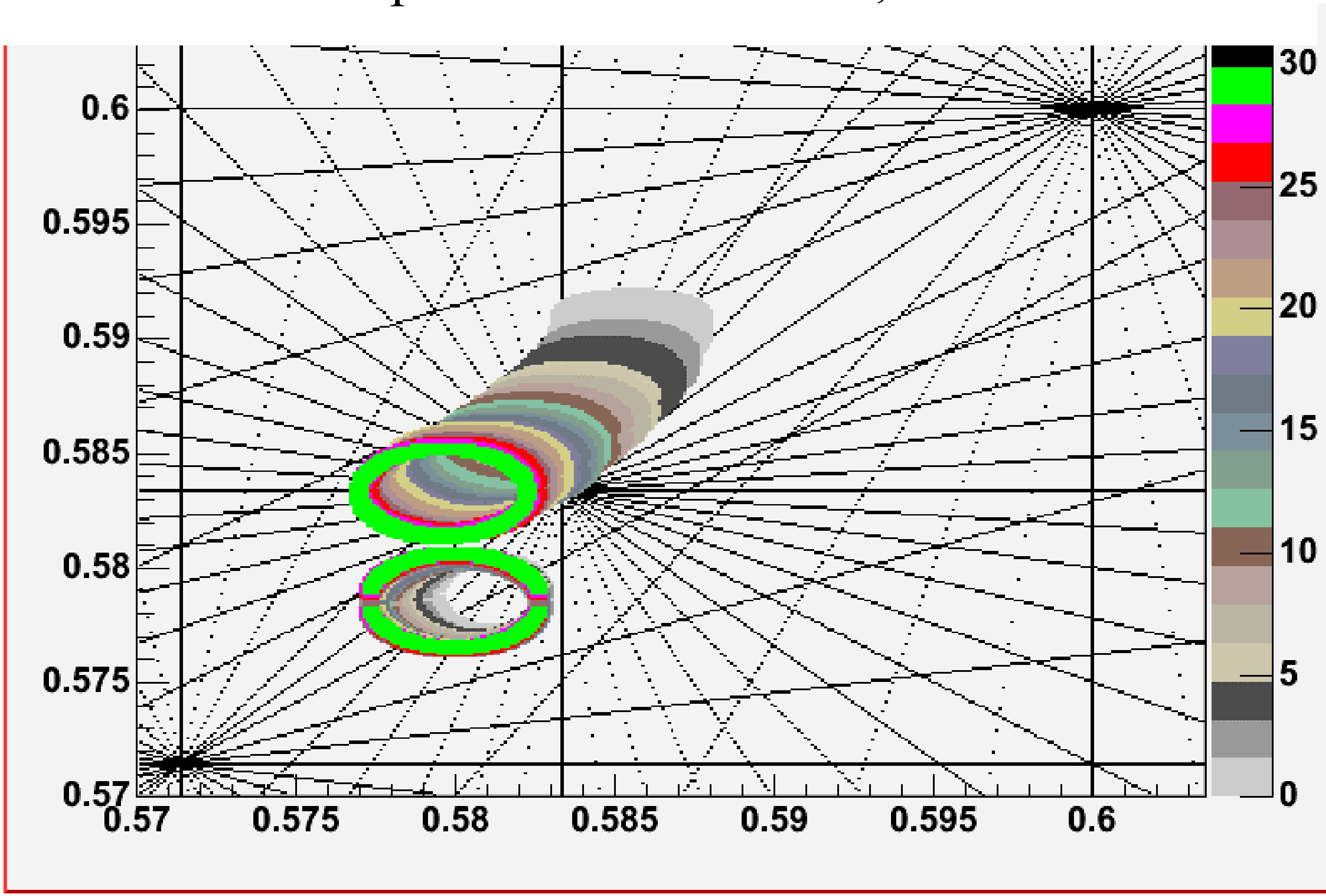


1.7 GHz Results, same scale!

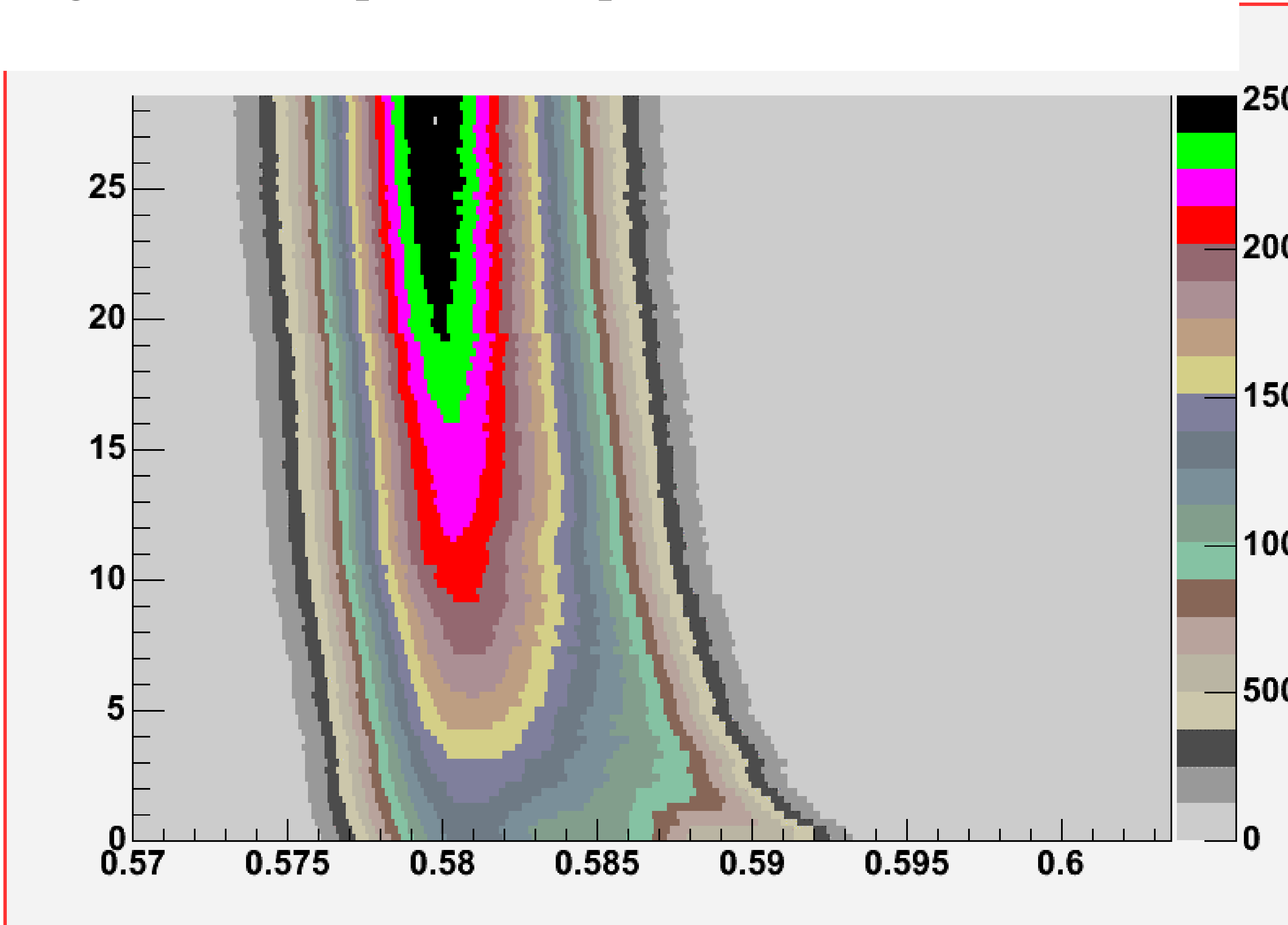



Water-Fall Plot, W2H-1p7Data-XYNowidth
T (hours)
T =0.
End
Of store.
0.6
0.595
0.59
0.585
0.58
0.575
0.57
0.57
0.575
0.58
0.585
0.59
0.595
0.6
30
25
20
15
10
5
0

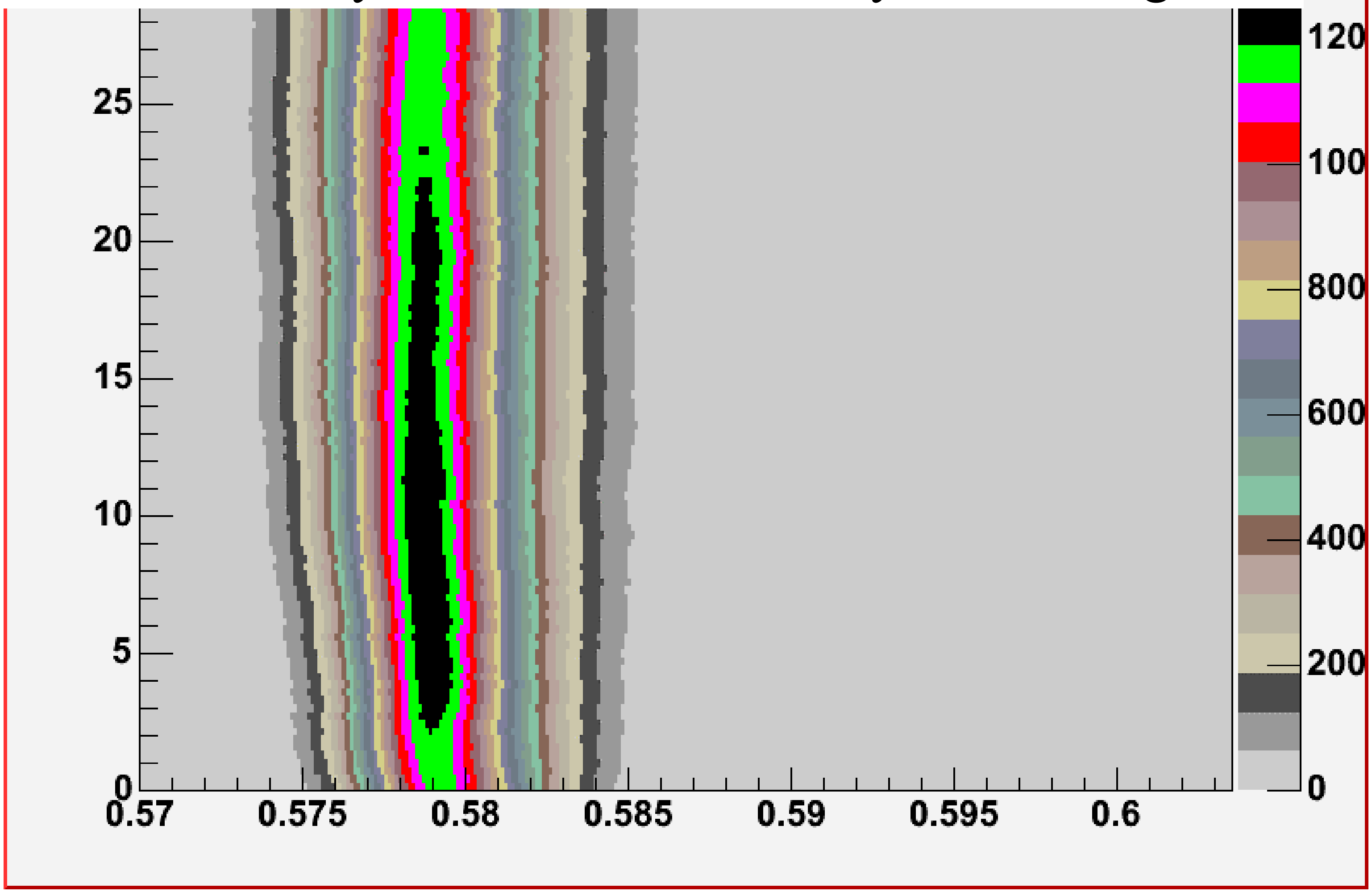
Assuming a very crude model of Schottky noise at 21.4 MHz, the width of these points ~ Chrom*dP/P, we should see:



Or, going back to the previous representation, we should see:



However, the previous plot assumed that the proton and pbar have the same beam intensity & emittance. Down-weighting the pbar based solely on the beam intensity ratio, one gets:



Comments on 1.7 Ghz vs 21.4 MHz during HEP

- A simple model with two Gaussians (or 3) will not described the 21.4 MHz. More discrete lines appear, shifting the broad tune.
- No sign of clean synchrotron oscillation.. Emittance too big, and/or masked by complex beam excitation. Or signal simply too noisy.
- No obvious detailed and consistent mapping of these excitation lines in terms of lattice betatron resonances. Influence of 5th and 7th order resonance is likely…Pbar close to the 5th one at the beginning of the store..
- Pbar is probably seen in Proton channel, as small distortions that varies over the store duration.
- Signal strength dominate by these discrete excitation lines,
- ***Precursor of non-luminous beam losses?***

On beam losses & strong discrete lines on the 21.4 MHz

- During the ramp, we tend to see these lines when losses are high, that is, during snap-back, when it is difficult to control the chromaticity.
- 21.4 MHz is quiet at the end of the ramp, where we don't loose beam.
- We loose relatively more beam at the beginning of the store, where the 0.575 line is strong.
- However, detailed time dependence analysis of the .575 line and C:LOSTP or non-luminous proton lifetime is a bit inconclusive, because assigning an accurate strength to this line is difficult. Yet, the correlation is very likely.
- See Non-Luminous Proton lifetime analysis (an other talk).

Dedicated Beam Studies…

- At 980: (150 GeV calib. have been largely done parasitically)
- Un-coalesced, make sure the 21.4 MHz tune scale is calibrated in "T:Qxxx" units
- Coalesced, 12x0, Proton only:
  - **Tune Scale**
    - Verification 1.7 GHz and 21.4 MHz tune scale calibration with respect to T:QY…Change by T:QY… 0.001, measure, repeat…
    - How to really verify absolute tune calibration? → Trust the bench measurement of digitizer and VSA frequency scale. I think this is o.k. within ~0.0001 in tune units.
    - What we really are after is systematic bias due to signal contamination!
  - **Chrom scale**: Change base chromaticity (sextupole circuits), record 21.4 and 1.7 GHz data.
  - 1.7 GHz / Sync-Light **emittance calibration** with respect to flying-wire.
  - Record 21.4 MHz data when we approach the 7th order resonance, and losses are high.

Supporting Other Studies, Beam Physics in particular..

- Shame on me (us?) if the tune fitters are not running when:
  - Lattice measurement.
  - Cross calibration of emittance measurements.
  - Cross calibration of the ``3rd tune device"
- Beam-Beam studies: we have to measure these tunes!..
- If the beam-beam induced non-luminous losses becomes a real impediment to luminosity lifetime or background at CDF, a more strenuous and systematic study program will have to be undertaken…
- Support of use of TEL, TEL2,…

Conclusions

- The 21.4 MHz and 1.7 GHz ``Schottky" detectors are very much complementary to each other. We needed both! (We might need a third one)
  - The 1.7 GHz behaves almost as a ``true Schottky", yet, we have work to do to measure emittance with an accuracy of a few %! Noise is still too large…
  - The 21.4 MHz spectrum are dominated by ``coherent" (non-Schottky), transient beam excitation that are quite complex. We now start to have the front-end, DA and Analysis tools to consider quantifying this complex behavior.
- A bit of work on software maintenance on both system is needed, but nothing major…
- Available to support beam studies, and HEP tune/chrom tuning..