The Electron-Cloud Instability in the SPS

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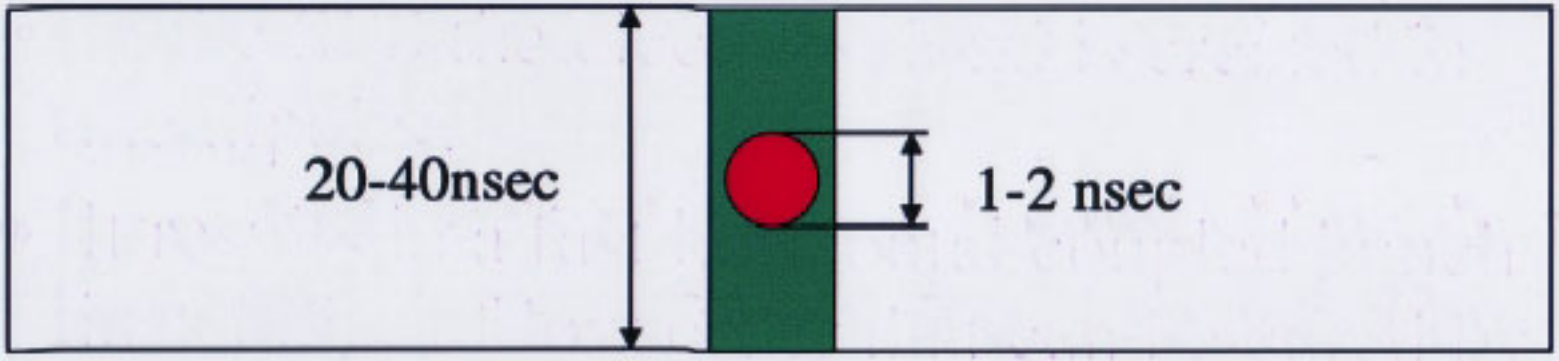
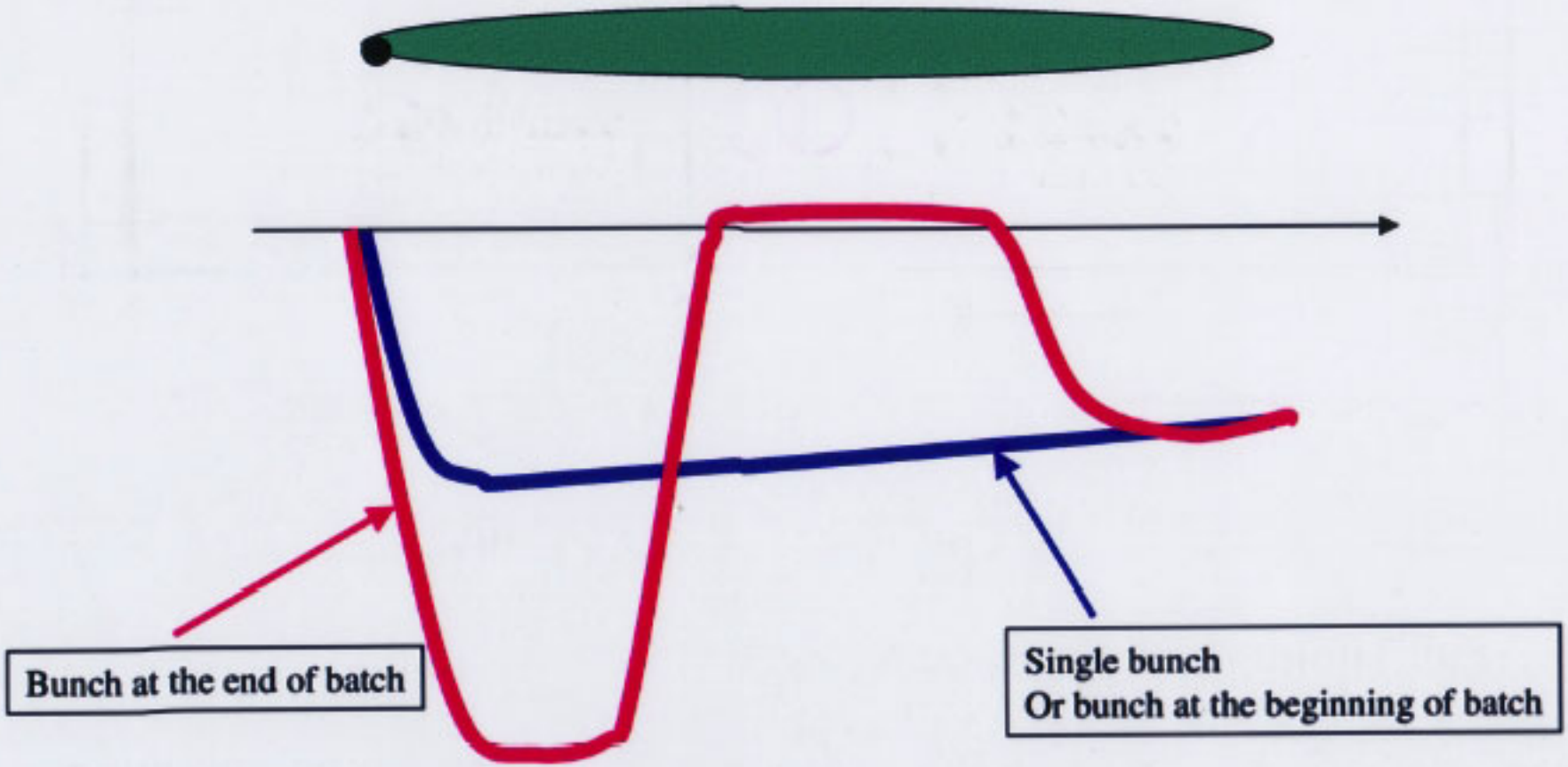
Conclusions

- In the SPS the electron cloud is created in the dipoles.
- It results in a fast horizontal coupled bunch instability of low order that can be cured by feedback.
- The vertical instability is of single bunch nature (higher head tail mode). The growth rate depends on intensity.

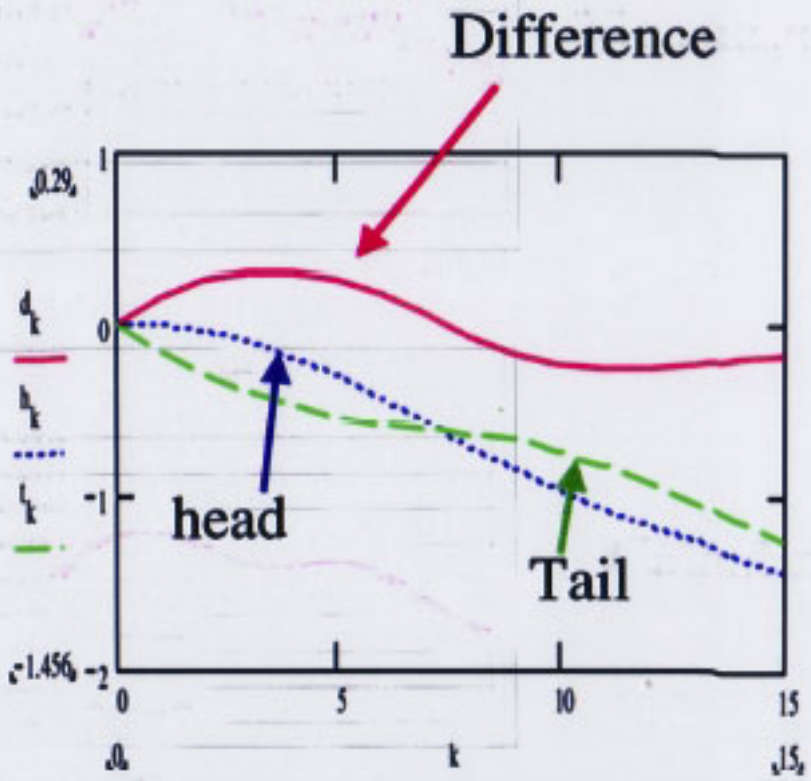
A simple picture



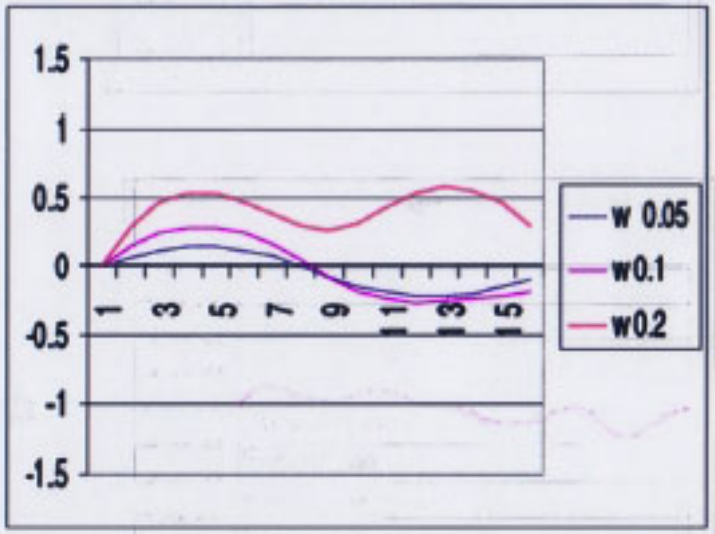
The Vertical Wakefield



Phase advance and Impedance

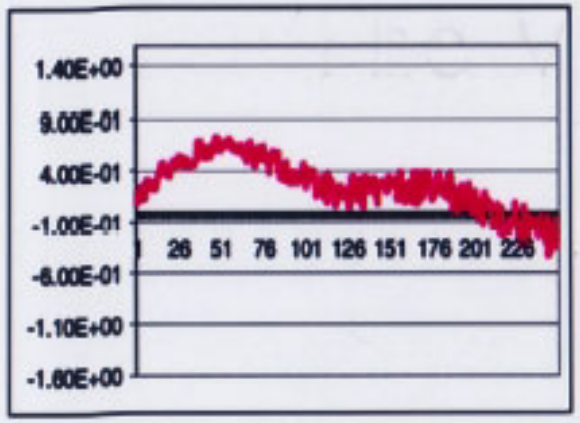


Phase advance of head and tail after kick over 1 synchrotron period

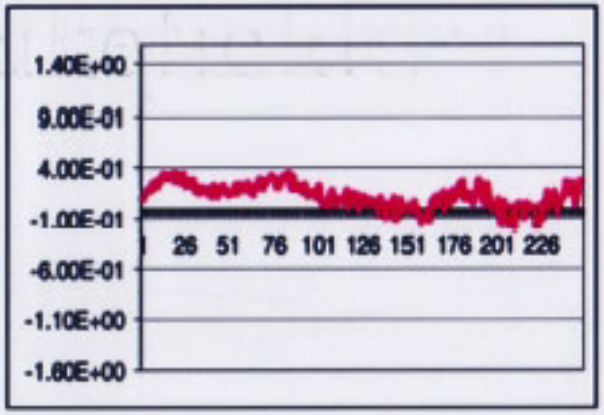


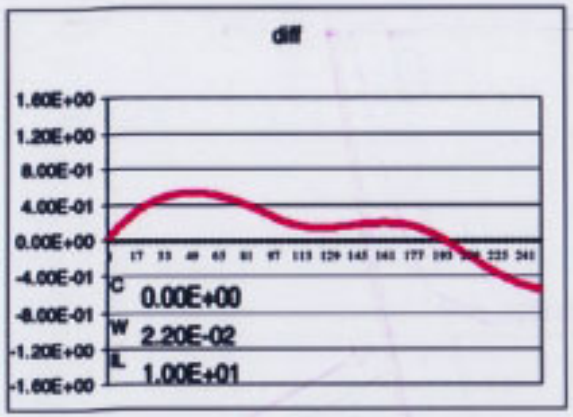
ϕhead – ϕ_{tail} as function of intensity.

Difference between head and tail of batch

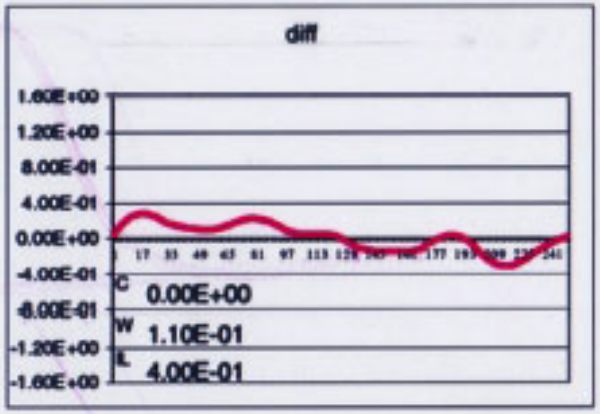


Measurement

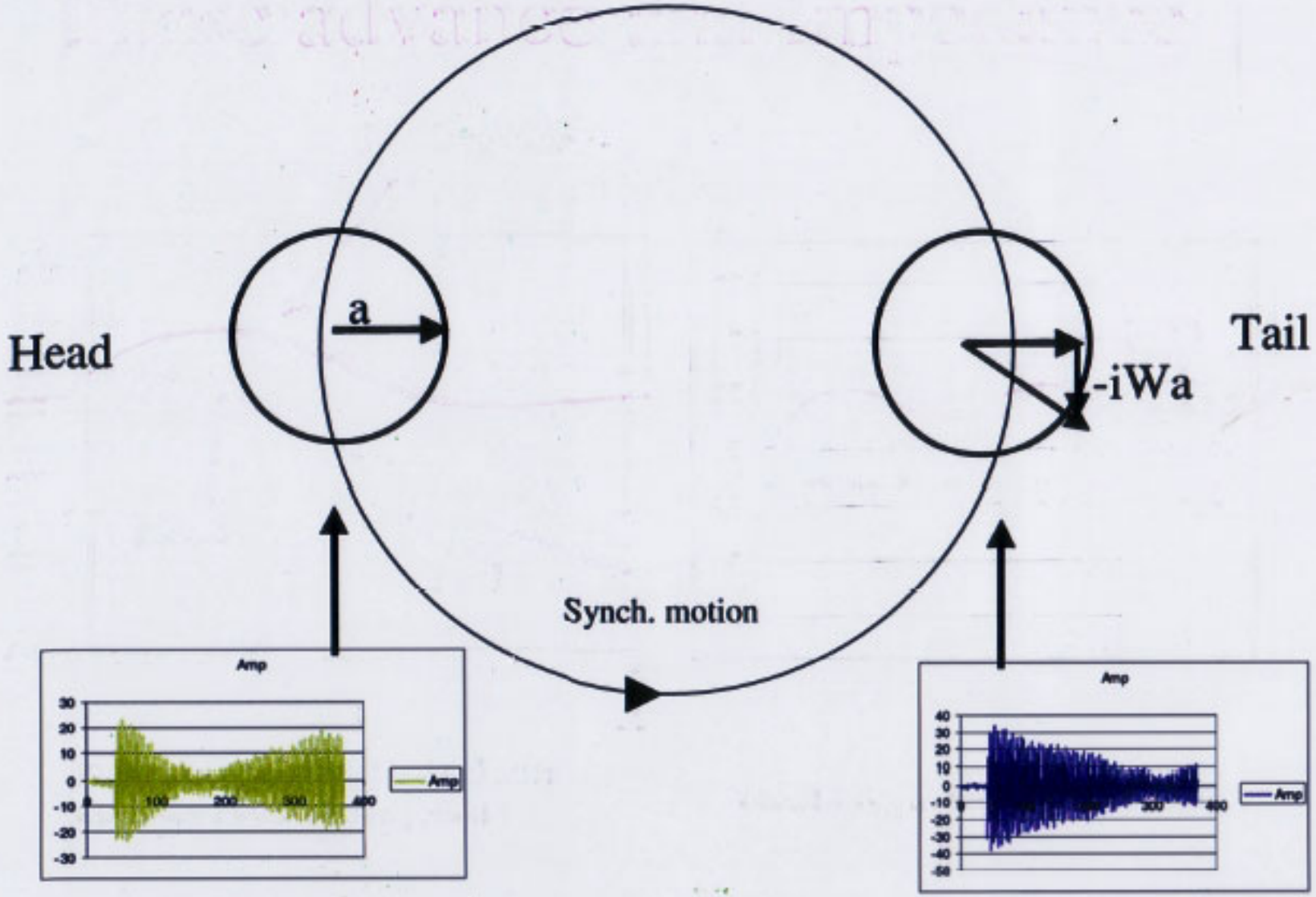




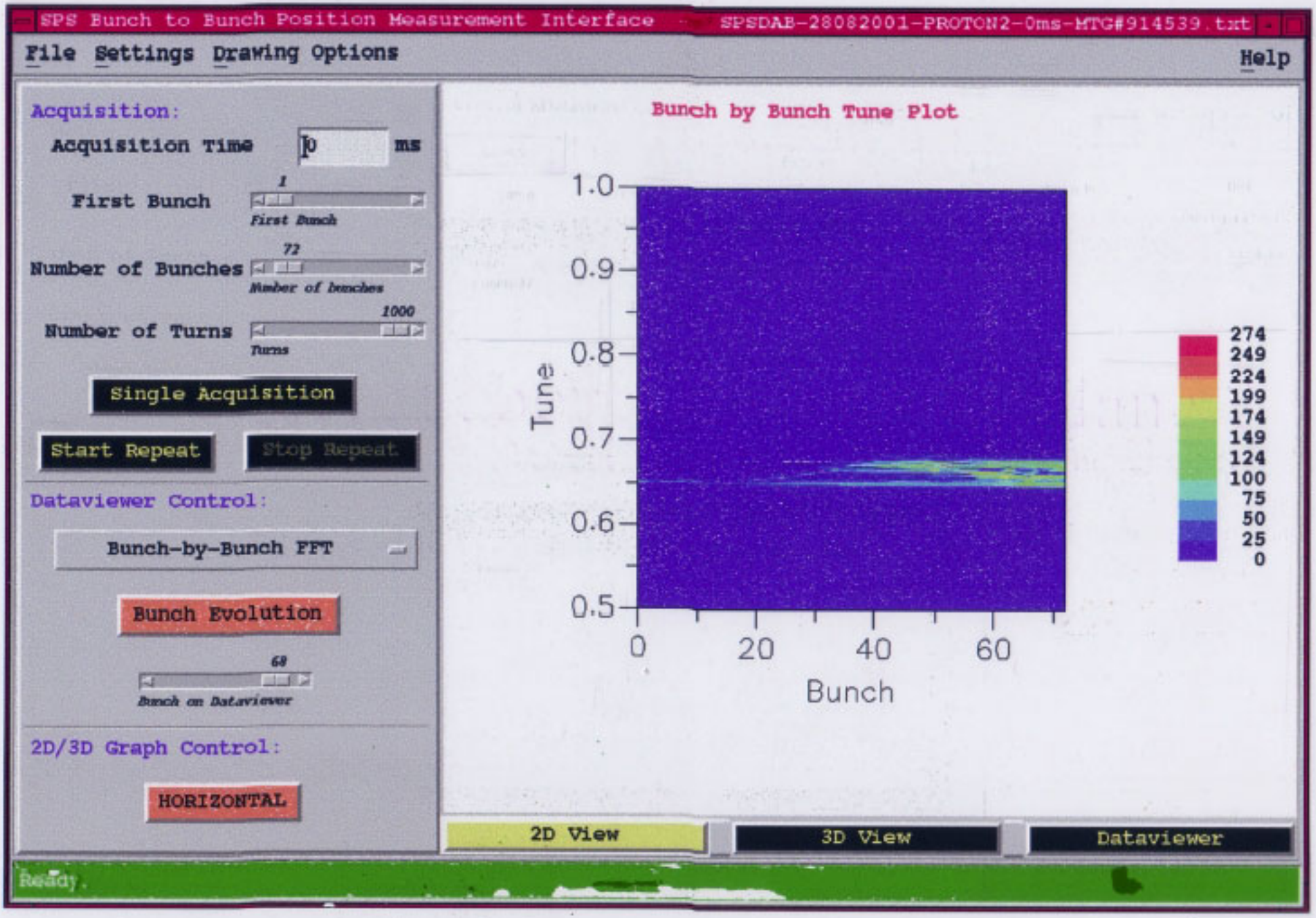
Calculation



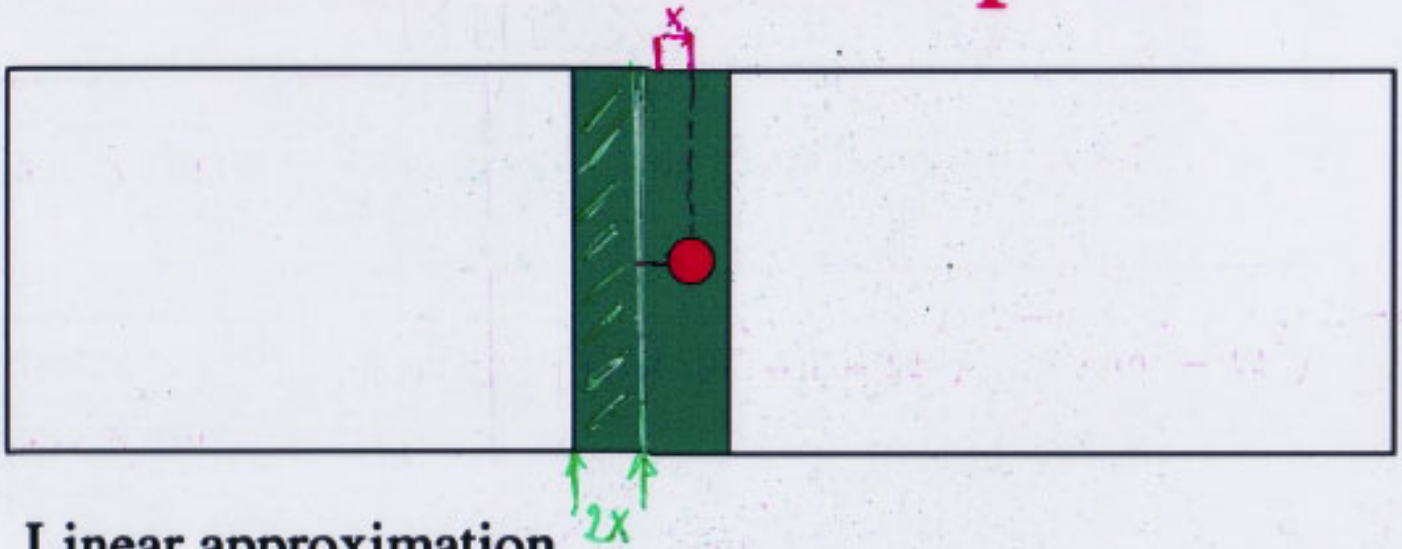
Phase difference due to impedance



What about the Vertical plane ?


SPS Bunch to Bunch Position Measurement Interface
SPSDAB-28082001-PROTON2-0ms-MTG#914539.txt
File Settings Drawing Options
Help
Acquisition:
Acquisition Time
0
ms
First Bunch
1
First Bunch
Number of Bunches
72
Number of bunches
Number of Turns
1000
Turns
Single Acquisition
Start Repeat
Stop Repeat
Dataviewer Control:
Bunch-by-Bunch FFT
Bunch Evolution
68
Bunch on Dataviewer
2D/3D Graph Control:
HORIZONTAL
Bunch by Bunch Tune Plot
Tune
1.0
0.9
0.8
0.7
0.6
0.5
0
20
40
60
Bunch
274
249
224
199
174
149
124
100
75
50
25
0
2D View
3D View
Dataviewer
Ready.

In the horizontal plane



Linear approximation

$$\frac{dF}{dx} = \frac{e\rho}{\epsilon_0}$$

$$\frac{d(dp)}{ds\,dx} = \frac{e\rho}{\epsilon_0 c}$$

$$k = -\frac{\rho}{\epsilon_0 \underbrace{26\,10^9}_{E}} \qquad \left[\rho \text{ in } \frac{C}{m^3}\right]$$

$$dQ = \frac{\rho \langle \beta \rangle L}{\epsilon_0\, 26\, 10^9} \qquad (L \text{ total length of dipoles})$$

$$dQ \simeq 0{,}03$$

A simple description of coupled Bunch motion

$$\frac{d^2}{dt^2} X_1 + \omega^2 \cdot X_1 := 0$$

.....

$$\frac{d^2}{dt^2} X_n + \omega^2 \cdot X_n := 0$$

$$\frac{d^2}{dt^2} X_{n+1} + \omega^2 \cdot X_{n+1} := k \cdot \left(X_{n+1} - X_n\right)$$

....

$$\frac{d^2}{dt^2} X_{72} + \omega^2 \cdot X_{72} := k \cdot \left(X_{72} - X_{71}\right)$$

Eigen frequencies :

$$0 := \left(\omega^2 - k - \Omega^2\right)^{72-n} \cdot \left(\omega^2 - \Omega^2\right)^{72-n}$$

$$\Omega^2 := \omega^2$$

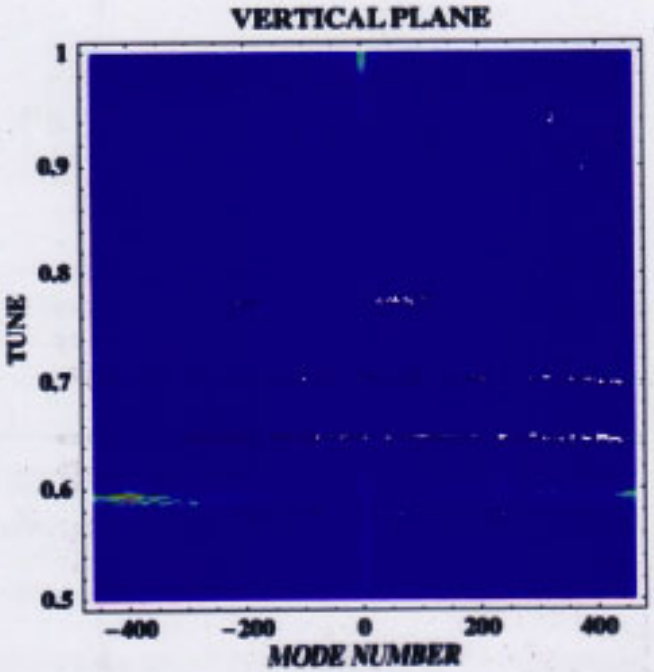
$$\Omega^2 := \omega^2 - k$$

Sumarising

- In the Horizontal plane the e-cloud provokes a fast growing coupled bunch instability of low order. Growth rate is ~50turn. Does not change much with intensity.
- In the vertical plane the instability looks like single bunch instability.Growth rate : ~500 turns just above threshold going to ~100 turns at two times the threshold.

```
fig1v=ListDensityPlot[Abs[verfour1], PlotRange->{1,Max[Abs[verfour1]]},Mesh →False,
ColorFunction→cf,MeshRange→{{-461,462},{0.5,1}},
FrameLabel->{"MODE NUMBER","TUNE"},DefaultFont -> {"Times-Bold",12},PlotLabel-
>FontForm["VERTICAL PLANE",{"Times-Bold",14}],ImageSize->320];
```

General::spell1 : Possible spelling error: new symbol name "fig1v" is similar to existing symbol "fig1h".




```
Max[Abs[horfour1]]
```

101.793

```
Max[Abs[verfour1]]
```

265.067

```
figh1D=ListPlot[maxhorft,AxesOrigin->{0,0.61},PlotRange->{{0,72},{0.61,0.65}},Frame-
>True,PlotJoined->False,
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ImageSize->320];
```

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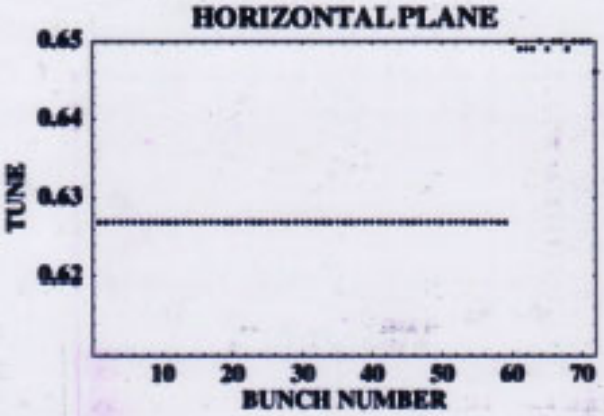


```
figlh=ListDensityPlot[Abs[horfour1], PlotRange->{1,Max[Abs[horfour1]]},Mesh →False,
ColorFunction→cf,MeshRange→{{-461,462},{0.5,1}},
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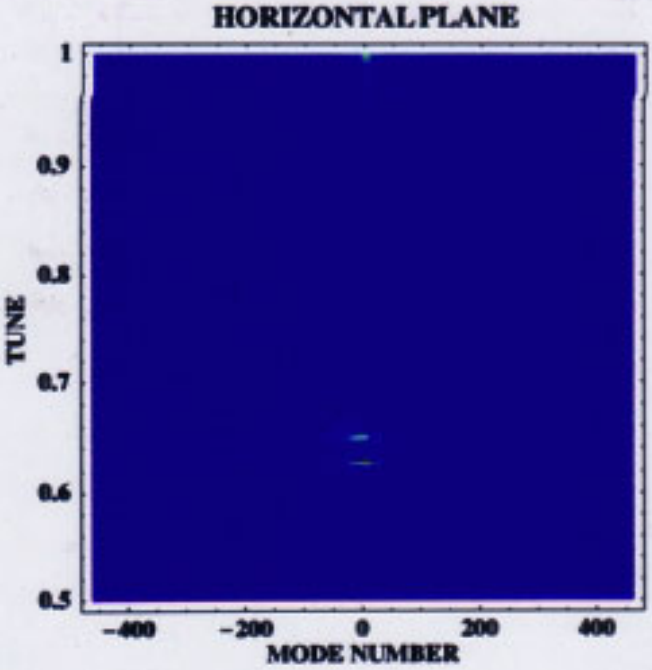

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figh1D=ListPlot[maxhorft,AxesOrigin->{0,0.61},PlotRange->{{0,72},{0.61,0.65}},Frame->True,PlotJoined->False,
FrameLabel->{"BUNCH NUMBER","TUNE"},DefaultFont -> {"Times-Bold",12},PlotLabel->FontForm["HORIZONTAL PLANE",{"Times-Bold",14}]];
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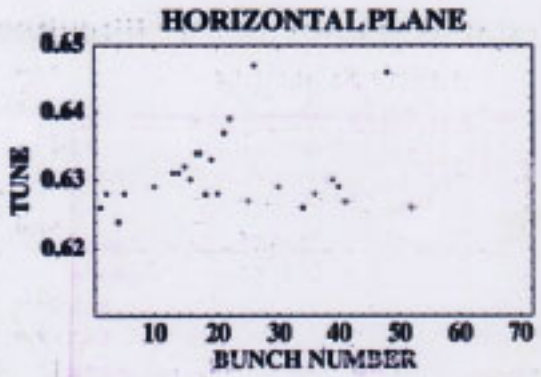


```
fig1h=ListDensityPlot[Abs[horfour1], PlotRange->{1,Max[Abs[horfour1]]},Mesh →False,
ColorFunction→cf,MeshRange→{{-461,462},{0.5,1}},
FrameLabel->{"MODE NUMBER","TUNE"},DefaultFont -> {"Times-Bold",12},PlotLabel->FontForm["HORIZONTAL PLANE",{"Times-Bold",14}],ImageSize->320];
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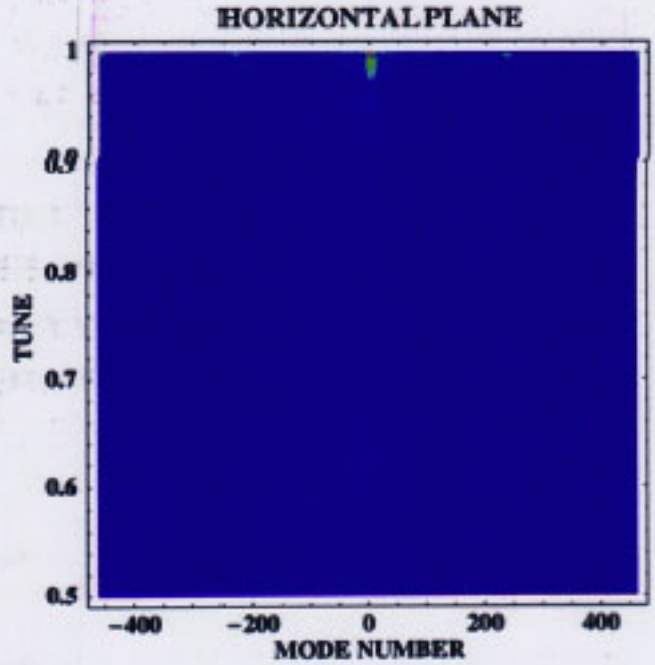

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fighD=ListPlot[maxhorft,AxesOrigin->{0,0.61},PlotRange->{{0,73},{0.61,0.65}},Frame-
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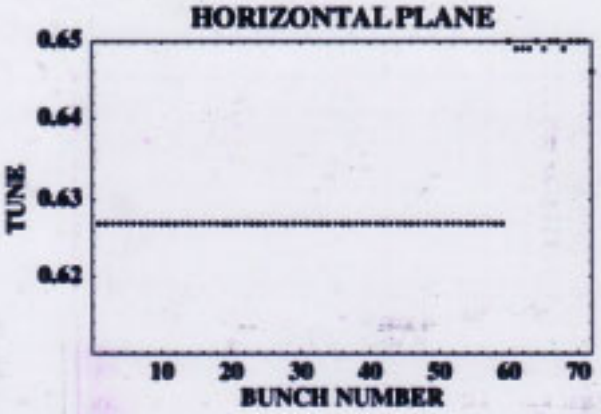
General::spell1 : Possible spelling error: new symbol name "fighD" is similar to existing symbol "figvD".
```




```
figh=ListDensityPlot[Abs[horfour1], PlotRange->{1,Max[Abs[horfour1]]},Mesh →False,
ColorFunction→cf,MeshRange→{{-461,462},{0.5,1}},
FrameLabel->{"MODE NUMBER","TUNE"},DefaultFont -> {"Times-Bold",12},PlotLabel-
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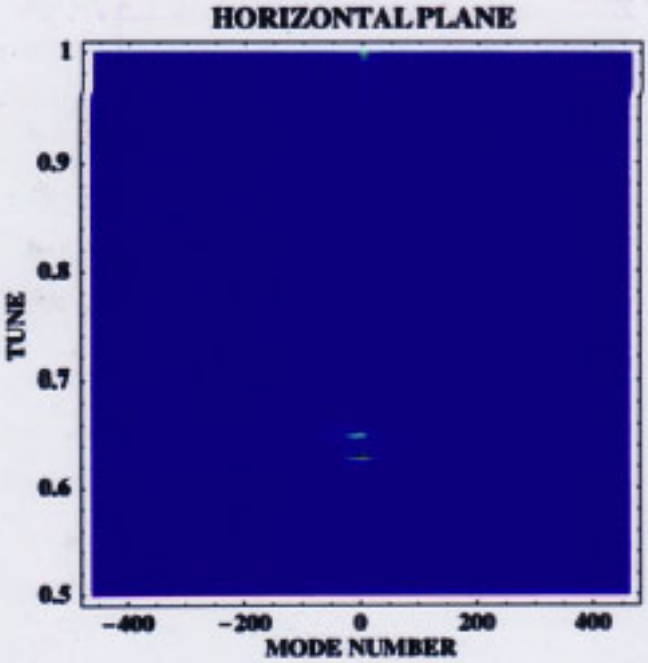



SPS Bunch to Bunch Position Measurement Interface
SPSDAB-28082001-PROTON2-0ms-MTG#916444.txt
File Settings Drawing Options
Help
Acquisition:
Acquisition Time
0
ms
First Bunch
1
First Bunch
Number of Bunches
72
Number of bunches
Number of Turns
1000
Turns
Single Acquisition
Start Repeat
Stop Repeat
Dataviewer Control:
Bunch-by-Bunch FFT
Bunch Evolution
42
Bunch on Dataviewer
2D/3D Graph Control:
VERTICAL
CERN/SL XDataviewer 6.4
Info
Kick
Clean
Reverse
Views
Subview
External
Editor
Select
Plot
Grid OFF
Zeroline OFF
OP ONE
Zoom In
Box
Profiles
07/09/01 14:26:00
Horizontal Tune Plot
0.47
Tune
1.03
Bunch 42
187.4
1/Amp
-9.0
Da 0.50000 2.001 dy 154.304
Cu 0.49980 157.185 pl_hor
Vertical Tune Plot
0.47
Tune
1.03
Bunch 42
65.3
1/Amp
-3.2
Da 0.50000 5.6140 dy 43.83
Cu 0.49824 49.4440 pl_ver
2D View
3D View
Dataviewer
Ready ...

SPS Bunch to Bunch Position Measurement Interface SPSDAB 28082001 PROTON2-0ms-MTG#916109.txt

File Settings Drawing Options Help

Acquisition:

Acquisition Time 10 ms

First Bunch 1 First Bunch

Number of Bunches 72 Number of bunches

Number of Turns 1000 Turns

Single Acquisition

Start Repeat Stop Repeat

Dataviewer Control:

Bunch-by-Bunch FFT

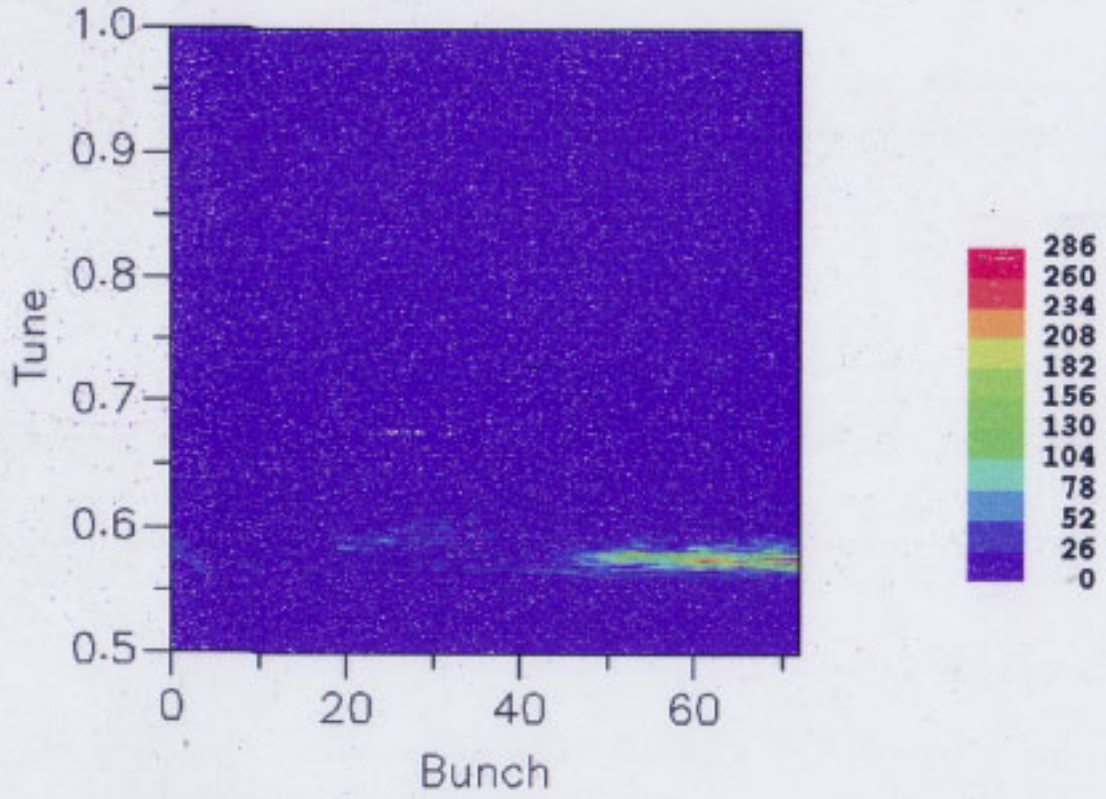
Bunch Evolution

46 Bunch on Dataviewer

2D/3D Graph Control:

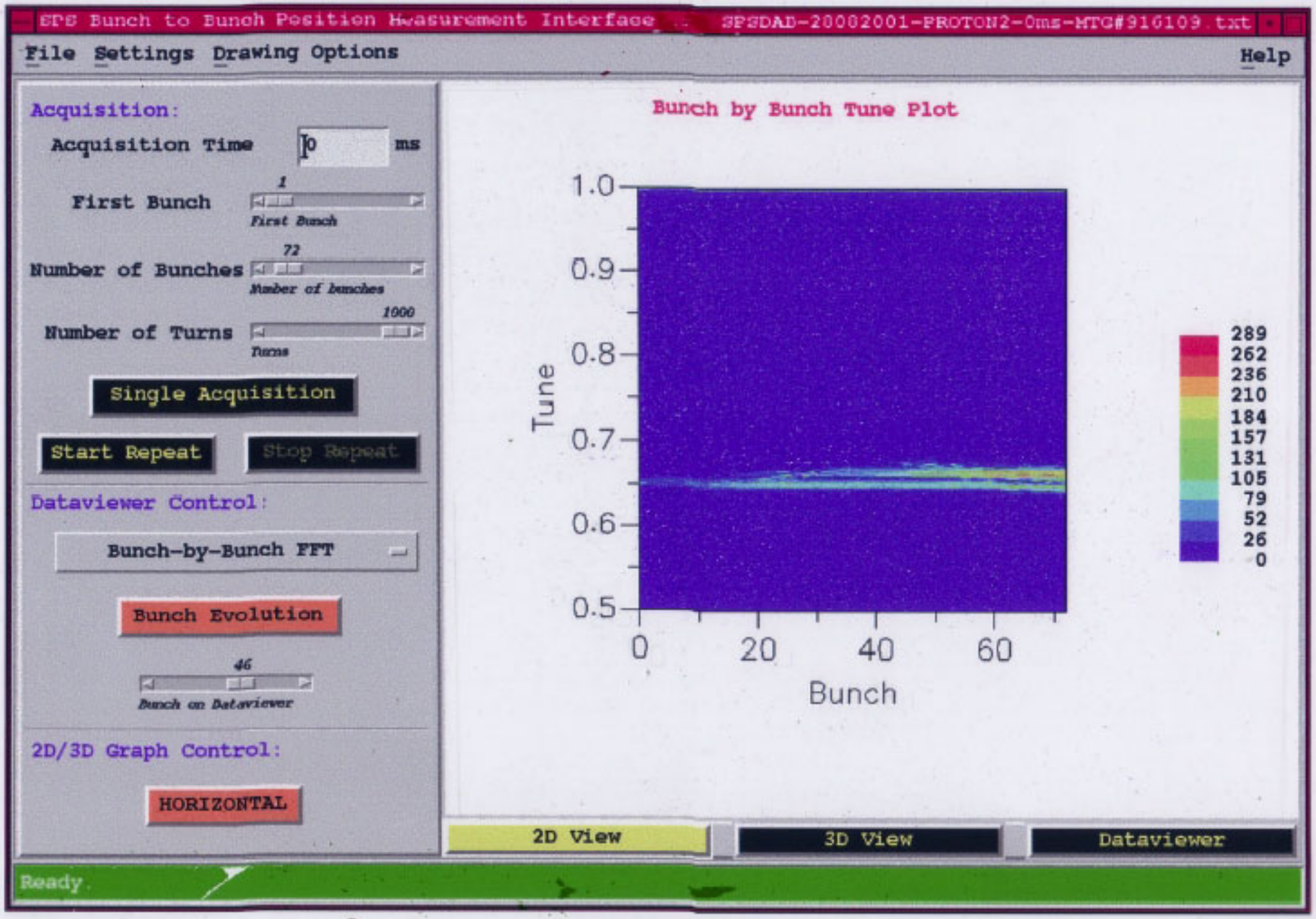
VERTICAL

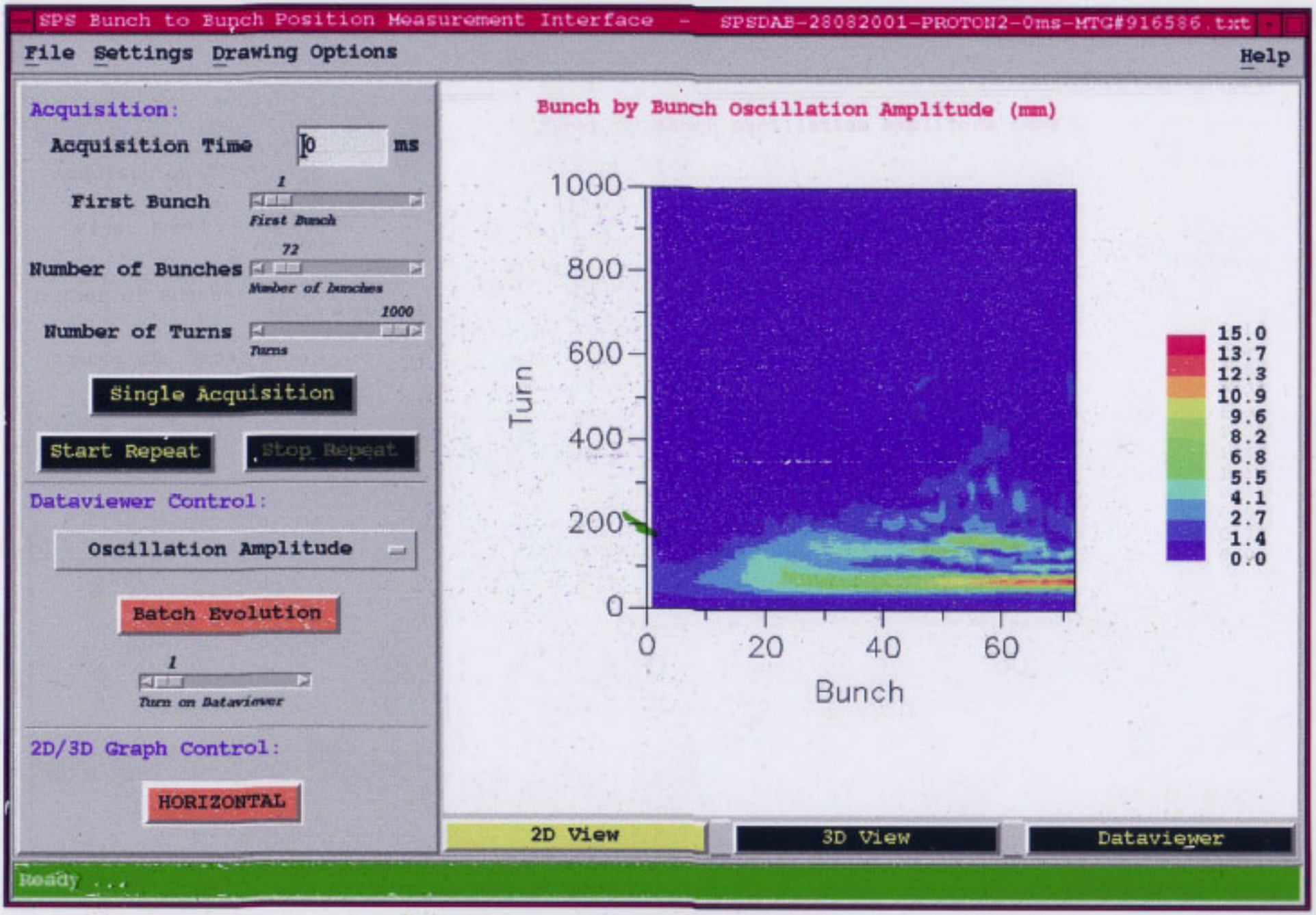
Bunch by Bunch Tune Plot



2D View 3D View Dataviewer

Ready


SPS Bunch to Bunch Position Measurement Interface
SPSDAD-20002001-PROTON2-0ms-MTG#916109.txt
File
Settings
Drawing Options
Help
Acquisition:
Acquisition Time
0
ms
First Bunch
1
First Bunch
Number of Bunches
72
Number of bunches
Number of Turns
1000
Turns
Single Acquisition
Start Repeat
Stop Repeat
Dataviewer Control:
Bunch-by-Bunch FFT
Bunch Evolution
46
Bunch on Dataviewer
2D/3D Graph Control:
HORIZONTAL
Bunch by Bunch Tune Plot
Tune
1.0
0.9
0.8
0.7
0.6
0.5
0
20
40
60
Bunch
289
262
236
210
184
157
131
105
79
52
26
0
2D View
3D View
Dataviewer
Ready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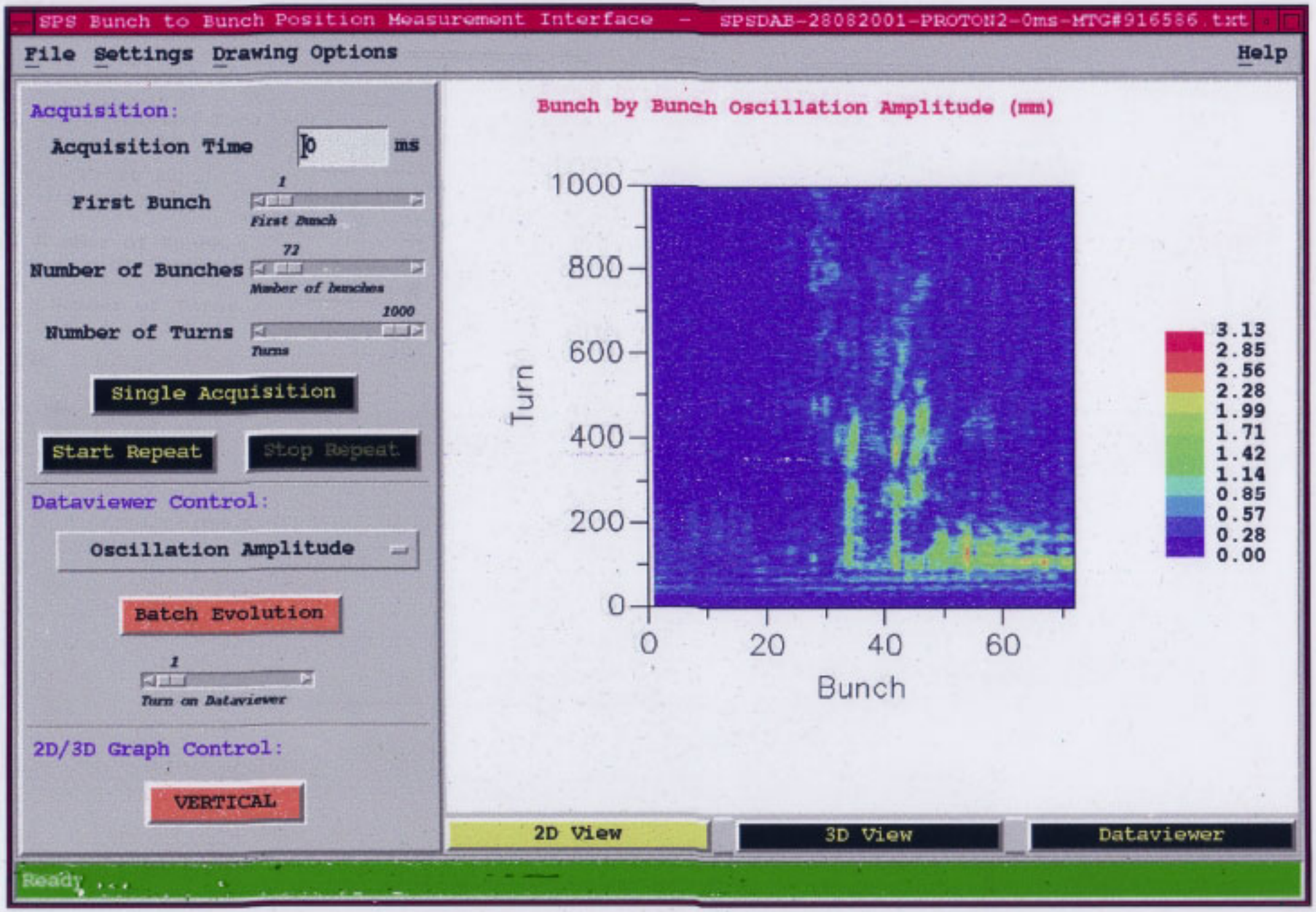
File Settings Drawing Options
Help
Acquisition:
Acquisition Time
0
ms
First Bunch
1
First Bunch
Number of Bunches
72
Number of bunches
Number of Turns
1000
Turns
Single Acquisition
Start Repeat
Stop Repeat
Dataviewer Control:
Oscillation Amplitude
Batch Evolution
1
Turn on Dataviewer
2D/3D Graph Control:
HORIZONTAL
Bunch by Bunch Oscillation Amplitude (mm)
Turn
1000
800
600
400
200
0
0
20
40
60
Bunch
15.0
13.7
12.3
10.9
9.6
8.2
6.8
5.5
4.1
2.7
1.4
0.0
2D View
3D View
Dataviewer
Ready ...


SPS Bunch to Bunch Position Measurement Interface - SPSDAB-28082001-PROTON2-0ms-MTG#916586.txt
File Settings Drawing Options
Help
Acquisition:
Acquisition Time
0
ms
First Bunch
1
First Bunch
Number of Bunches
72
Number of bunches
Number of Turns
1000
Turns
Single Acquisition
Start Repeat
Stop Repeat
Dataviewer Control:
Oscillation Amplitude
Batch Evolution
1
Turn on Dataviewer
2D/3D Graph Control:
VERTICAL
Bunch by Bunch Oscillation Amplitude (mm)
Turn
1000
800
600
400
200
0
0
20
40
60
Bunch
3.13
2.85
2.56
2.28
1.99
1.71
1.42
1.14
0.85
0.57
0.28
0.00
2D View
3D View
Dataviewer
Ready ...