IMPEDANCE OF PS KICKERS FOR THE NEW CT AND BEAM DYNAMICS CONSIDERATIONS

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- **Measurement of the longitudinal impedance vs. transverse offset by F. Caspers and T. Kroyer (cf. previous talk)**
- **Transverse "generalized" impedance deduced from Panofsky-Wenzel theorem**
- **Comparison between measurements and theory**
- **Consequences on beam dynamics**

INTRODUCTION (1/3)

1. **The following kickers are installed presently in the PS machine**
   a. **Injection kicker in section 45**
   b. **Extraction kicker in sections 71 and 79**
   c. **BFAs (pedestal and staircase) in sections 9 and 21**
   d. **Injection kicker for ions in section 28**

2. **The following kickers will be installed for the first stage of the novel multi-turn extraction**
   a. **Two new kickers in sections 13 and 21. The modules are similar to those of the extraction kicker**
   b. **One new kicker in section 4. The modules are recuperated from the extraction kicker for leptons**
   c. **All the kickers mentioned under the point 1. will be also present**

3. **For the second stage it is foreseen to**
   a. **Decrease the rise-time of the kickers in section 13 and 21. At the same time a new design of the modules could be made so to reduce the impedance seen by the beam**
   b. **The BFA in section 21 will be removed**
   c. **The BFA in section 9 will stay in the machine**
   d. **Injection kickers (section 28 and 45) and the extraction kicker (sections 71 and 79) will, of course, remain in the machine**

INTRODUCTION (2/3)

- **Measured longitudinal impedance vs. transverse offset, using a single displaced wire (in a symmetric structure)**

$$Z_{\parallel}^{\text{measured}}(f) = Z_{\parallel,0}(f) + Z_{\parallel,1x}(f)\,x_0^2 + Z_{\parallel,1y}(f)\,y_0^2$$

$$\Rightarrow \quad Z_x = Z_x^{\text{driving}} - Z^{\text{detuning}} = \frac{c}{2\pi f} Z_{\parallel,1x}(f)$$

$$Z_y = Z_y^{\text{driving}} + Z^{\text{detuning}} = \frac{c}{2\pi f} Z_{\parallel,1y}(f)$$

$$\int_L F_x\, ds = -q^2 x_0 W_x(z) + q^2 x D(z)$$
$$\int_L F_y\, ds = -q^2 y_0 W_y(z) - q^2 y D(z)$$

⇒ **The sum (or difference) of the dipolar (driving) and quadrupolar (detuning) impedances is measured with a single displaced wire**

⇒ **This explains why very different results are measured with the 2-wire method (which measures only the dipolar impedance) and the single-wire method (where >0, 0, or <0 impedances can be measured)**

INTRODUCTION (3/3)

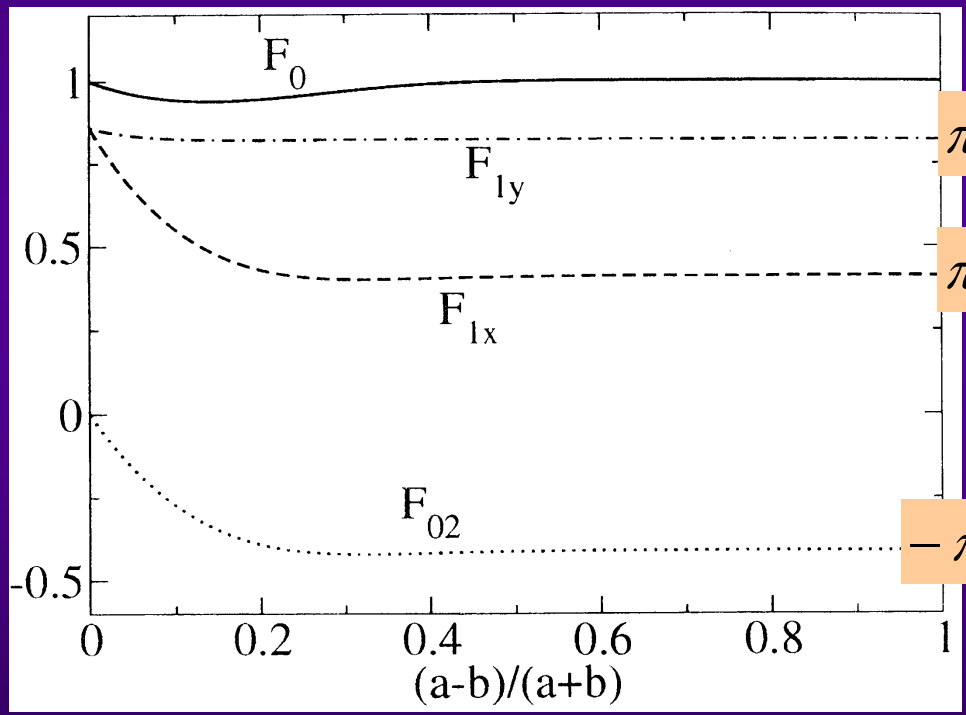
- **Example given by Tsutsui (CERN-SL-Note-2002-034 AP)**

Longitudinal (classical) resistive-wall impedance (with a single wire) for a 2D rectangular metallic pipe of height 2b and width 2a

$$Z_{\parallel} = \frac{1+j}{2\pi b \sigma \delta} L F_0$$

$$+ \frac{1+j}{\pi b^3 \sigma \delta} L \left(F_{1x} + F_{02} \right) x_0^2$$

$$+ \frac{1+j}{\pi b^3 \sigma \delta} L \left(F_{1y} - F_{02} \right) y_0^2$$



$\pi^2/12$

$\pi^2/24$

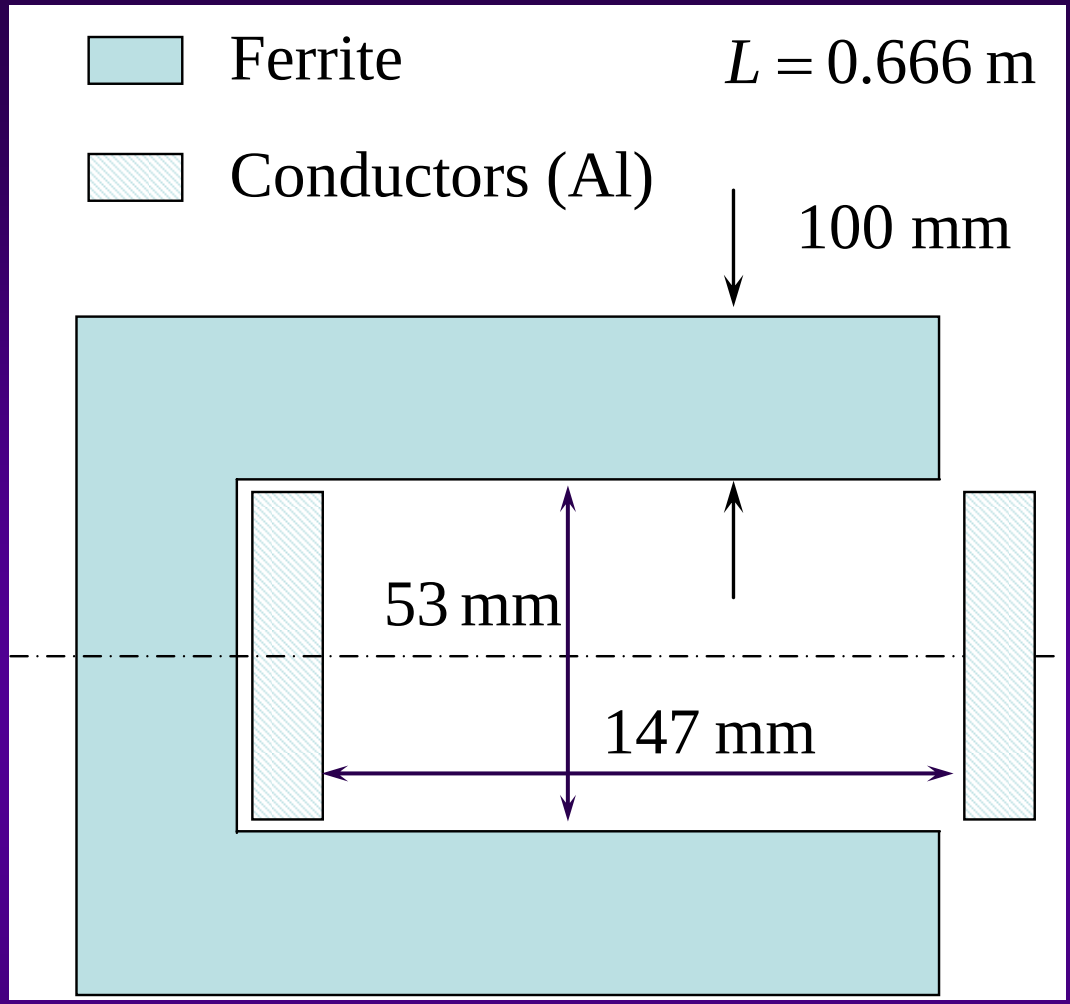
$-\pi^2/24$

⇒ **This explains why a zero impedance can be measured in the horizontal plane of a flat chamber, with a single wire**

Kicker 1

$\Longrightarrow$ 2 will be installed in the PS (SS 13 and 21)

$\Longrightarrow$ It is the same type as the extraction kicker KFA 71 (but 4 times smaller)



$$\beta_x^{13} \approx 22.1\,\text{m}$$

$$\beta_y^{13} \approx 12.5\,\text{m}$$

$$\beta_x^{21} \approx 20.4\,\text{m}$$

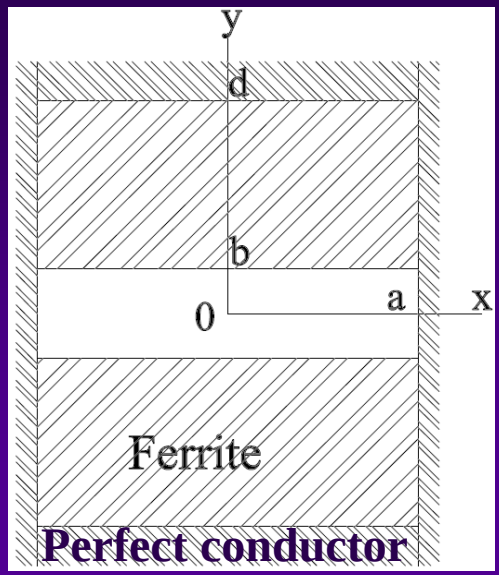
$$\beta_y^{21} \approx 11.9\,\text{m}$$

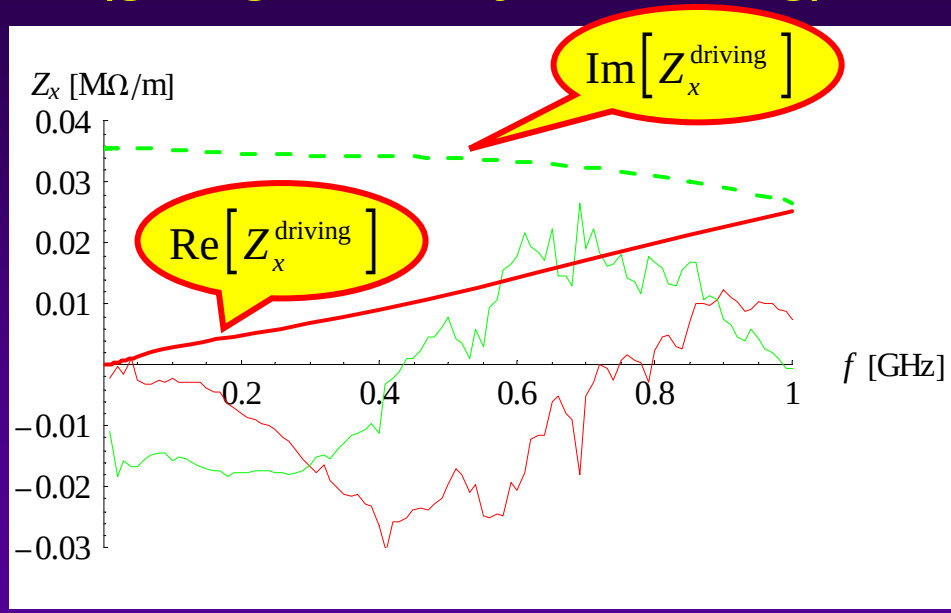
$\Longrightarrow$ The ferrite is split longitudinally in many cells

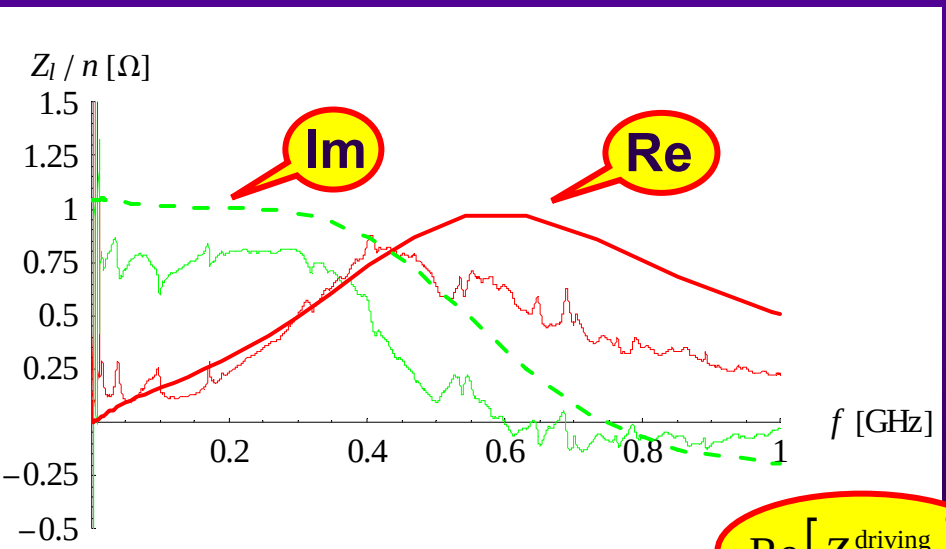
$\Longrightarrow$ Each cell is 24 mm long
(19 mm of ferrite + 5 mm of Al)

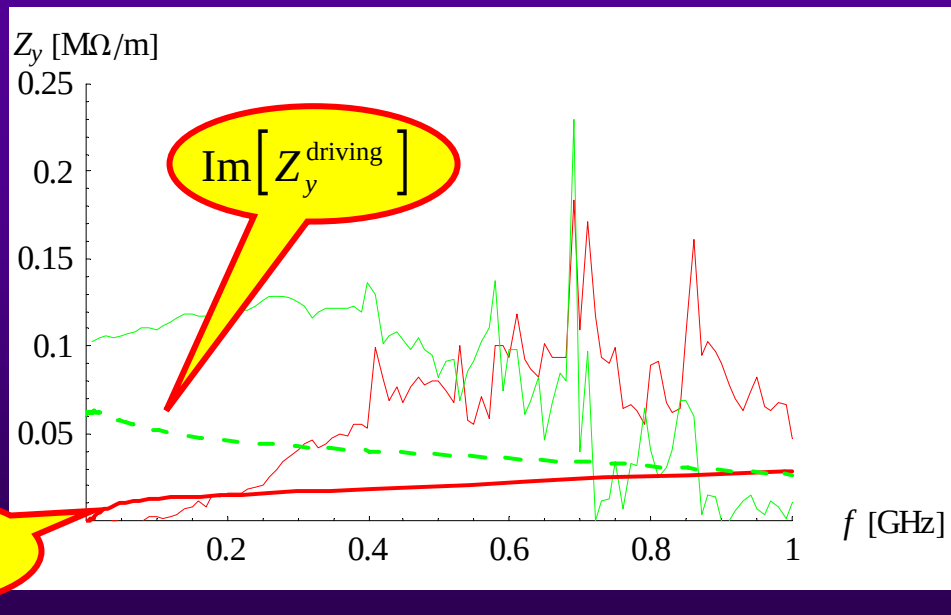
Kicker 1 $\Longrightarrow$ Measurements vs. Tsutsui (giving here only the driving)

Tsutsui's model



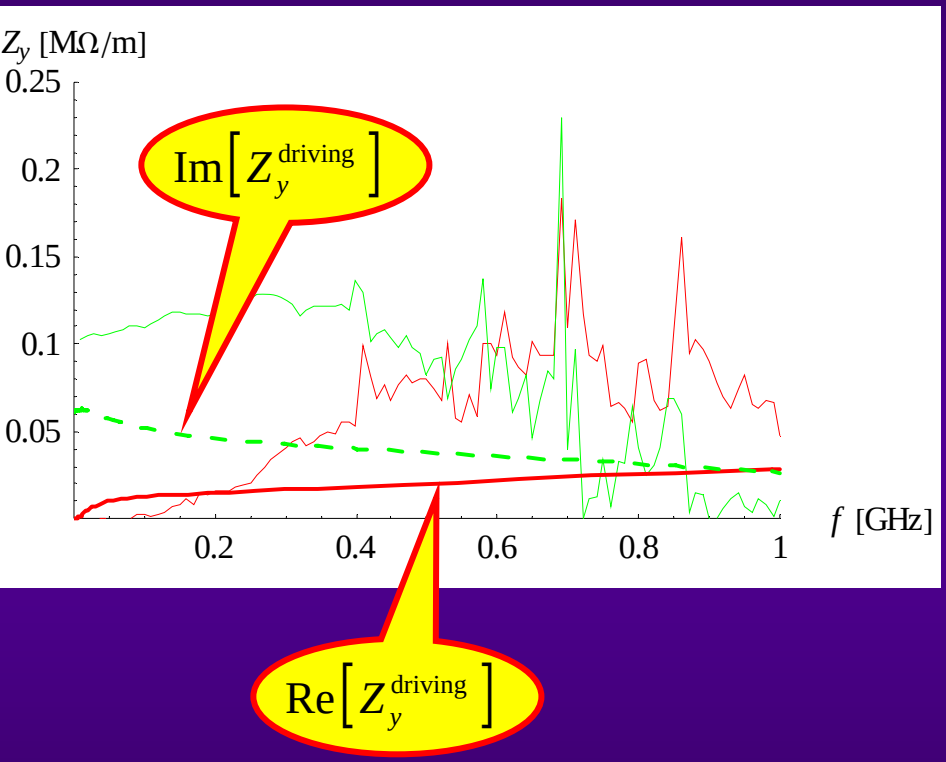




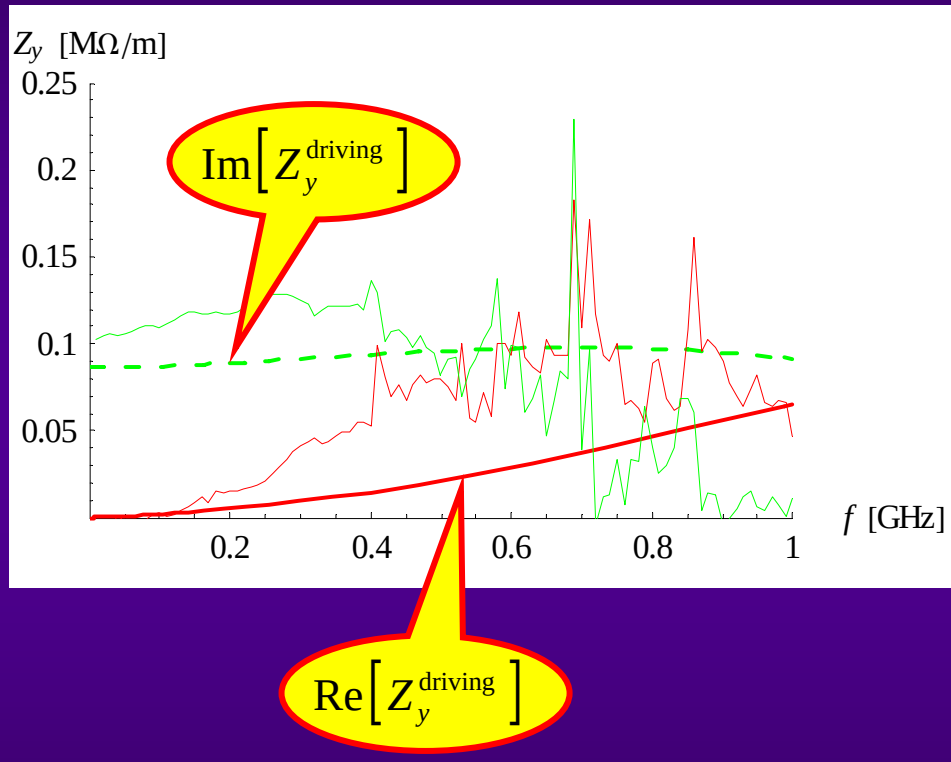


Kicker 1 $\Longrightarrow$ Comparison Tsutsui-Burov&Lebedev for the vertical driving impedance

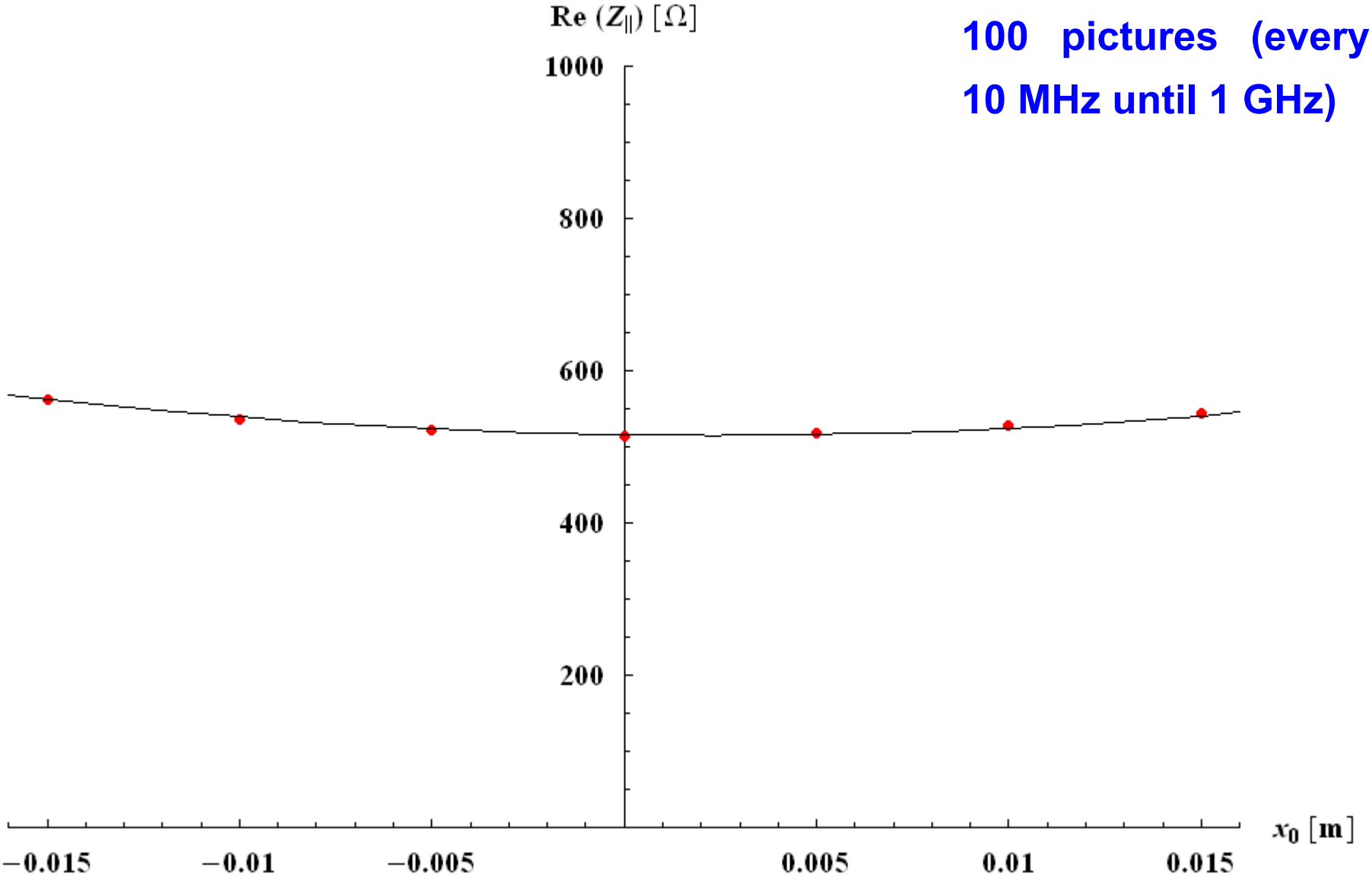
Measurements vs. Tsutsui



Measurements vs. Burov-Lebedev

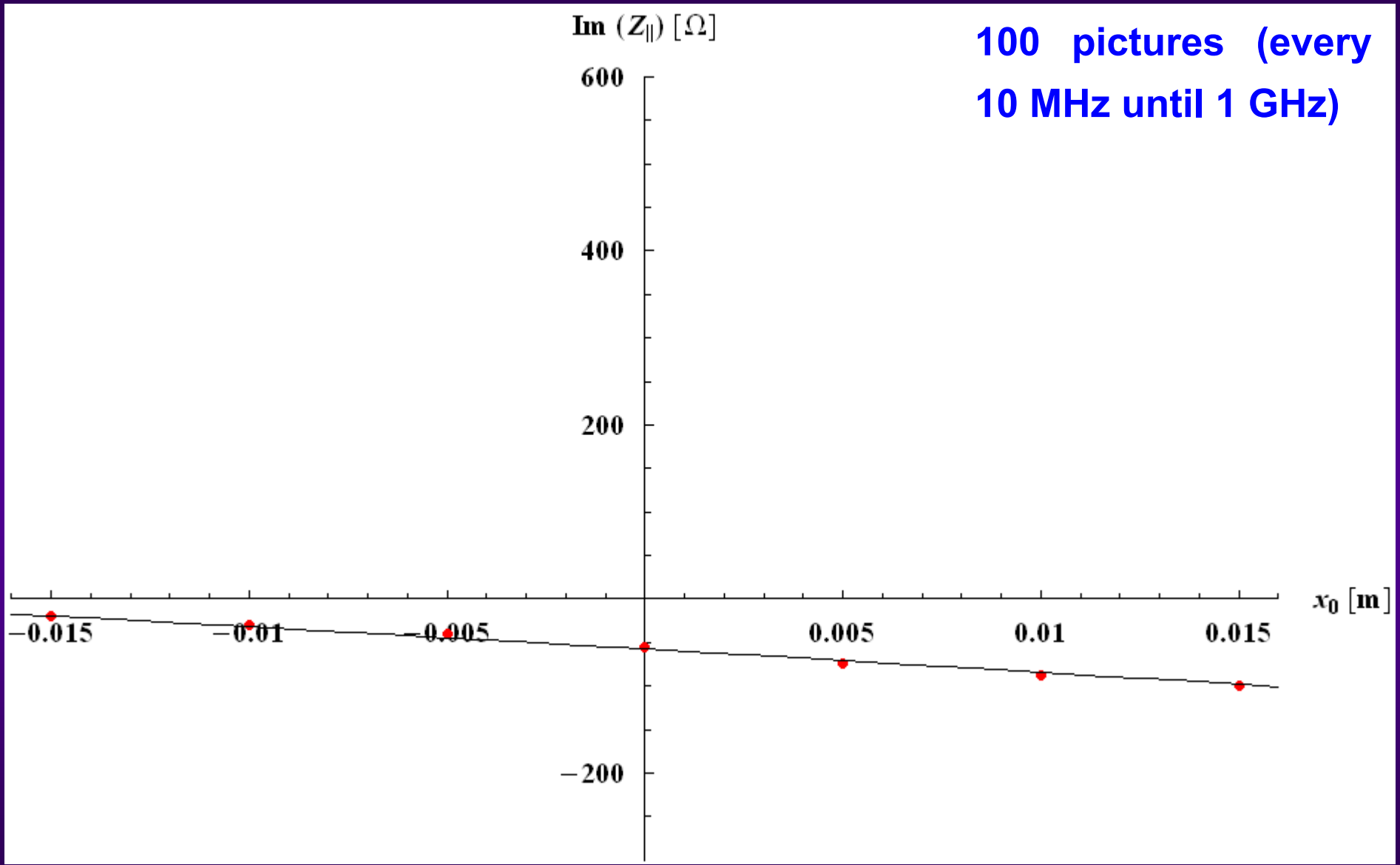


MEASURED LONGITUDINAL IMPEDANCE (Re) VS. HORIZONTAL OFFSET



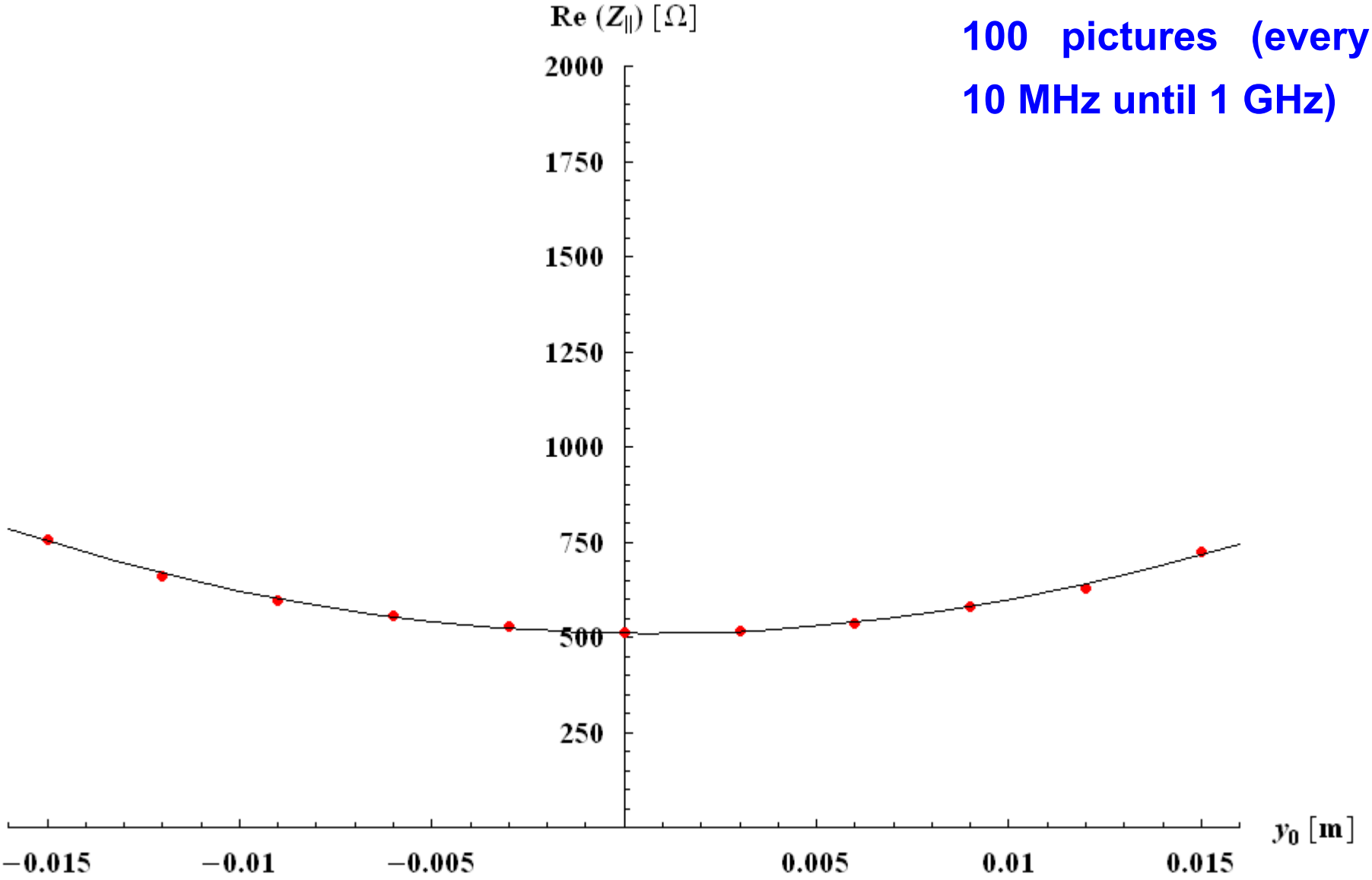
100 pictures (every 10 MHz until 1 GHz)

MEASURED LONGITUDINAL IMPEDANCE (Im) VS. HORIZONTAL OFFSET



100 pictures (every 10 MHz until 1 GHz)

MEASURED LONGITUDINAL IMPEDANCE (Re) VS. VERTICAL OFFSET



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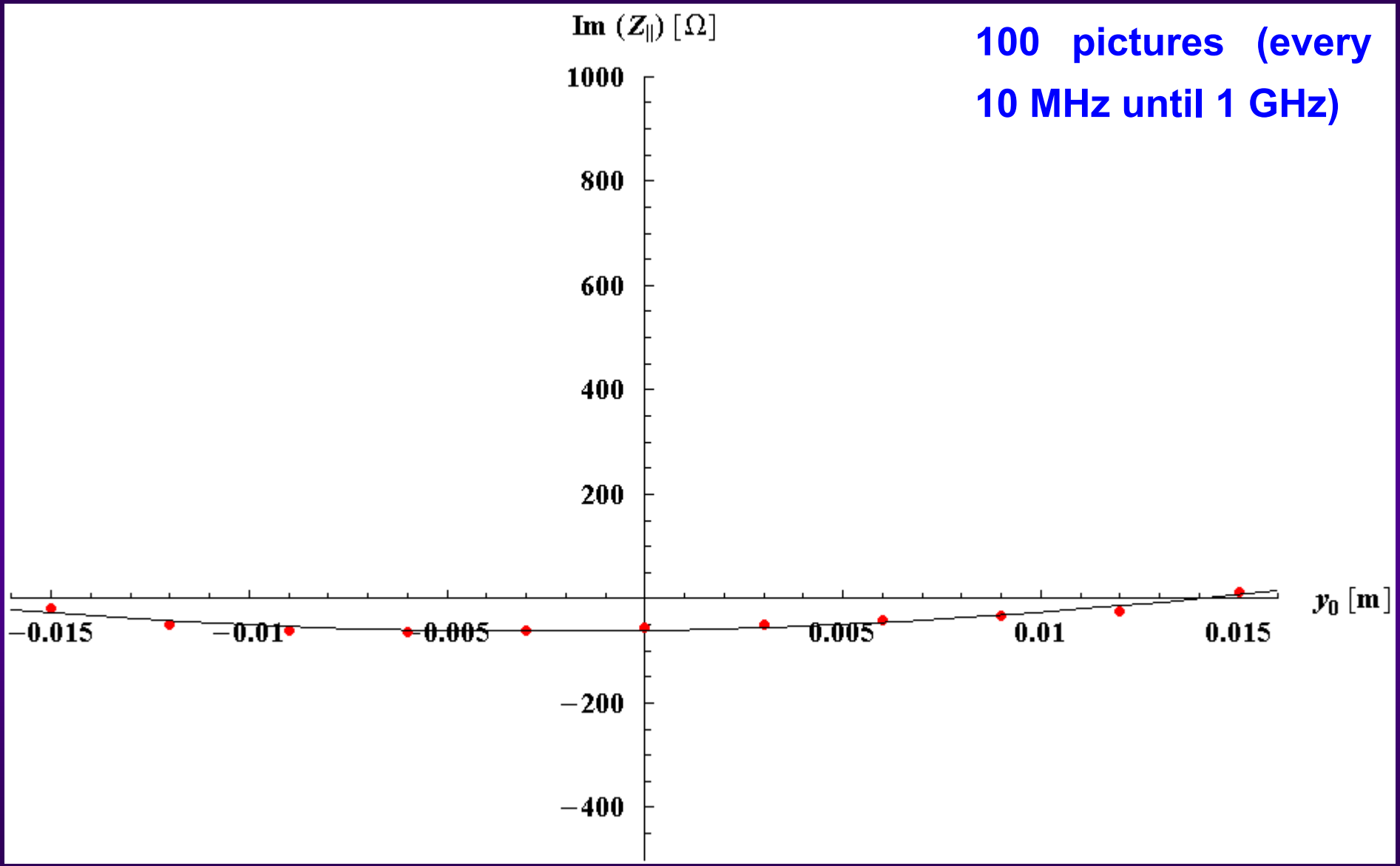
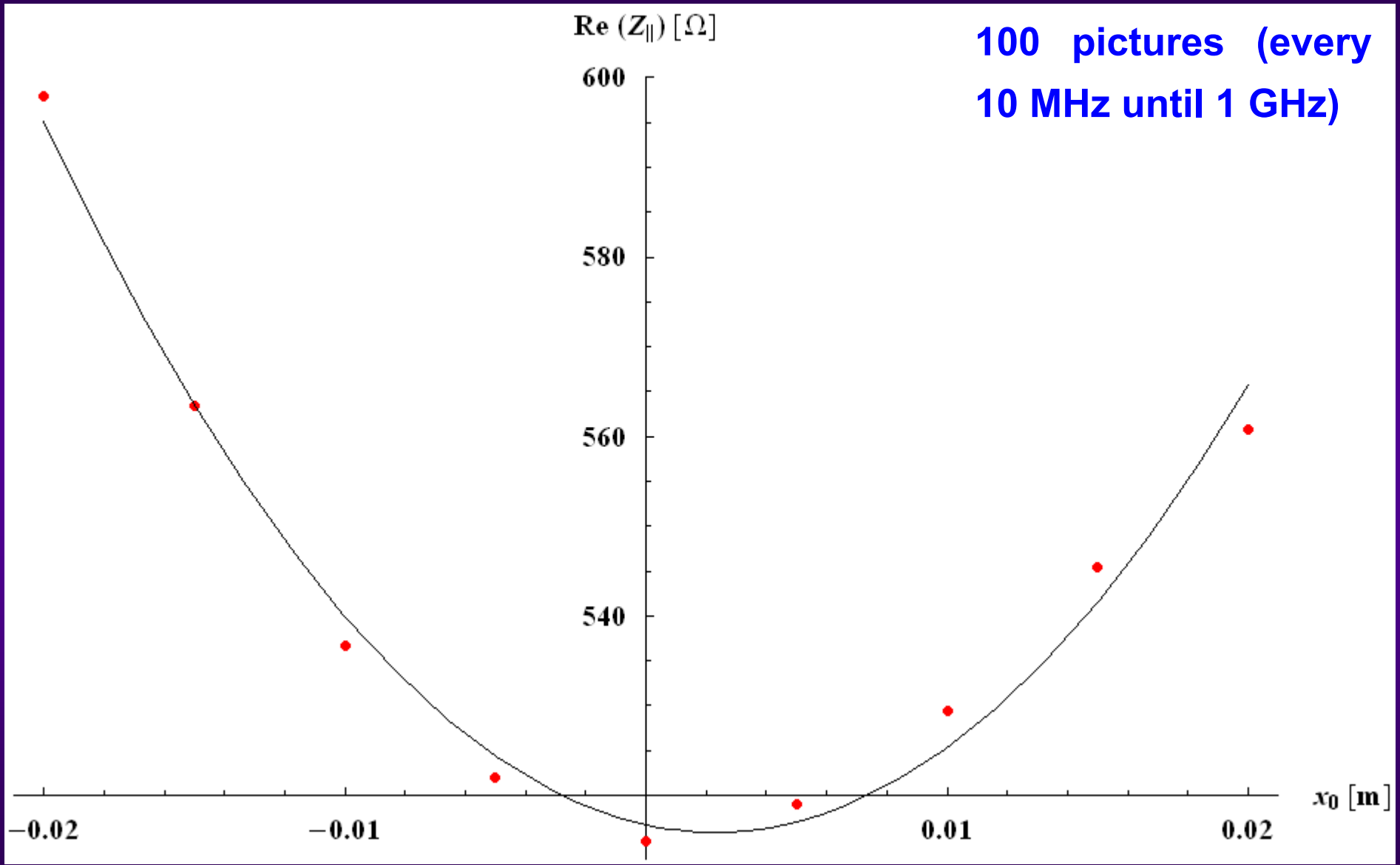
MEASURED LONGITUDINAL IMPEDANCE (Im) VS. VERTICAL OFFSET

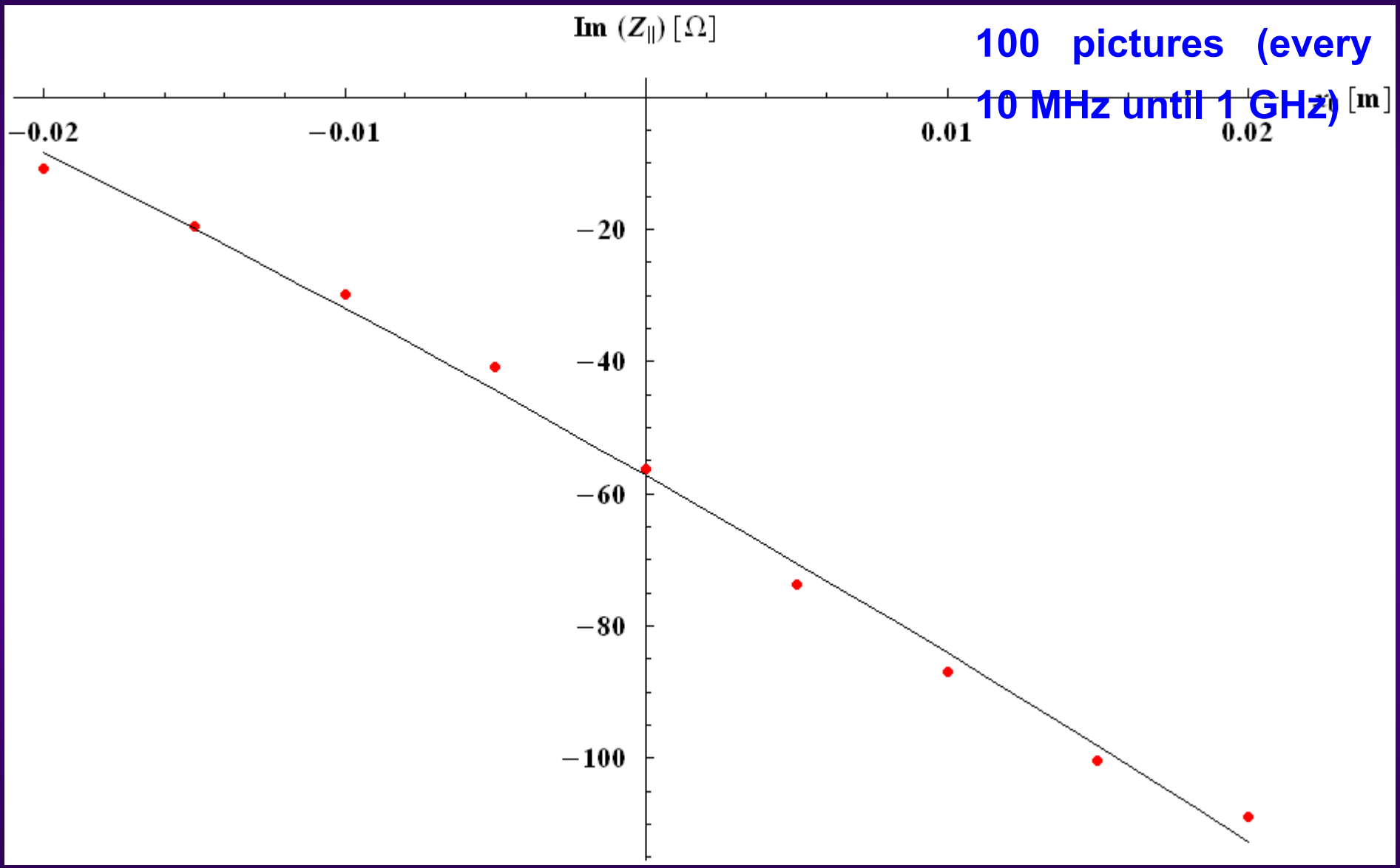


100 pictures (every 10 MHz until 1 GHz)

THE NEXT 4 SLIDES ARE THE SAME AS THE PREVIOUS 4 ONES, BUT WITHOUT A FIXED VERTICAL SCALE



100 pictures (every 10 MHz until 1 GHz)



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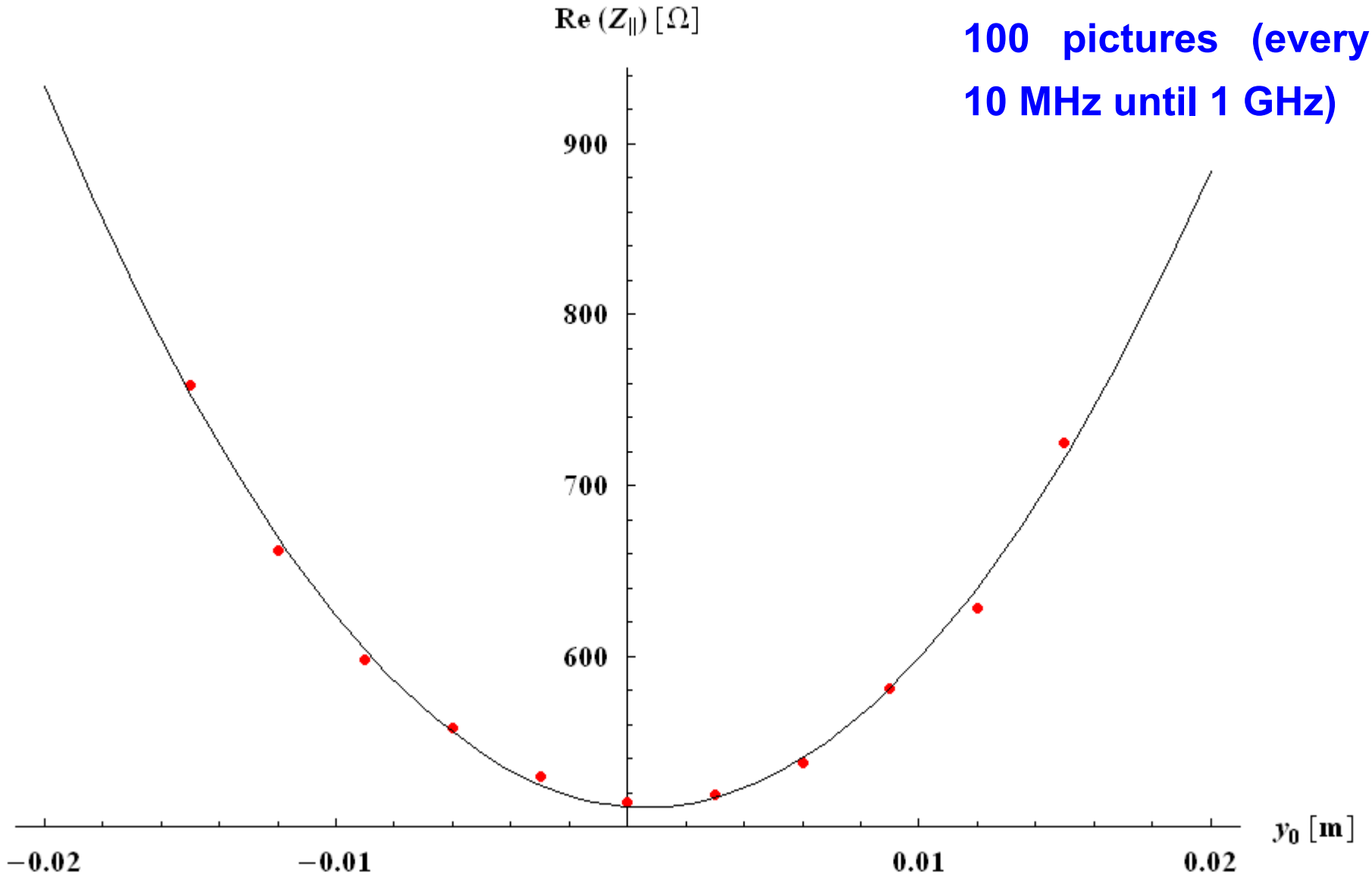
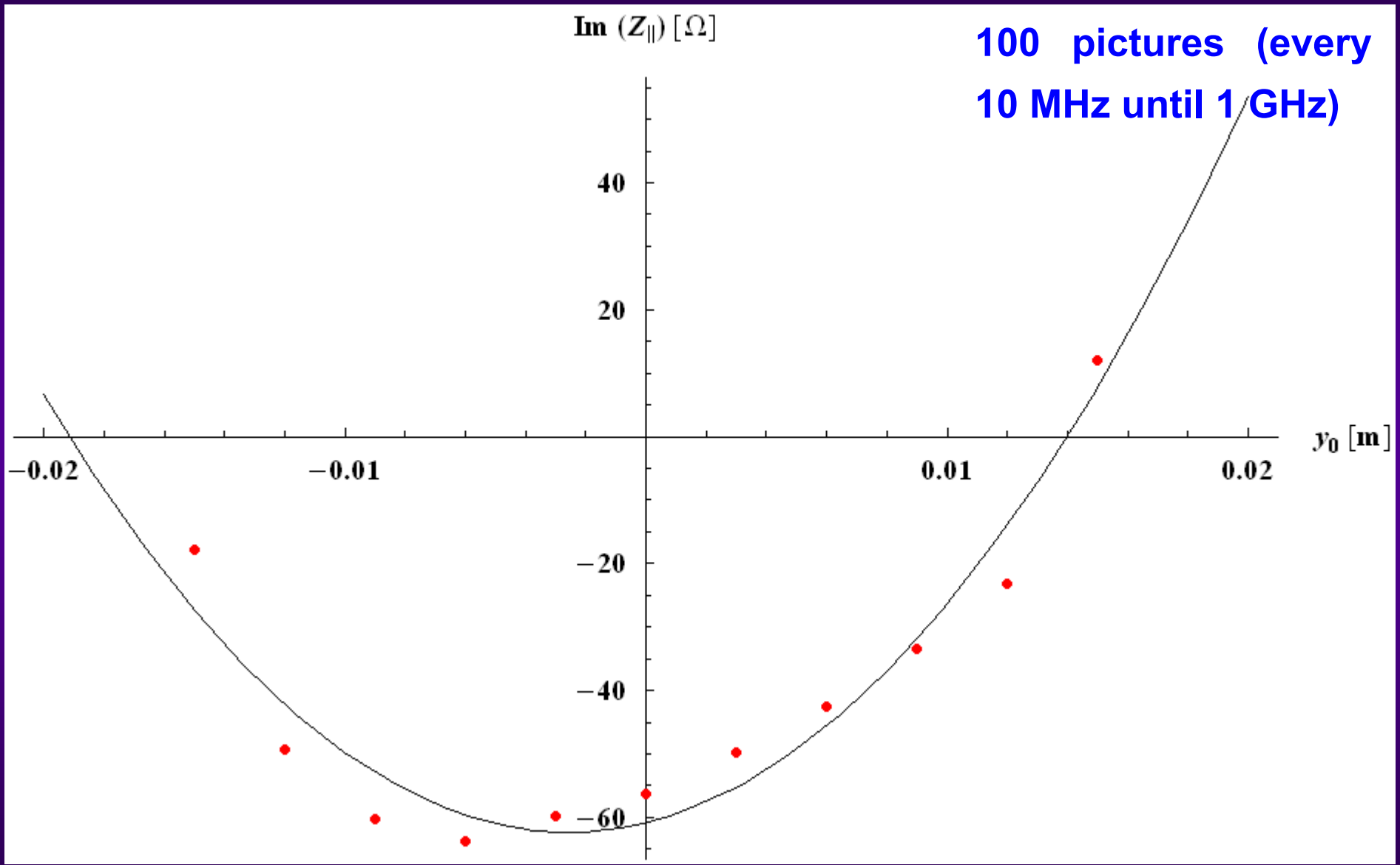
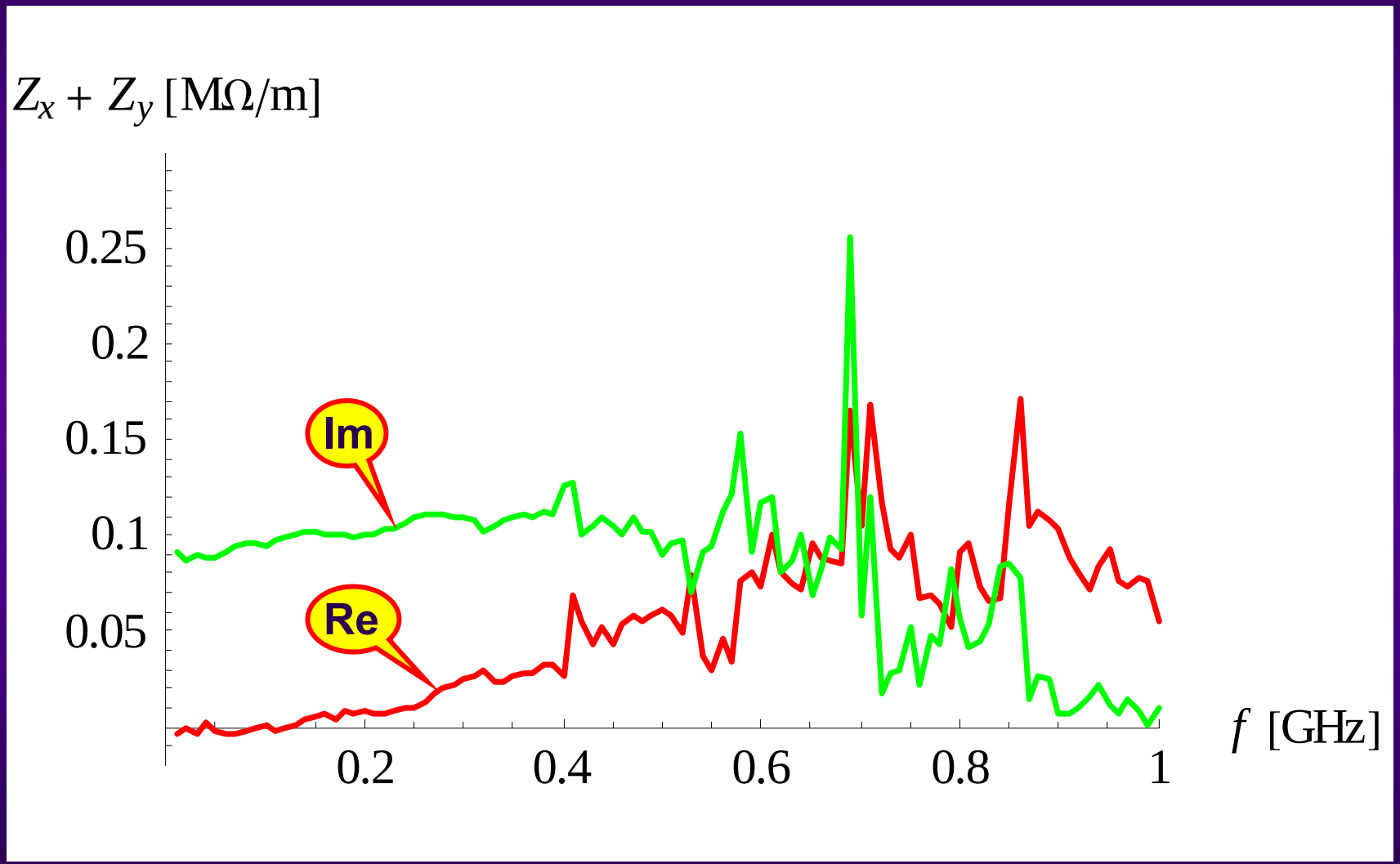


100 pictures (every 10 MHz until 1 GHz)


Im $(Z_{\|})$ $[\Omega]$
100 pictures (every 10 MHz until 1 GHz)
40
20
−20
−40
−60
−0.02
−0.01
0.01
0.02
y_0 [m]

Kicker 1 $\Longrightarrow$ Measured horizontal + vertical driving impedances (as when we sum the measured transverse impedances the detuning impedance disappears)



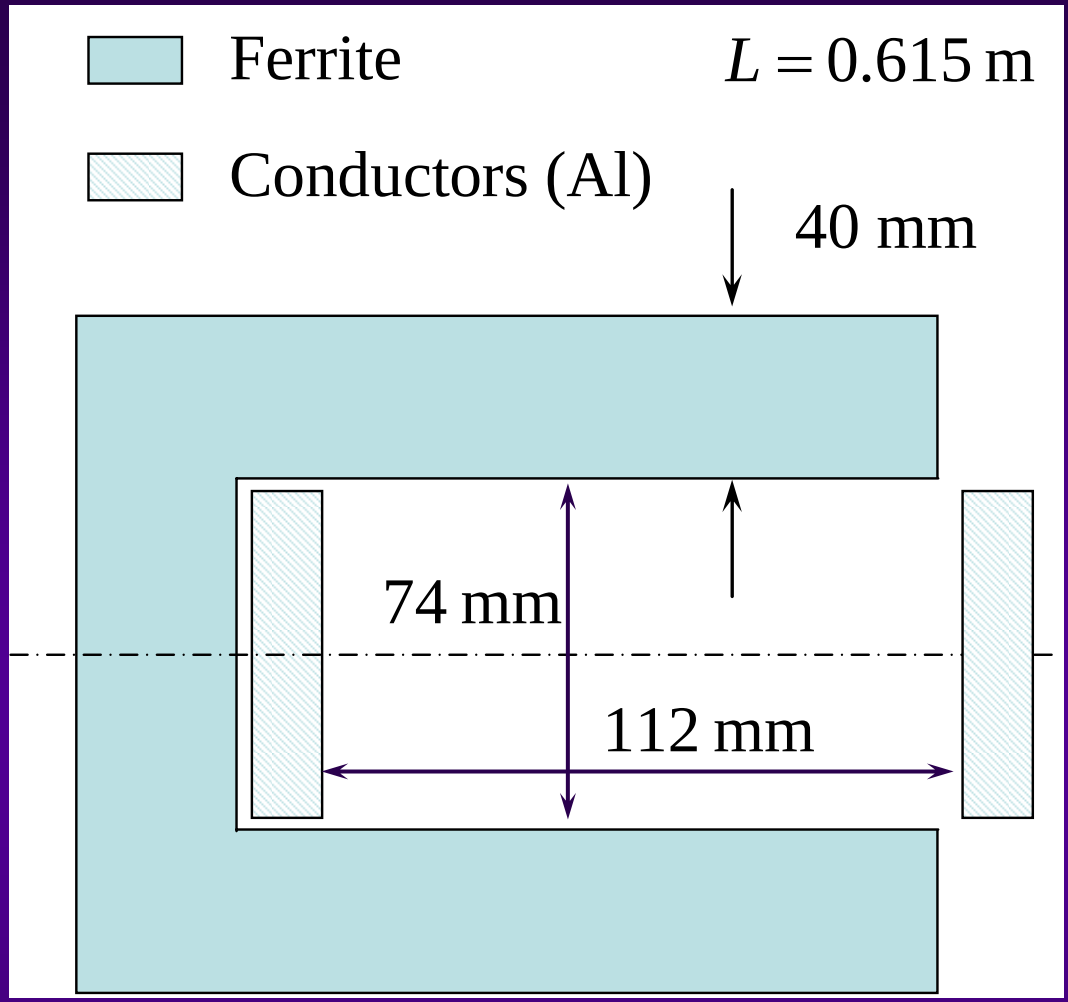
Kicker 2

$\Longrightarrow$ 1 will be installed in the PS (SS 4)

$\Longrightarrow$ Modules recuperated from the extraction kicker for leptons

$$\beta_x^4 \approx 12.6 \text{ m}$$

$$\beta_y^4 \approx 22.0 \text{ m}$$



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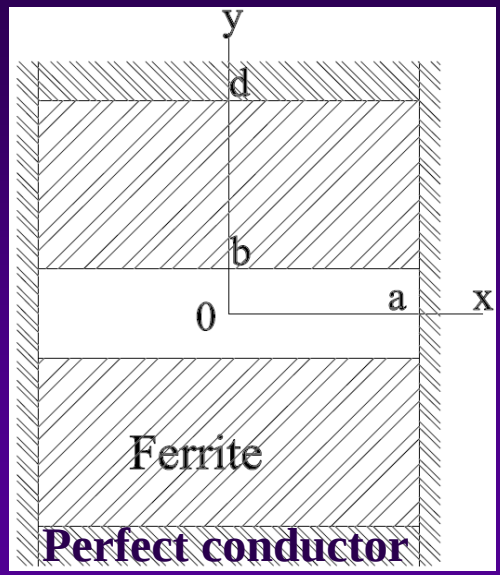
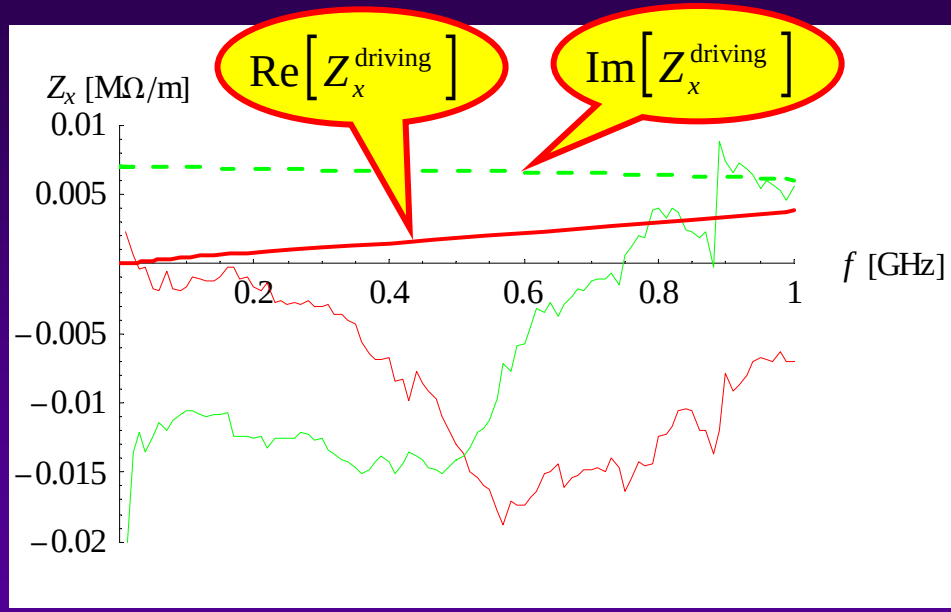
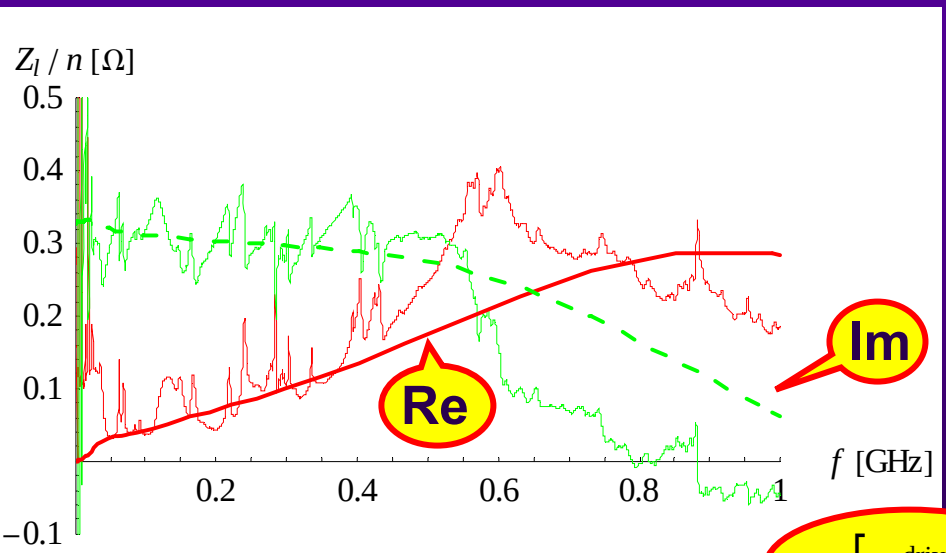
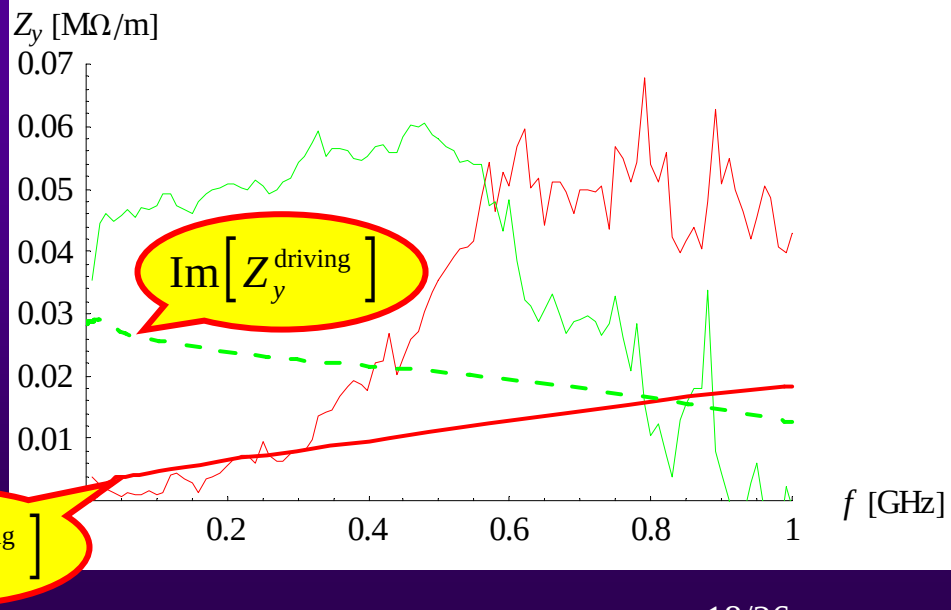
Kicker 2 $\Longrightarrow$ Measurements vs. Tsutsui (giving here only the driving)

Tsutsui's model









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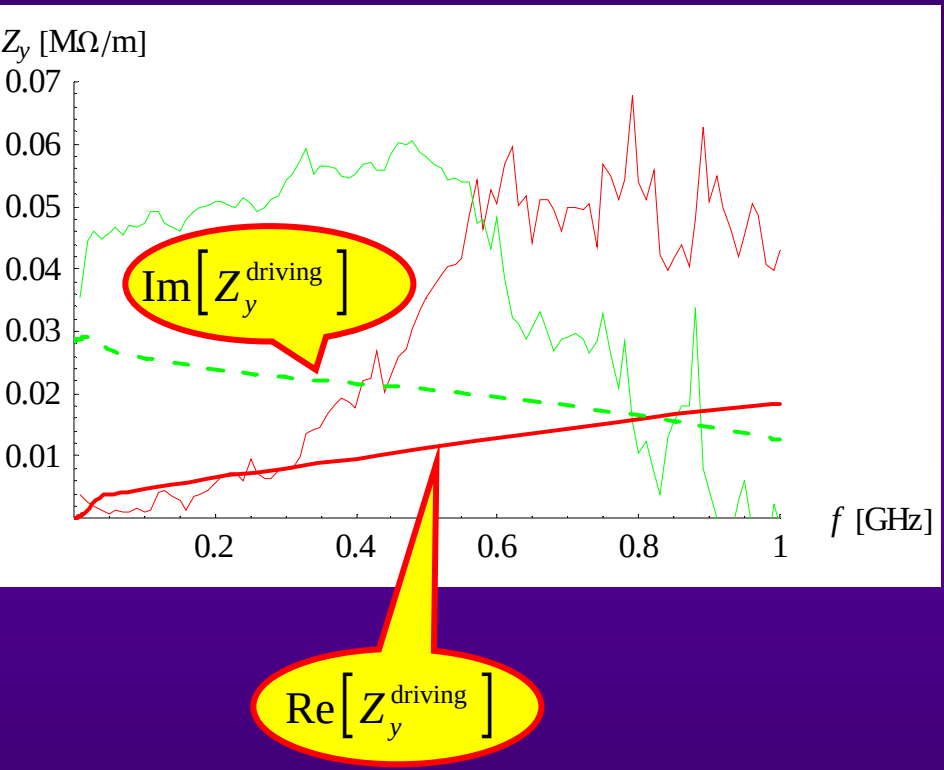

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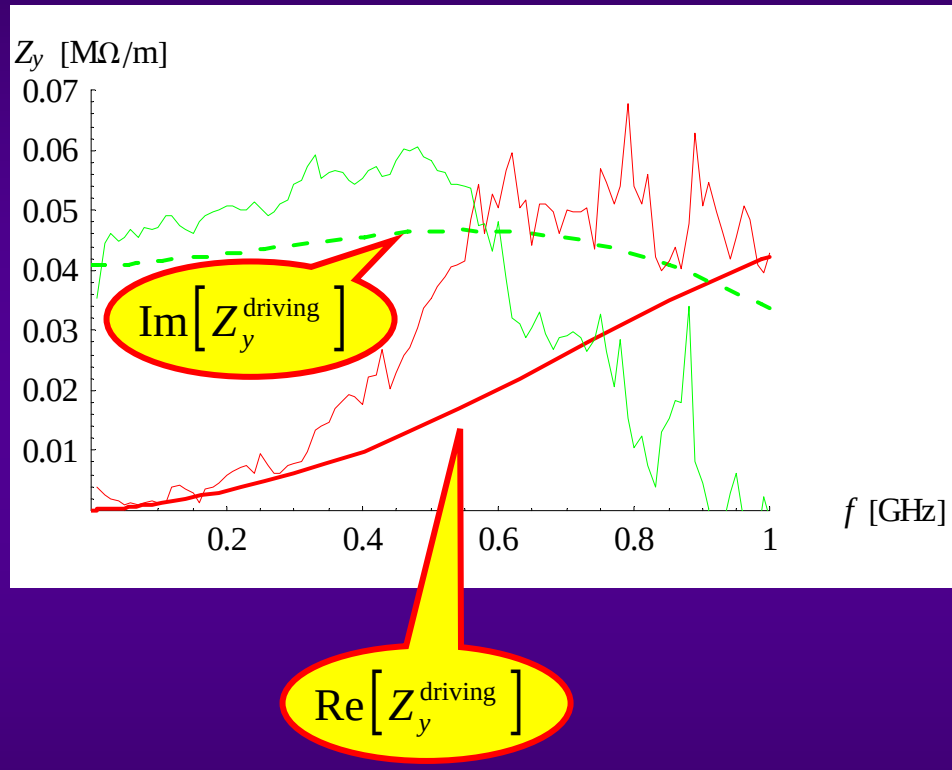
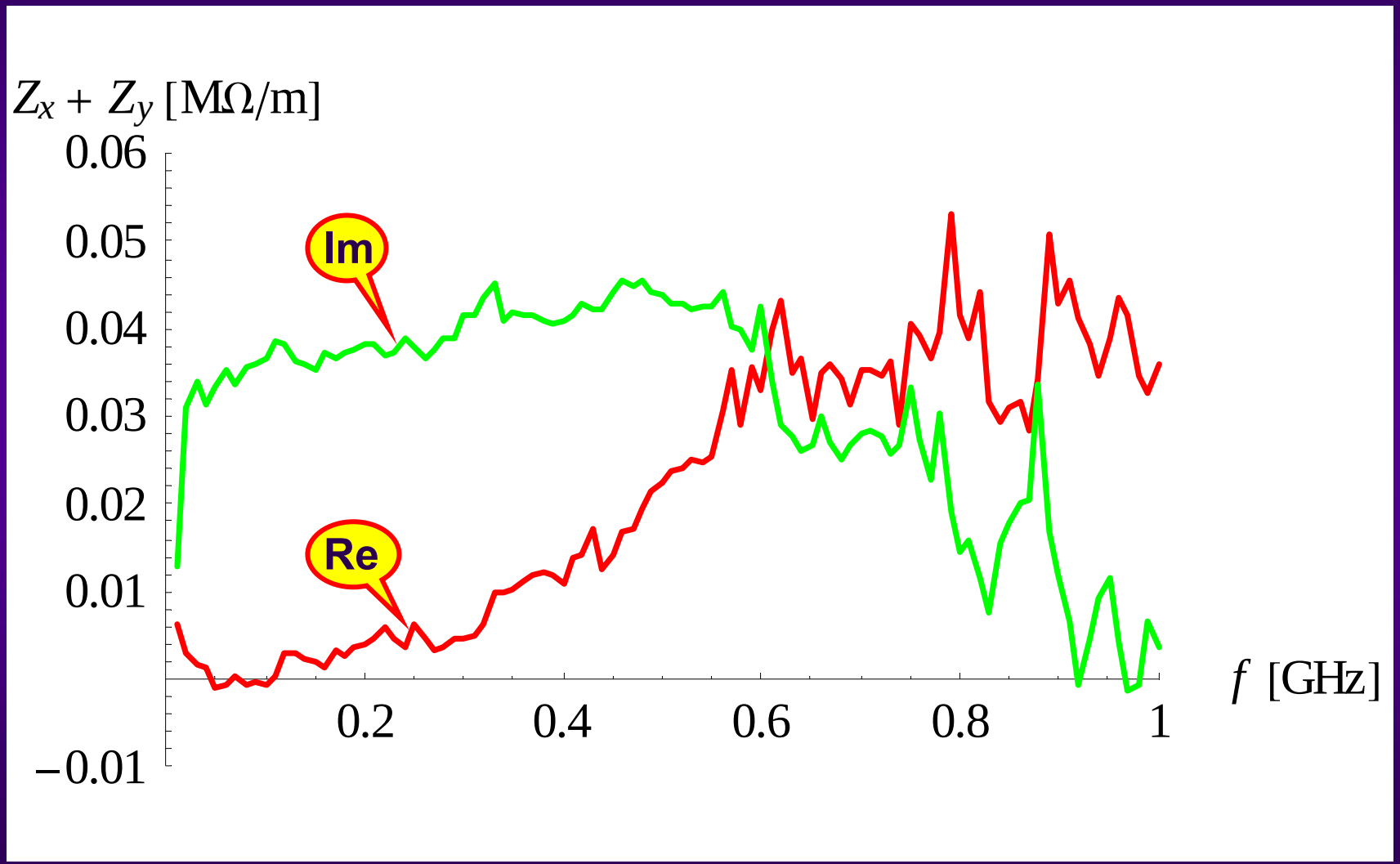


Kicker 2 $\Longrightarrow$ Measured horizontal + vertical driving impedances (as when we sum the measured transverse impedances the detuning impedance disappears)



CONCLUSIONS FROM THE MEASUREMENTS

- **2 kickers of type 1 (at large β_x and small β_y) + 1 kicker of type 2 (at small β_x and large β_y) will add to the PS machine**
  - **A longitudinal Broad-Band impedance of ~ 2 Ω, with a resonance frequency near ~ 400-500 MHz**
  - **A maximum (upper limit) transverse Broad-Band (driving) impedance of ~ 0.25 MΩ/m, with a resonance frequency near ~ 700 MHz. Taking into account the β's leads to a normalized impedance of ~ 0.2 MΩ/m**

COMPARISON WITH THE PS "MEASURED" IMPEDANCES

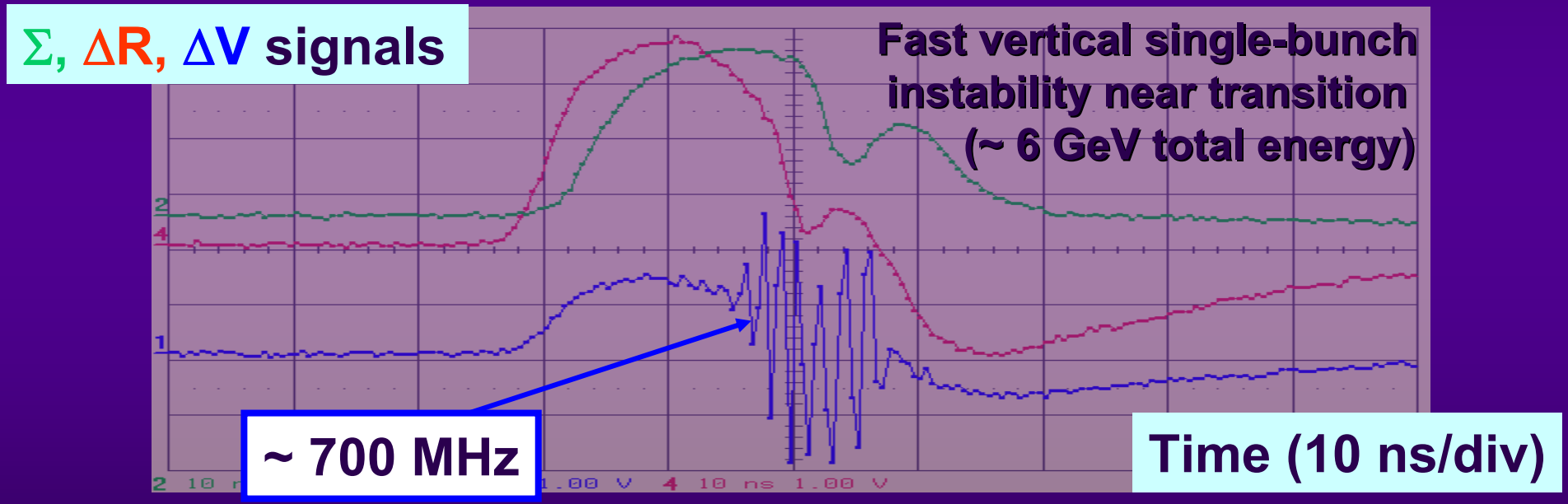
- **The (usual) Broad-Band impedances measured in the PS machine are**
  - **A longitudinal Broad-Band impedance of ~ 20 Ω, with a resonance frequency near ~ 1.4 GHz**
  - **A horizontal Broad-Band impedance of ~ 1 MΩ/m, with a resonance frequency near ~ 1.4 GHz**
  - **A vertical Broad-Band impedance of ~ 3 MΩ/m, with a resonance frequency near ~ 1.4 GHz**

$\Rightarrow$ The 3 kickers for the new CT will increase

- **The longitudinal impedance by ~ 10%**
- **The transverse impedance by ~ 10%**

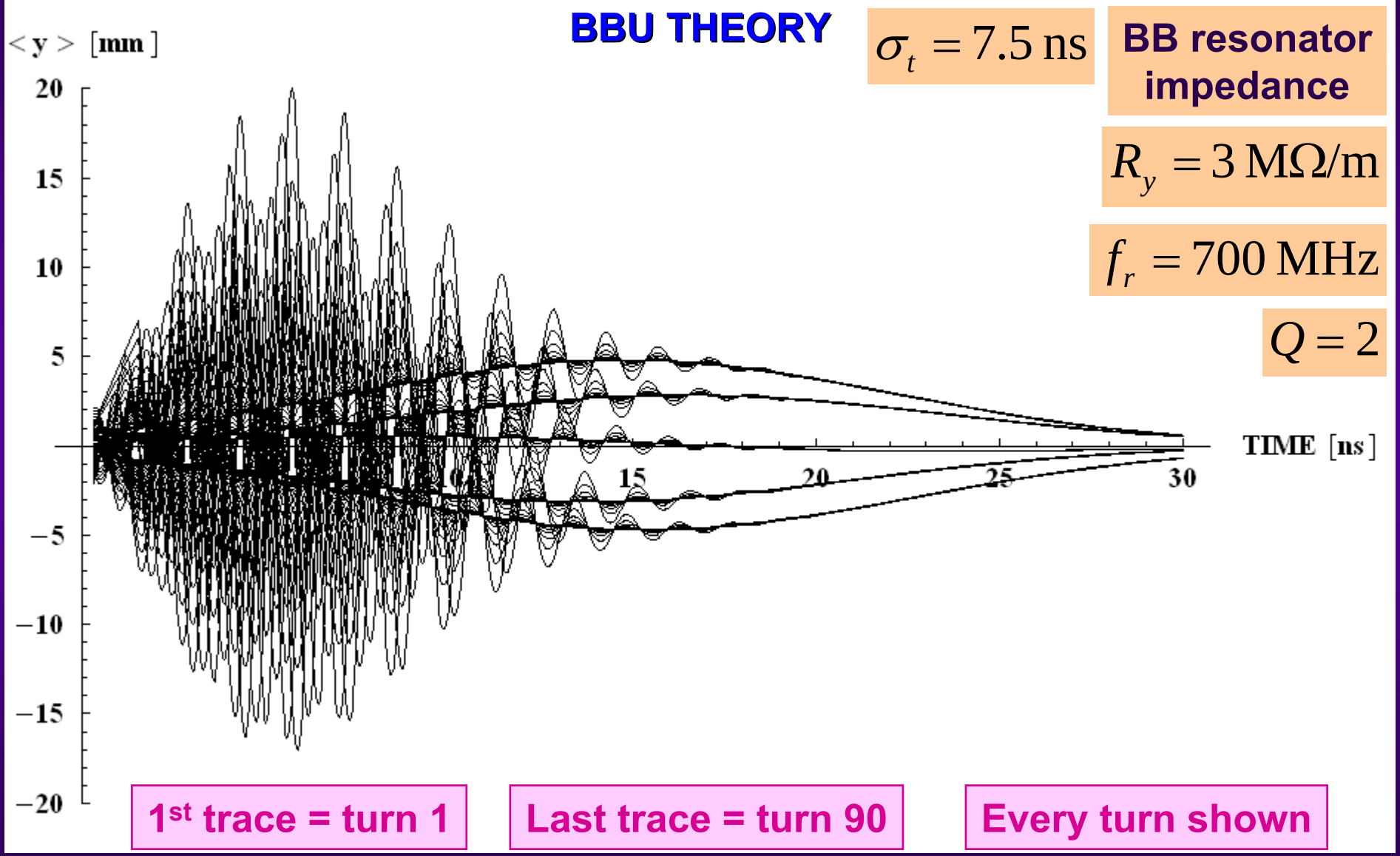
CONSEQUENCES ON BEAM DYNAMICS (1/3)

- Check longitudinal beam stability in particular for LHC beams $\Rightarrow$ Can only be done with measurements (S. Hancock)
- The vertical plane is the most critical due to the fast vertical single-bunch instability observed at transition with high-intensity beams $\Longrightarrow$ Will be more critical at transition for nTOF



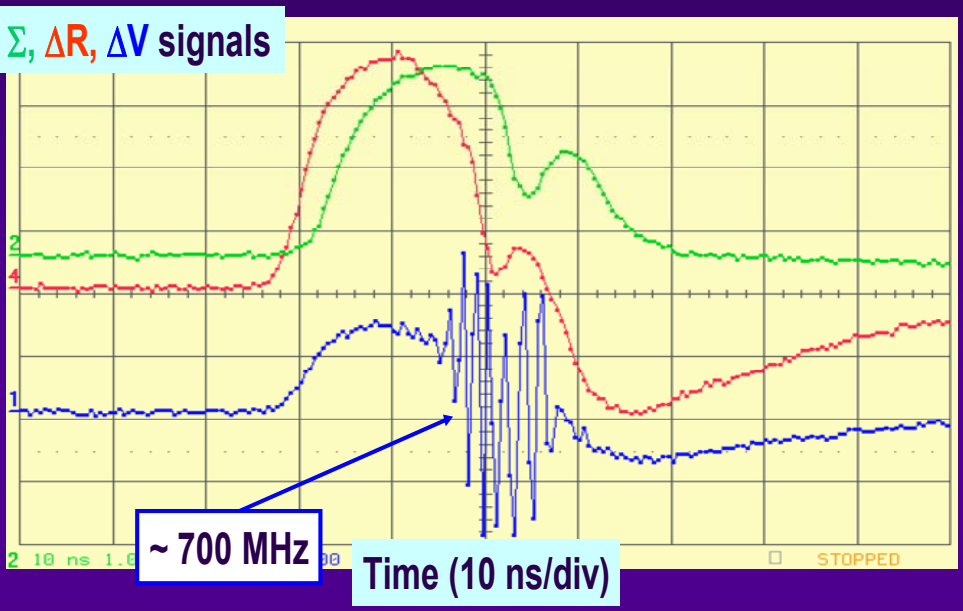
$\Longrightarrow$ Instability suppressed by increasing the longitudinal emittance to ~ 2.2 eVs $\Longrightarrow$ The longitudinal emittance will have to be slightly increased. Still possible with the removal of some 200 MHz cavities?

CONSEQUENCES ON BEAM DYNAMICS (2/3)

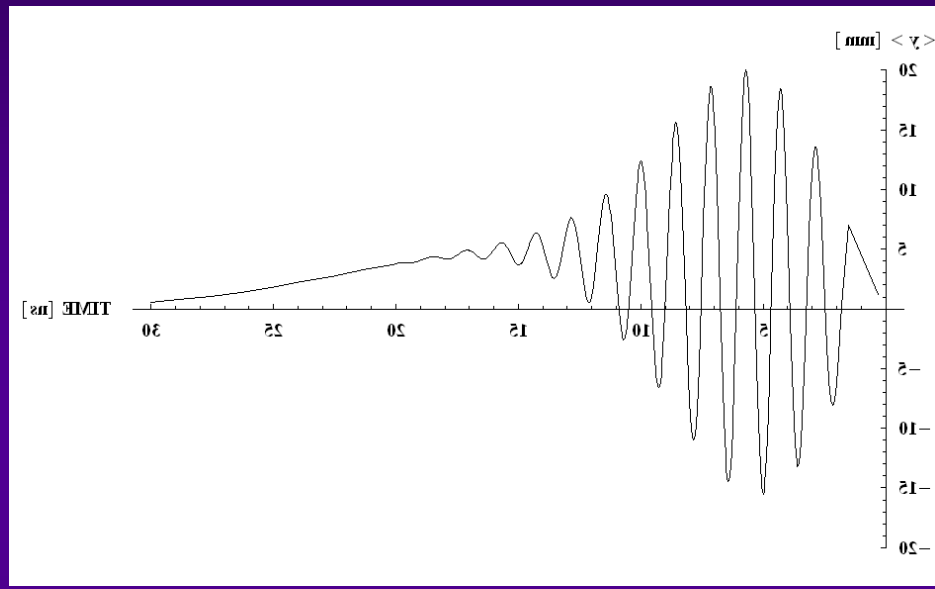


CONSEQUENCES ON BEAM DYNAMICS (3/3)

MEASUREMENTS IN 2000



BBU THEORY
AFTER 90 TURNS (~ 200 μs)



⇒ Seem very close except head and tail exchanged!!! It may start only for the maximum peak intensity, i.e. in the middle…

⇒ Try to produce the same movie with measurements next year (as we did for the SPS fast instability at injection)

CONCLUSION

- The installation of 3 kickers for the new CT will add ~10% to the longitudinal and transverse broad-band impedances of the PS machine
- The 114 MHz RF cavities were removed from the PS machine during the 2000-2001 shutdown
- The kicker tanks in SS72 and SS94 (for leptons) were removed from the PS machine on 7/1/2003
- The fully nominal LHC beam was produced before we removed the lepton kickers (S. Hancock's talk at Chamonix 2003) $\Longrightarrow$ These kickers were not too harmful for the (nominal) LHC beam production
- Two 200 MHZ RF cavities have been removed from the PS machine during this long shutdown $\Longrightarrow$ What is the reduction of the impedance? Will it be possible to increase the longitudinal blow-up if necessary?

$\Rightarrow$ Should be OK!

APPENDIX

Name	Magnet type No. of cells × l (mm)	Element	mech. Aperture hor×ver (cm) of 1 magnet module	magn. Aperture w×h (cm²)	Air field (Gauss)	leff (cm)	Int.Bdl (Gauss m) in SS	Rise - Fall time (5-95)% ns	Flattop µs
Pedestal	Lumped L	BFA 9/21 P	15.8 × 5.25	15.8 × 5.25	478.5	50	239.2	131	12.6
Staircase	Lumped L	BFA 9/21 S	15.8 × 5.25	15.8 × 5.25	765.6	39	298.6	260	12.6
Kicker 28	Lumped L	KFA 28	15.9 × 7.0	15.9 × 7.0	251.2	92.5	232.4	255	0.6 - 6.8
TIK Proton	Delay line 8×25	KFA 45	15.0 × 5.3	15.0 × 5.3	355.5	22.1 × 4	314.2	39	2.6
FAK71/79	Delay line 9×24	KFA 71/79	14.7 × 5.3	14.7 × 5.3	628.0	22.2 × 12	1671.9	68 - 70	0.1 - 2.1
PS e+/e- inj.	Delay line 24×24	KFA 72/94	11.2 × 7.4	11.2 × 7.4	424.3	61.5	261.0	87 - 90	0.1 - 2.1