BPMs for the PIP-II Linac

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Fermilab

U.S. DEPARTMENT OF ENERGY

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Objective

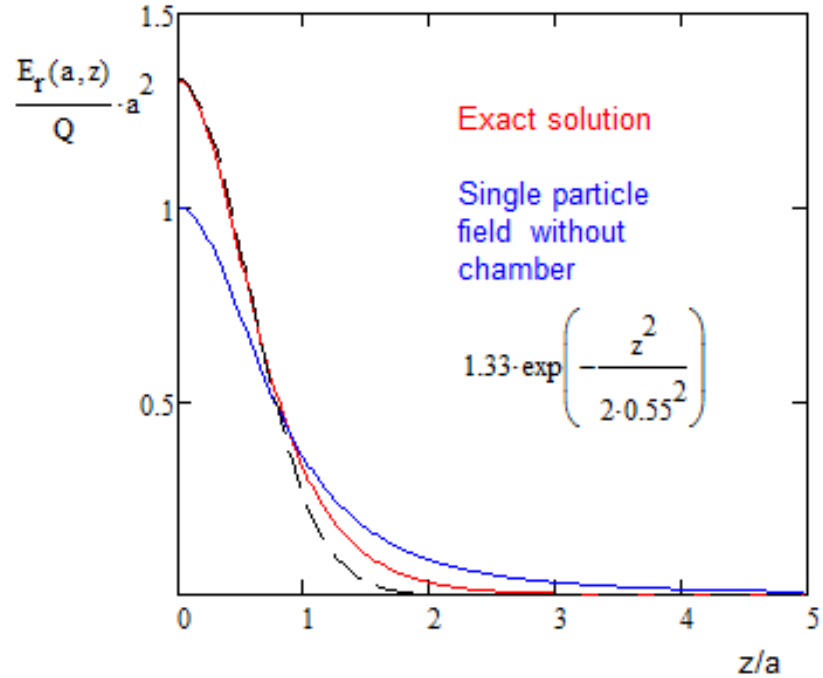
- Button BPMs are used in PXIE and planned to be used in SSR1&SSR2 cryomodules
  - Shall we use the button BPMs for the rest of the PIP-II linac
- The spectrum of button BPM signal is widening with beam energy increase (i.e. beam velocity increase)
  - The spectrum widening could require different treatment in the electronics
    - Another set of electronics?
      - Possible but not desirable
- Shall we replace the button BPMs with stripline BPMs which signal can have narrower band?

The Bunch Length and the Field Length

- The length of particle field (length of charge image) is: σ ≈0.55 a

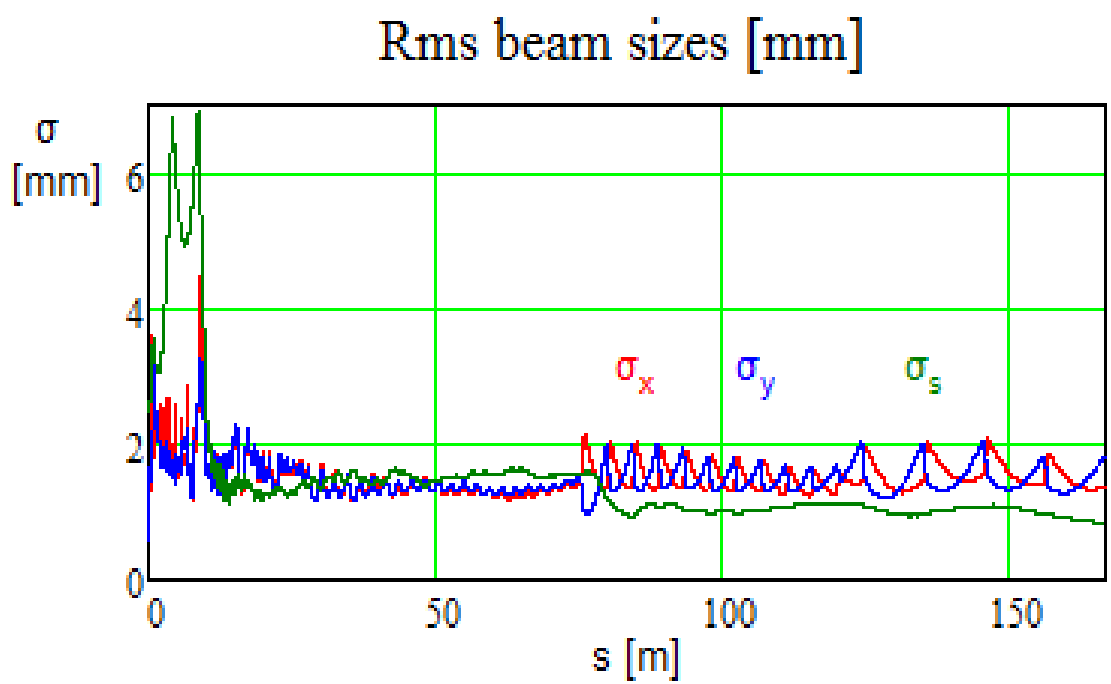
	PXIE	SSR2
a, mm	18	22
σ, mm	10	12

  - To maximize the signal for the button BPM the length of the pickup should be >2σ , i.e. > 20 mm



- Bunch length is smaller than the image size, with exception of MEBT
- Signal duration is determined by the plate length and beam velocity

$$\sigma_t = \frac{\sigma}{c\beta}$$



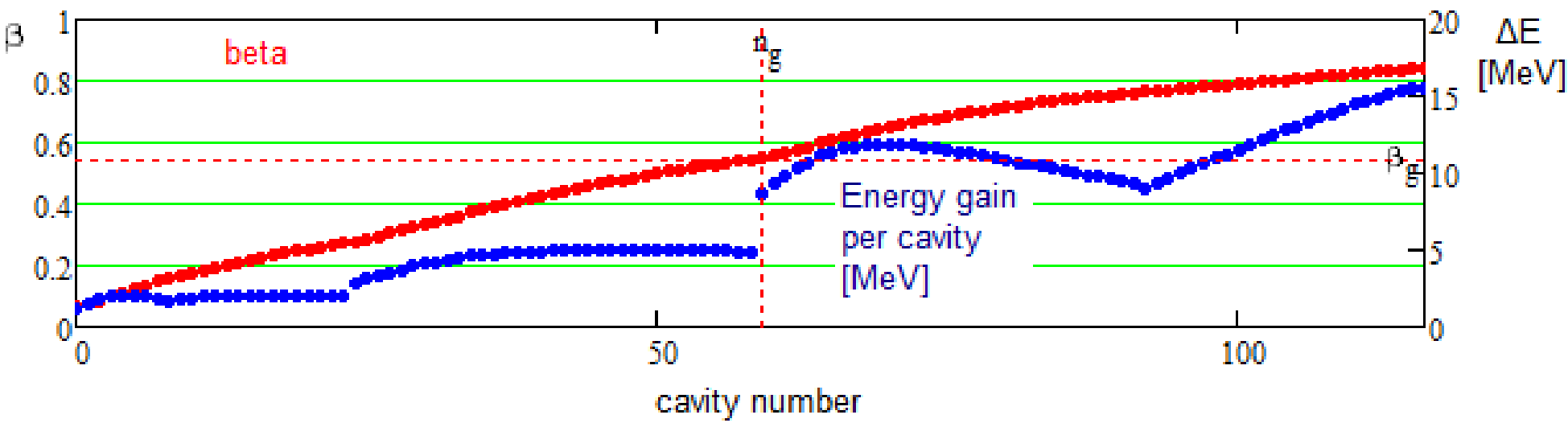
Energies and Velocities through the Linac

Aperture requirement for BPMs

	Aperture, 2a [mm]
MEBT – SSR1	36
SSR2	40
LB650-HB650	44

Energies and velocities

	Energy [MeV]	β
MEBT	2.1	0.067
End of PXIE	25	0.23
End of SSR2	185	0.55
Linac End	800	0.842

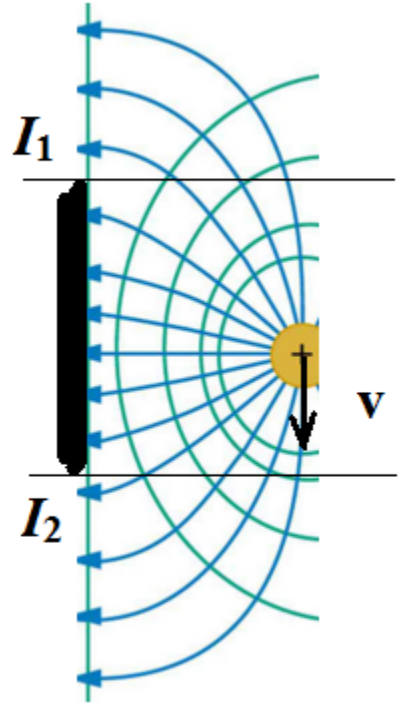


Button BPMs

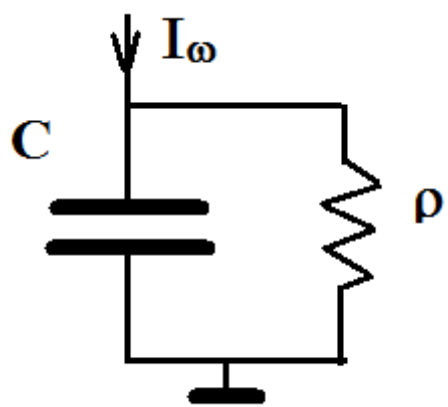
- Designed to be compact and cleanable and to achieve good coupling to the beam
- If BPM capacitance can be neglected than its signal is

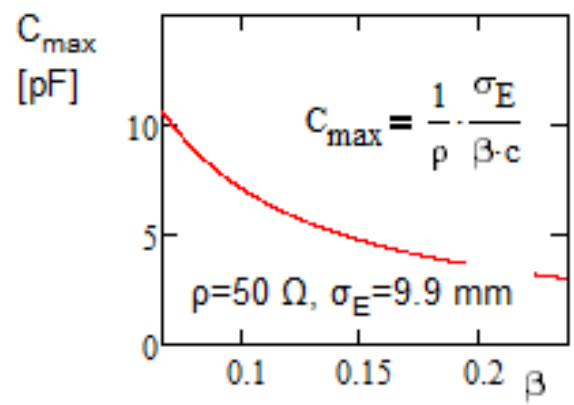
$$U = \rho \frac{dQ}{dt} = \rho(I_2 - I_1),$$

$$\frac{1}{\omega C_0} >> \rho, (\rho = 50\,\Omega)$$



- For small β it the required parasitic capacitance has realistic value (C_0 <2 pF)

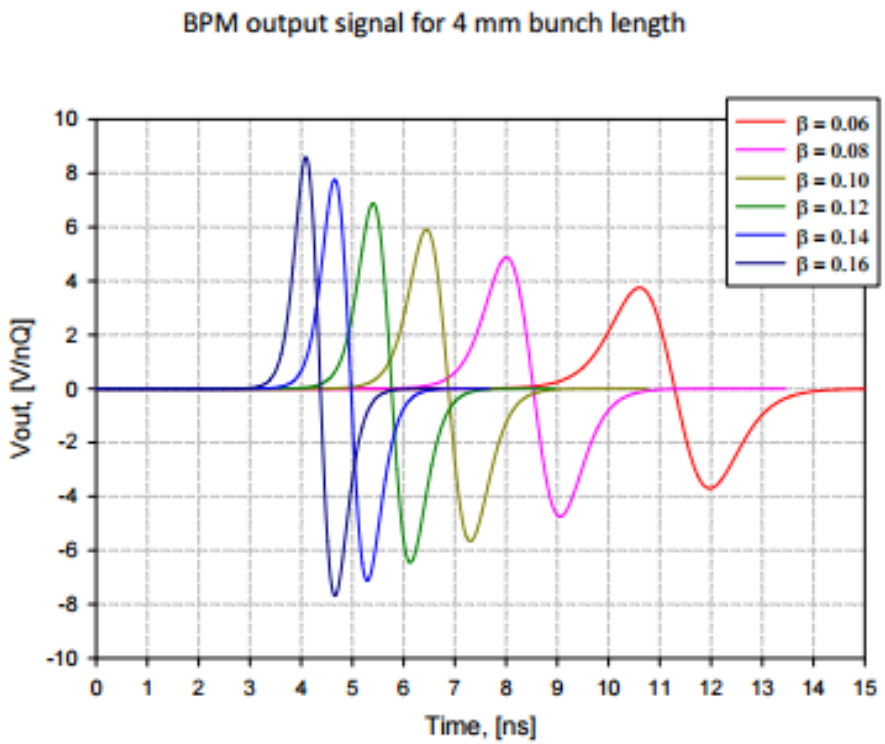


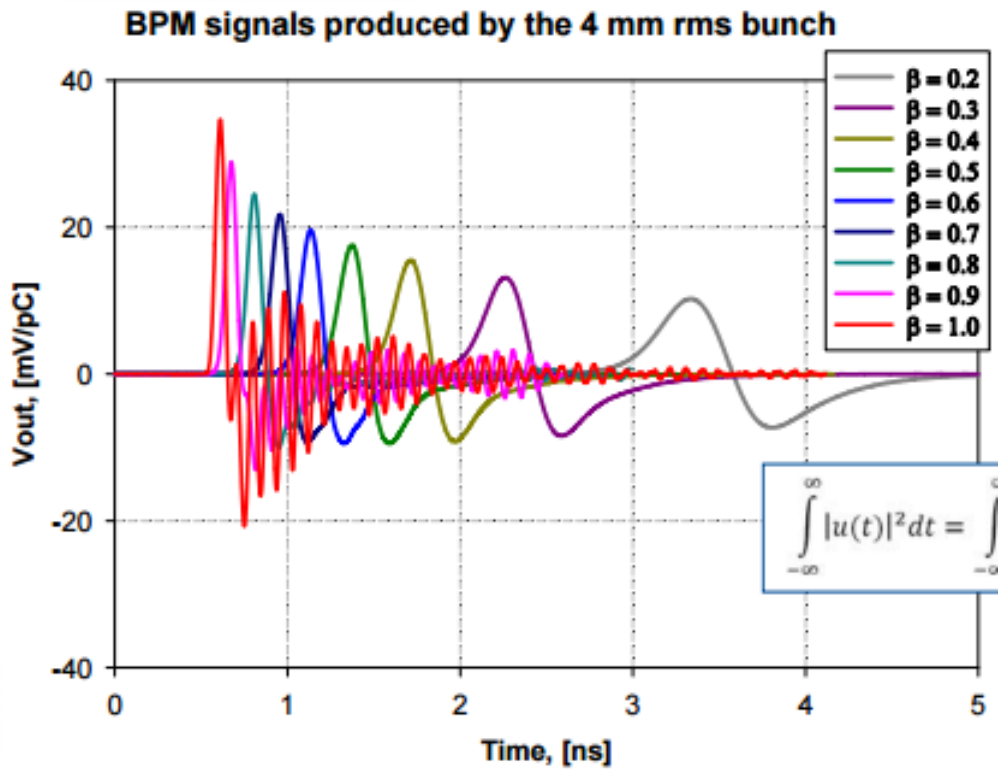


- Otherwise the parasitic capacitance has to be accounted (high β case)

$$C_0 \frac{dU}{dt} = (I_2 - I_1) - \frac{U}{\rho}$$

Numeric Simulations of HWR & SSR1 Button BPMs



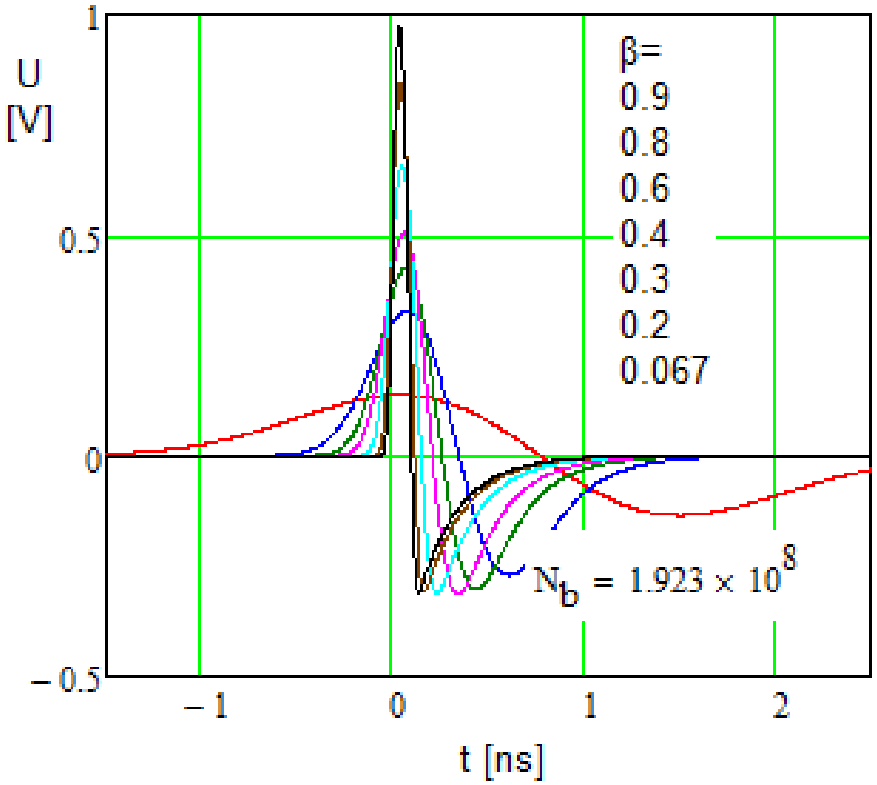


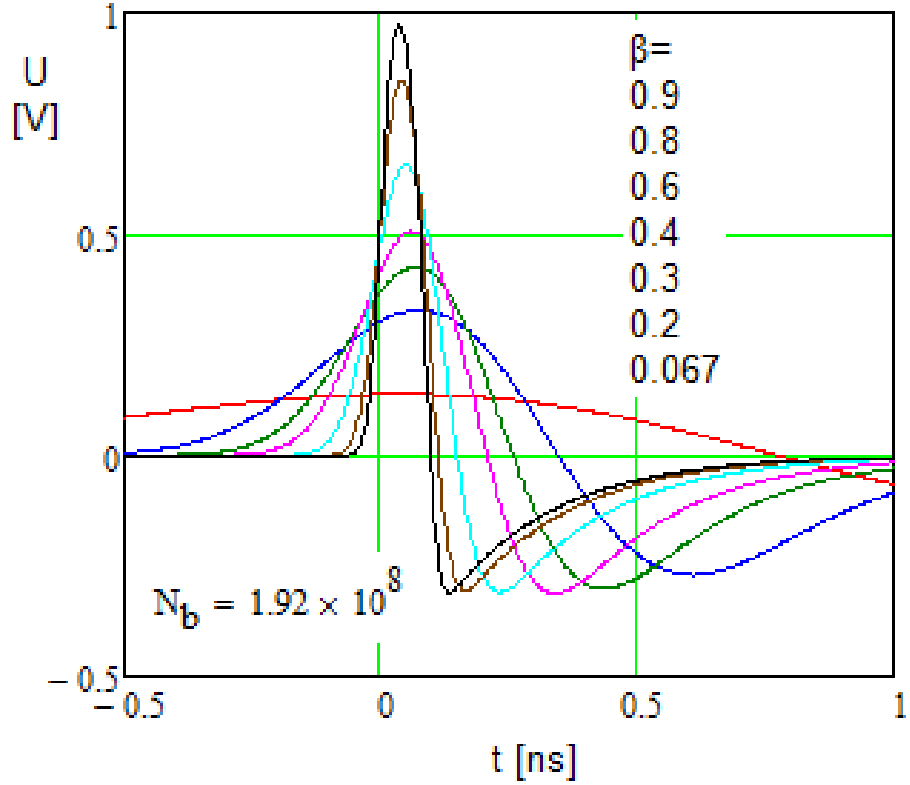
Simulations were performed by A. Lunin see details in

http://pxie.fnal.gov/PIPIImeetings/index.htm (entry from Jan. 12/2016)

- Good coincidence between numeric simulations and analytical model for C=3.5 pF

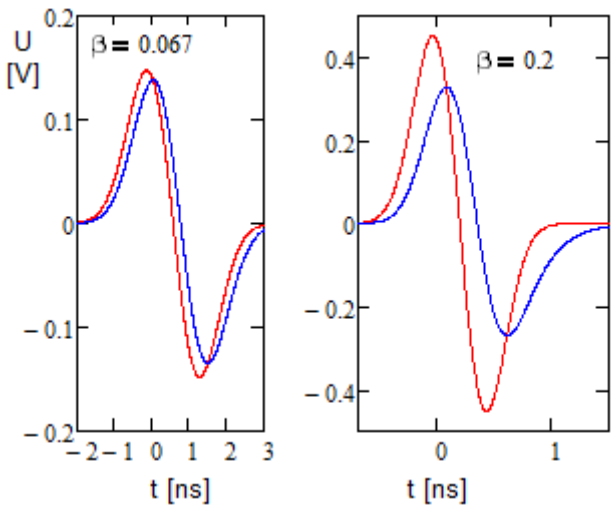
Signals of HWR style Button BPMs (analytical model)



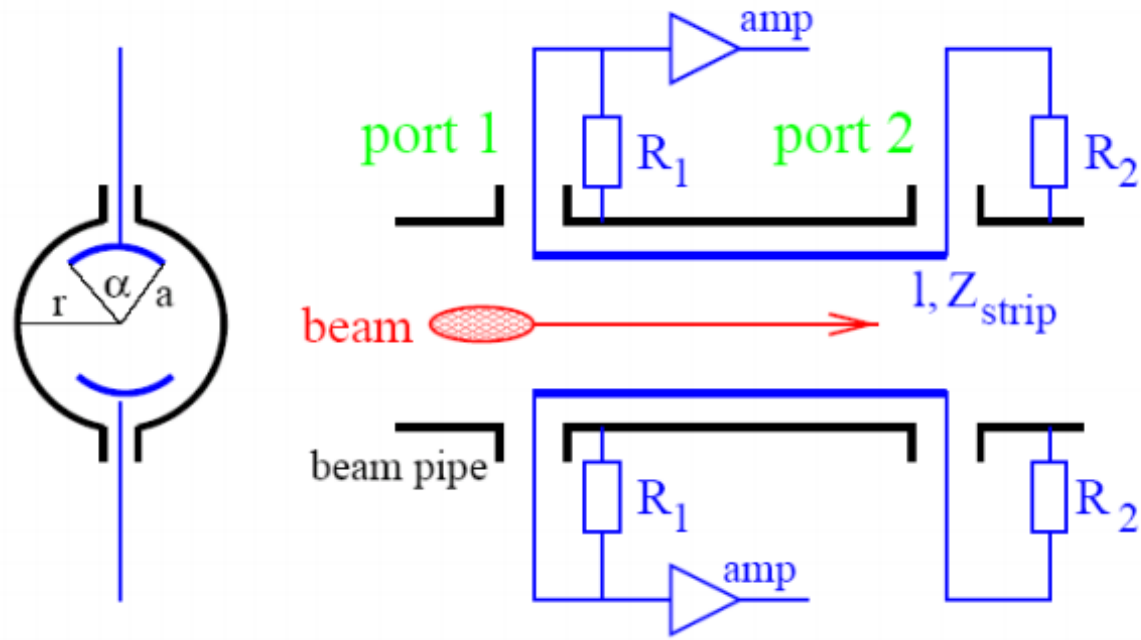


RFQ current is 5 mA, HWR style BPM scaled from a=18 mm to a-22 mm, bunch length 1.2 mm

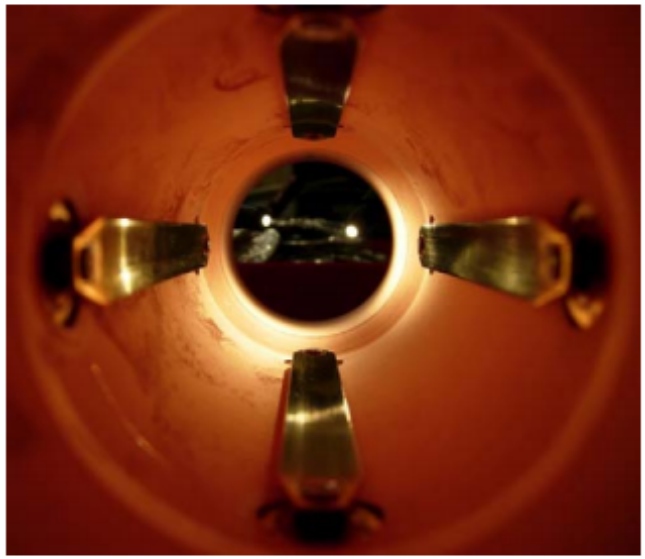
- Signal grows with particle velocity but gets quite short at β~1
- Parasitic capacitance significantly distorts signal for high β



Strip-line BPMs



LHC stripline BPM, l=12 cm



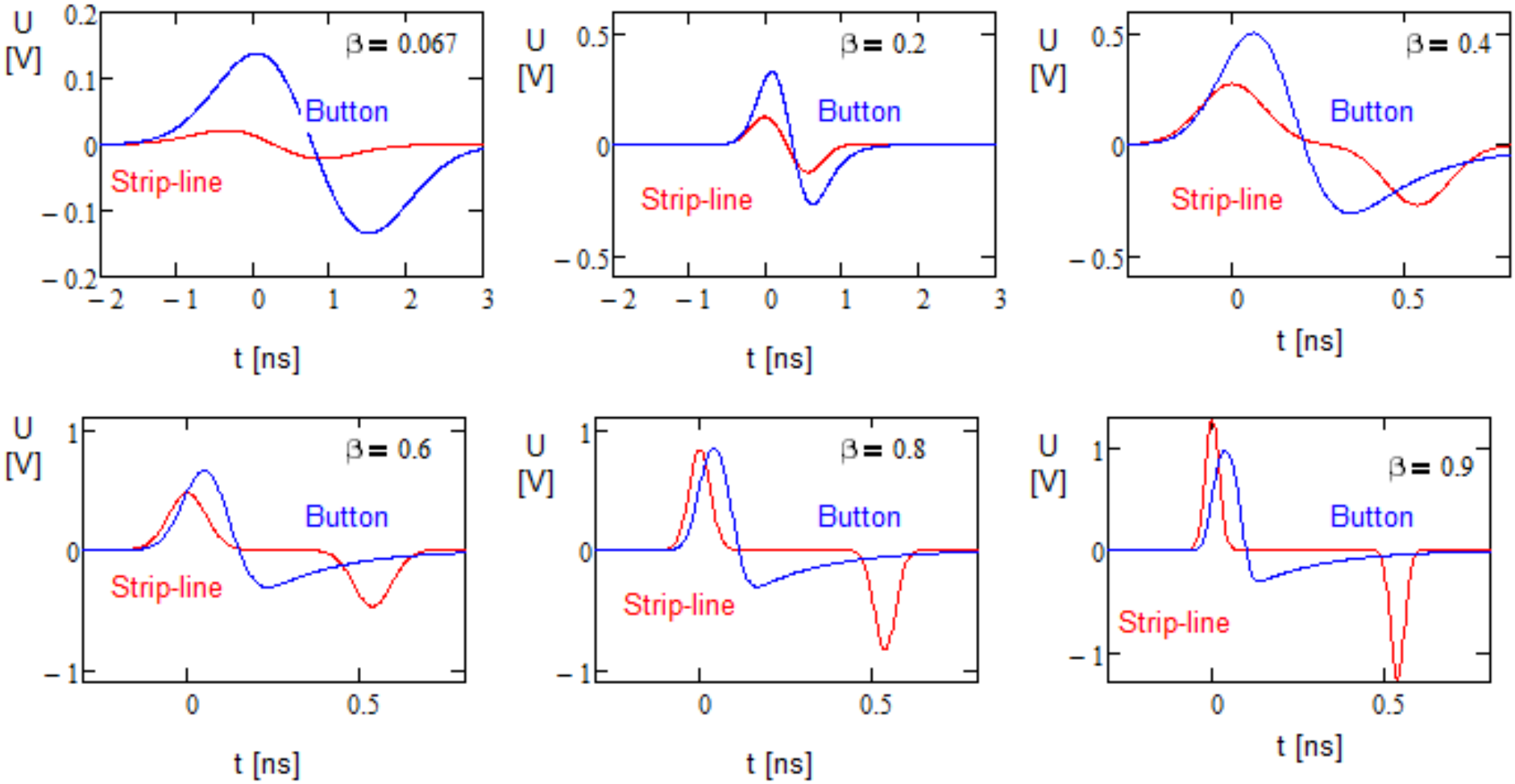
From C. Boccard, CERN

- Duration of the signal is determined by the BPM length
- For R_2=0 the resulting voltage formally does not depend on the beam velocity

$$U_1(t) = \frac{1}{2} \cdot \frac{\alpha}{2\pi} \cdot Z_{strip} \left(I_{beam}(t) - I_{beam}(t - 2l/c) \right)$$

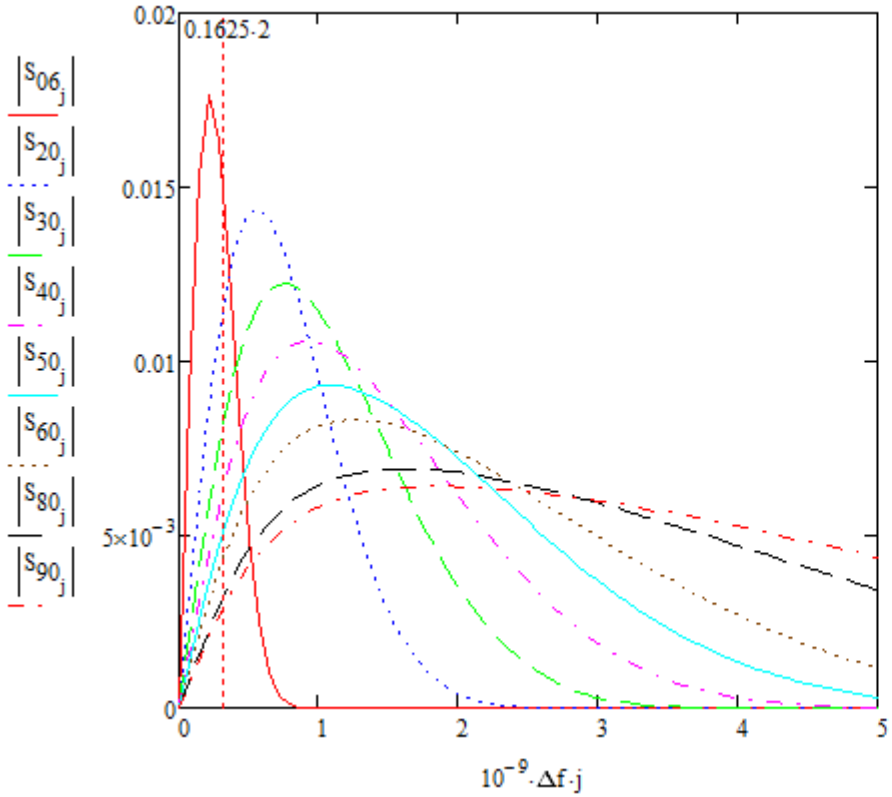
  But direct and reflected signals strongly compensate each other for small beam velocity: $2l/c < l_{bunch}/\beta c$
- It strongly suppresses the beam signal for non-relativistic beam and is the major reason while we do not use stripline BPMs in PXIE

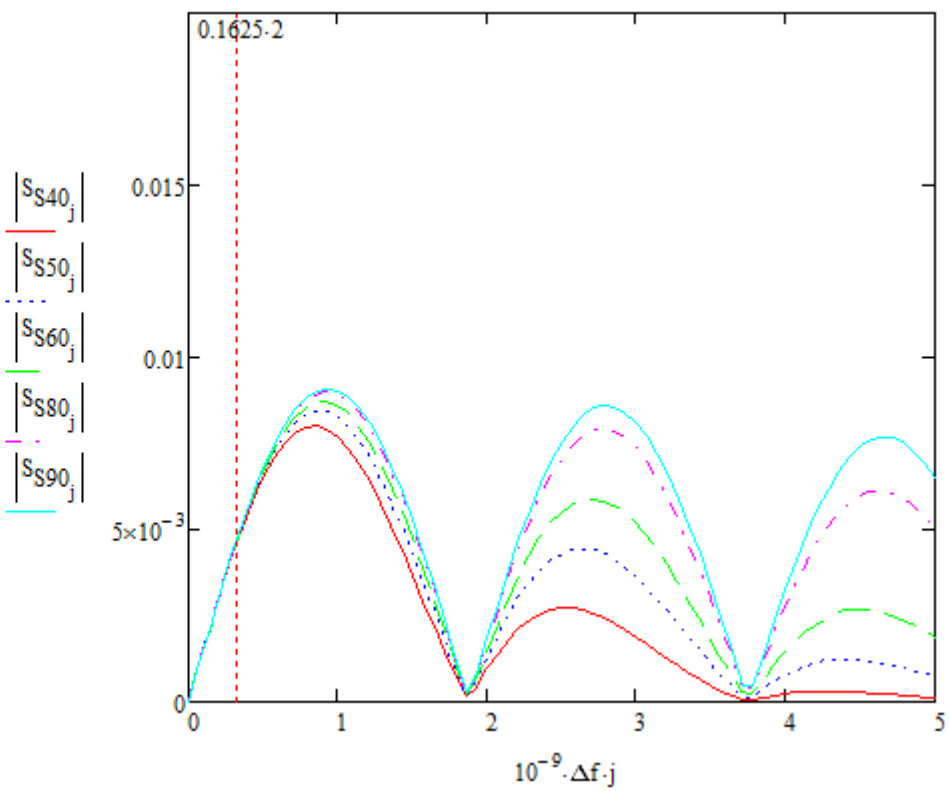
Comparison of Button and Stripline BPMs signals



RFQ current 5 mA, bunch length 1.2 mm. Aperture 2a=44 mm for both types. Button BPM is scaled from HWR stile BPM. Stripline BPM: L=8 cm, $\alpha=2\pi/12$.

Spectra of Button and Stripline BPMs signals





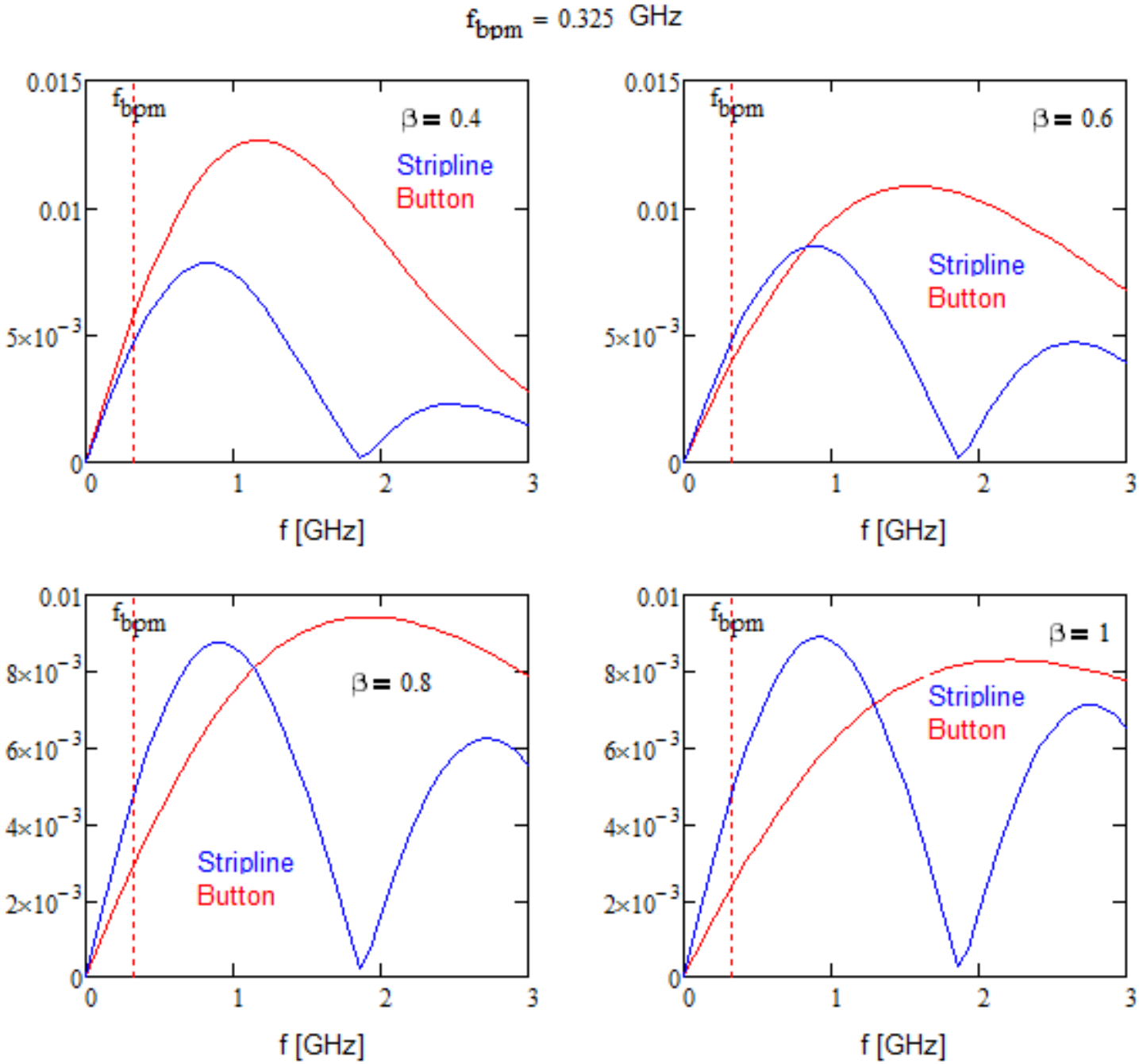
Button BPMs Stripline BPMs

Bunch length 1.2 mm. Aperture 2a=44 mm for both types.

Button BPM is scaled from HWR stile BPM.

Stripline BPM: L=8 cm,

Spectra of Button and Stripline BPMs signals (2)



Discussion & Conclusions

- At high beam energy the spectral density of stripline BPM is larger at frequencies which BPM electronics is going to use or could use. Therefore there is a soft preference to have the stripline BPMs instead of the button BPMs in the high energy part of SC linac
- However
  - The button BPMs have significantly smaller cost
  - And, what is even more important, the mechanical accuracy achievable for the button BPMs is much better than for the stripline BPMs
    - This mechanical accuracy is extremely important to achieve good absolute measurements of beam positions
- The latter consideration strongly supports the button BPMs
  - To maximize the BPM sensitivity the design of button BPMs has to minimize the capacitance of the button to the ground
    - Required aperture for LB650 and HB650 sections is 2a=44 mm
    - Mechanical accuracy of the BPM design has to support absolute accuracy of BPM measurements better than 1 mm
    - BPMs have to have 4 buttons. It supports measurements of both x- and y-positions. Electronics has to provide measurements of arrival time (s-position)