SPS Wideband Transverse Kicker Evaluation and Design

Progress and Plans

J. M. Cesaratto[1]

Kicker Design Contributors:

J. M. Cesaratto[1], J. D. Fox[1]
S. DeSantis[2], Z. Paret[2], H. Qian[2], A. Ratti[2]
W. Hofle[3]
D. Alesini[4], A. Drago[4], S. Gallo[4], F. Marcellini[4], M. Zobov[4]

[1]Accelerator Research Department, SLAC National Accelerator Laboratory
[2]Lawrence Berkeley National Laboratory
[3]BE-RF Group, CERN
[4]INFN-LNF

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Outline

1. Introduction, the need for a wide band kicker, design evaluation criteria
2. Kicker designs, possible implementations, simulation results
   - Cavity
   - Stripline
   - Slotted, 3 flavors
3. Summary

Purpose: Need for a Wide Band Kicker

- The current SPS tapered stripline rolls off at 200 MHz, kicker of larger bandwidth necessary is for intra-bunch dynamics control.
- For the application of controlling electron cloud (ecloud) and transverse mode coupling instability (TMCI)
- Establish a baseline for implementation of a vertical kicker system in the super proton synchrotron (SPS)
- Review, evaluate, and determine the capabilities of several possible implementations with the criteria:

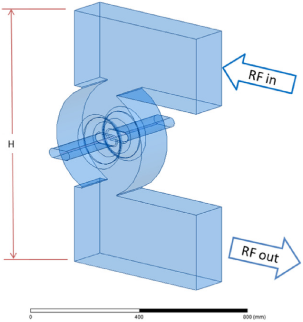
1. Shunt impedance
2. Beam coupling broadband impedance
3. Bandwidth
4. Heating issues
5. Fabrication complexity & complications
6. Vacuum chamber compatibility
7. Ease of coupling to external amplifiers

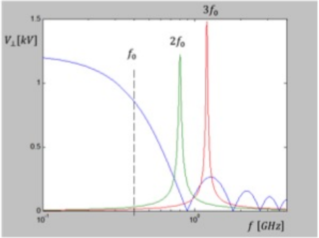
Progress in 2012 – 2013

- Evaluation of three structures for use as wide band transverse kickers in the SPS, cavities, striplines, slotted structures
- Refinement on specification of the SPS beam stay-clear and aperture requirements
- Revised stripline design compatible with beam stay-clear
- Extensive modeling of the slotted slow wave structure, investigated three variations
- Established collaboration between SLAC – LBNL – CERN – LNF, interest by LNF to build a prototype kicker for installation into SPS

Cavity kicker

- Use several narrow band cavities to kick at high frequencies
- Used in conjunction with a stripline for the low frequencies
- Several processing channels necessary
- Phasing between multiple kickers necessary

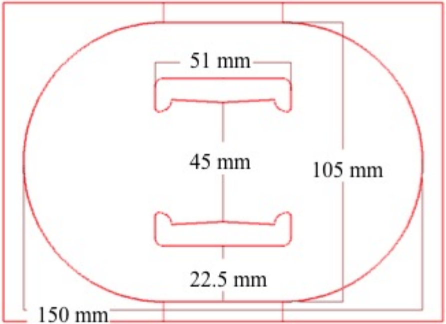


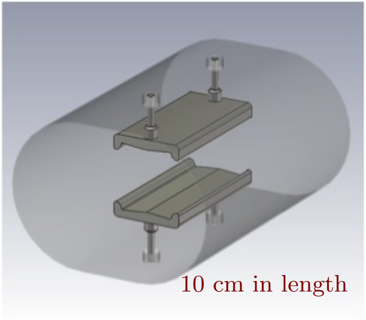


	Kicker #1	Kicker #2	Kicker #3
Type	Stripline	Cavity, TM110 defl. mode	Cavity, TM110 defl. mode
3-dB bandwidth	DC – 400 MHz	800 ± 16 MHz	1200 ± 16 MHz
Length	17 cm	15 cm	10 cm
Filling time	0.6 ns	10 ns	10 ns
Q_L	---	25	38
Shunt Impedance	≈ 1.5 kΩ (@ DC)	≈ 1.5 kΩ (@ 800 MHz)	≈ 2.2 kΩ (@ 1200 MHz)

Stripline Kicker

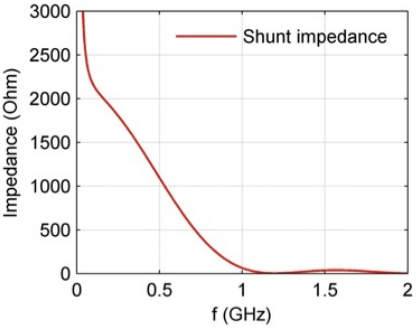
- Redesigned to comply with SPS beam stay-clear requirements
- Derived from ALS camshaft kicker (which is 3 times smaller)
- Modeled in CST MS





Stripline Kicker - Transverse Shunt Impedance

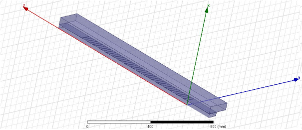
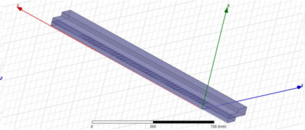
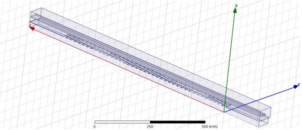
- 2 wire method in MS to determine $R_\perp T^2$ (breaks down at DC)
  - 1 kΩ at 500 MHz,
  - 400 Ω at 750 MHz
- Larger dimensions increase stray capacitances and lower HOM cutoff, disrupting shunt impedance at higher frequencies.
- As it is now, kicker could likely be used in the DC – 500 MHz range.
- In order to reach to 1 GHz, needs to be used with high frequency structure



Power estimate at 750 MHz → $P_{\mathrm{max}} = 25$ kW!

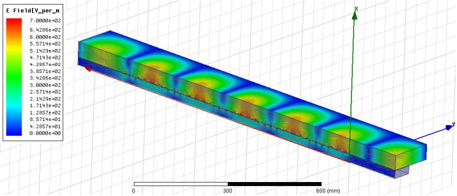
Slotted Kicker

- Similar structures to those used in stochastic cooling at Fermilab and CERN
  - McGinnis type – Waveguide
  - Faltin type – Coaxial
- Investigated three variations of slotted kickers
  - Waveguide
  - Ridged waveguide
  - Coaxial
- Quarter geometries shown (and on next slides)

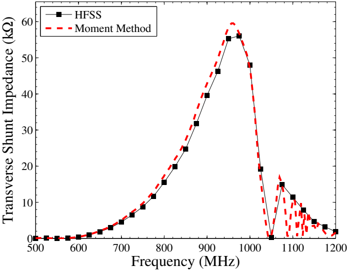




Slotted Kicker - Fermilab's model

E-field at 800 MHz



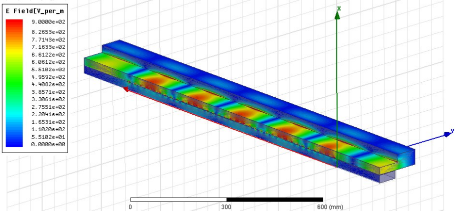
Agreement between independent methods

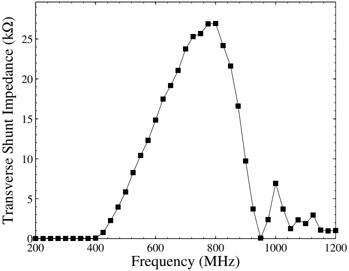


- Waveguide and beam pipe couple together by slots
- Initial simulations carried out by moment method calculation, *Slotted Pickups*
- Simulations verified with HFSS
  - A more flexible tool, more quantitative output
  - Different geometries simulated easily

Slotted Kicker - Ridged Waveguide

E-field at 500 MHz

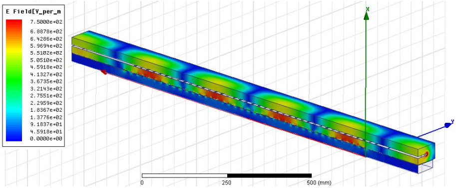


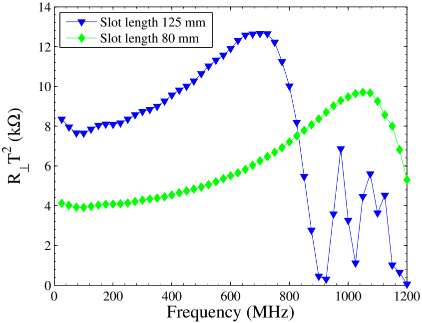


- With HFSS, explore variations of the slotted structure
- Including a ridge in the waveguide increases the bandwidth, and lowers the operating frequency.
- The shunt impedance is reduced, but still at very acceptable levels

Slotted Kicker - Coaxial, Shunt Impedance

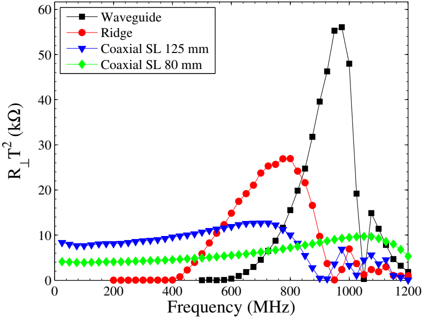
E-field at 500 MHz

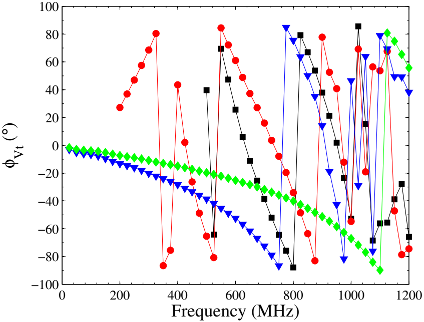




- Including a coaxial line in the waveguide increases the bandwidth of the slotted structure
- Shunt impedance is markedly reduced, but still at very acceptable levels
- Voltage phase response linear at low frequency, see next slide
- Very promising candidate

Shunt Impedance Comparison of 3 structures



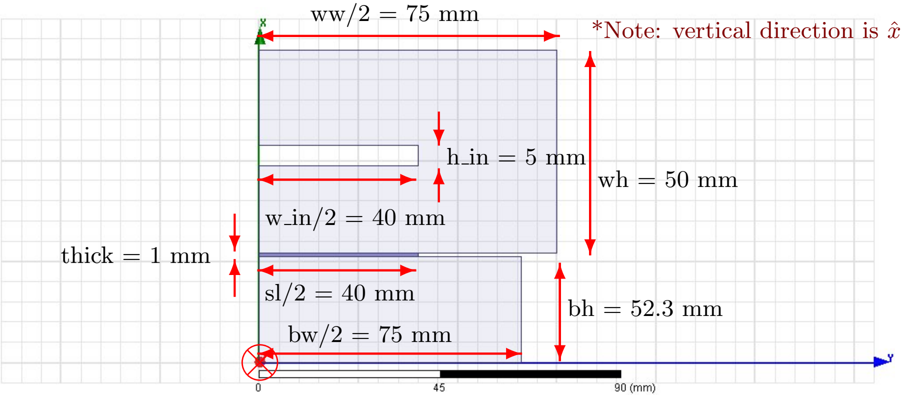


$$R_\perp T^2 = \frac{V_\perp^2}{2P_{\text{in}}}$$

$$V_\perp = \int_0^L (E_x - cB_y) e^{\frac{i\omega z}{c}} dz$$

*Note: vertical in model $\hat{x}$ direction

Initial Coaxial Type Parameters



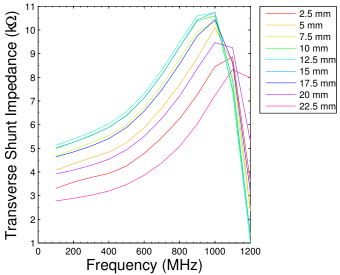
In z-direction (⊗, beam axis into page):

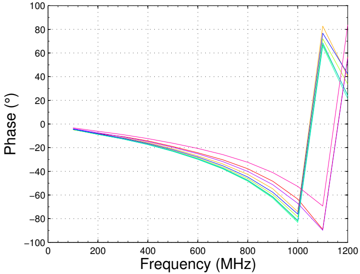
- slotted length, al = 1000 mm
- slot width, sw = 5 mm
- slot spacing, ss = 20 mm

*Note: sl/2 is shown to be 40 mm, but initially was 72.5 mm

Optimizing Slot Width - Spacing

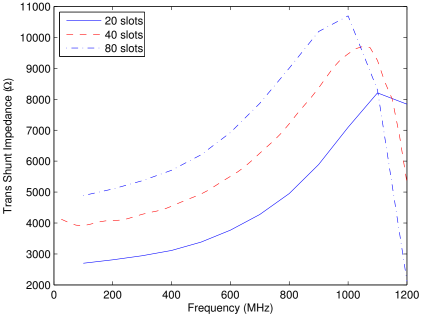
- All parameters of the structure were varied with the goal of maximizing shunt impedance and bandwidth
- As an example, slot width and spacing periodicity
- Slot width and spacing in the z-direction, direction of the beam.
- 40 slots, over 1 m
- Initially started with 5 mm width, 20 mm spacing, aspect ration 1:4
- The aspect ratio which maximized the shunt impedance is $\sim$ 1:1
- Phase of transverse voltage nearly linear up to 600 MHz $\rightarrow$ important for feedback function



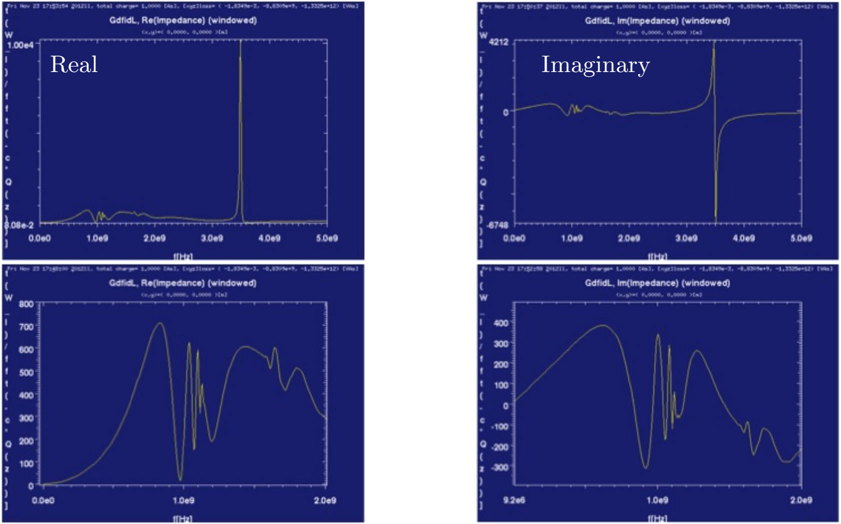


Increasing/Decreasing the Number of Slots

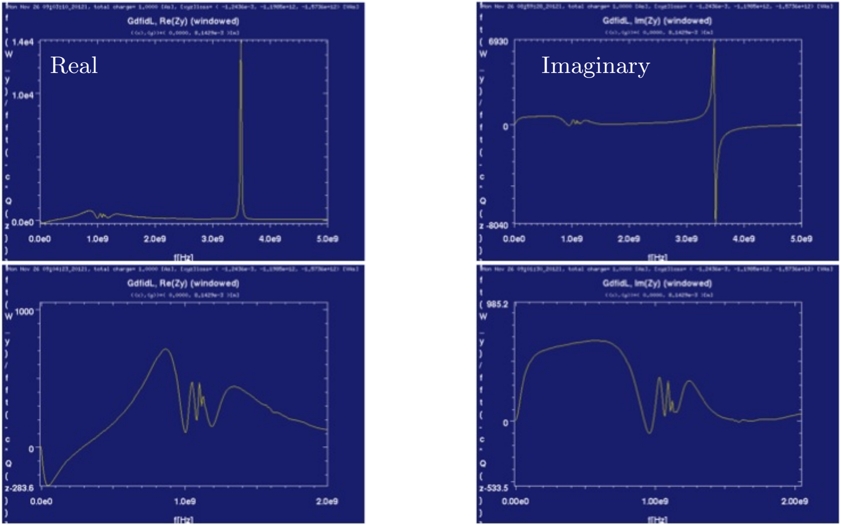
- More kick strength can be achieved by increasing the periodicity of slots - length of slotted section fixed at 1 m
- Beam coupling impedance increases as well
- Coupling impedance calculations on going with GdFidL as design evolves (see slides 16 and 17).
- Discussions with CERN ABP group necessary to specify SPS impedance budget for this structure



Slotted Kicker - Coaxial, Longitudinal Coupling Z

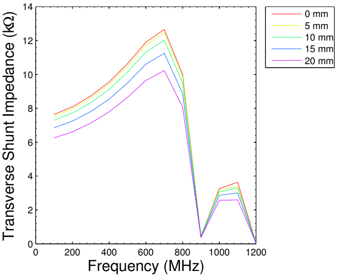


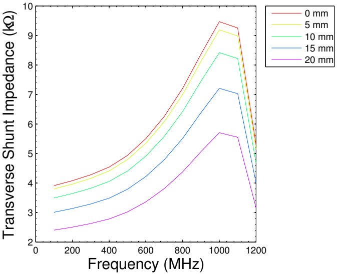
Slotted Kicker - Coaxial, Transverse Coupling Z



Transverse Uniformity

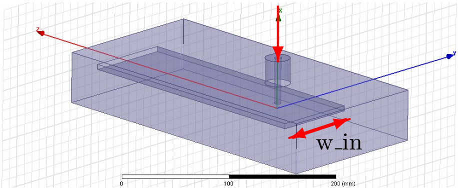
- How does the shunt impedance vary off the axis of the beam?
- Presented for two slot length (horizontal direction) cases:
  1. 125 mm
  2. 80 mm
- Transverse displacement modeled up to 20 mm off axis
  1. Shunt impedance reduced by 18%
  2. Shunt impedance reduced by 39%
- Discussions with CERN ABP group necessary to properly determine the necessary uniformity.

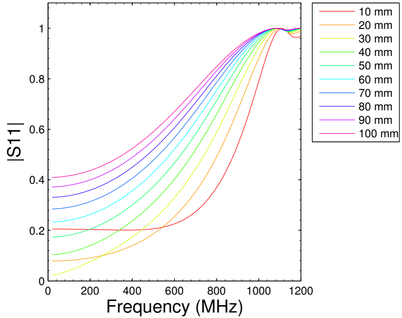




Optimize Coax to Stripline Interface

- Matching input port power power to stripline
  - Optimize the stripline, waveguide, and coaxial dimensions to achieve proper matching consistent with parameters necessary to maximize shunt impedance and transfers kick uniformity.
  - Simulations on going, may be difficult to achieve minimal reflection over entire frequency band.
- Example, varying the coaxial width, w_in.



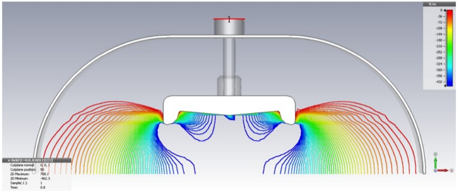


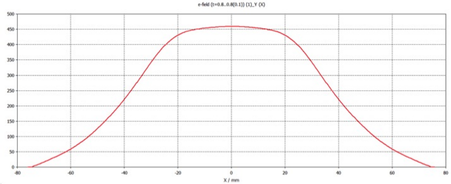
Summary

- Three structures have been explored as possible kicker options for the SPS wide band feedback effort
- Options:
  - A stripline operating from DC - 400 MHz, with two or three cavities
  - A stripline with a slotted kicker
  - Array of striplines
  - A slotted coaxial kicker
- Ideally, would like one structure to cover the entire band. The coaxial type slotted kicker is an attractive option
- Slotted kicker simulations on going to fine tune dimensions for matching the structure
- Design report being written now, compiling all results and analysis from evaluation study, to be submitted to CERN
- LNF interested in building a vacuum compatible prototype of the kicker, detailed mechanical drawings necessary
- Acknowledge essential collaboration between the four laboratories

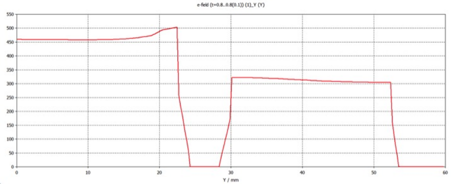
Stripline Kicker - Transverse Uniformity

- Isolines of E_y at steady state
- Each line separated by 2%
- Wider electrodes, to ensure high field uniformity, cause overall dimensions to be larger in order to maintain 50 Ω characteristic impedance
- Note, in model vertical is $\hat{y}$ direction





- E_y vs. x at y = 0



- E_y vs. y at x = 0

Stripline Kicker - Coupling Impedance and Matching