Beam Instrumentation Day 2012

RF Simulations for the LHC

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BE / BI / QP

Dec 6, 2012

Outline

Tools	WCMs	Non-linearities
Modeling	BPMs	HOMs
Meshing	Strip-lines	Beam loss
	Collimators	Heating
	BSRT	

Electromagnetic tools

Modeling process

EM tools usage

Beam, TD, FD

CST

CST PARTICLE STUDIO®

Beam, TD, FD

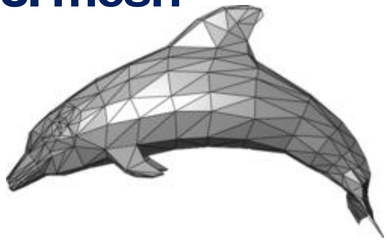
ACE3P

FD

HFSS™

2. model

3. mesh



4. realistic result

Electromagnetic tools Modeling process

EM tools usage

Beam, TD, FD

CST
CST PARTICLE STUDIO®

Beam, TD, FD

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2. model

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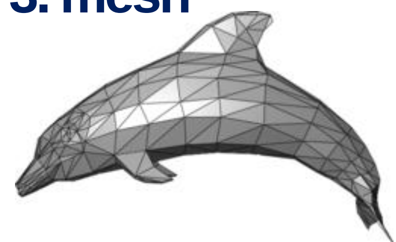
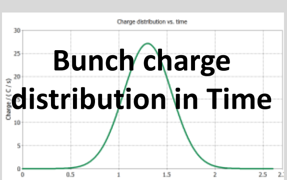
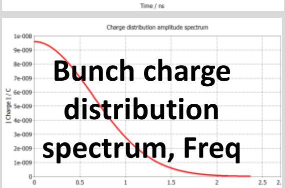
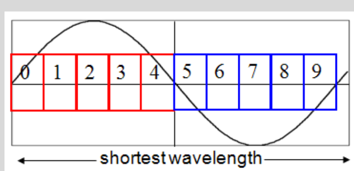


4. Otherwise…
surrealistic result

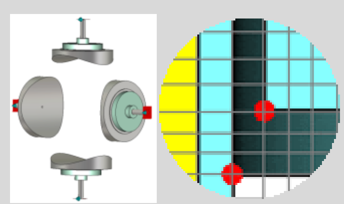






Max bunch frequency

Geometry &
Smallest detail



Simulation constraints:

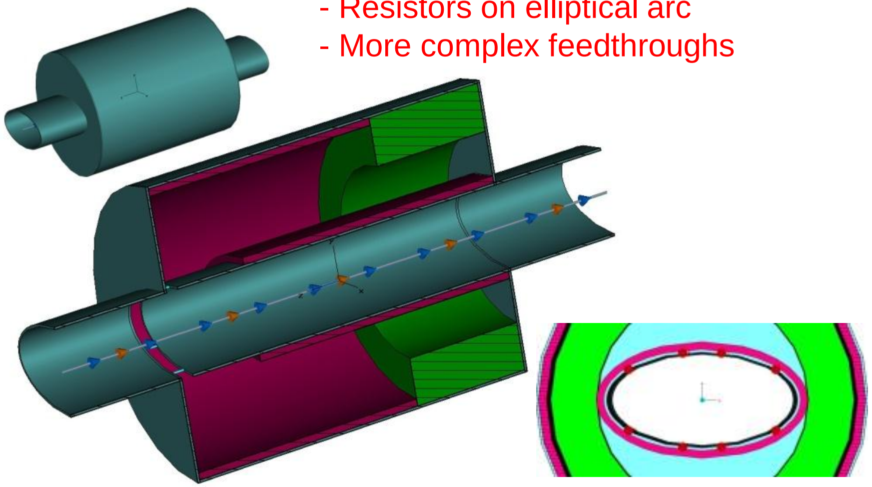
- Smallest/largest meshcell
- Total meshcount
- Simulation timestep
- Frequency range

EM study of PS-dedicated Wall Current Monitors

Target: a WCM with 3GHz bandwidth to be used for beam shape monitoring and longitudinal tomography.

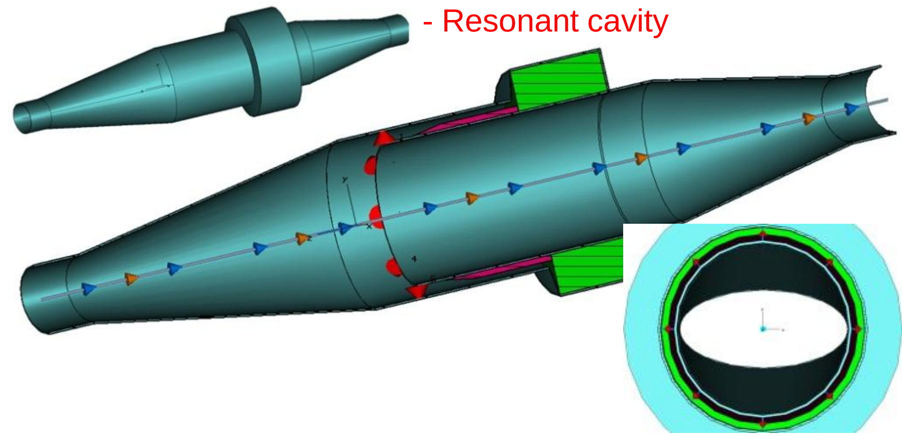
Pill-box WCM

+ Short
+ No transitions
- Resistors on elliptical arc
- More complex feedthroughs

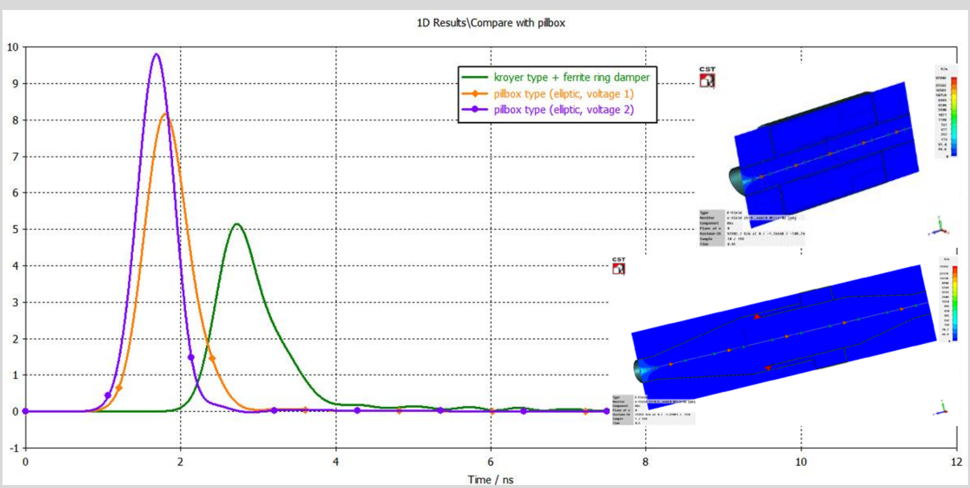


Transition WCM

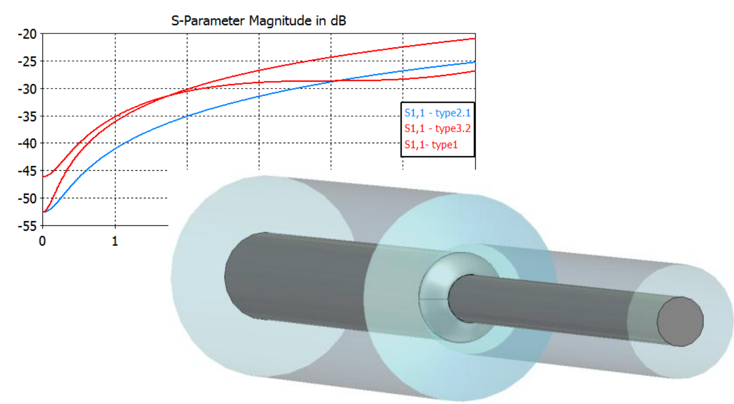
+ Simple feedthroughs
+ Resistors on circular arc
- Long design
- Resonant cavity



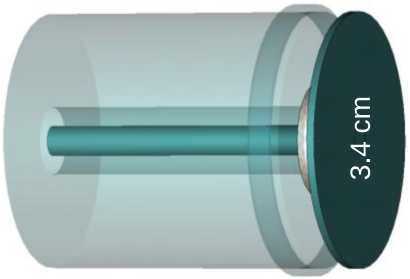
Simulated time response of resistors for both types of WCM.



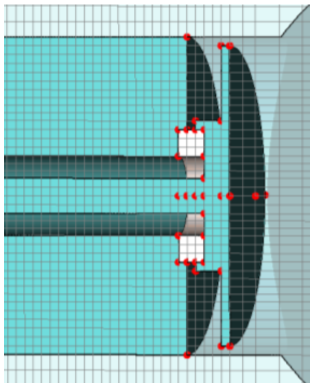
Feedthrough design for WCM

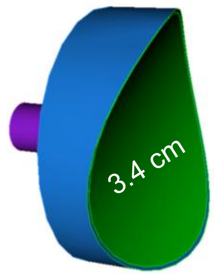


Beam Position Monitors: types / purposes / meshing

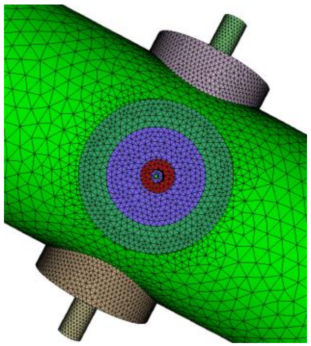


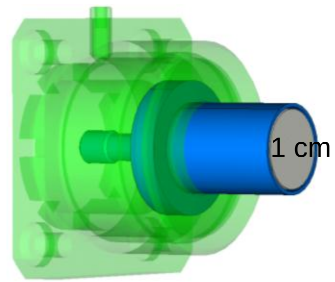
Flat-head buttons: Transfer lines



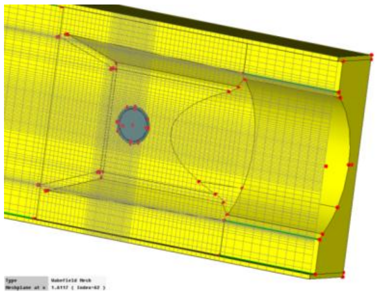


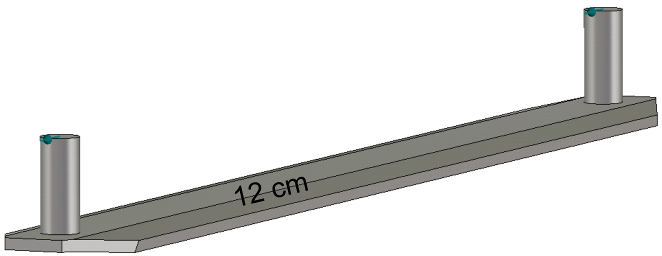
Curved-head buttons: LHC



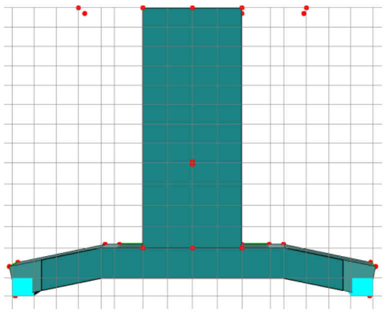


Movable buttons: LHC Collimators



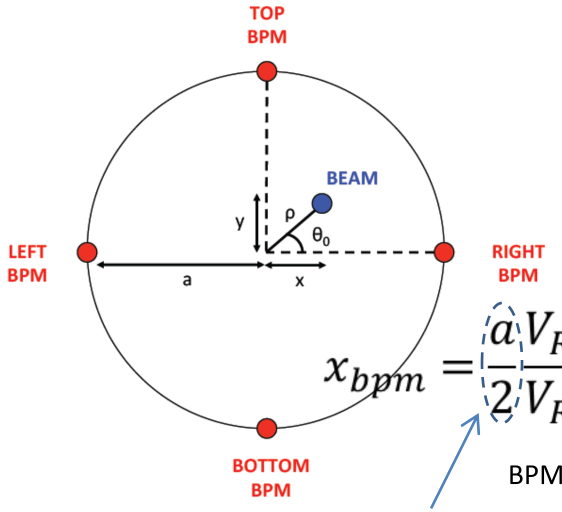


Strip-lines: directional PS/LHC BPMs



Beam Position Monitors: 1D/2D non-linearity and correction

What is BPM non-linearity?

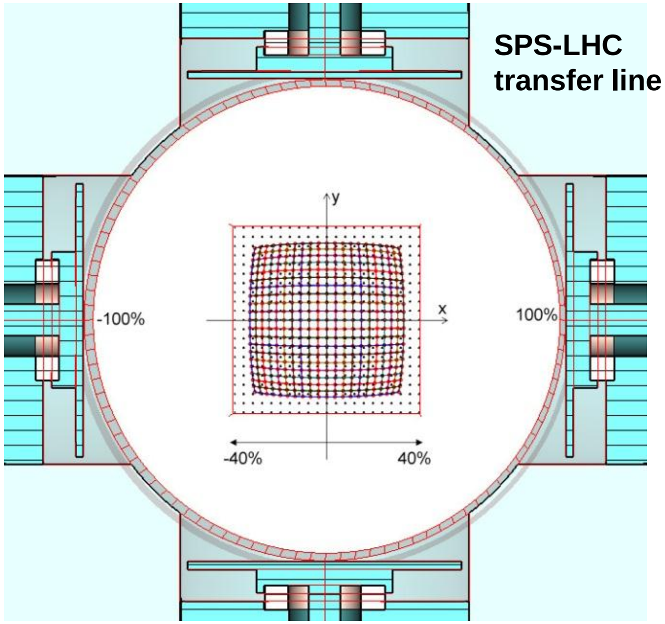


An approximation!

$$x_{bpm} = \frac{a}{2}\frac{V_R - V_L}{V_R + V_L}$$

Geometrical scaling factor

BPM readout



SPS-LHC transfer line BPMI

Beam Position Monitors: 1D/2D non-linearity and correction

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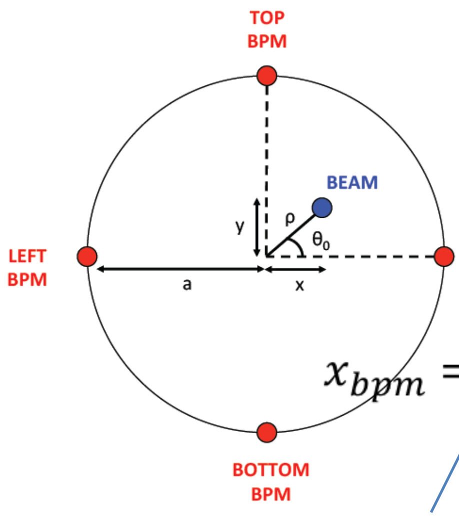

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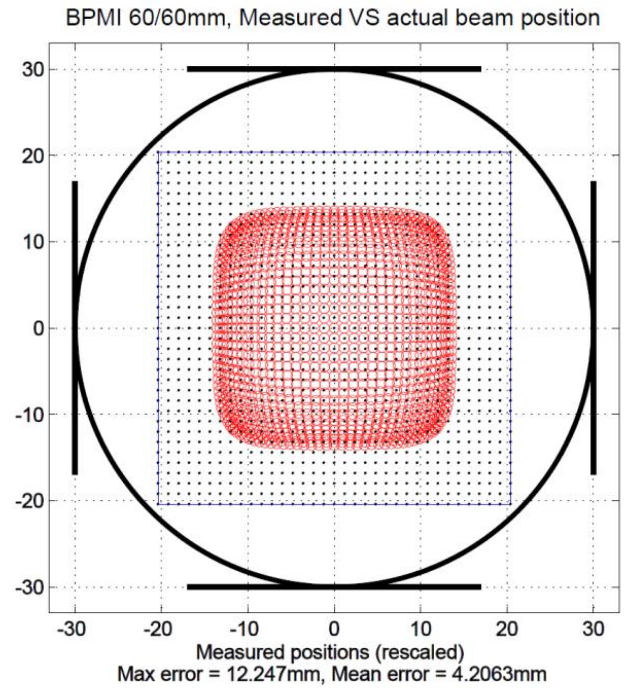
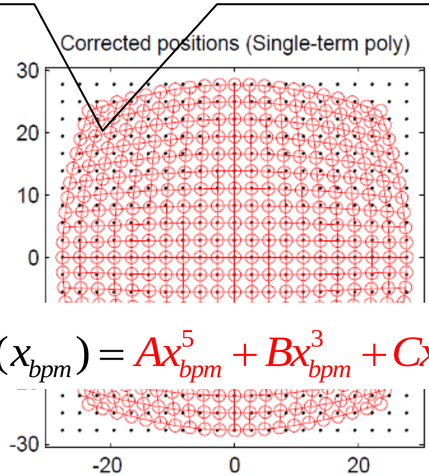
BPM readout

Geometrical scaling factor

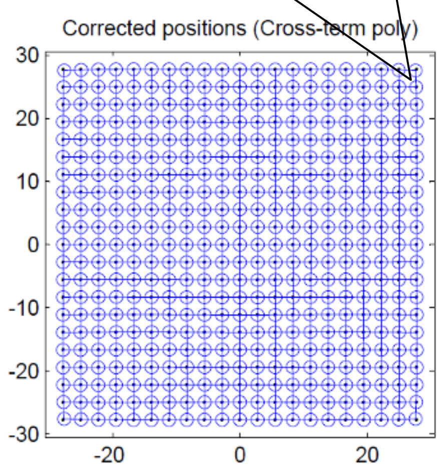


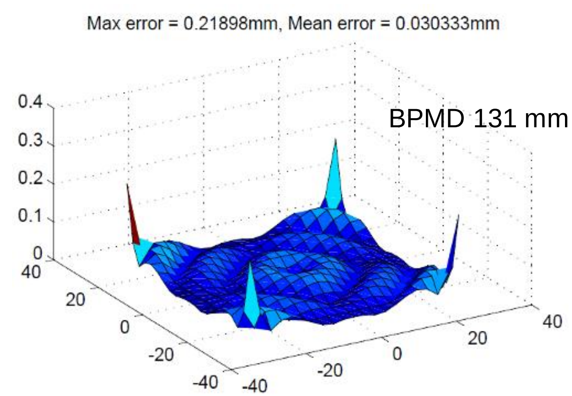
Average error in beam allowed area: 1.1 mm
Max error for on-diag beam: 6mm!



$$P(x_{bpm}) = Ax_{bpm}^5 + Bx_{bpm}^3 + Cx_{bpm}$$

Max error for on-diag beam: < 100 um

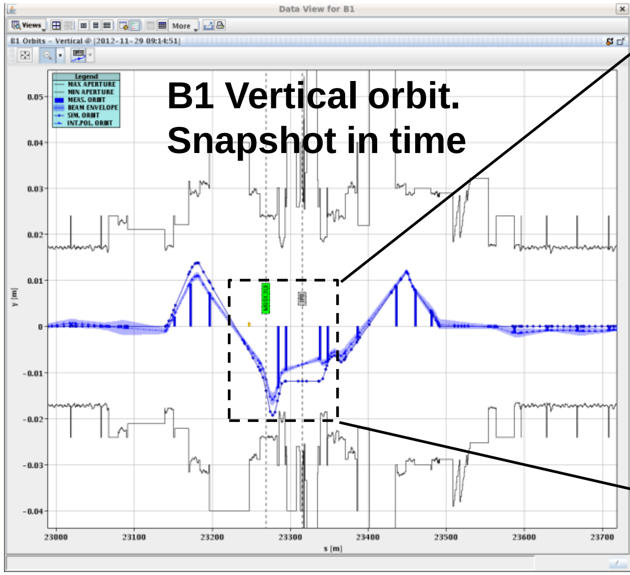


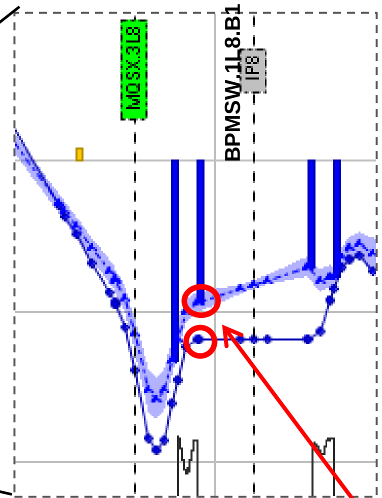


$$P(x_{bpm}, y_{bpm}) = Ax_{bpm}^5 + Bx_{bpm}^3 + Cx_{bpm} + Dx_{bpm}^3 y_{bpm}^2 + Ex_{bpm} y_{bpm}^4 + Fx_{bpm} y_{bpm}^2$$

Before BPM "pillow-shaped" readback versus initial beam position map **After**

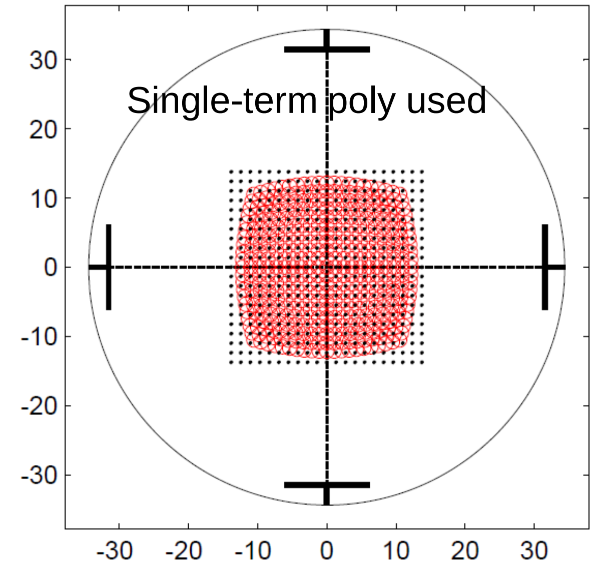
Beam Position Monitors: BI MD4 IR8 scan (29 Nov. 2012)





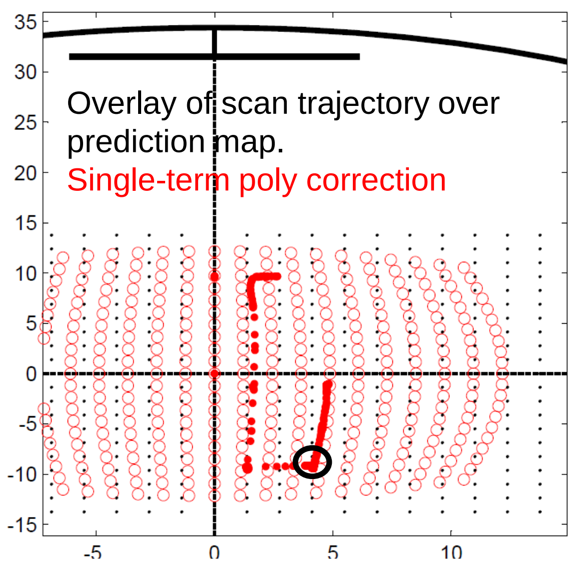
Difference btw Optics prediction and BPM measurement: **~2mm**

BPMSW 68.8mm

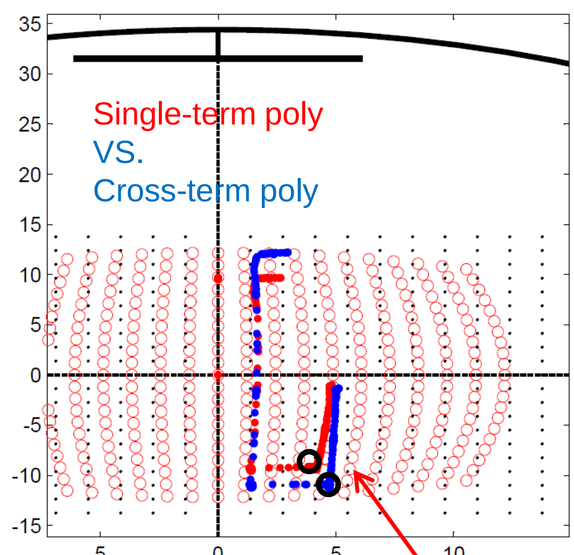


EM Model: prediction map

BPMSW 68.8mm

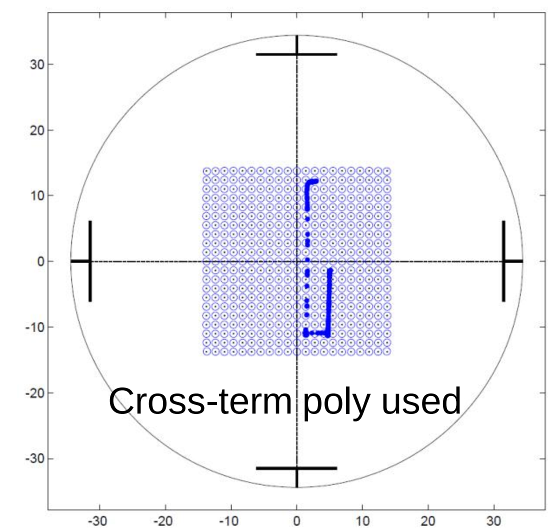


BPMSW 68.8mm

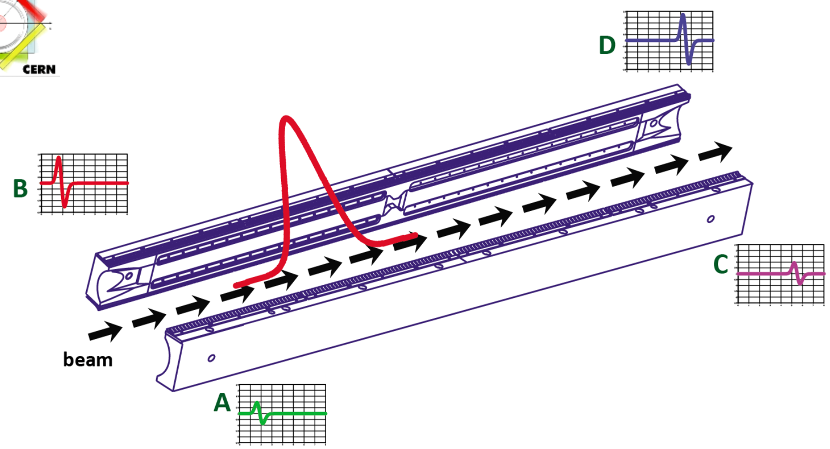


Difference between positions: **~1.8mm**

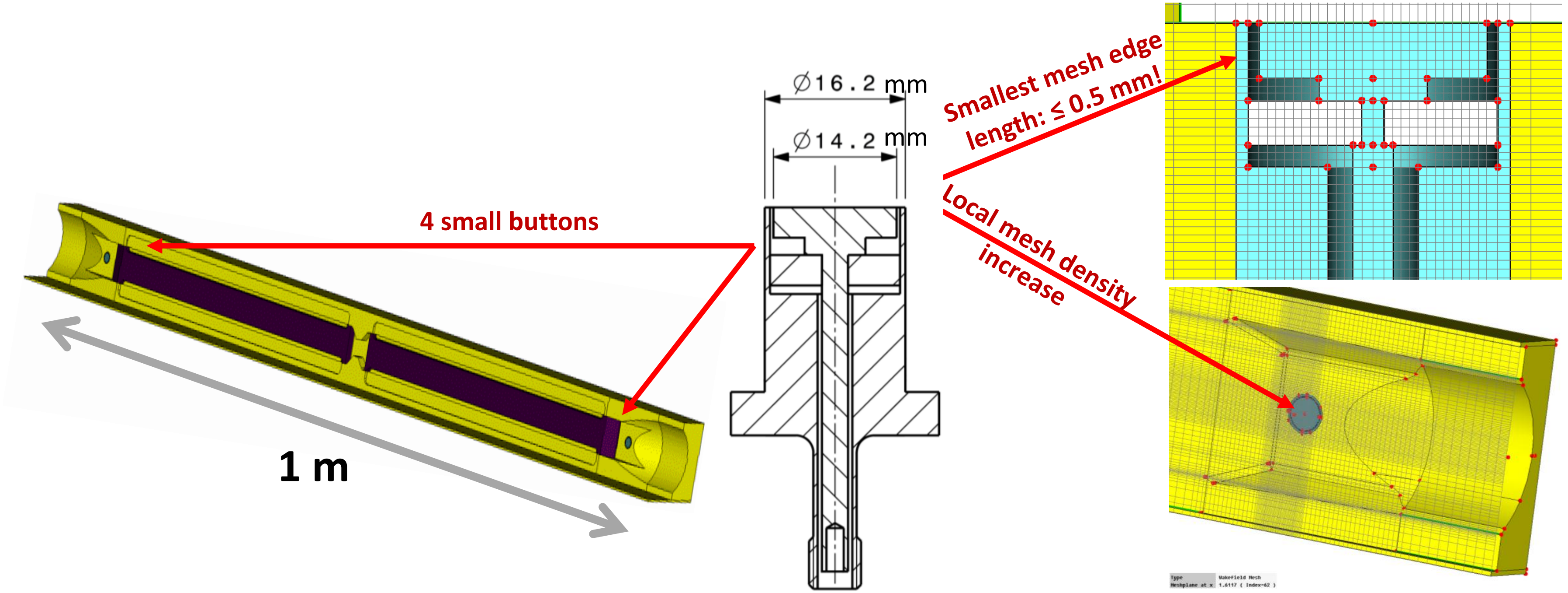
BPMSW 61/68.8mm



Collimators with embedded BPMs: LHC prototype in SPS



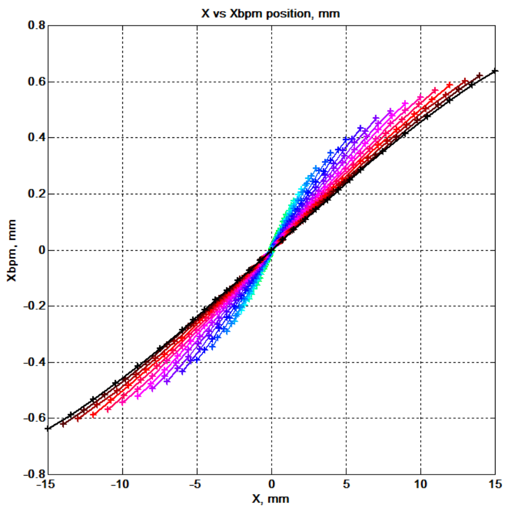
Used for LHC beam-cleaning, the cryo-cooled collimators have embedded button BPMs in the ends of each jaw to ensure fast and accurate centering of jaws around the beam.



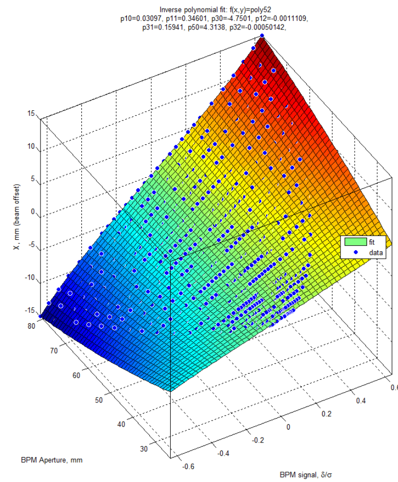
Small pick-ups increase model's mesh density.

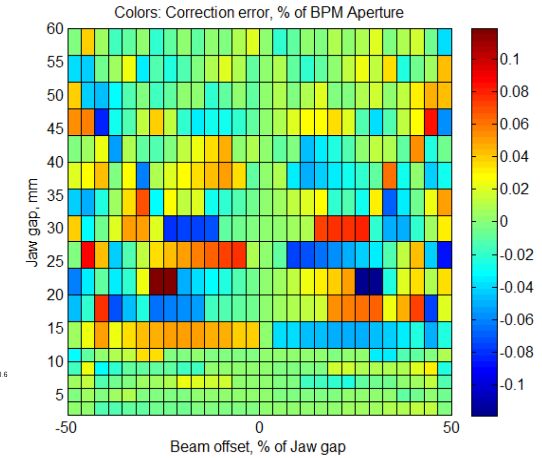
Delicate BPM parts require manual mesh refinement

Collimators with embedded BPMs: non-linearities

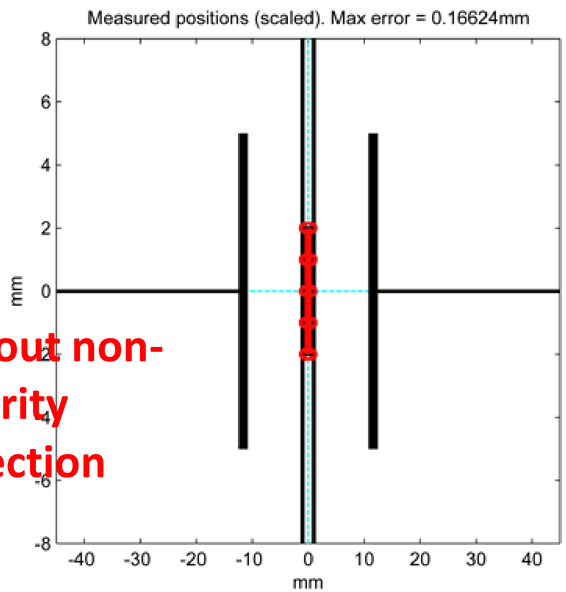


2D non-linearity: Jaw gaps VS. BPM signals

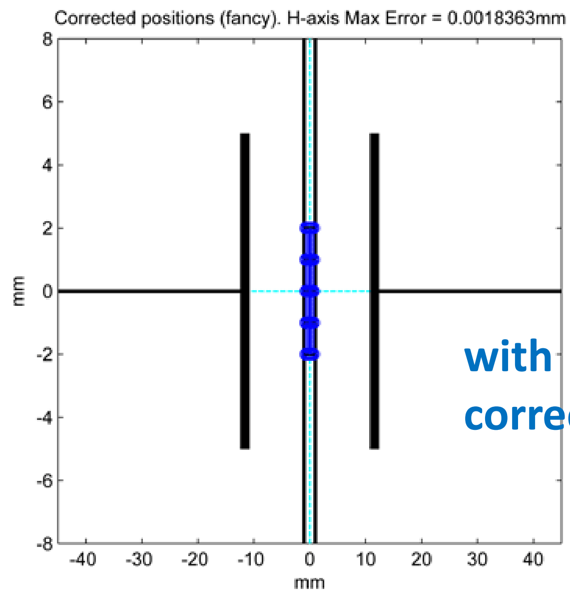




By mapping beam offsets for various jaw gaps it is possible to build a 2D correction polynomial (3D surface): Xbpm = f(Gap,LRsignals)



without non-linearity correction



with correction

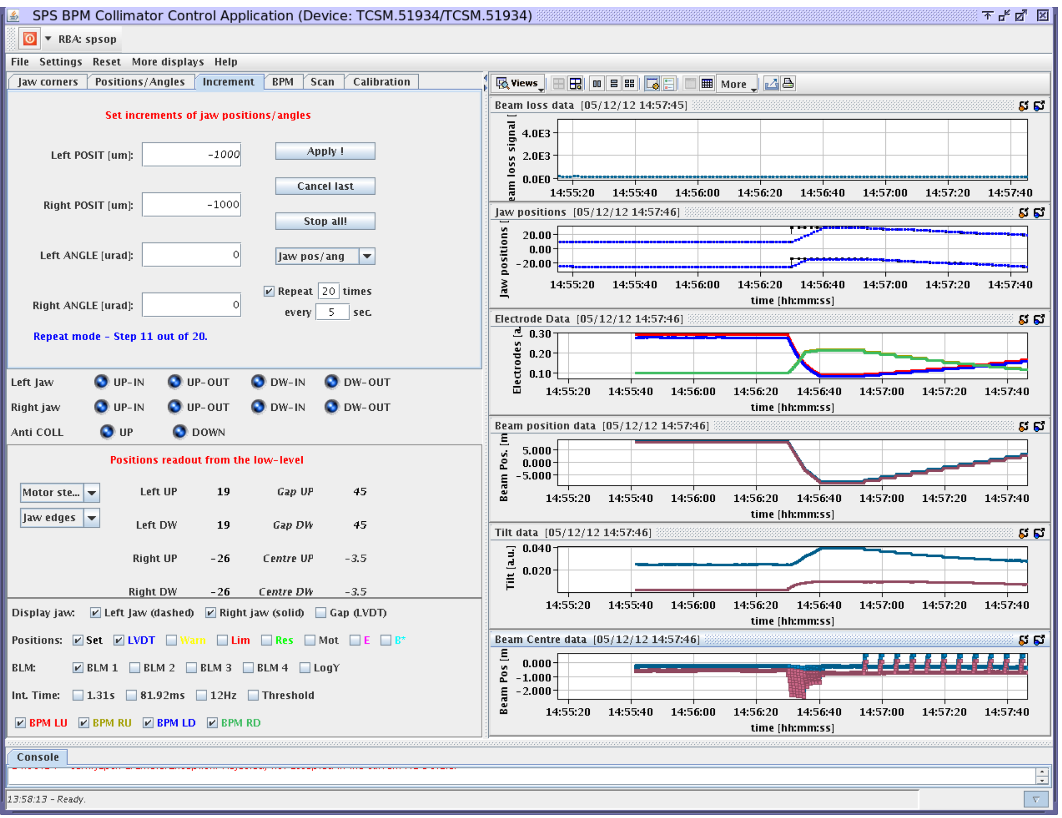
Animation of simulated H&V beam-sweep maps.

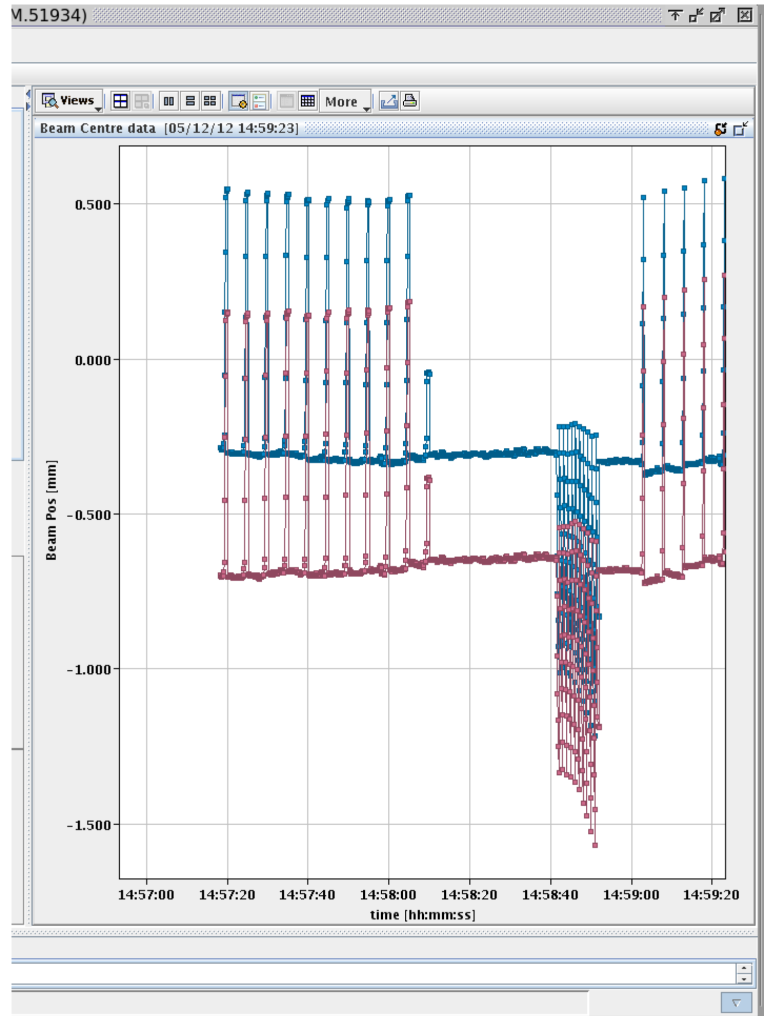
Jaws gaps vary: 2, 10, 20, 40, 60 mm

Collimators with embedded BPMs: SPS coasting MD (5 Dec.2012)

Using the most advanced corrections at the moment: for electronic gain/offset (M.Gasior) and 2D non-linearity correction (A.Nosych) , the SPS collimator with embedded BPMs was used for beam position measurement and automatic centering with moving Collimator jaws (jaw position and jaw distance).

The compensation of the BPM and electronics errors allowed large improvement of the absolute accuracy of the beam position measurement.



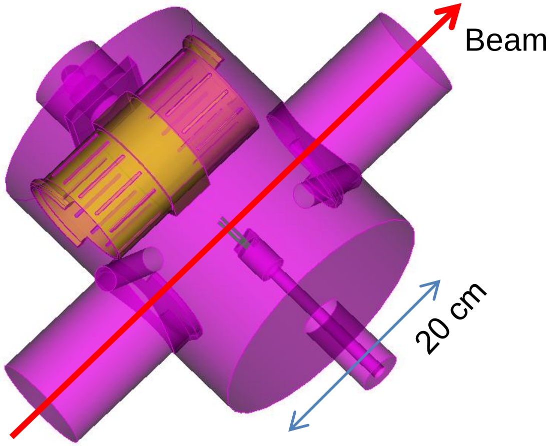


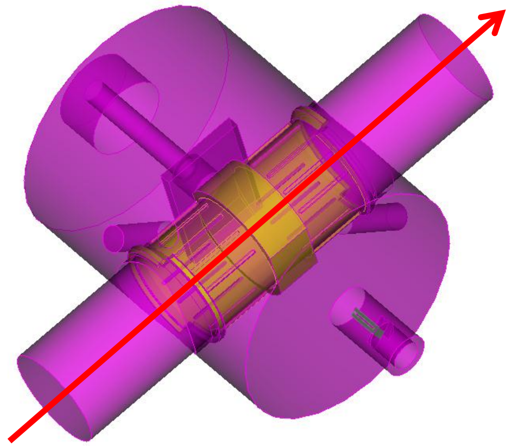
Credits: S. Redaeli, M. Gasior, G. Valentino, R. Bruce, B. Salvachua, A. Nosych

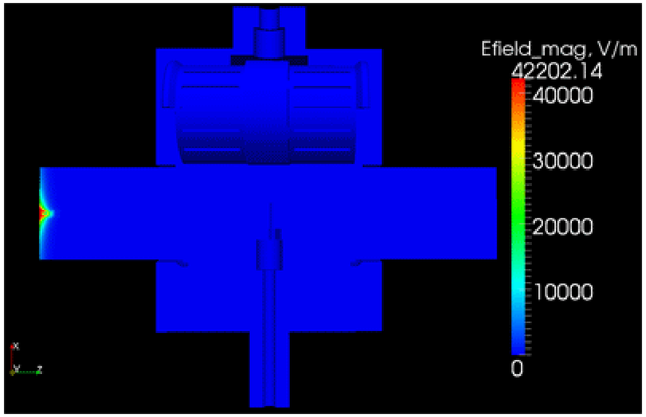
CLIC damping ring ODR chamber: modes of operation

1. ODR detector (fork) in the beam. Replacement chamber retracted.

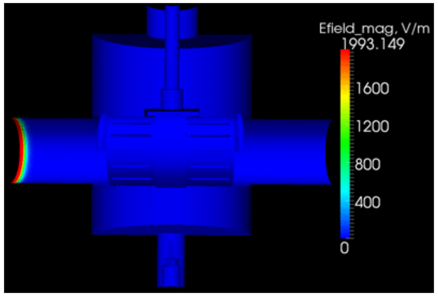
2. Replacement chamber inserted. Detector hidden from the beam.





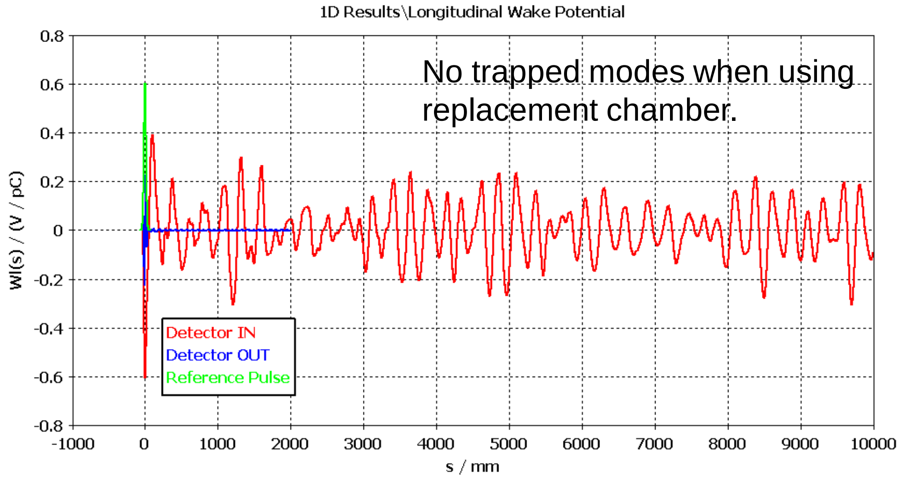


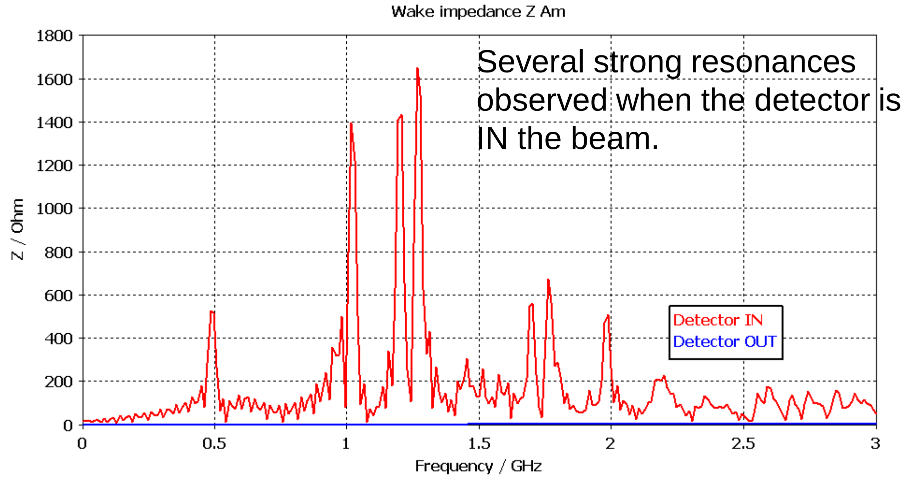
E-field magnitude of a single bunch (σ = 10mm) pass through ODR



Objective:

Study structure for HOMs and Estimate heating areas

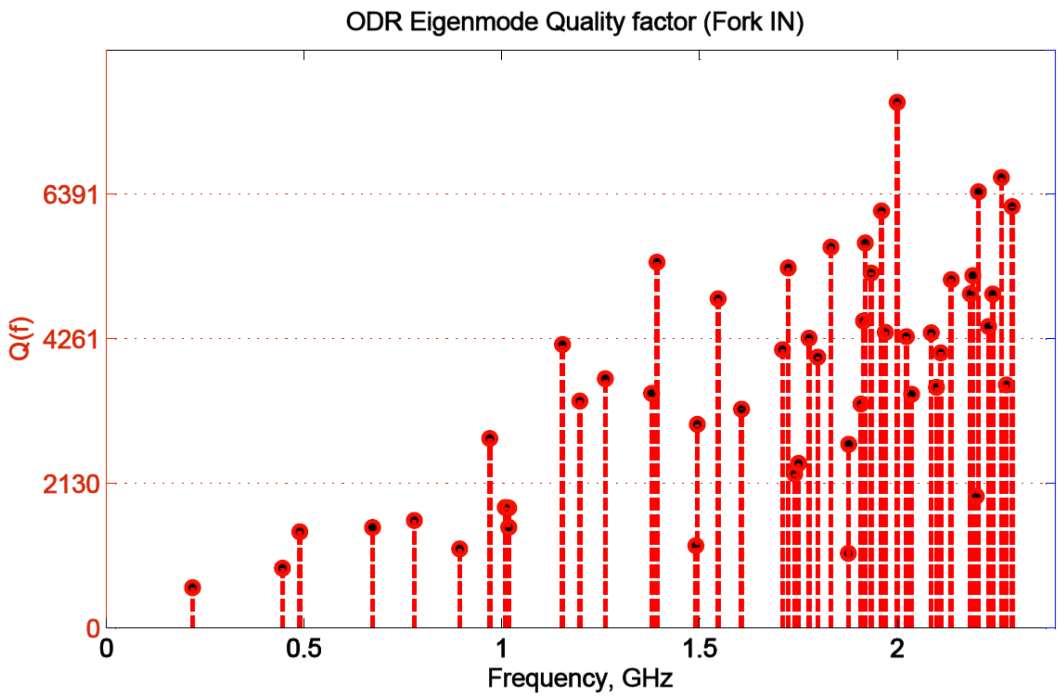


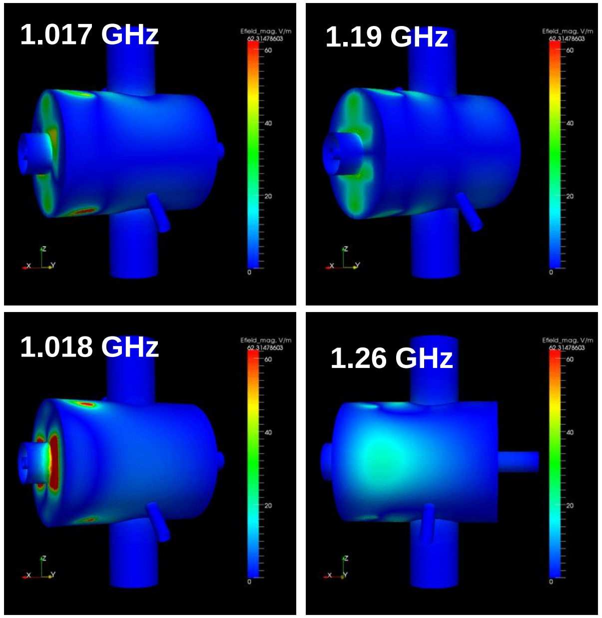


With L. Bobb
CERN, Uni. of Cornell, R.H. Uni. Of London

CLIC ODR chamber: HOM and Power loss calculation

Search for trapped modes (HOMs) with Eigenmode Frequency domain solver:
many eigen-solutions, but it doesn't mean that they are all excited by beam





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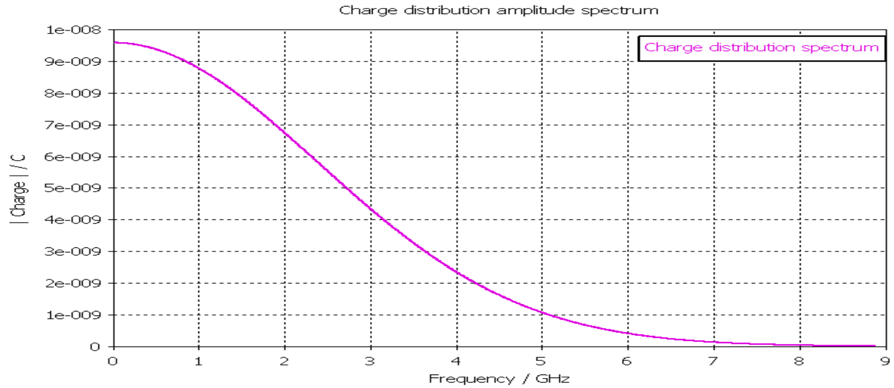
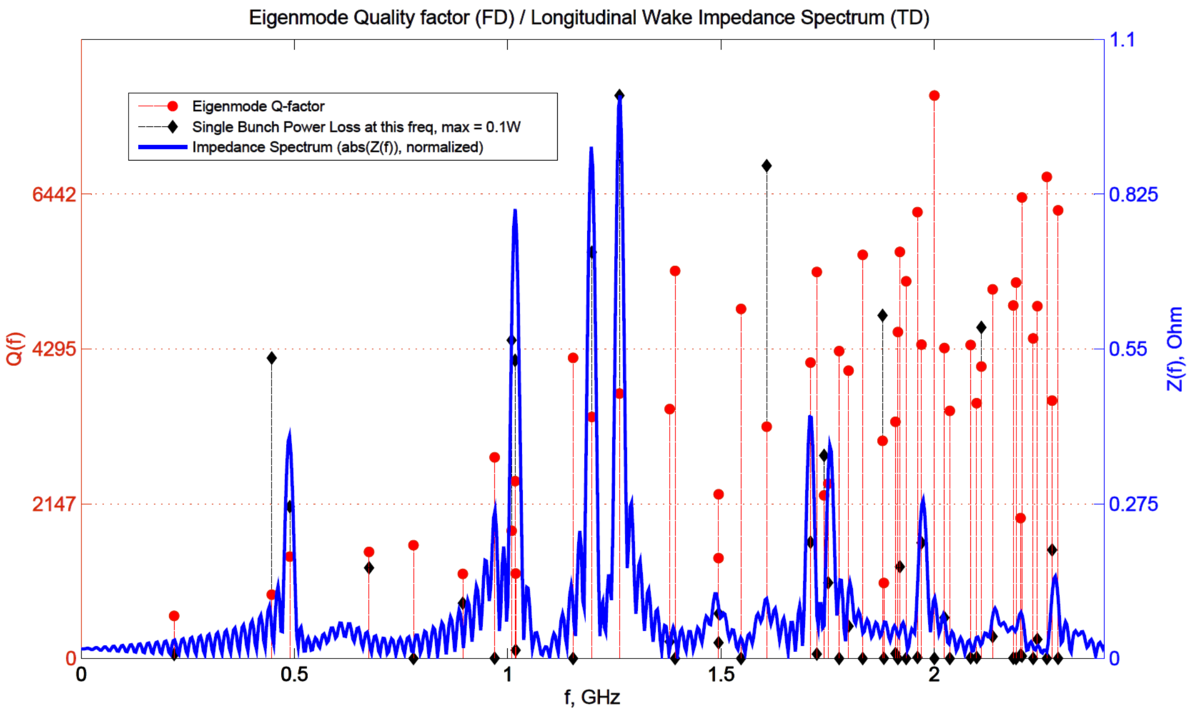
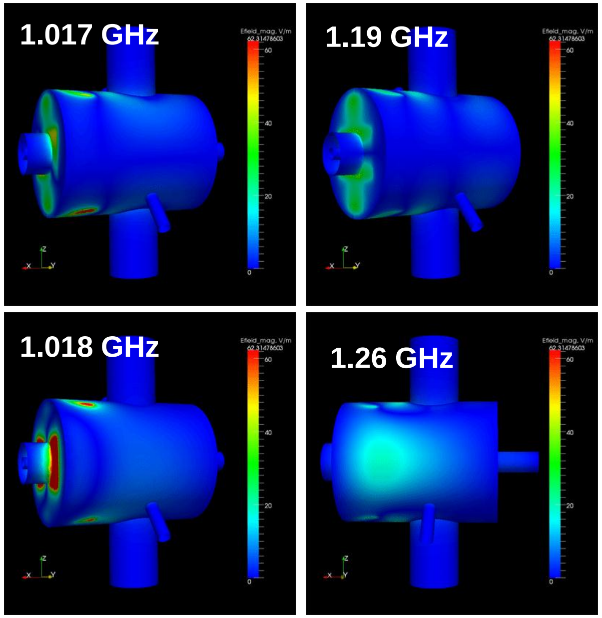


CLIC ODR chamber: HOM and Power loss calculation

It appears that not all resonant modes are present in current ODR setup: only a few can be selected as potential beam power loss / heating threat





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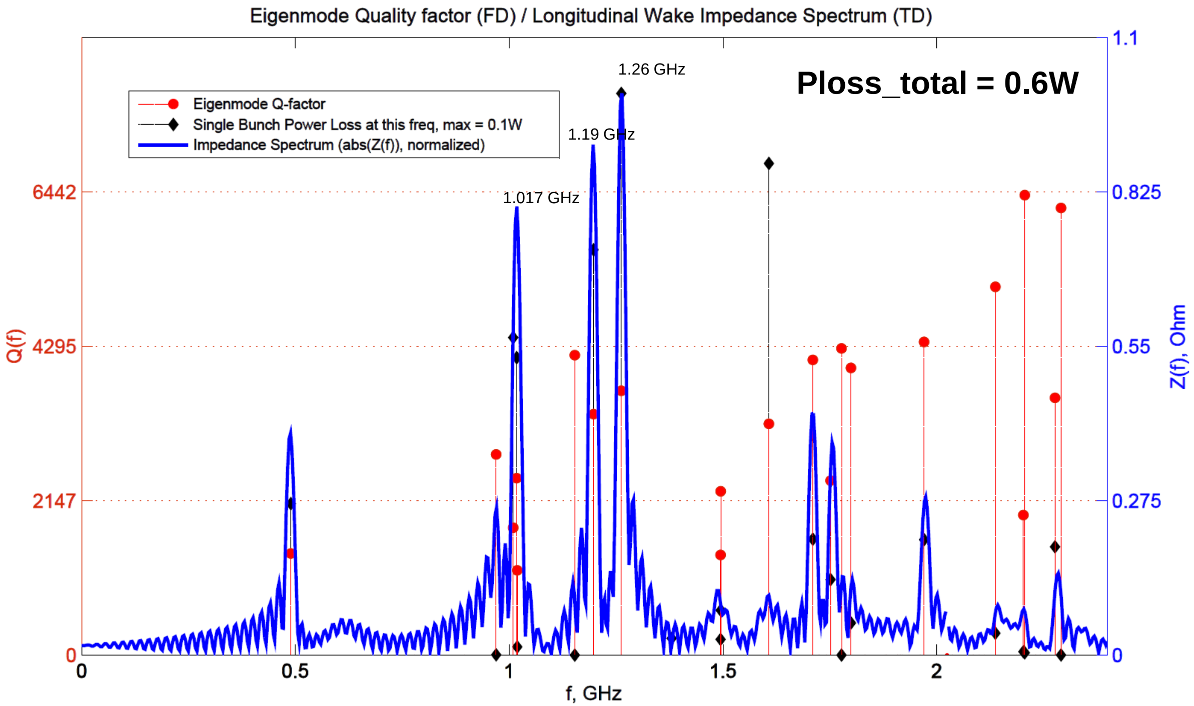
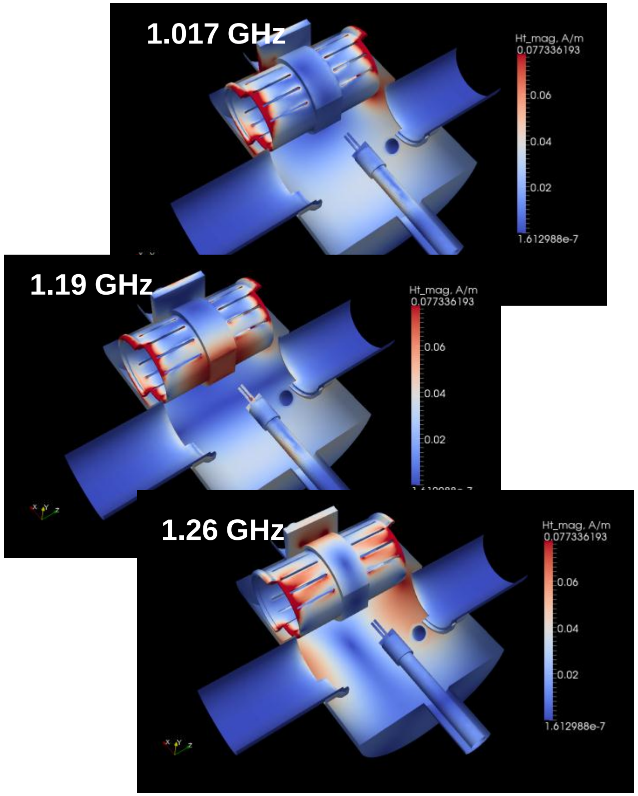
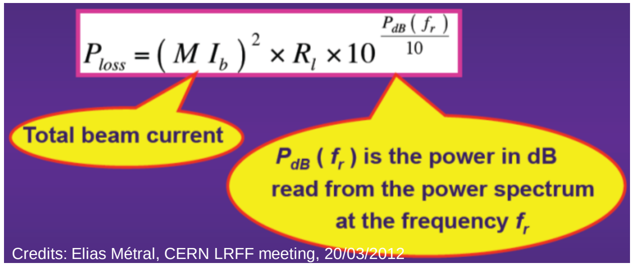
CLIC ODR chamber: HOM and Power loss calculation

For each resonant modes the Beam Power Loss is calculated (for 1-2 cm bunch).
Surface loss maps are calculated from H-field of resonant mode (surface tangents complex magnitude)





Total Power loss estimation for Sharp resonances (cycling beam)



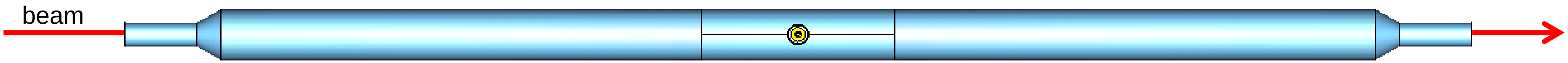
Surface power loss maps for given eigenmodes

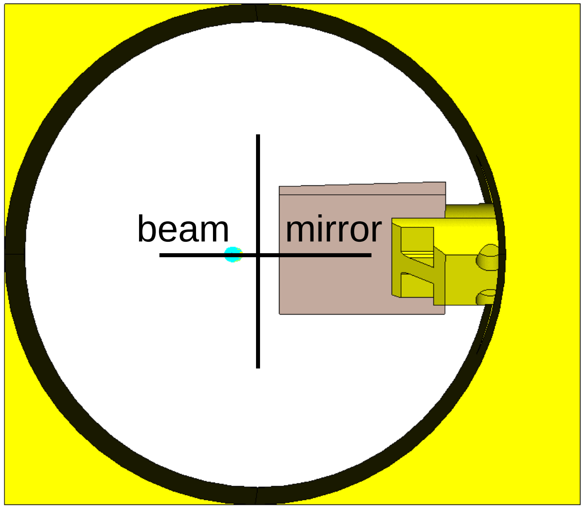
Considered:

- R: longit. shunt impedance
- I = 1 mA
- M = 1 (num of circ. bunches)
- Pdb(f) = 0 (assumed for f < 2 GHz)

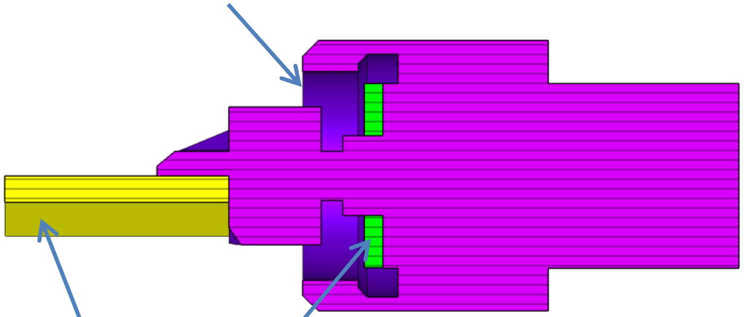
LHC BSRT extraction mirror: Power loss calculation

BSRT is placed in a beampipe of extended diameter (212 mm vs. normal 80mm)
Transition-to-transition length of ~20m makes it a long cavity





Downstream view into BSRT



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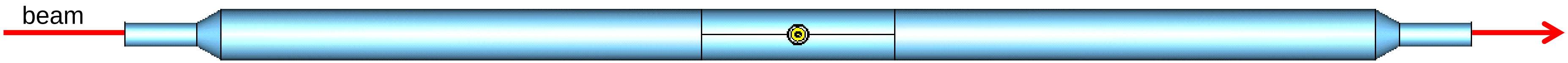
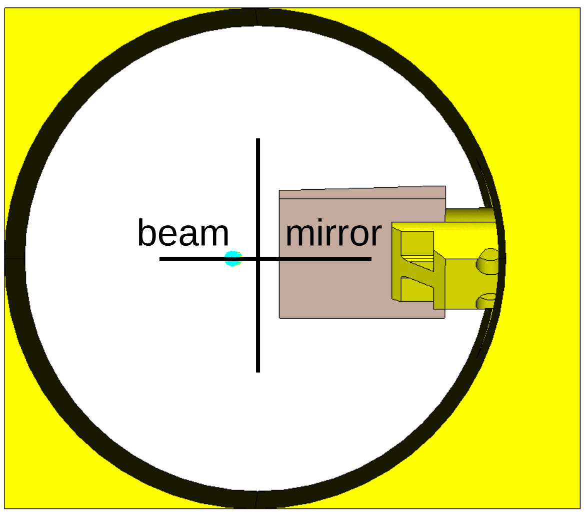
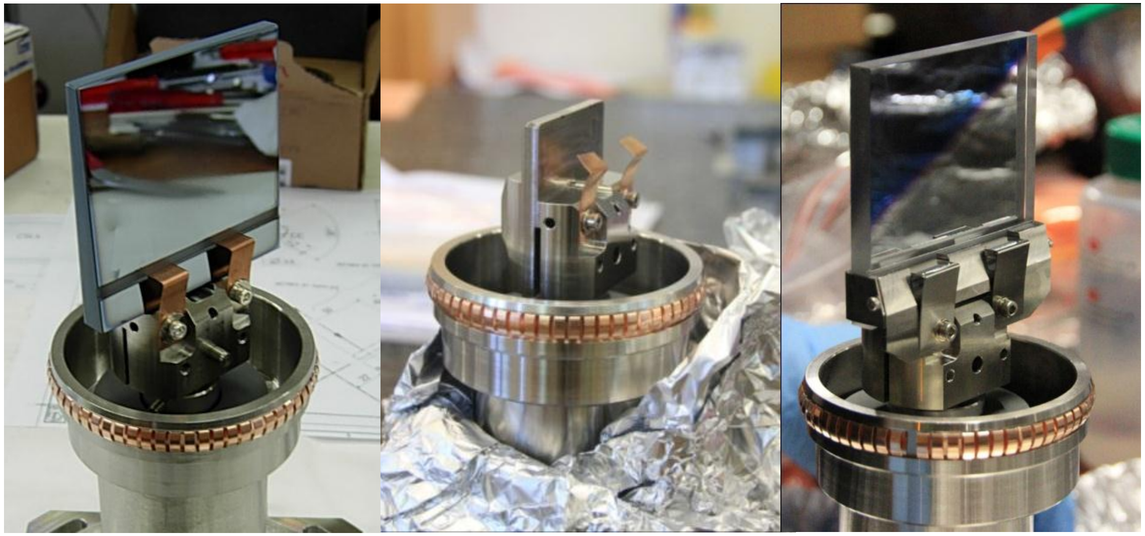




Downstream view into BSRT

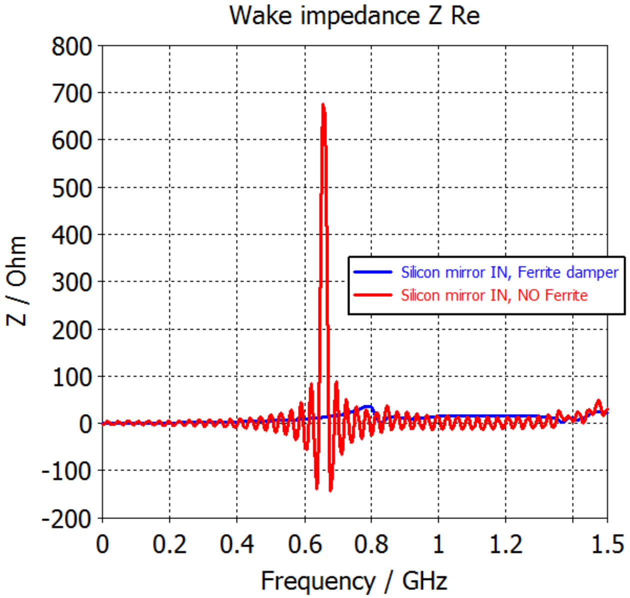
Before Aug.2012 | Main damage: clamps, mirror | After Sept.2012



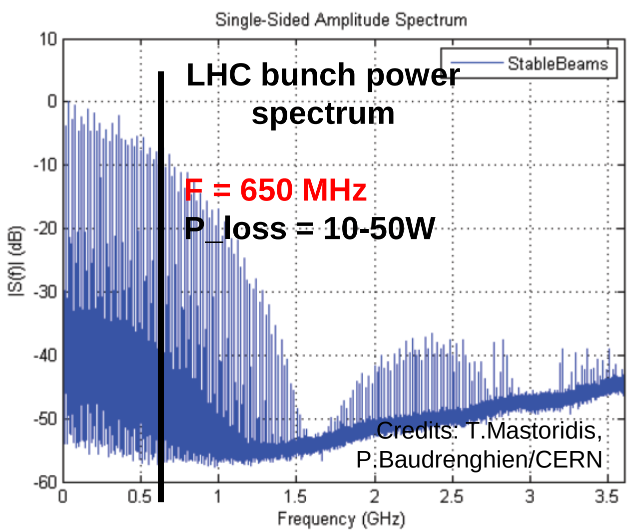
Extreme RF heating of the mirror holder (up to 500 C) lead to intervention and replacement, and still poses a threat to LHC machine protection until LS1.

LHC BSRT extraction mirror: RF resonance + Power loss calculation

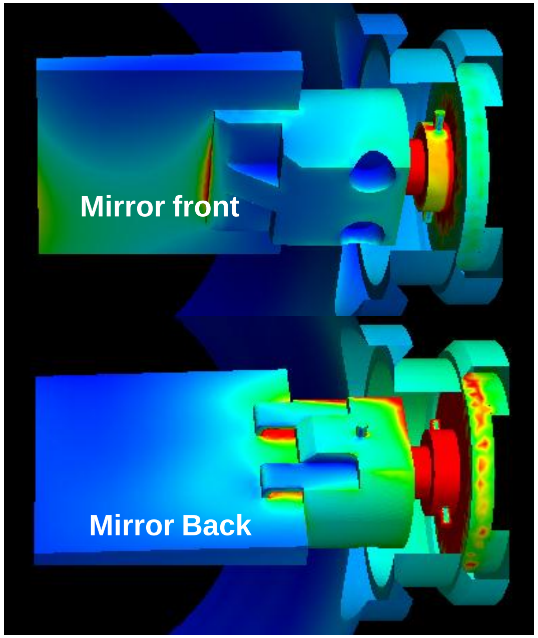
Time domain: 6 LHC bunches with 50 ns spacing.
First bunch introduces clear resonance, next bunches contribute.



Longit. wake impedance of BSRT with Ferrite damping and without



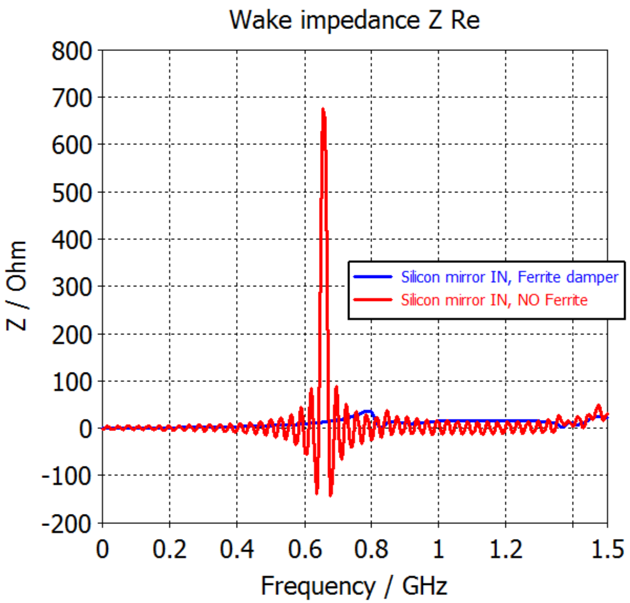
Measured LHC bunch power spectrum. A 650 MHz resonance is very dangerous.



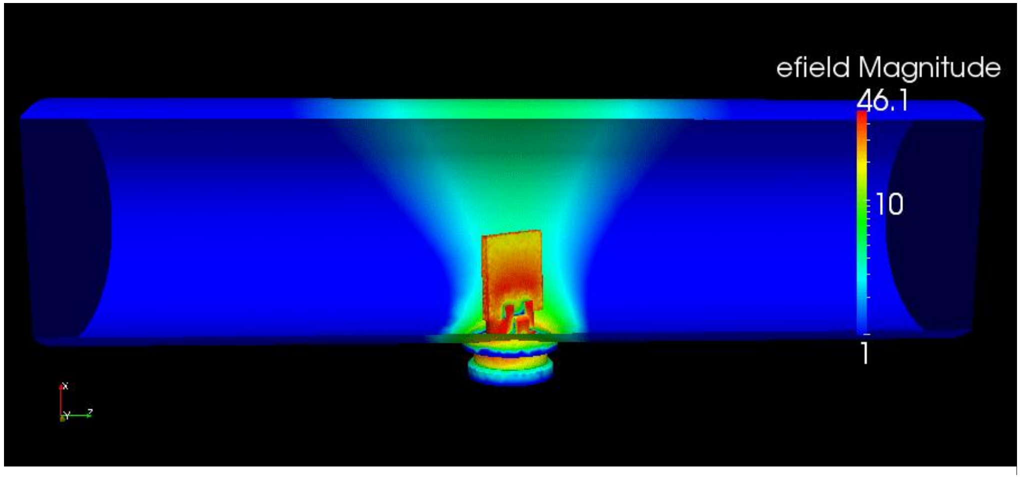
B-filed of the beam in Time Domain.
Red = Hot (bigger current density)
Blue = Cold

Time domain: 6 LHC bunches with 50 ns spacing.

First bunch introduces clear resonance, next bunches contribute.



Longit. wake impedance of BSRT with Ferrite damping and without



E-field of a dominant resonating mode at 650 MHz. (Q = 1263 / Rsh = 25841 Ohm)

Conclusions, plans, wishlist

Acknowledgements:
Marek Gasior, Christian Boccard, Eva Calvo, Ralph Steinhagen and each and every one in QP section;

Special thanks to Rhodri Jones, Federico Roncarolo, Gianluca Valentino, Jeroen belleman, Benoit Salvant, Jorg Wenninger, Oleksiy Kononenko, and many others!

Thank you!

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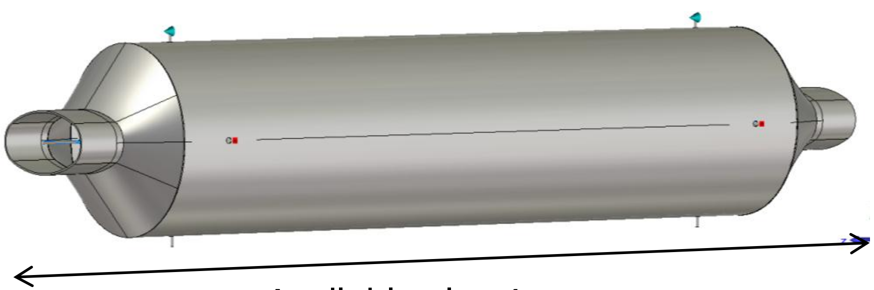
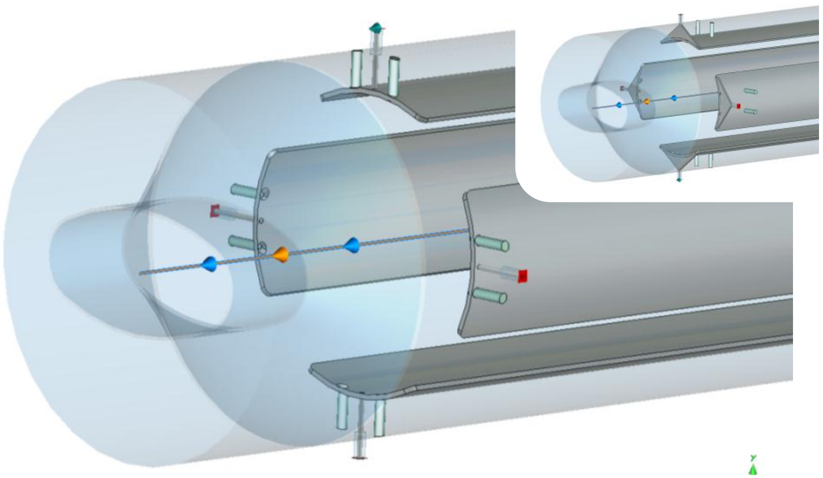
Special thanks to Rhodri Jones, Federico Roncarolo, Gianluca Valentino, Jeroen belleman, Benoit Salvant, Jorg Wenninger, Oleksiy Kononenko, and many others!

EM study of a PS-dedicated stripline pick-up prototype

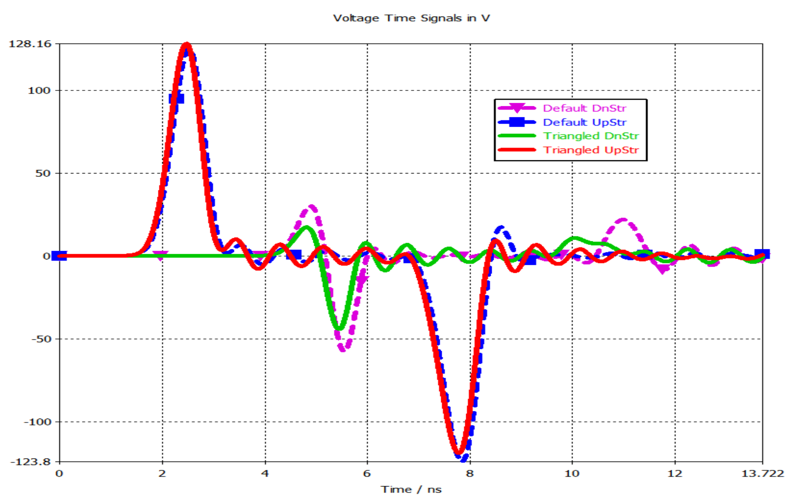
Pick-up is designed to cover the available slot length and aimed for proton/ion bunches up to 50 ns in length.

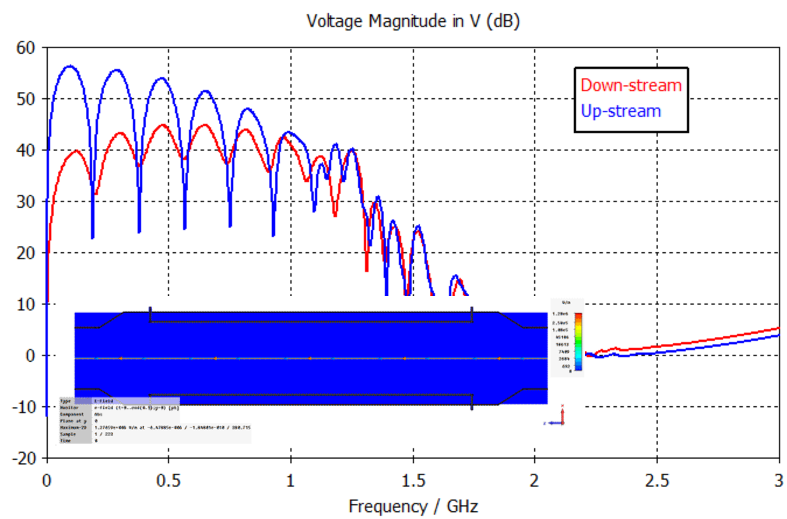


Available slot: 1 m



A close-up on electrodes, standard configuration (and a proposed “triangled” mod.)

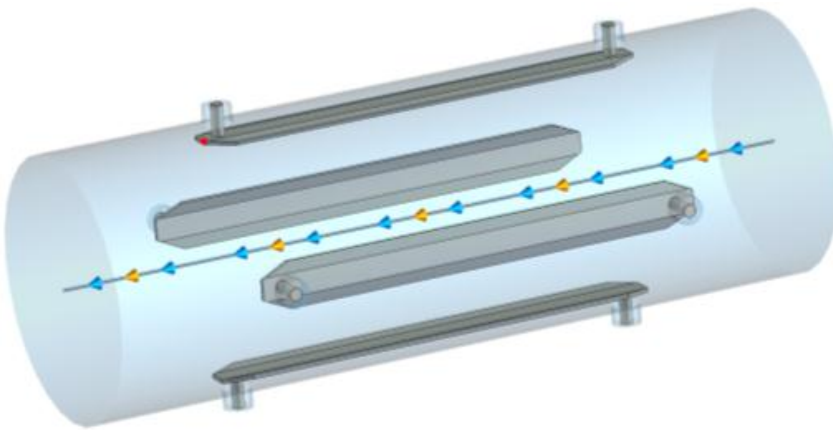




Simulated time and freq response of up-stream / down-stream ports.
No significant influence of electrode modification yet.

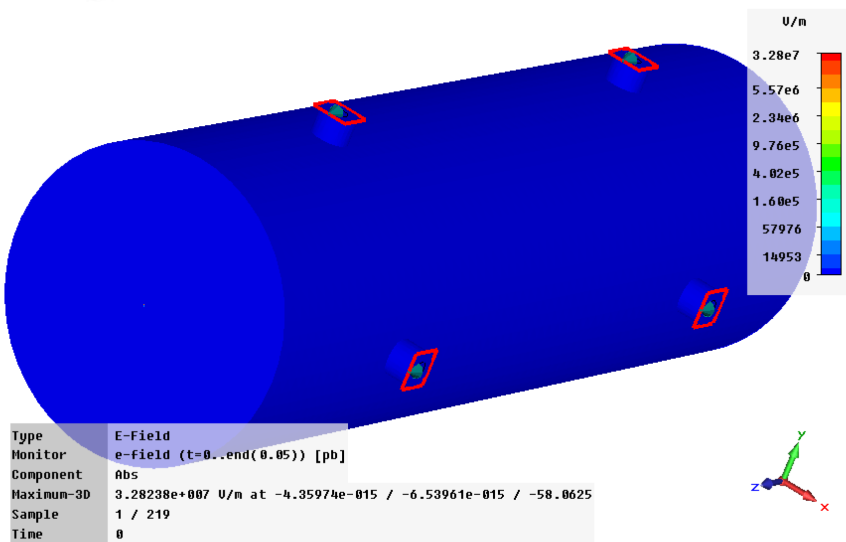
LHC stripline

Two-beam directional stripline BPM (around interaction points): BPMSW, BPMS:

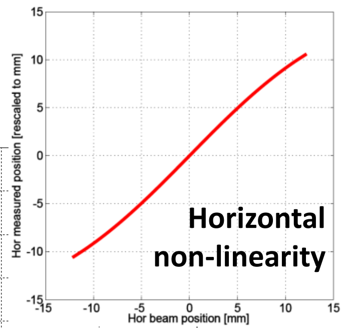


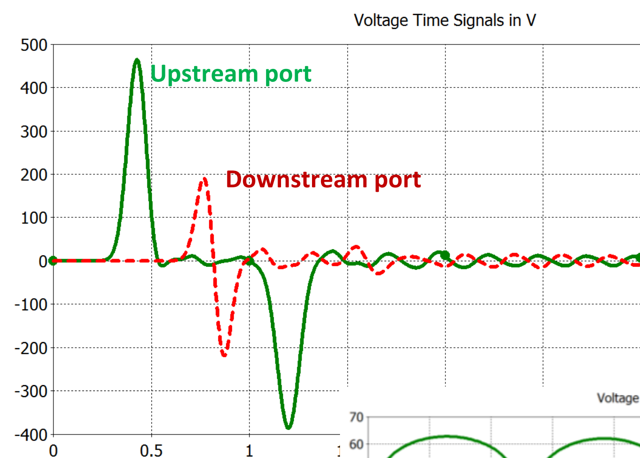
BPMSW:

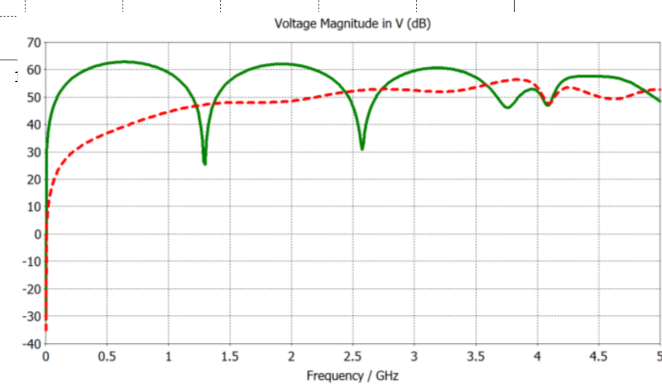
- **120mm stripline length**
- **61mm beampipe diameter**
- **~1M mesh cells (less for longer bunches)**
- **20 minutes of CPU time per simulation (3.1 GHz 2 core PC)**



E-field of a short bunch (sigma=25mm) passing through BPMSW



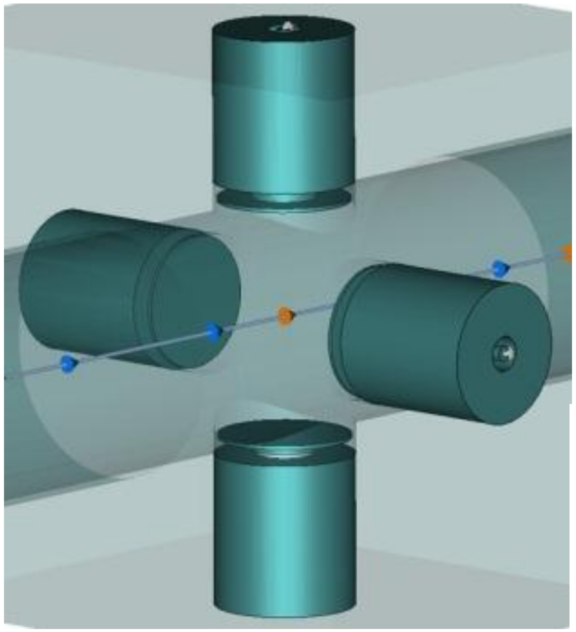




V(time) & V(Freq) of upstream and downstream ports

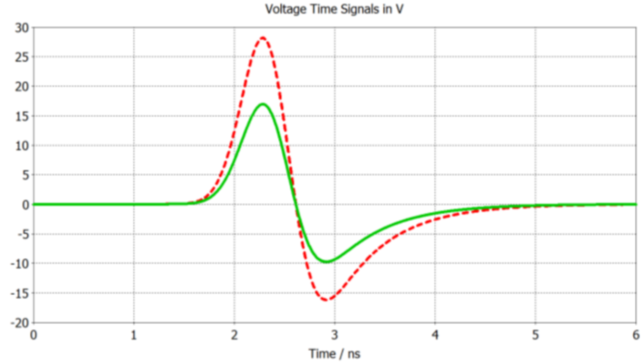
Flat button BPM

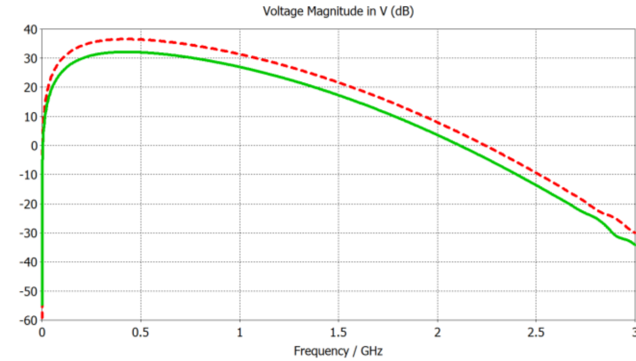
Flat LEP-button BPM family (transfer lines warm pick-up): BPMI, BPMIA, BPMBV, BPMBH



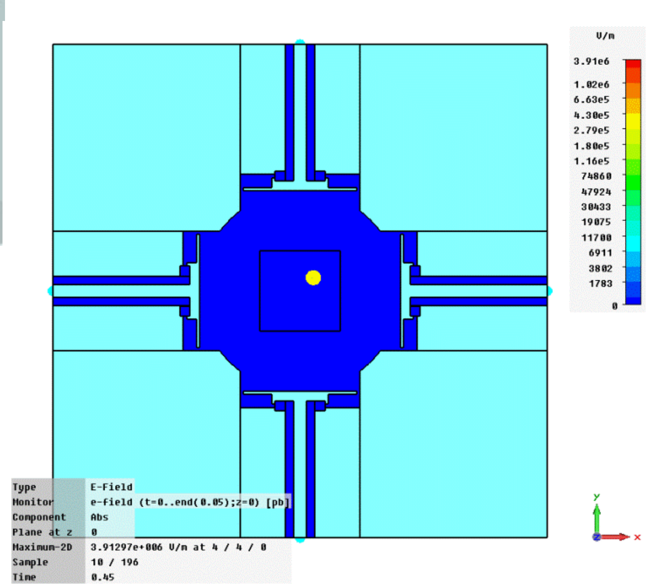
BPMI:

- **60mm beampipe diameter**
- **34mm button head diameter**
- **~2M mesh cells**
- **40 minutes of CPU time per simulation**

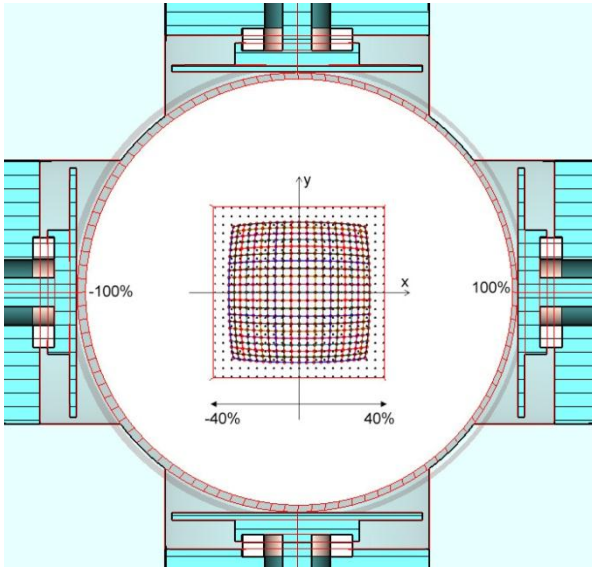




V(time) and V(Freq) response for offset bunch

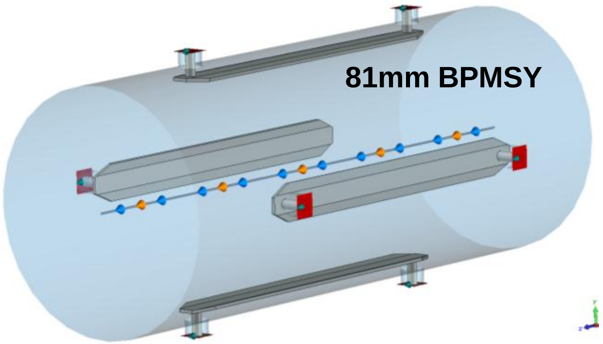


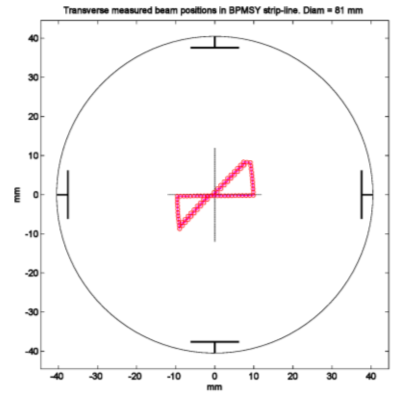
E-field of the off-centered nominal LHC bunch passing through BPMI



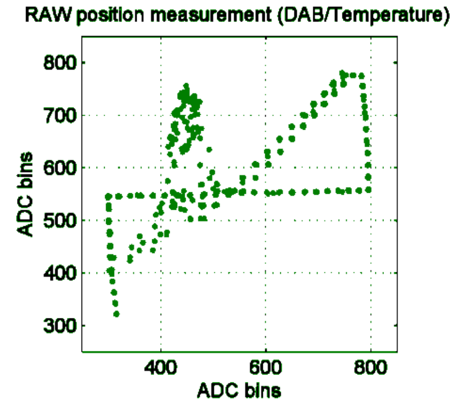
BPMI non-linearity map

Non-linearity correction experiment with LHC beam





Position scan with LHC beam



Obtained noisy measurements

Objective: Scan BPMSY with LHC beam & test the new simulated correction polynomial.

<u>Result of the scan:</u>
Verification of CROSS-term polynomial correction.

On axis beam: correction identical to single-term polynomial.

Off-axis beams: cross-terms reduce error down to ~20 um within 10mm (~500 um with single-terms)