

ICFA Beam Dynamics Workshop  
2010, Daresbury

# CLIC Crab Cavity and Wakefields

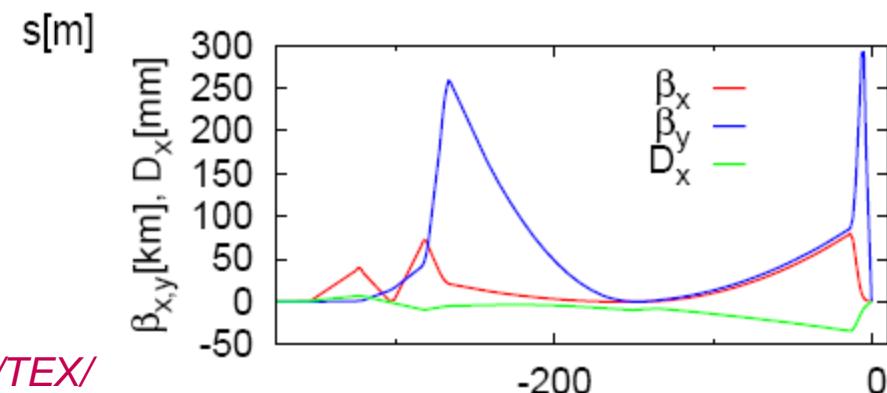
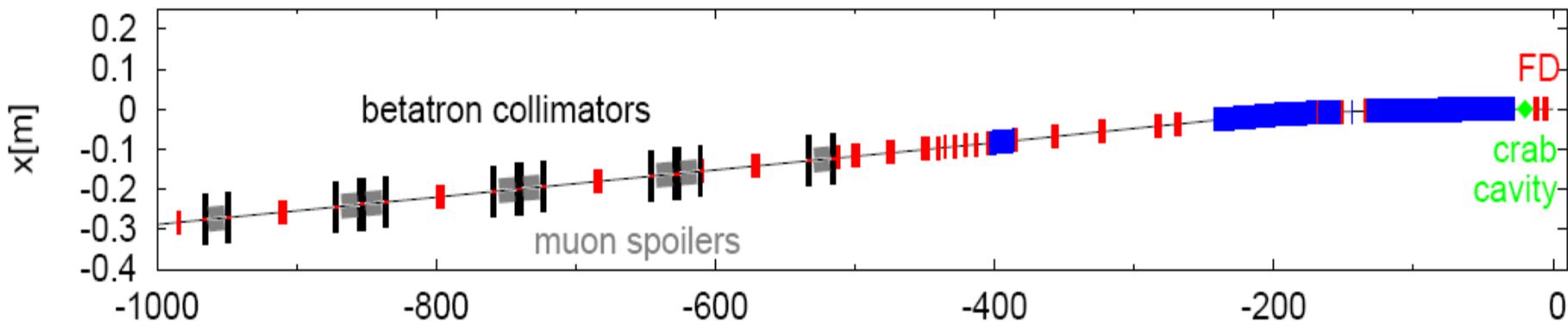
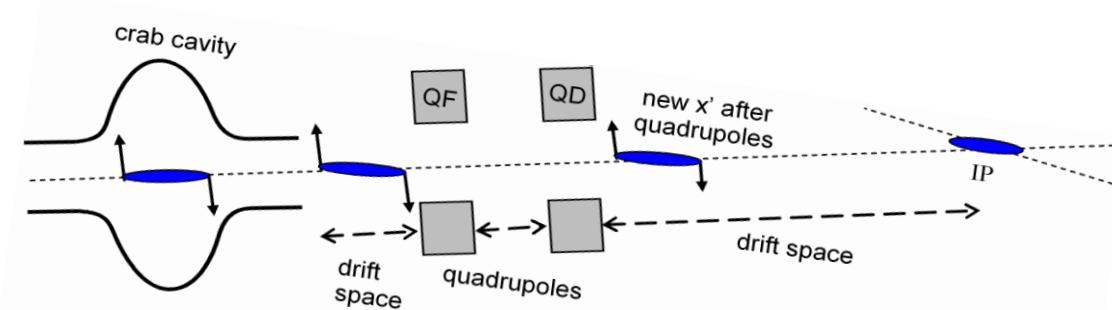


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# Crab Cavity Operation



# Technology choice

## High group velocity / TW cavity:

- beam-loading correction
- phase control , than SW cavity
- $a = 5 \text{ mm}$ ,  $v_{\text{gr}} = 2.95 \%$

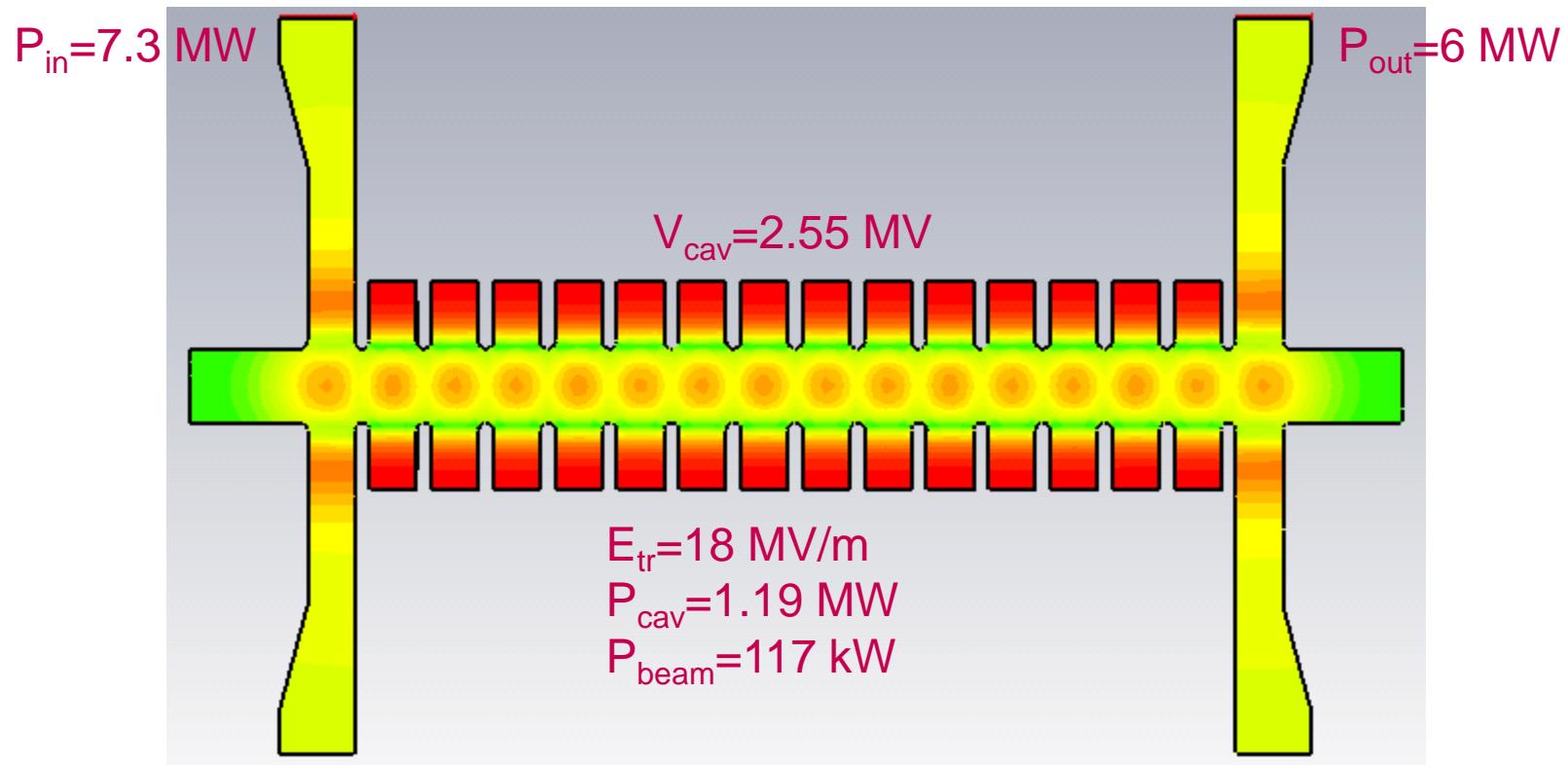
## 12 GHz cavity:

- availability of X-band Klystron
- kick per cavity
- phase tolerance

## *Heavily damped or moderately damped-detuned cavity:*

- *Transverse and longitudinal wakefield*

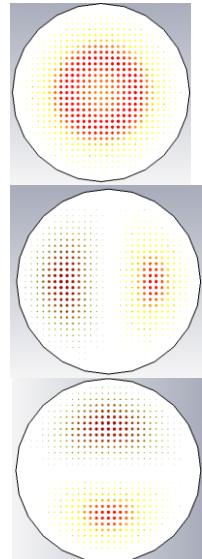
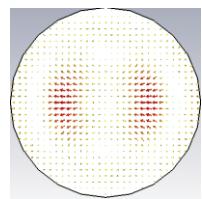
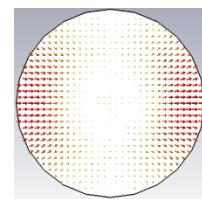
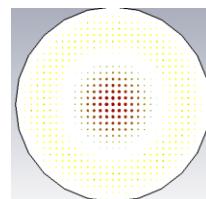
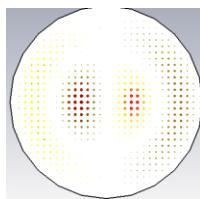
# 16 cell Crab Cavity



# Wakefield effects in crab cavity

Bunch(es) can excite a variety of modes with different properties

- Lower order mode → energy spread → inefficient focus
- Crab / operating mode → beamloading → amplitude error
- Same order mode → vertical deflection → bunches miss at IP
- Higher order modes (HOMs) → both monopole and dipole contributions



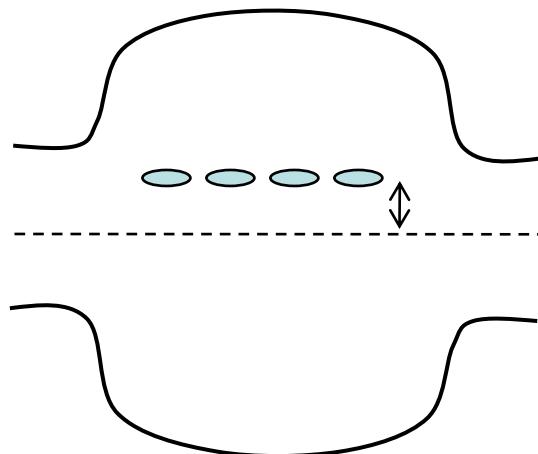
*The most dangerous in the group is the SOM which has the same frequency and kick as the operating mode but in the vertical plane.*

# Multibunch wakefield in the undamped cavity, Q=6000

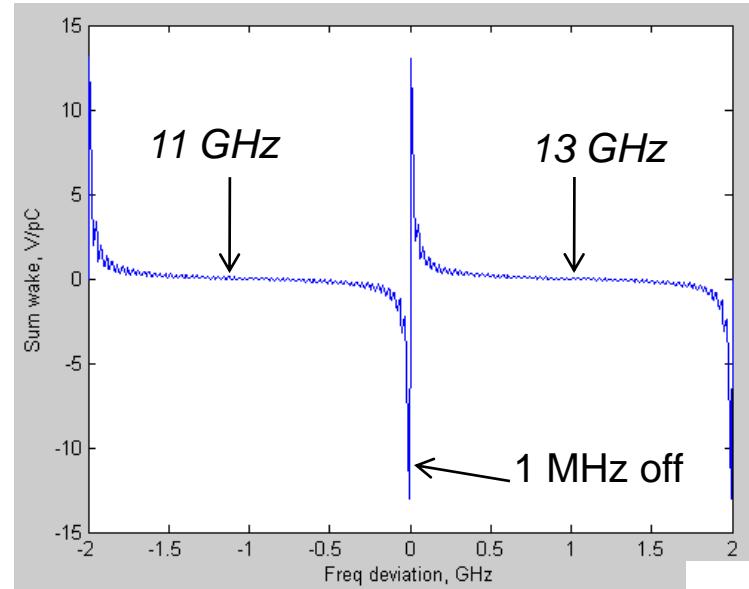
Single mode-Multibunch-Transverse wake:

$$W_{m,t} = 2rK_{m,t} \sum_{n=1}^{N_b-1} \sin(n\omega_m T_b) \exp(-nT_b / T_d)$$

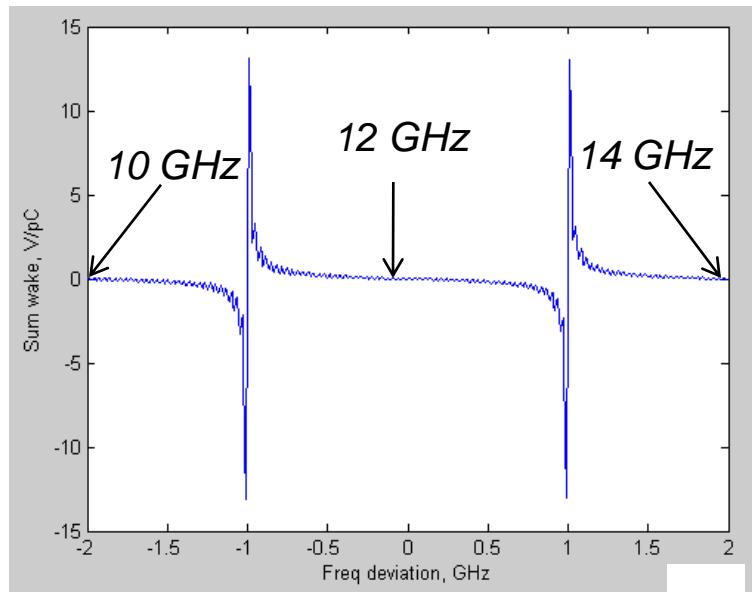
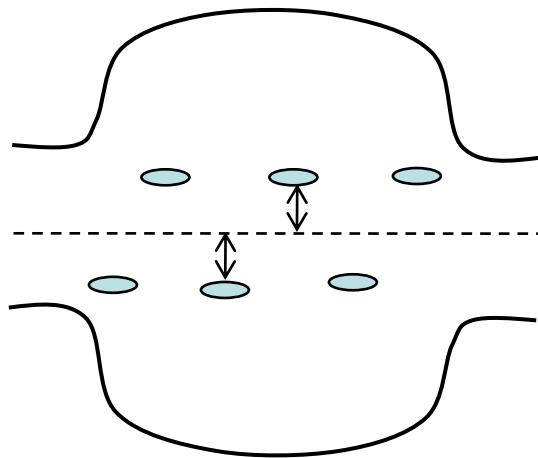
- Since the multi-bunch transverse wake field is a sum of sinusoidal oscillations, there are frequencies where the wakefield is essentially zero
- This happens at harmonics of half bunch frequency ( $n.1\text{GHz}$ ,  $n=1,3, 5..$ ), no need of any SOM damping *iff the bunches are coming at the same offset from the axis*



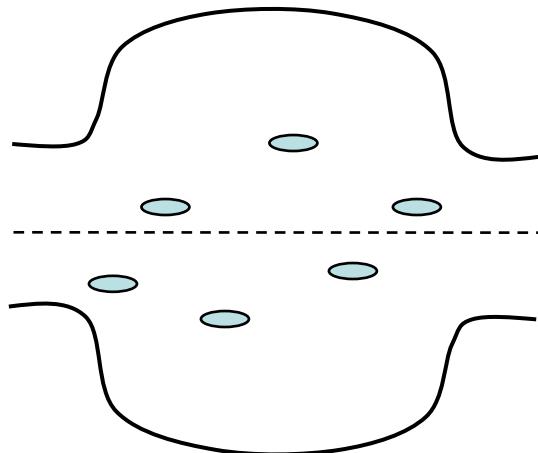
1) Fixed offset for all bunches



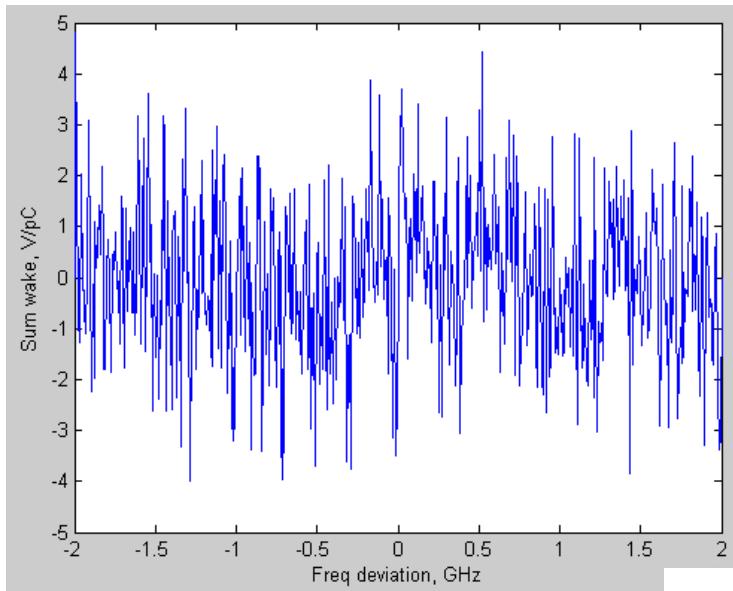
## 2) Fixed offset and sign alternation bunch-to-bunch



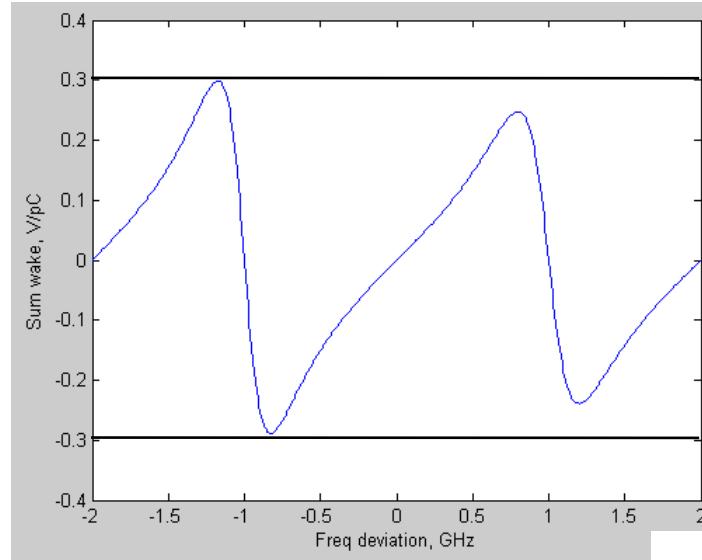
## 3) Random offset and random sign



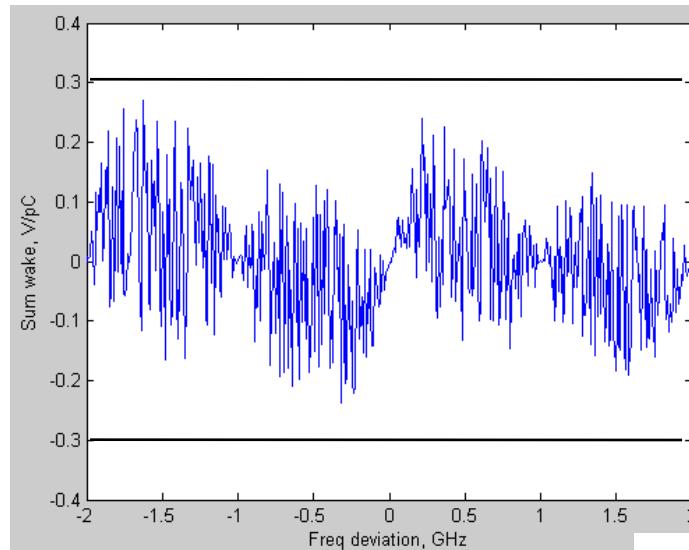
*Damping is essential !*



## Fixed offset and sign alternation bunch-to-bunch , Q=30



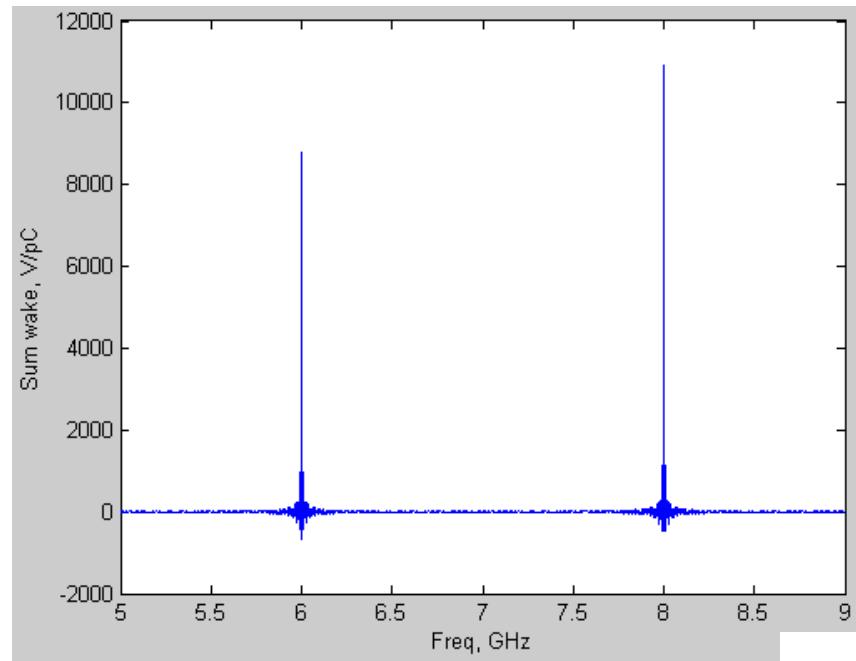
## Random offset and random sign, Q=30



- The maximum longitudinal wake occurs at the bunch harmonic
- In the 12 GHz dipole cavity, the LOM occurs between 8.3 and 8.8 GHz which are far off-resonance

Single mode-Multibunch-Longitudinal wake:

$$W_{m,z} = K_{m,z} \left( 1 + 2 \sum_{n=1}^{N_b-1} \cos(n\omega_m T_b) \exp(-nT_b / T_d) \right)$$



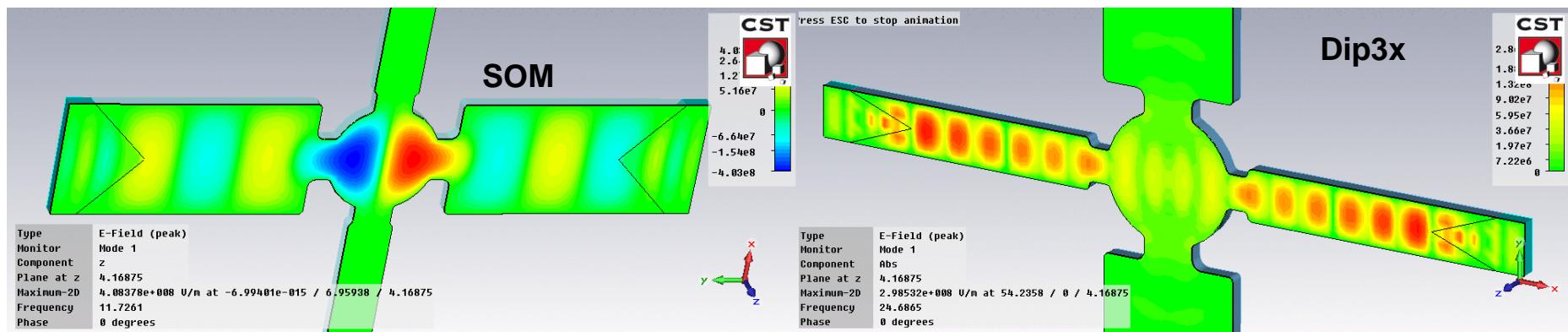
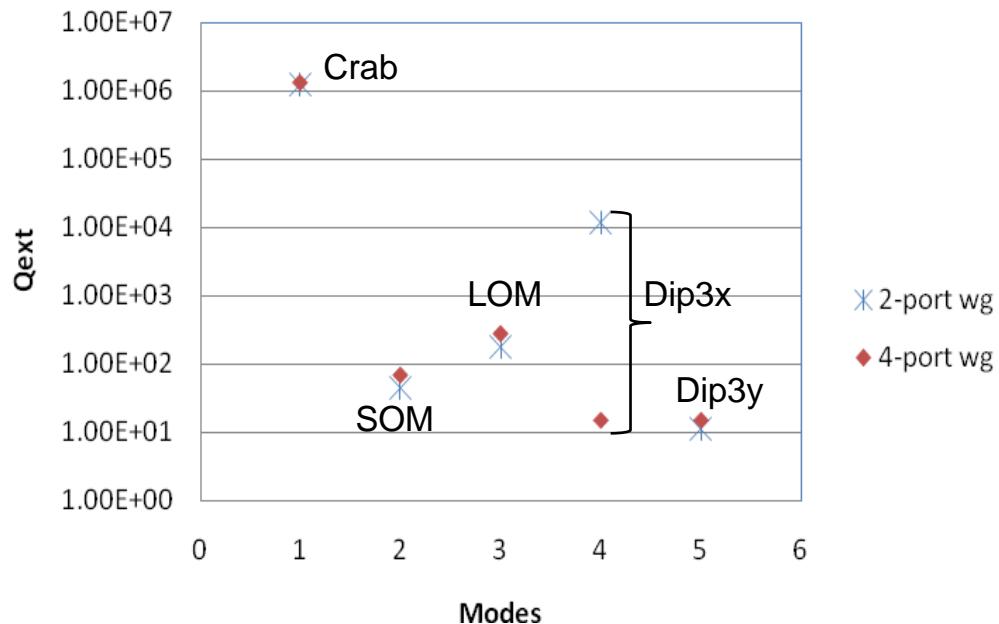
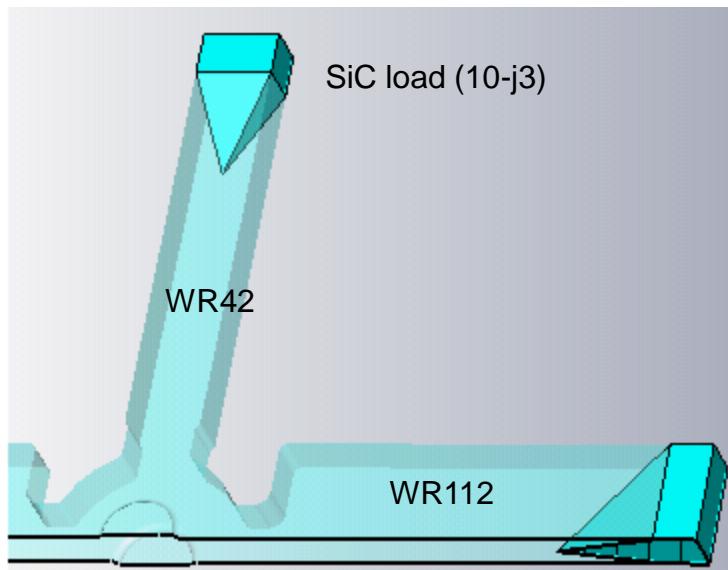
- However, geometry modifications for damping dipole modes may shift the LOM also to resonance. So *LOM damping is also essential*

# Damping tolerances

- Transverse wake: Luminosity loss is under 2 %  
Tolerance: 0.3 V/pC, for a 16 cell cavity
- Longitudinal wake: Bunch energy spread is under 1e-4%,  
Tolerance: 2500 V/pC for a 16 cell CC
- Worst case Qs: Calculated at the frequency of maximum kick / loss factor

mode	Freq., GHz	df for max wake, MHz	$Q_{\text{ext}}(x)$	$Q_{\text{ext}}(y)$
<b>Dipole modes (offset = 35 μm)</b>				
Dip1	11.9942	1	--	33
Dip3	24.0663	2	225	211
Dip4	25.634	2.14	457	429
Dip6	32.8852	2.74	611	572
<b>Monopole modes (offset = 0)</b>				
Mon1	8.6683	668	665	
Mon2	20.854	854	1229	
Mon3	28.7514	751	1111	

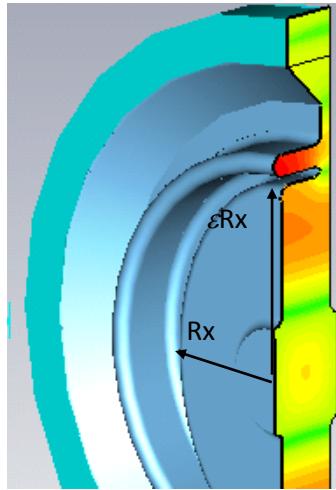
# Waveguide damping



# Choke-mode damping

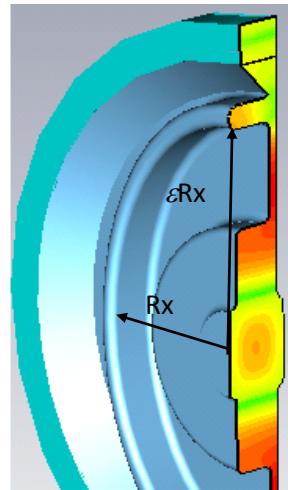
The basic choke-mode cavity can't damp the SOM, so we need to device asymmetric choke-mode dampers

Elliptical cavity

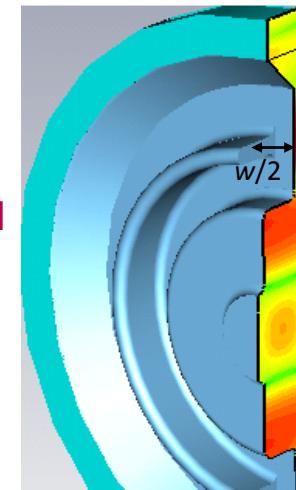


SiC load

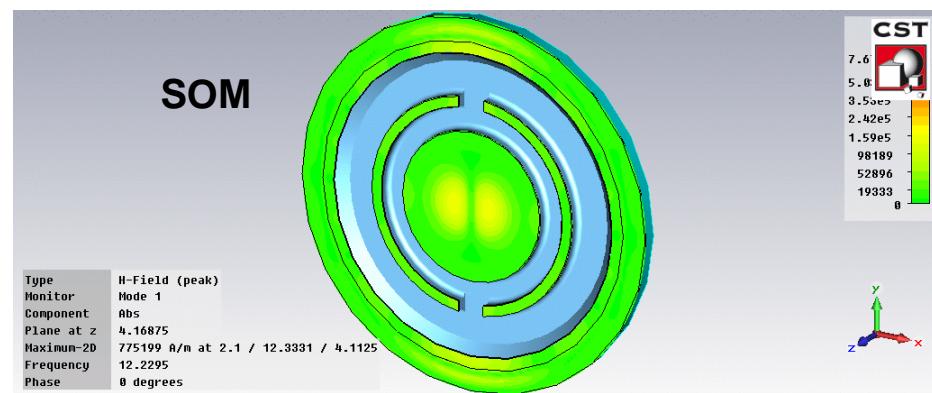
Elliptical choke



Slotted choke

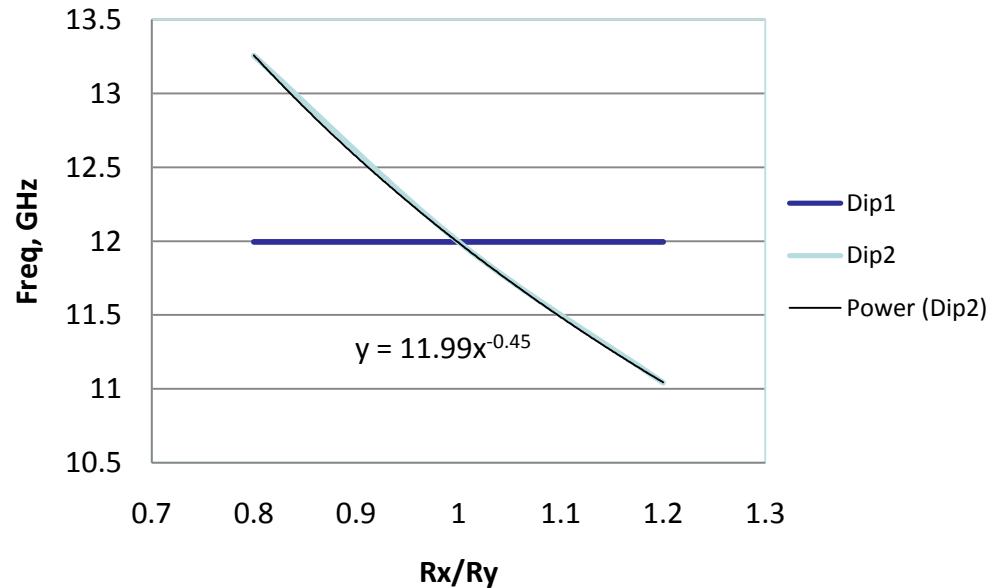
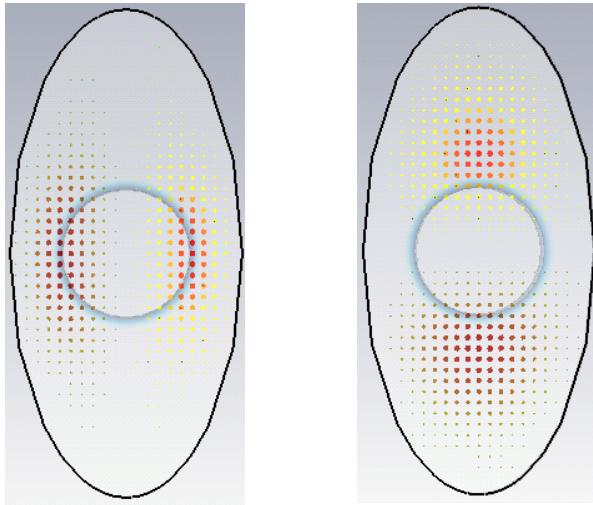


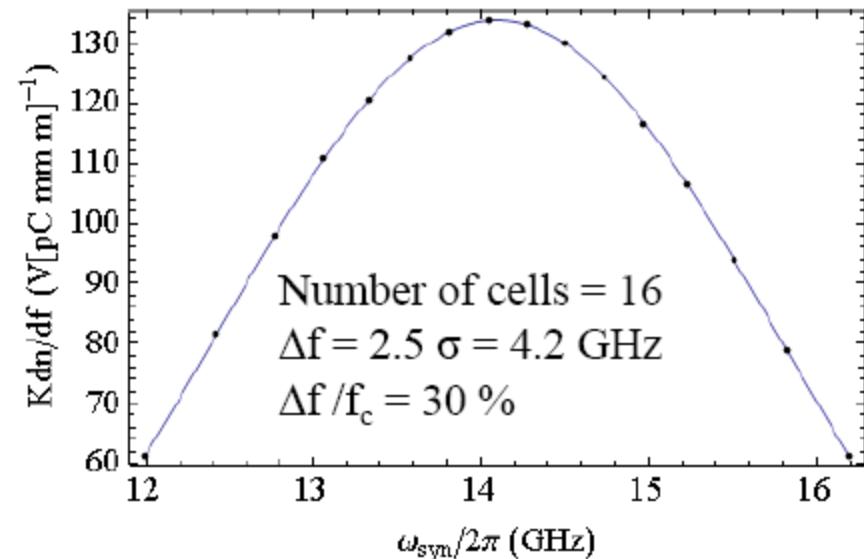
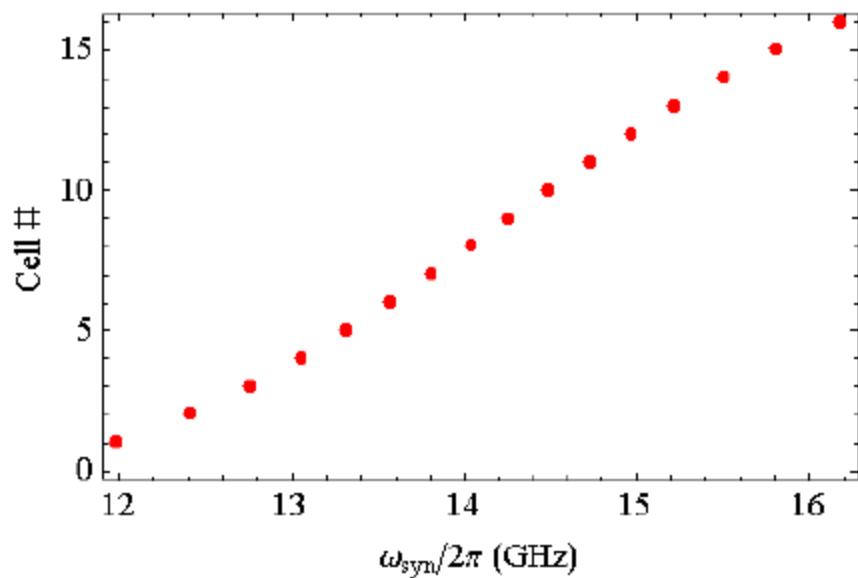
Shape	$Q_{ext}$		
	Crab	SOM	LOM
Basic choke mode cavity	1.906E+04	1.906E+04	218
Elliptical cavity	1.554E+04	240	15
Elliptical choke	1.557E+04	587	172
Slotted Choke	1.557E+04	172	67



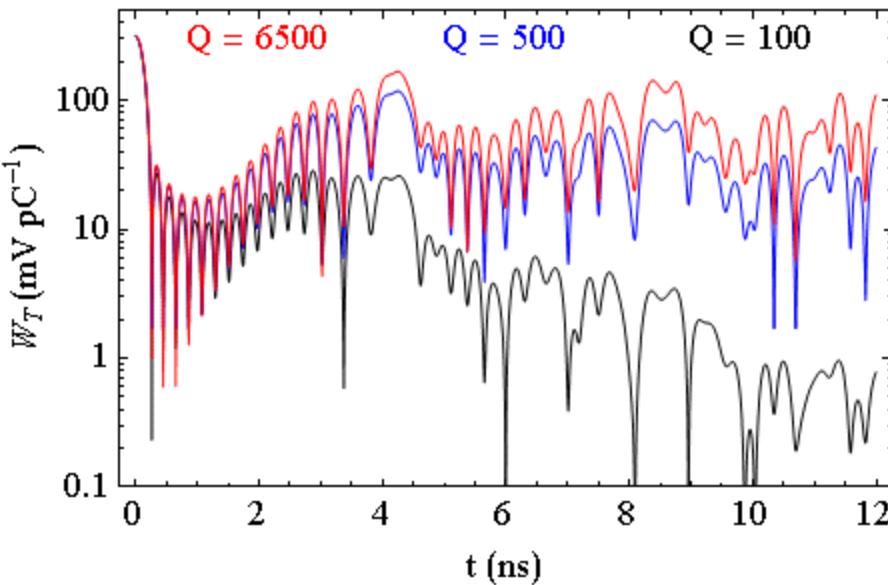
# Detuning to decohere SOM wake

- Detuning assisted by moderate damping already in progress for the CLIC main linac
- Detuning the SOM to have a spread of frequencies by changing the equator ellipticity downstream
- This allows the SOM wake to decay with Gaussian profile over a few bunch times

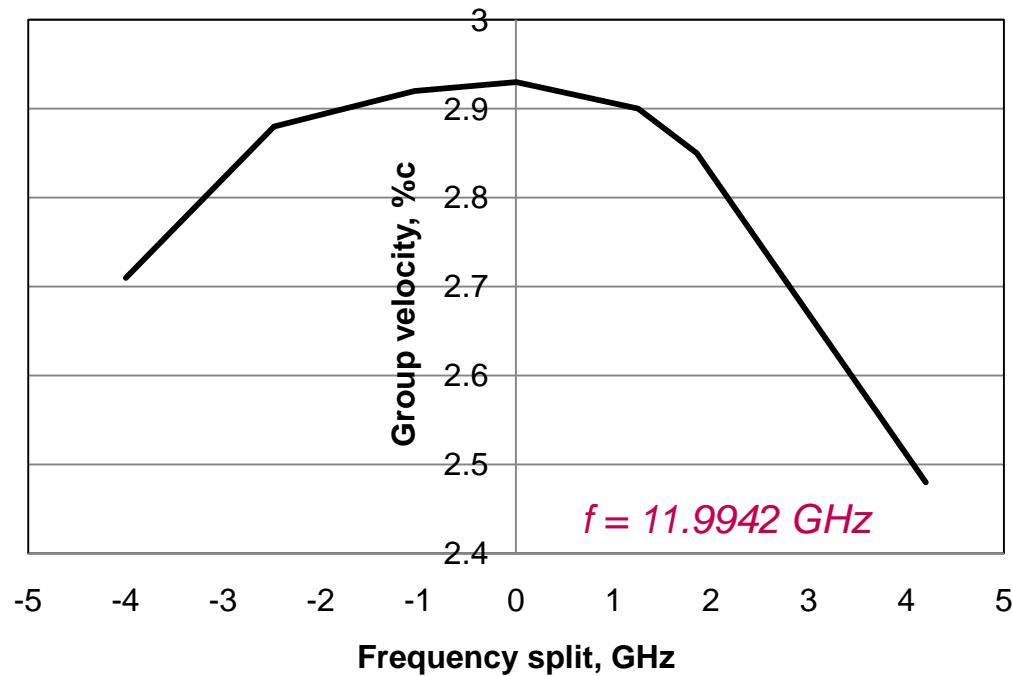




## Uncoupled calculation



<b>Q</b>	<b>Sum wake (V/pC)</b>
6500	2.443
500	0.165
100	0.028



- SOM spread for detuning is limited by the group velocity of operating mode

# RF properties

Cavity	Trans R/Q, Ω	Trans R <sub>sh</sub> , MΩ/m	V <sub>gr</sub> , %c	E <sub>s</sub> /E <sub>tr</sub>	H <sub>s</sub> /E <sub>tr</sub>
Undamped	53.92	41.4	2.93	3.57	0.012
Choke mode (Q <sub>som</sub> ~50)	47.46 (-12 %)	26.5 (-36 %)	2.84	3.55	0.024 (+100 %)
Waveguide (Q <sub>som</sub> ~50)	52.86	37.8	2.63 (-10 %)	3.55	0.012
Detuned (df=4.2 GHz)	50.2	37	2.48 (-15 %)	3.39	0.01

# Conclusions

## 1) Waveguide damping:

- ✓ Meets the required wakefield tolerance ( $Q \sim 30$ )
- ✓ Group velocity concern
- ✓ Fabrication difficulty

## 2) Choke mode cavity:

- Moderate damping ( $Q \sim 200$ )
- Higher surface magnetic field

## 2) SOM detuning:

- Meets required wakefield tolerance, combined with moderate damping ( $Q \sim 500$ )
- Group velocity reduction restricts achievable SOM spread
- Choke-mode-detuned cavity is a good option for a possible prototype