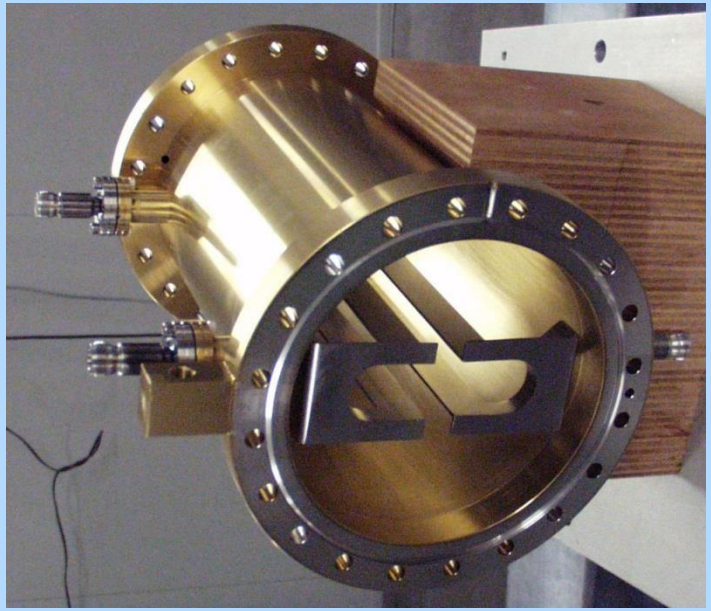
PAUL SCHERRER INSTITUT

Fast Kickers for Multi Bunch Feedbacks

M. Dehler

Paul Scherrer Institut, Switzerland

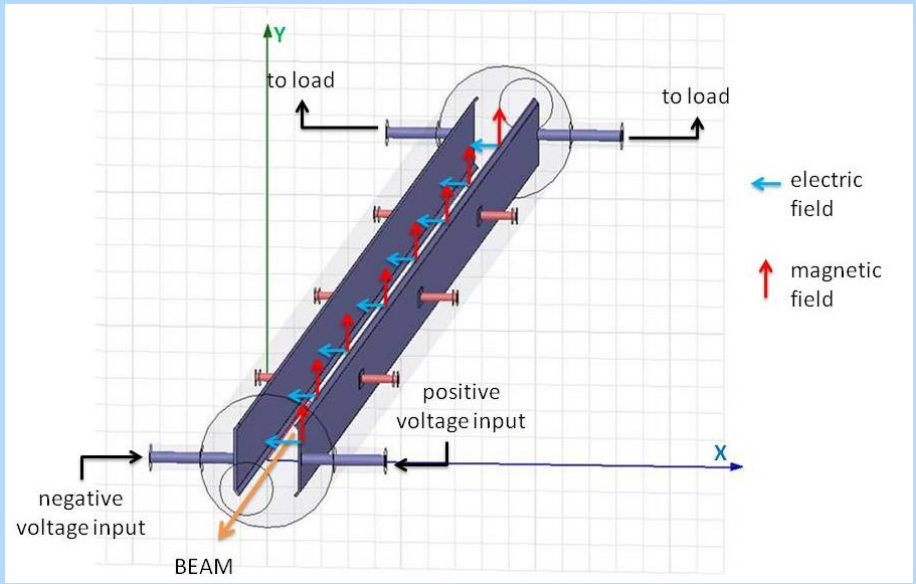


Task list

- High efficiency, strong kick with reasonable amplifier power
- For some applications, transverse homogeneity of kick
- Low broad band impedance/short range wake fields
- Negligible contributions from higher order modes
- No thermal problems with heat up due to wake fields or synchrotron radiation

Some Basics

The classical way of thinking about kickers



- Pair of electrodes driven in odd mode
- Counter propagating TEM wave creates deflecting force $\vec{F} = q\left(\vec{E} + \vec{v}\, x\, \vec{B}\right) = 2\mathrm{q}c\vec{E}$ (Copropagating wave gives zero force due to $E \sim c\, B$

Instead of thinking in terms of electric and magnetic fields distributed over a 3D volume, there are two conceptual tools greatly simplifying understanding the behavior!

(court. C Belver-Aguilar)

Tool #1: Panovsky Wenzel Theorem

For particles moving at (or sufficiently near to) speed of light, the integrated kick is determined by the transverse variation of the longitudinal integrated acceleration

- $j\frac{\omega}{c}\vec{F}_{\perp} = \Delta_{\perp}F_{\parallel}$ (Frequency domain)
- $\vec{F}_{\perp} = \int \Delta_{\perp}F_{\parallel}\, ds$ (Time domain)

(Panovksy, Wenzel, RSI 27, 1957)

True for all field, beam excited or externally driven!

Instead of thinking about transverse electric and magnetic fields (each 2 components) and how they add or cancel, need to know

- What is the acceleration seen by the beam?
- How does it vary with beam offset?

How about the transverse distribution of acceleration?

Tool #2: Indirect wake field integration schemes

If nothing sticks inside the beam pipe, the transverse distribution of the longitudinal kick follows quite simple laws:

- In cylindrical coordinates (Weiland NIM 216, 1983)

$$F_{\parallel} = \sum_m a_m \binom{sin}{cos}(m\varphi)\, r^m$$

- In general 3D structures (Vaganian/Henke, Particle Accelerators, vol 48, 239-242, 1995)

$$\Delta F_{\parallel} = 0$$

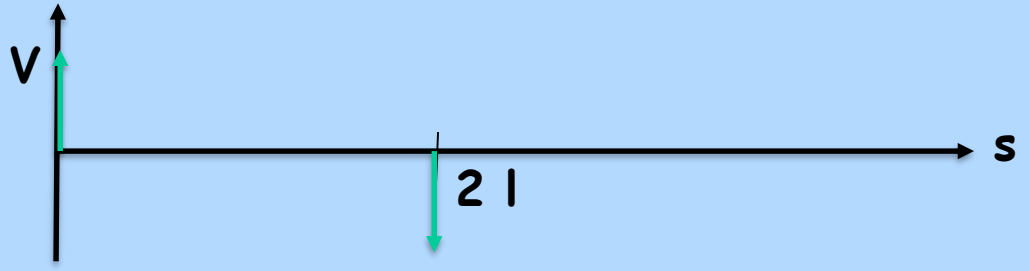
(If something sticks in, see papers by Napoly, Henke …)

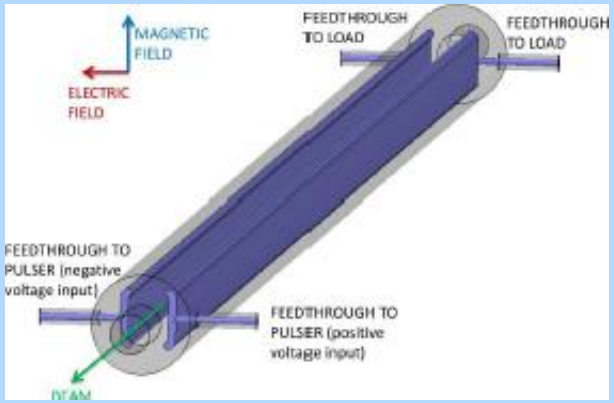
- To have the full information, we only need only the kick at the beam pipe…
- In a strip-line kicker, the only acceleration/deceleration happens at the longitudinal gaps at the beginning and the end of the electrodes …

Applying this to the basic kicker

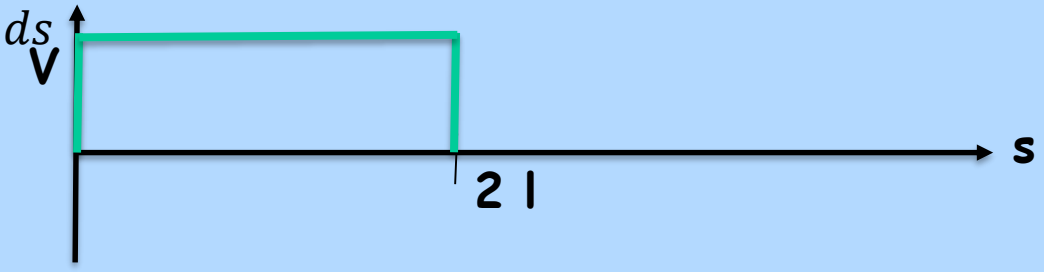
Applying short (Dirac) pulses to the input couplers

- Integrated longitudinal acceleration with the beam passing at the blade

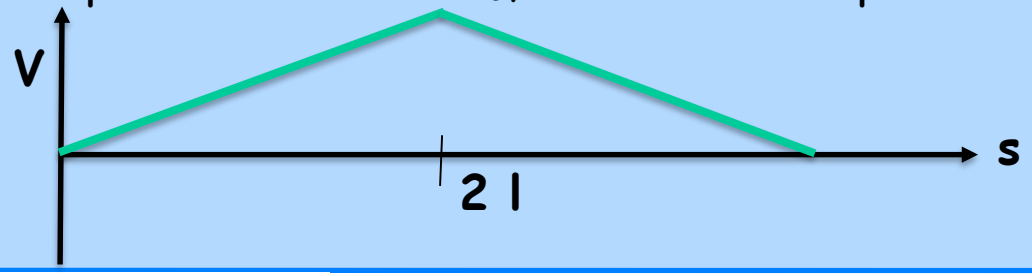




- Tool #2: long. Voltage varies linearly between blades
- Tool #1: $V_\perp = 2/d \int V_\parallel ds$



- Feeding with rectangular pulse with $\Delta t = {}^{2l}/_{c}$, trans shunt impedance $Z_\perp = 50\ \Omega \frac{2l^2}{d^2}$



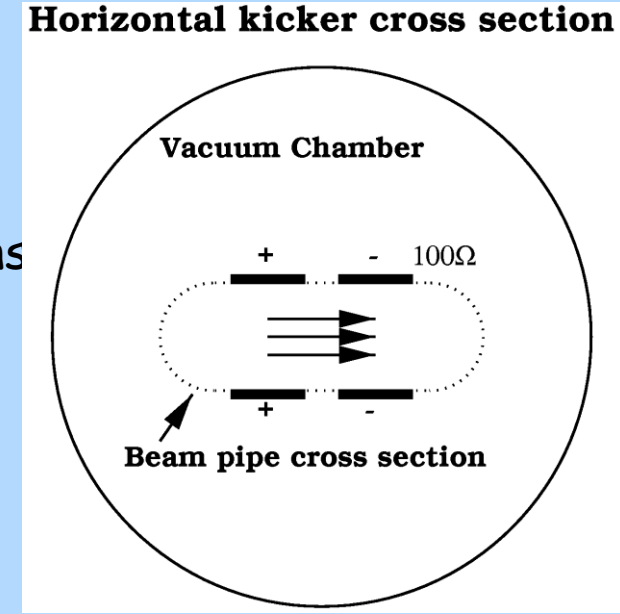
Efficiency

How to optimize the shunt impedance? Basic kicker formula gives

$$Z_\perp = 50\ \Omega \frac{2l^2}{d^2}:$$

- Stripline length is determined by specified rise time.
  - How about loading with dielectrics/ferrites? Apart from lengthing the rise time, may cause pulse distortions.
- Effective distance between blades given by vacuum chamber considerations but be creative!!
- Using multiple kickers increases the effective shunt impedance with the number of kickers (as e.g. in PETRA 3)
- Crazy idea (never was able to make it work):

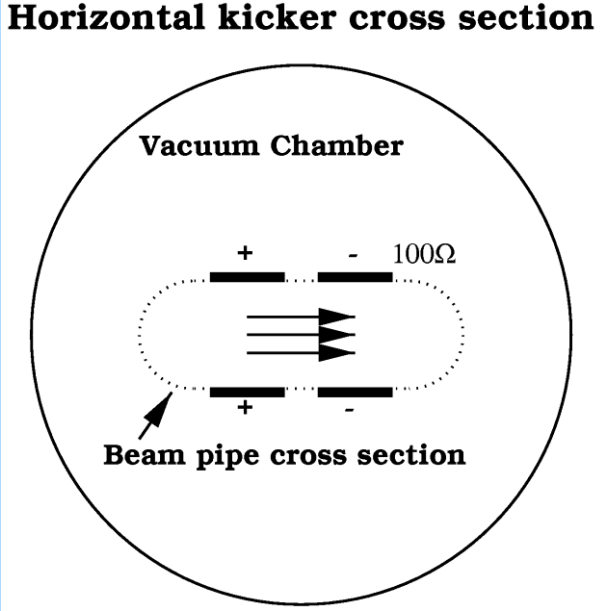
  - Design stripline kicker with 100 Ω, now $Z_\perp = 100\ \Omega \frac{2l^2}{d^2}$
  - Two kickers driven in parallel by 50 Ω amp give factor 4 improvement!

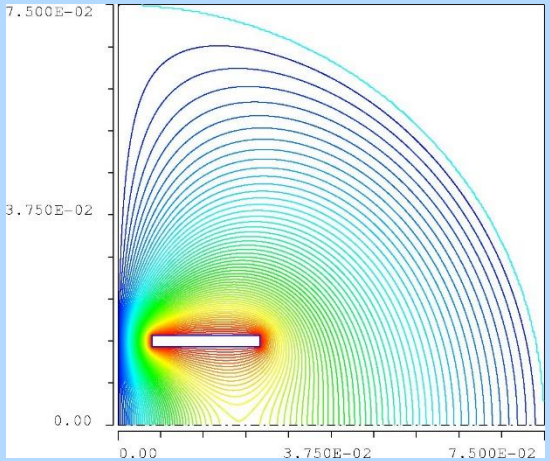


Homogeneity

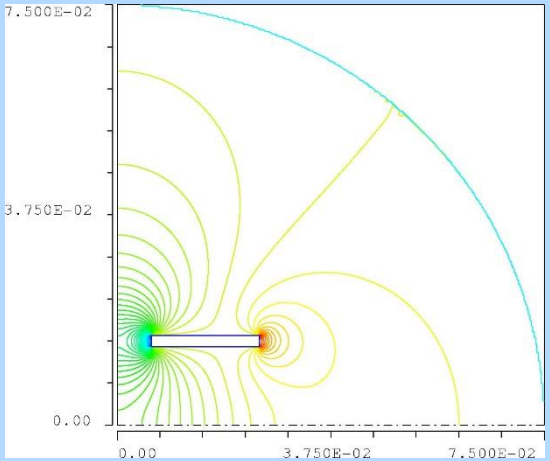
Standard strategy: maximize shunt impedance

= locate and shape electrode to maximize variation of potential





Isolines of potential
(electrodes and wakes..)



Isolines of deflection
strength

Should we care about homogeneity of deflection?

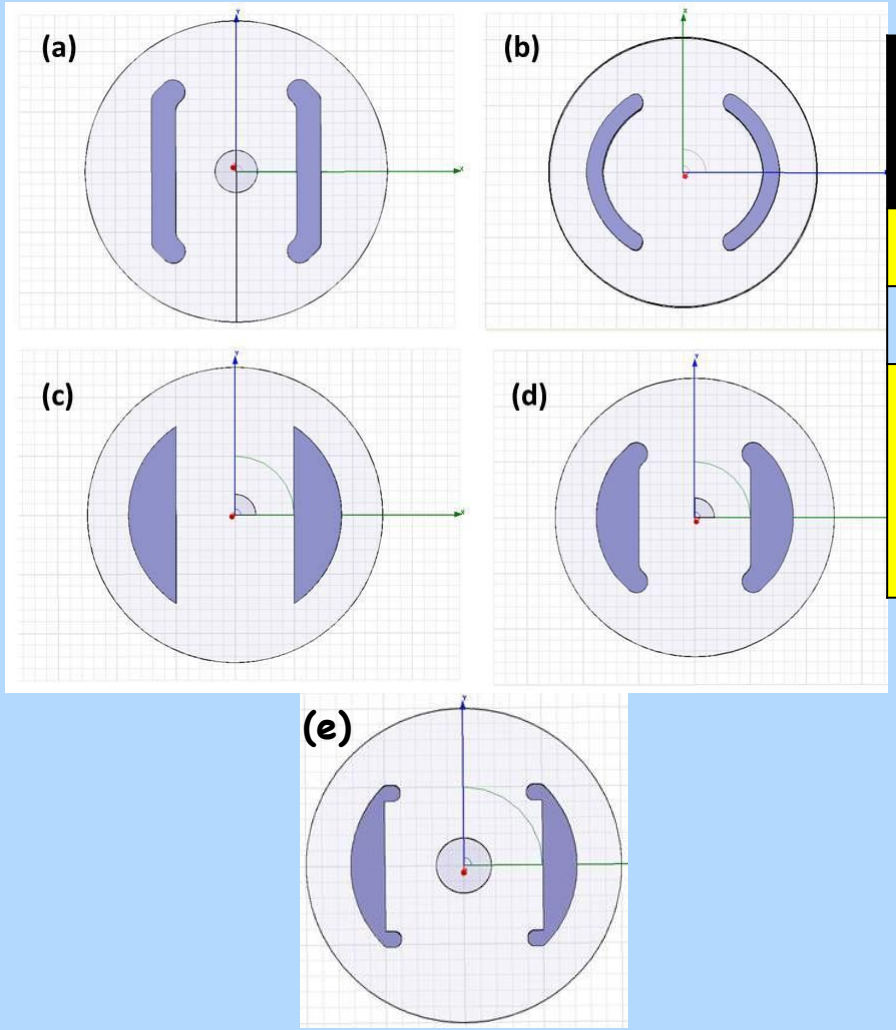
- **Kickers for feedbacks**
  - With amplifier power of several hundred Watts, we will generate deflections of few µrad, inhomogeneities will account for tens of nrad max.
  - Transverse single bunch emittance (even of pm rad) will not be affected, the beam size and so the kick variation over the cross section of the beam is too small.
  - A shift in the kick strength due to e.g. orbit variations leads to a change in the open loop gain of the feedback of a few % (= 0.x dB). Variations due to frequency dependencies in the analog signal chain are probably much higher

No problem at all

- **Fast injection/extraction system e.g. for swap-out injection**
  - Deflections much higher (0.8 mrad/kicker for APS-U)
  - Needs to do a well defined deflection to work

Yes, needs to be examined

Study of cross sections of kicker electrodes (C. Belver-Aguilar/IFIC, LCWS 2012)



Configuration		R (mm)	ϕ_0 (radians)	Z_{odd} (Ω)	Field inhomogeneity (%)
Flat electrode	**(a)**	25	2.0	36.8	± 0.01
Curved electrode	(b)	20	2.6	37.0	± 1.3
Halfmoon electrode	(c)	30	1.5	35.2	± 0.03
	(d)	30	2.2	34.2	± 0.01
	(e)	20	1.8	40.9	± 0.01

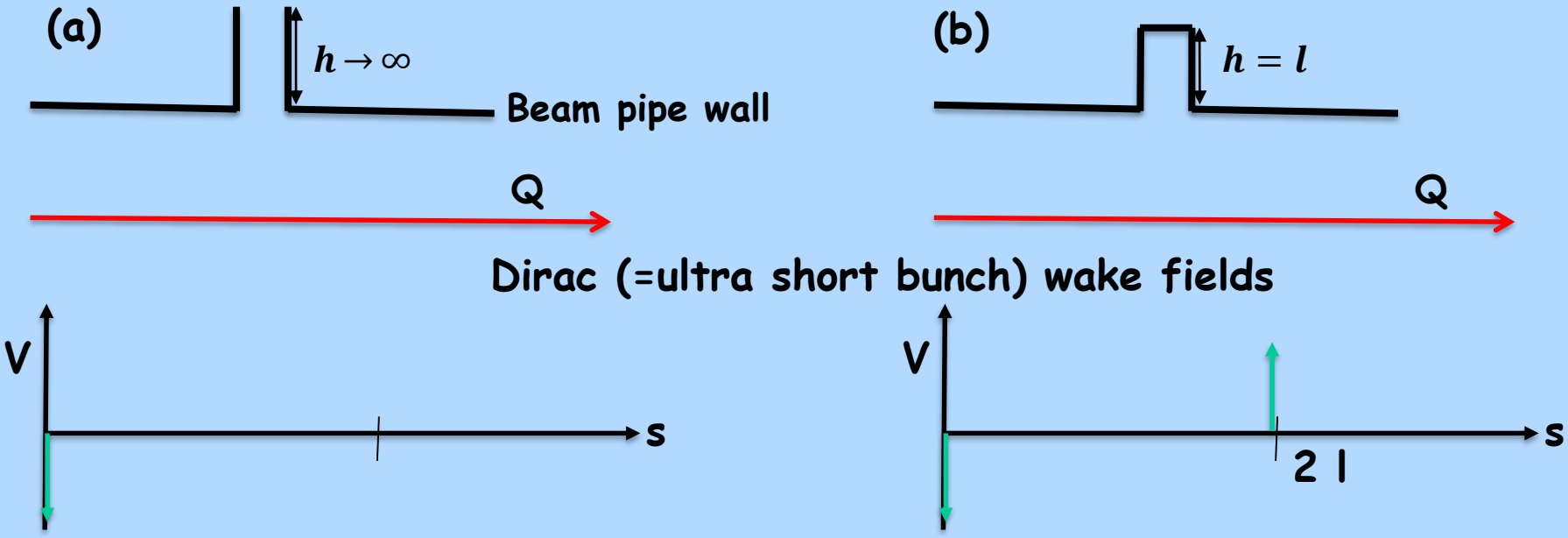
Field inhomogeneity in vicinity of 1 mm around the beam axis

Short term wakes

What are the sources?

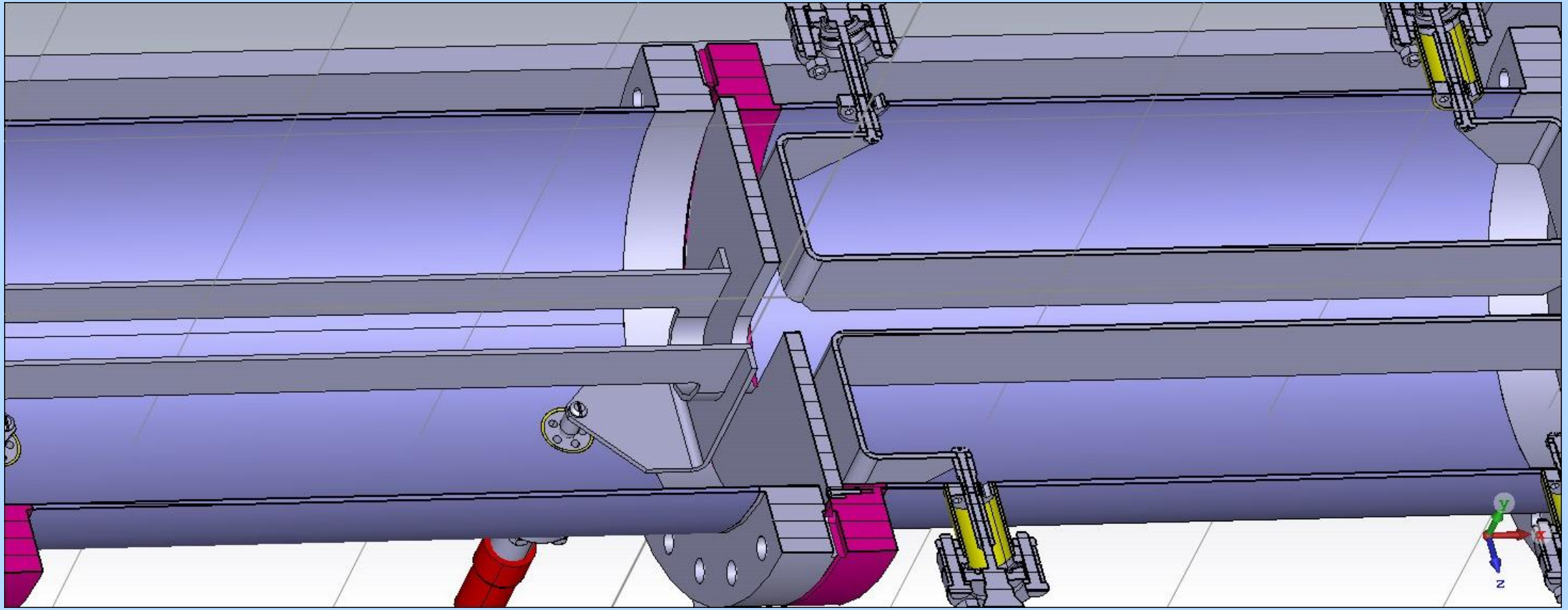
- Possibly tapers from the beam pipe cross section to that of the kicker (So - do you really need these specially shaped electrodes?)
- Longitudinal gaps at beginning and end of the electrodes (You remember tools #1 and #2 a few slides before, do you?).By the way, we also need to connect to the feedthroughs …

Some basic things about wakes in small gaps

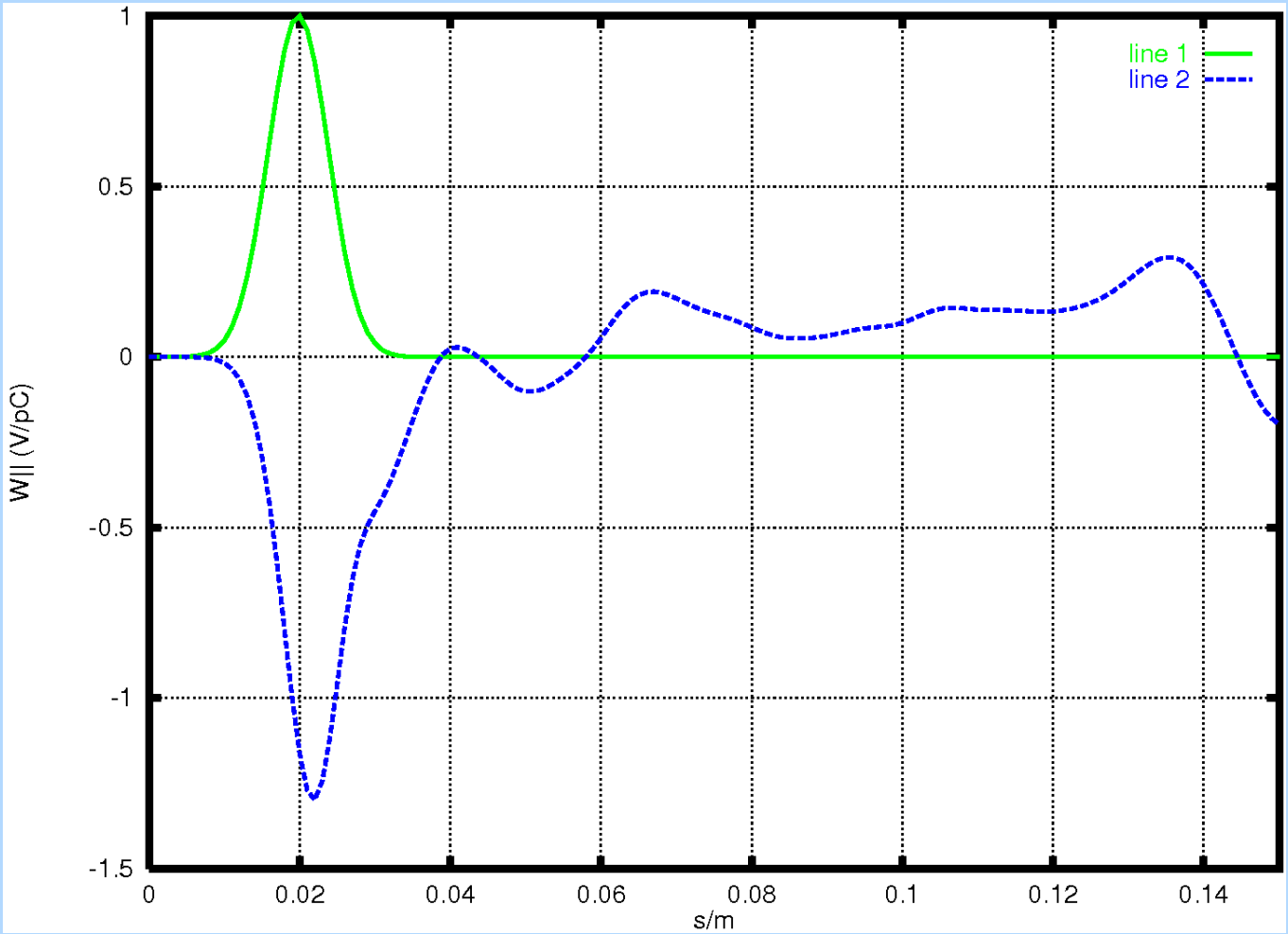


- In case (a), the bunch will (mainly) irradiate into the gap, the resulting impedance will be resistive with an increase in the loss factor and a none to negligible increase in |Z/n|
- Case (b) will be also resistive for very short bunches (length << 2 l), since the bunch has already passed, when the reflection comes back.
- **In Case (b), with a bunch length similar to the gap height, energy radiated by the head is fed into the tail, the impedance is reactive affecting |Z/n| (microwave instability threshold …)**

Sometimes a deeper gap is better …


y
z

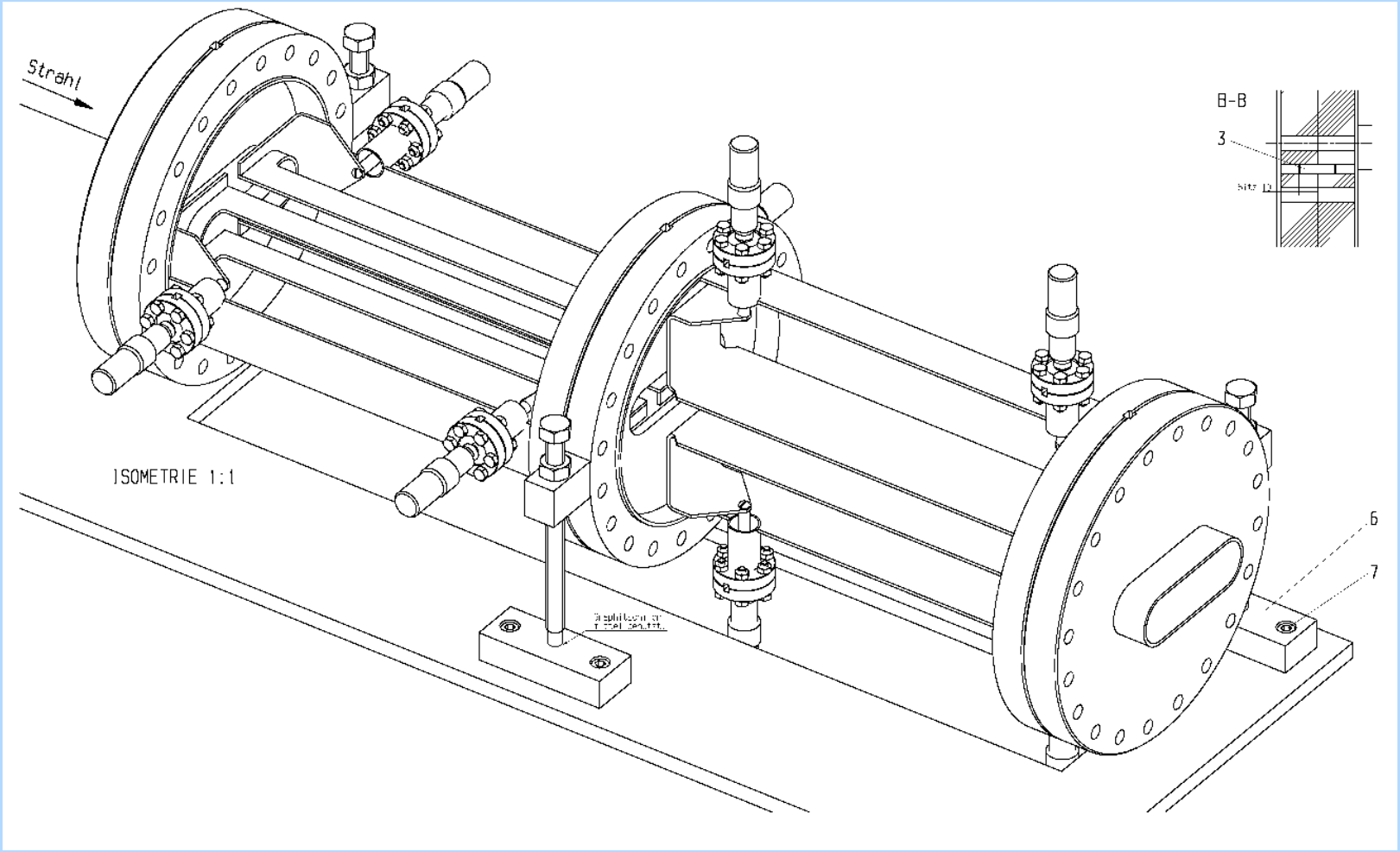
Single bunch wake for horizontal kicker of SLS



(Generally) Useful: Subadditive combination of wakes by close positioning

Passing a gap (of a kicker, BPM, …), the self field of the bunch is getting diffracted and needs some time (=distance along trajectory) to recover.

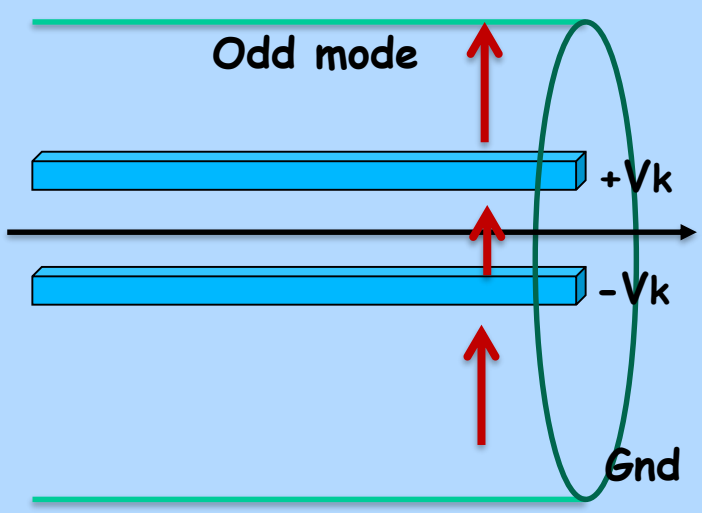
A second perturbation/gap encountered within this recovery time will have a reduced wake field/loss factor/Z over n

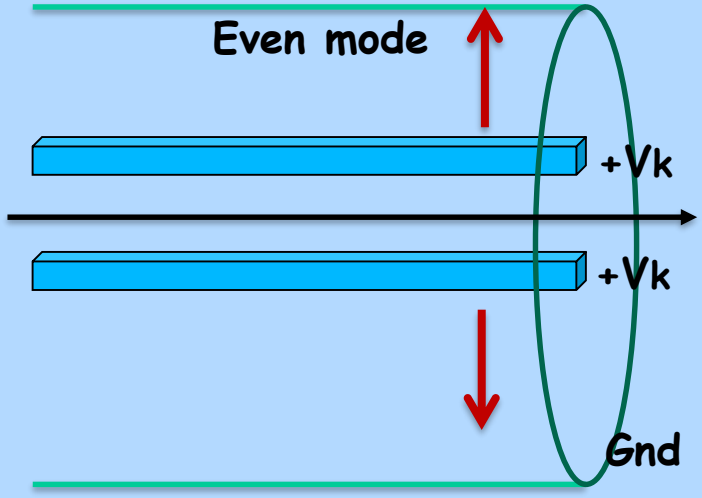


Higher order modes

How about longitudinal modes?

The kicker is a three conductor system – 2 blades and the surrounding tank: we have two TEM modes:

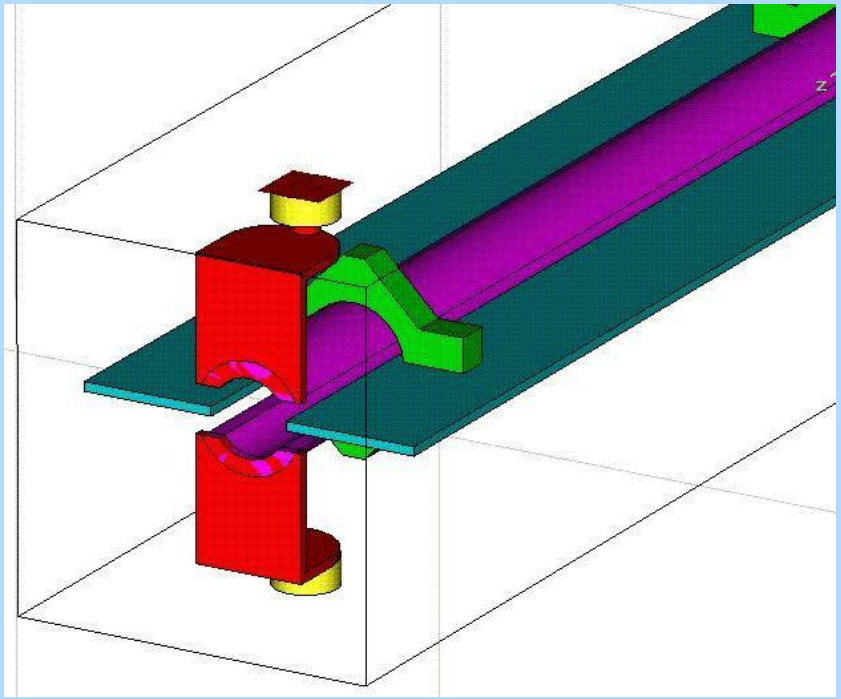




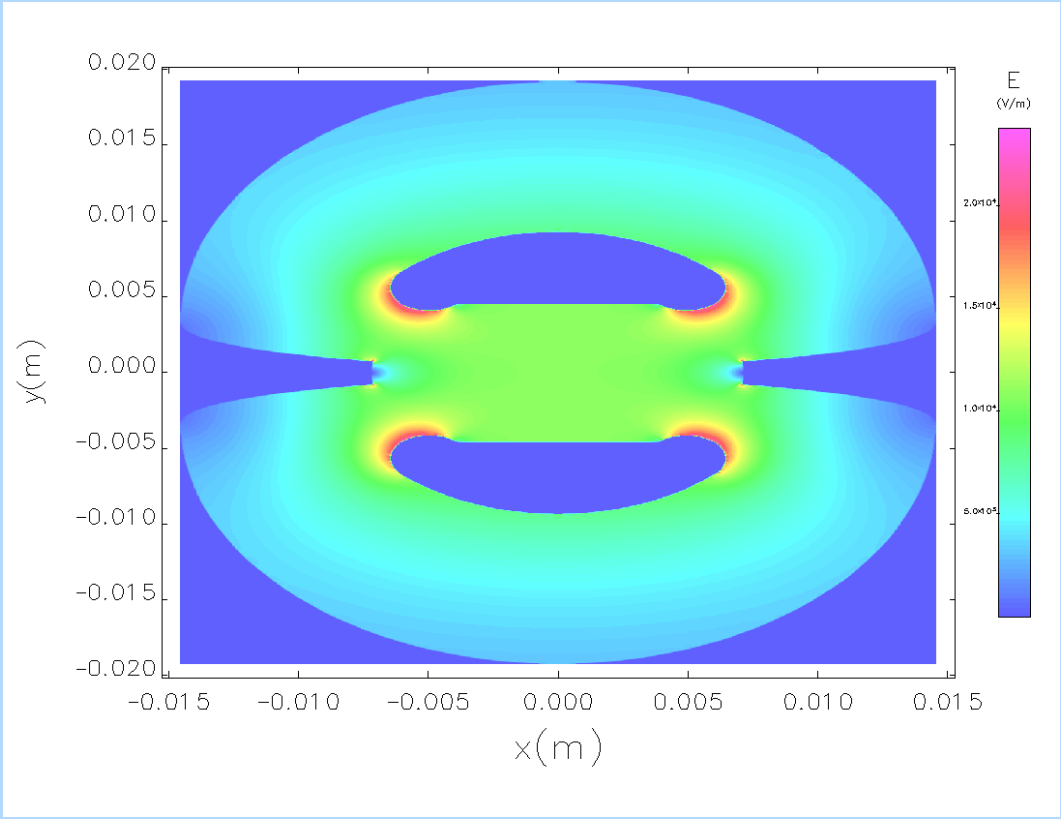
The odd mode, used for deflection, is well matched by definition.

But the even mode (responsible for the longitudinal coupling at lower frequencies) typically has an elevated impedance (typically 60-70 Ω) and will not be matched.

If you worry about even mode impedance, best strategy to decouple blades by introducing shielded side vanes

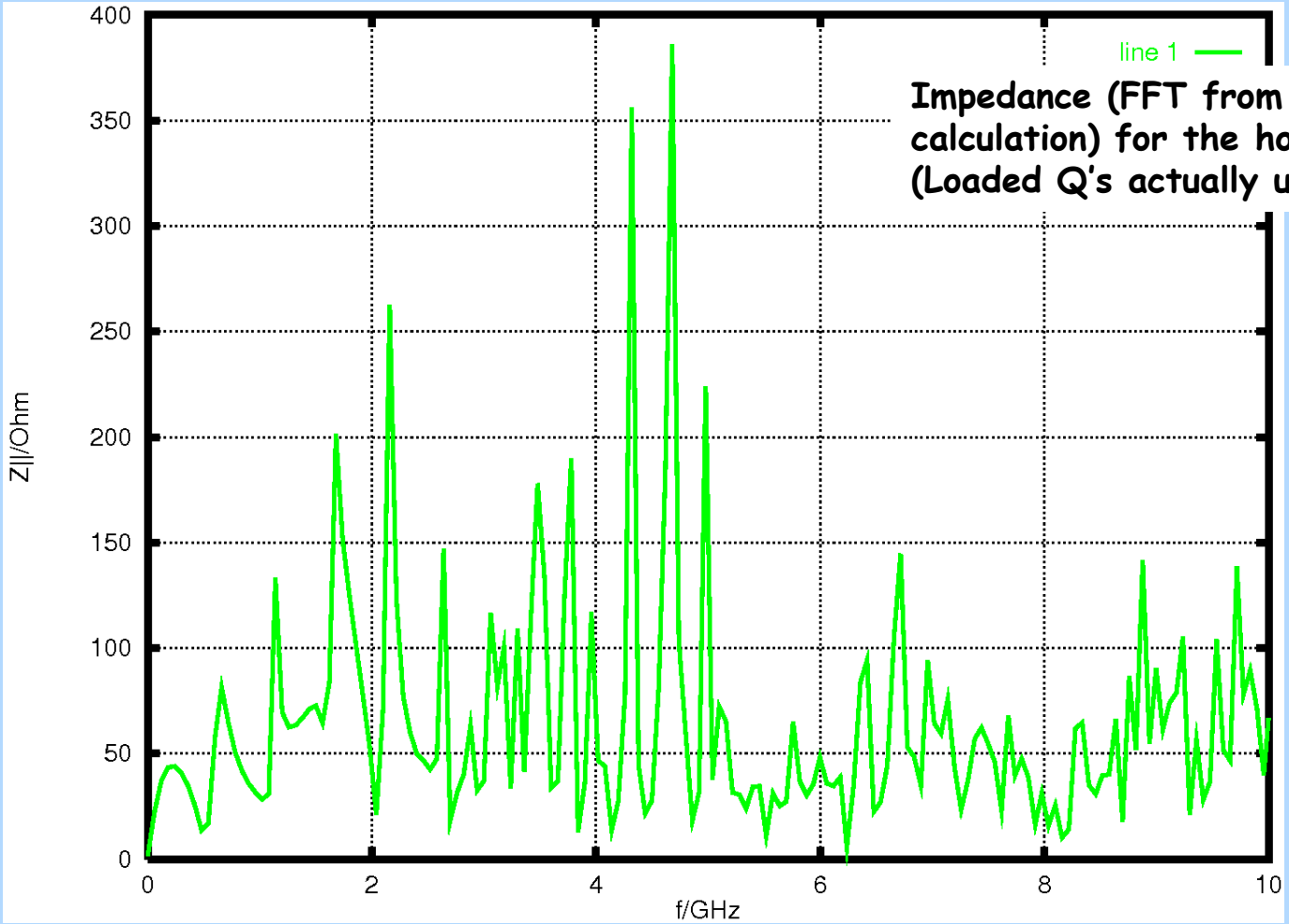


Stripline kicker for intra bunch train feedback at FLASH/EXFEL
(Dehler et al, BIW '08)



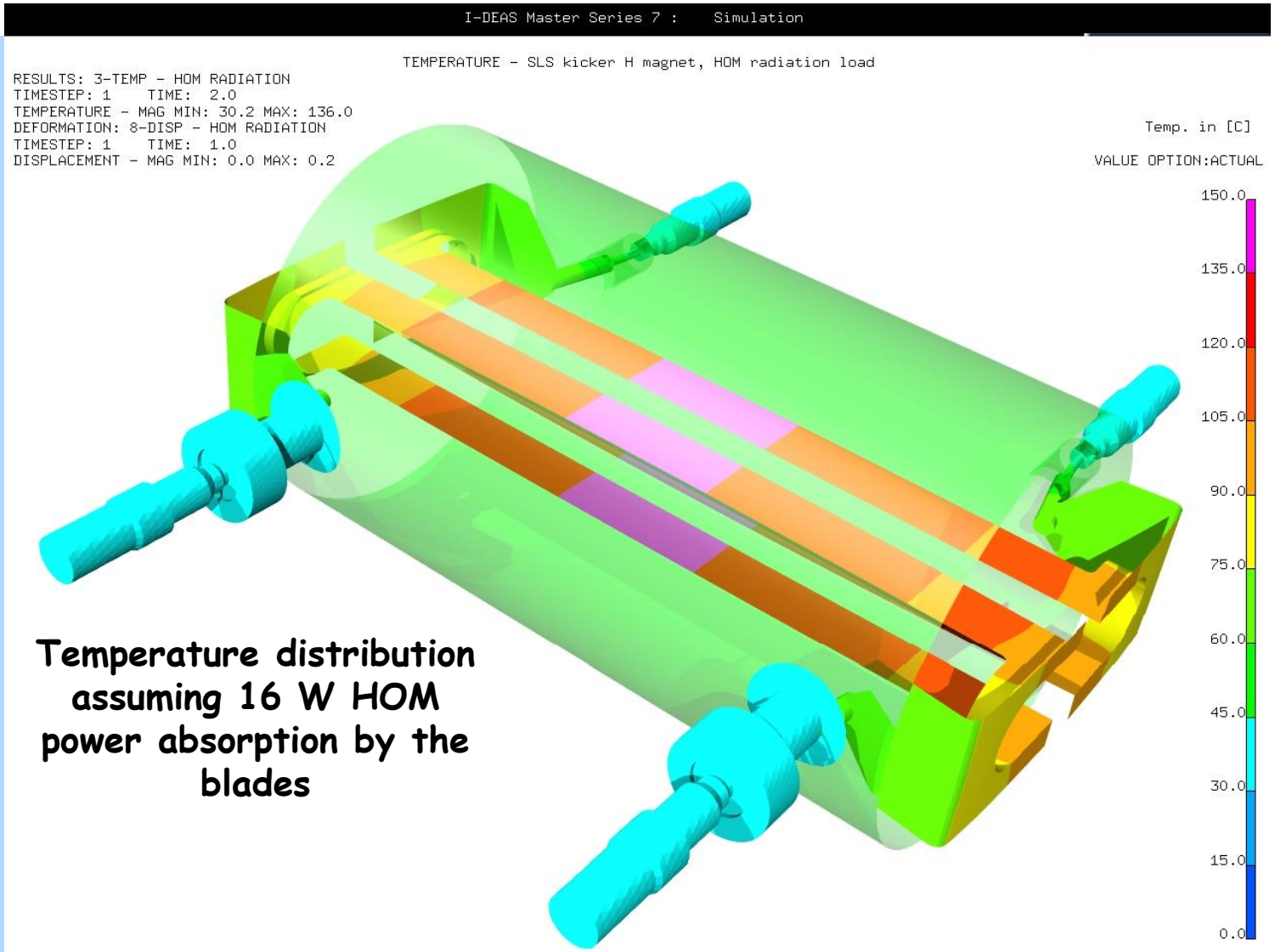
Kicker for swap-out injection at APS-U
(Yao et al, IPAC'15)

With lots of power couplers, all HOMs should by damped quite strongly, right?



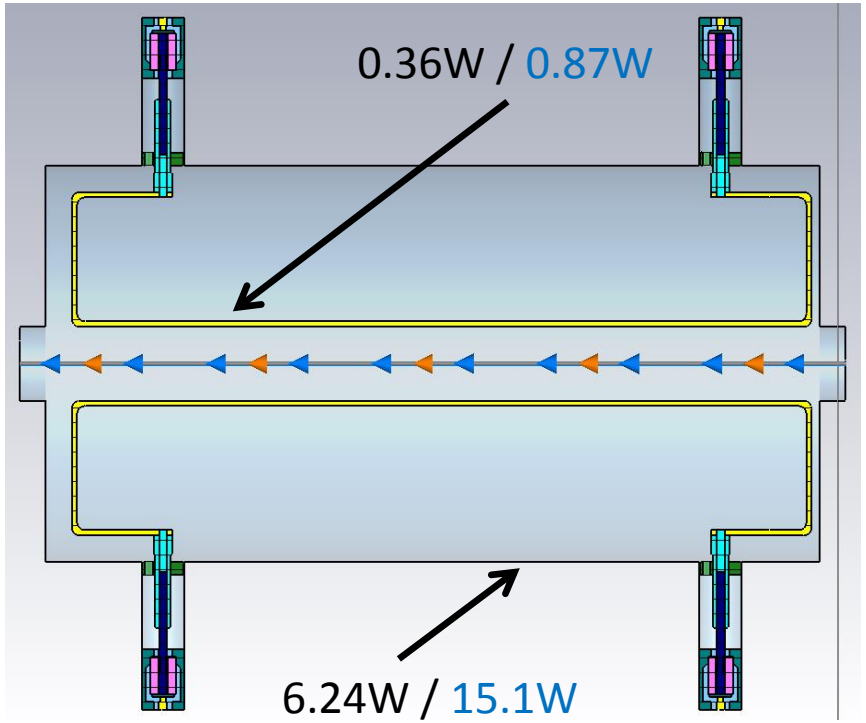
Impedance (FFT from a long range wake calculation) for the horizontal kicker/SLS (Loaded Q's actually underestimated …)

The electrodes (and possibly the ground vanes) shield the beam quite well, so CBI excitation via HOMs is not a big topic, but the electrodes are relatively well thermally isolated and need to absorb part of the HOM power

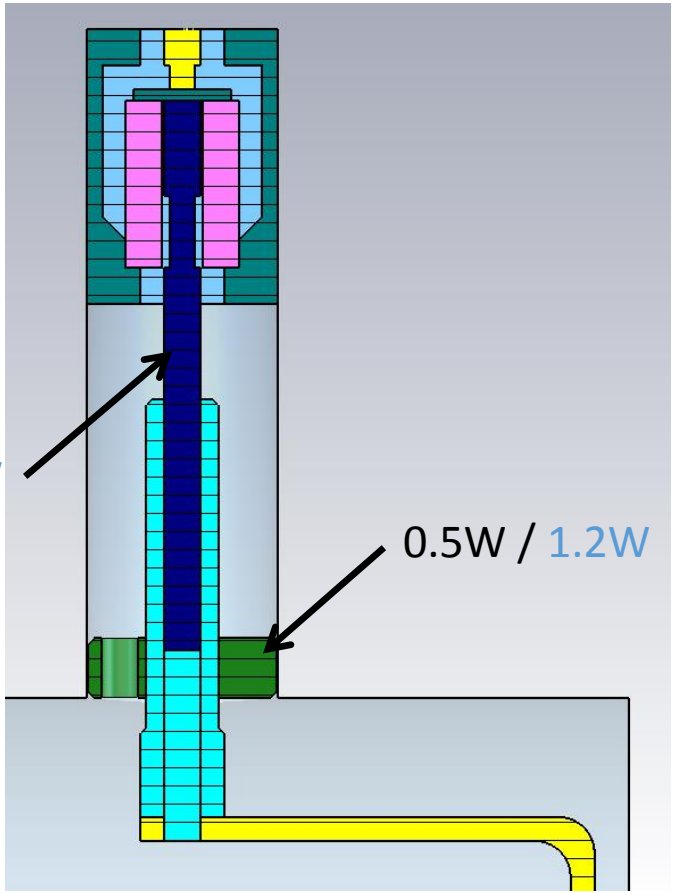


Temperature distribution assuming 16 W HOM power absorption by the blades

Thermal troubles with virtually the same kicker at Diamond (slide court. G Rehm, A. Morgan)



Stripline power distribution



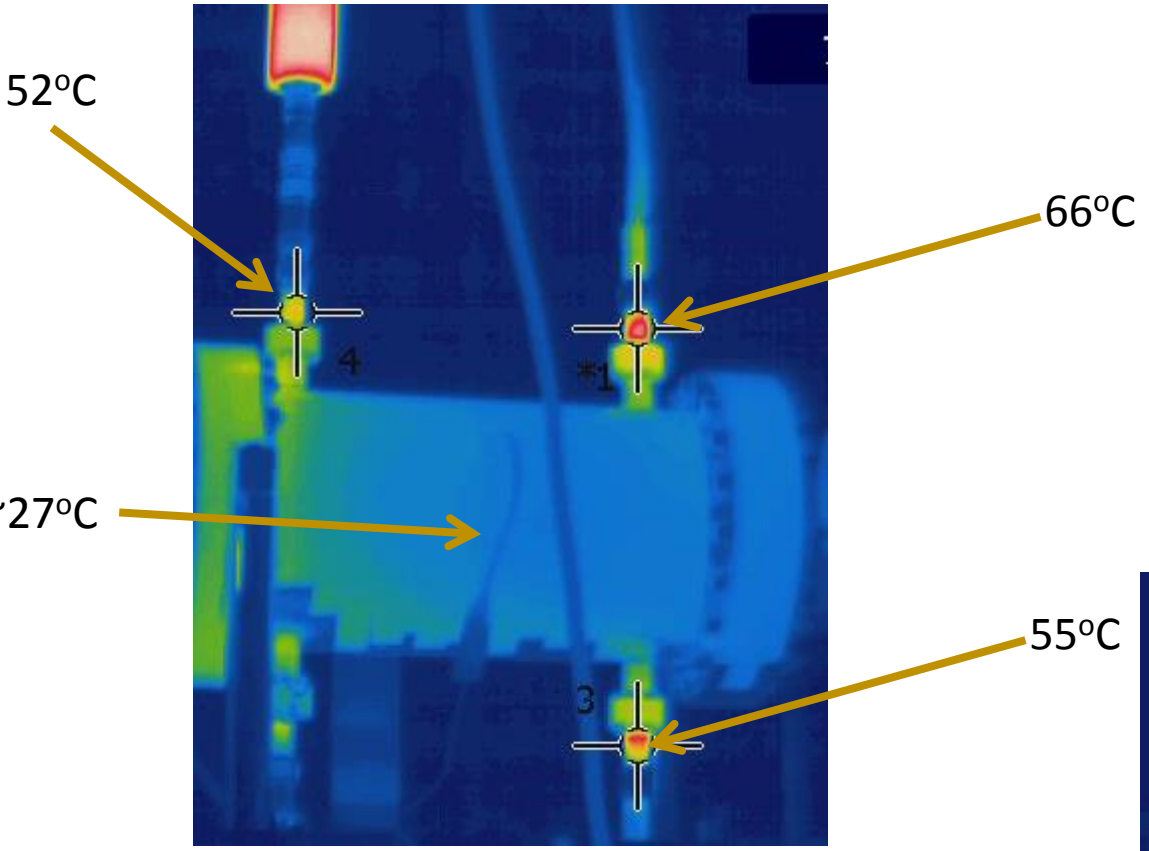
Power lost into structure

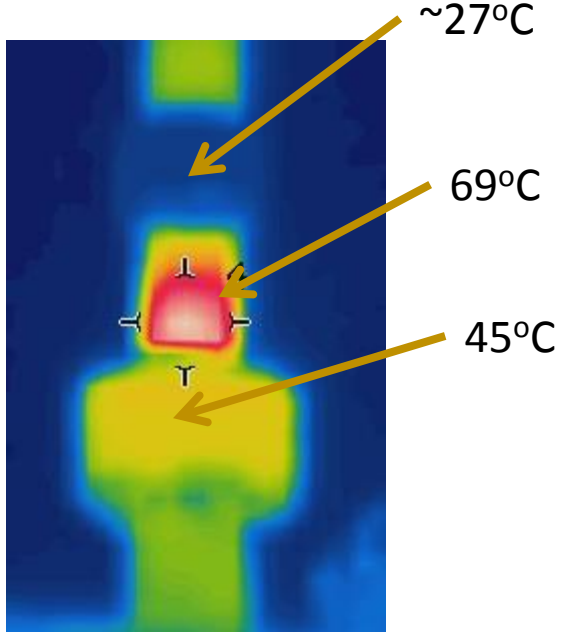
24W @ 300mA 686 bunches

58W @ 500mA 686 bunches

Plus 2.9W / 7W delocalised loss

Measurements with 300mA stored beam



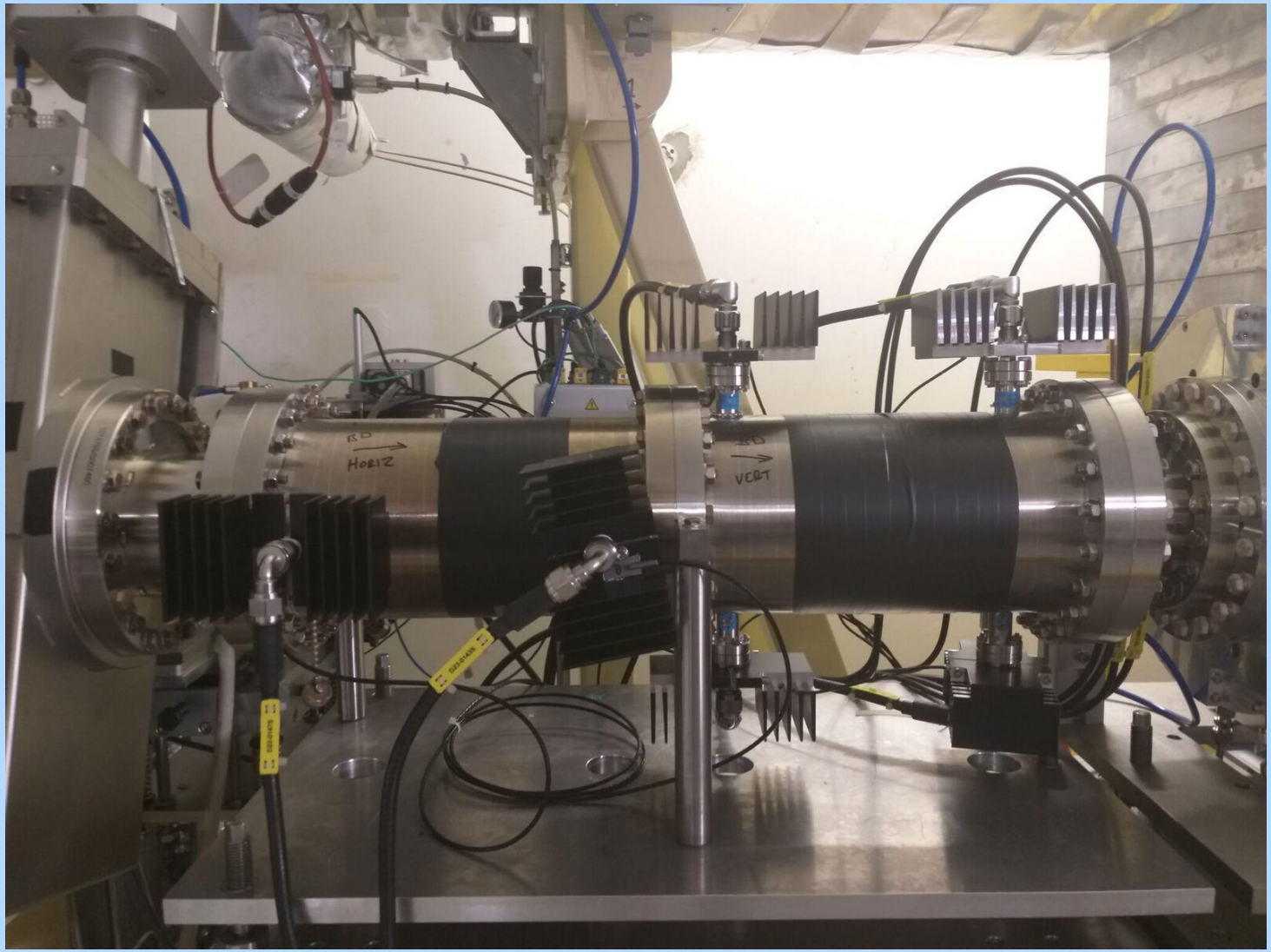


Differences to SLS:

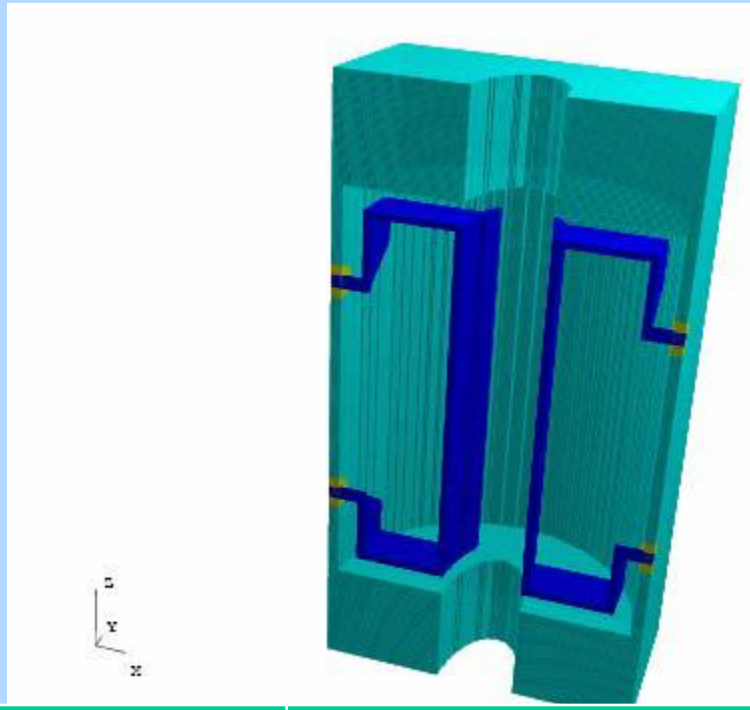
- Different bunch spectrum (shorter bunches)
- Vacuum feedthroughs with COVAR conductors (bad conduction)
- ?

Situation currently stable, since no 600 mA operation planned

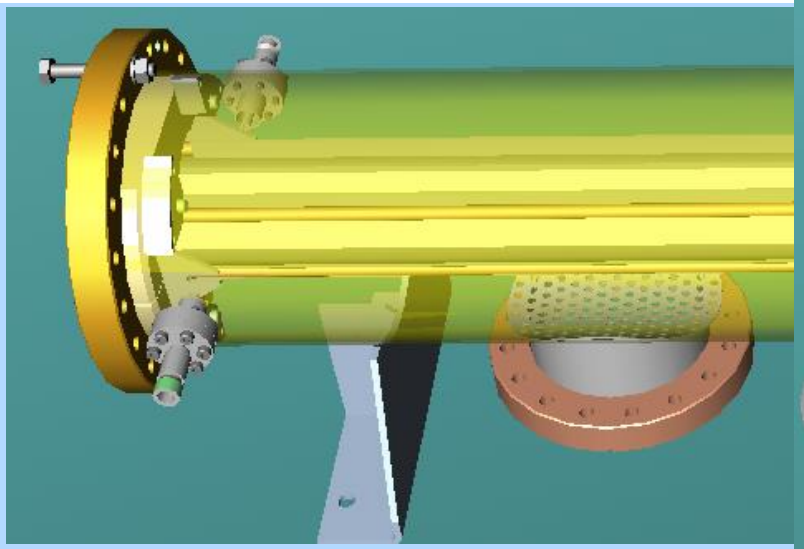
DIAMOND: Just to be on the safe side

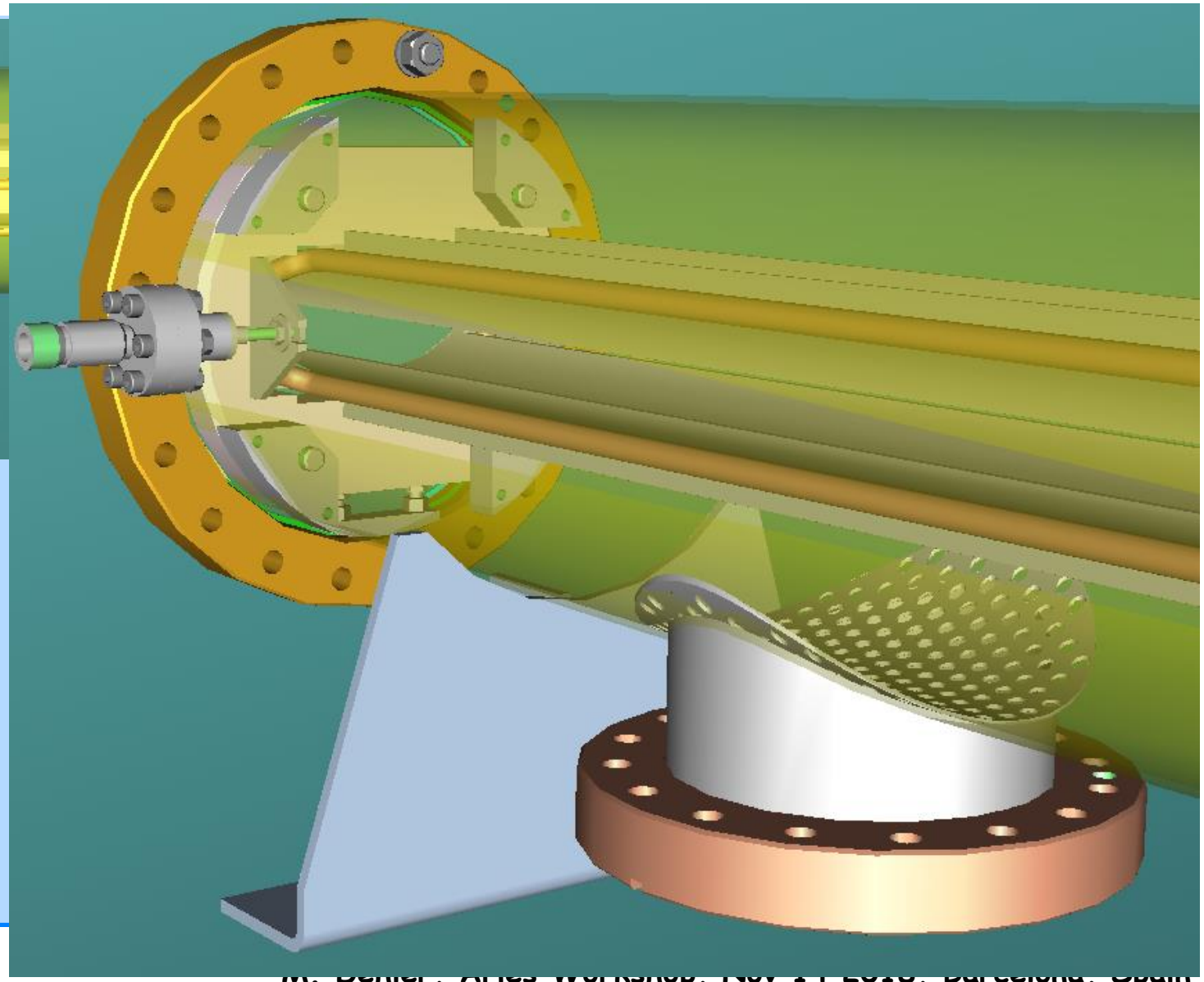


Petra III: Fully water cooled
(pictures court. R. Wanzenberg/F. Obier)



Length	1 m
Bandwidth	130 MHz
# of kicker	2/plane
Rshunt	30 kΩ
Deflection (P=250W)	1 μraq





Active cooling of the blades via in-vacuum cooling system

Probably even OK with thermal heating by synchrotron radiation!

To finish

- There is n … always machine specific sc…
- Efficiency … st task
- Be careful … ecially long range
- Even more …

Thanks for your attention!!