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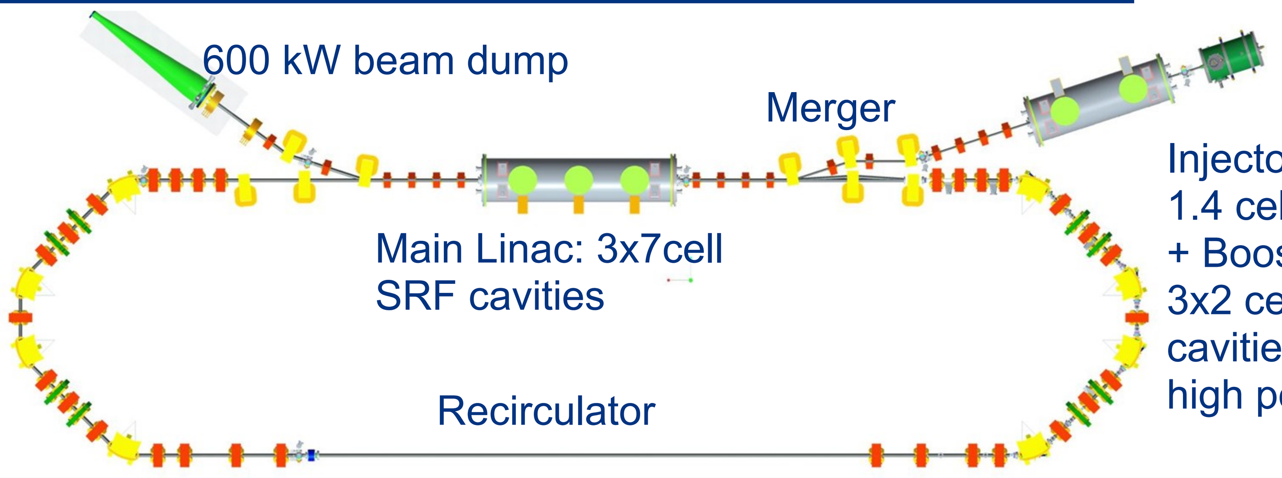
HZB Helmholtz Zentrum Berlin
bERLinPro

Final Design for the bERLinPro Main Linac Cavity

The bERLinPro Energy Recovery Linac

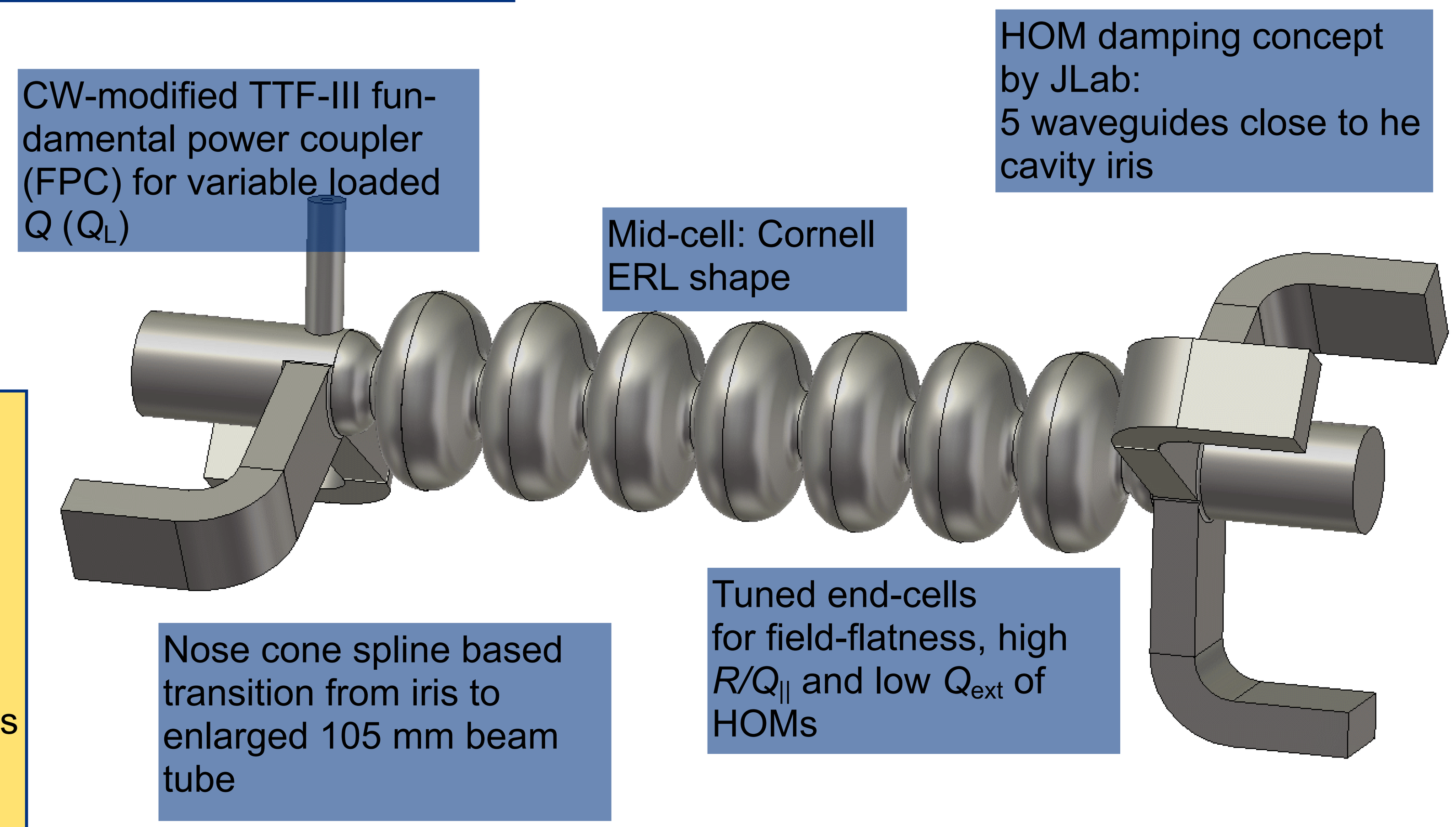


Injector:
1.4 cell photo-injector cavity
+ Booster:
3x2 cell Cornell style
cavities using modified KEK
high power couplers

50 MeV ERL accelerating a 100 mA beam at a normalized emittance of better than 1 mm mrad filling every RF bucket at 1.3 GHz [1].
The main Linac cavities have to accelerate and on second pass decelerate the beam from 6.5 MeV injection energy to 50 MeV and vice versa.

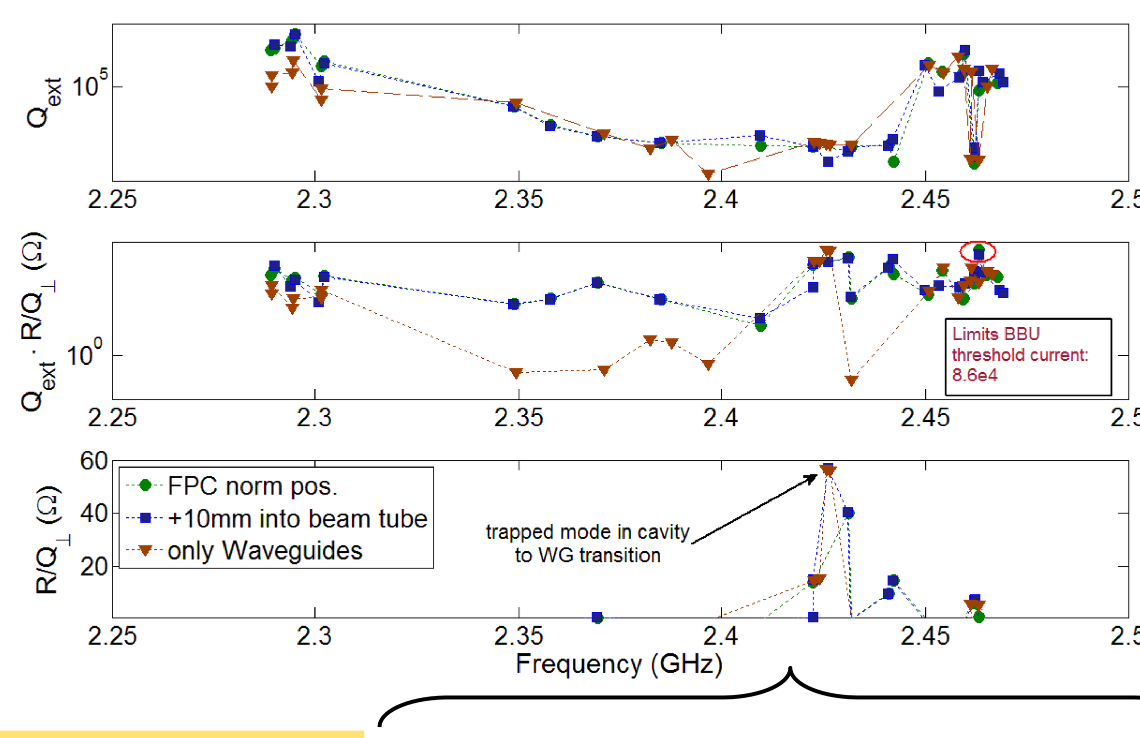
Thus, the cavities operate at high CW accelerating gradient of about 20 MV/m and interact with two 180 deg. in phase shifted high current beams.
The cavity design therefore requires excellent RF properties as high R/Q and low peak field ratios for the fundamental, but also good propagation of higher order modes (HOM) and subsequent damping.
Any unwanted coupling between the beam and dipole-like field patterns of any HOM can contribute to the beam-break-up (BBU,[2]) instability.

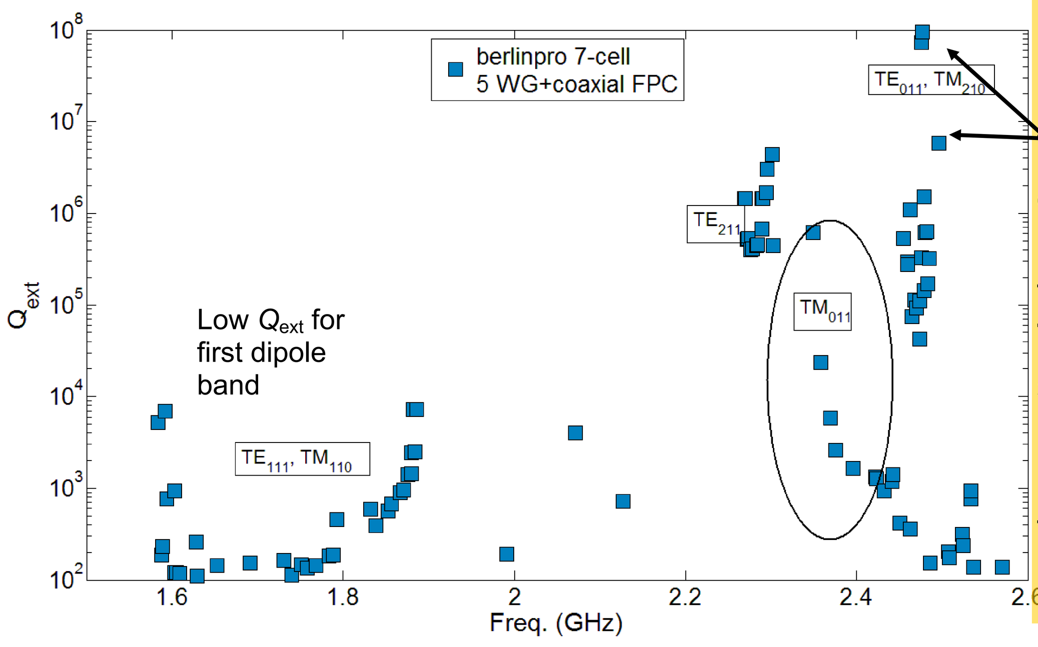
The Linac Cavity design



RF and HOM damping performance

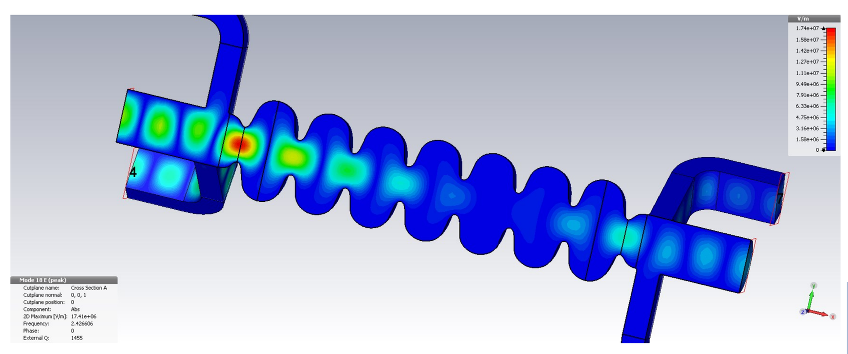
Number of cells	7
$R/Q_{\|\|}$	788 Ω
$f_{TM_{010}-\pi}$	1.3 GHz
E_{peak}/E_{acc}	2.08
B_{peak}/E_{acc}	4.4 mT/MVm^{-1}
Q_{ext} TM_{110} dipole	$\leq 8 \cdot 10^3$
Beam tube TE_{01} cutoff	1.596 GHz
Waveguide TE_{10} cutoff	1.576 GHz
Q_L for TM_{010}-π	$1 \cdot 10^7 - 1 \cdot 10^8$
$P_{forward}$ at $Q_L = 5 \cdot 10^7 (\Delta f = 0)$	1.4 kW





For localized high Q_{ext} TM_{mnp} m≥2 modes an on-axis dipole-like component were observed, thus R/Q_{trans}≥0 [6,7]. This triggered further studies, whether the break of the symmetry by the coaxial FPC lead to that effect.

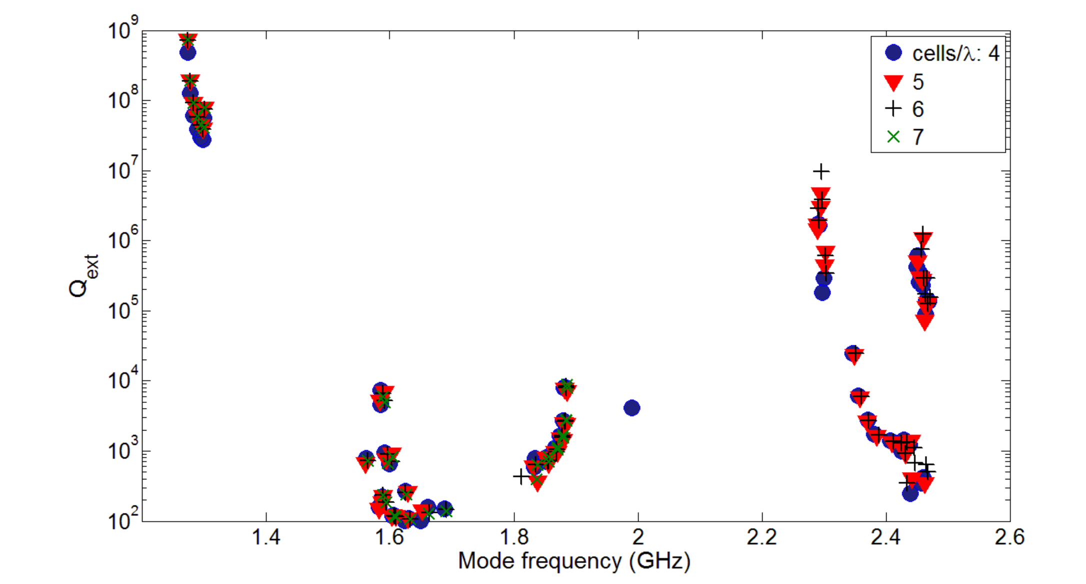
R/Q_{trans}, Q_{ext} and BBU current threshhold parameter R/Q_{trans}xQ_{ext} for an all WG system compared to the 5WG+coax. system for two different coupling strength of the FPC.
The limit is set by a TM_{210} mode for the sysrems with coaxial FPC.



Localized mode between iris and waveguide dampers. This mode is the second strongest harmful mode regarding BBU.

HOM damping of the RF design after a particle swarm based optimizatin of the end-cells while keeping peak field ratios low, field-flatness above 98% and $R/Q_{||}$≥110 Ω/cell [9,10].

Convergence studies:
Optimization and calculations up to high frequencies of up to 10 GHz using 2D codes is prohibited by the non-symmetric design. To reliably predict a BBU limit, Q_{ext} should be at least determined with an accuracy below an order of magnitude. Thus, convergency studies were conducted for the Q_{ext} of HOMs, especially of the limiting quadrupole passband. Using CST's 2014 new mesh type, a convergence for the rather low Q TM mono– and dipole modes was demonstrated.
However, high *Q* quadrupole modes still show a variation with mesh density. At higher mesh density computational time was increasing and the solution itself would not converge.

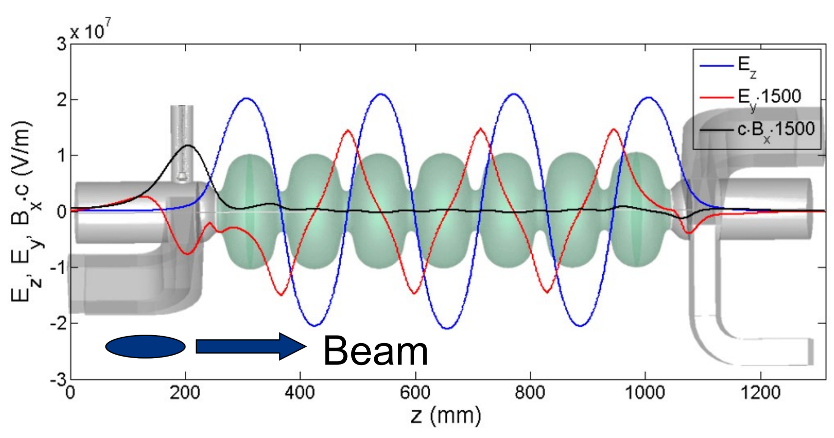


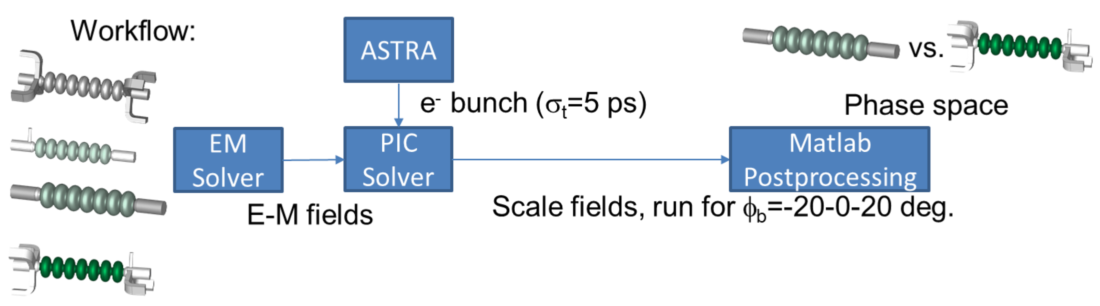
Conclusion:
Due to the localized mode in the endgroup and a non-vanishing dipole component of high Q_{ext} quadrupole modes, the endgroups have to be reworked accompanied by a thorough multipole analysis of the HOMs.

Coupler kick and emittance dilution calculations

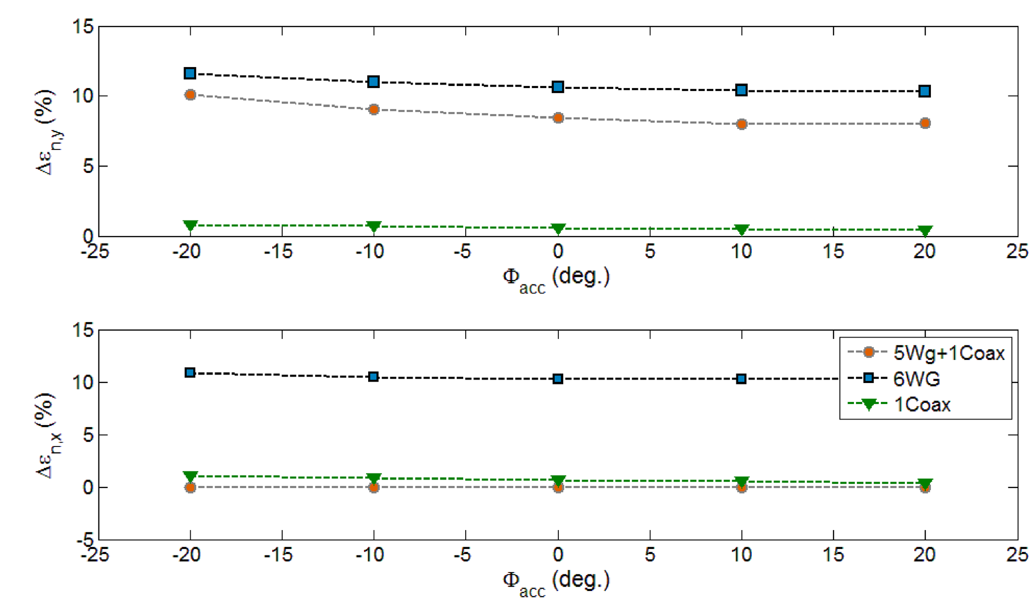
$\epsilon_{n,y,x}$	1 mm mrad
σ_t	5 ps rms
$\sigma_{y,x}$	≈0.7 mm rms
$I_{avg,beam}$	100 mA
$E_{kin,ini}$	6.5 MeV
V_{acc}	15 MV
E_{acc}	18.56 MV/m
Φ_{acc}	-20 to 20 deg

Table showing the electron bunch and cavity operating parameters for the coupler kick study.

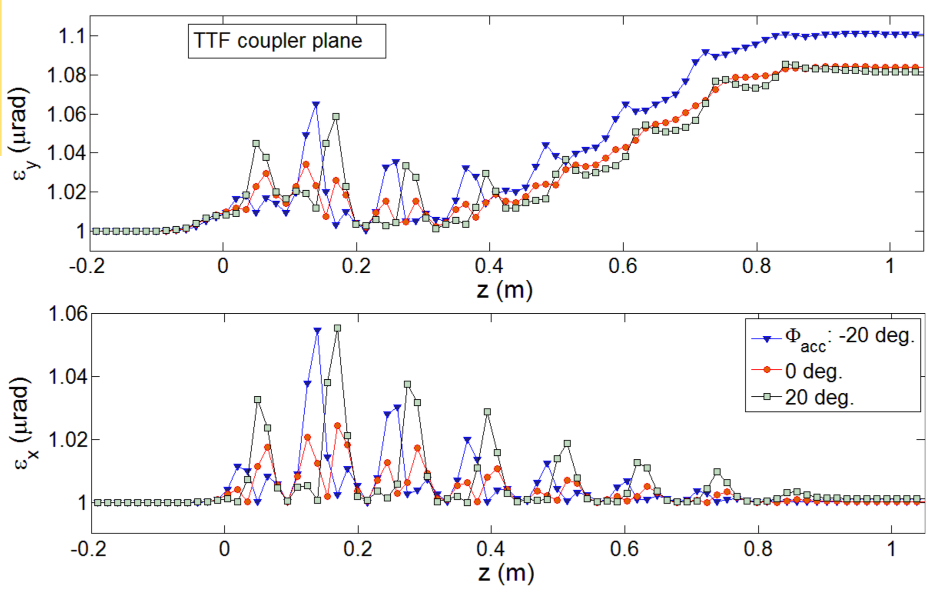


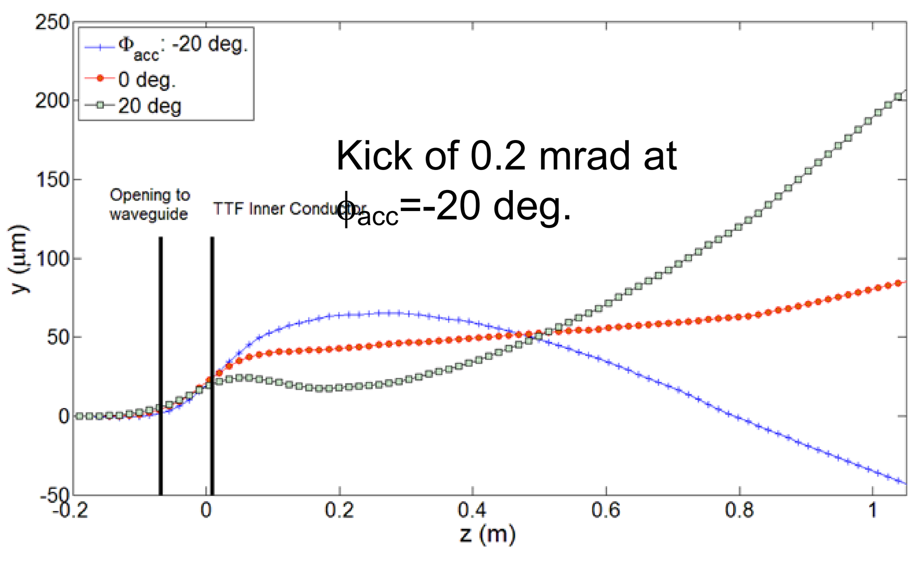


Workflow for coupler kick calculations of the fundamental mode for standing wave regime comparing the current design and alternative coupling schemes with a bare cavity without coupler using CST MWS and PS PIC solver [11].



Evolution of the normalized transverse emittance within the cavity





Conclusions:
Besides the HOM coupler kick effect, a strong emittance increase and coupler kick effect was seen in simulation by the fundamental mode. It seems to be a combination of the coaxial FPC and the WG couplers. Simulations of the full three cavity module are underway, so that an ordering for minimum emittance increase and orbit kick can be achieved.
However, a coupler kick compensating stub and a smoothening of the beamtube to waveguide transitions might have to be inserted.

In total a more detailed analysis and reworking of the endgroups are needed to achieve a production ready RF design.

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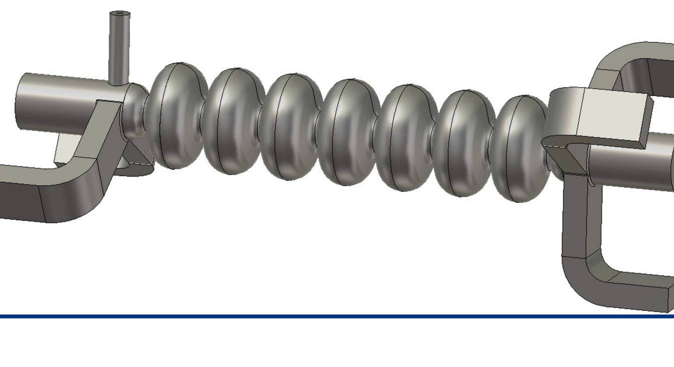

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