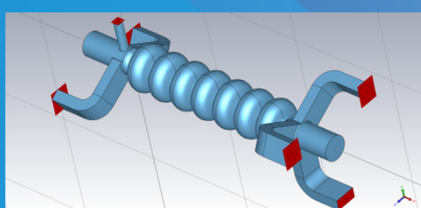
Status of the HOM Calculations for the B*ERL*inPro main Linac Cavity*

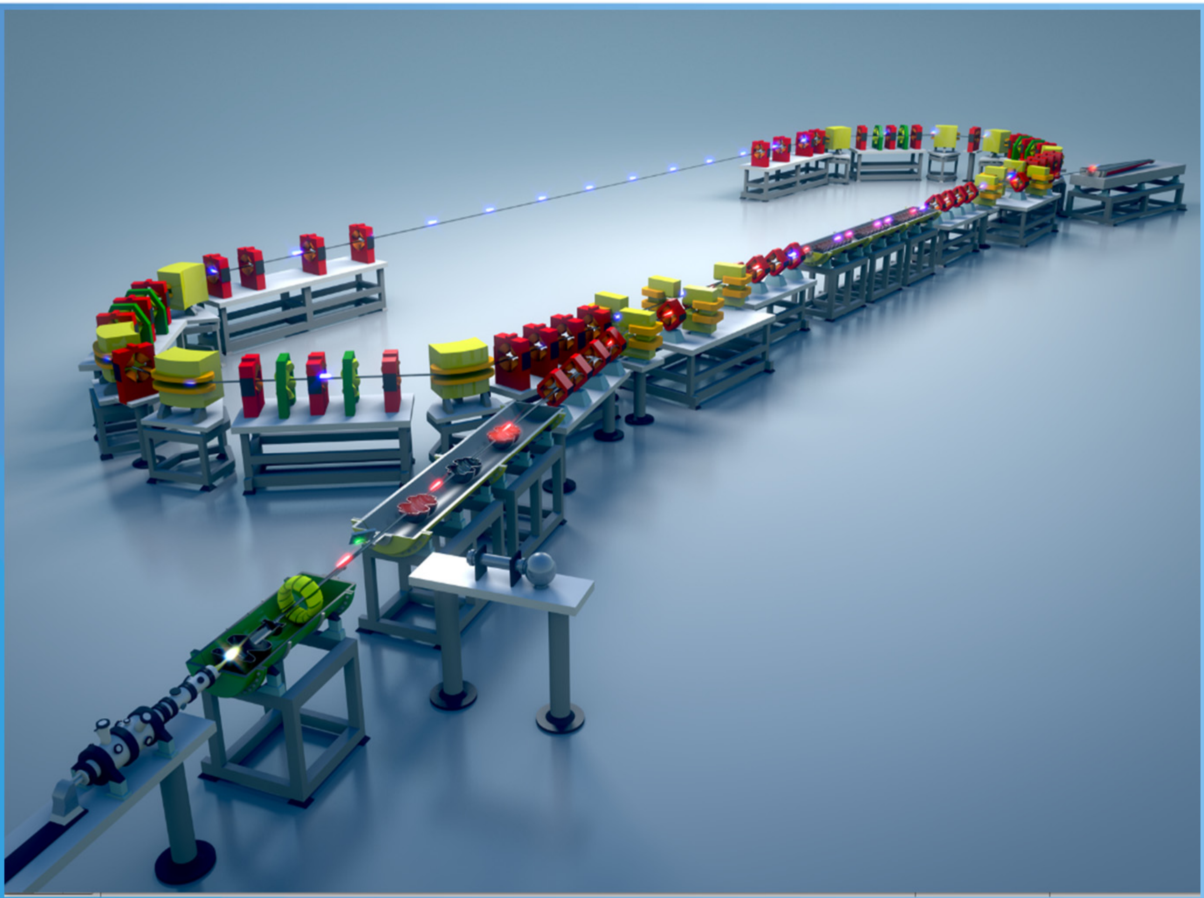
*Work supported by Federal Ministry for Research and Education BMBF under contract 05K10HRC and 05K10PEA



Axel Neumann for the **DoHRo** Collaboration (TU Dortmund, U Rostock, HZB)

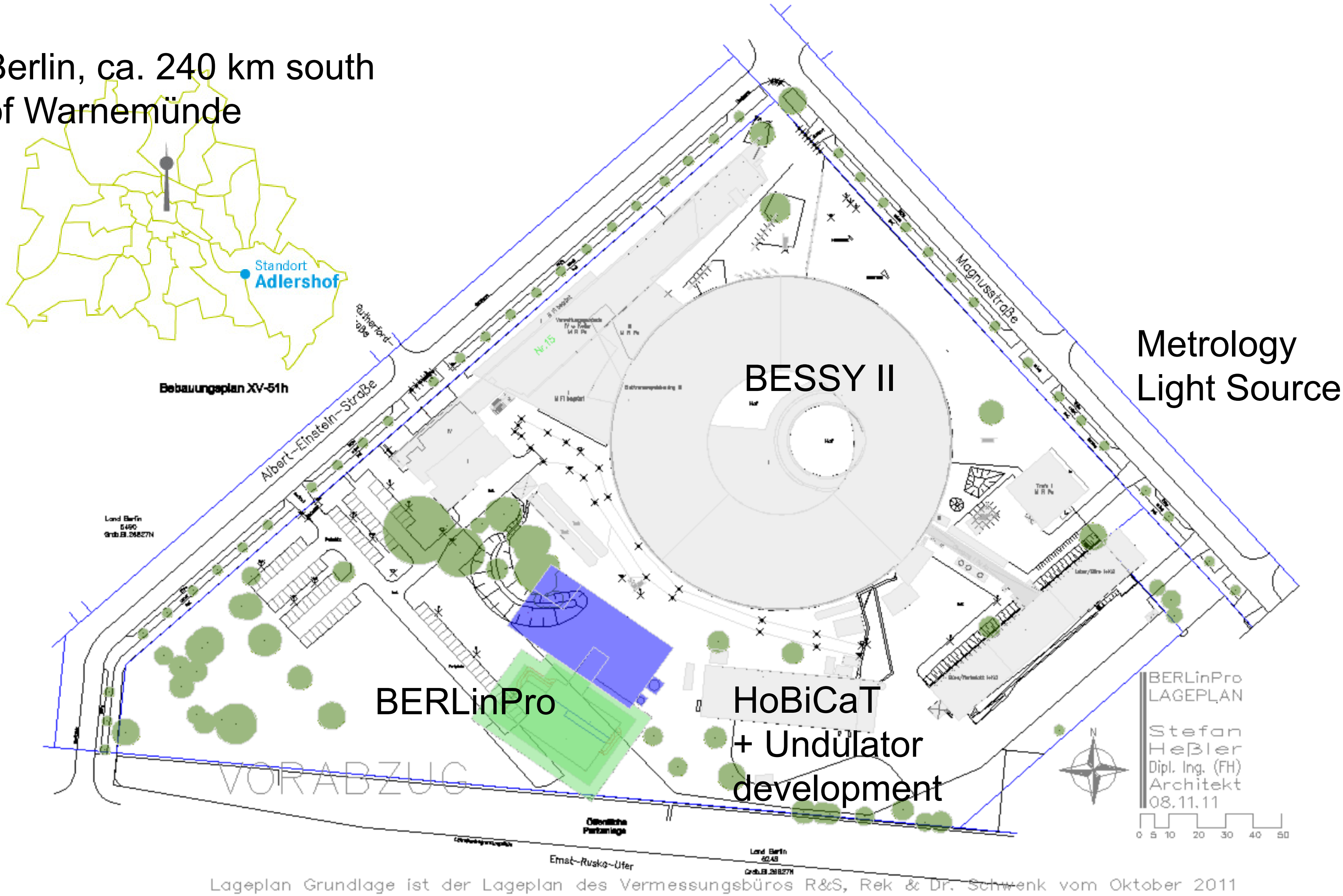
ICAP12, 24.08.12

Warnemünde, Germany



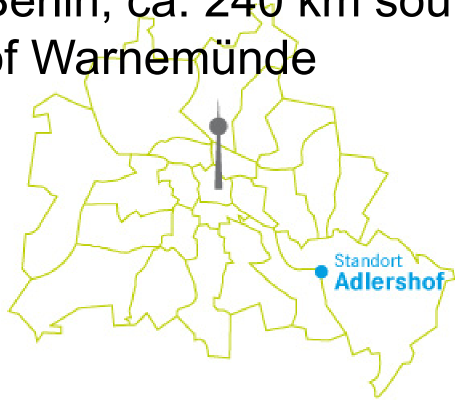
Site for B*ERL*inPro

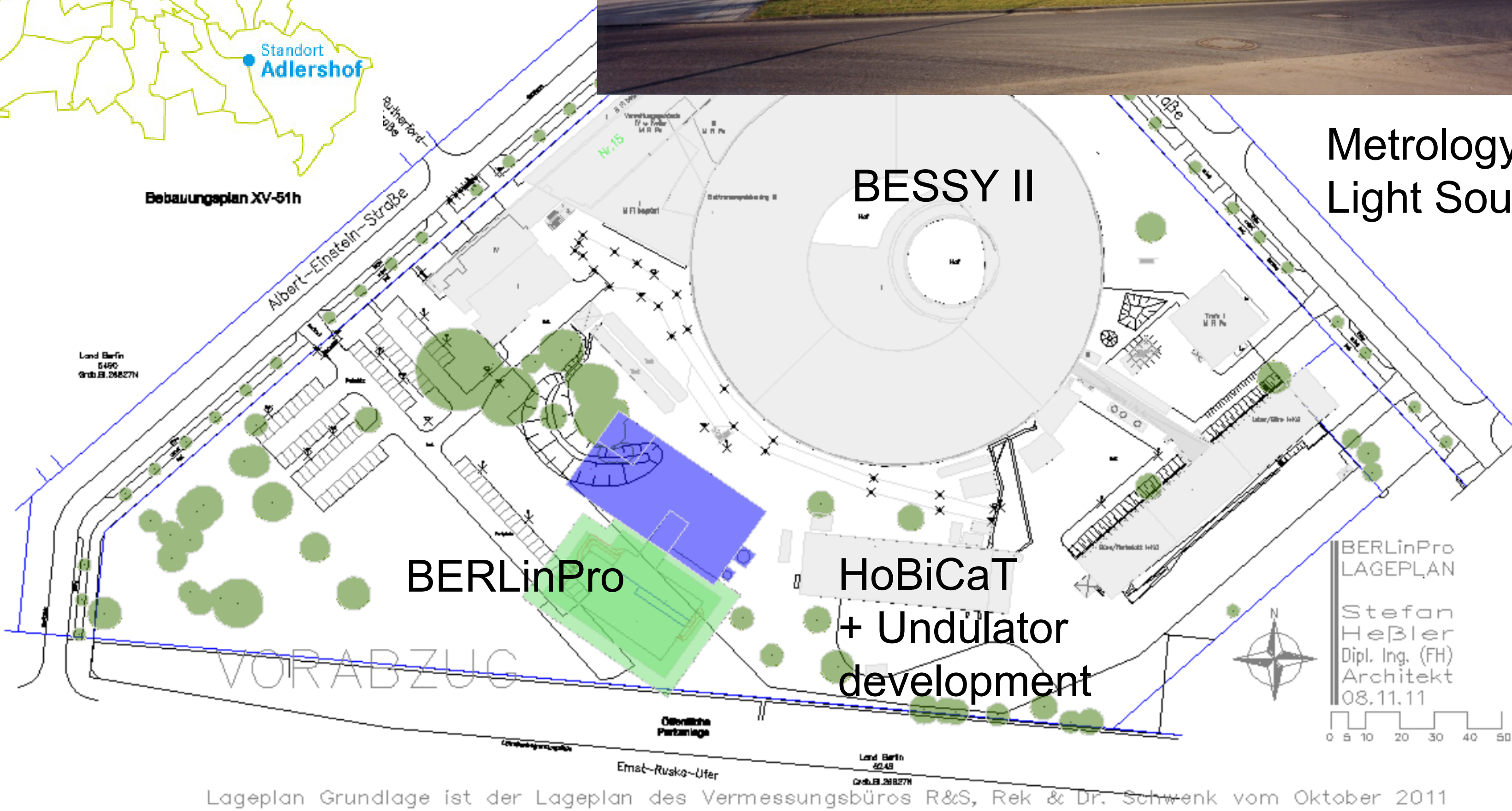
Berlin, ca. 240 km south of Warnemünde



Site for BERLinPro

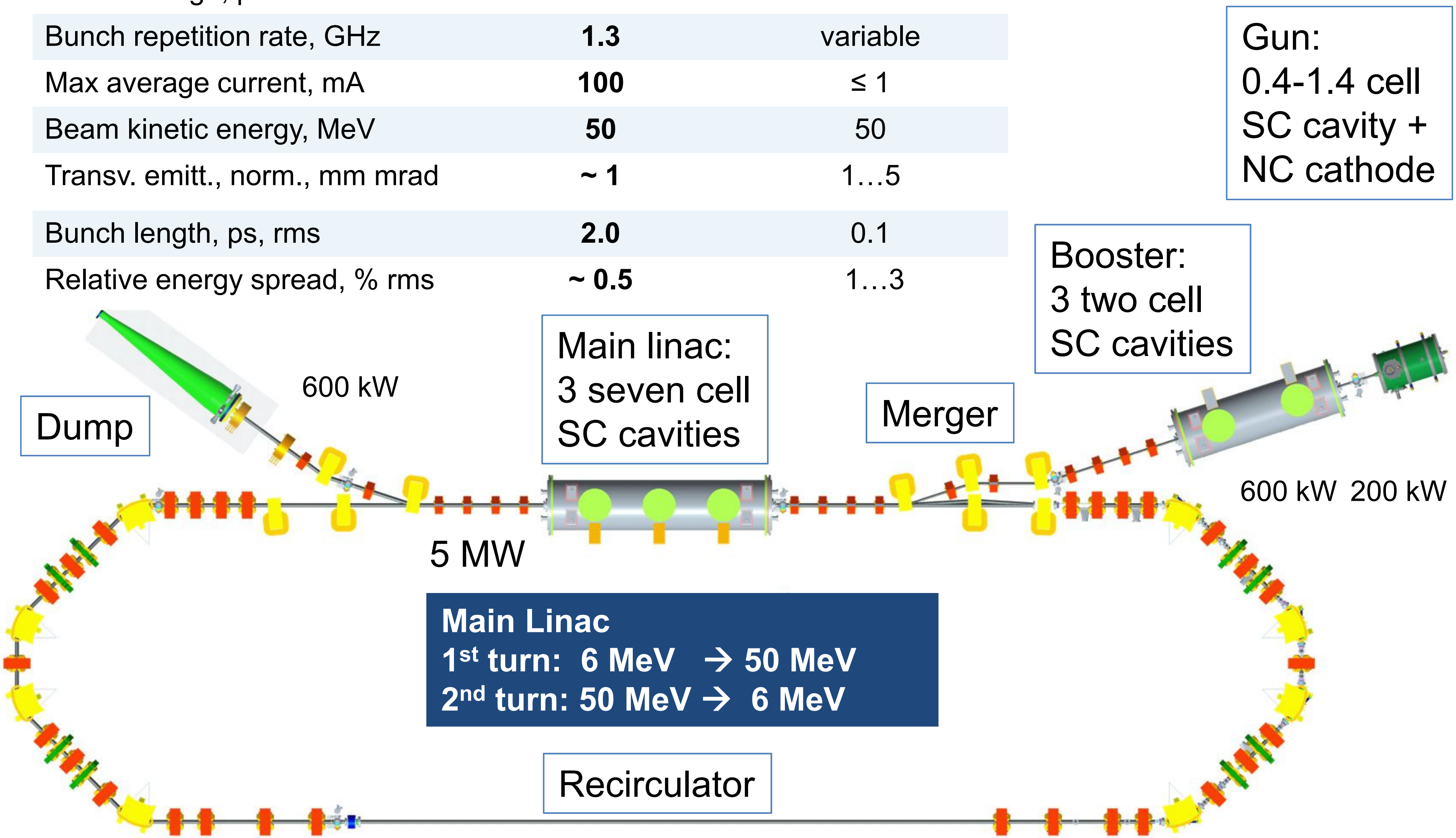
Berlin, ca. 240 km south of Warnemünde



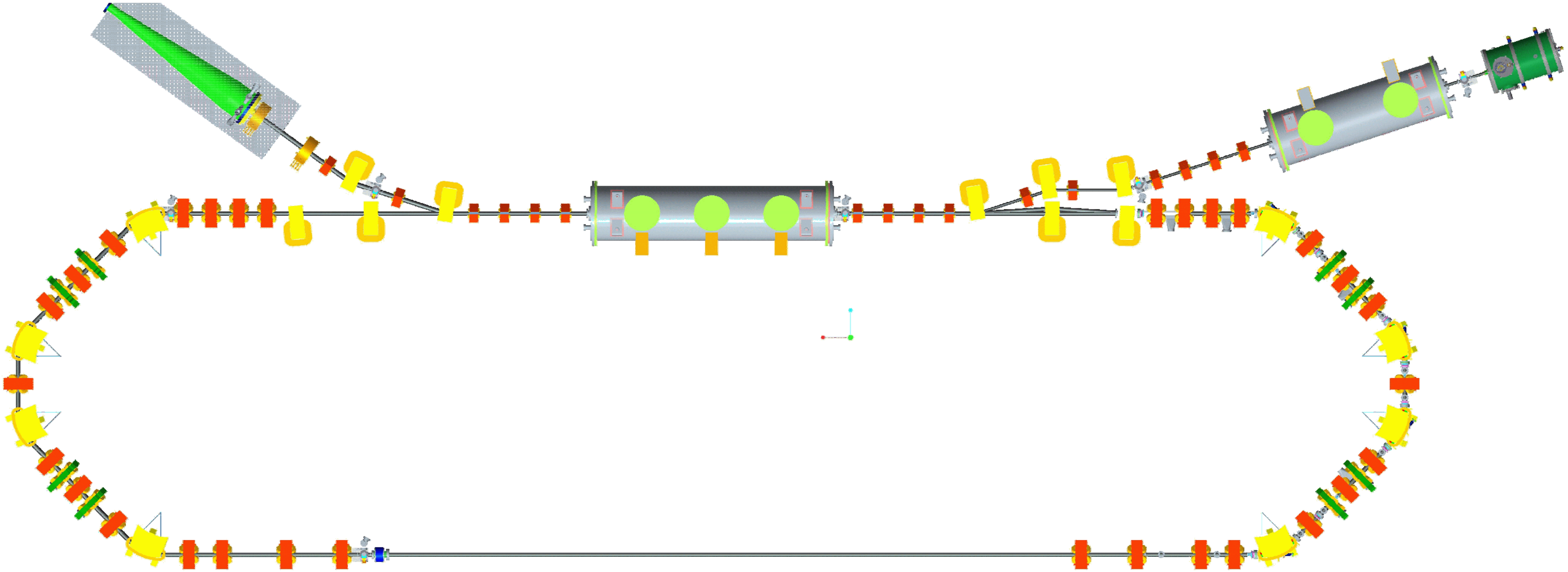


(current) Layout of B*ERL*inPro

	Basic Mode	Short Bunch Mode
Bunch charge, pC	**77**	~ 10
Bunch repetition rate, GHz	**1.3**	variable
Max average current, mA	**100**	≤ 1
Beam kinetic energy, MeV	**50**	50
Transv. emitt., norm., mm mrad	**~ 1**	1…5
Bunch length, ps, rms	**2.0**	0.1
Relative energy spread, % rms	**~ 0.5**	1…3



BERLinPro: Cavity types and HOM absorbers



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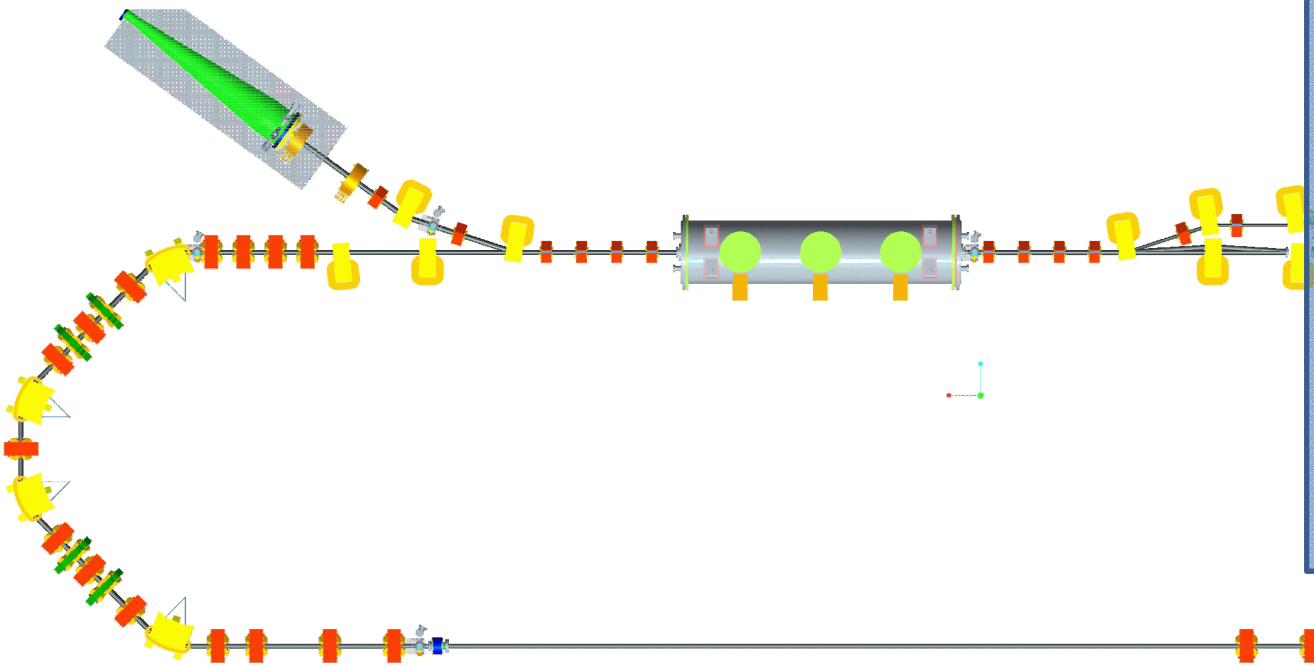
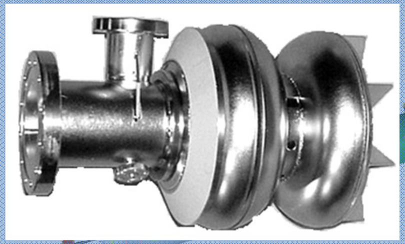


SRF Photo-injector

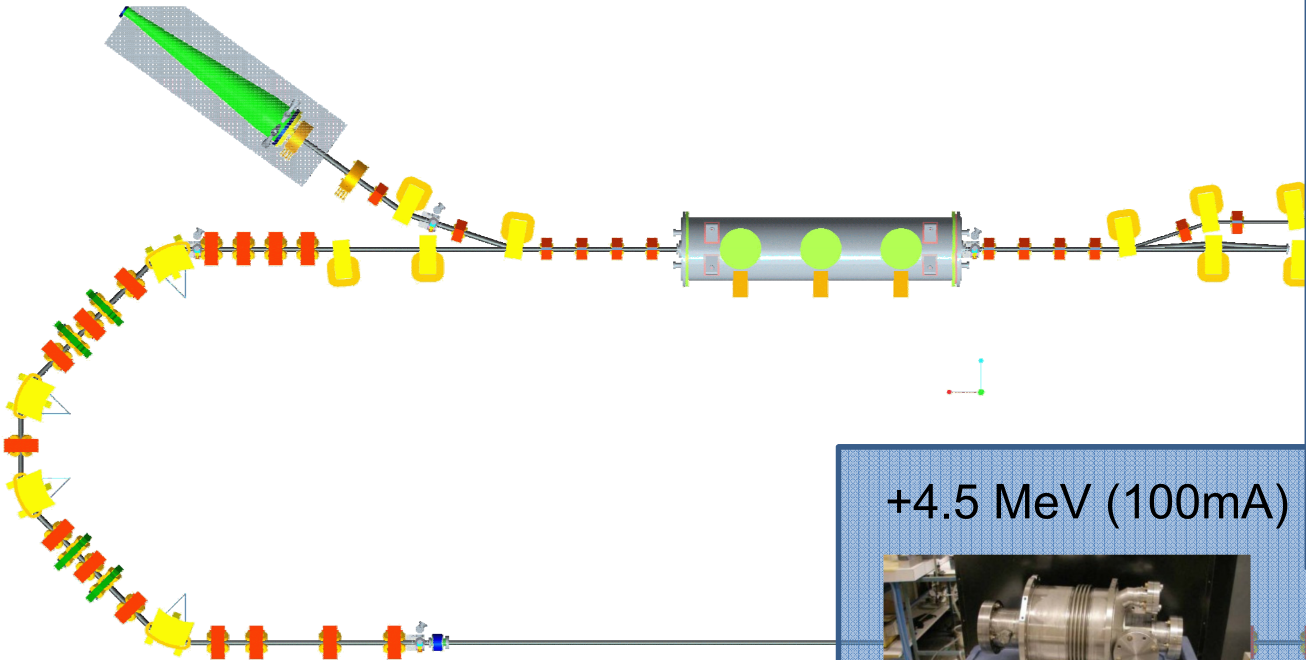


1.5-2 MeV, 100 mA

- High beam power
- High beam current
- Intermediate field levels 12 MV/m

→ **Beam pipe absorber**

BERLinPro: Cavity types and HOM absorbers



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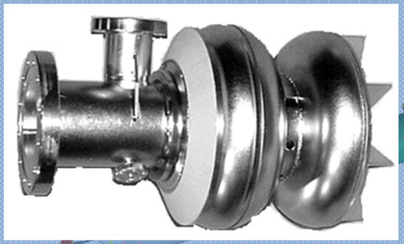

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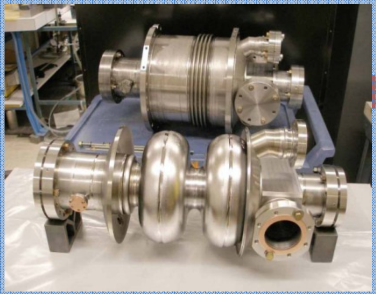
+4.5 MeV (100mA)

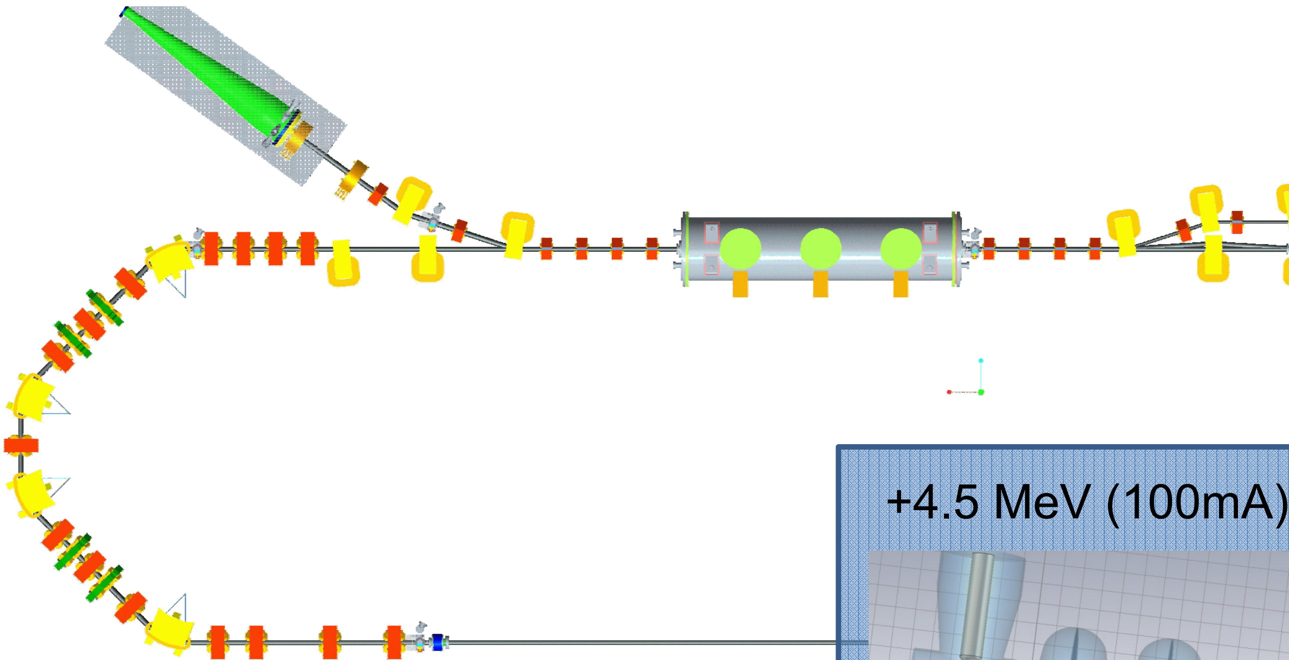


SRF booster cavity (Cornell)

- High beam power
- High beam current
- Intermediate field levels 10 MV/m

→ **Beam pipe absorber**

BERLinPro: Cavity types and HOM absorbers



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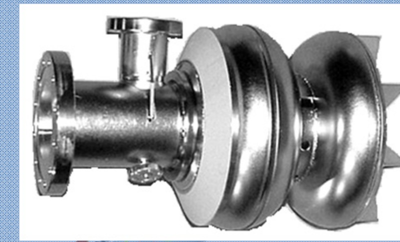

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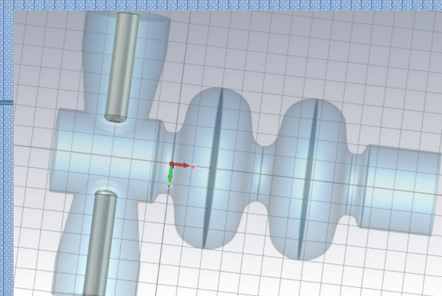

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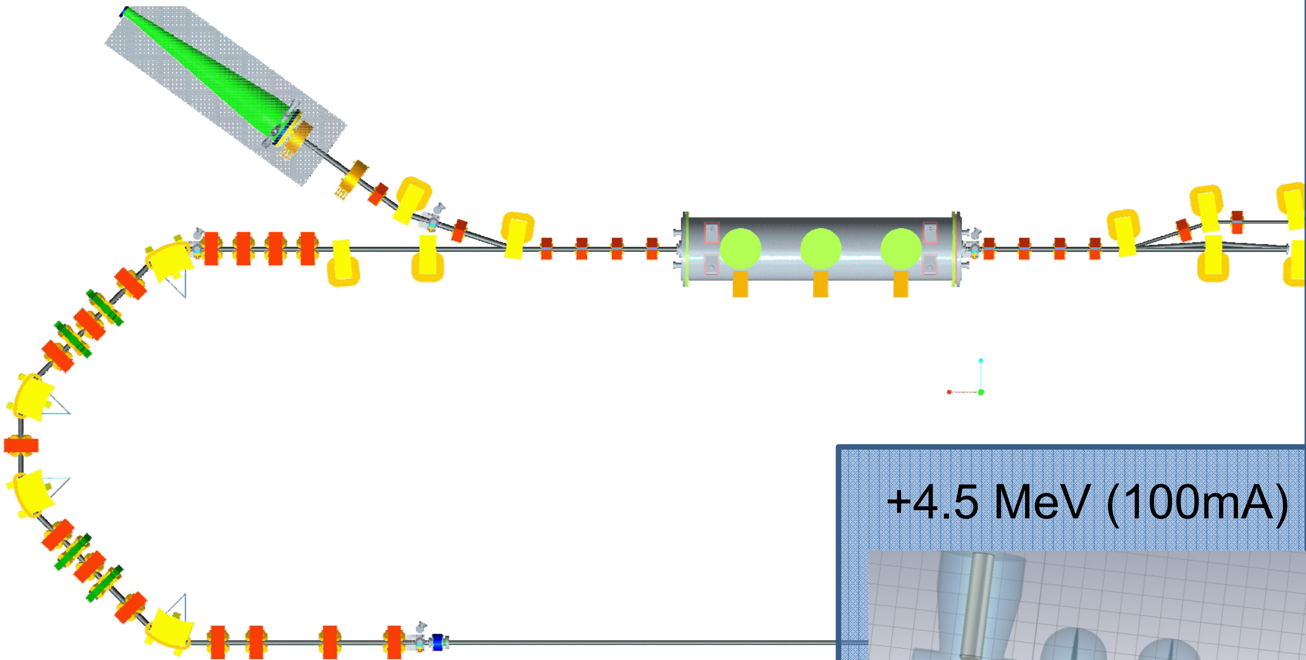

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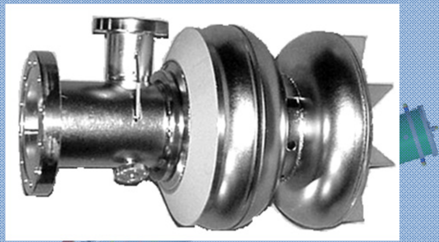

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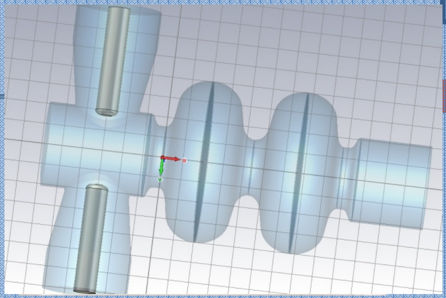

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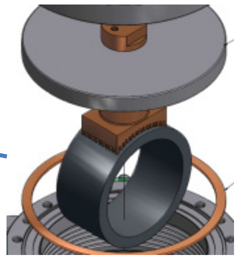
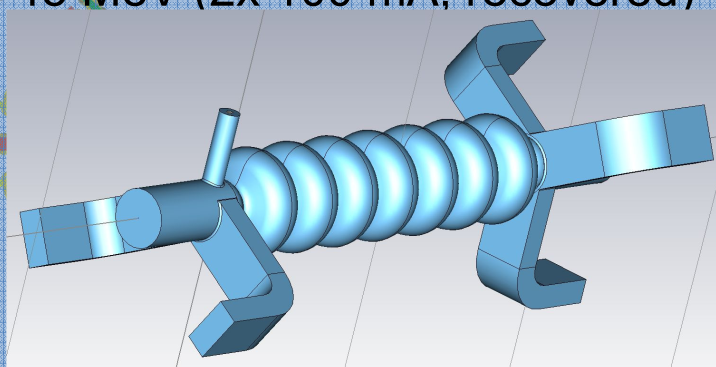


Courtesy of
J. Sekutowicz
DESY

BERLinPro: Cavity types and HOM absorbers

+45 MeV (2x 100 mA, recovered)

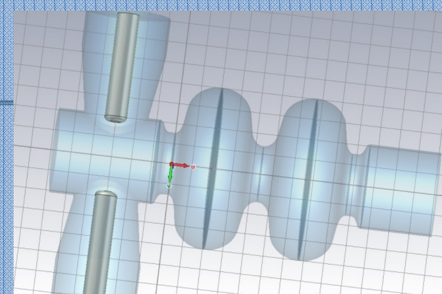


Main linac cavity

- Low beam power
- High beam current
- Higher field levels 19 MV/m
- Multi-pass beam

→JLAB style waveguide absorber

+4.5 MeV (100mA)



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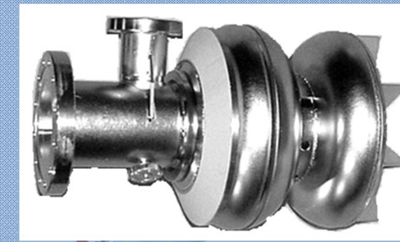
SRF Photo-injector



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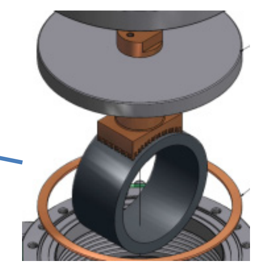

Courtesy of
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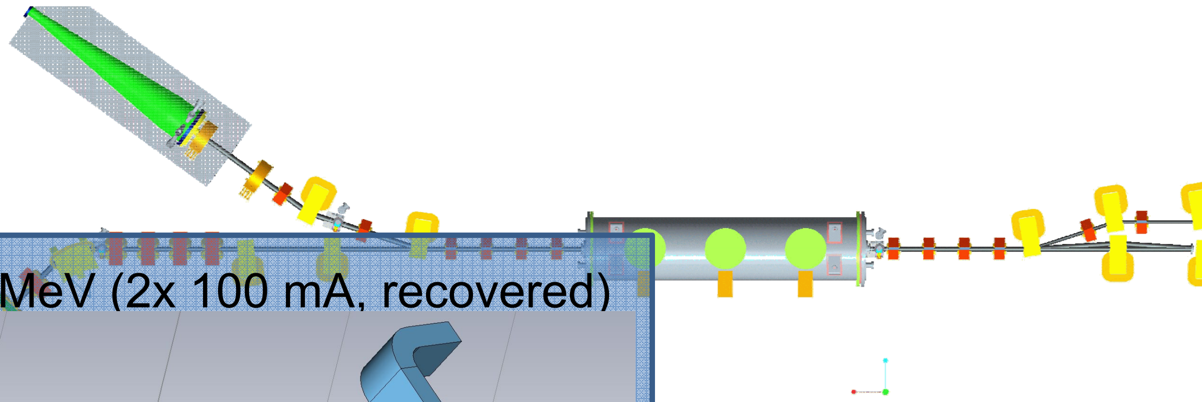
DESY

V.D. Shemelin et al., Proc. of SRF 2011

BERLinPro: Cavity types and HOM absorbers



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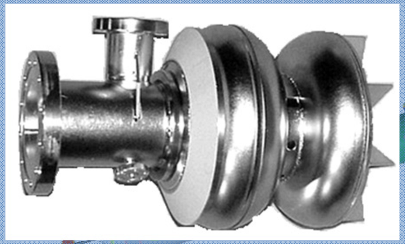

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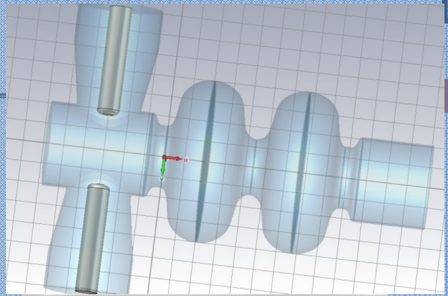

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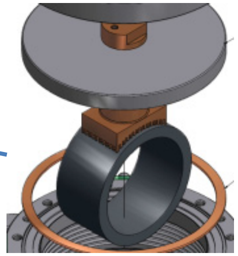
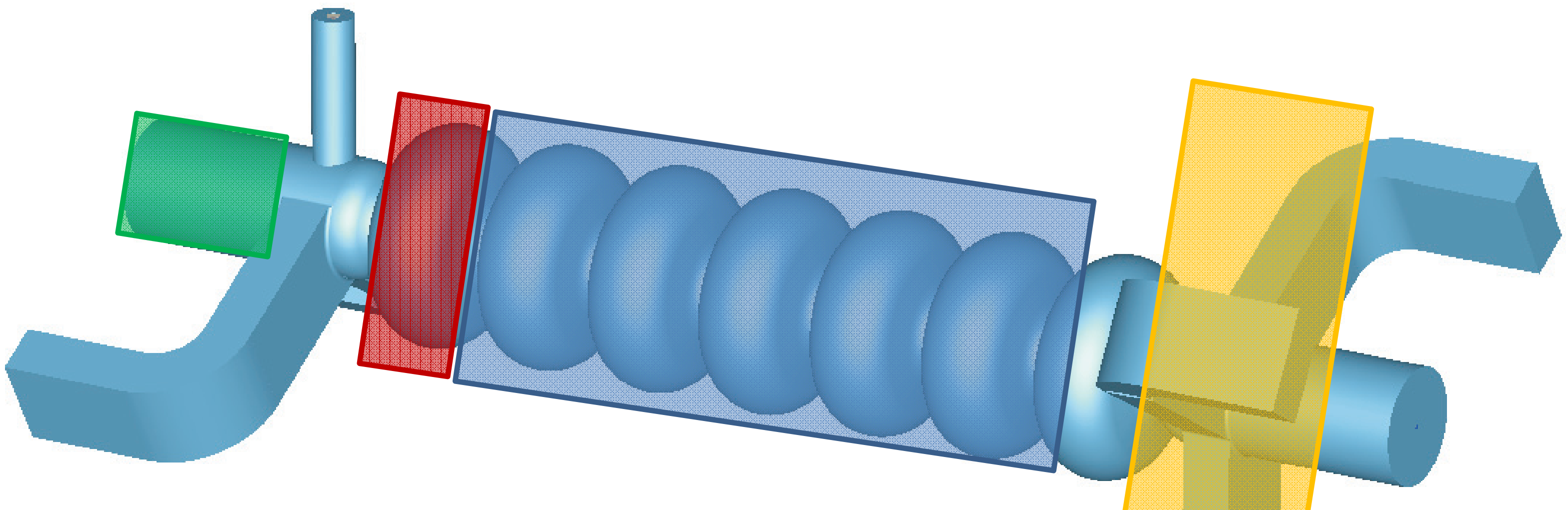


Courtesy of
J. Sekutowicz
DESY

Linac cavity components



▪Center cells

- Determine cavity figure of merit: E_{peak}, H_{peak}, R/Q
- Properties of HOM spectrum
- Controls frequencies of HOM passbands and dispersion relations!
- Determines cell-to-cell coupling and how sensitive HOM spectrum is to variation in cell shape

▪End cells

- Asymmetric design helps prevent trapped modes
  but field flatness of fundamental TM_{010} has to be maintained
- Responsible for coupling HOMs to HOM absorber
- Directly controls quality factors of HOMs

(See N. Valles et al.
HOMSC12, Daresbury)

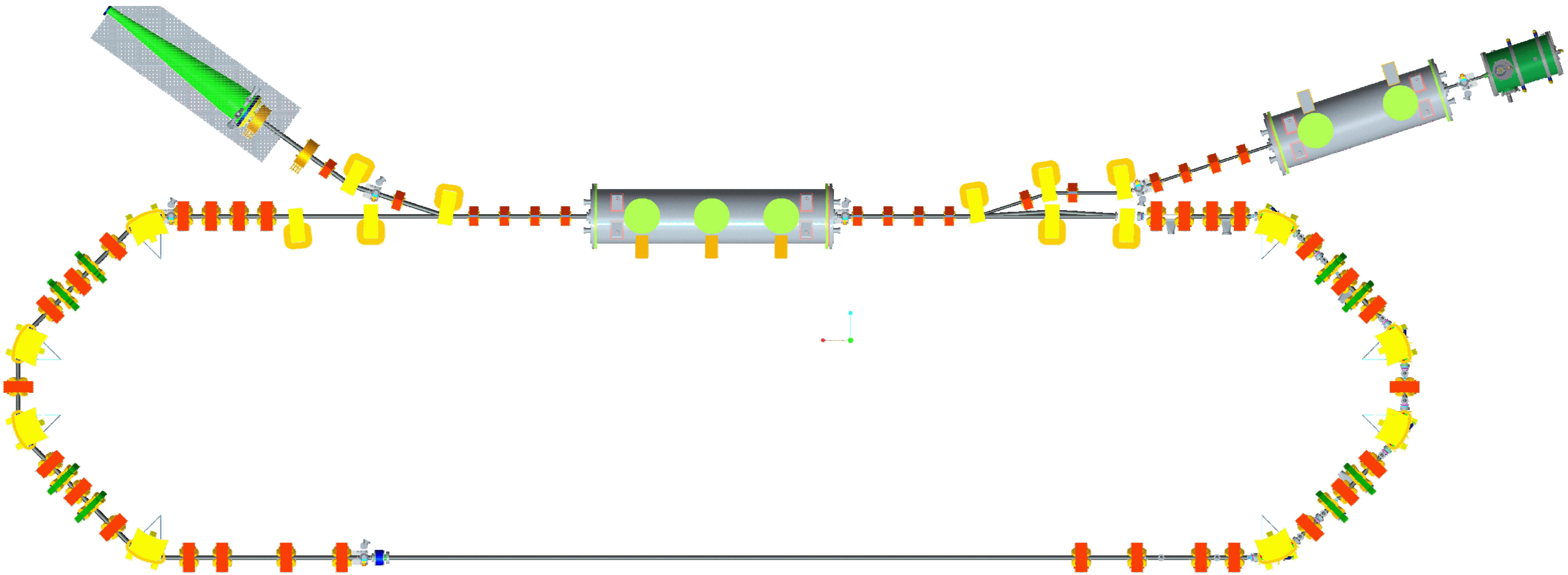
▪Beam Pipe

- Diameter determines cutoff of propagating modes + coupling of HOMs to WGs

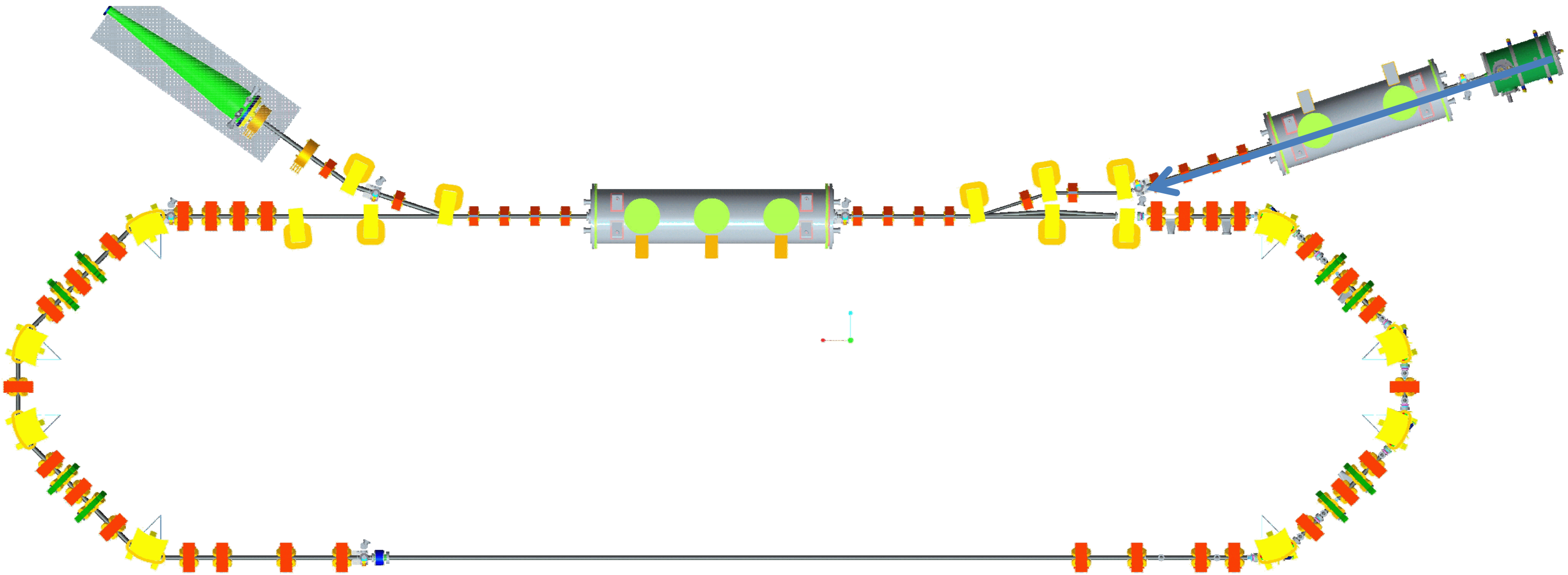
▪HOM absorber + load

- Absorber material properties determine specific mode losses.
- Dimensions of WG determine cutoff frequency and residual losses of fundamental
- Orientation determines coupling to polarized modes

Requirements for the Linac Cavity: Avoid Beam Break Up



Requirements for the Linac Cavity: Avoid Beam Break Up



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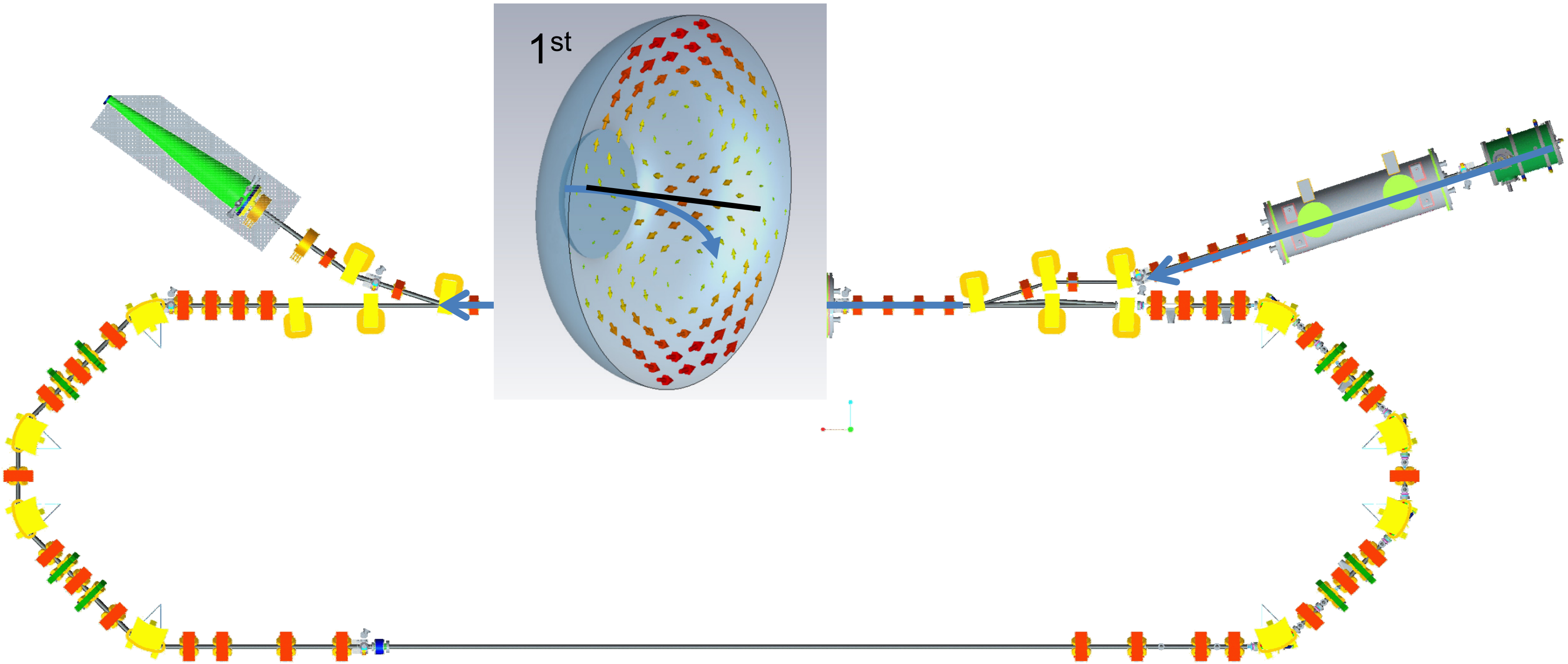

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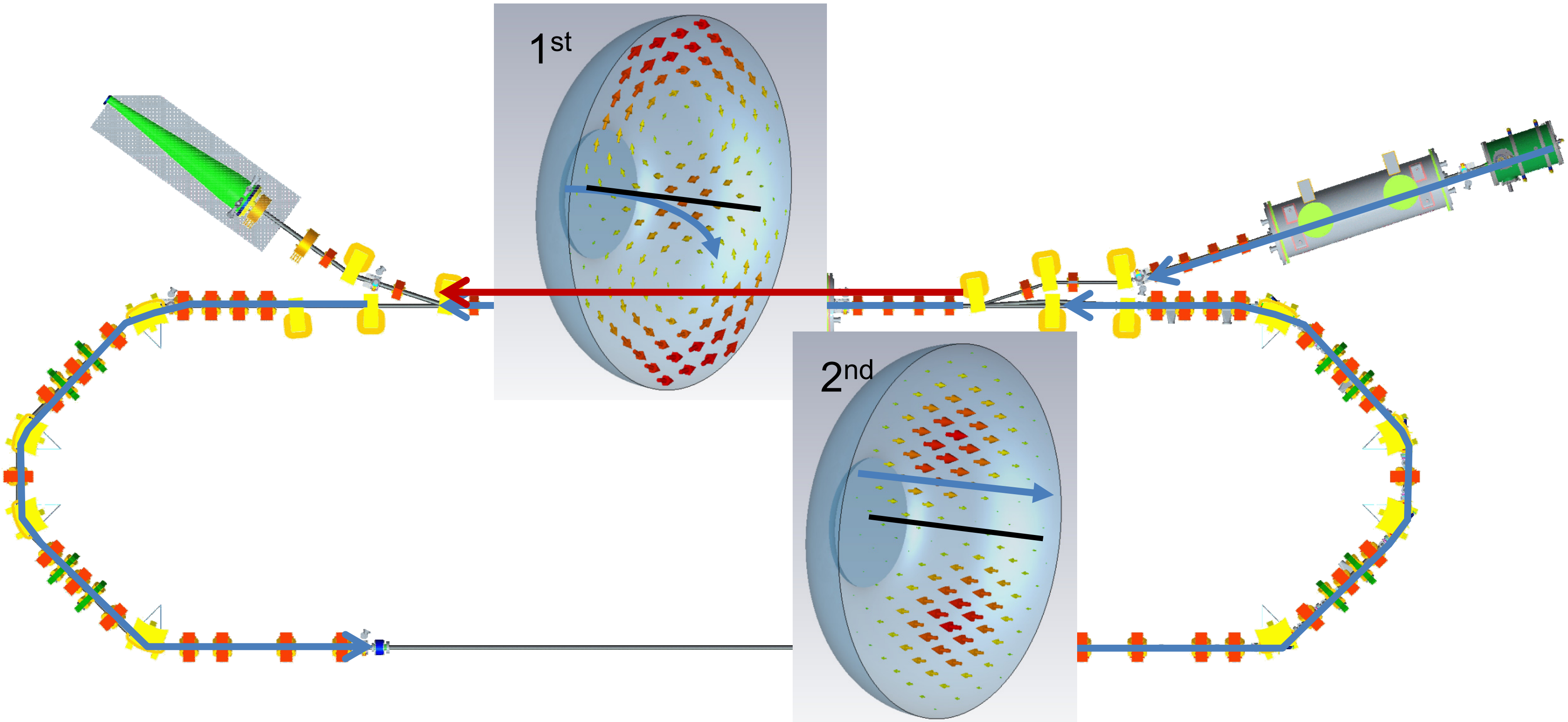


$$I_{\mathrm{th}} = -\frac{2\gamma}{e}\frac{c}{\frac{R}{Q}_{\perp} Q_{\mathrm{ext}}\omega M_{12}}\frac{1}{\sin\left(\omega t_{\mathrm{r}}\right)}$$

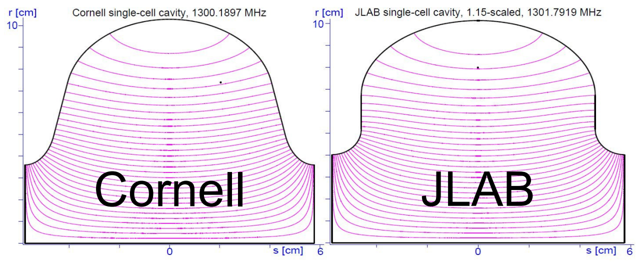
Accessible by cavity design

$$\tau = \frac{\omega_0}{2Q_{\mathrm{ext}}}$$

SC cavity!

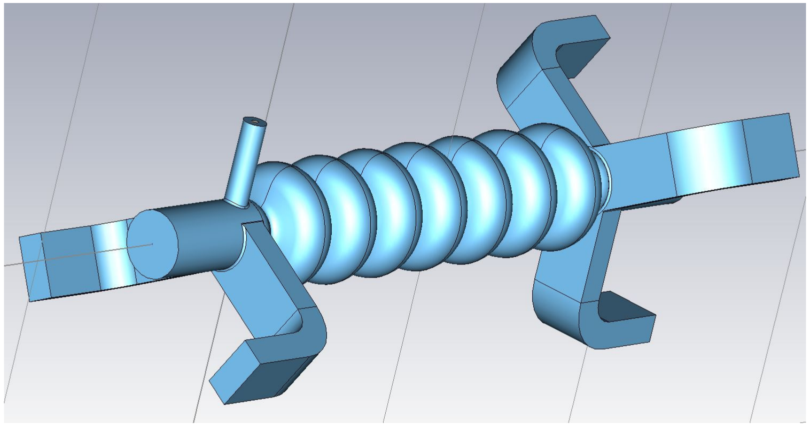
Cavity design options

	Cavity electro-magnetic parameter	
Parameter for β=1	**JLAB** design scaled (mid-cell)	**Cornell** design (mid-cell)
R_{iris} (mm)	**40.25**	36.0
R/Q (Ω) per cell	104.2	**111.1**
Transit time factor	0.77	0.77
Geometry constant G (Ω)	**278.9**	272.8
E_{peak}/E_{acc}	2.44	**2.06**
B_{peak}/E_{acc} (mT/(MV/m))	4.14	**4.02**
Cell-to-cell coupling (%)	**3.2**	2.2
Q_{ext} operational range	$3{\cdot}10^7$-$1{\cdot}10^8$	$3{\cdot}10^7$-$1{\cdot}10^8$



B. Riemann et al., IPAC 11

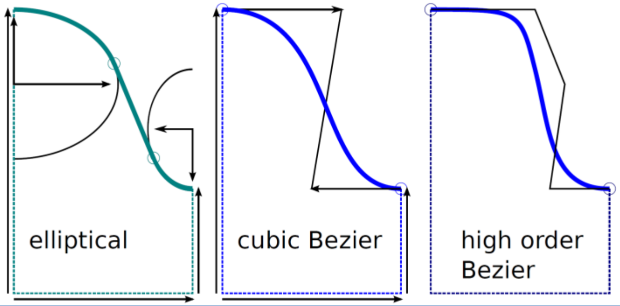
Best option so far seems Cornell cell geometry combined with JLAB style HOM Dampers, combined with flexibility of DESY/BESSY type TTF-III FPC



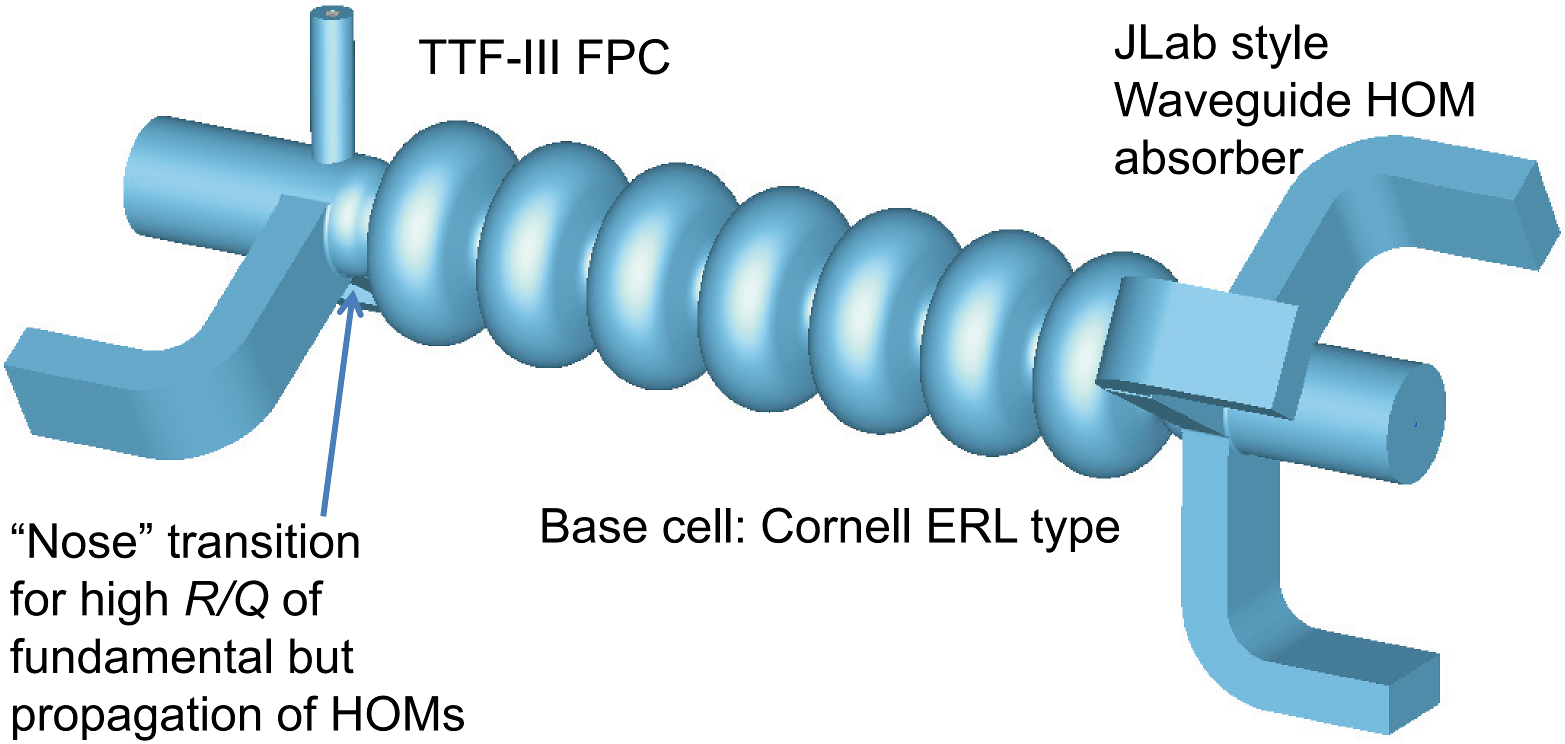
Model for calculation purposes

Current design

Alternative geometry design method: by Splines (e.g. cubic Bezier spline) see WEP14 B. Riemann et al.



The current Linac Cavity design



Parameter	Value
$R/Q(\Omega)$	754
$E_{\text{surf}}/E_{\text{acc}}$	2.07
$\Delta\nu$ (MHz)	1.54
Q_{ext}	$5 \cdot 10^7$
Geometry factor $G(\Omega)$	272.7

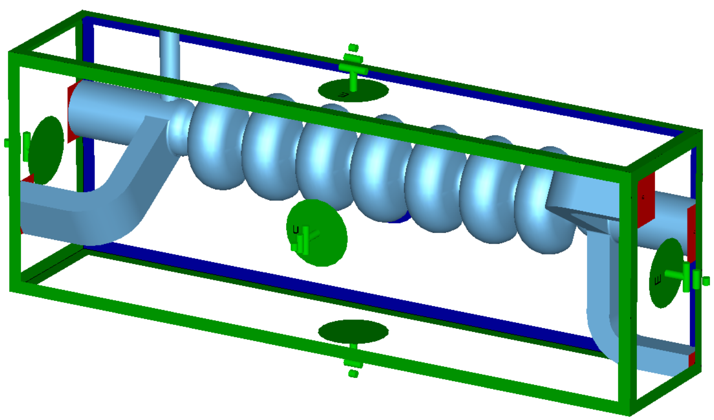
Limits peak electric field to about 40 MV/m

Calculate HOM/BBU performance

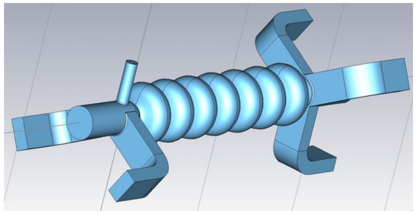
Calculation: Methods

- Only symmetry plane in fundamental coupler plane
- No axial symmetry prohibits use of 2-D based cavity optimizer schemes (using e.g. Superfish, SLANS/CLANS)
- 3-D MWS CST® eigenmode used to calculate cavity modes (Jacobi-Davidson method)
- Cavity modeled in tetrahedral or hexahedral mesh type
- To calculate Q_{ext} with post-processing hexahedral mesh had to be used
- Transverse *R/Q* was directly calculated by Lorentz forces of on-axis fields:

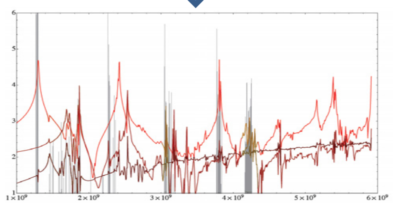
(Panofsky-Wenzel theorem)
using MATLAB™ based scripts and exported field distribution along curves



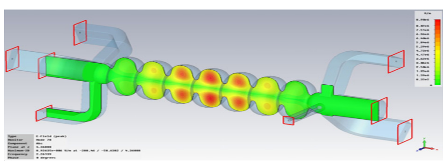
Design iteration so far



Modeling of cavity, change in geometry, waveguide assembly



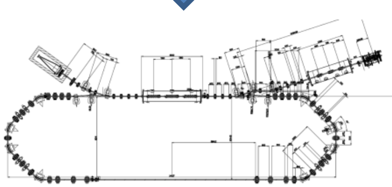
Time domain wakefield calculations to determine mode spectrum



EM Solver calculations to determine field distribution, verify time domain results

$$\frac{R_\perp}{Q} \equiv Z_0 \frac{c^3}{\omega_D^3} \frac{\left| \int \frac{\partial E_z}{\partial x} e^{j\omega_D z/c} dz \right|^2}{\int E^2 dV}$$

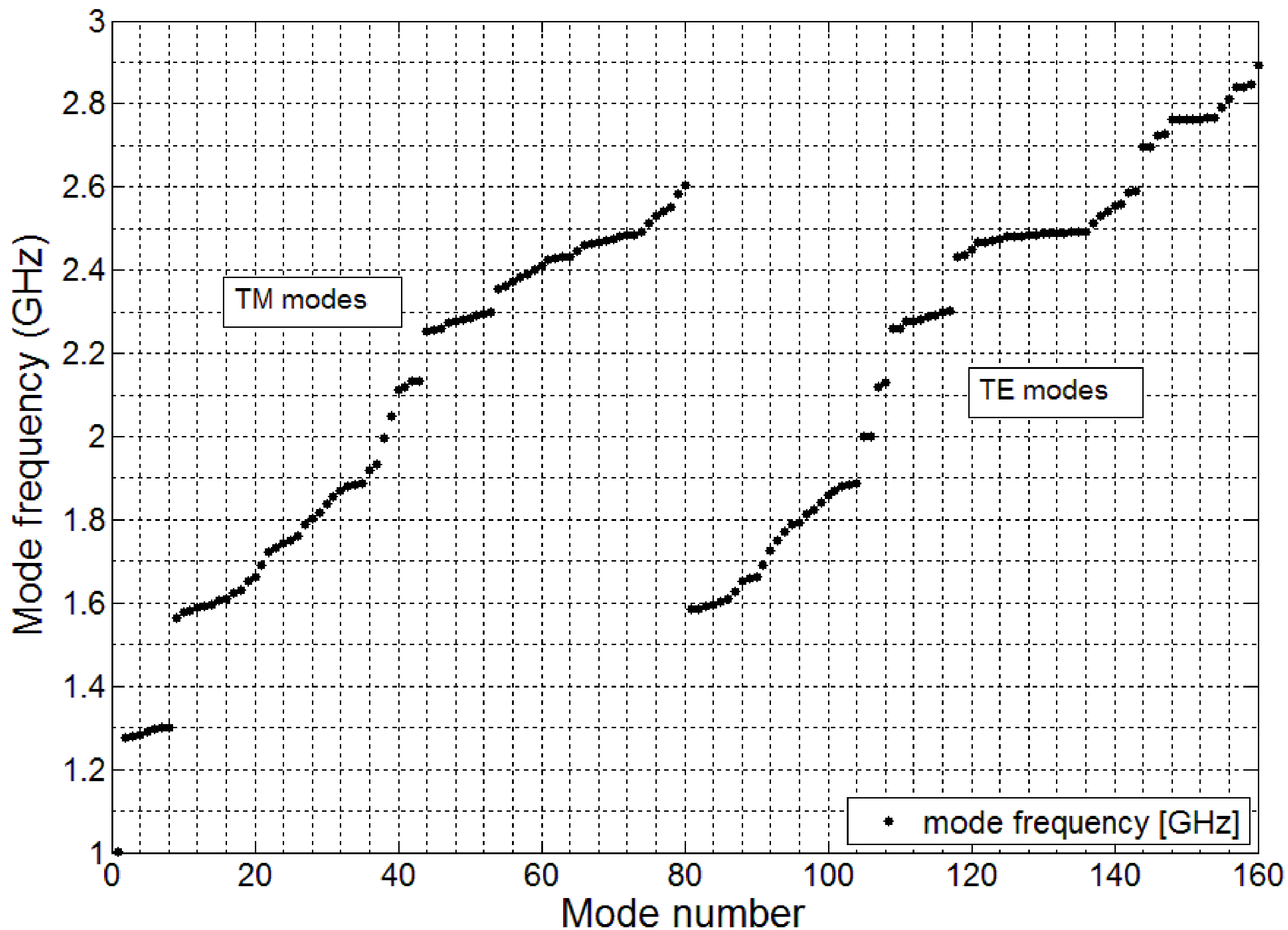
Determine transverse shunt impedance of HOM plus all BBU relevant parameters (*R/Q*, Q_{ext}, ω, ϕ_{Pol})
Matlab based post-processing



BBU calculations to determine threshold current and identify most dangerous modes

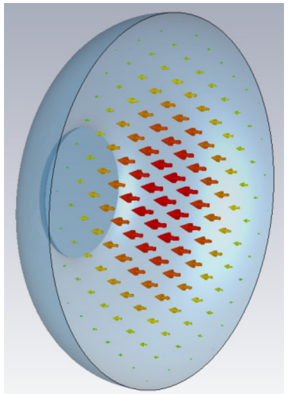
See Y. Petenev et al., IPAC2011, San Sebastian, Spain

HOM calculations

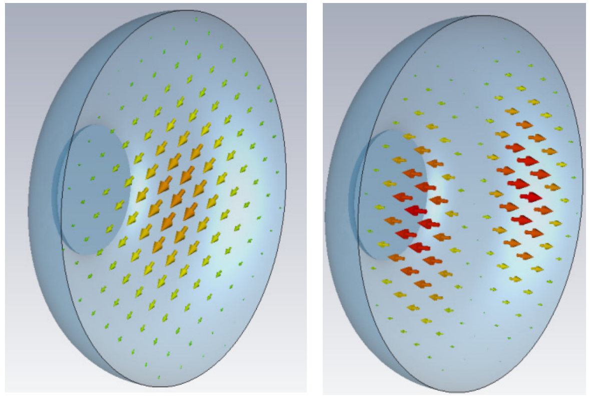


Limited to about 3 GHz due to computational time, 12-15 lines/wavelength

Modes considered

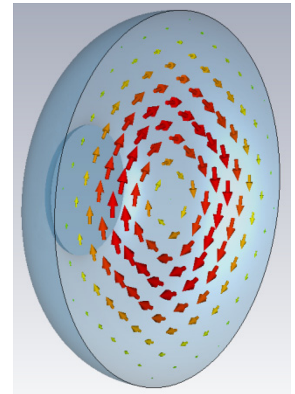


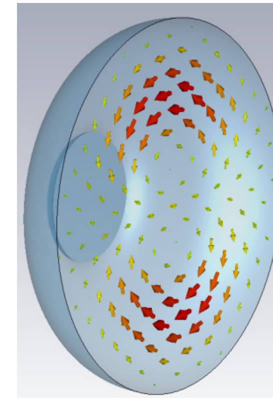
TM_{010}



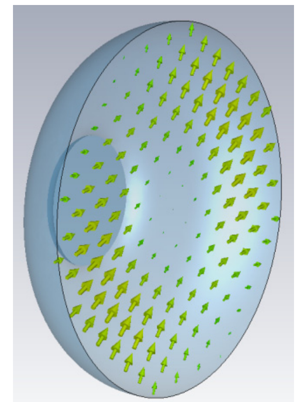
TM/TE_{11}

TE_{011}

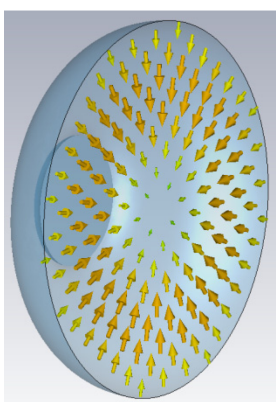




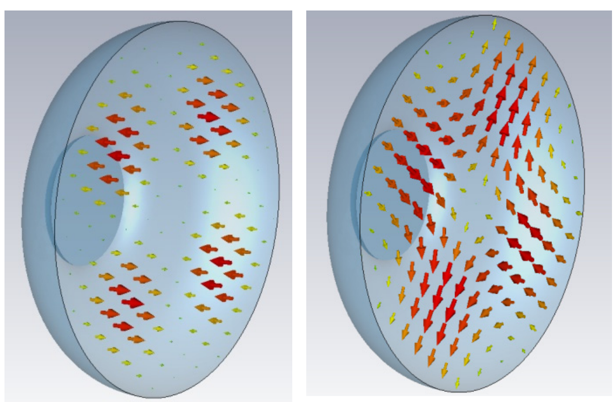
TE_{111}



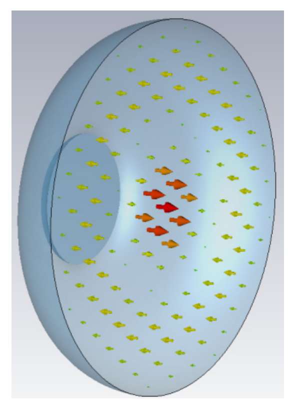
TM_{011}



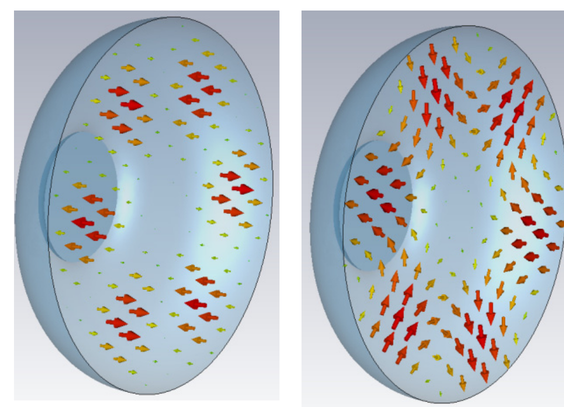
TM/TE_{21}



TM_{020}

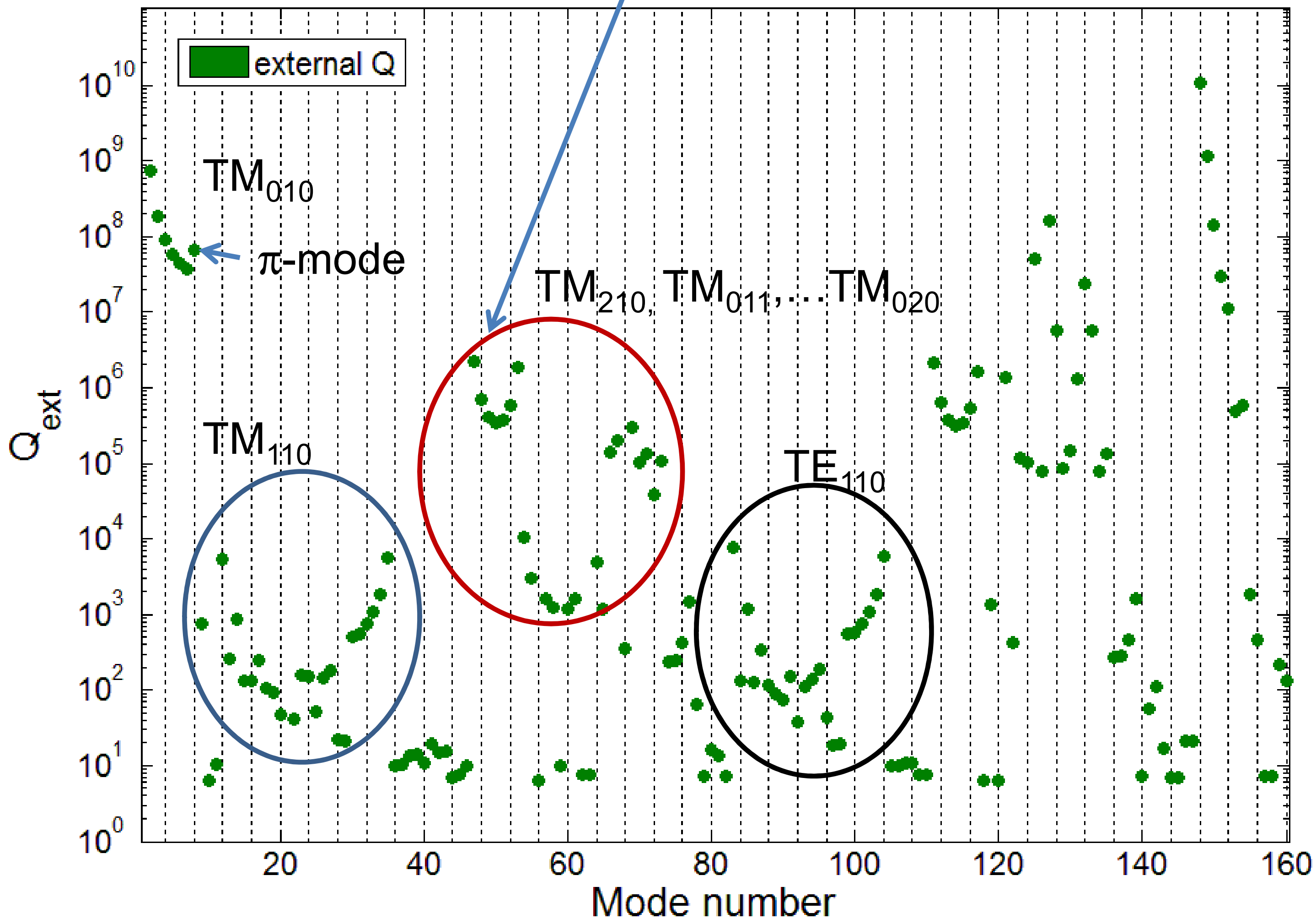


TM/TE_{31}



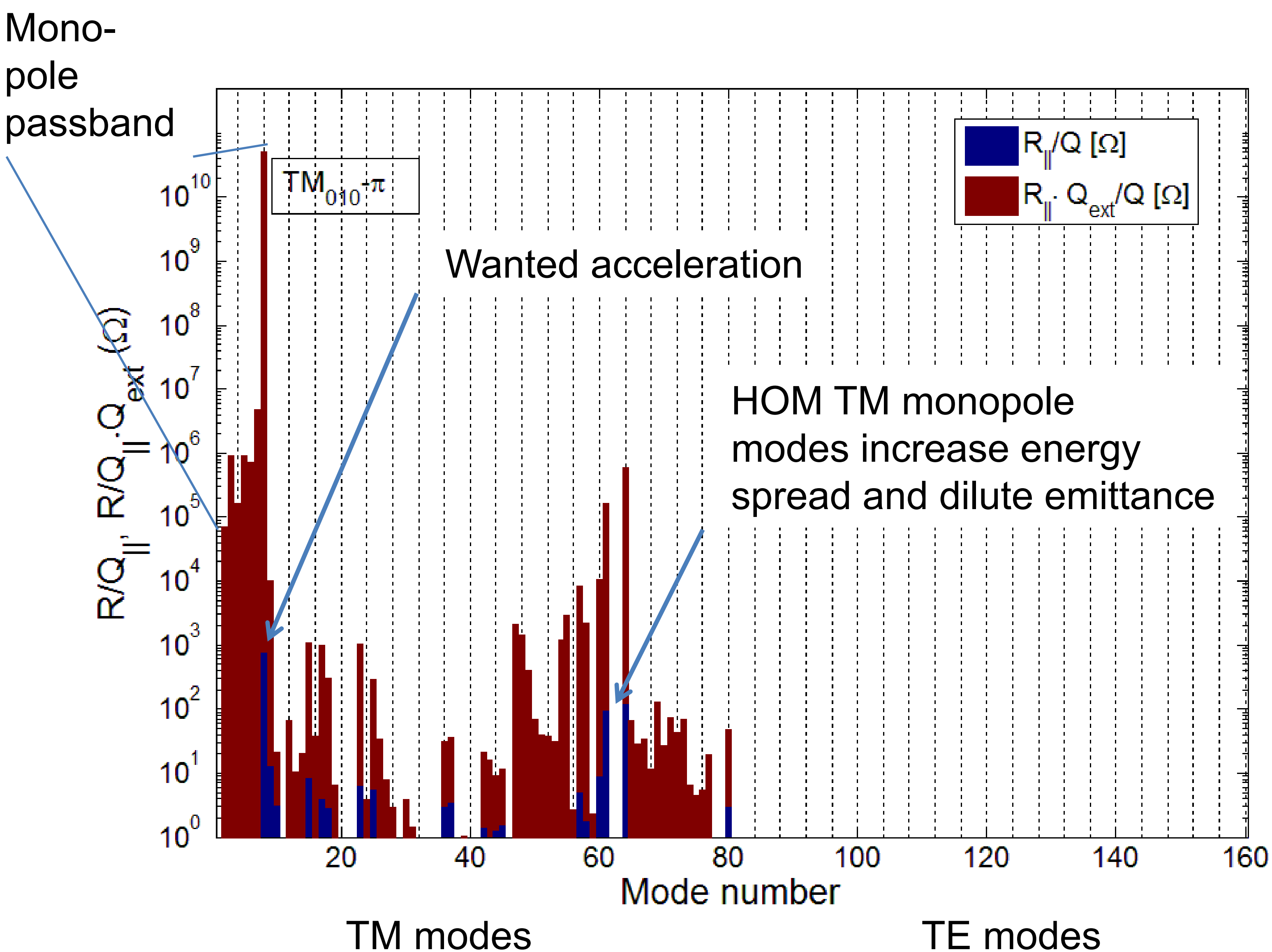
HOM calculations

High Q quadrupole modes, quasi localized within the structure
Are they of any concern?

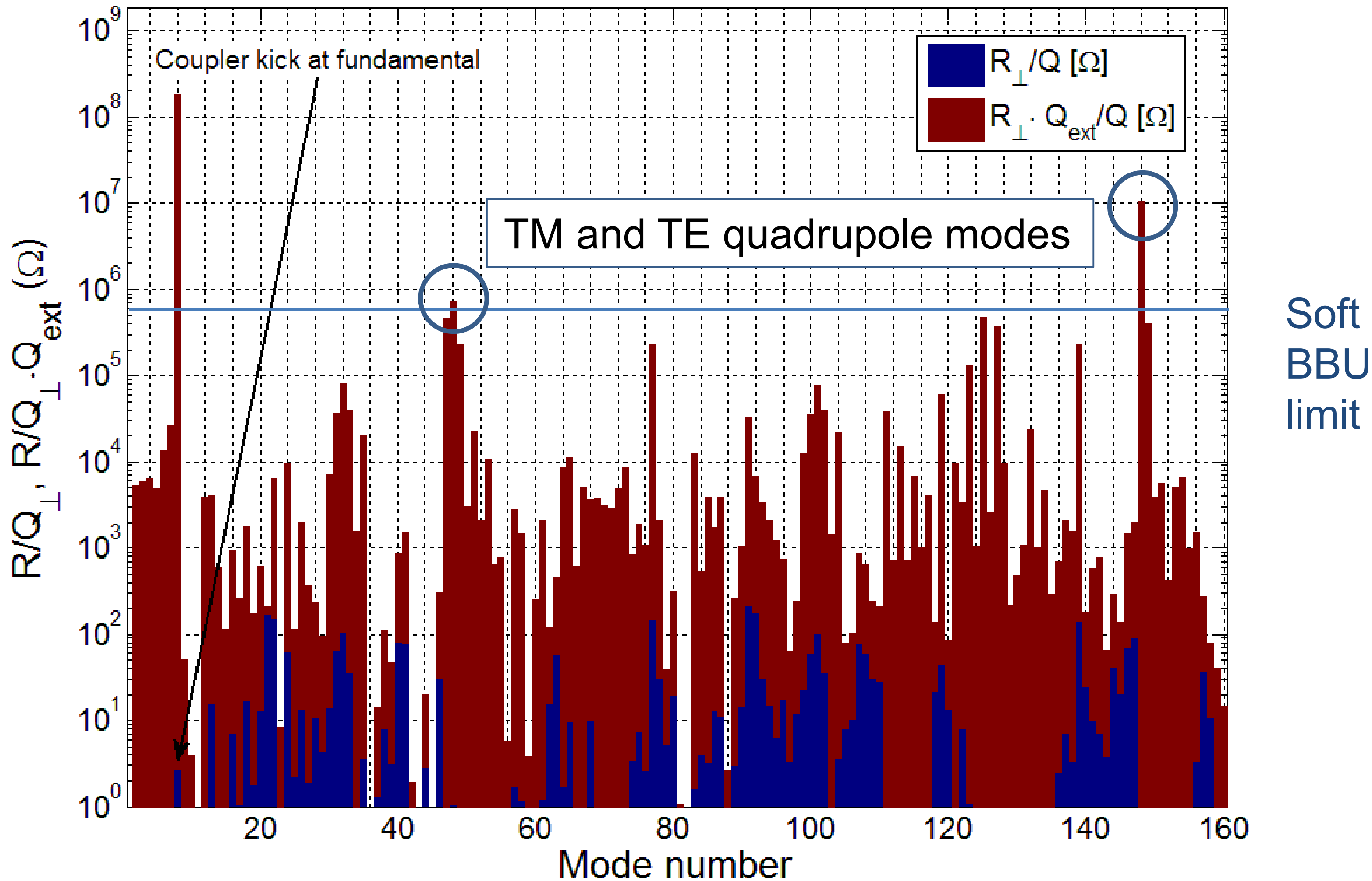


BBU limit given by R/Q^*Q_{ext} → Calculate normalized shunt impedance on axis

HOM Calculations: longitudinal R/Q spectrum

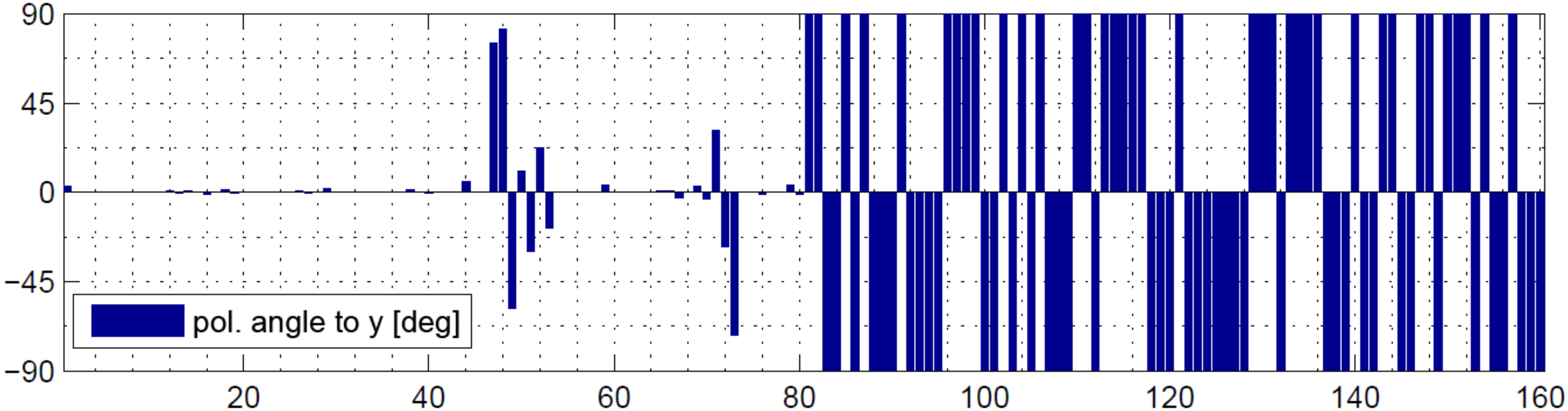


HOM calculations: transverse R/Q spectrum

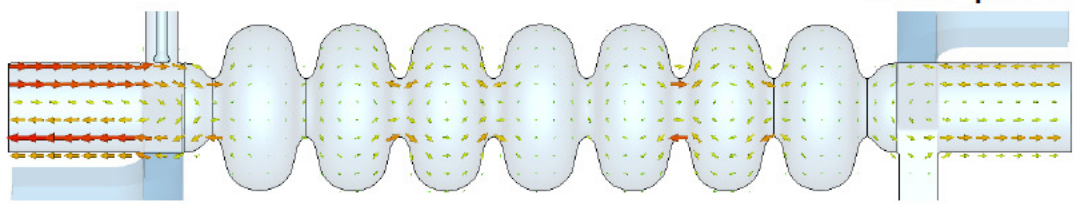
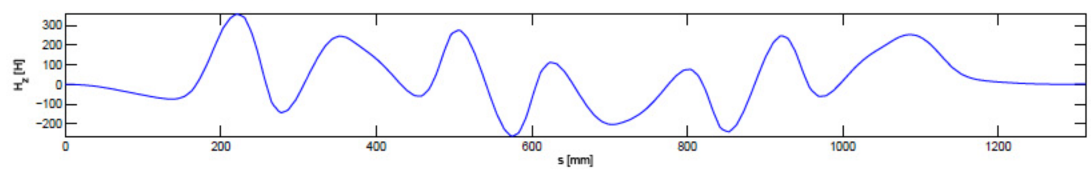


Residual $R/Q_\perp$ of quadrupoles along beam path below 10^0. Why?

A closer look into the modes

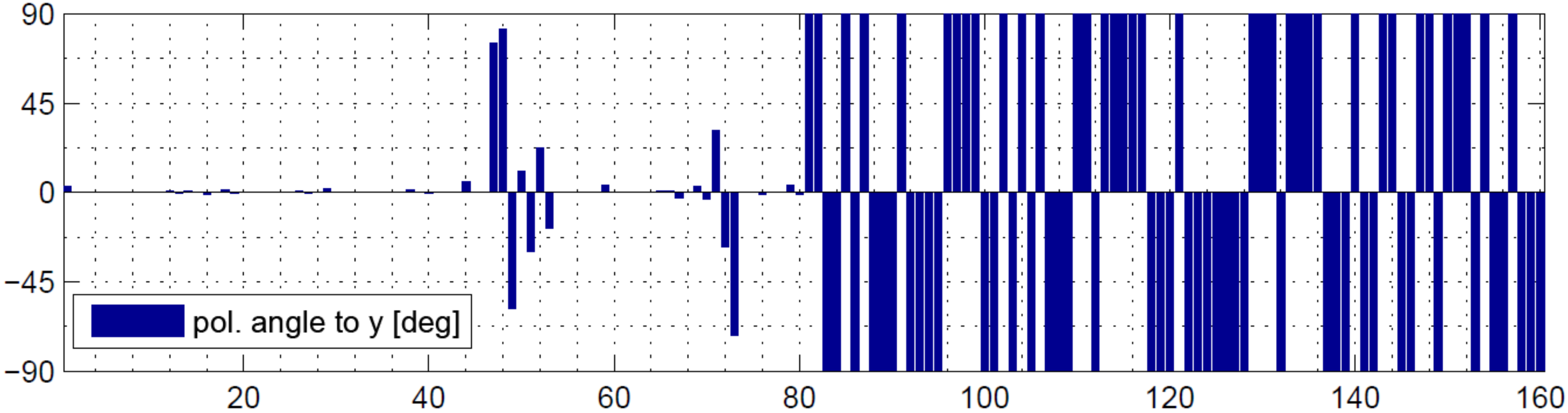


Polarizations varying strongly from expected hint at numerical errors

ν[GHz]	Q_{ext}	R/Q [Ω]	field plots
1.58	$2 \cdot 10^9$	15.5	 

Sort out beam tube modes, like here TE_{11}
Due to boundary condition they form SW

A closer look into the modes



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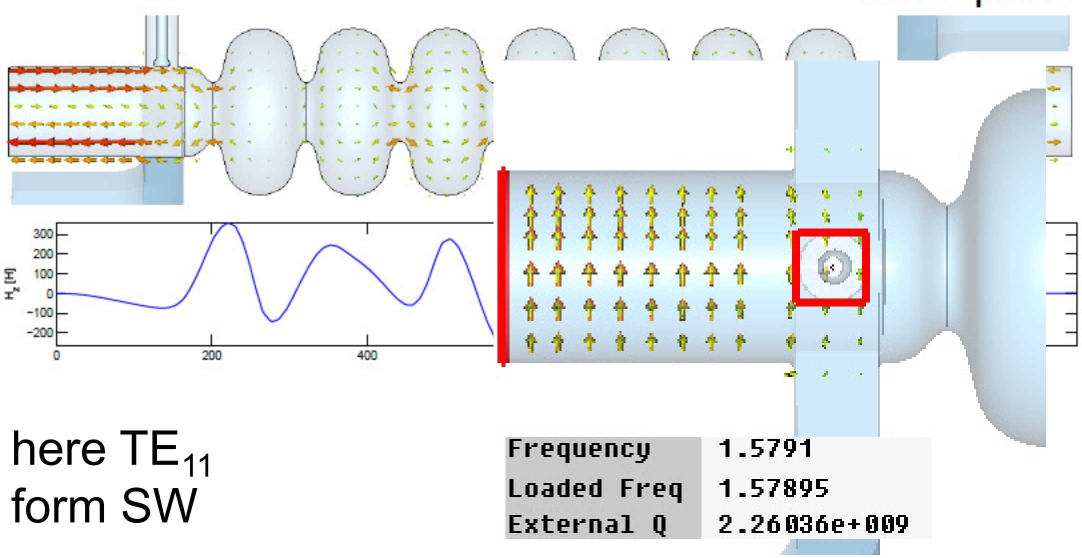
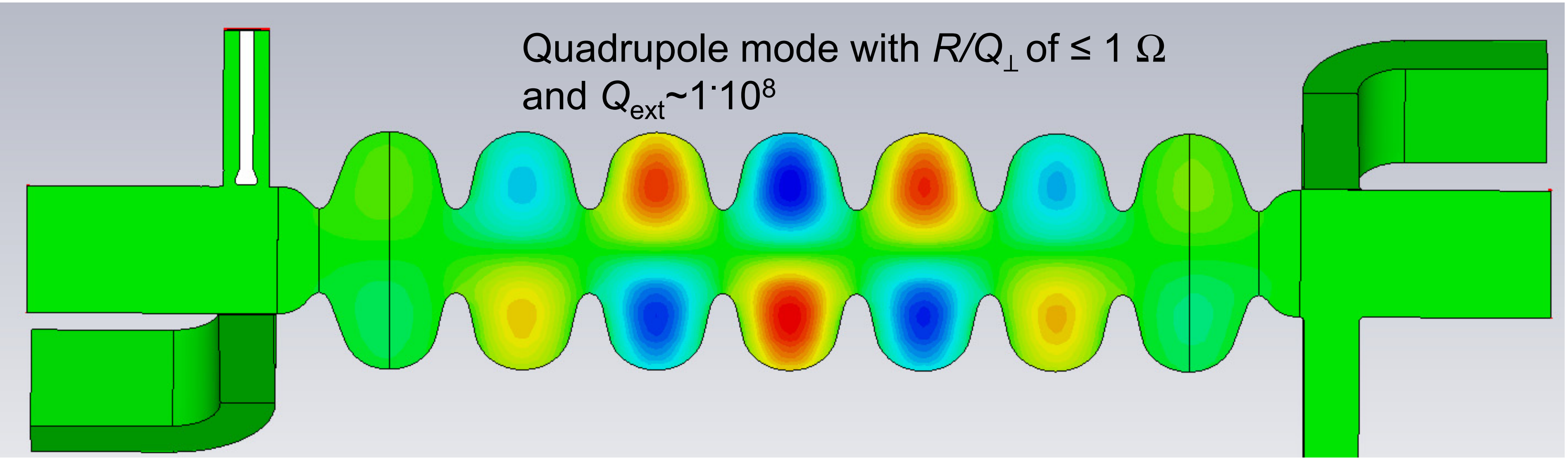
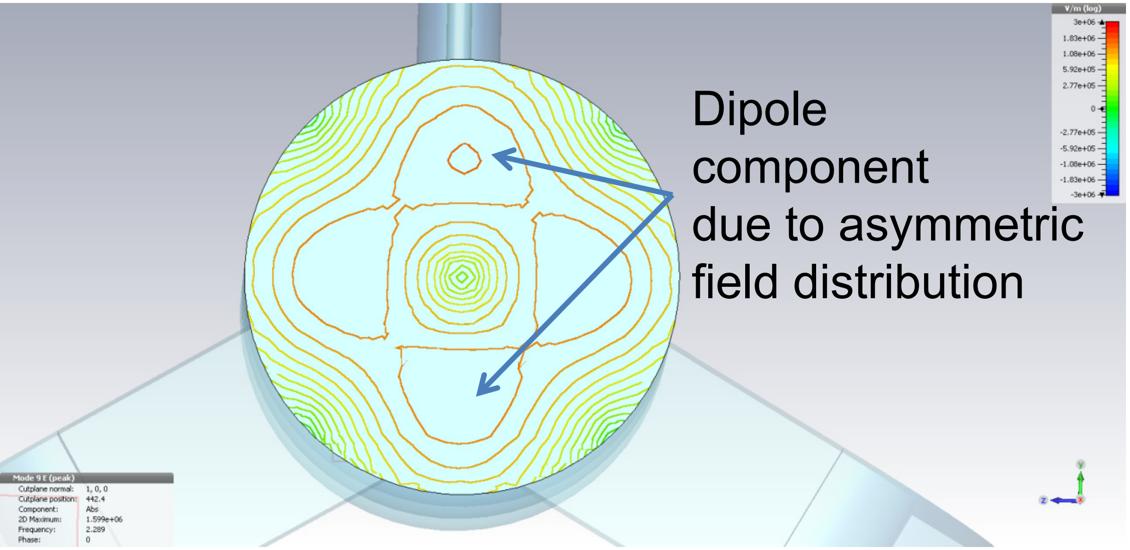


Sort out beam tube modes, like here TE_{11}
Due to boundary condition they form SW

Trapped Modes → sorting the modes



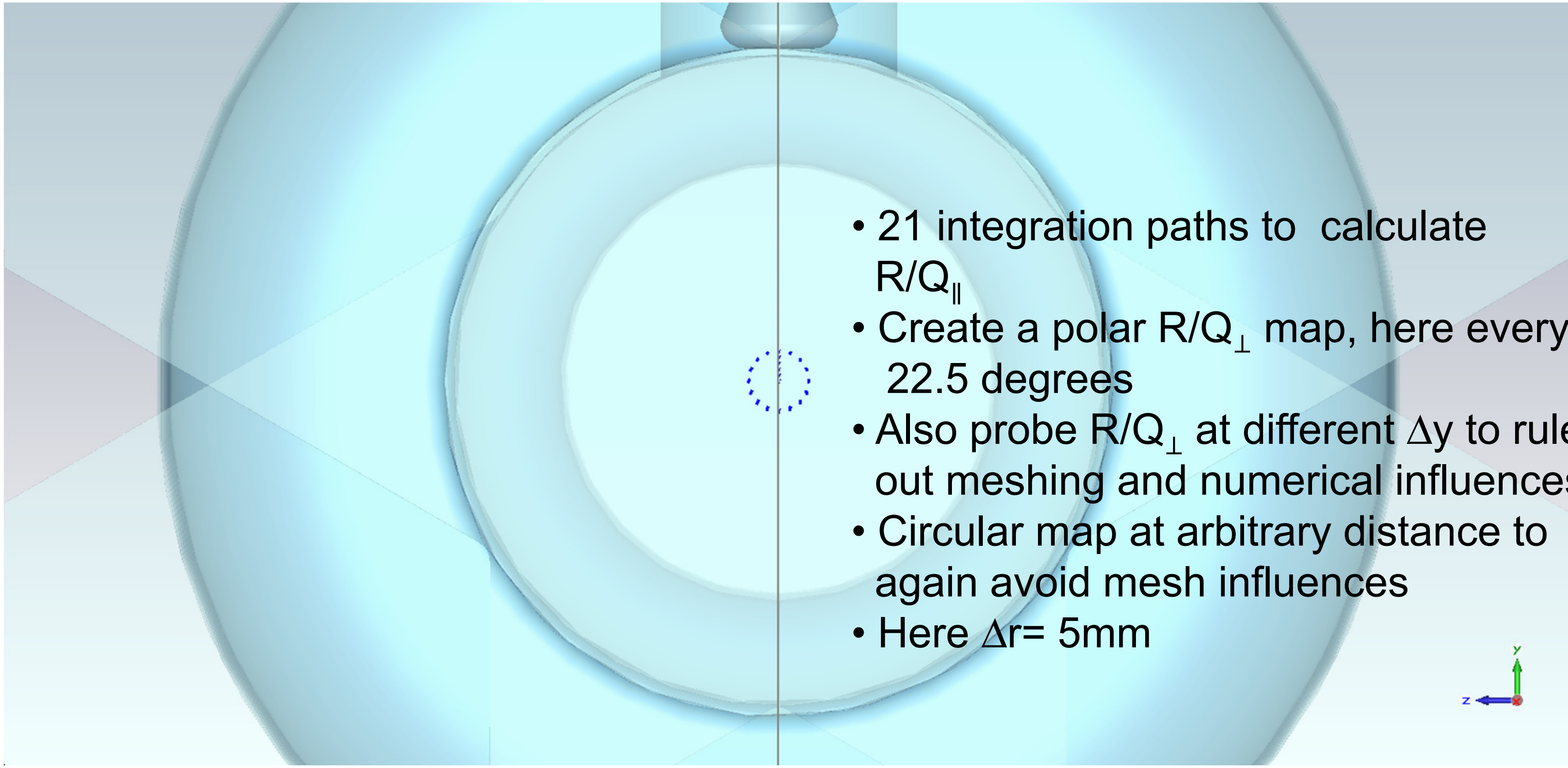


Is that a real effect?

Assume a coupler kick at the HOM or numerical inaccuracies?

Perform *R/Q* calculations at different integration paths

Identify modes by polar *R/Q* maps

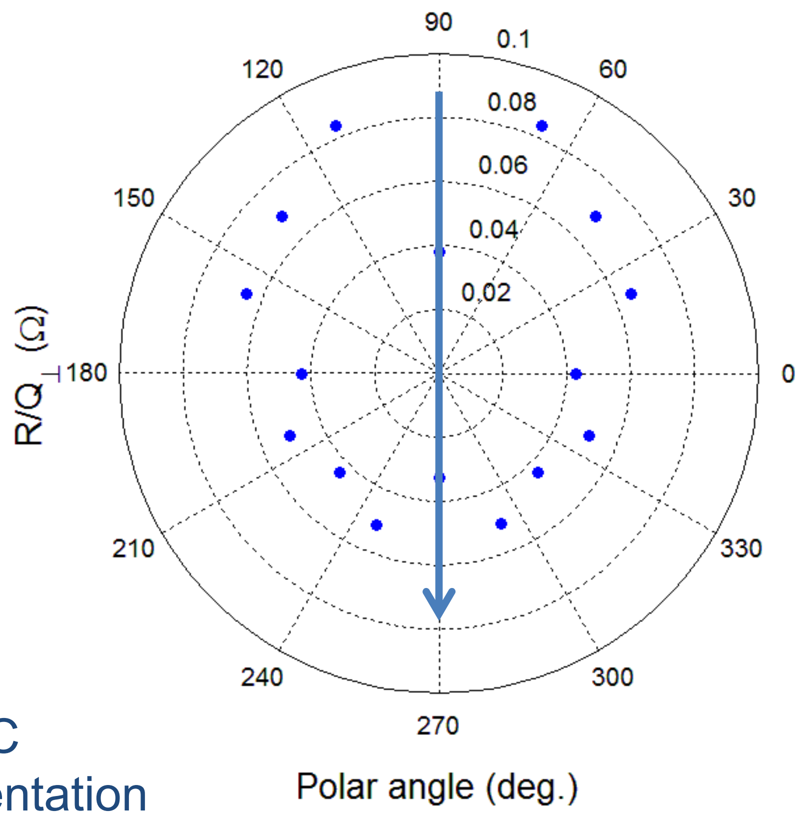


- 21 integration paths to calculate $R/Q_{\parallel}$
- Create a polar $R/Q_{\perp}$ map, here every 22.5 degrees
- Also probe $R/Q_{\perp}$ at different Δy to rule out meshing and numerical influences
- Circular map at arbitrary distance to again avoid mesh influences
- Here Δr= 5mm

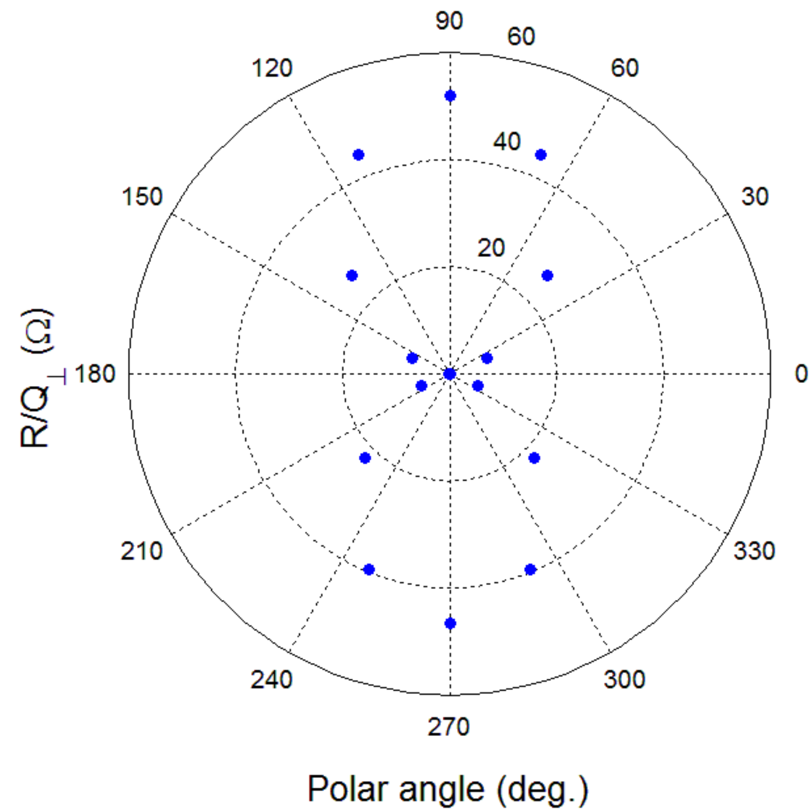
$$R_{\perp x} \approx \left| \frac{c}{\omega} \frac{\sqrt{R_{\parallel}(x_2)} - \sqrt{R_{\parallel}(x_1)}}{x_2 - x_1} \right|^2$$

Example modes

2.43 GHz Quadrupole mode
Small $R/Q_{\perp}$, but high Q_{ext}



1.7 GHz Dipole mode
Large $R/Q\perp$, but low Q_{ext}



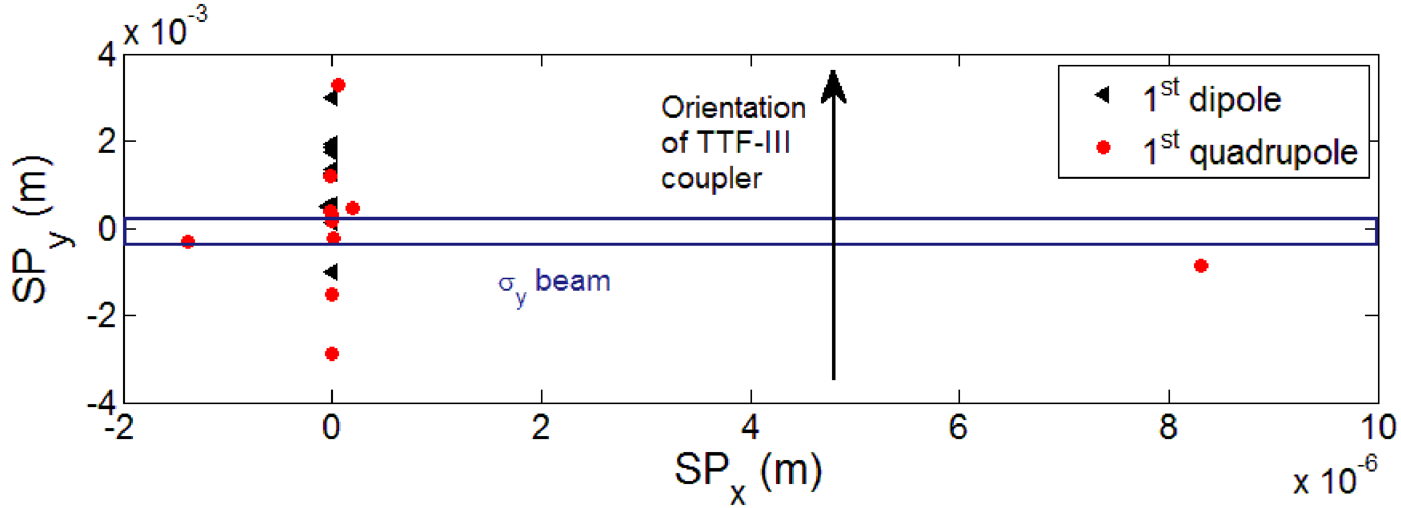
FPC orientation

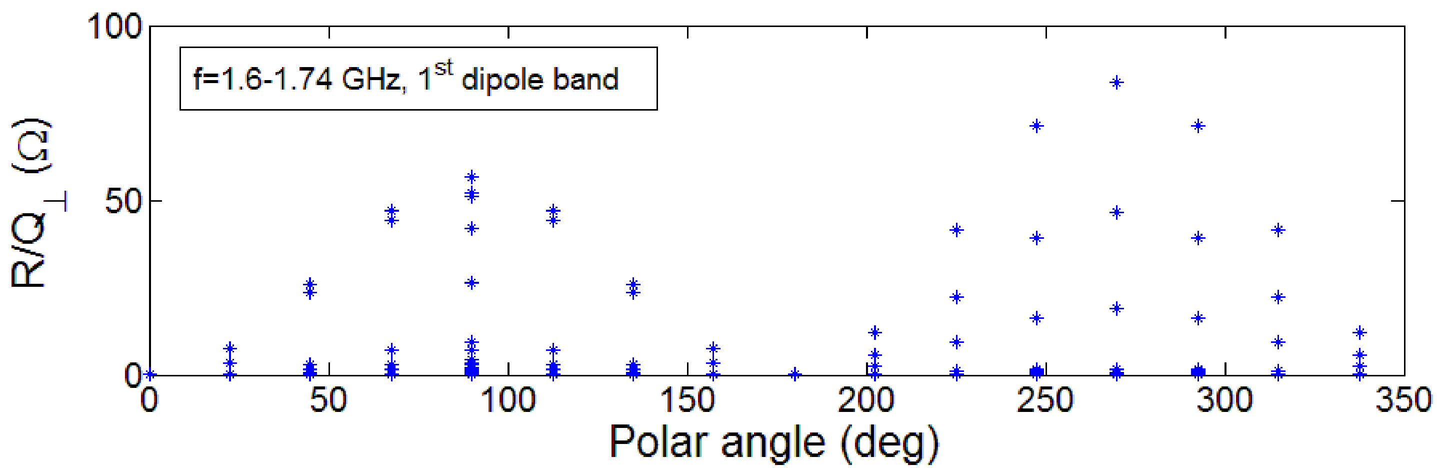
asymmetric
"Butterfly" distribution

fairly symmetric

Polar FFT or multipole expansion to determine contribution of each pole

Shift of mode's e-m center with respect to beam axis



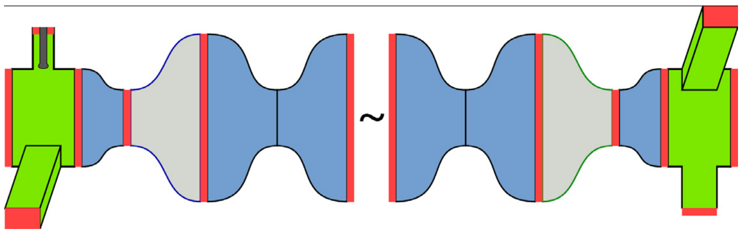


Mode's center shifted by more than vertical beam size σ_y in FPC direction

What now?

- We are facing three problems to solve:
  1. Residual $R/Q_{\perp}$ components on axis for quadrupole modes
     → further studies with different meshes and varibale FPC positions needed
  2. Solve problem of most dangerous modes by tuning HOMs to lower Q_{ext} while still preserving TM_{010}-π properties

     High computational effort so far: Apply CSC scheme of segmented cavity (see WEP17, T. Galek et al.)

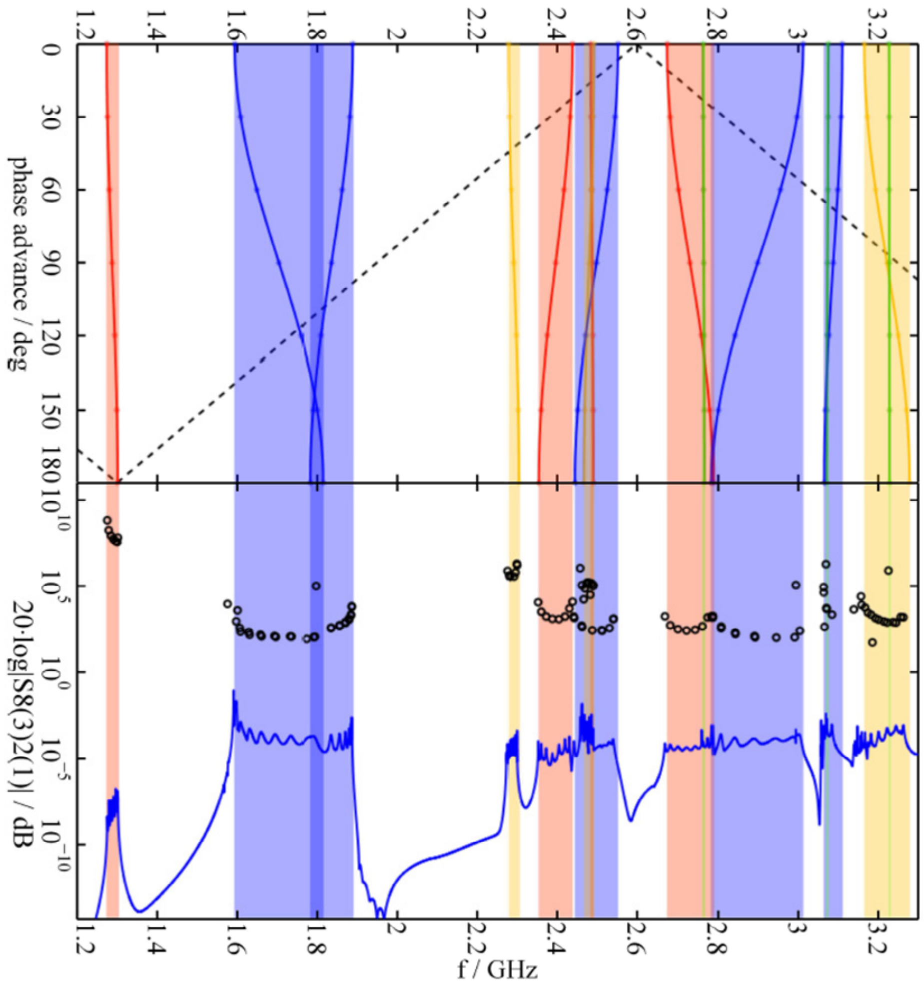


Allows 2-D calculation of the symmetric parts
Compute S-parameters of all sub-structures and concatenate the results

Fields and R/Q to be calculated by 2-D Eigenmode Solver (MAFIA)
Extract the Q_{ext} by Vector Pole Fitting of the resulting S_{21} curve

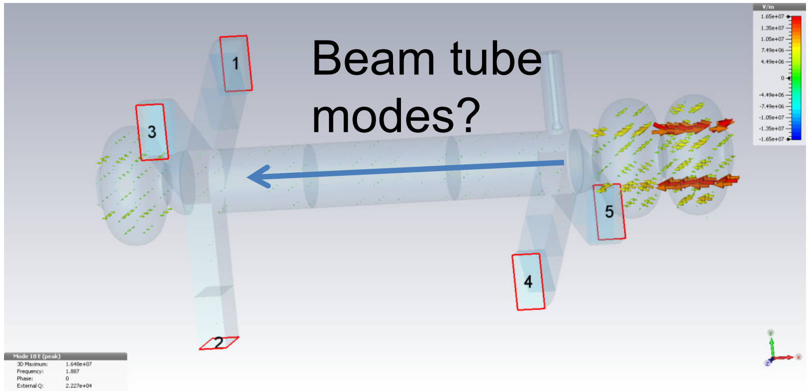
CSC for HOM tuning + Cavity string analysis

Full Brillion diagram by computing with periodic boundary conditions under 0 and π cell-to-cell phase shift



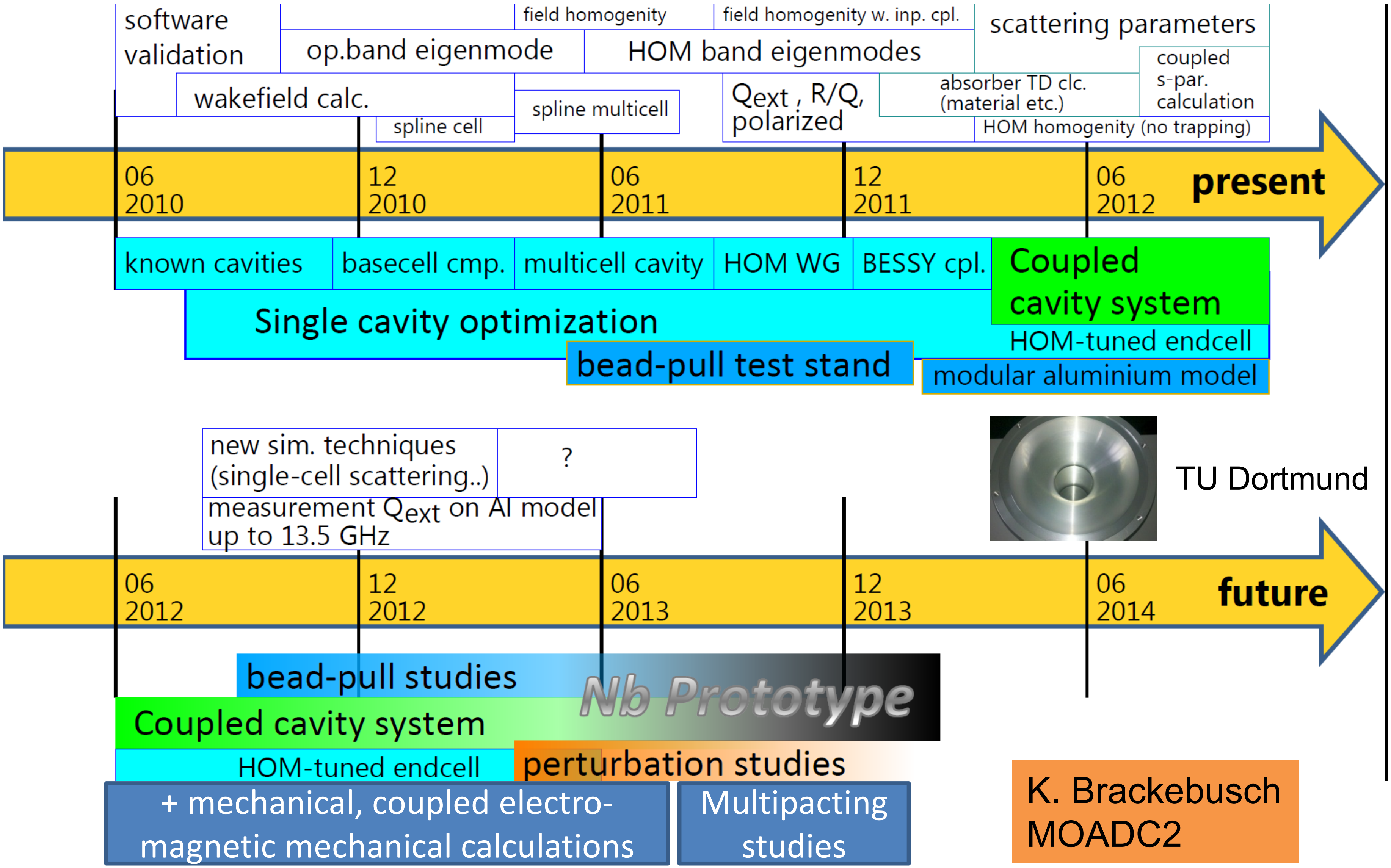
T. Galek, WEP17

- First dipole already propagates to next cavity's WG structure
- Need to compute coupled structure of three cavity string
- Apply CSC method or Lumped Equivalent Circuit Model: see T. Flisgen et al, THACI1



3. Modes above cutoff propagating

Future plans: Tune HOMs → prototyping



That's it

Thank you for your attention and many thanks to all people involved:

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* now μMuons Inc., $^+$now at CERN

Colliding ship experiment under crossing angle α observed in Warnemünde

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Jefferson Lab Thomas Jefferson National Accelerator Facility