Design of a compact Ka-Band Mode Launcher for High gradient Accelerators

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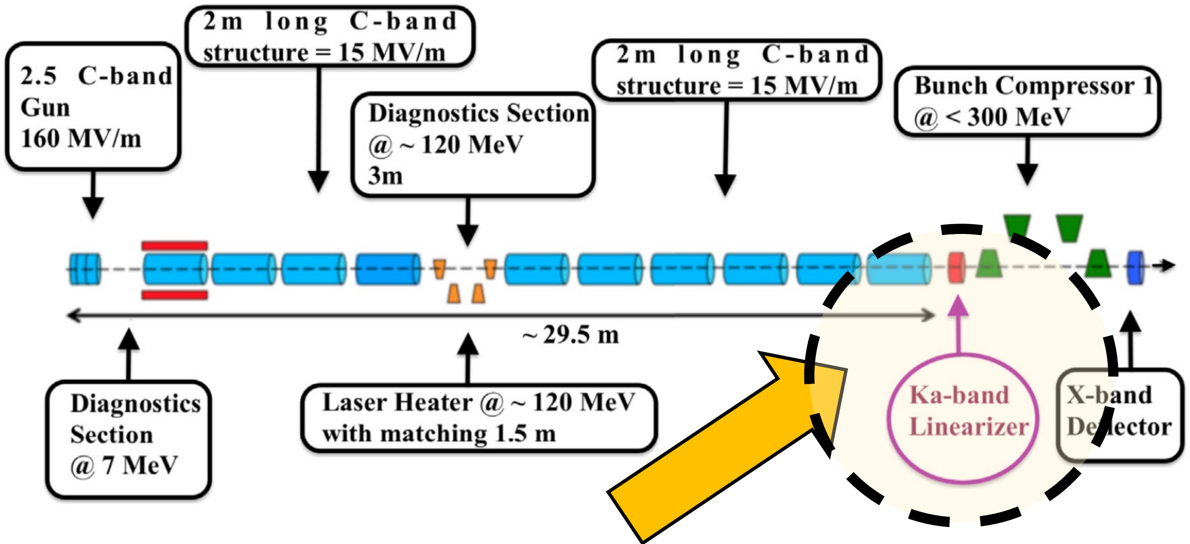
Introduction and Motivation

- Strong demand for accelerating structures able to achieve **higher gradients** and more **compact dimensions**

[M. Behtouei et al; NIM A: 984, 2020, 164653, https://doi.org/10.1016/j.nima.2020.164653.]



- ultra-high gradient higher harmonic RF accelerating structure is needed for the **linearization of the longitudinal phase space**.

State of ART: SW Ka-Band linearizer

[M. Behtouei, L. Faillace, B. Spataro, A. Variola, M. Migliorati, "*A SW Ka-Band linearizer structure with minimum surface electric field for the compact light XLS project*", NIM A: 984, 2020, 164653, https://doi.org/10.1016/j.nima.2020.164653.]

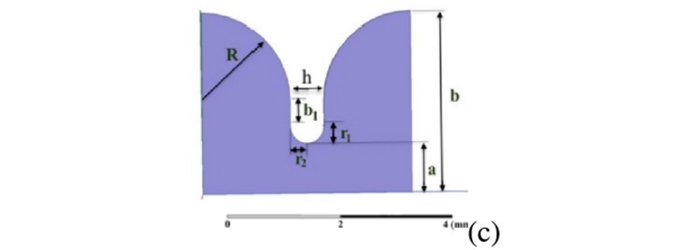


Table 1
Parameters list for the cavity design.

Design parameters	
Frequency [GHz]	35.982
Average accelerating Electric Field [MV/m]	100
Axial length[cm]	8
Number of cells	20
Iris Aperture diameter [mm]	2
On-axis peak decelerating electric field [MV/m]	133
Ratio of phase to light velocity (v_ϕ/c)	1
Pulse charge [pC]	75
Rms bunch length ($\sigma_\tau(fs)$)	350
Pulse repetition rate frequency [Hz]	1–10

- **preliminary RF design** of a table-top Ka-Band LINAC operating at ~35 GHz. ✓
  - Accelerating structure choice ✓
  - Accelerating structure design ✓

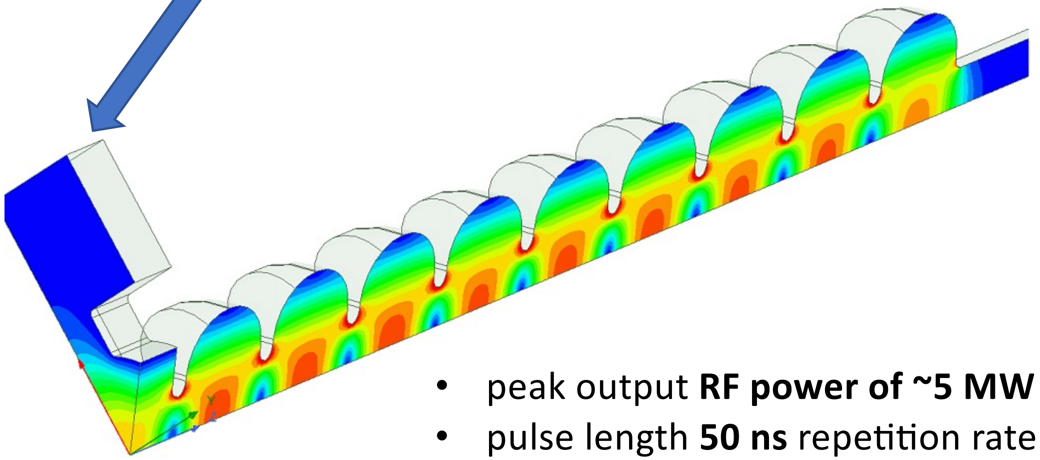
Design of a compact Ka-Band Mode Launcher

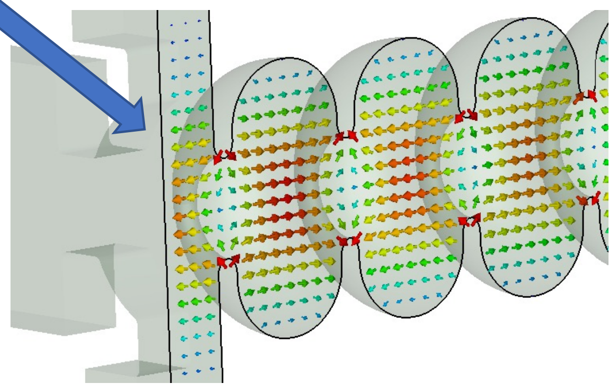
This work is focused on:

RF coupler design

Optimization of geometry in terms of

reflection coefficient**, field **flatness**, field **azimuthal symmetry

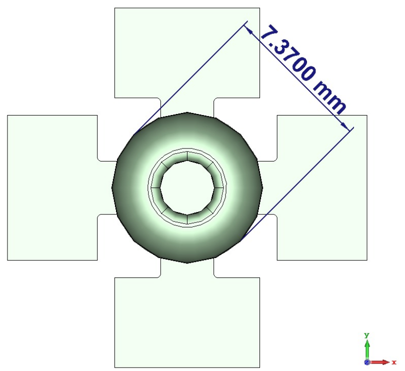




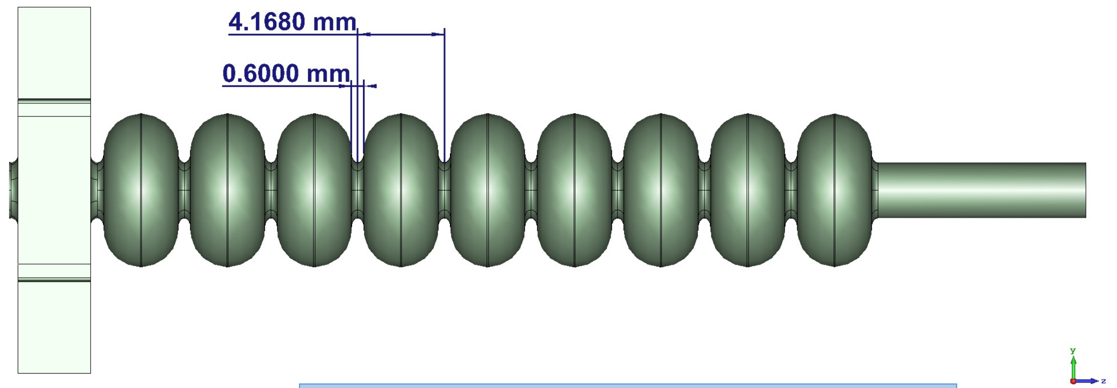
- peak output **RF power of ~5 MW**
- pulse length **50 ns** repetition rate up to 100 Hz
- **Ka-Band** linear accelerator at very high accelerating gradients **(above 100 MV/m)**.

RF Design: Geometry

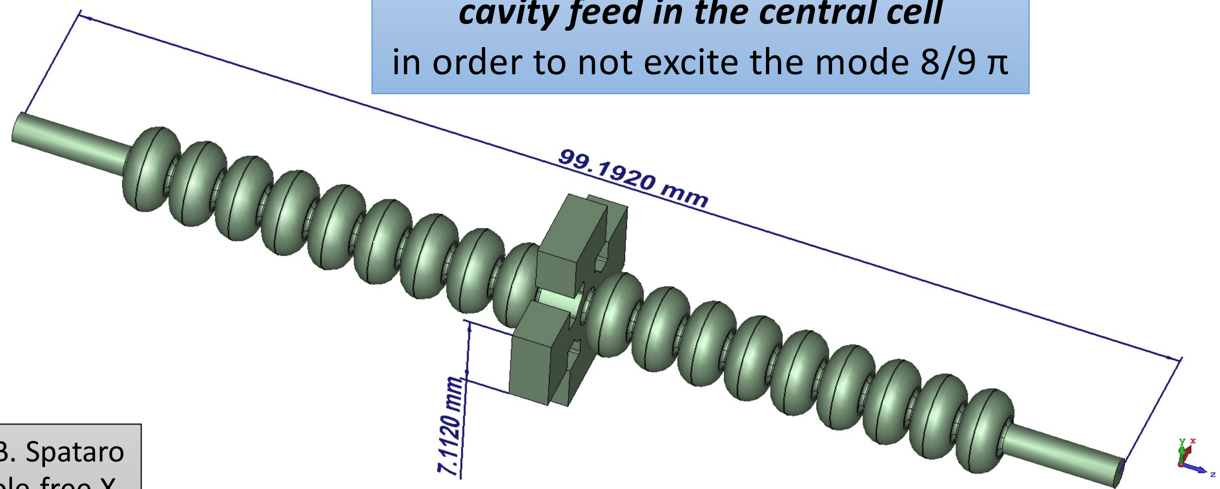
The structure comprises **four WR28 rectangular-TE10-to-circular-TM01 transitions**



The total structure (19-cells) length is equal to **99.1926 mm.**



cavity feed in the central cell
in order to not excite the mode 8/9 π

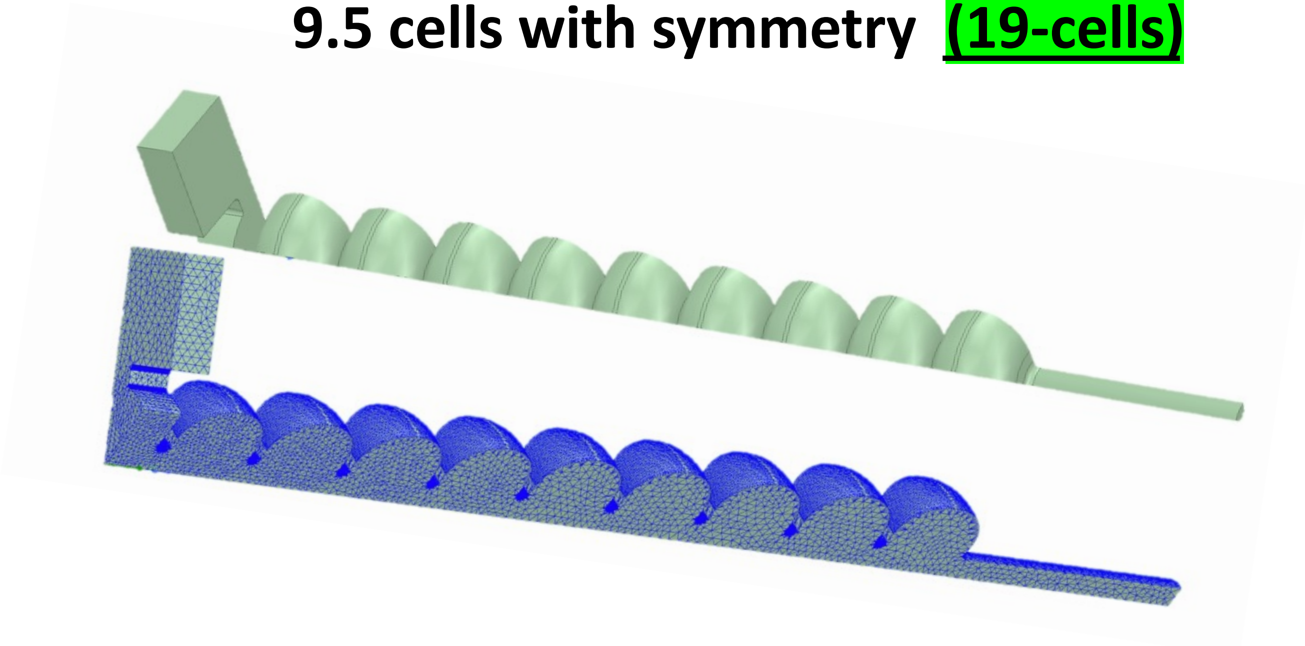


[G. Torrisi, G. S. Mauro, G. Sorbello, G. Castorina, L. Celona, L. Faillace, B. Spataro and V. Dolgashev, (2020). RF design and experimental test of a quadrupole-free X-band TM 01 mode launcher. URSI Radio Science Bulletin. 22-27. 10.23919/URSIRSB.2020.9318433]

HFSS Simulations: Numerical Simulation

The numerical optimization has been performed in the case of **iris radius** ***a*** **= 1 mm** and ***a*** **= 1.333 mm.**

9.5 cells with symmetry **(19-cells)**



Numerical Simulation

Objectives		**PARS**
Resonant Frequency f=35.98 GHz	→	Radius of Acc. cells R_c
Matching S_{11}<-30 dB	→	width, position of coupling slot
Flatness ~few %	→	Radius of Acc. cells R_c

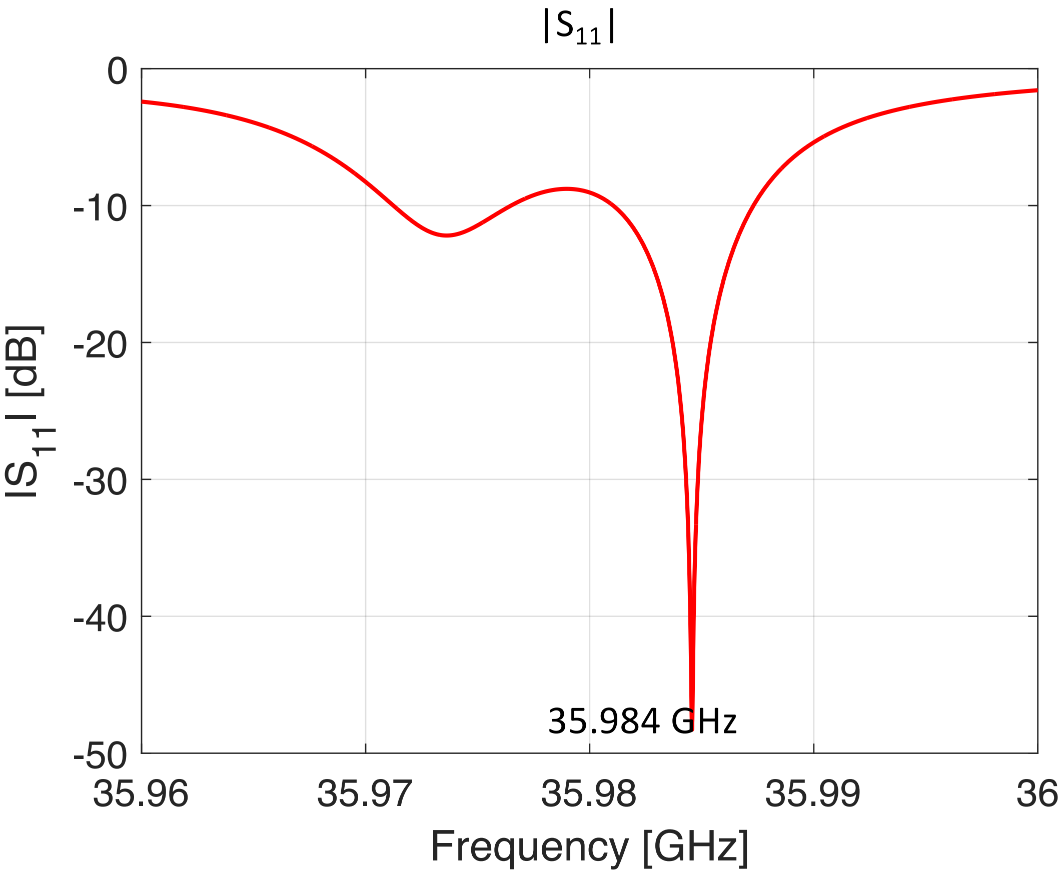
RESULTS: iris radius *a* = 1 mm

Resonant Frequency
f=35.98 GHz ✓

Matching
S_{11}<-30 dB ✓

Δf=10 MHz x

- Rc_coupling cell= 3.126 mm
- w_slot= 1 mm
- h_slot= 0.533 mm



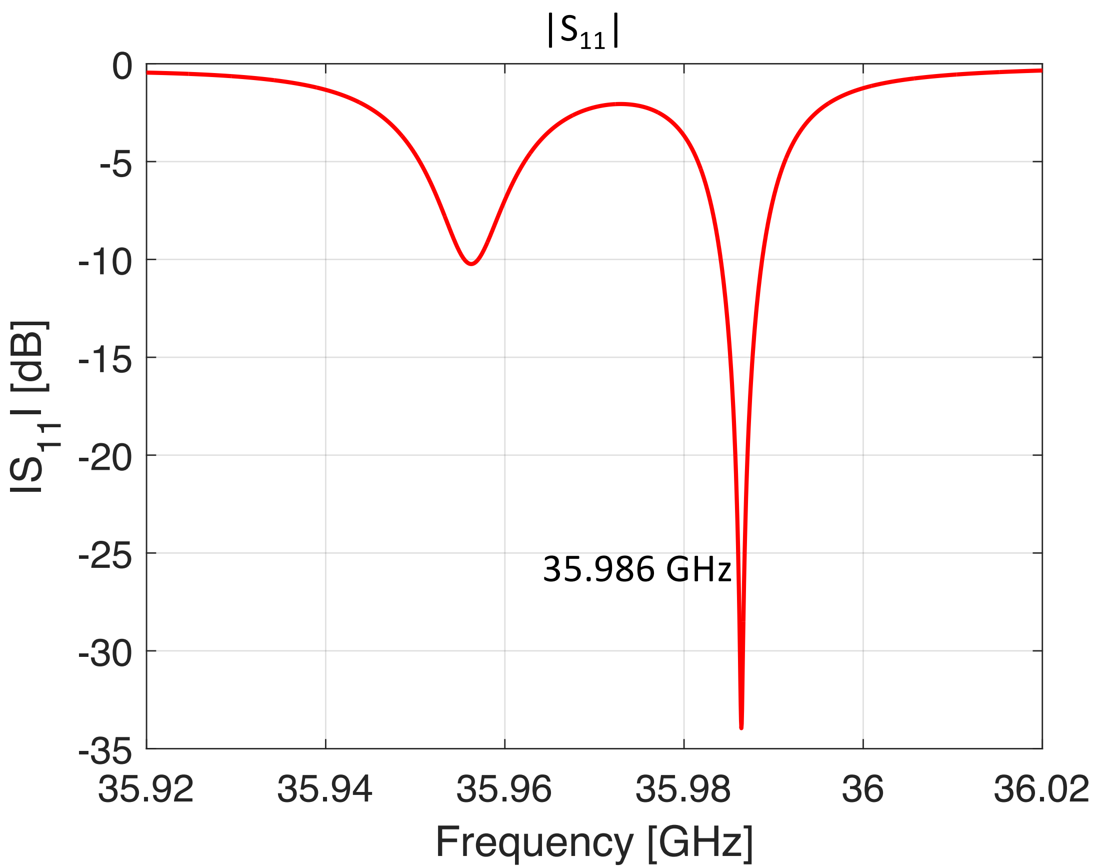
RESULTS: iris radius *a* = 1.333 mm

Resonant Frequency
f=35.98 GHz ✓

Matching
S_{11}<-30 dB ✓

Δf=30 MHz ✓

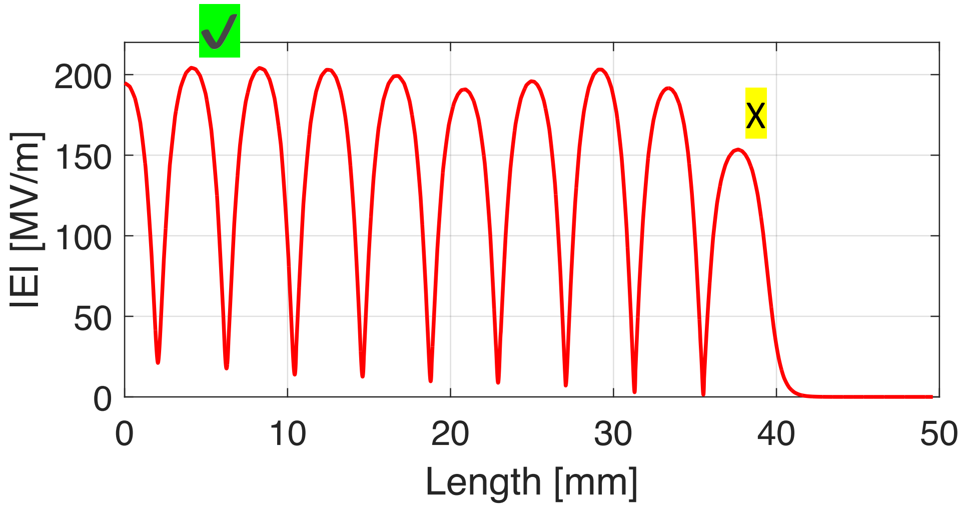
- Rc_coupling cell= 3.103 mm
- w_slot= 1.3 mm
- h_slot= 1.24 mm

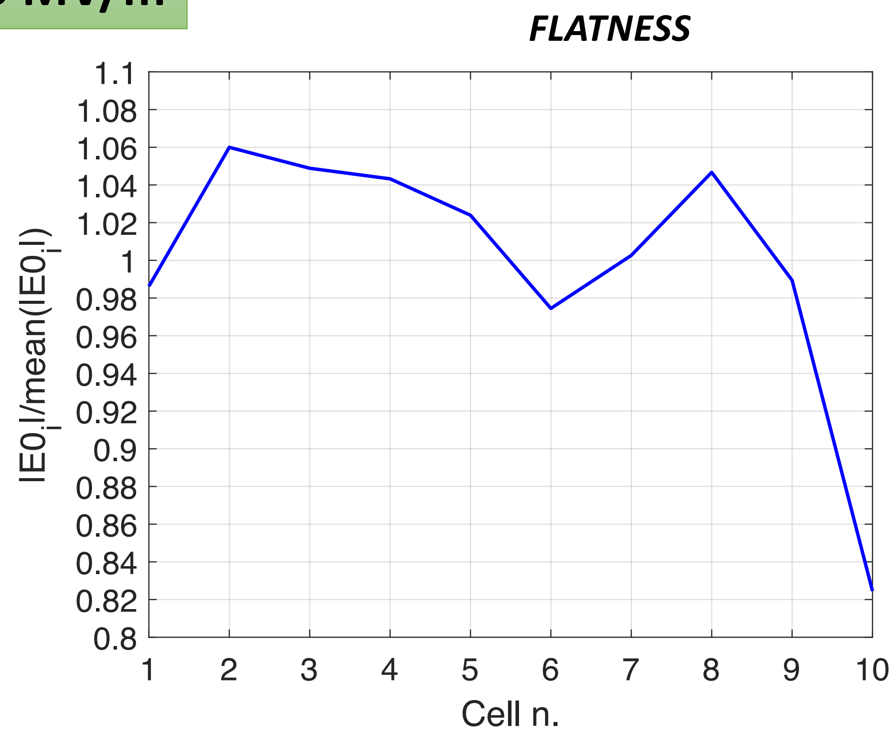


FLATNESS @ a = 1 mm

G= 115 MV/m

Electric field on axis at the
π-mode resonant frequency (HFSS simulations).





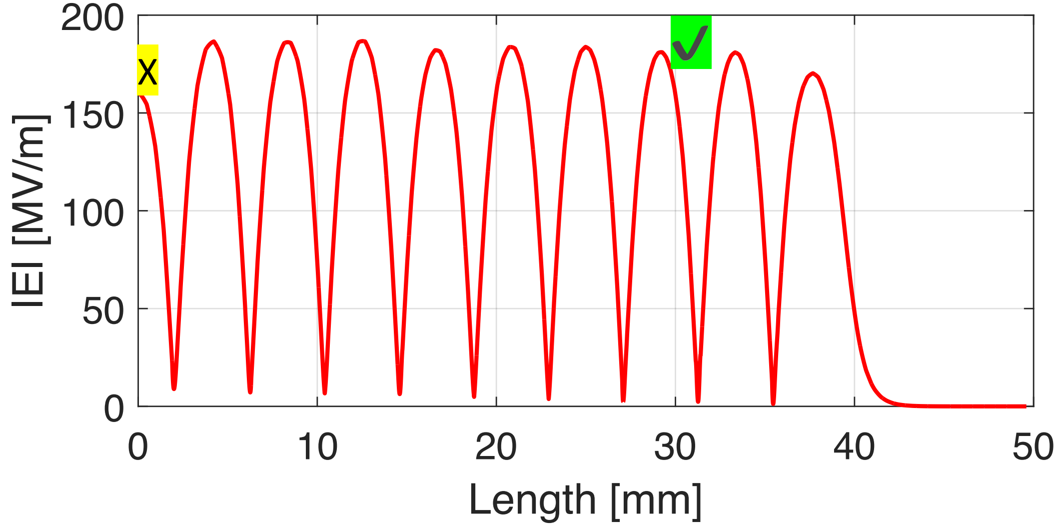
FLATNESS from +-4% (w/o last cell) to +-12% (with last cell)

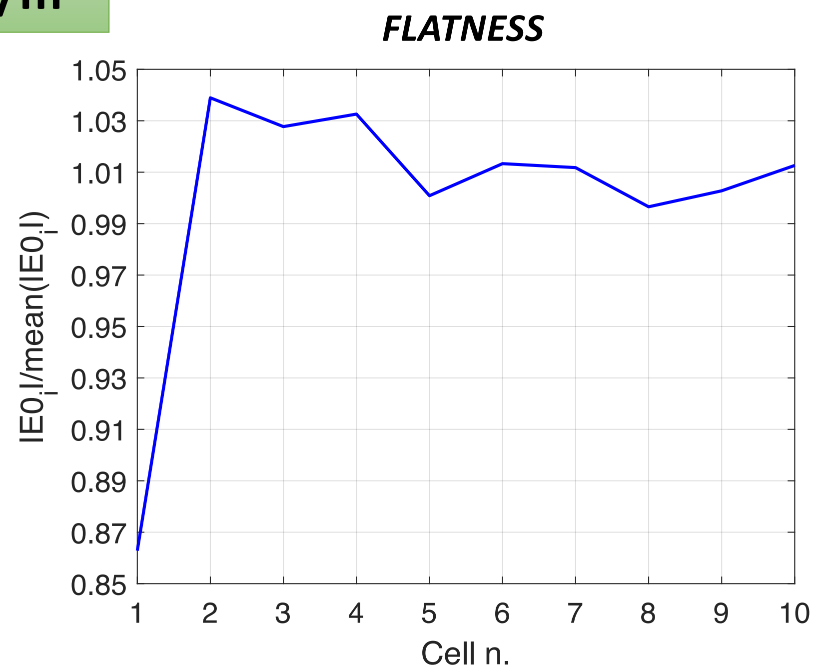
Field flatness has to be improved by slightly reducing **the end cells** radius, and tuning.

Flatness @ *a* = 1.333 mm

Electric field on axis at the
π-mode resonant frequency (HFSS simulations).

G= 102 MV/m





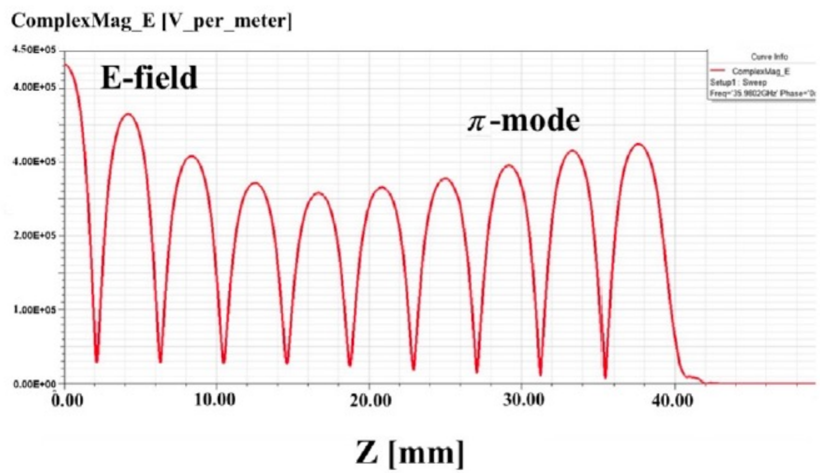
FLATNESS from +-2% (w/o first half-cell)
to +-8.7% % (with first half-cell)

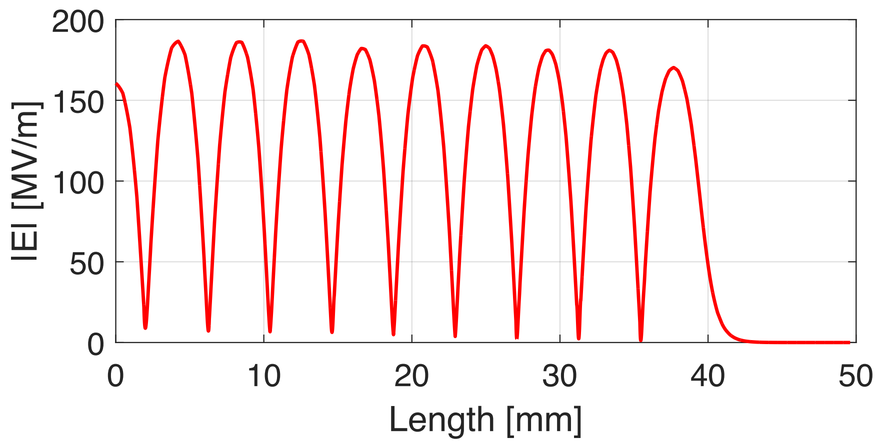
Field flatness has to be improved by slightly reducing **the coupling cell** radius, and tuning

PROGRESS *ON* FLATNESS

[A SW Ka-Band ***linearizer*** structure with minimum surface electric field for the compact light XLS project
M. Behtouei a,∗, L. Faillace a, B. Spataro a, A. Variola a, M. Migliorati b.]

[this Conf. Proceeding]





RF PULSED HEATING STUDY

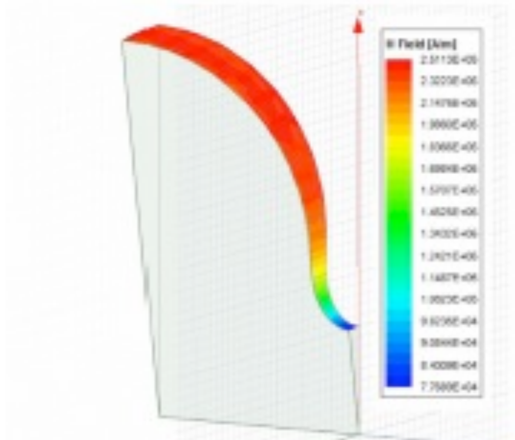
[B. Spataro, workshop in California @ SLAC]

a) Magnetic field magnitude

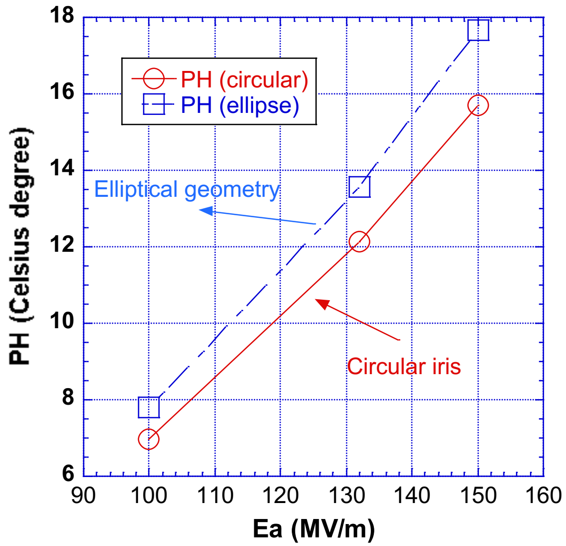
50 ns RF flat top

1mm iris aperture radius

0.667 mm iris thickness



https://indico.cern.ch/event/948498/contributions/3985617/attachments/2092926/3517033/Spataro_Sw_K-band_Updates.pdf

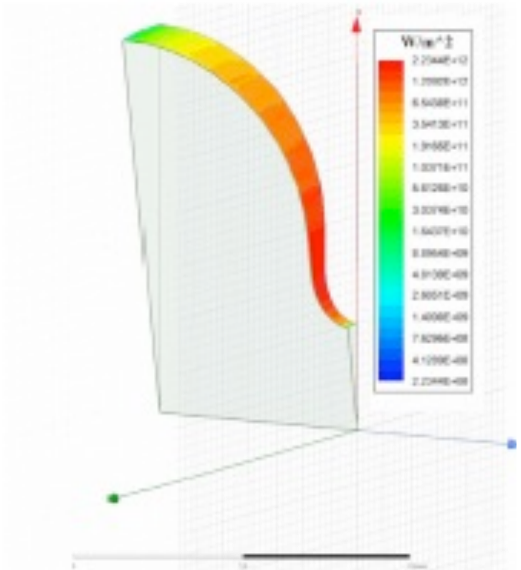


@ 132 MV/m the PH is about 13.6 Celsius degree for the elliptical iris against of 12 Celsius degree than the circular one.

The safety threshold is estimated to be about 50 Celsius degree (SLAC-CERN)

RF PULSED HEATING STUDY

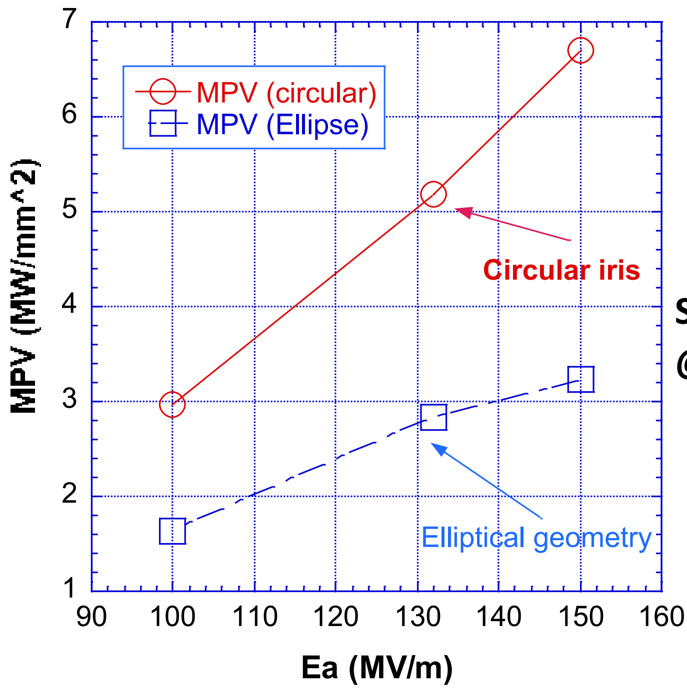
[B. Spataro, workshop in California @ SLAC]



b) Modified Poynting Vector (MPV)

https://indico.cern.ch/event/948498/contributions/3985617/attachments/2092926/3517033/Spataro_Sw_K-band_Updates.pdf

50 ns RF flat top **1mm iris aperture radius** **0.667 mm iris thickness**



Safety threshold Sc < 6.3 MW/mm^2 @50ns RF flat top (CERN-SLAC)

@ 132 MV/m the MPV is 3 MW/mm^2 for elliptical iris against of 5 MW/mm^2 than the circular one.

RF PULSED HEATING STUDY

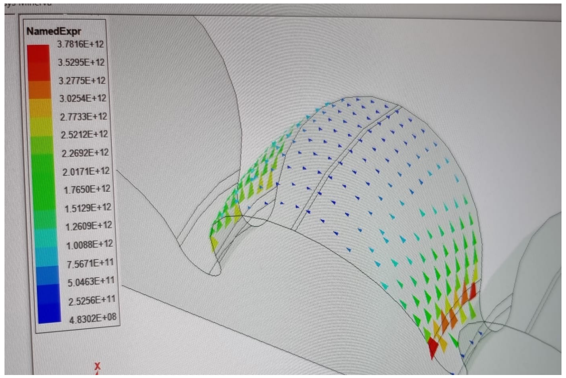
$$\Delta T[°\mathrm{C}] = 127 \left| H_{\parallel}[\mathrm{MA/m}] \right|^2 \sqrt{f_{RF}[\mathrm{GHz}]} \sqrt{t[\mu\mathrm{s}]}$$

On the cell: ✓

- **ΔT= 17.44 °C for** *a* =1 mm ✓
- **ΔT= 20.86 °C** for *a* = 1.333 mm ✓

On The Input coupler: X

- **ΔT= 76 °C for** *a* =1 mm X
- **ΔT= 83. 47°C for** *a* = 1.333 mm X

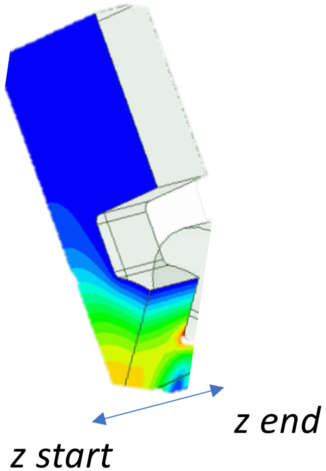


modified Poynting vector

S_c=3.78 MW/mm^2 @ 102 MV/m ✓

Harmonic Analysis Ka-band Coupler, a = 1.33 mm
Discrete Fourier Coefficient

	M1	M2	M4	M8
1 port	7.9305e-04	8.5099e-4	1.2041e-5	1.8054e-5
2 ports	2.2718e-18	2.6565e-4	5.1880e-5	2.9473e-7
4 ports	1.9052e-16	1.1989e-16	0.0168	4.6767e-4



$$V_{\mp}(r,\theta) = \int_{z_{start}}^{z_{end}} E_z(r,\theta,z)e^{\mp ik_0 z}\mathrm{d}z,$$

$$M_{\mp,s}(r) = \frac{1}{\sqrt{n}}\Sigma_{j=1}^{n} V_{\mp}(r,\theta_j)e^{2\pi i(j-1)s/n},$$

[A. Cahill et al;, *"TM01 Mode Launcher for Use in High Brightness Photoguns", 7th IPAC2016"*

($r = R_c/8$
$\boldsymbol{\theta}_j$ step=5°)

Next steps

$$B_\phi(r,\phi,z) \cong A_0(z)r + \sum_{n=1}^{\infty} A_n(z)\cos(n\phi)\, r^{n-1}$$

- consider the quadrupole component of the magnetic field

- **mechanical layout to** simplify future manufacturing to reduce fabrication costs and reduce the probability of RF breakdown

- **further optimization are needed to improve the flatness and reduce the pulse heating**

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THANK YOU!!

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