# XLS – Ka Band Linearizer

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On behalf of WP3 – D3.4 working group,
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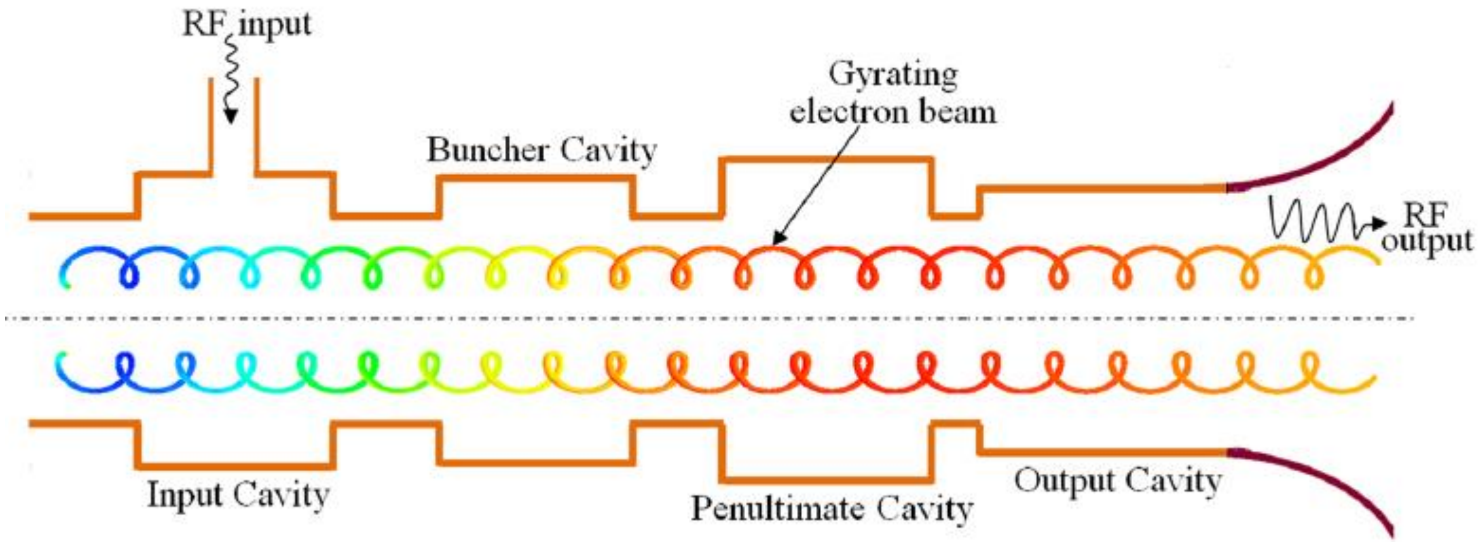
# Outline

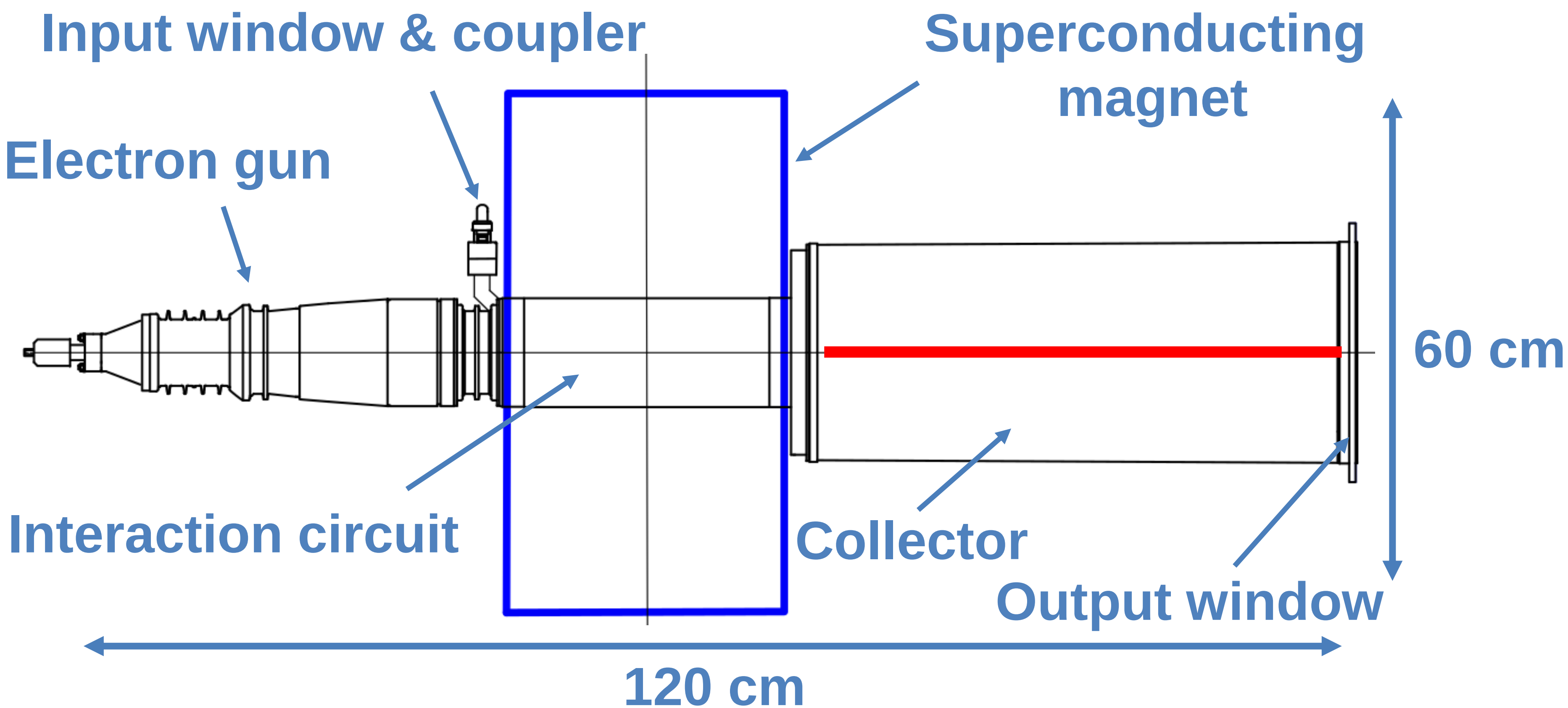
- **Ka-Band RF sources:**
  - **Gyro-klystron.**
  - **Multi-Beam klystron.**
- **Pulse Compressor considerations.**
- **RF Network concepts.**
- **Structure options:**
  - **SW – cavity.**
  - **Cryo – Cu option.**
  - **TW – structure.**
- **Beam Dynamics remarks.**

# Options for a linearizer system @300 MeV

- Bunching in azimuthal direction, TE modes.
- Lower axial velocity due to the beam alpha results in larger cavity size.
- Operating frequency determined by the external magnetic field.
- Open output cavity, high power capability



# 36Ghz Gyro-klystron – Layout




**Output from axial direction,**
**Output mode TE02 in circular waveguide**

# Gyro-klystron for a linearizer system @300 MeV

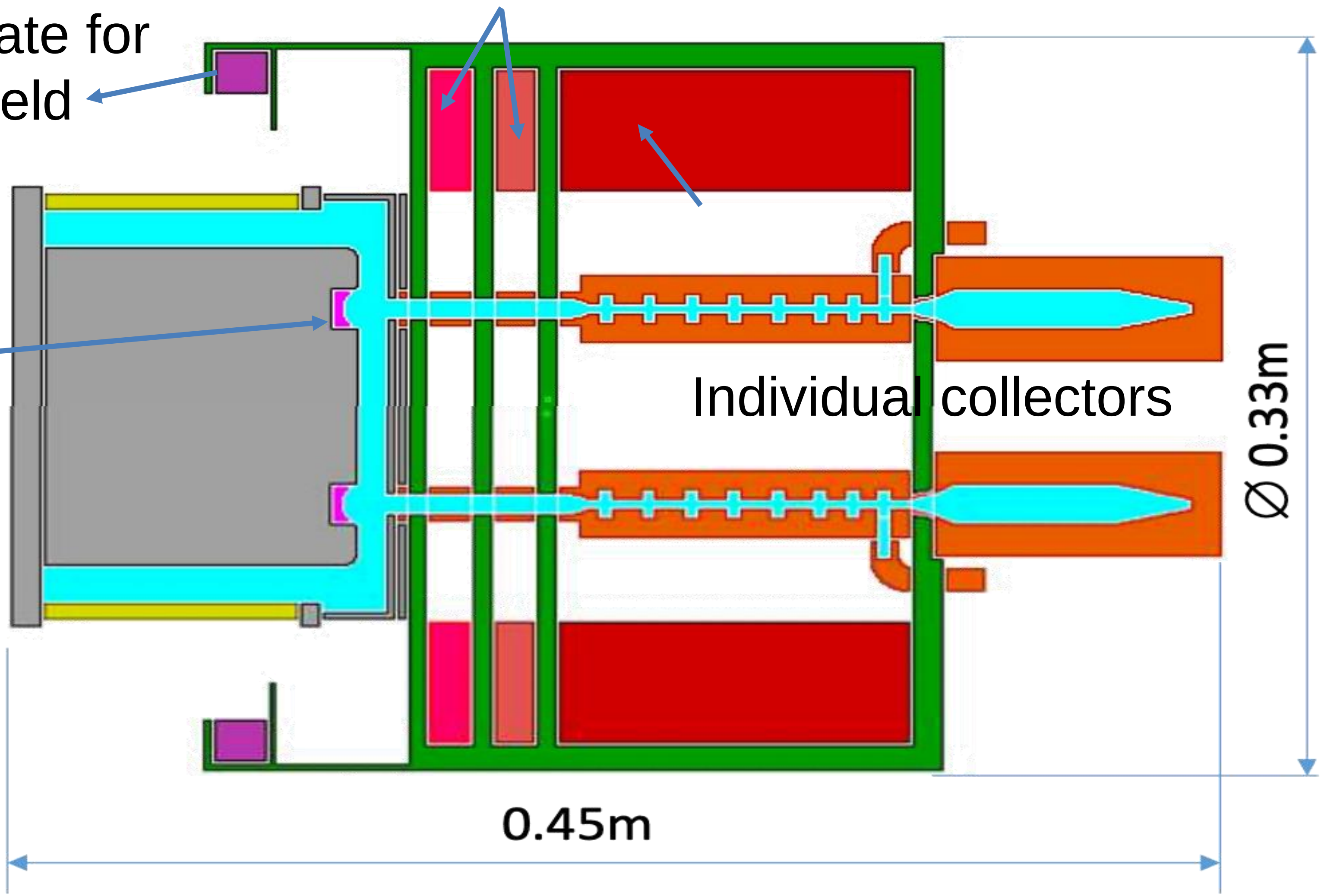
- τ=1.5μs, **f=1000Hz**；U=150kV；I=50A, η=40%；
- Electron beam power 7.5MW;
- **Output microwave power 3MW;**
- We ignore the loss power（for it is small);
- Power in the spent beam 4.5MW;
- Average spent beam power >6.75kW；
- Collector design for full electron beam power 7.5MW; Average spent beam power 15kW；
- Structure optimized for higher average power capability with fins;
- Average power 4.5kW, the temperature of window <40℃;
- Solenoid field (SC) 1.5 T.

# 36GHz Multi-Beam Klystron Topology

Amend coils to further confine the beam

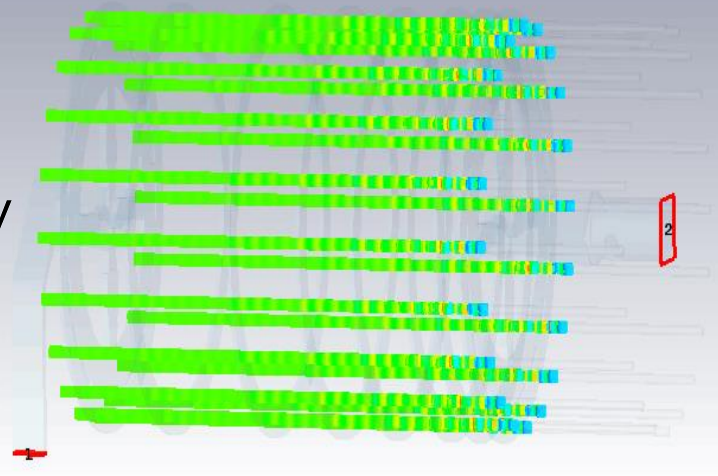
Compensate for B-field shield

Small electron Gun for primary convergence



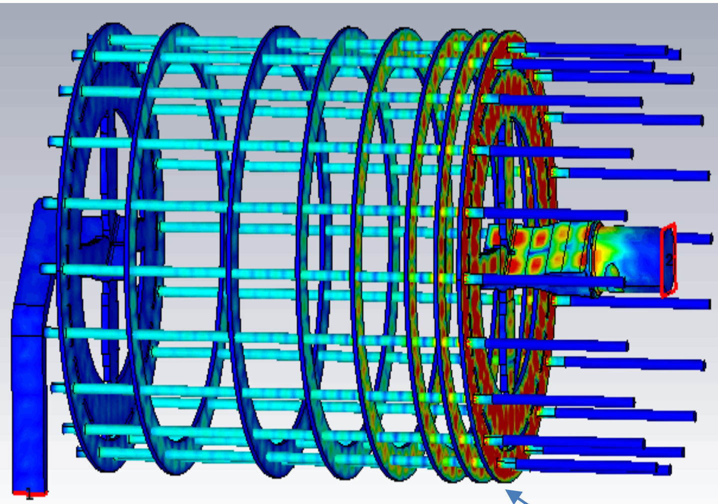
# 36GHz Multi-Beam Klystron

V beam = 60kV
I beam = 6A



Pin=200W

Pout=2.57MW
Eff. = 35.6%



Emax~90kV/mm

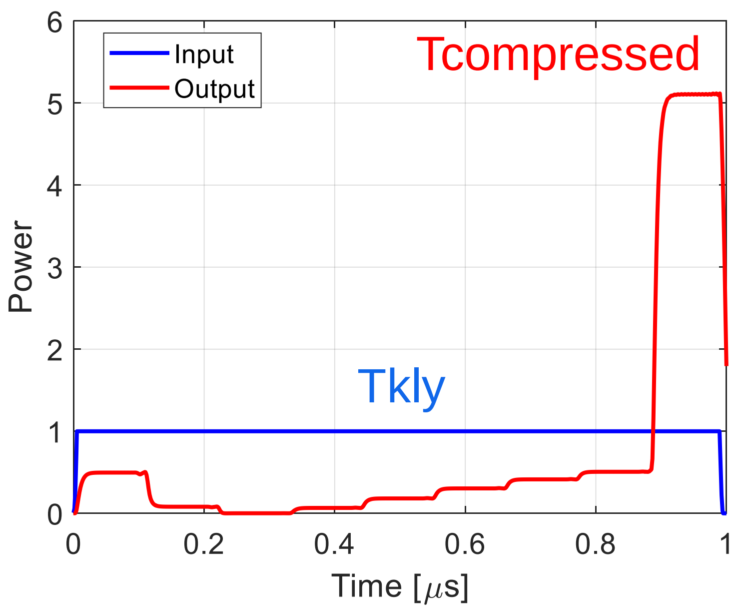
| Parameter | Value | Unit |
|---|---|---|
| Voltage | 60 | kV |
| N beams | 20 | -- |
| Current/beam | 6 | A |
| Current/total | 120 | A |
| **Power in saturation** | **2.57** | **MW** |
| RF efficiency | 37.5 | % |
| Power gain | 41 | dB |
| -3dB Bandwidth | 50 | MHz |
| Solenoidal field | ~0.2 | T |
| Total tube length | 0.45 | m |
| Max. cathode current density | 9 | $A/cm^2$ |
| RF pulse length | 1000 | ns |
| Max. rep. rate (diode mode) | <2 | kHz |
| **Max. rep. rate (RF mode)** | **<4** | **kHz** |

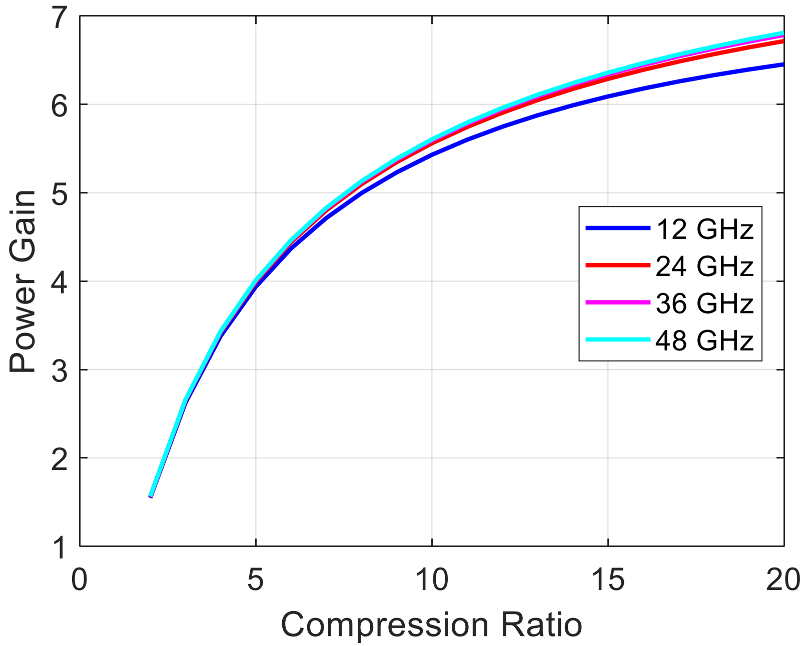
# 36GHz Multi-Beam Klystron

- GUN and Magnetic system design are almost finished. Ongoing optimizations to improve beam transmission.
- Preliminary design for Collector done, to be checked with full tube simulation in CGUN/KlyC.
- PIC simulation with practical beam optics imported from TRK will be done as a final verification (Cathode-RF circuit-Collector).
- Evaluation of the cooling circuit (feasibility analysis).

# Pulse Compressor - SLEDII

- Compression ratio= Tkly / Tcompressed.
- Similar gain curve at different frequencies:
  - Shorter structures => Higher compression ratio.
  - Longer Input pulse => Higher compression ratio.



# 36Ghz Gyro-klystron – Pulse Compressor transmission

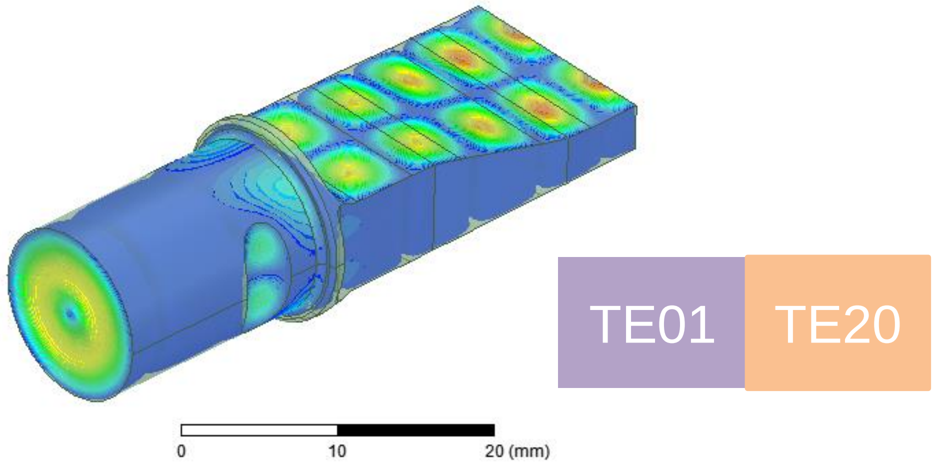
- Gyro-klystron baseline design is TE01/TE02 with TE02 output in circular waveguide.
- A transmission line system has also been validated.
- If PC requires a Gaussian mode, with a low loss HE11 mode transmission line. An alternative configuration can be achieved adding a quasi-optical mode launcher before the collector.
- Note: The TEM00 (fundamental Gaussian mode) has ~98% similarity with HE11 mode in corrugated waveguide and is regarded as the same mode in terms of the quasi-optical launcher design.

# Ka-Band Linearizer RF Network

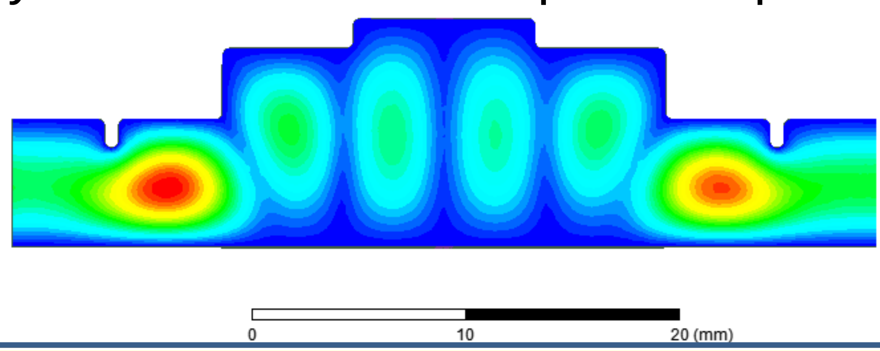
- Low RF losses waveguide system is strongly recommended to improve the RF power distribution efficiency.
- RF network at TE01 mode is the optimal.
  - Thorough control of the TE11 mode polarization in the various RF components is challenging.
- TE01 circular waveguide interface in all RF components is recommended to avoid contact-gasket problems in the system with high average power.
- X-band TE01 based RF components already designed and tested at CERN:
  - Direct scaling (x3) to 36 GHz will save lots of time.
  - Scaled down, the circular WG diameter is 12mm, with Ohmic losses of -0.255dB/m (5.7%/m).
  - For the long straight WG sections, diameter can be increased (matched taper) to 20 mm (-0.035dB/m; 0.8%/m).

# Ka-Band Linearizer RF Network

Basic building brick for the H01 devices is TE20 -> TE01 converter (A. Grudiev design).



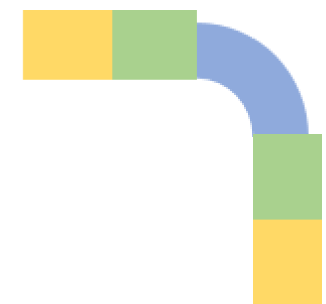

TE01 window with TW in ceramic (scaled from 12 GHz/ C. Serpico). Window diameter 21.8mm – very convenient for 3MW peak RF power.



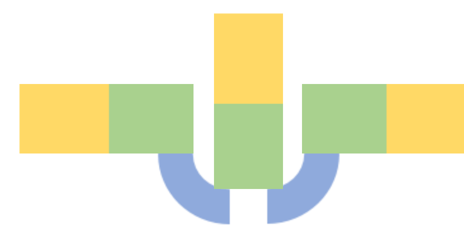

All the necessary TE01 RF devices can be quickly designed using TE20 -> TE01 converters.

3B hybrid

Bends

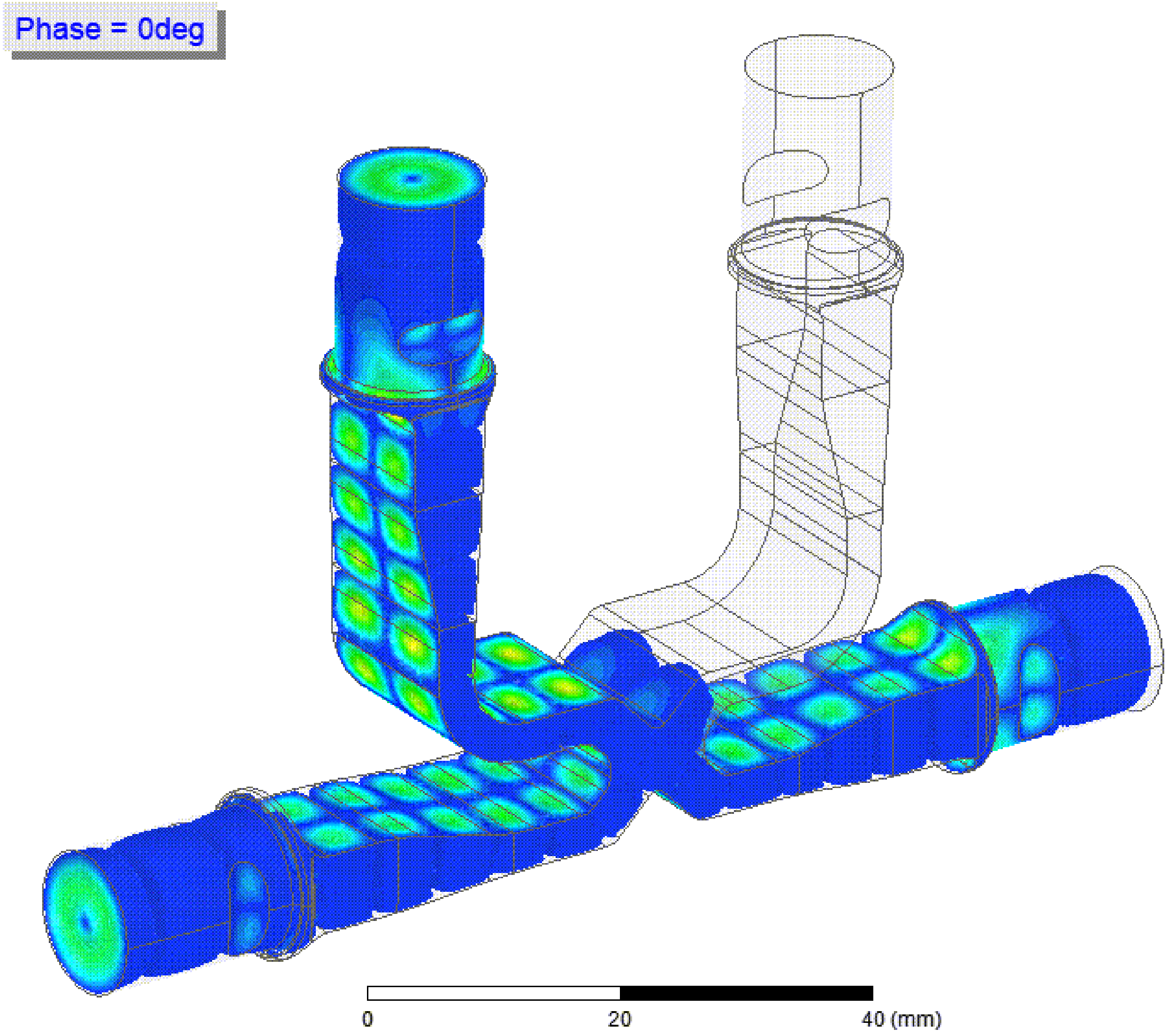


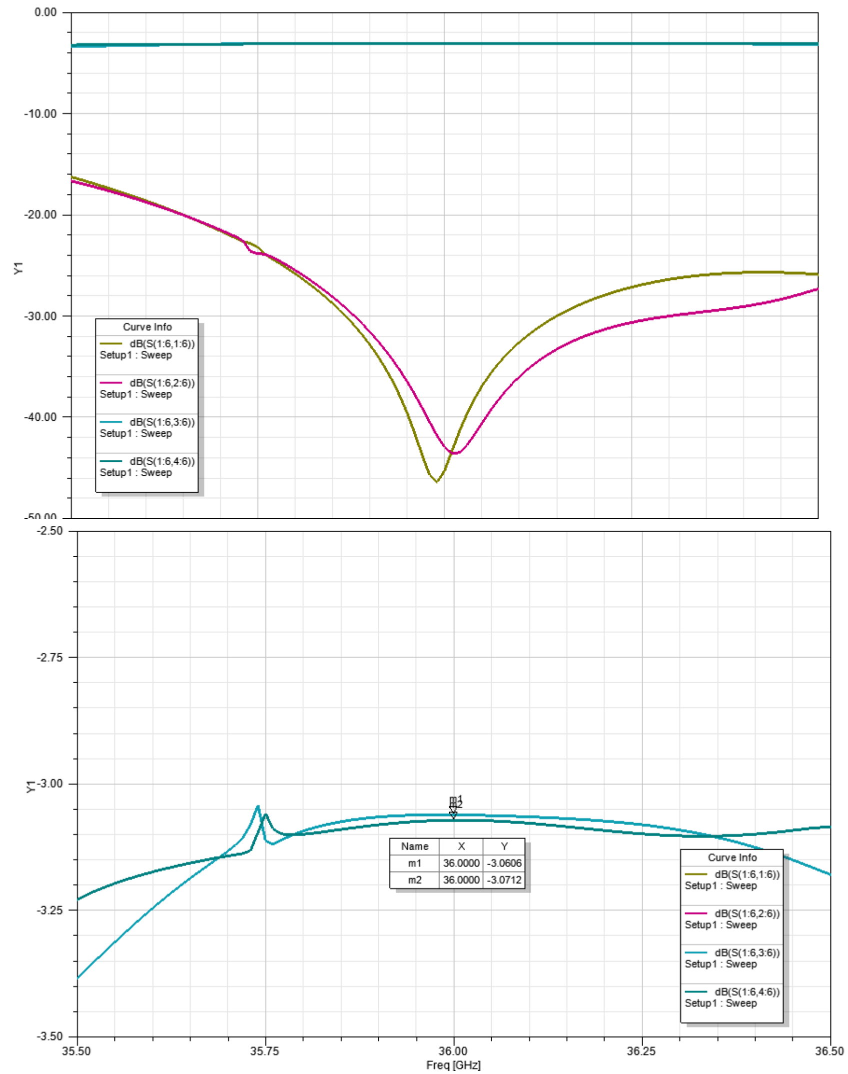
3dB splitters



… and others

# 3dB E01-H20 hybrid. Power head for PC and/or Klystron combiner



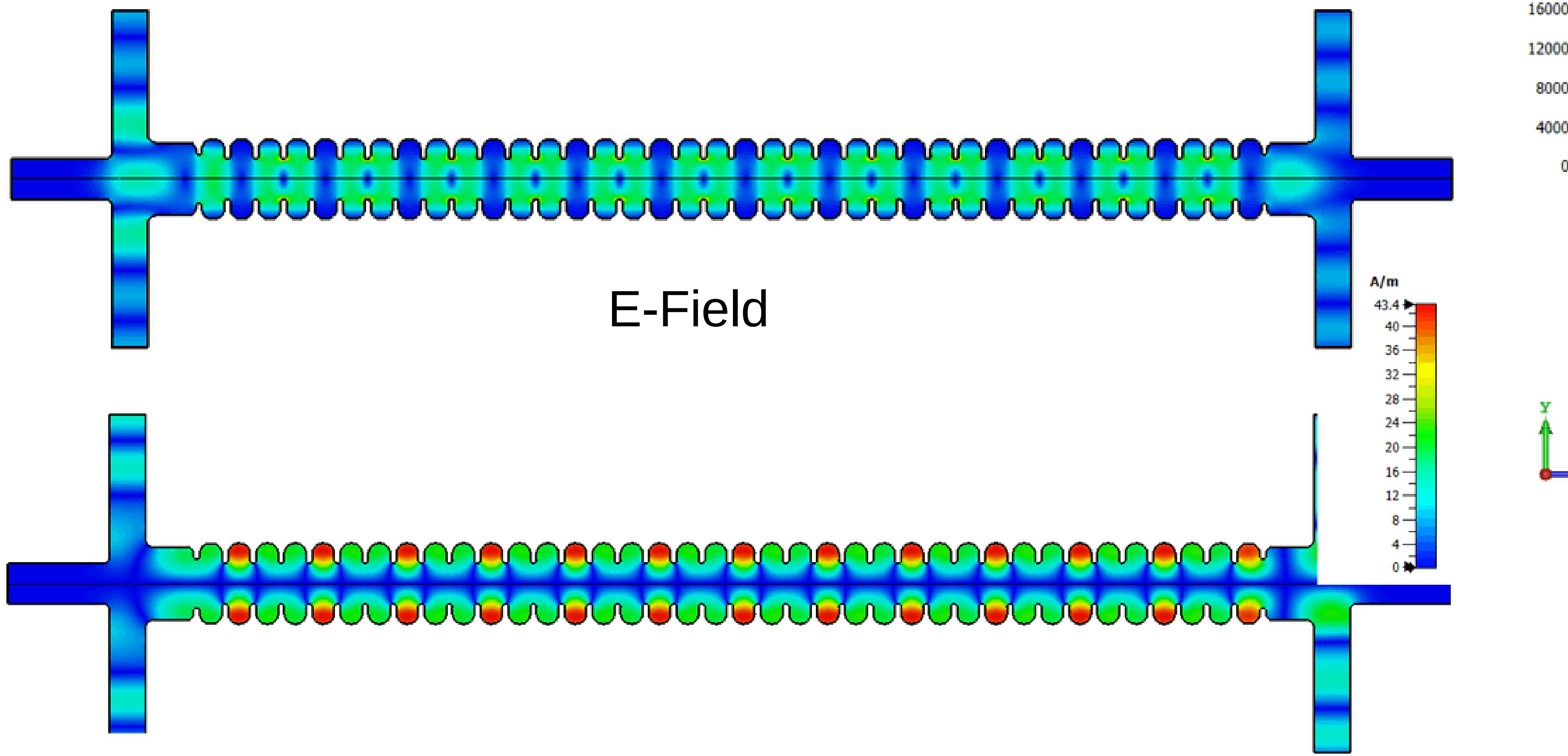



# Structure Options

- Ka-band SW solution.
  - Considers 12MW matched input power (w/SLED).
  - Integrated voltage of 11MV/section (10cm), see: link.
  - If higher voltage is needed, then multiple sections are needed (i.e. for 20MV, 2 sections suffice).
  - 2 structures + hybrid needed to avoid reflections to the source.

- SW in a cryo-structure (T=77K).
  - Considers 12MW matched input power (w/SLED).
  - Integrated voltage of 16MV/section (10cm).
  - Heat load and cryogenic capacity to be checked.

# 10cm (15cm effective) Travelling Wave Structure

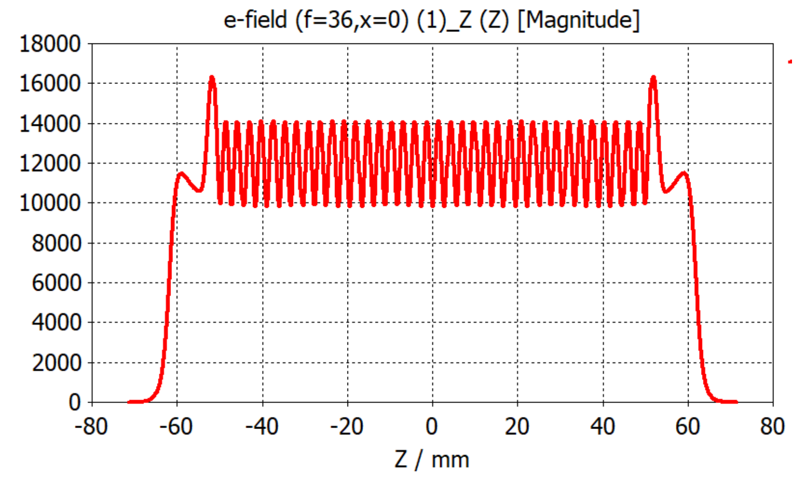


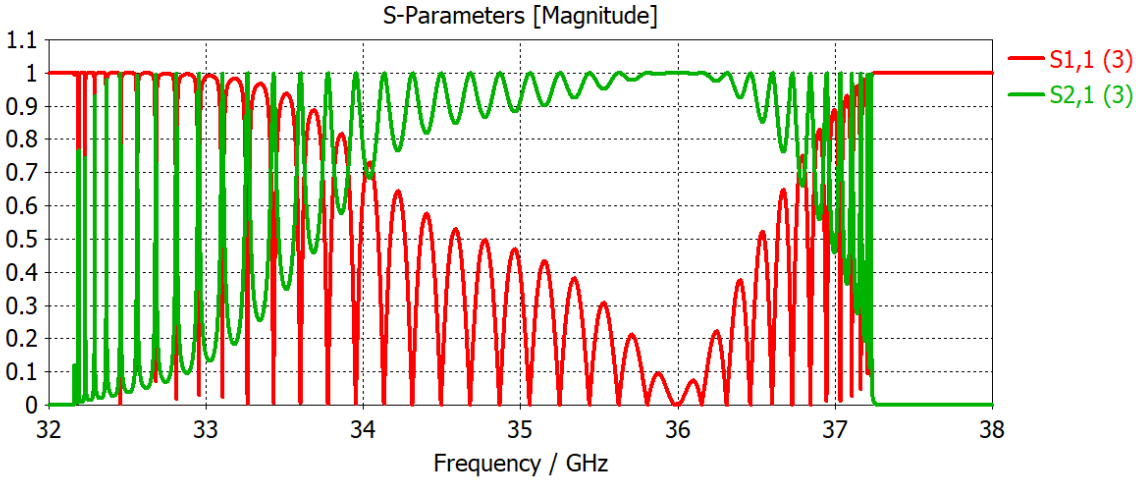

E-Field

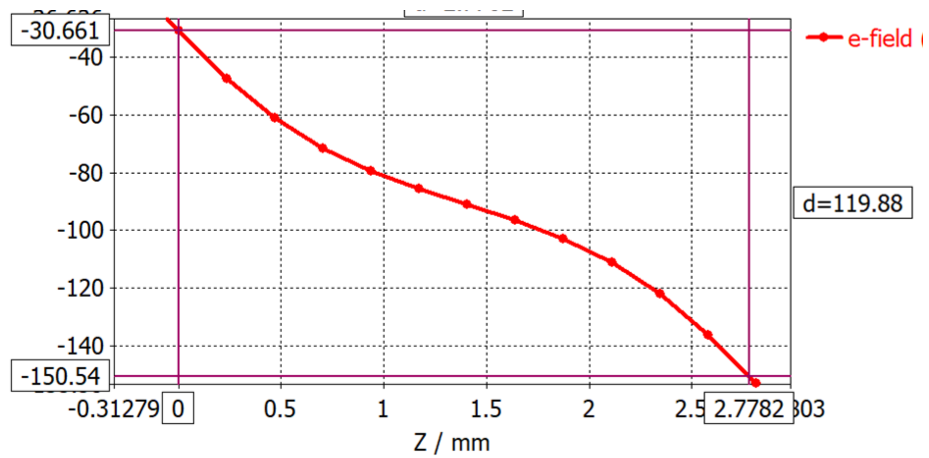
H-Field

# 10cm (15cm effective) Travelling Wave Structure

- 5.67MV integrated voltage.
- Good matching.
- <2.5% field flatness.



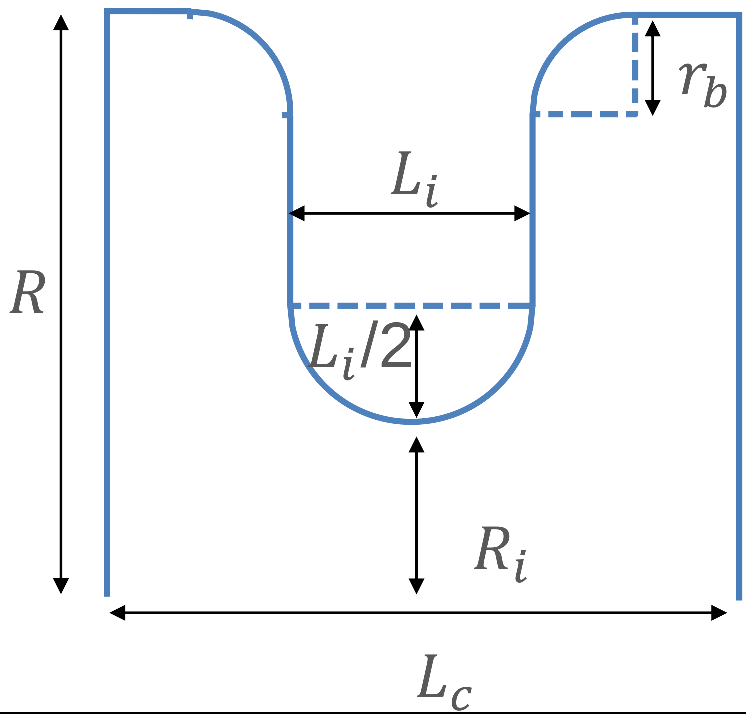



# TW-Single Cell Recap

Simple cell, constant impedance.

A geometry is proposed.

$H_p \approx 205$kA/m and $E_p \approx 148$MV/m @57MV/m.




| Parameter | Value | Units |
|---|---|---|
| Freq. | 36 | GHz |
| Q | 4392 | -- |
| $r_L$ | 106 | MΩ/m |
| $v_g$ | 0.12 | c |
| $\alpha_0$ | 0.7 | $m^{-1}$ |
| $E_p^*$ | 2.6 | MV/m |
| $R$ | 3.96 | mm |
| $R_i$ | 2.00 | mm |
| $L_c$ $(\varphi = {}^{2\pi}/_3)$ | 2.78 | mm |
| $L_i$ | 0.60 | mm |
| $r_b$ | 1.00 | mm |

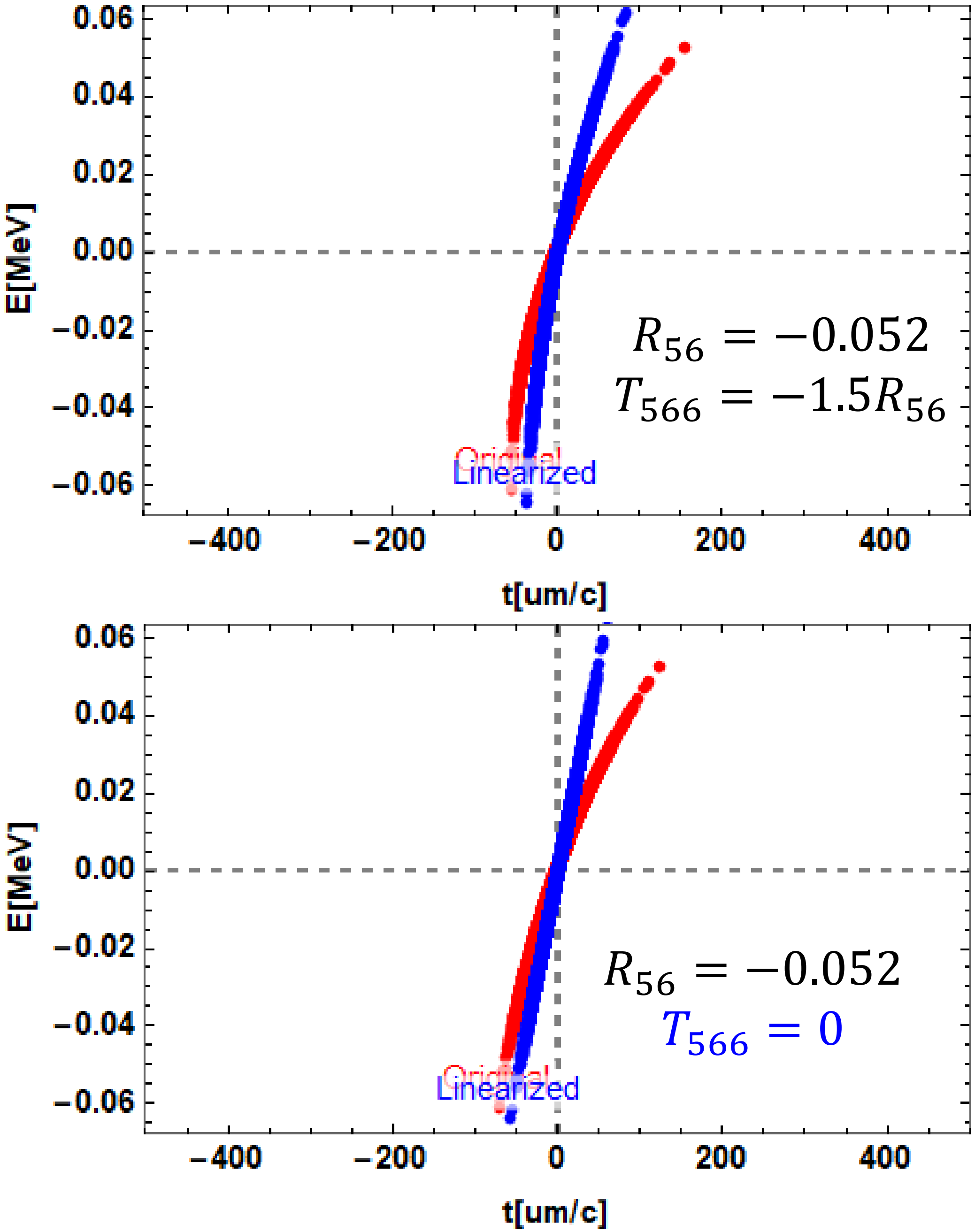
*normalized to $E_z = 1\ MV/m$

# Beam Dynamics Remarks

$$\Delta z_2 = \Delta z_1 + R_{56}\delta + T_{566}\delta^2 + O(\delta)^3$$

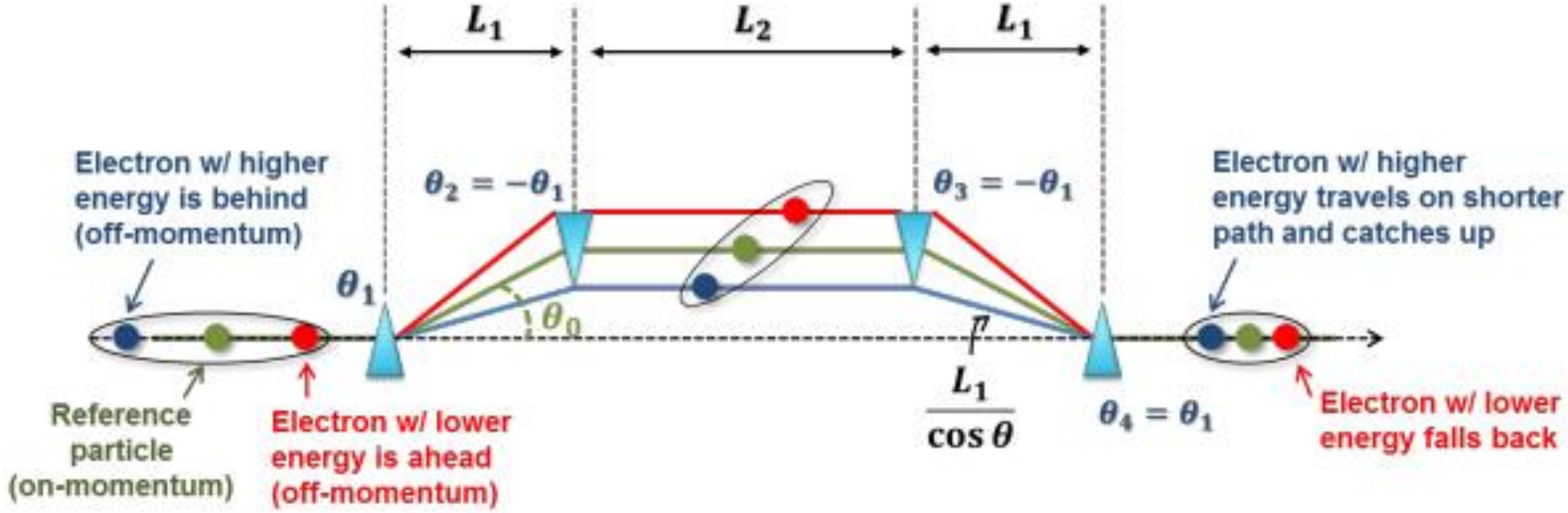
| Linear [MV/mm] | Second-order [(MV/mm)^2] | E0 [MV] |
|---|---|---|
| 27.9086 | -136.703 | 43.3182 |
| 45.4832 | -311.146 | 38.4575 |
| 26.2731 | -88.7487 | 43.3343 |
| 41.6635 | -0.934987 | 38.4787 |

$$V_h = \frac{V_0 Cos\phi_s}{h^2}$$



# Beam Dynamics Follow-up Studies

- Voltage dependence on:
  - the distribution from the injector.
  - two-stage compression scheme (BC1 - BC2) with longitudinal short-range wake fields.
- Design comparison on the choice of T566.



# Summary

- Mature options for RF sources at the required levels.
- Pulse compressor and RF network components are either available or easy to scale to Ka-band:
  - Low loss transmission is necessary at this frequency.
- Structure options are mature up to minor detailing:
  - A two structure + hybrid set-up is necessary for a SW solution.
  - Cryogenic load needs to be checked for a Cryo-Cu option.
  - TW w/mode launcher needs wakes and multipole content study.
- Comparison criteria are being developed to down select baseline:
  - Source.
  - Structure.
- Beam dynamics needs final iteration using updated injector layout.

# WP3 D3.4 - collaborators

- **Adrian Cross**
- **Wenlong He**
- **Laurence Nix**
- **Li Wang**
- **Liang Zhang**

- **Jinchi Cai**
- **Igor Syratchev**

- **Xiaowei Wu**
- **Walter Wuensch**

- **Mustafa Behtouei**
- **Luigi Faillace**
- **Bruno Spataro**

- **Graeme Burt**
- **Alejandro Castilla**

- **Andrea Latina**
- **Xingguang Liu**

- Apologies if I missed someone's name…

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# Thank you!

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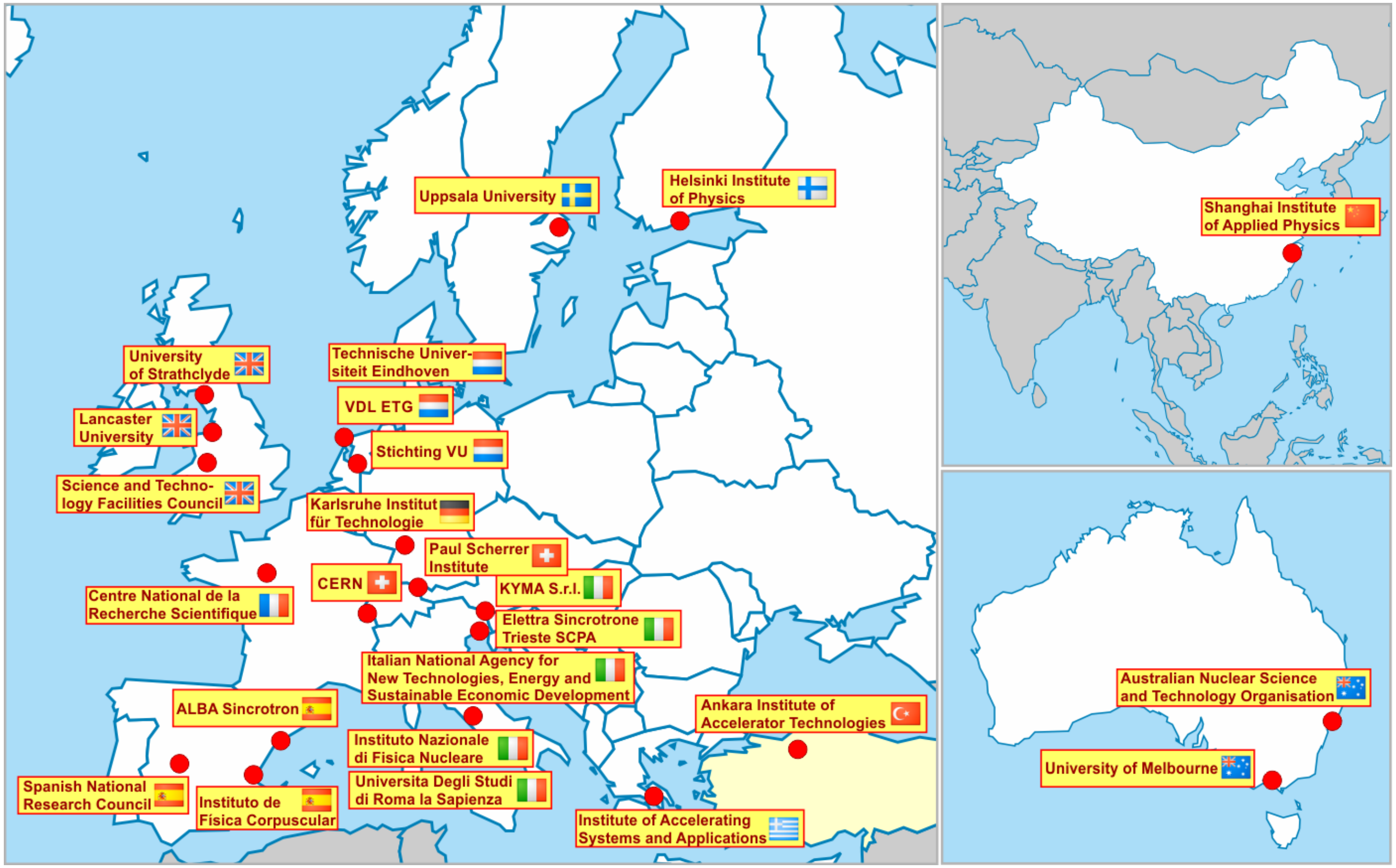


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# Options for a linearizer system @300 MeV

| Freq. [GHz] | Iris aperture [mm] | Required voltage [MV] | Structure length [m] | Ave. gradient per cavity [MV/m] | Integrated voltage per cavity [MV/cavity] | Num. of structures [#] | Total available power [MW] |
|---|---|---|---|---|---|---|---|
| **12** | 2.0 | 56.2 | 0.5 | 56.2 | 28.1 | 2 | 104 (2x 52) |
| **18** | 2.0 | 25.0 | 0.3 | 83.3 | 25.0 | 1 | 52 |
| **24** | 2.0 | 14.1 | 0.2 | 70.5 | 14.1 | 1 | 44 |
| **36** | 2.0 | 6.2 | 0.1 | 56.7 | 5.6 | 1 | 23 |
| **48** | 2.5 | 3.5 | 0.1 | 35.0 | 3.5 | 1 | 14 |

- Changing the frequency of the injection opens some room for comparison of different frequencies.
- Ka-band seems to be in a optimal point for either choice of the injector.
- Iteration with beam dynamics undergoing, to be confirmed soon!

# Structure and power considerations for the options

- Ka-band seems to be in a optimal point for either choice of the injector.
- Iteration with beam dynamics undergoing, to be confirmed soon!

| Freq. [GHz] | Vg [c] | Filling time [ns] | Source output [MW] | PC gain Klystron pulse width= 700 ns | PC gain Klystron pulse width= 1500 ns | Total Power for K.p.w. 700ns [MW] | Total Power for K.p.w. 1500ns [MW] |
|---|---|---|---|---|---|---|---|
| **12** | 0.01 | 333.6, (166.8) | 20, 50 | 1.85 | 3.54 | 37, (52), 92.5, (130) | 70.8, 177 |
| **18** | 0.01 | 200.1, 100.1 | 12 | 2.68, 4.39 | 4.67, 5.89 | 32.1, 52.6 | 56, 70.6 |
| **24** | 0.025 | 53.4, 26.7 | 6.7 | 5.68, 6.62 | 6.76, 7.41 | 38, 44.3 | 45.2, 49.6 |
| **36** | 0.12 | 16.7, 8.3, 5.6 | 3 | 7.05, 7.47, 7.56 | 7.68, 7.94, 7.97 | 21.1, 22.4, 22.6 | 23, 23.8, 23.9 |
| **48** | 0.3 | 3.3, 2.2, 1.1 | 2 | 7.69, 7.62, 7.38 | 8.07, 7.96, 7.68 | 16.1, 15.9, 14.7 | 16.1, 15.9, 14.7 |