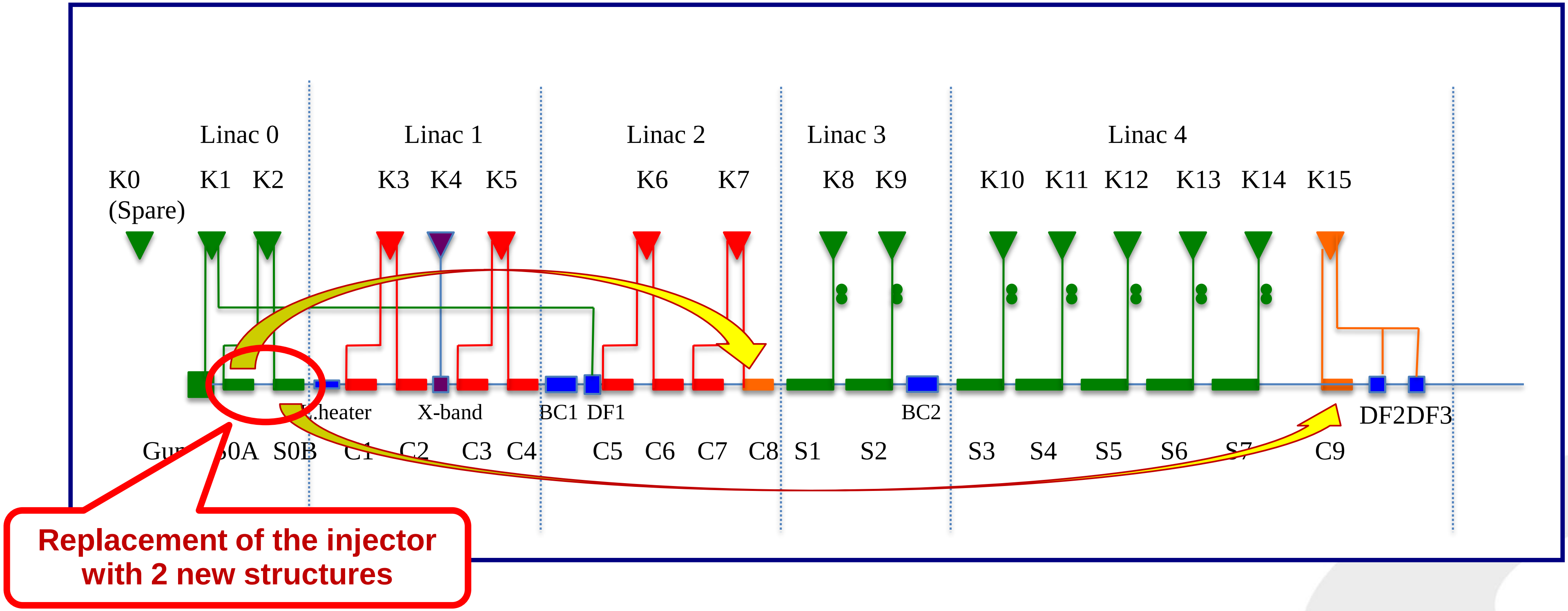
Elettra Sincrotrone Trieste

# Current status of the FERMI Project

## The S-band Linac

## *Linac Layout*

1. Two single feed accelerating structures are actually installed in the injector region.
2. Two dual feed structures, for the injector upgrade, have been commissioned to ***Research Instruments*** (delivered at Elettra on August 2015).
3. The exsisting structures have to be moved to the high energy part of the Linac.



# *Tuning Data – Structure no. 1*

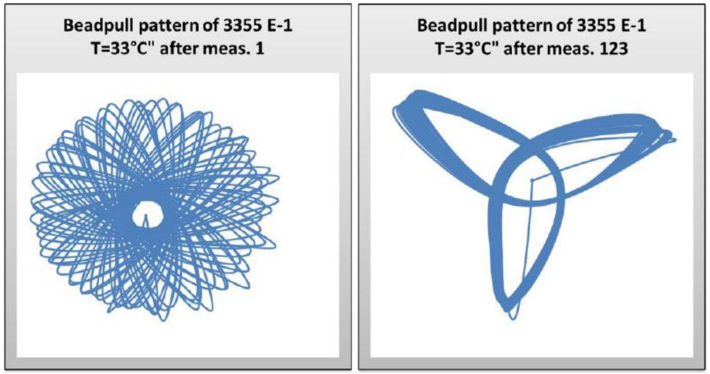



**Figure 2-2** Beadpull pattern before and after tuning

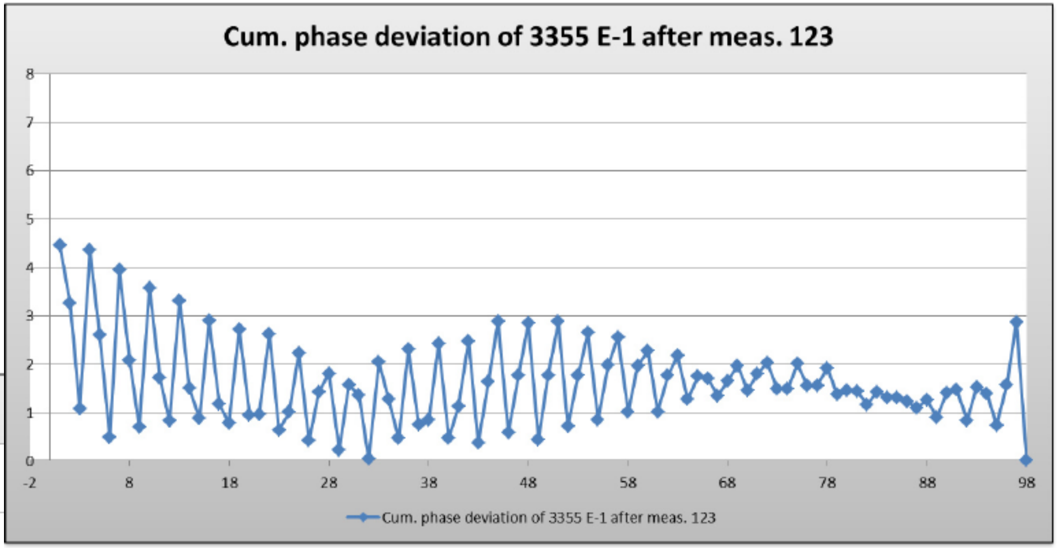



**Figure 2-3** Cumulated phase deviation

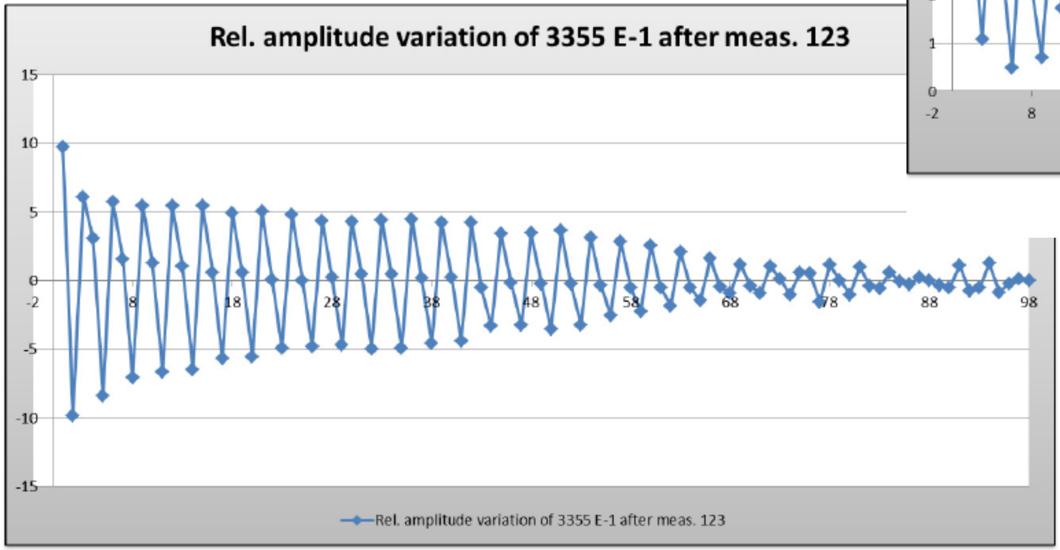



**Figure 2-4** Cell to cell amplitude variation

# *Tuning Data – Structure no. 2*

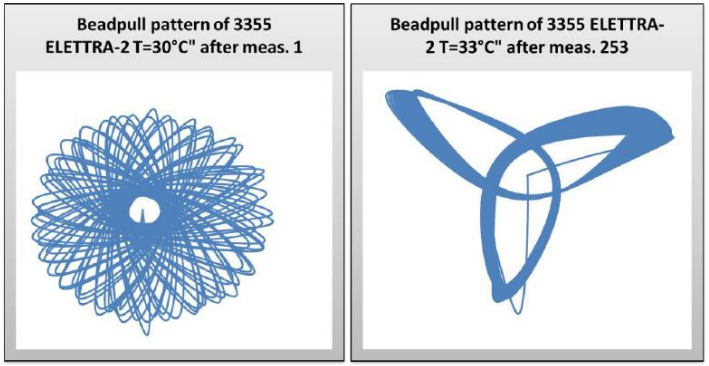



**Figure 2-2** Beadpull pattern before and after tuning

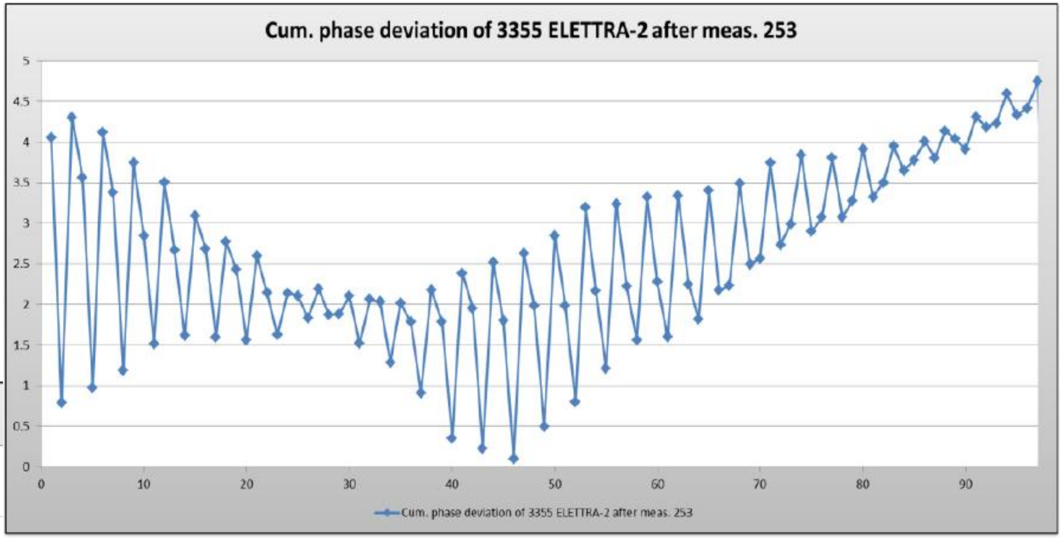



**Figure 2-3** Cumulated phase deviation

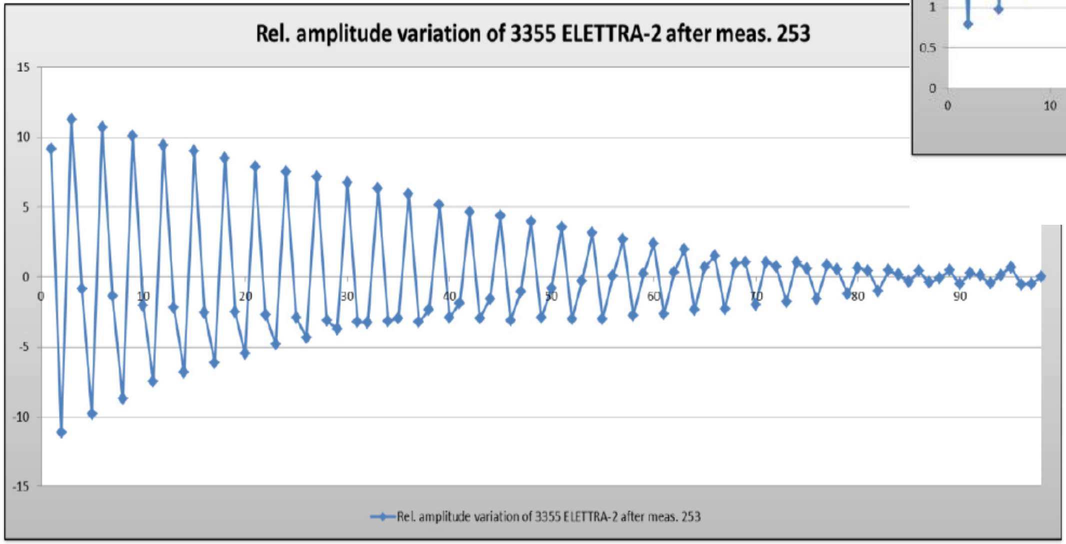
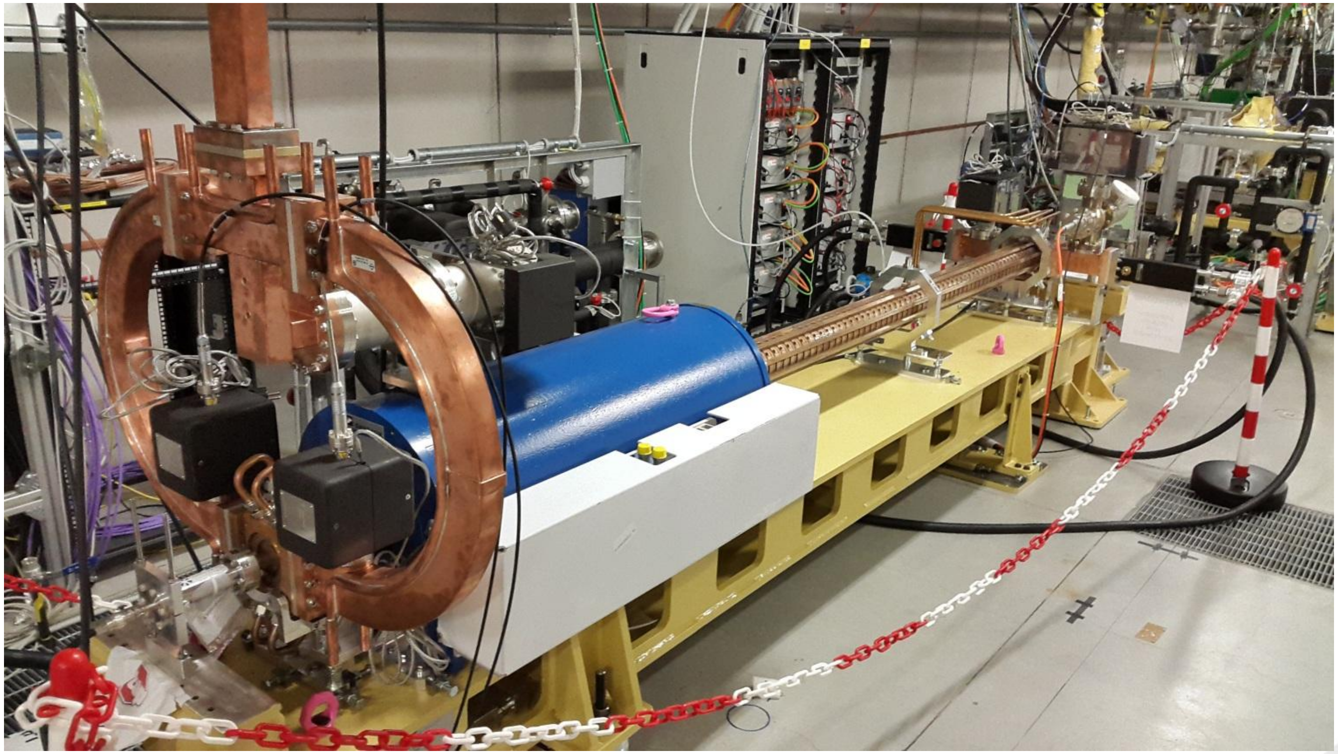



**Figure 2-4** Cell to cell amplitude variation

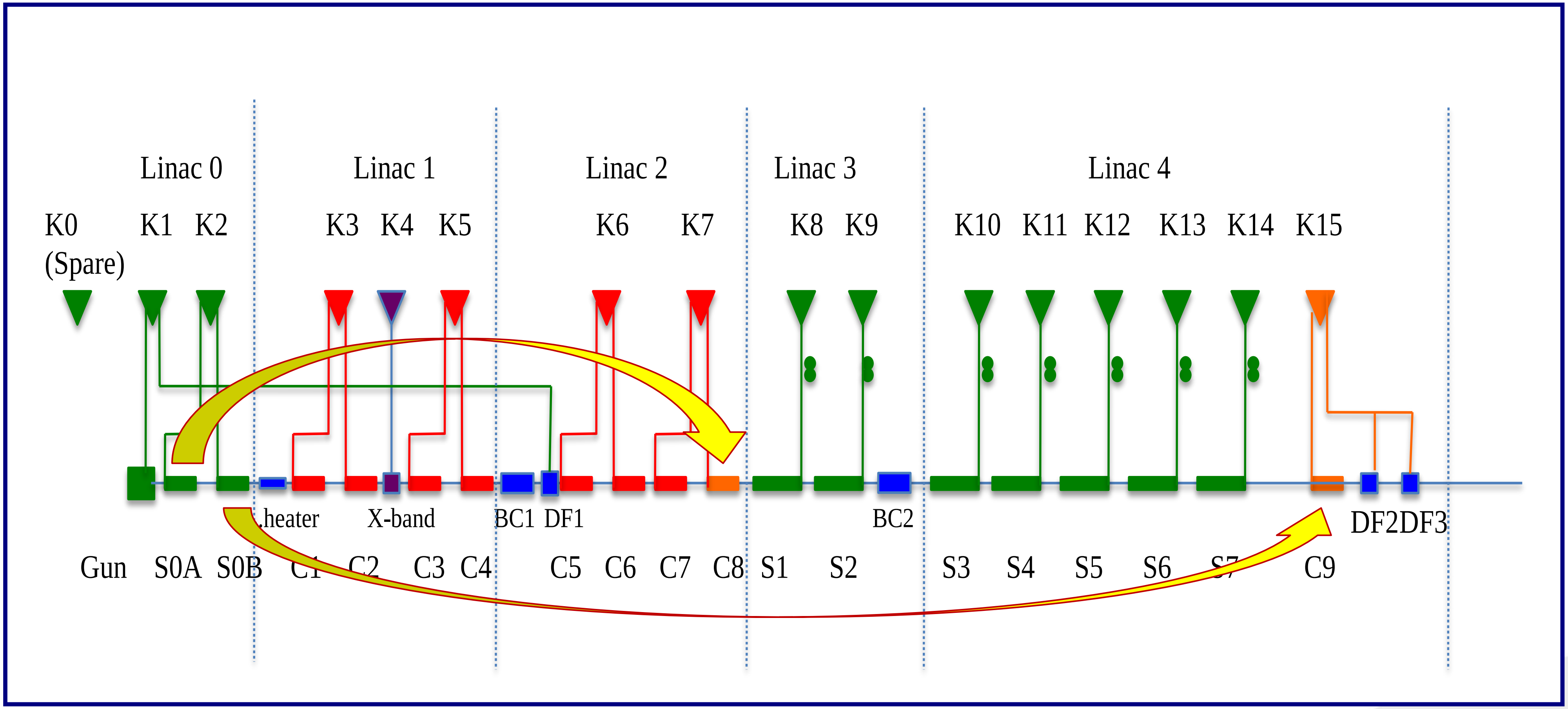
# THE RI ACC. STRUCTURES

1. Both RI accelerating structures have been successfully RF conditioned in our Test Facility up to the nominal gradient.
2. **Installation in the injector will take place in January 2016.**



# Installation of C8 and C9

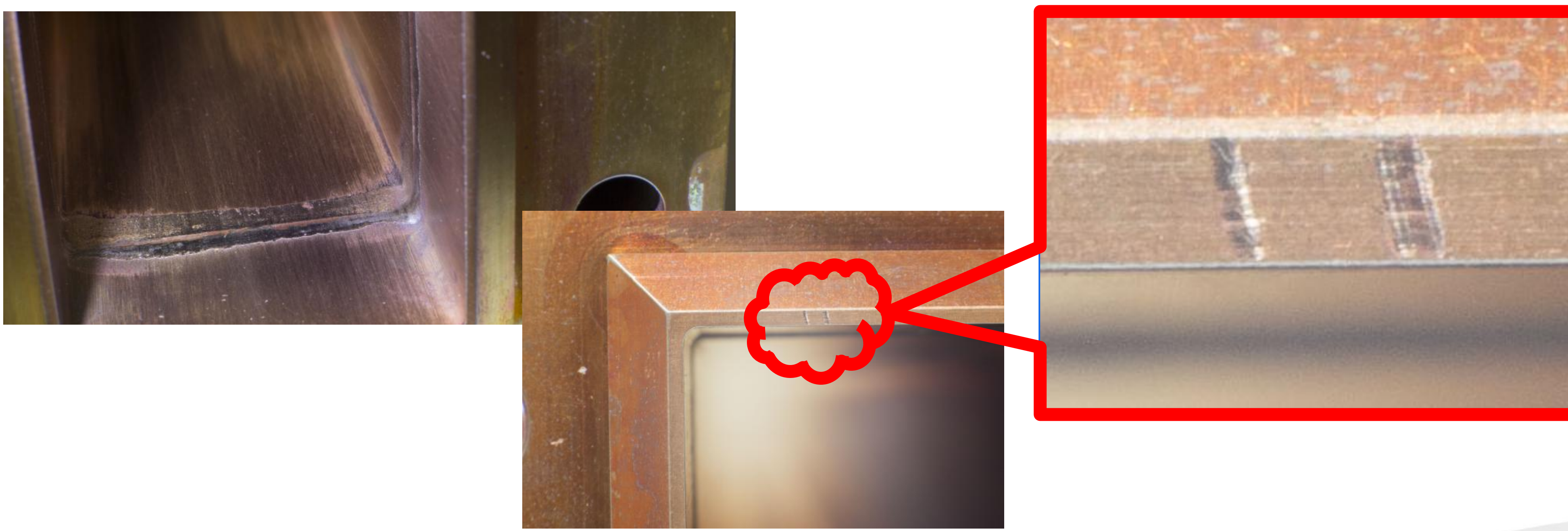
## *Linac Layout*



# INSTALLATION OF C8 AND C9

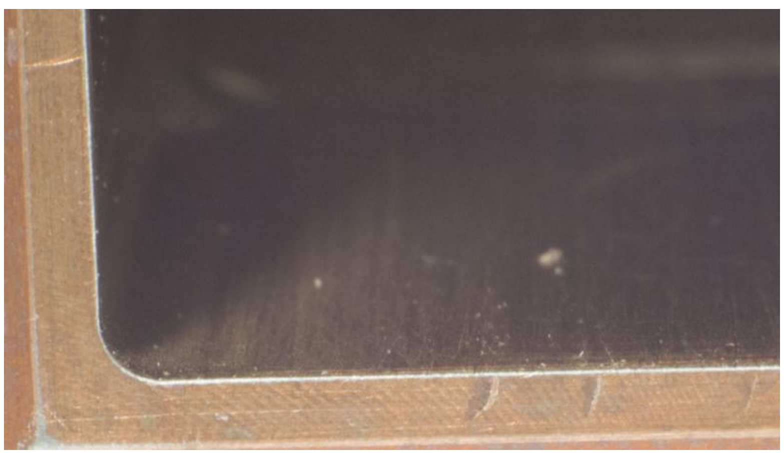
The two single feed accelerating structures (actually installed in the injector region) are planned to be moved in the high energy part of the Linac during January 2016.

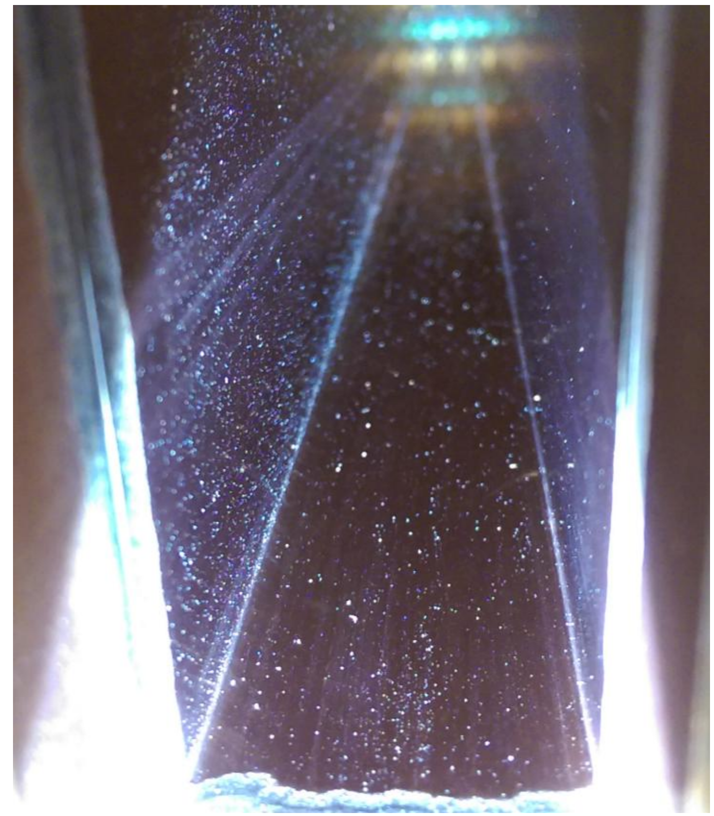
**A longer shoutdown period (about 6 weeks) has been allocated but....**



**Mega Industries delivered very poor quality WR284 waveguide components (straight, E-bends and H-bends)!**

## *Waveguide Components*





- **All the components have not been vacuum cleaned.**
- **More than 50% of the LIL flanges are dented and/or scrathced. This could compromise the vacuum thightness of the system**

## *Waveguide Components*

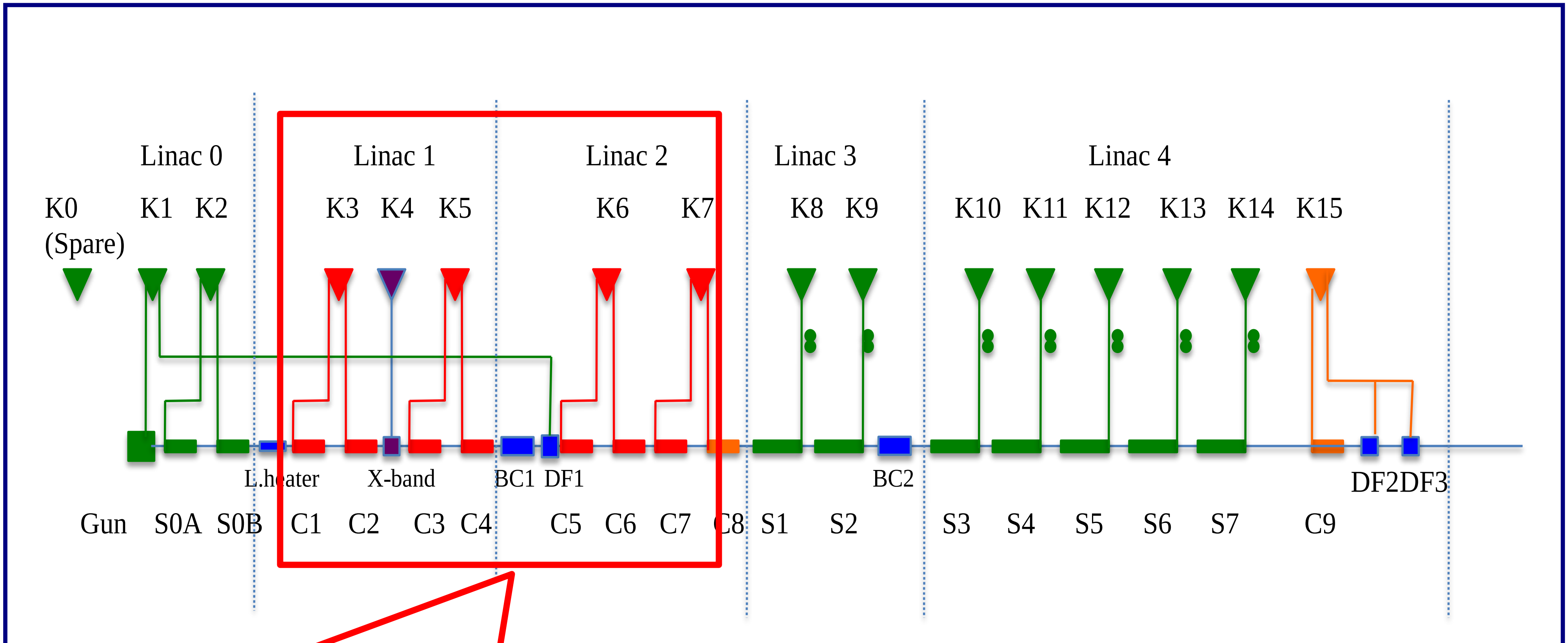
**16 out of 21 waveguide components have been rejected!**

Elettra Sincrotrone Trieste

# CERN Structures:

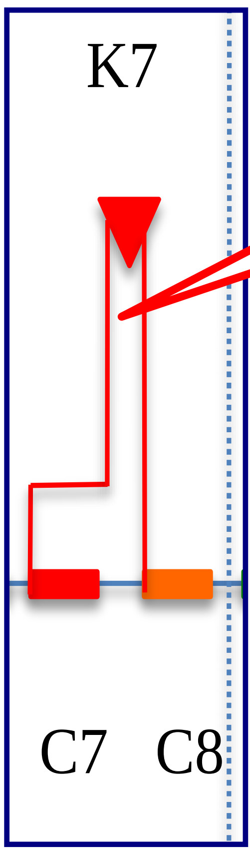
# High Power Testing

## *Linac Layout*

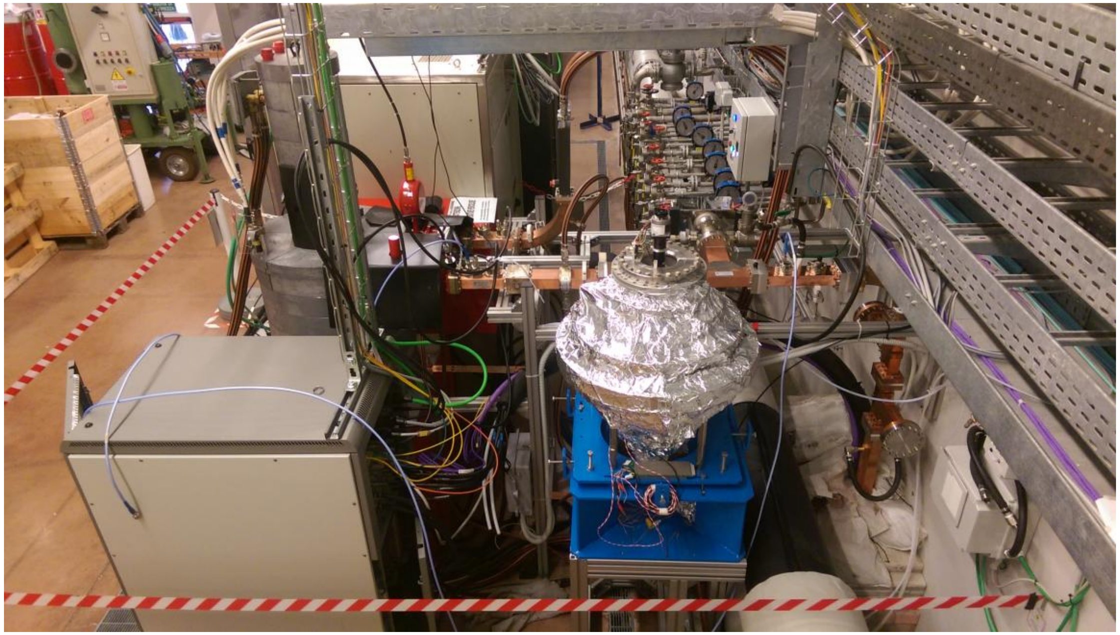



**Actually all CERN accelerating structures are operated at 55 MeV and 10 Hz.**
**We need to verify the uptime/reliability when operating at about 90 MeV and 50 Hz. An upgrade of 4 RF plant with pulse compressor is in fact under investigation.**

## *Linac Layout*




**A Barrel Open Cavity (BOC) has been received from CERN and installed on one arm of K07**



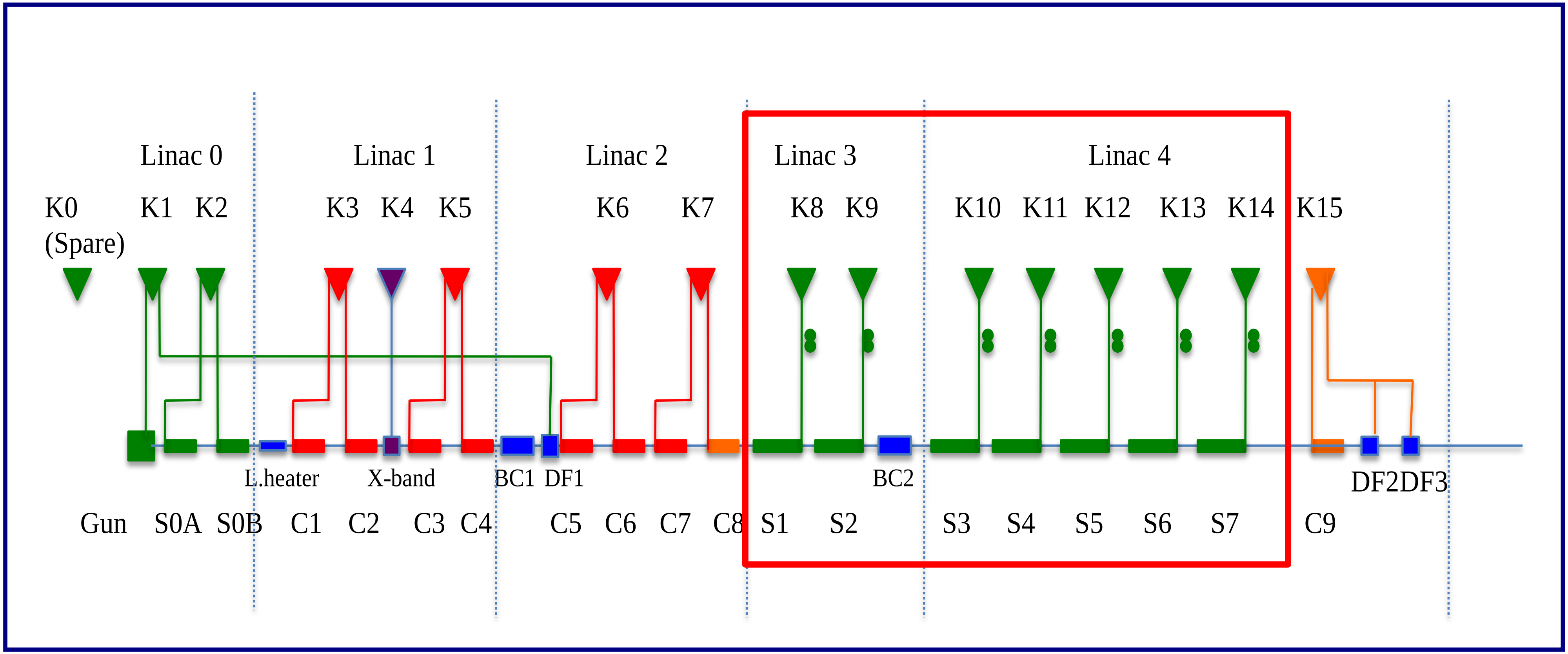
**Right now, the structure is being operated at 60 MeV and 50 Hz. After mid of October we foresee to turn on the BOC to increase the peak power to the structure.**

# Proposal for an Upgrade of the existing S-Band Linac

## New S-band accelerating structures and test facility

# New S-Band Accelerating Structures

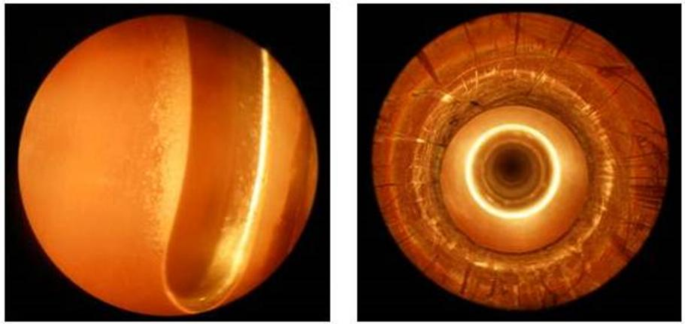
## *Linac Layout*



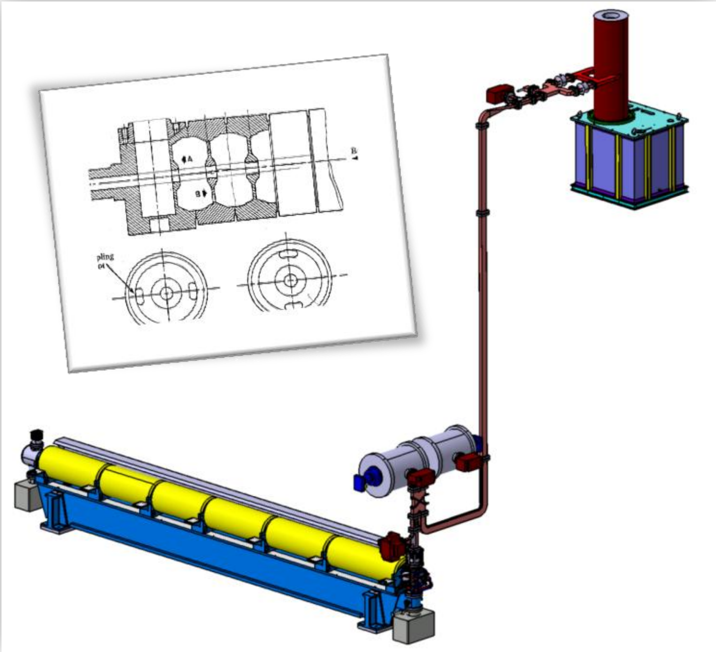
# MOTIVATION

S-type structures are 6.1 m long Backward Traveling Wave (BTW) structures comprised of 162 nose cone cavities coupled magnetically.

- BTW accelerating structures showed that such structures suffer heavy breakdown phenomena when pushed to high gradient.



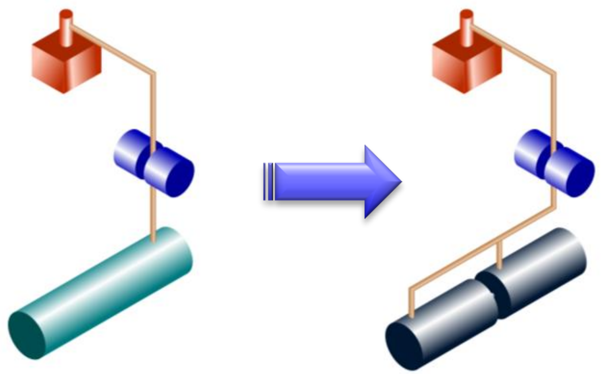
- Small beam aperture (i.e. 5 mm iris radius) of the BTW structures has a huge impact on beam dynamics in terms of longitudinal and transverse wakefields.



# RF Plant Configuration

C. Serpico, A. Grudiev (CERN)

The new accelerating module will be comprised of two 3-m long (approximately) accelerating structures



| | | |
|---|---|---|
| **Acc. module length** | **~ 6.43** | **m** |
| **Kly. pulse duration** | **~ 4000** | **ns** |
| **$Q_0$** | **190000** | |
| **$Q_{ext}$** | **19000** | |

- Optimal RF parameters have been evaluated to benefit from pulse compression.

| | | |
|---|---|---|
| **a** | **10** | **mm** |
| **$Q_0$** | **14900** | |
| **$R_{sh}$** | **71.7** | **MΩ/m** |
| **Filling Time** | **672** | **ns** |
| **$v_g/c$** | **1.49** | **%** |

2 times the radius of the BTW structures.

- "Modified Poynting vector"[1] on cell's surface has been evaluated for a **25 MV/m** accelerating gradient.

**Sc_max = 0.7 W/μm²**

**Scaling this value to the pulse length of 672 ns results in BDR = 2e-15 bpp/m.**

**For 40 m long linac it will be 8e-14 bpp[2].**

[1] A. Grudiev, New local field quantity describing the high gradient limit of accelerating structures, Phys. Rev. ST Accel. Beams 12, 102001

[2] A. Grudiev, Private Communication

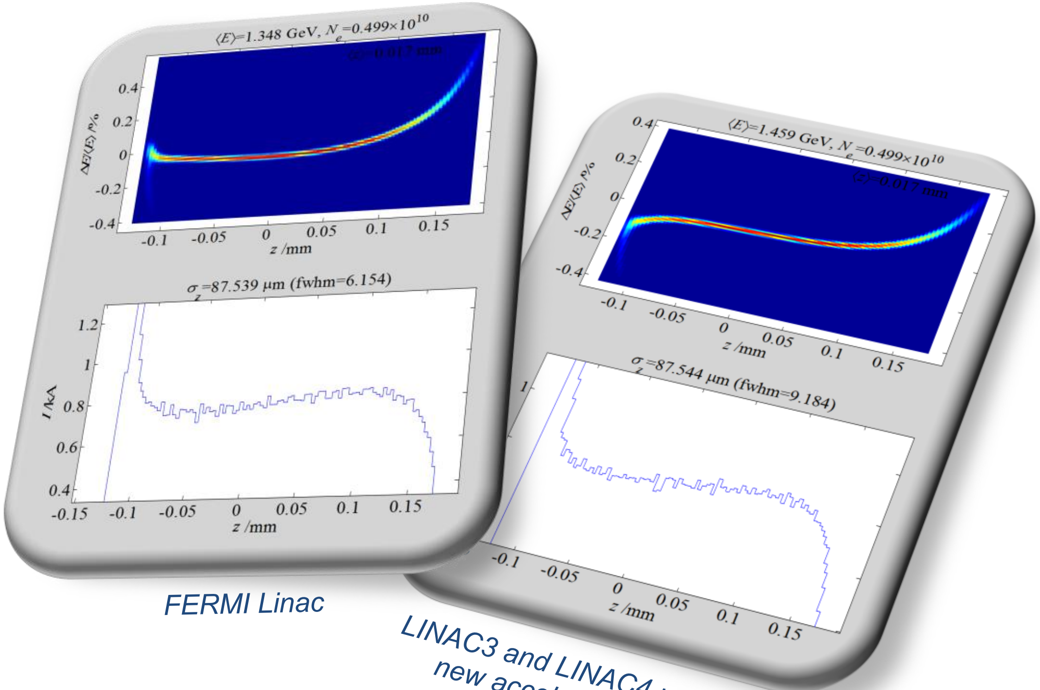
# LONGITUDINAL BEAM DYNAMICS

**C. Serpico, G. Penco, S. Di Mitri**

| Bunch & Linac Parameters | | |
|---|---|---|
| Bunch Charge | 800 | pC |
| rms $\sigma_{z_0}$ | 0.9 | mm |
| rms $\sigma_E/E$ | 0.2 | % |
| BC1 compression factor | ~10 | |
| Linac3 & Linac4 Acc. Gradient | 25 | MV/m |

| E-beam Parameters | | |
|---|---|---|
| **Bunch Current** | **~800** | **A** |
| $\Delta E/\langle E\rangle$ | **0.2** | **%** |

**LiTrack Longitudinal Tracking**




*FERMI Linac*

*LINAC3 and LINAC4 upgrade with new accelerating structures*

To get a Bunch Current of about 800 A, with an Energy Spread of 0.2 %, it is necessary to put off-crest some accelerating structures in the last part of the Linac:

- With the actual Linac configuration, the energy loss **could be up to 130 MeV.**
- **The new accelerating structures will give the possibility to reach the same beam parameters while loosing only 20 MeV with respect to on-crest operation.**

**S. Di Mitri**

- Short-rage transverse wake function in the Bane's model (periodic structure):

$$w_{\perp}(z) \propto \frac{Z_0 c}{\pi a^4} s_1 \left[ 1 - \left( 1 + \sqrt{\frac{z}{s_1}} \right) \cdot e^{\left(-\sqrt{z/s_1}\right)} \right]$$

***~1x10^16*** V/C/m$^2$ for the existing BTW structure,

***~7x10^14*** V/C/m$^2$ for new S-band structure at larger iris.

- The emittance growth due to misaligned structures goes like (Raubenheimer's model):

$$\frac{\Delta\varepsilon}{\varepsilon} \cong \left( \sqrt{1 + A\frac{Q^2 \overline{W}_{\perp}^{\,2} \Delta^2}{\gamma_f \varepsilon}} - 1 \right),$$

where *A* accounts for linac optics and accelerating gradient

- This model fits well the present linac setting and the observed emittance growth **Δγε ~ 1–2 μm** with an equivalent rms linac-to-beam misalignment **Δ ~ 100–150 μm**.

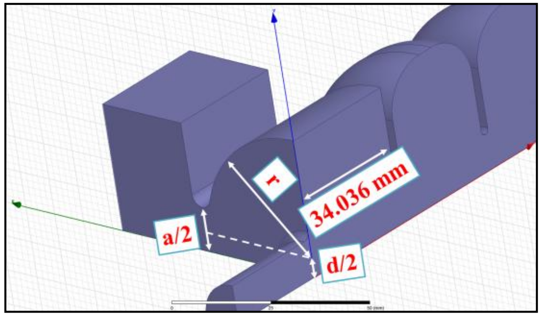
With the new S-band structures, same linac optics, accelerating gradient and equivalent misalignment, we expect **Δγε < 0.1 μm.**

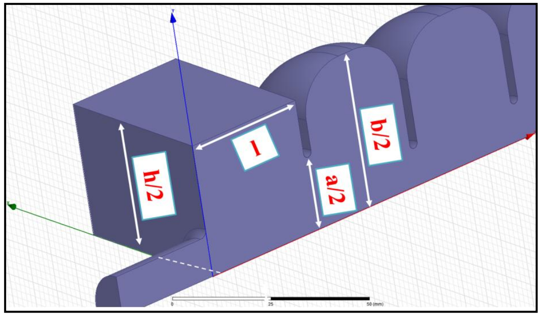
In addition, shorter structures (3 vs. 6 m) promise smaller “bookshelfing” effect, smaller distortions, better alignment overall.

# RF Coupler Analysis

C. Serpico, A. Grudiev (CERN)

## *Magnetic Coupled* vs *Electric Coupled*

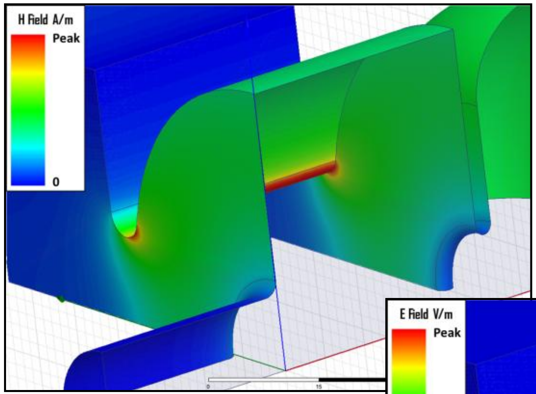


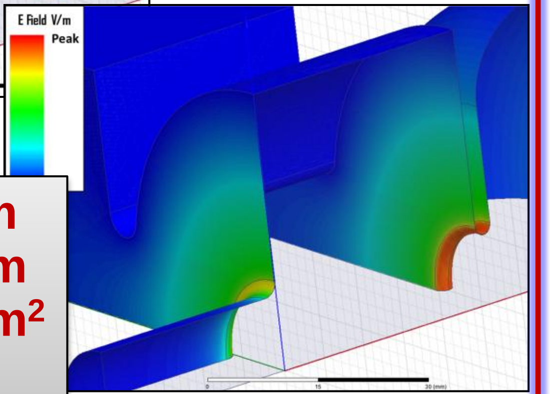




**Working Point**

$V_0$ = 30 MV/m

$\Delta T$ = 700 ns



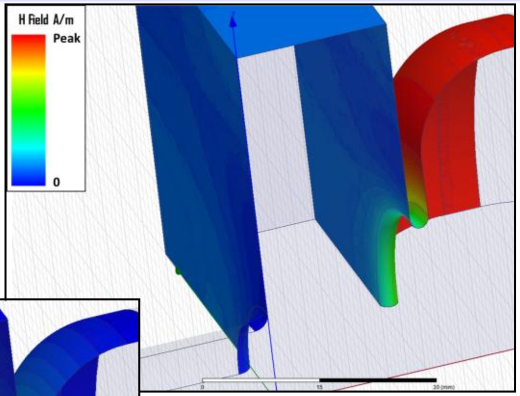



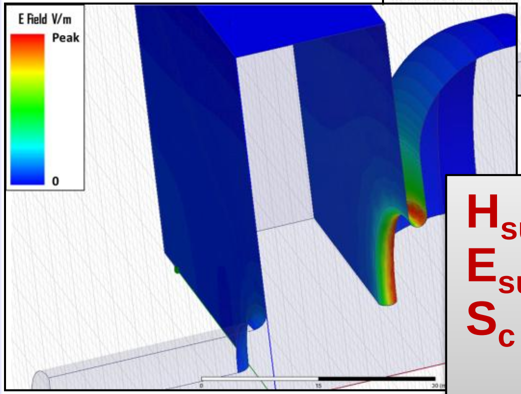

$H_{surf\ max}$ = 175 kA/m

$E_{surf\ max}$ = 93 MV/m

$S_{c\ max}$ = 0.7 W/μm$^2$

BDR = $10^{-12}$ bpp/m




$H_{surf\ max}$ = 78 kA/m

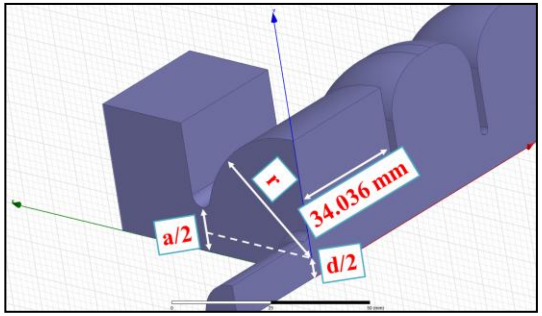
$E_{surf\ max}$ = 81 MV/m

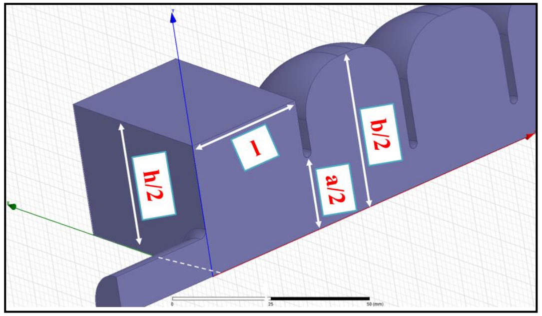
$S_{c\ max}$ = 0.57 W/μm$^2$

BDR = $10^{-12}$ bpp/m

C. Serpico, A. Grudiev (CERN)

***Magnetic Coupled*** **vs** ***Electric Coupled***

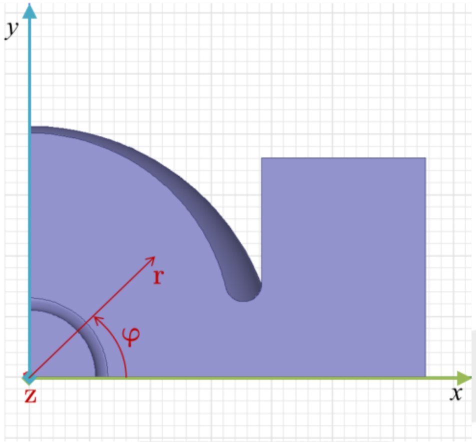



## Minimization of the residual quadrupole component

$$F_\varphi(z) = [F_x(r = 5\,mm, \varphi = 45°, z) - F_y(r = 5\,mm, \varphi = 45°, z)]$$

$$k_q = \frac{1}{qr}\left|\int_0^L F_\varphi(z) e^{\pm j\frac{\omega}{c}z} dz\right|$$



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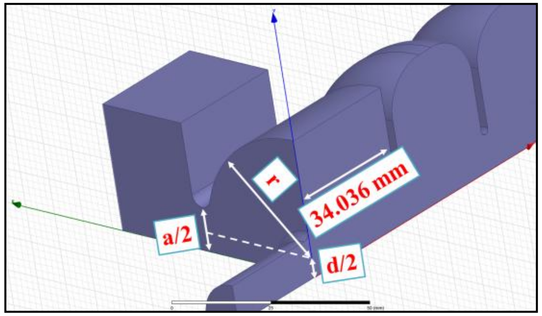
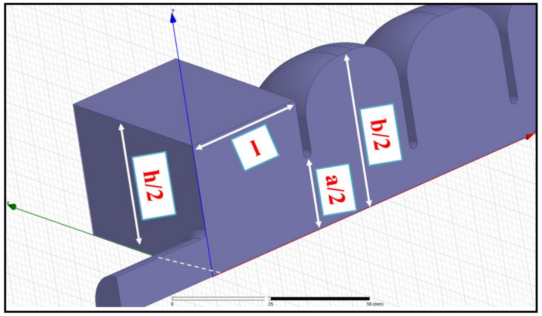
# RF Coupler Analysis

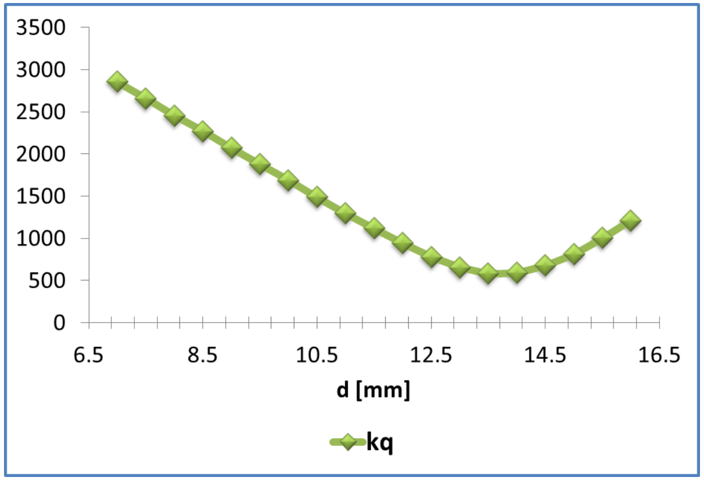
C. Serpico, A. Grudiev (CERN)

## *Magnetic Coupled* vs *Electric Coupled*

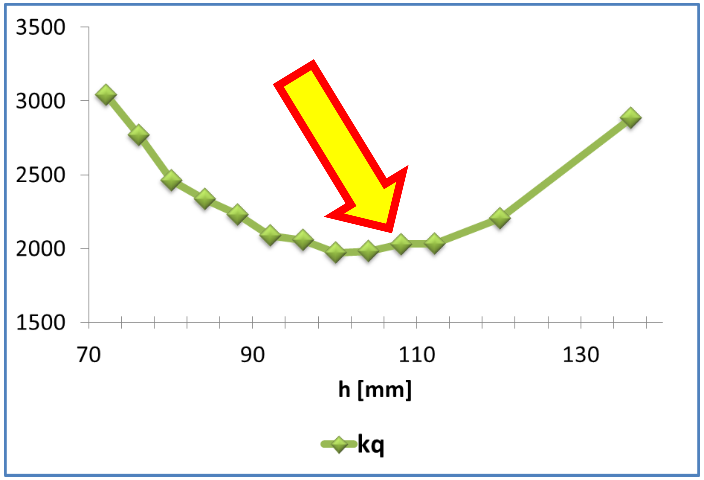



## Minimization of the residual quadrupole component




*Integration is limited to the input coupler region*

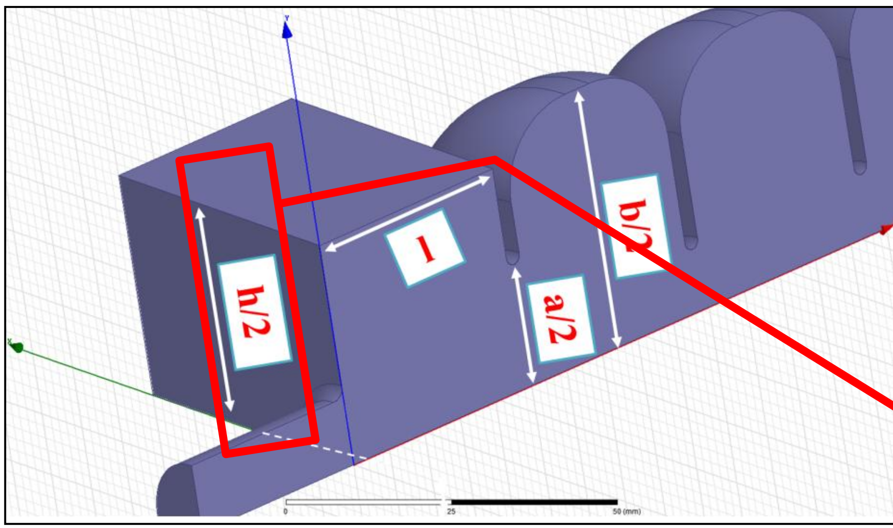


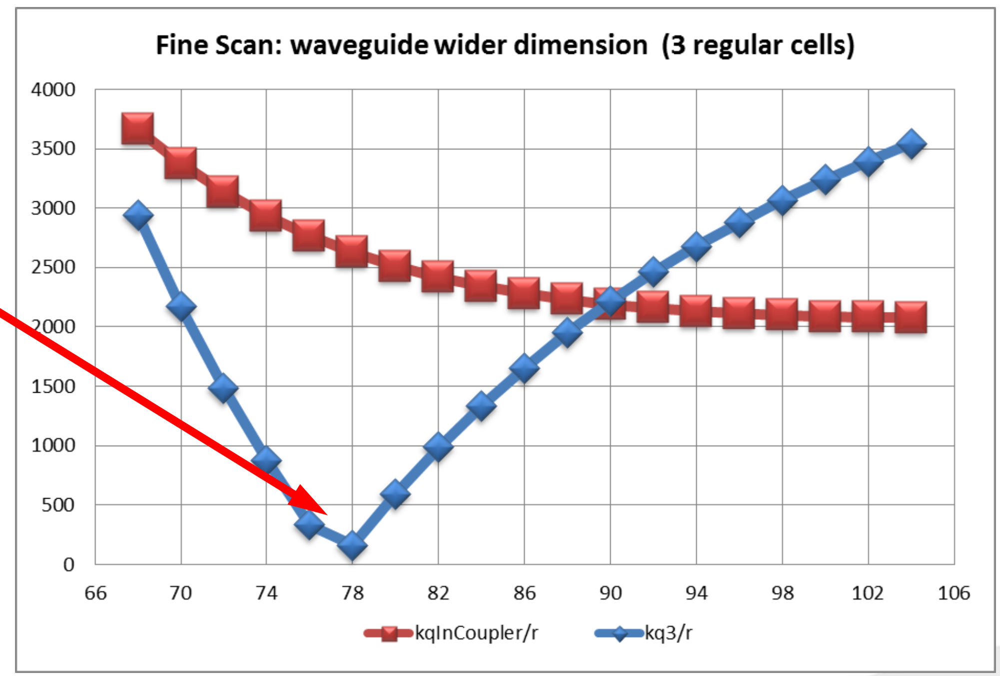

- **EC coupler – Pros**: E-field and H-field are lower for the EC.
- **EC coupler – Cons**: residual quadrupole component is bigger for the EC coupler.

# EC Couplers: Quadrupole Component Minimization

**C. Serpico, A. Grudiev (CERN)**

Playing with the relative phase of the fields in the input and output couplers it is possible to further minimize the overall residual quadrupole component



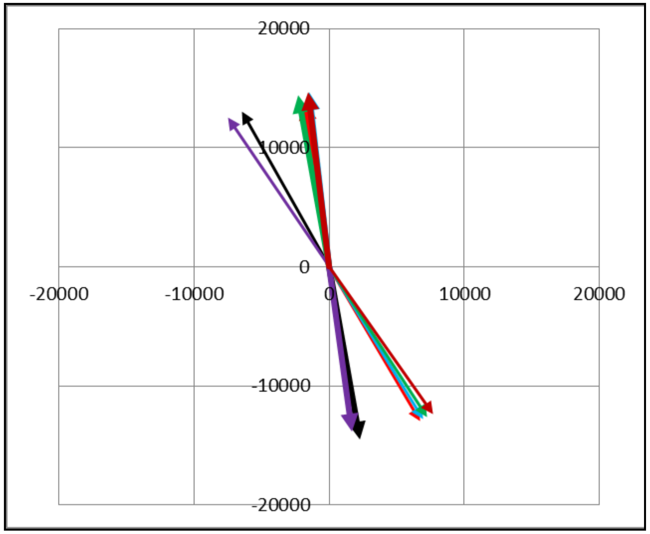




***The results have been obtained just considering a PEC boundary condition. Using copper, we will not get a perfect compensation of the residual quadrupole component.***

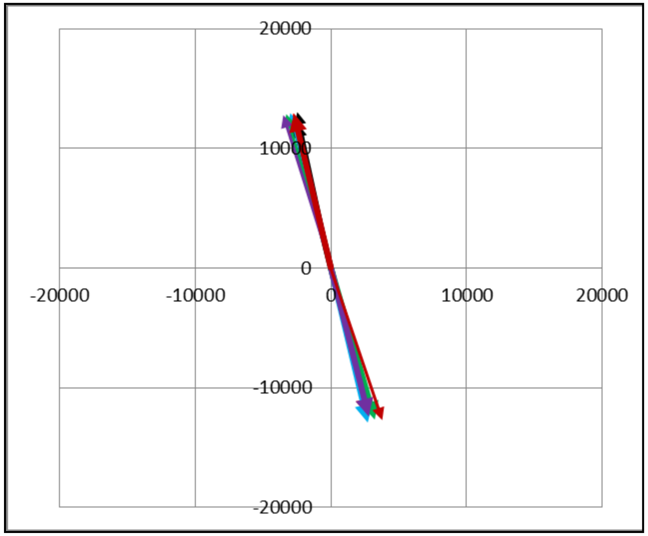
# EC Couplers: Quadrupole Component Minimization

C. Serpico, A. Grudiev (CERN)

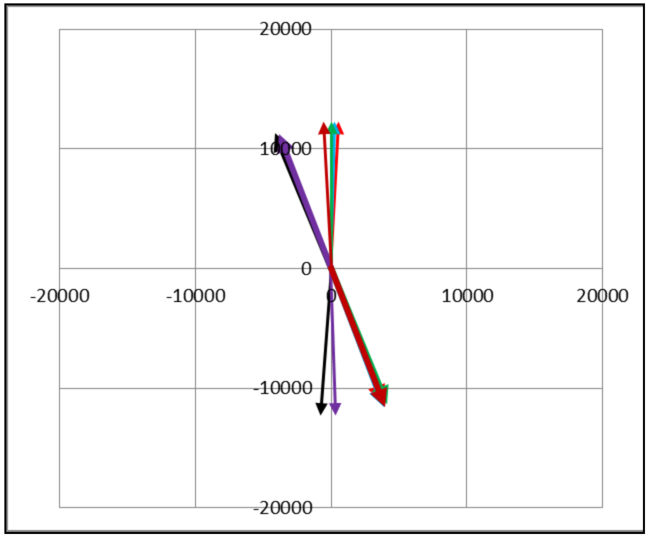
**WG wider dimension: 74 mm**

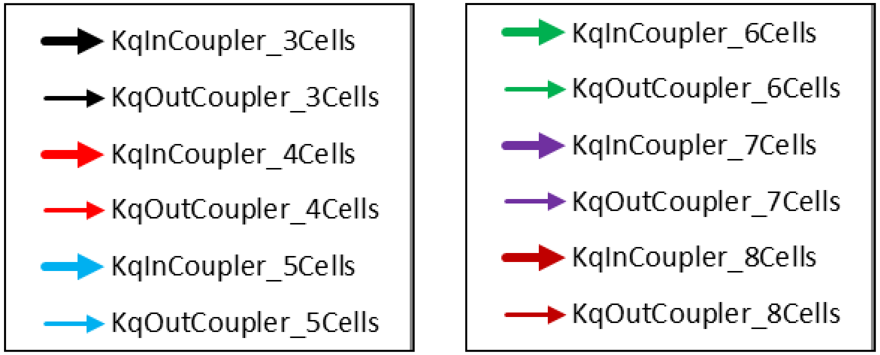



**WG wider dimension: 78 mm**




**WG wider dimension: 82 mm**



# PROTOTYPE

**For the machining of the first prototype, different hypotesis have been considered:**

a) **~ 0.5 meter long** accelerating structure

b) **2.5 meter long** accelerating structure

c) **~ 3 meter long** accelerating structure (one half of the complete accelerating module

**For each option a trade off between cost/benefits has been considered.**

# PROTOTYPE

## Option a)

**~ 0.5 meter long** accelerating structure

### Pros:

1. Reduced cost.
2. Easy to design (no girder, no allignment, no optimized cooling system needed).
3. A ‘proof of principle’ is possible: upgrading our Test Facility, the reliability of an operation at **50 MV/m** and **50 Hz** could be demonstrated.

### Cons:

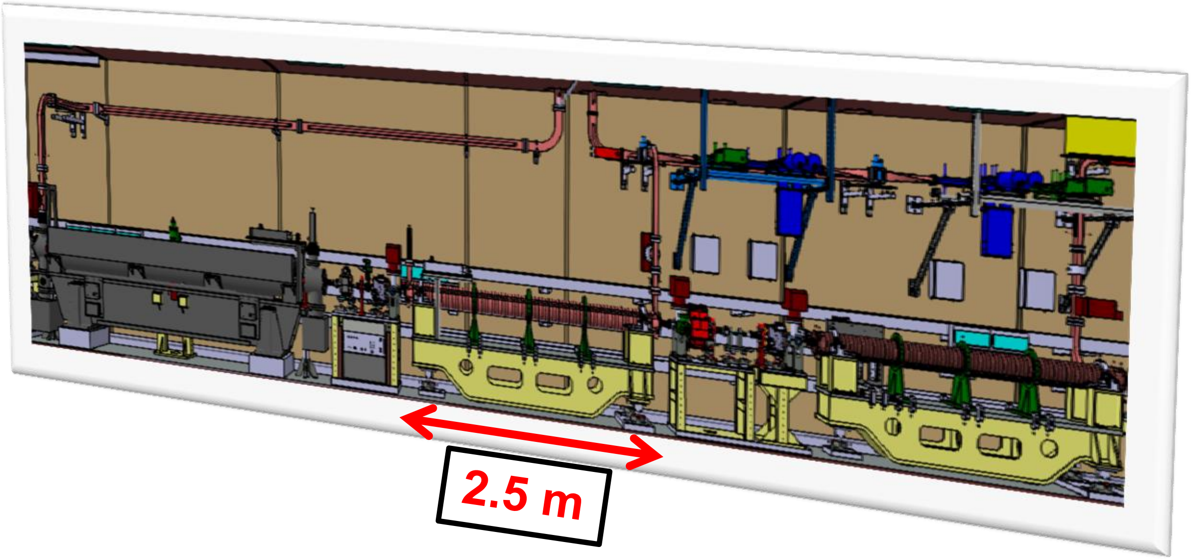
1. After the completion of the high power conditioning/test, the prototype will not be re-used.

## Option b)

### 2.5 meter long accelerating structure

**Pros:**

1. A 'proof of principle' is possible: upgrading our Test Facility, the reliability of an operation at **40 MV/m** and **50 Hz** could be demonstrated.
2. After the completion of the high power conditioning/test, the prototype could be reinstalled along the machine, in place of one 2.5 meter long deflecting cavity.




**Cons:**

1. Higher cost.
2. Major changes to the waveguide layout will be needed - **Not yet quantified**.
3. Just small improvement of the overall beam energy could be achieved - **With the available power, the energy gain would be approximately 40 MeV.**
4. The e-beam will change when the deflector is activated (less energy and different profile)

# PROTOTYPE

## Option c)

**~ 3 meter long** accelerating structure - one half of the complete module

**Pros:**

1. A ‘proof of principle’ is possible: upgrading our Test Facility, the reliability of an operation at **40 MV/m** and **50 Hz** could be demonstrated.
2. This structure can be re-used when the first accelerating module has to be installed.

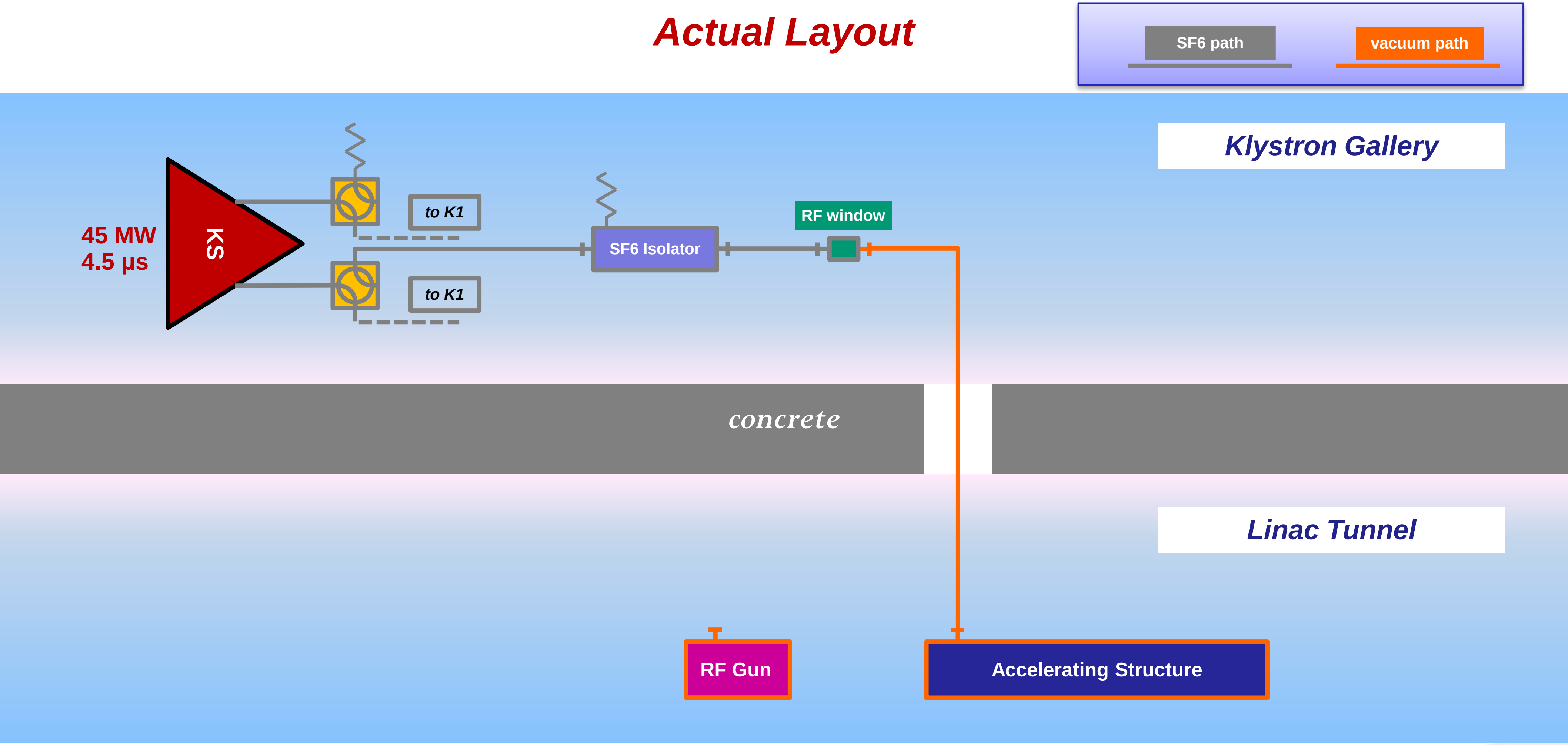
**Cons:**

1. Higher cost.

**A 0.5 m long prototype seems to be the optimal solution!**

# Test Facility Layout

## *Actual Layout*




- A spare RF Gun is actually available at Elettra: such an RF Gun is commonly used for cathode testing.
- When the plant is needed for testing/conditioning purposes, the RF Gun has to be disconnected.

## *Actual Layout*

### Advantages:

1. KS is connected to K1/K2 to be used as an hot spare for the first 2 RF plants feeding the RF Gun and the injector.

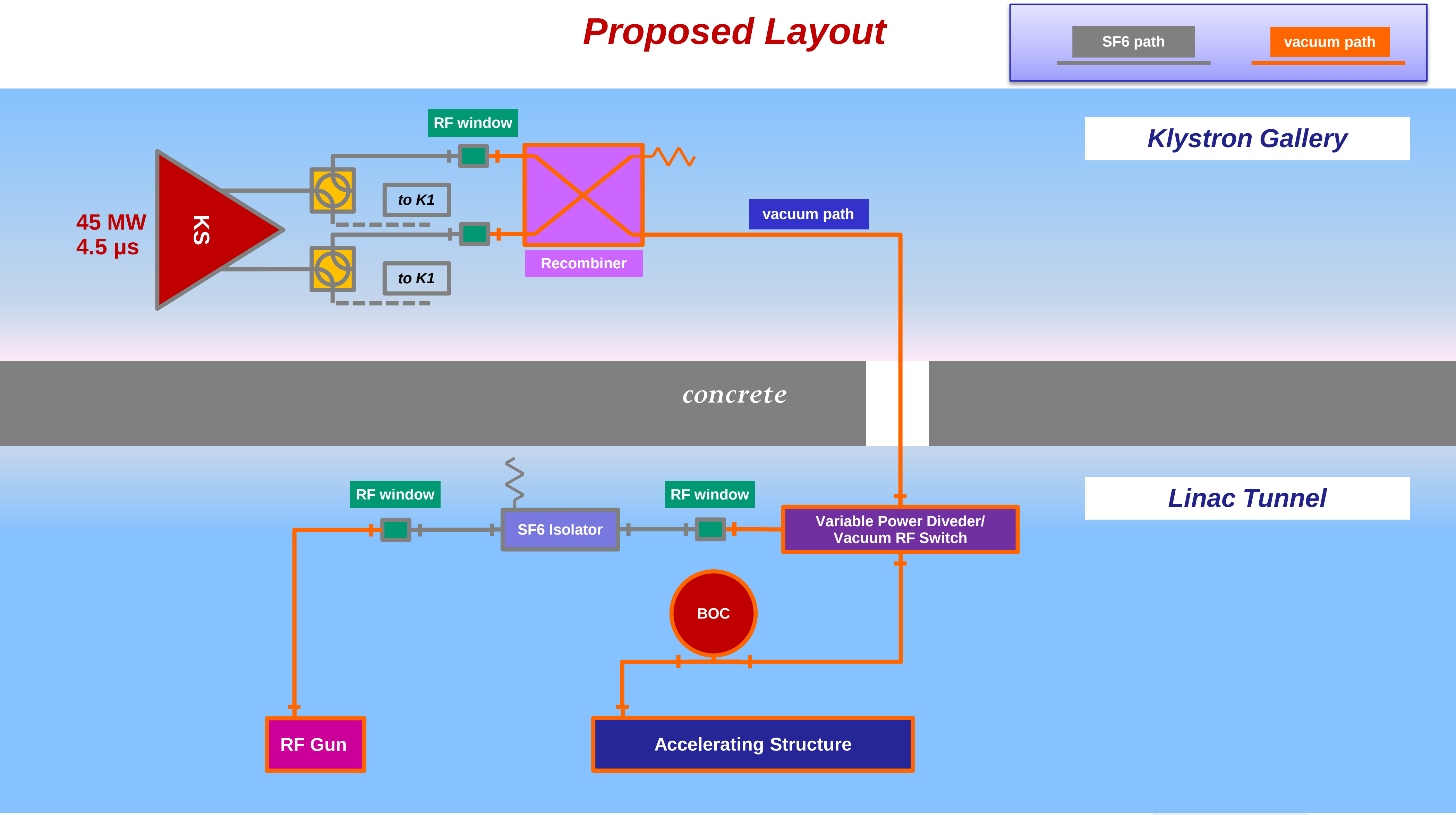
### Limits:

1. Actually KS is not yet configured as a versatile Test Facility.
2. Just one device at time can be installed. Each installation requires quite huge changes to the waveguide layout, the cooling system and the vacuum system.
3. The maximum RF power that could be delivered to the DUT is approximately 20 MW: in case of an high power testing of the accelerating structure prototype, **just a gradient of nearly 16 MV/m could be achievable** (**30 MV/m is the target operational gradient**).

**A change in the Test Facility layout is proposed to get a versatile radiofrequency plant able to deliver nearly 180 MW to the DUT**

# Test Facility Layout

## *Proposed Layout*



## *Proposed Layout*

**Advantages:**

1. Two different branches could be foreseen:
   a. The first branch will be suitable for **medium power** testing (**up to 25 MW**) of RF cavities (standing or traveling wave) and microwave components.
   b. The second branch will be suitable for **high power** testing of RF cavities (**up to 180 MW**) of RF cavities (traveling wave) and microwave components (directional couplers, ceramic windows, etc.).
2. Prototype testing:
   a. The new S-band accelerating structure are designed to **operate at a gradient of nearly 30 MV/m**: with the new layout it will be possible to perform RF conditioning **up to approximately 50 MV/m**.

## ACCELERATING STRUCTURE PROTOTYPE

Actual Plan/Next Actions:

1. The RF design of the accelerating structure (the power splitter will be integrated in the RF coupler as well) has to be completed by Elettra.
2. A draft of the mechanical design should also be implemented by Elettra.
3. A bid for the provisioning of the full prototype has to be issued: the final mechanical/construction drawings and the dimensioning of the cooling system will be in charge of the supplier*.

| Acc. Structure Prototype | Cost [€] |
|---|---|
| 0.5 meter long | 50.000 |
| 2.5 meter long | 190.000 |
| 3 meter long | 220.000 |

*This solution will be more expensive, but it would be preferrable.

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# Budget

## Test Facility Upgrade

| Items | Cost [€] | Notes |
|---|---|---|
| RF Ceramic Windows | 25.000 | |
| 3dB Hybrid/Recombiner | 20.000 | |
| Variable Power Diveder/Vacuum Switch | 20.000 | |
| SF6 isolator | | possible to use FERMI spare components |
| BOC | 60.000 | |
| Waterloads | | possible to use FERMI spare components |
| E/H-bends, straight sections | 30.000 | |
| | | |
| TOTAL | 155.000 | |

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