Seamless Quarter-Wave Resonator for HIE-ISOLDE

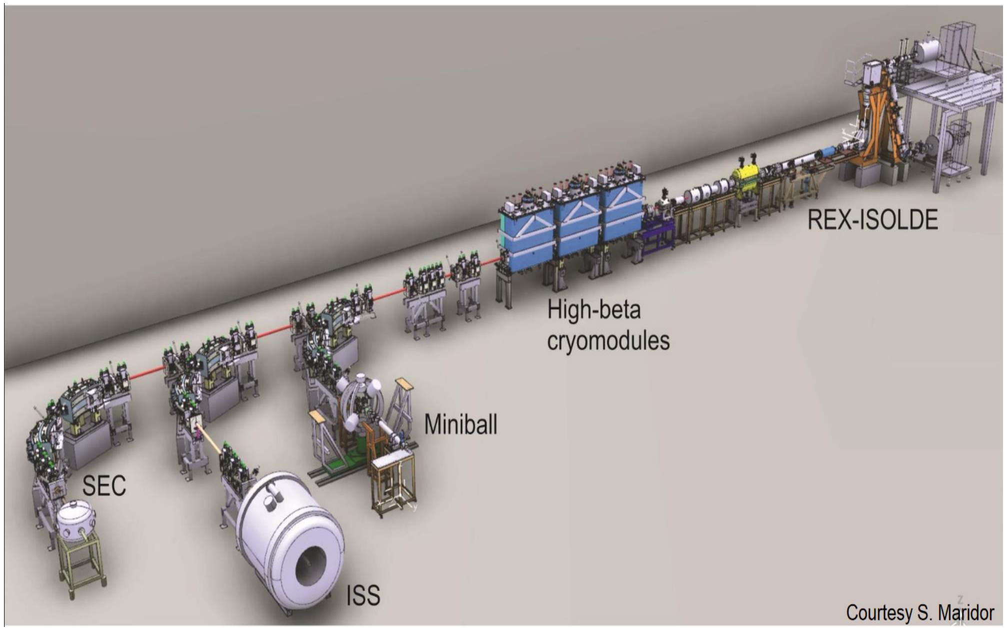
Silvia Teixeira López

M.A. Fraser, M. Garlasche, T. Mikkola, A. Miyazaki, A. Sublet, W. Venturini Delsolaro

18th International Conference on RF Superconductivity – Lanzhou, China
July 17-21, 2017

HIE-ISOLDE project

- The **High Intensity and Energy ISOLDE** (HIE-ISOLDE) project is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities.
- Energy increase of the delivered radioactive ion beam (RIB) **from 3 MeV/u to 10 MeV/u.**



- SC LINAC based on **Quarter Wave Resonators** (QWRs).
- High-β section consists on **4 cryo-modules** with 5 cavities each, installed during the next shut down.

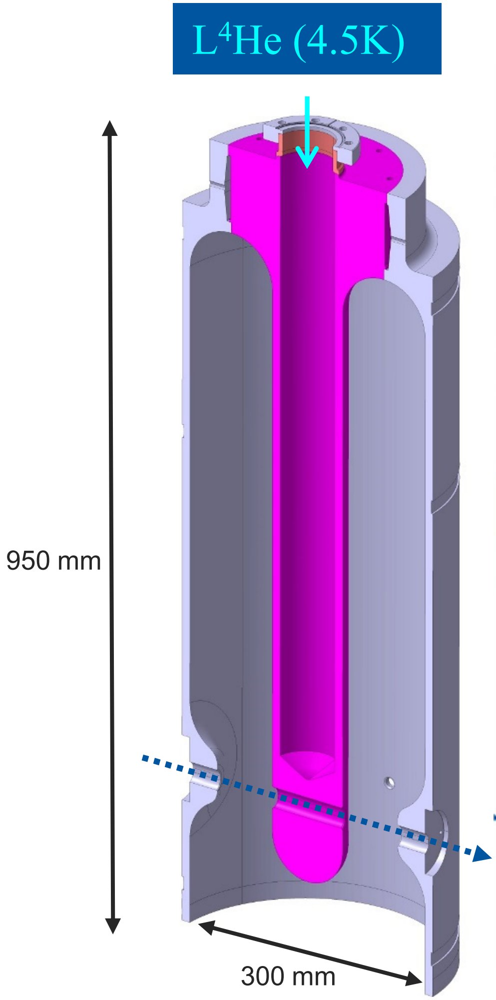
HIE-ISOLDE project

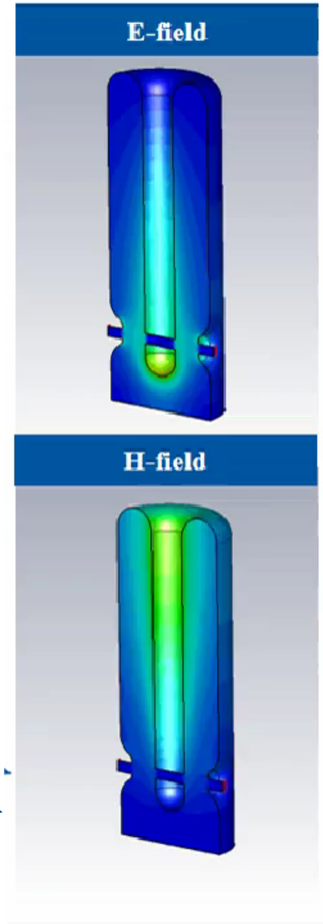
- The **High Intensity and Energy ISOLDE** (HIE-ISOLDE) project is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities.
- Energy increase of the delivered radioactive ion beam (RIB) **from 3 MeV/u to 10 MeV/u.**

CM3 installed January 24th

- SC LINAC based on **Quarter Wave Resonators** (QWRs).
- High-β section consists on **4 cryo-modules** with 5 cavities each, installed during the next shut down.

Quarter-Wave Resonator

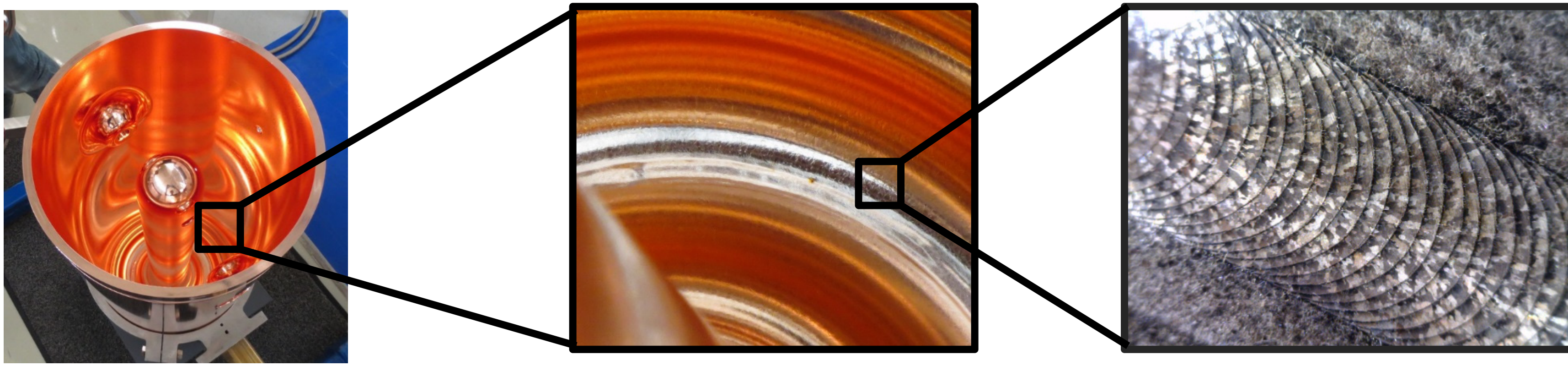


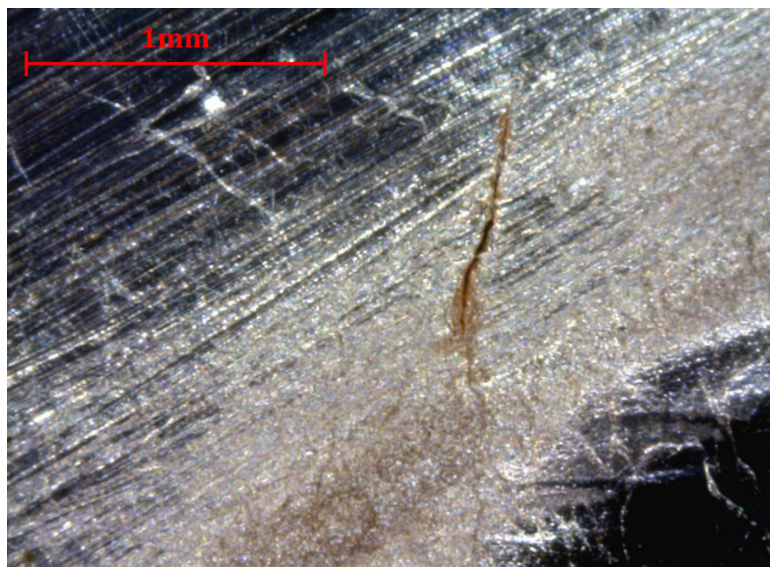


- Superconducting Nb/Cu cavity at **4.5 K**
- **Conduction cooling** through the copper substrate (good thermal conductivity of Cu)
- 3D-forged OFE copper
- **DC bias** sputtering system
- **Shrink fit and electron beam welding** in the high magnetic field region
- **Common vacuum:** Beam vacuum = isolation vacuum

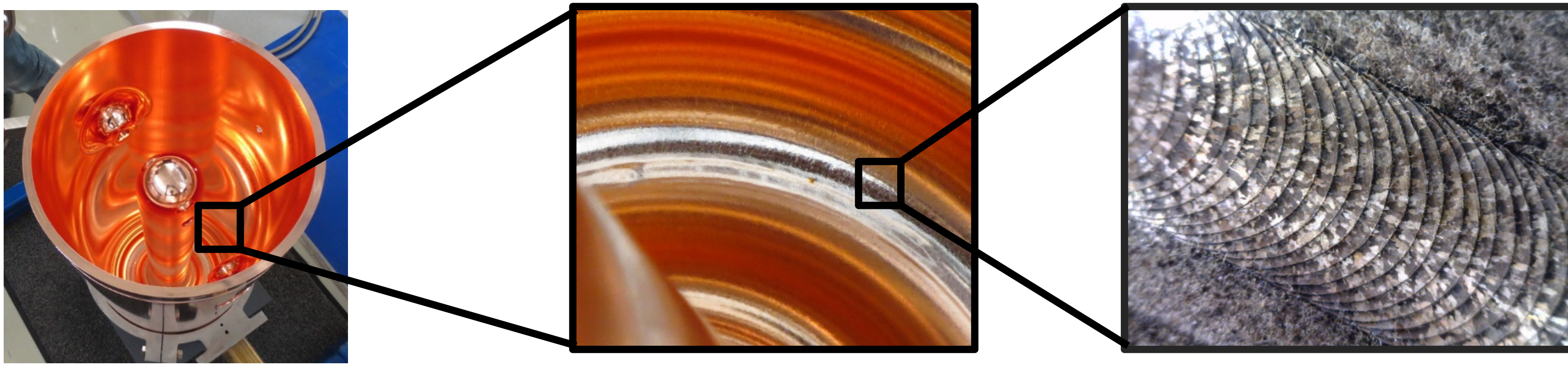
Frequency	101.28 MHz
E_{acc}	6 MV/m
$\beta_{optimum}$	10.9%
R/Q	553 Ω
E_{peak}/E_{acc}	5.0
B_{peak}/E_{acc}	96 G/(MV/m)
$G=R_sQ$	30.34 Ω
U/E_{acc}^2	0.207 J/(MV/m)²
P_c at 6MV/m	10W

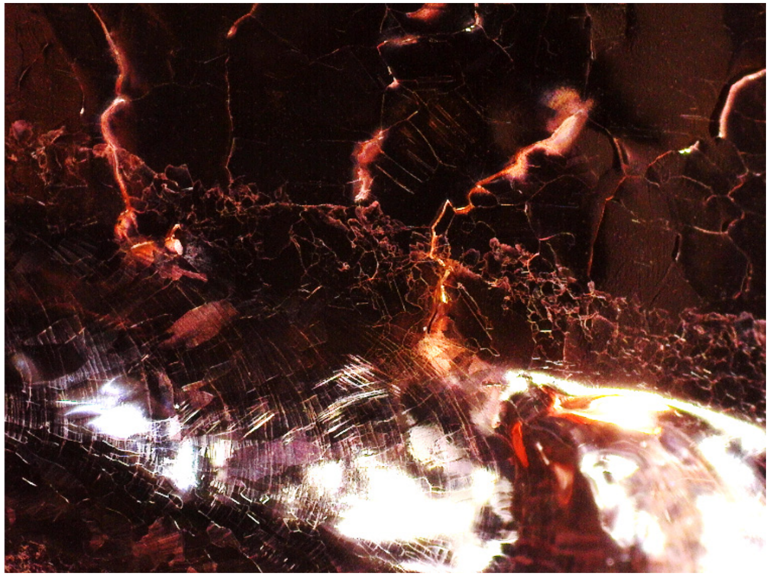
Why a new cavity design?



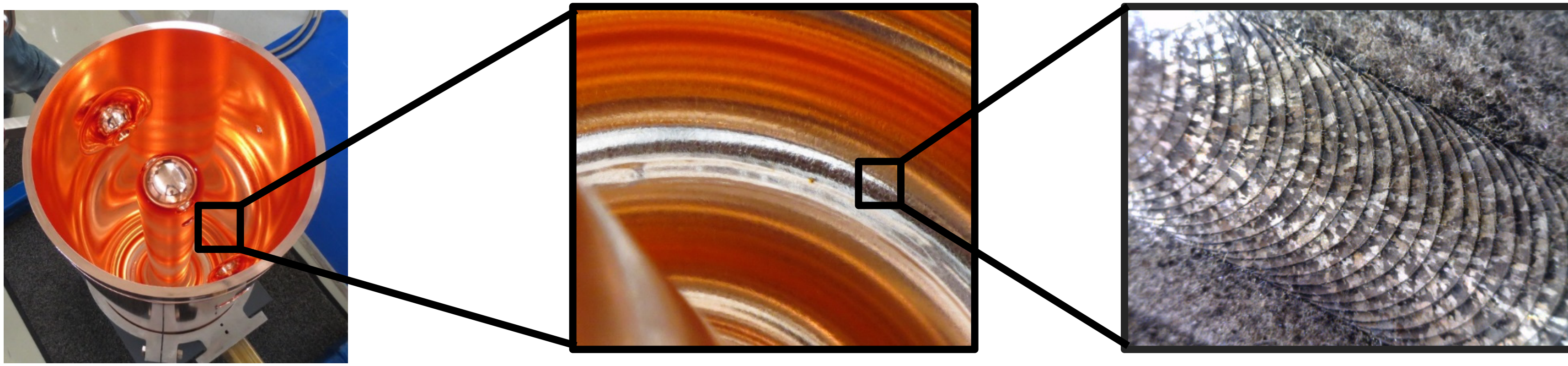


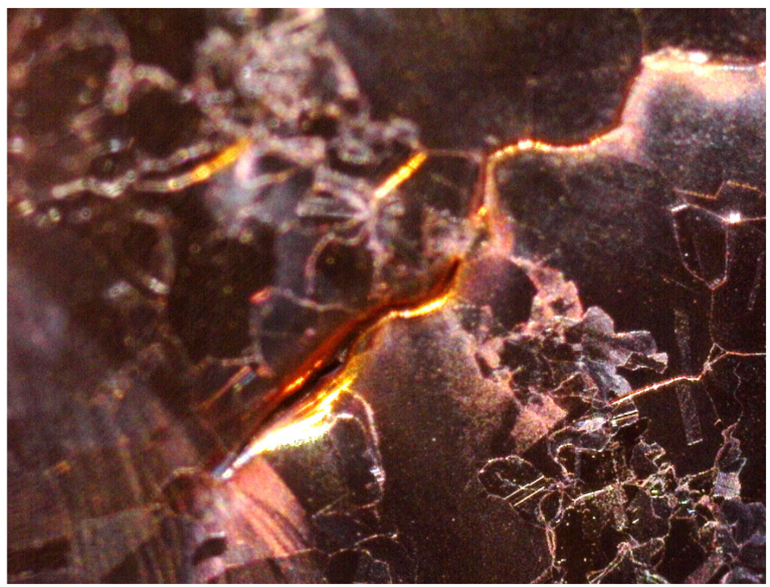
Why a new cavity design?



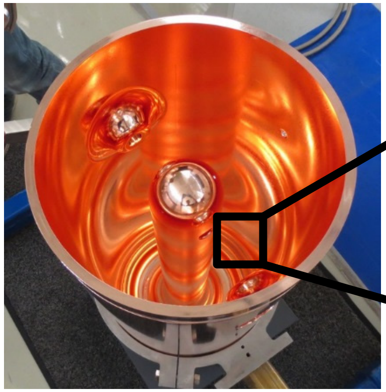


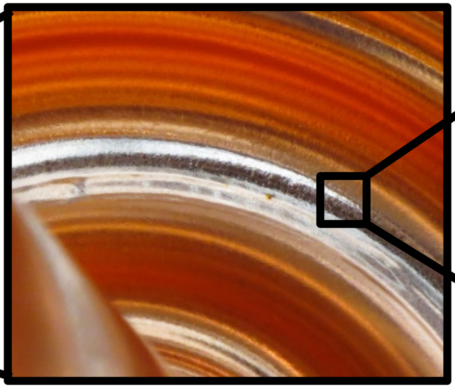
Why a new cavity design?

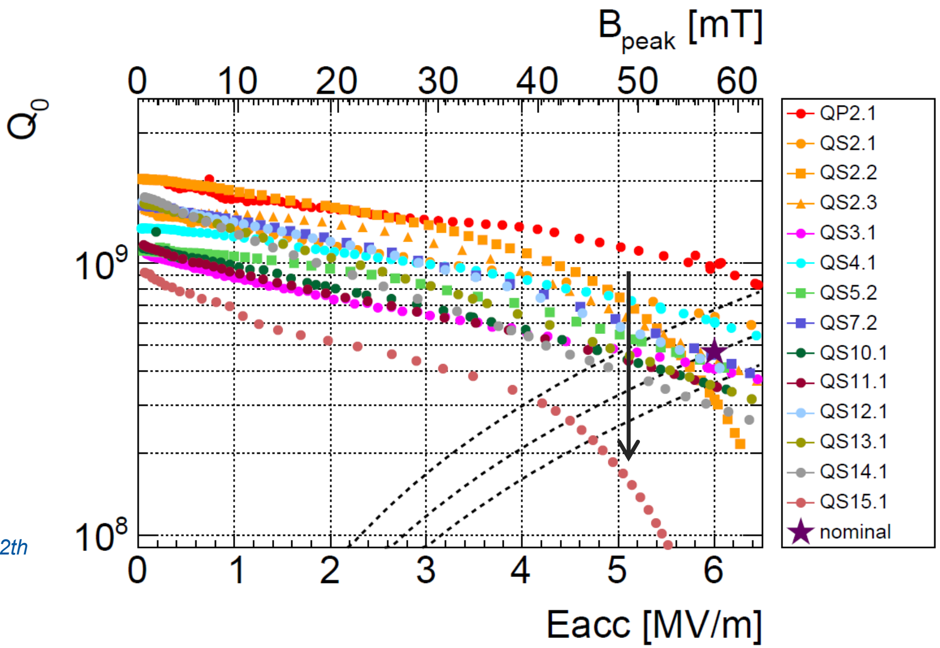




Why a new cavity design?

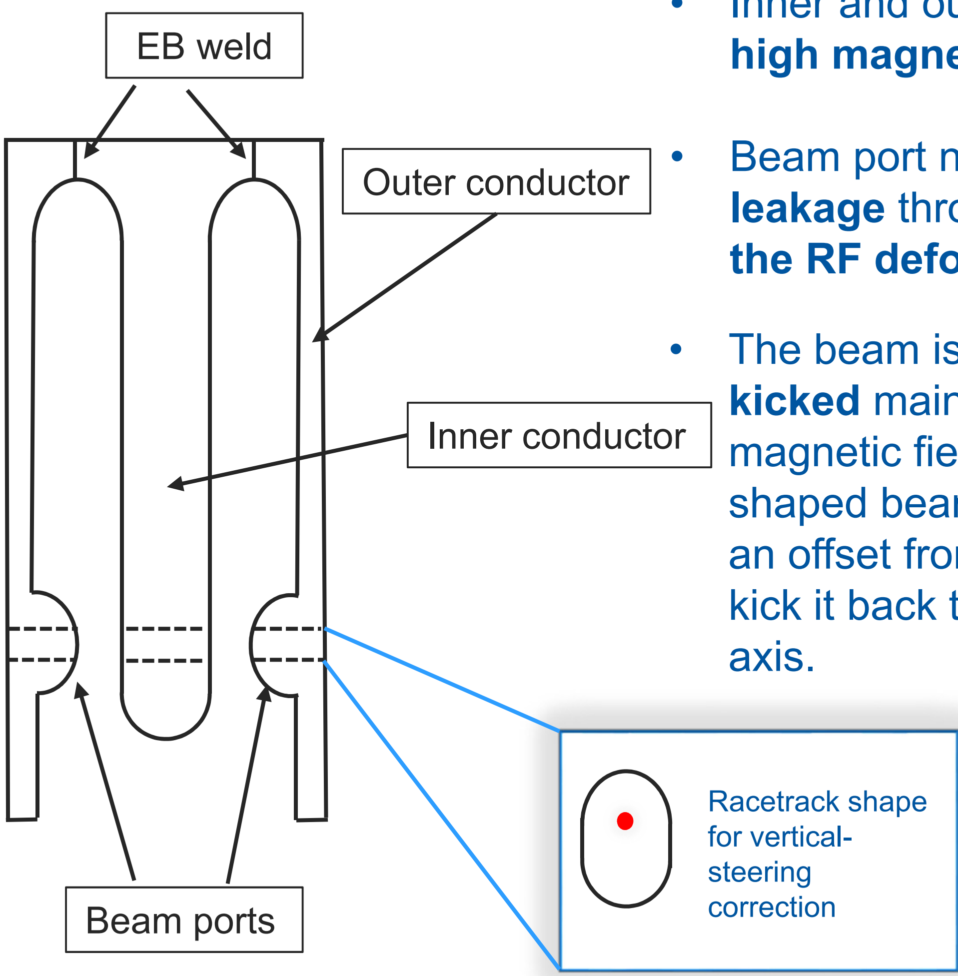




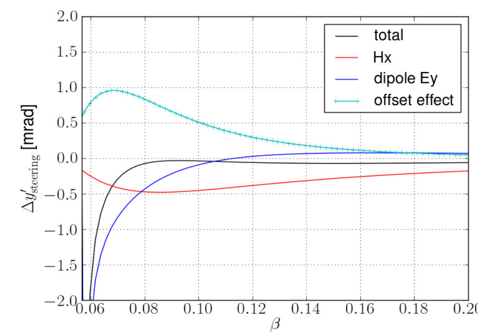


A.M. Porcellato, S.Stark, V. Palmieri, F. Stivanello "Niobium Sputtered QWRs", Proceedings of the 12th International Workshop on RF Superconductivity, Cornell University, Ithaca, New York, USA.

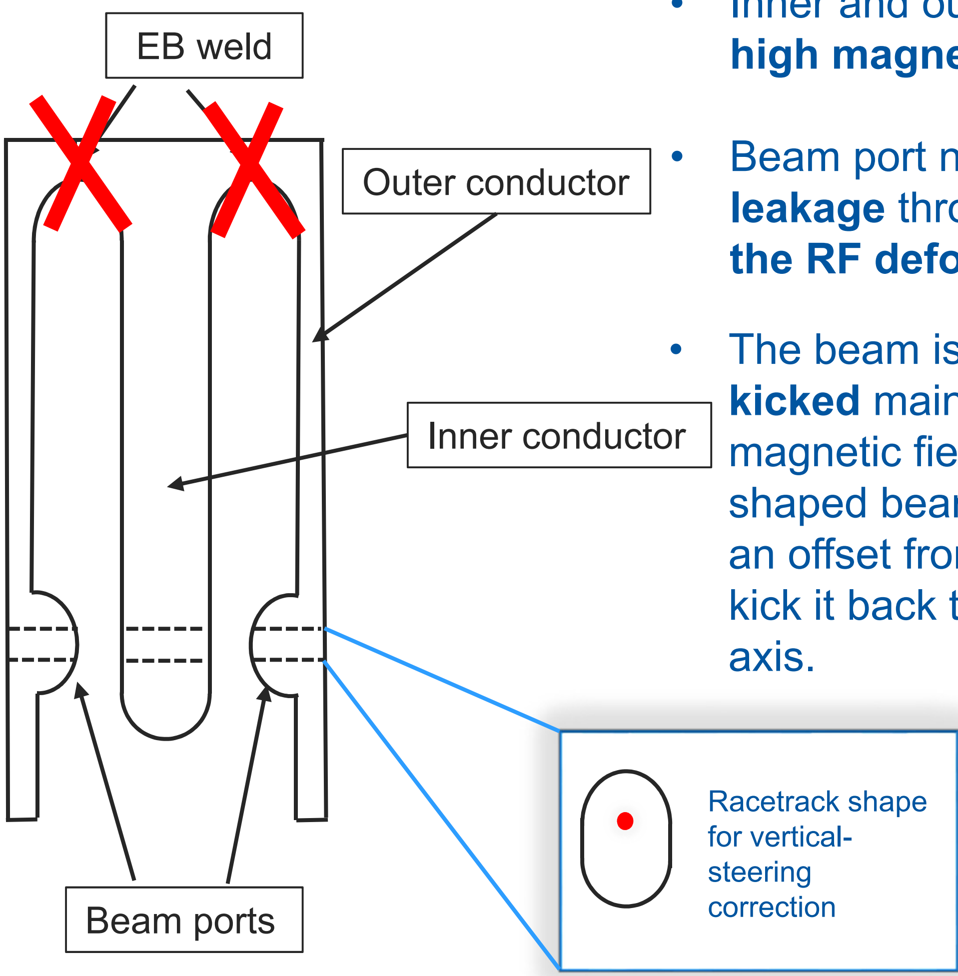
Features of the previous design



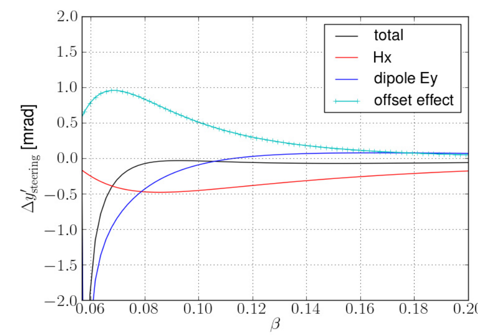
- Inner and outer conductor are welded at the **high magnetic field** region.
- Beam port noses **maximize R/Q**, **avoid RF leakage** through the beam ports and **correct the RF defocusing.**
- The beam is **transversely kicked** mainly by the magnetic field. Racetrack-shaped beam ports with an offset from the centre kick it back to the beam axis.



Features of the previous design

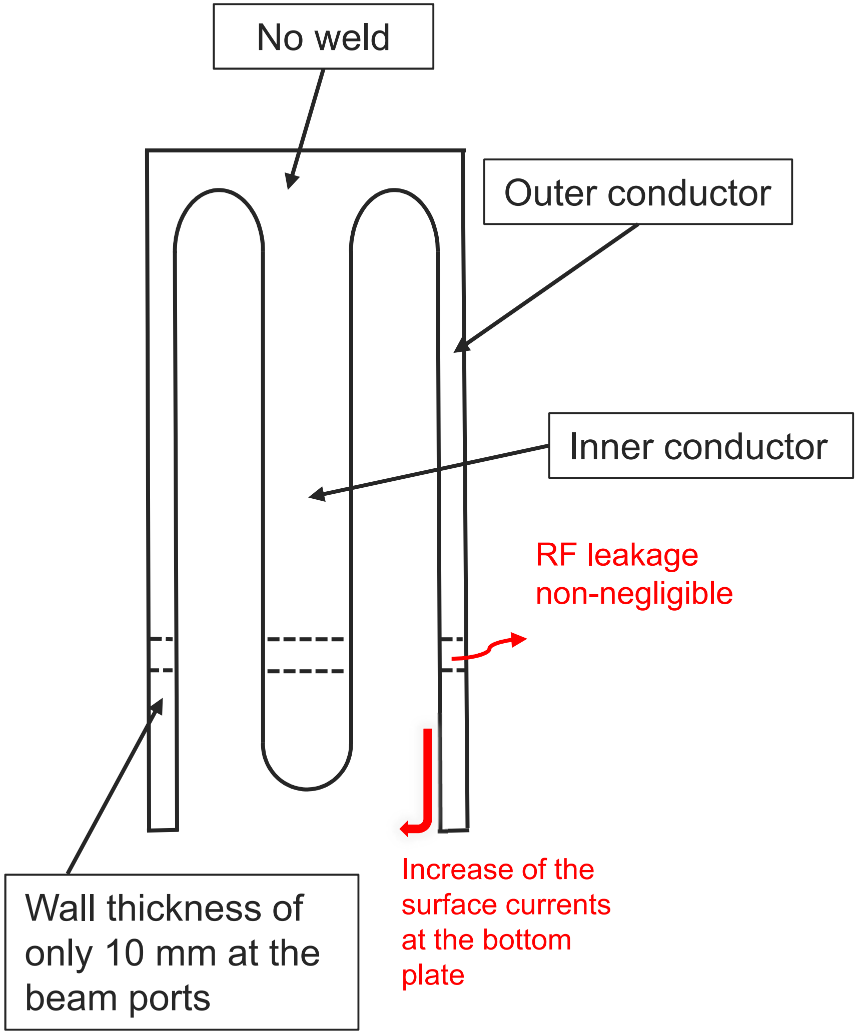


- Inner and outer conductor are welded at the **high magnetic field** region.
- Beam port noses **maximize R/Q**, **avoid RF leakage** through the beam ports and **correct the RF defocusing.**
- The beam is **transversely kicked** mainly by the magnetic field. Racetrack-shaped beam ports with an offset from the centre kick it back to the beam axis.



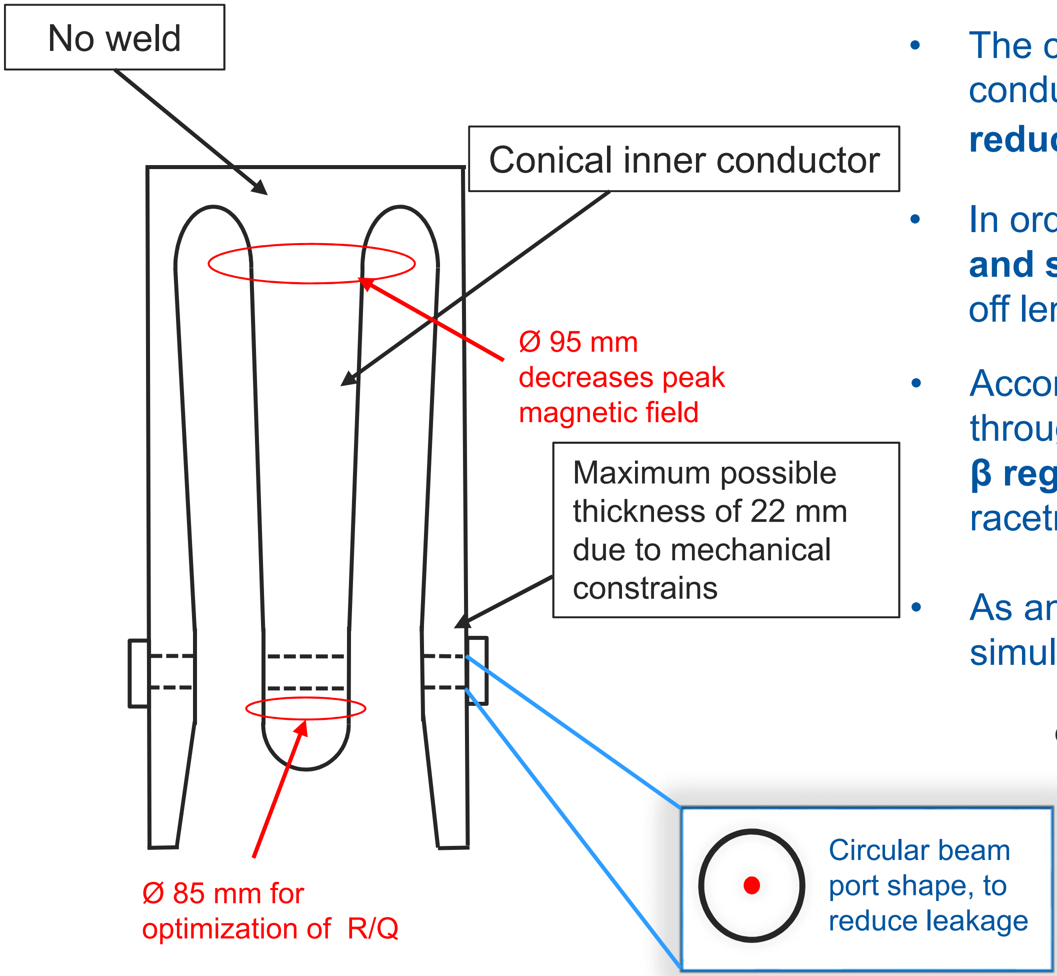
Machining from the bulk = rotational symmetry = no beam port noses

Seamless design process

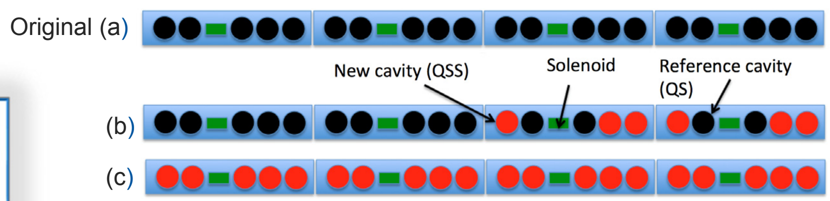


- The removal of the noses would cause:
  - Dramatic decrease of R/Q.
  - Increase of the **surface currents** at the bottom plate, which increases the RF losses.
  - Non-negligible **RF leakage** through the beam ports.

Seamless design process

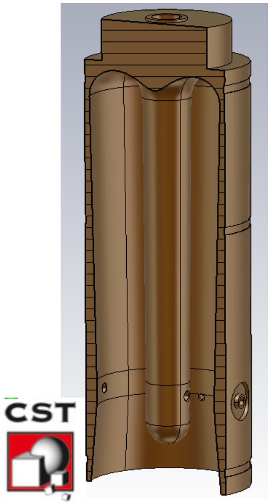


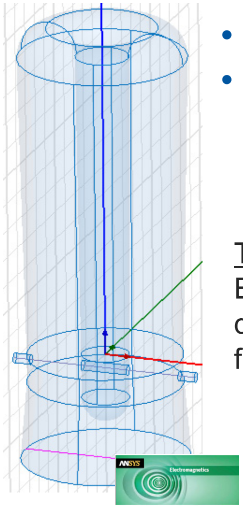
- The conical shape on the inner and outer conductor **decreases B_{peak}, optimizes R/Q** and **reduces the RF leakage** through the beam ports.
- In order to further reduce RF leakage, **extra pieces and shutters** have been designed to extend the cut-off length.
- According to a full numerical multi-particle tracking through the whole linac, **the vertical steering at high β region can be neglected**. No need for correction by racetrack.
- As an alternative, **beam port tilting** was already simulated and it will make the cavity useful at lower β.



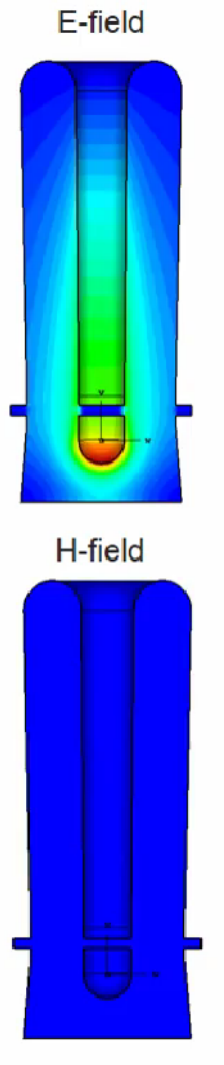
Cavity	Output Energy [MeV/u]	Transmission [%]	Transverse RMS Emittance Growth [%]
Original (a)	14.17	100	0
high β CM (b)	14.2	100	-0.3
All CM (c)	13.86	85	21.2

RF design



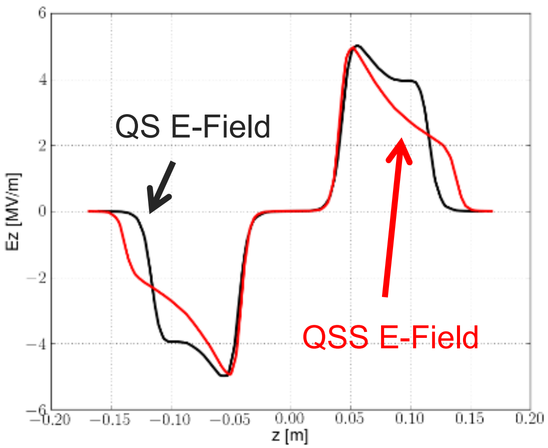


- Full parametrical study.
- Optimization for a higher beta.
  The cavity has to be **retuned** after every optimization iteration.

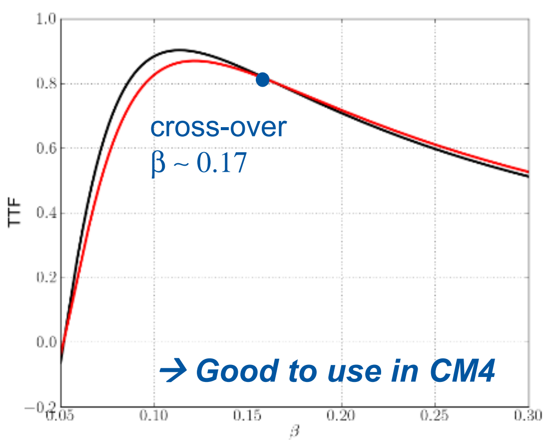


Transit Time Factor (TTF)
Efficiency of acceleration depending on the electric-field structure

$$V_{acc} = TTF \times \int_{-\infty}^{+\infty} |Ez(z)| dz$$



The new RF field is broader → Higher TTF at high β

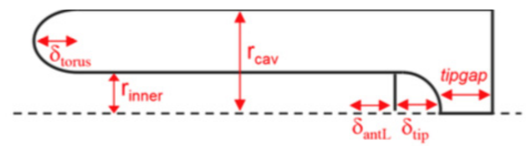


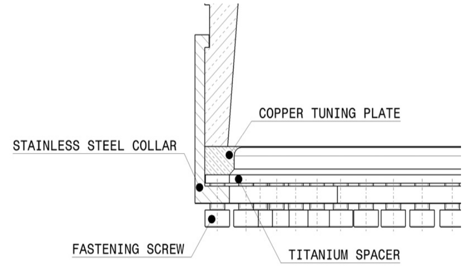
Parameters	QS	QSS
Frequency [MHz]	101.28	101.28
E_{acc} [MV/m]	6	6
β_{opt} [%]	10.9	12.2
R/Q at β_{opt} [Ω]	553	502
E_{peak}/E_{acc}	5.0	5.2
B_{peak}/E_{acc} [G/(MV/m)]	96	93
$G=R_sQ$ [Ω]	30.34	30.1
U/E_{acc}^2 [J/(MV/m)^2]	0.207	0.214

Mechanical design and fabrication

Tolerance study of the geometry determined for an acceptable pre-tuning uncertainty of the resonant frequency.

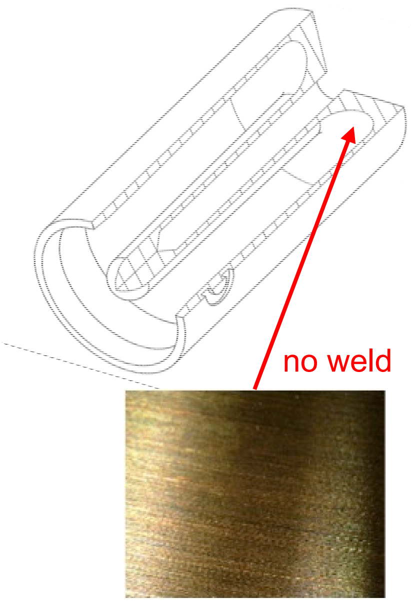
Parameters	Sensitivity [kHz/mm]	σ[mm]
δ_{antL}	155	±0.1
tip gap	16	±0.7
δ_{torus}	105	±0.2
r_{inner}	28	±0.3
r_{cav}	47	±0.2
δ_{tip}	106	±0.2

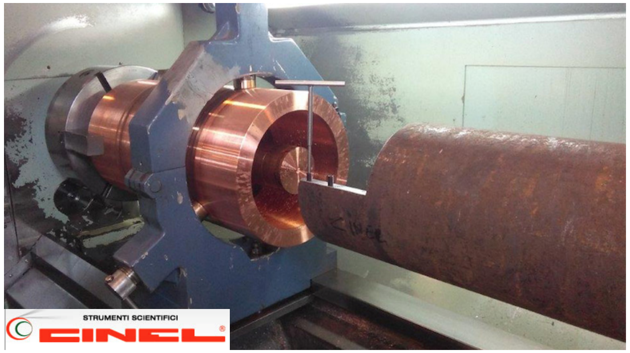




The changes to outer dimensions and interfaces were kept to mínimum.

New shutters and beam port extensions were designed and manufactured.

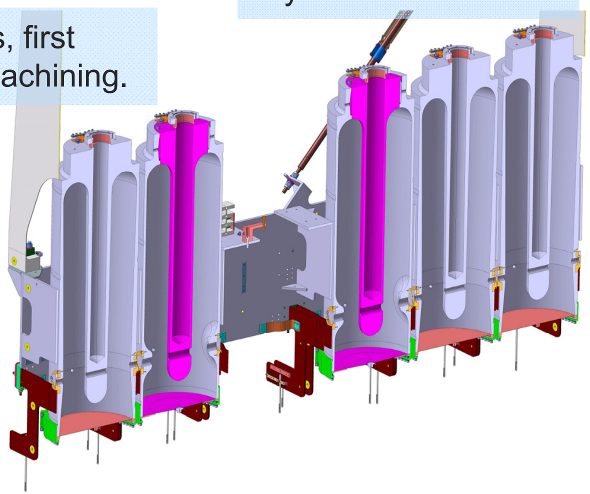




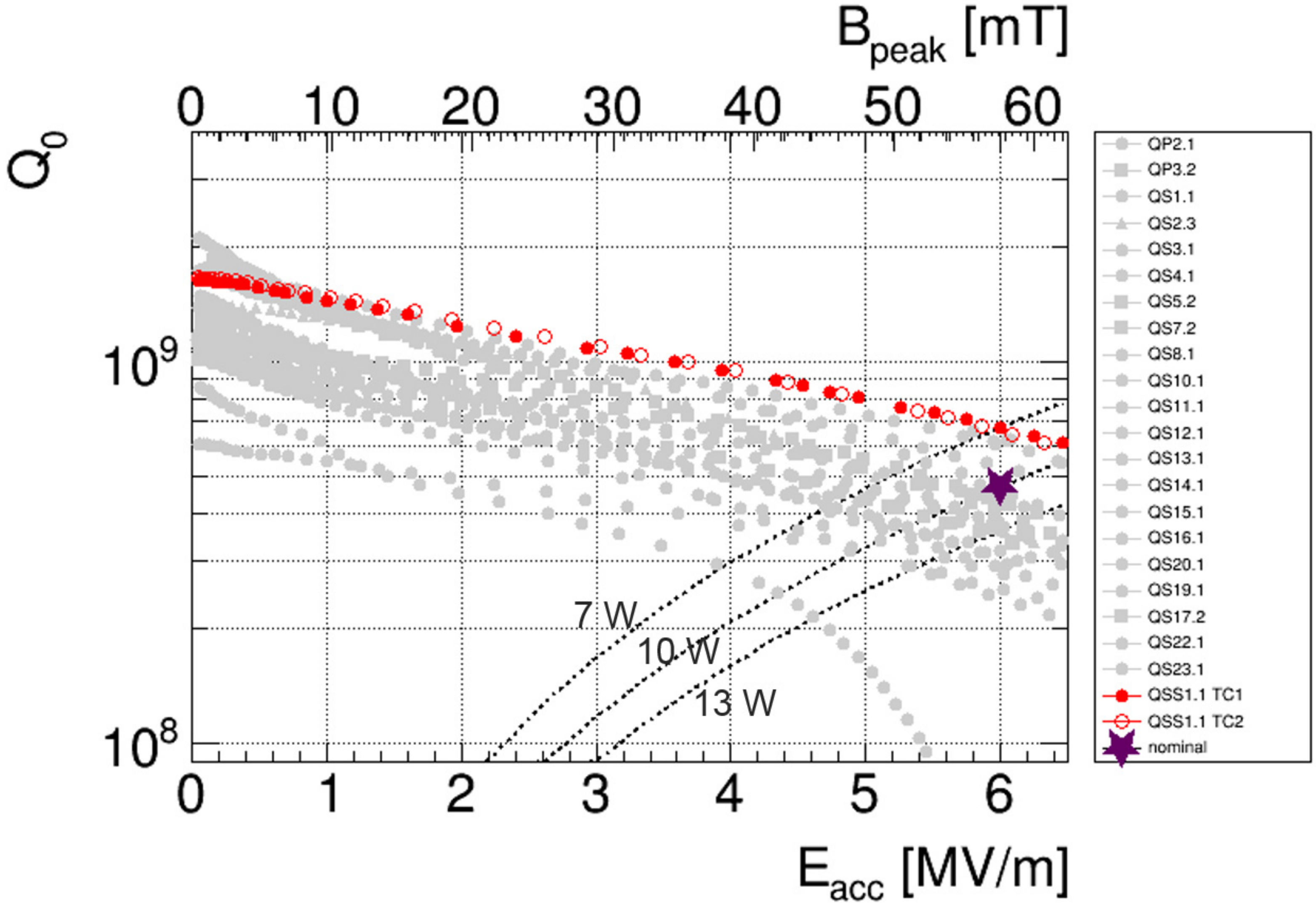
A blank test assembly was performed to ensure cavity insertion in the cryomodule.

Cavity manufactured in two steps, first deep drilling, then precise final machining.

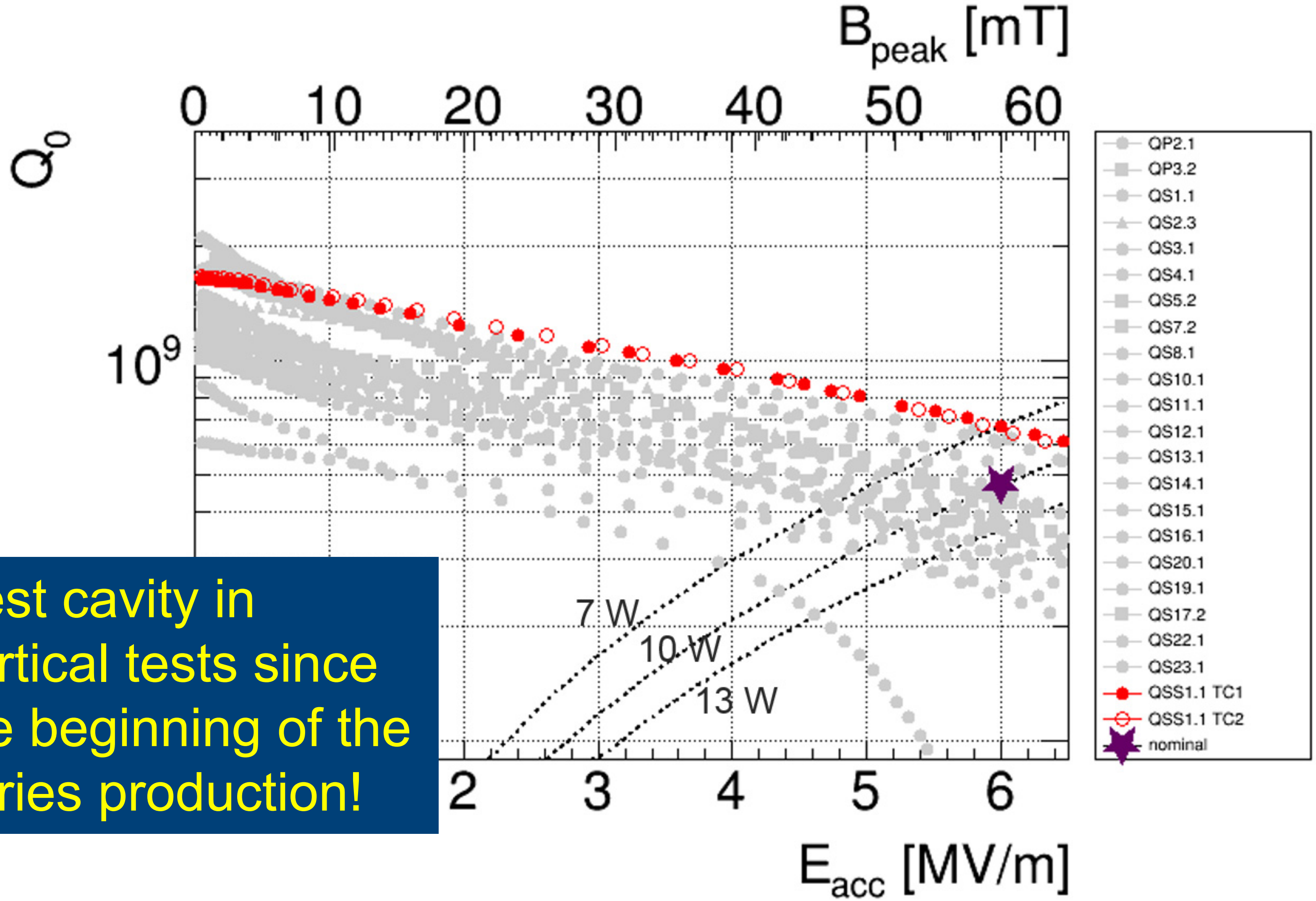
A prototype cavity was produced and confirmed the feasibility of the machining with lathe technique.



Cold test (vertical cryostat)



Cold test (vertical cryostat)



Best cavity in vertical tests since the beginning of the series production!

Future work

- Production of more cavities for a spare cryomodule ⟶ more statistics.
- Further design optimization.
  - Studies on beam dynamics for the lower energy section of the linac.
  - Low beta version for possible phase 3.

Conclusions

- A seamless QWR has been designed and prototyped, showing the **feasibility of machining the cavity out of the bulk**.
- The **figures of merit** of the QSS cavity have been compared to the nominal design (QS) showing a similar performance.
- Trade offs had to be made in terms of RF design, in order to **minimize the changes** of the interfaces (coating system, handling, cryomodule integration, etc.)
- Due to the increase in cross-section at the cavity top, the conduction cooling was more effective, showing **much smaller thermal gradients** (uniform cooling).
- The first seamless cavity produced (QSS1) displayed **excellent RF performance.**
- This cavity **will be installed in CM4.**

Thank you for your attention.

Questions?

CERN