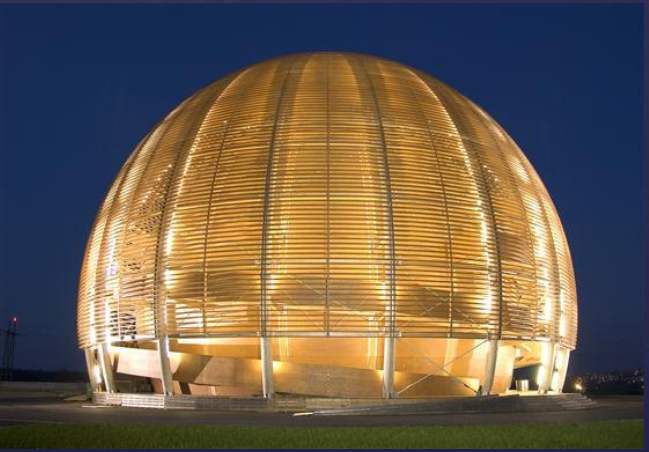
Nb sputtered Quarter Wave Resonators for HIE ISOLDE

W. Venturini Delsolaro[1]

L. Alberty, K. Artoos, S. Calatroni[1], O. Capatina, A. D'Elia[2], N. M. Jecklin[1],Y. Kadi[1], P. Maesen[1], I. Mondino[1], K. Schirm, A. R. M. Sublet[1], M. Therasse[1], P. Zhang[1]

[1]CERN, Geneva, Switzerland,
[2]CERN, Geneva & UMAN, Manchester, United Kingdom



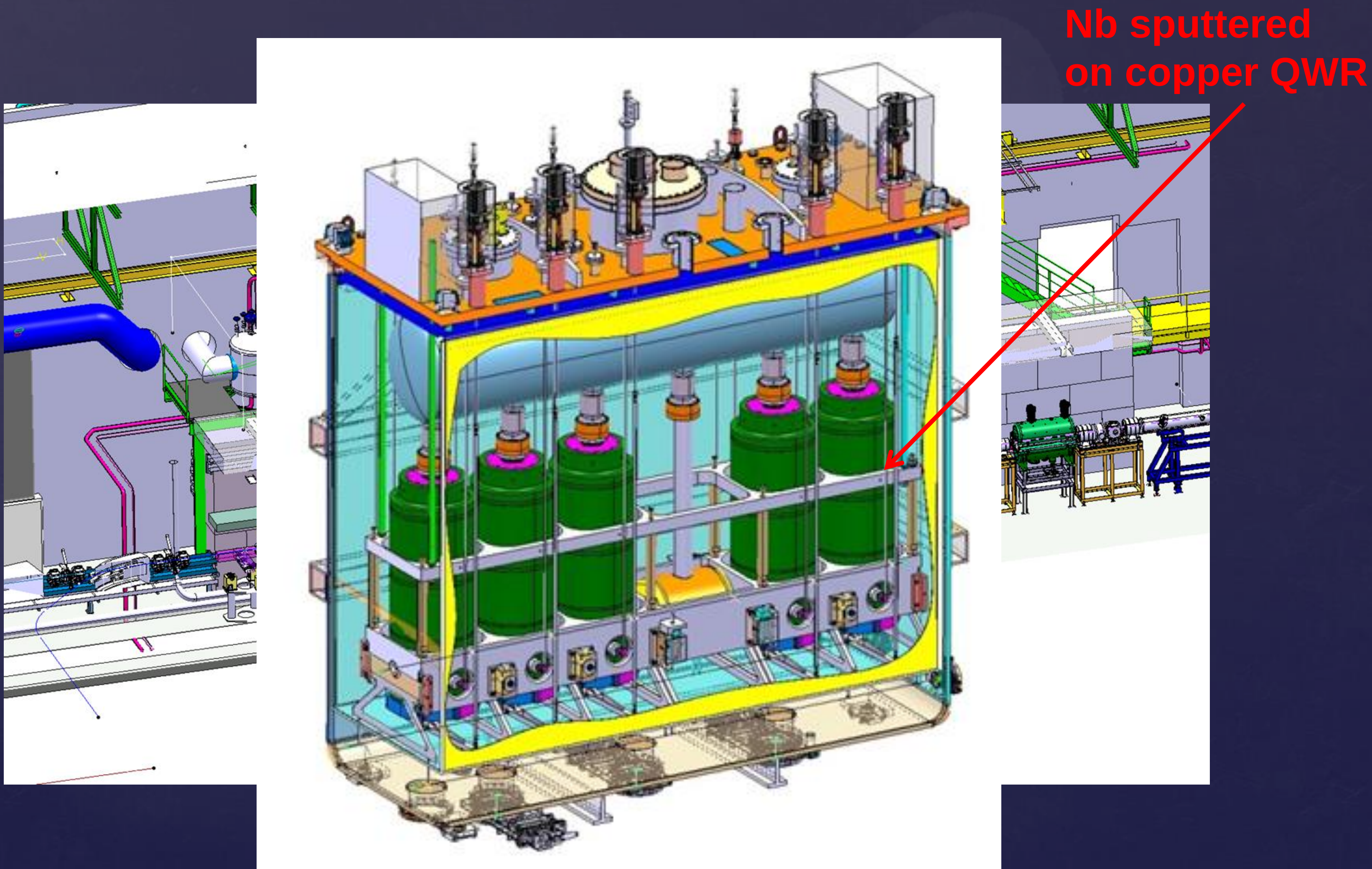
HIE-ISOLDE Workshop: The Technical Aspects
CERN, 28-29 November 2013

Contents

- HIE ISOLDE cavity technical aspects:
  - QWR features
  - Technology
  - Specifications and challenges
- Development of Nb/Cu QWR for HIE ISOLDE:
  - Thin Nb film evolution
  - Critical details
- Conclusions

The HIE ISOLDE Cryomodues

Common vacuum concept - Actively cooled thermal shield-
Superconducting active elements: RF cavities and solenoid

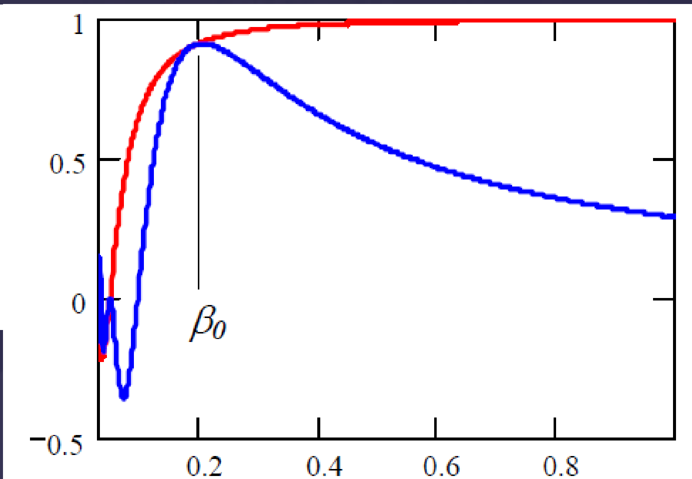


Elementary considerations on cavity choice

At low particle velocities, RF acceleration depends on transit time

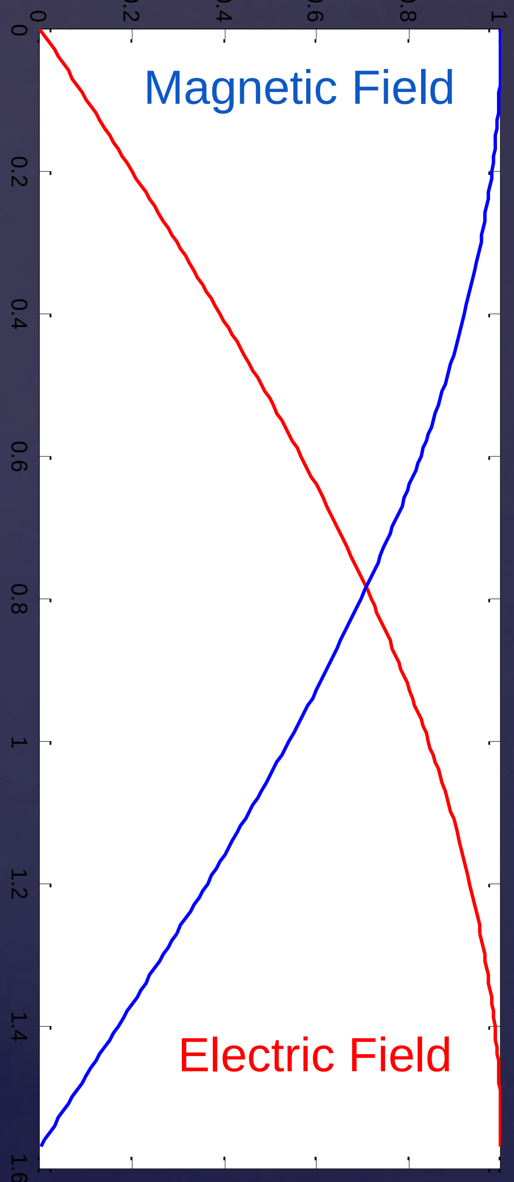
$$\Delta W_p = qE_a L T(\beta) \cos\varphi$$

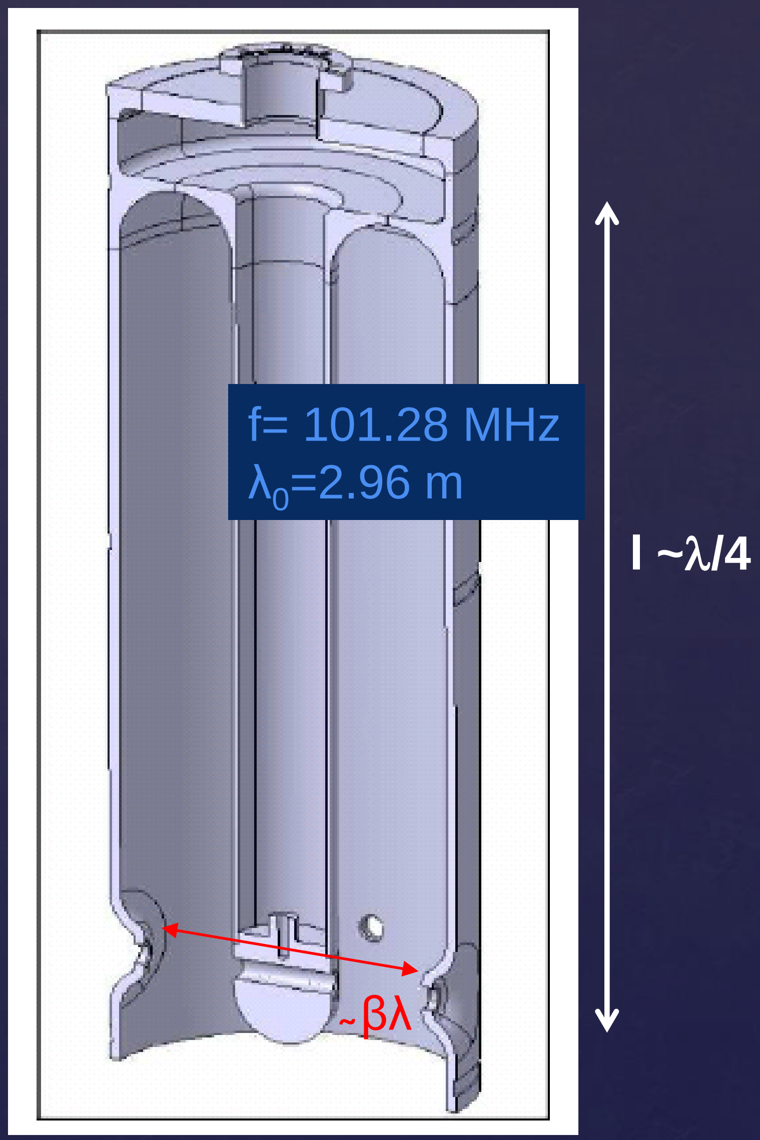
$$T(\beta) =$$



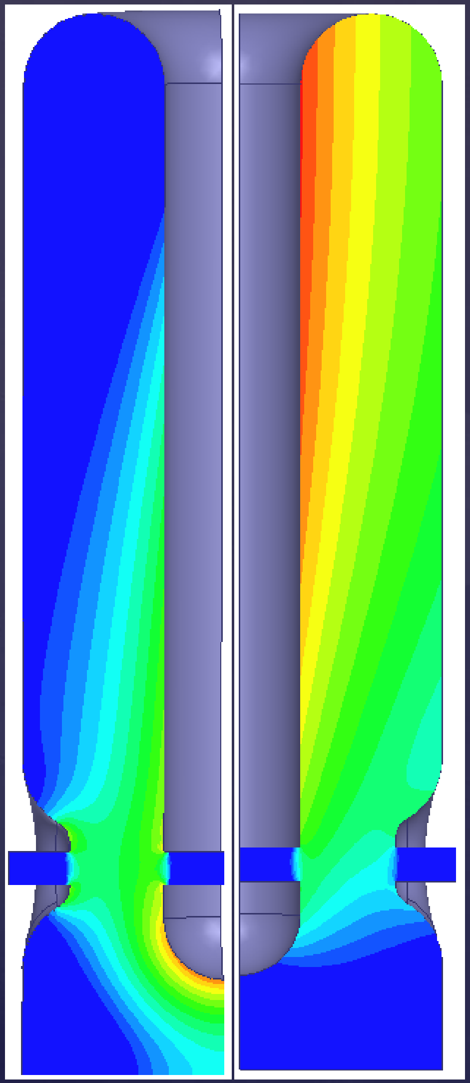
- Low frequency improves the TTF
- Multi (two) gap structure → TTF curve with a maximum (optimum beta)
- Quarter wave resonators have broader TTF(β) curves (larger energy acceptance); relatively favourable field ratios for a low beta structure, and high frequency of the lowest mechanical mode
- Low frequency → low BCS surface resistance → 4.2 K operation

Quarter Wave Resonator, TEM modes





High beta QWR design (electromagnetic)



HIE ISOLDE	Baseline†	New*
f_0 at 4.5 K [MHz]	101.28	101.28
β_{opt} [%]	10.86	10.88
TTF at β_{opt}	0.9	0.9
R/Q [Ω] (incl. TTF)	554	556
E_p/E_{acc}	**5.5**	**5.0**
H_p/E_{acc} [G/(MV/m)]	95.4	95.3
U/E^2_{acc} [mJ/(MV/m)^2]	208	207
$G=R_sQ$ [Ω]	30.7	30.8
P_{diss} @ 6 MV/m [W]	**10**	**10**
P_{diss} on bottom plate [W]	**0.0035**	**0.0018**

†Original tuning plate   *Simplified tuning plate

Ref. Proceedings of SRF2009, p. 609

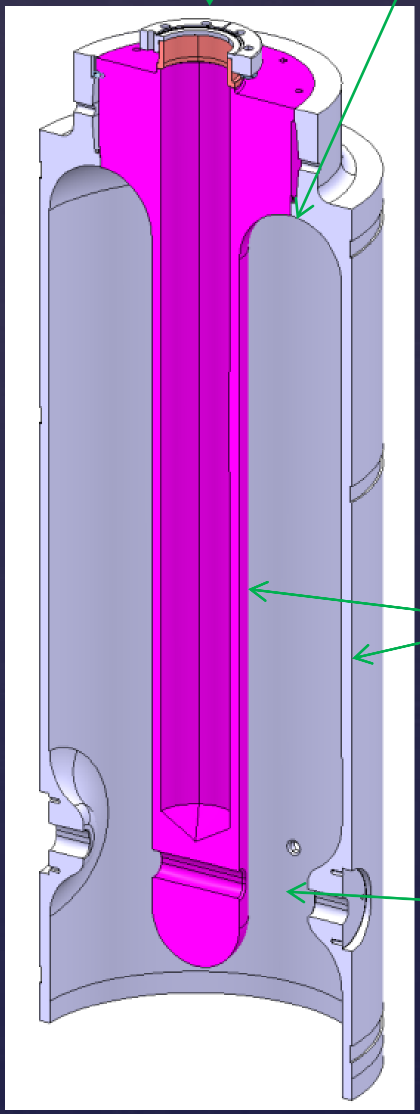
Cavity technology

Superconducting option

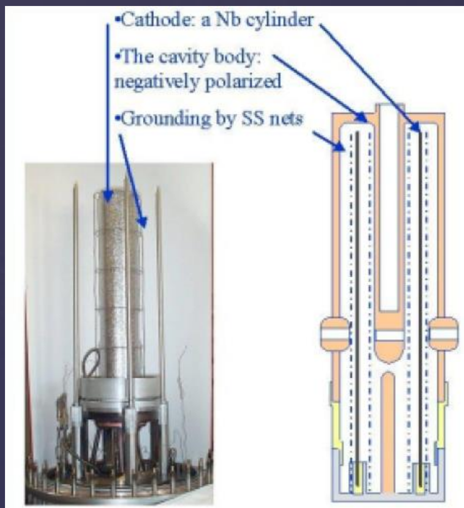
- High Q (low power dissipation)
- Cryogenics
- High CW fields (30 MV/m peak)
- Possible field emission, X rays

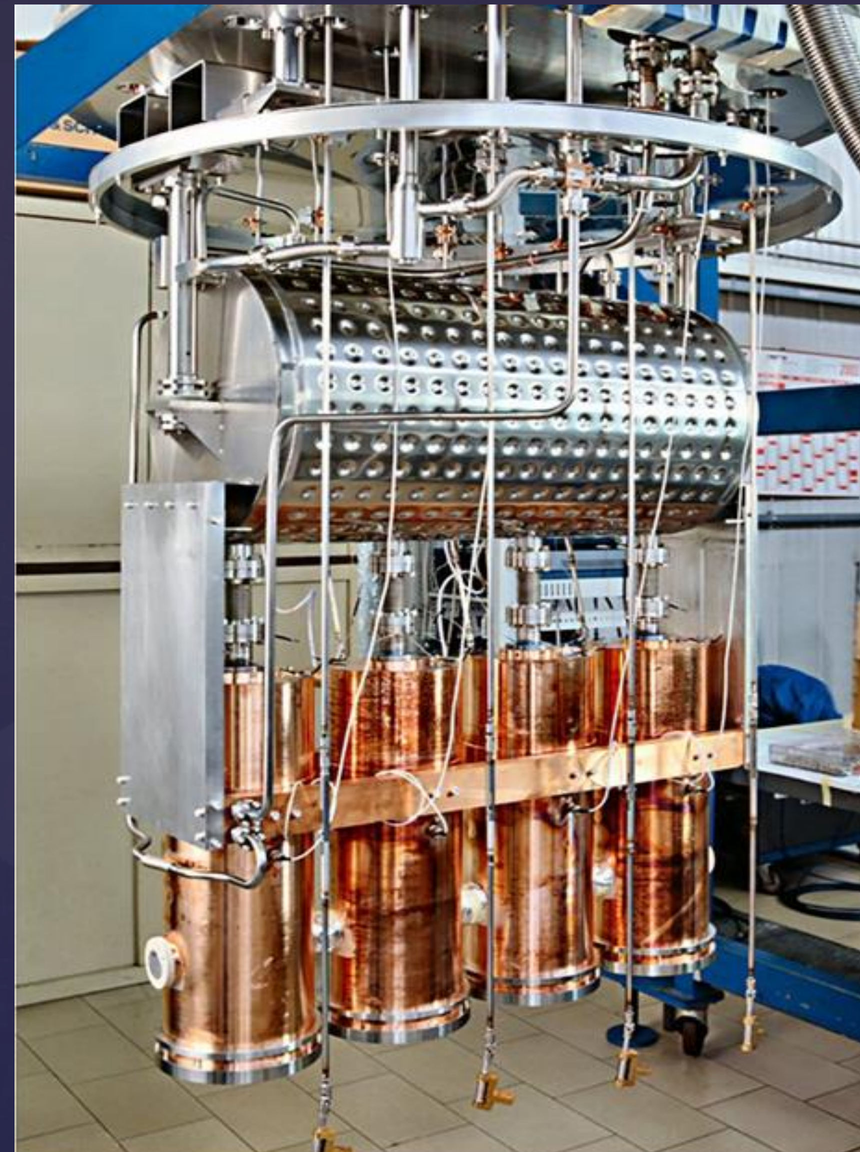
Niobium sputtering on copper

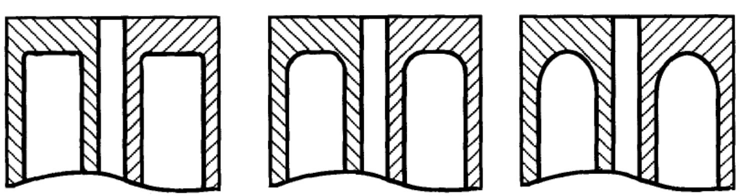
- Thermal stability
- Mechanical stability→ less sensitive to He pressure fluctuations and to mechanical vibrations→ Low RF power
- Less sensitive to magnetic fields→ no need of shielding the cryostat
- Potentially cheaper (especially for large series)
- Possible to recycle substrates



The ALPI experience: over 50 Nb/Cu QWR made at INFN -LNL installed between 1999 and 2003







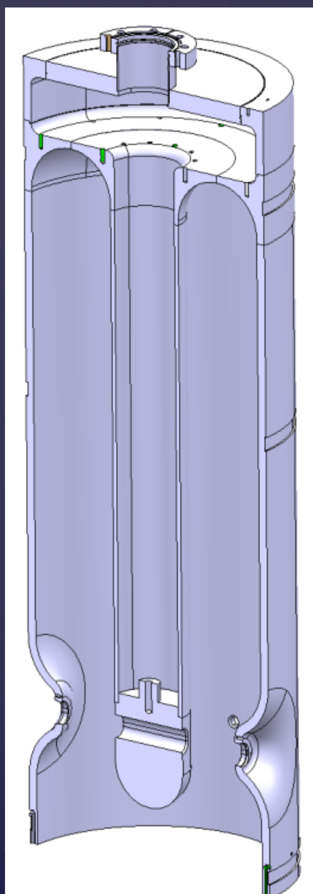
a b c

Fig. 6. Detail of resonator geometry: a) old model with curvature radius of 10 mm; b) modifyed model with curvature radius of 20 mm; c) definitive model with curvature radius of 30 mm.

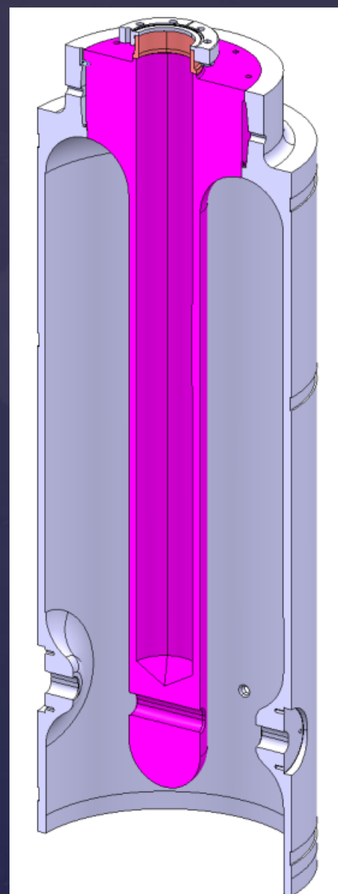
Evolution of resonator geometry
(from *V. Palmieri, V. L. Ruzinov, S. Stark, et al; Proceedings of the 6th Workshop on RF superconductivity, 1993)*

High beta QWR design (mechanical)

Version 1

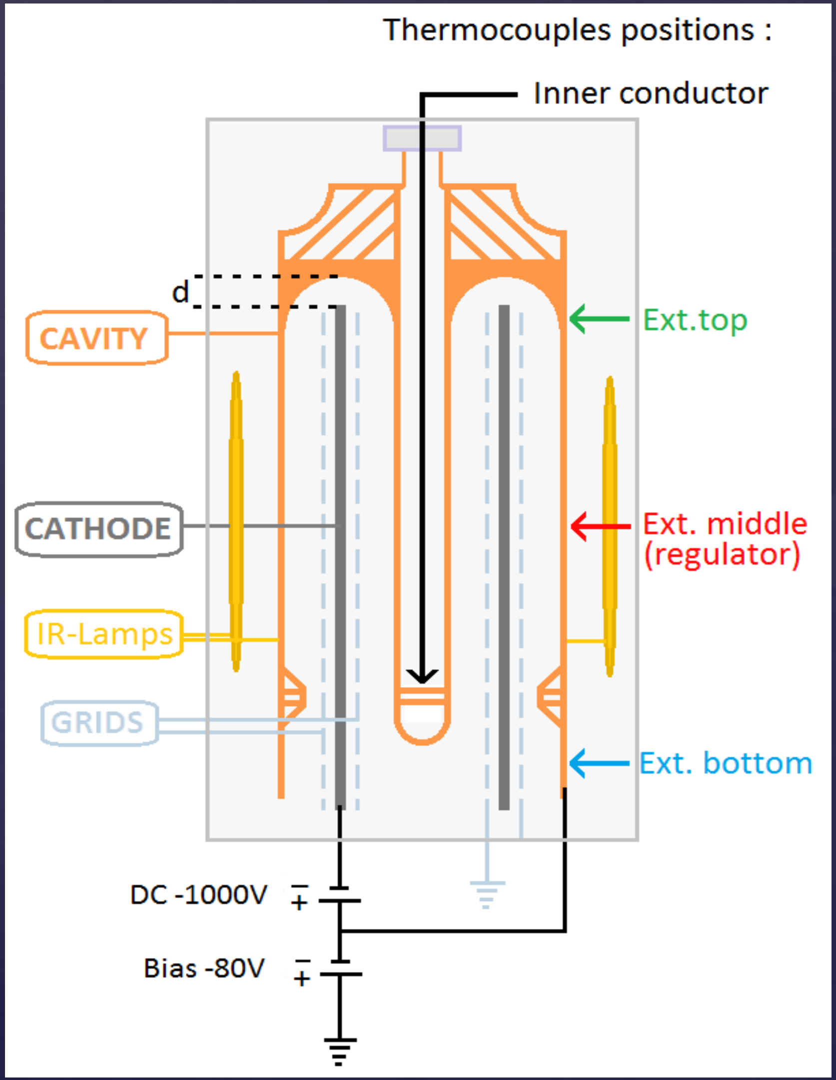


Version 2

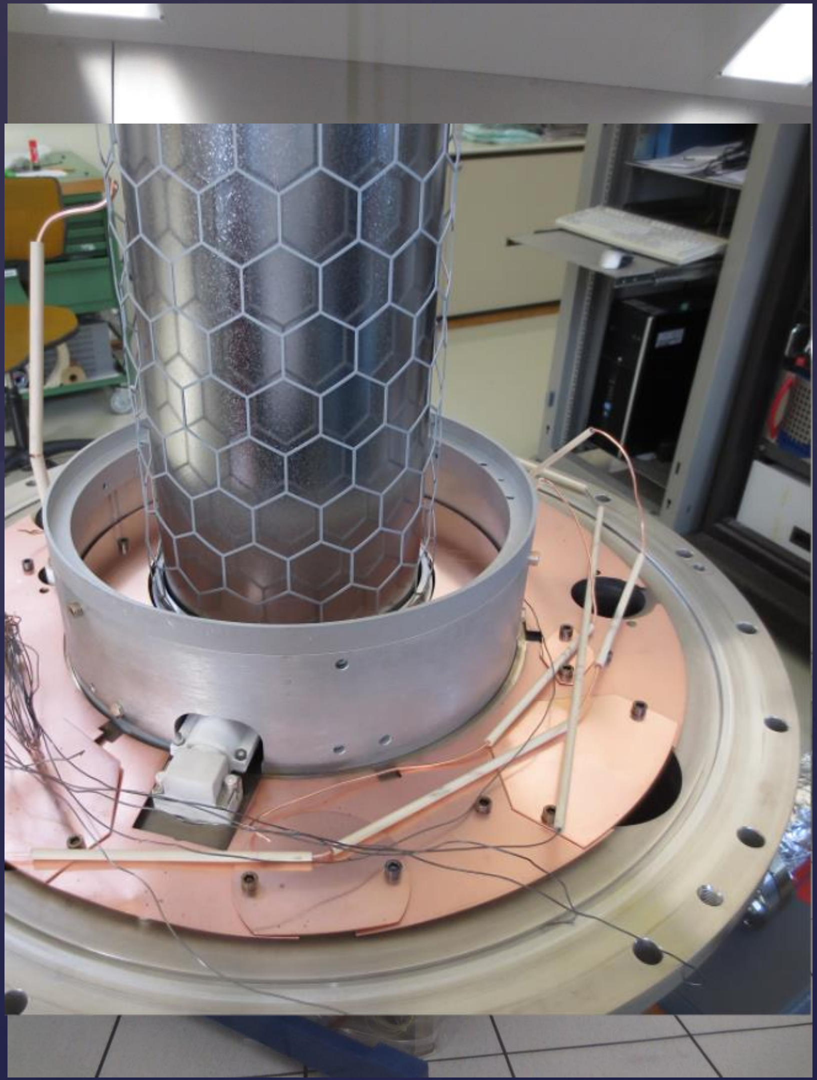


Bias diode sputtering system

Schematics



System assembly in clean room



Power dissipation, surface resistance

$$P_c = \frac{1}{2} R_s \int H^2 ds \qquad Q_0 = \frac{\omega U}{P_c} = \frac{\Gamma}{R_s}$$

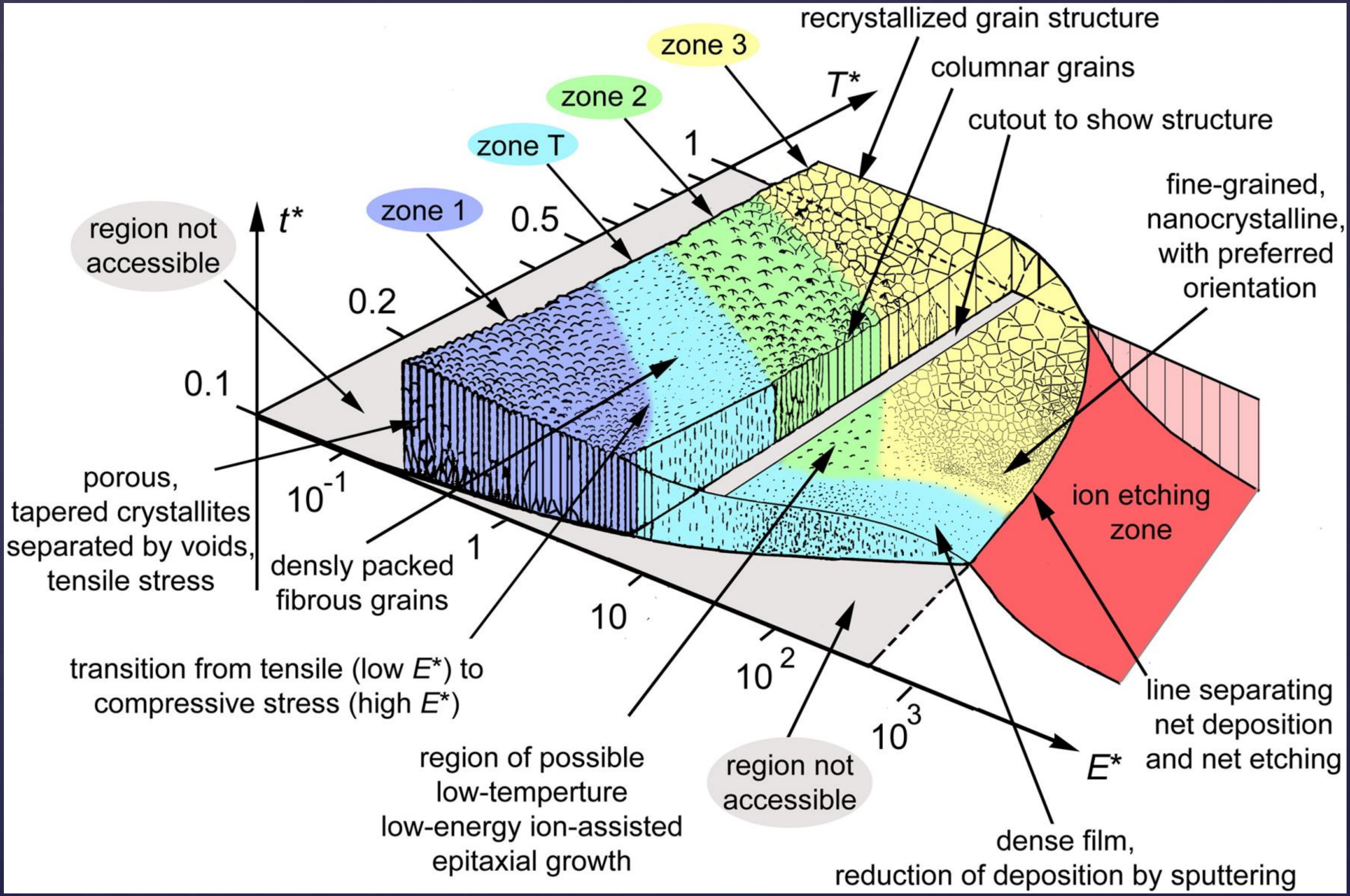
$$R_s = RB_{CS} + Rr_{es} \qquad R_{BCS} = \frac{A\omega^2}{T} \exp(-\frac{\Delta}{k_B T})$$

HIE ISOLDE low beta cavity:

R_{BCS} at 4.2 K and 101.28 MHz < 10% of total R_s

R_{res} is related to the "real" surface: defects, oxides, etc.

Thin film growth: structure zone models



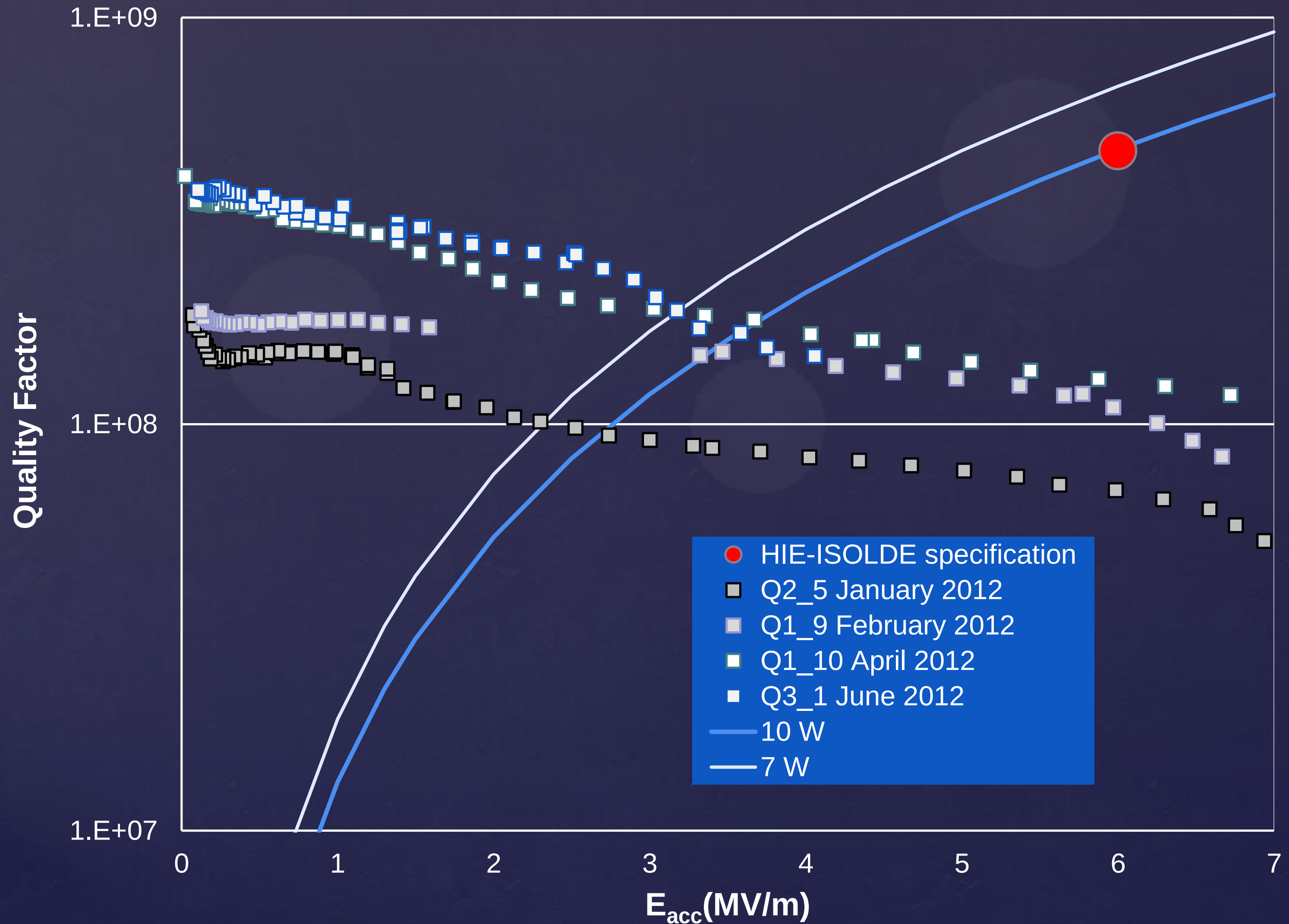
A. Anders, Thin Solid Films, Volume 518, Issue 15, 31 May 2010, Pages 4087–4090

Roadmap of developments (2011-2013)

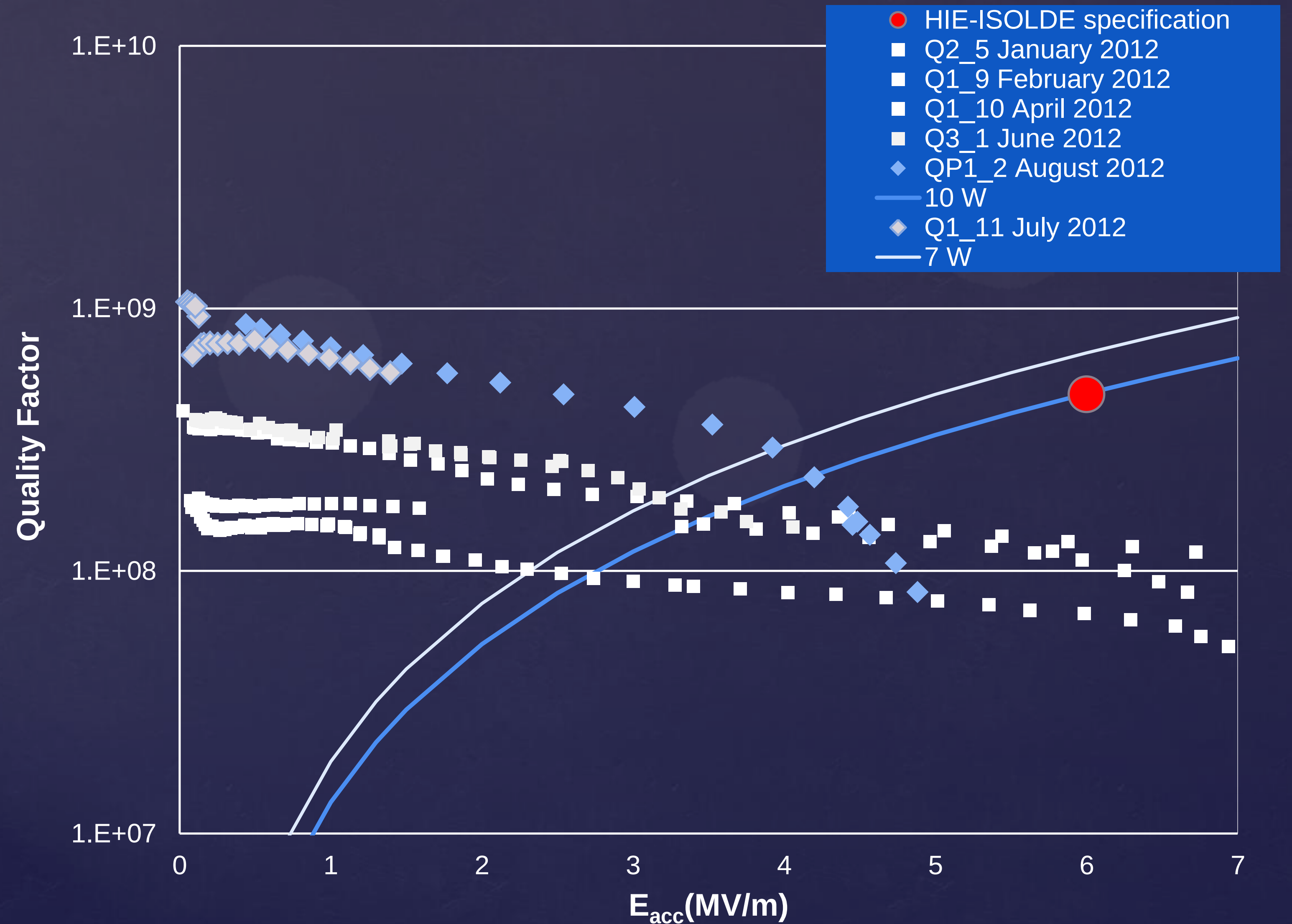
Strong development program focused on bias diode sputtering method. Main steps:

- Increasing baking and coating temperatures
- Increasing sputtering power (global deposition rate)
- Layered coatings
- Sputtering gas, venting gas
- Global film thickness
- Local film thickness

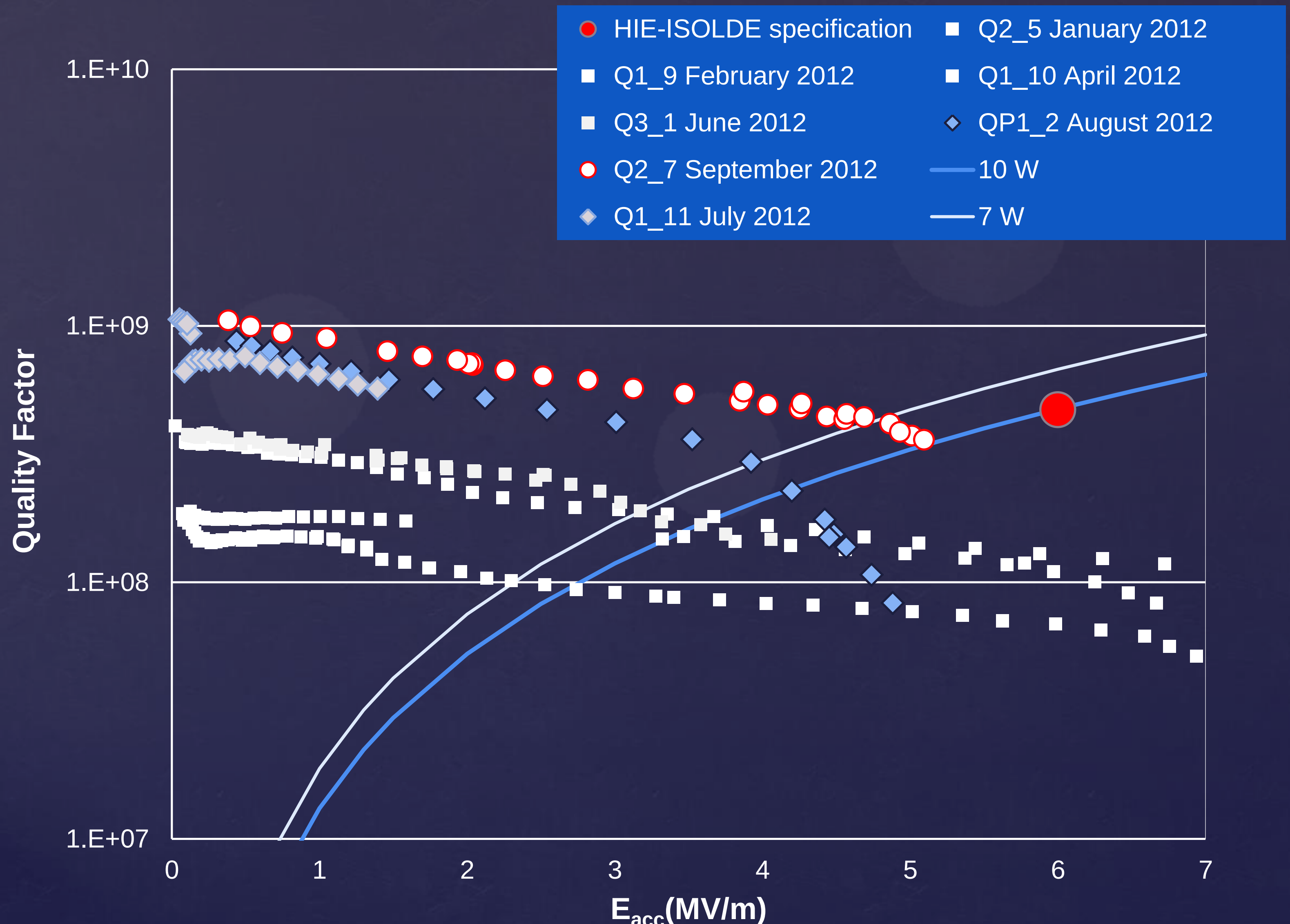
Increasing coating temperature, $T_{(bake\ out)} < T_{(coating)} \rightarrow 600\ °C$



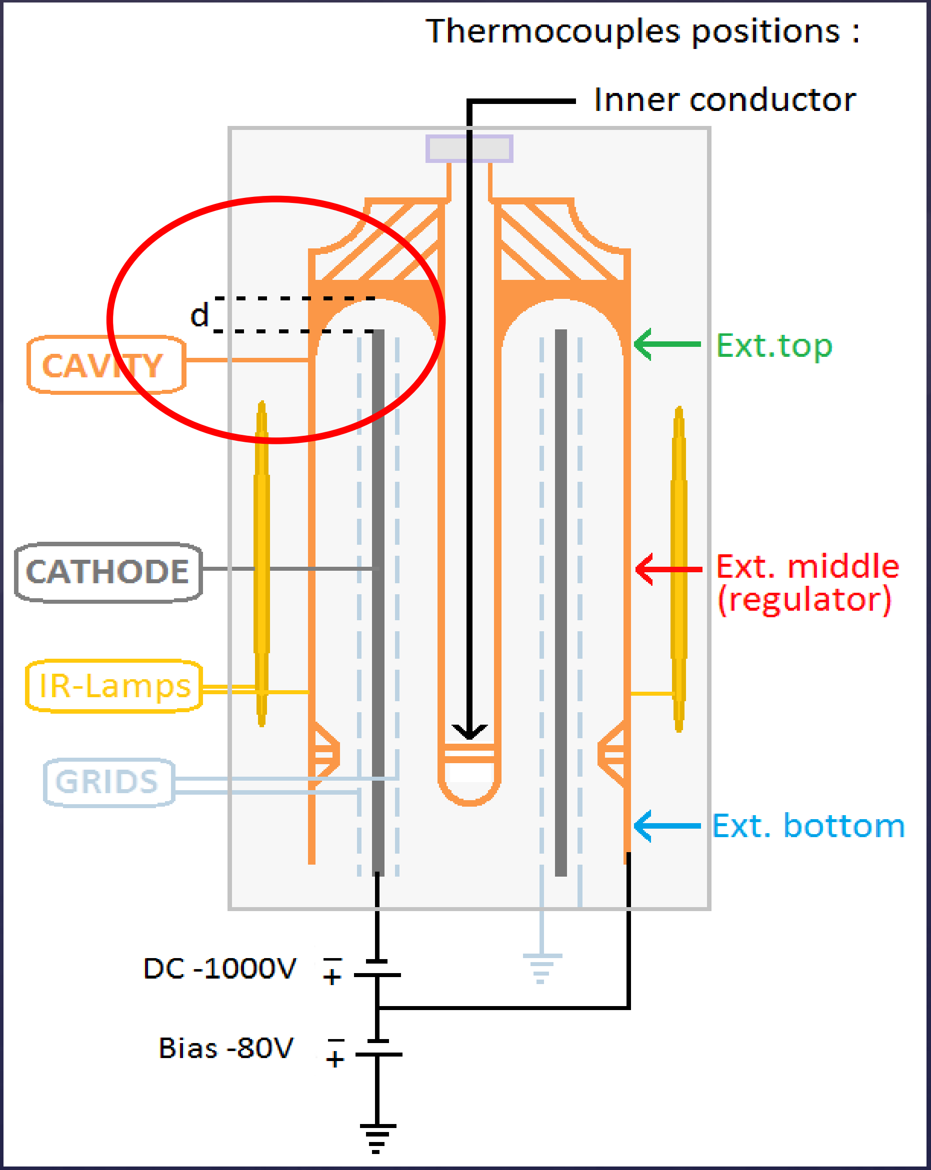
$T_{(bake\ out)} > T_{(coating)}$, higher sputtering power (layers), change of gases: Kr, dry air → Ar, N_2



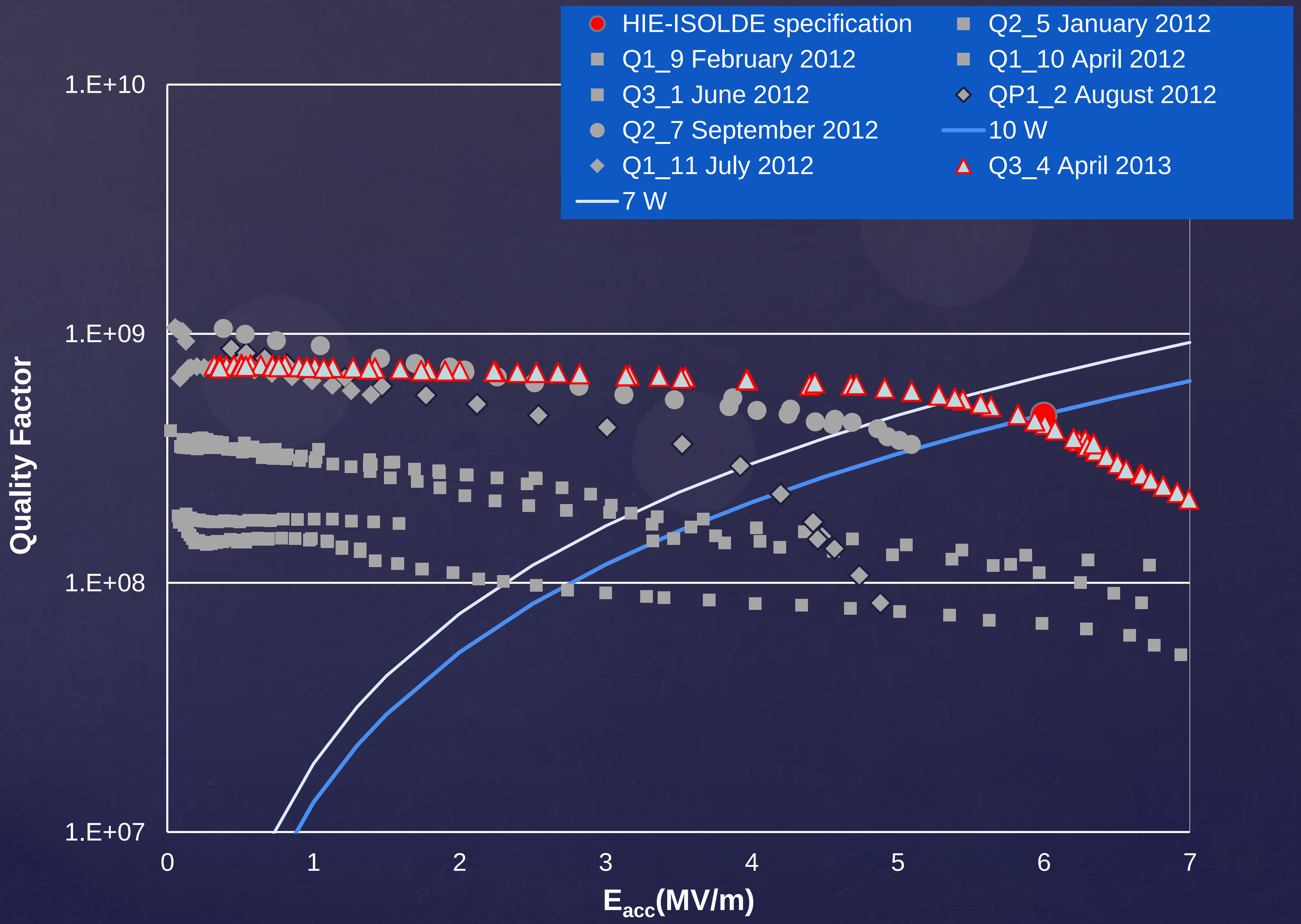
Increasing global Nb thickness by 25%



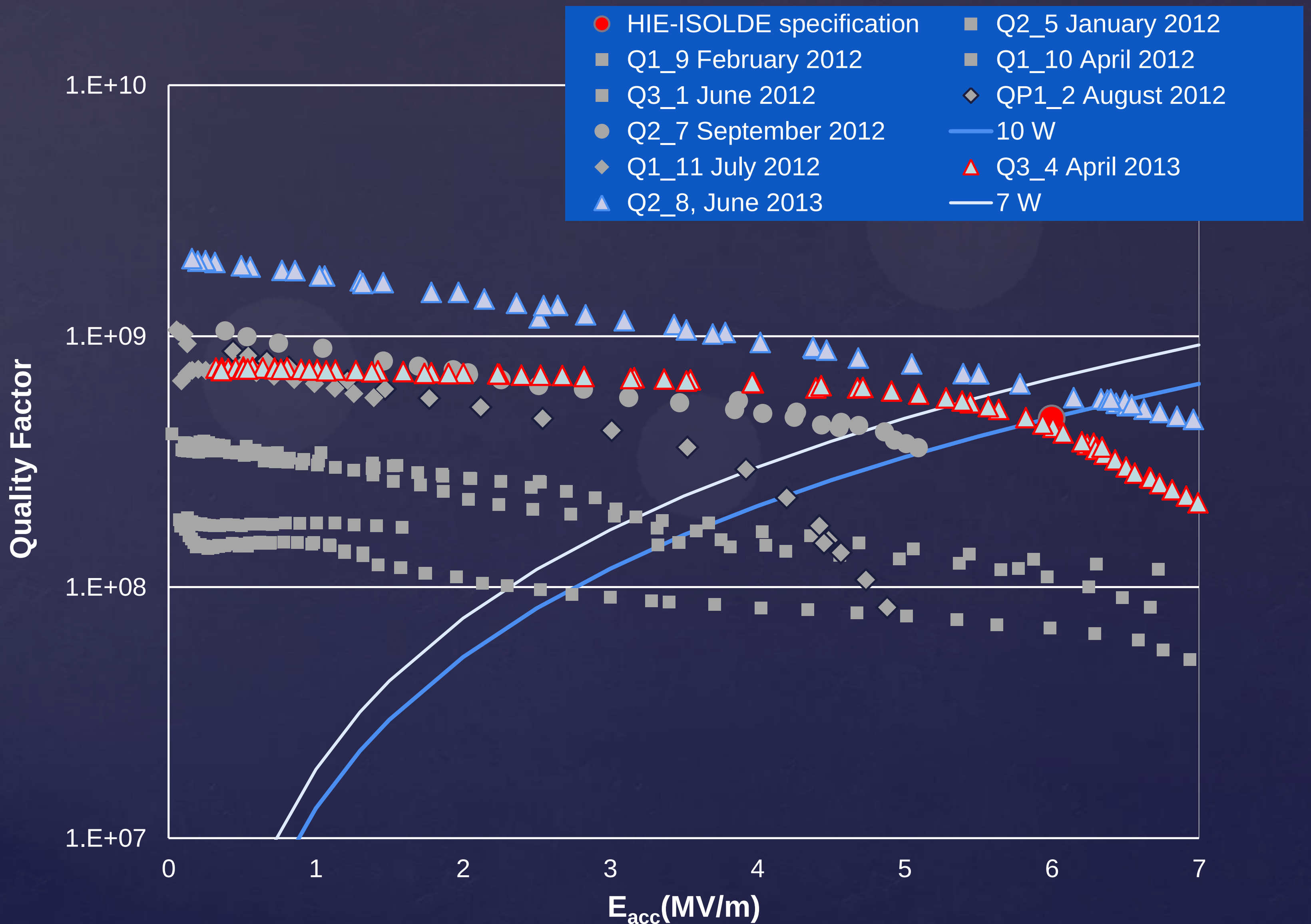
Scaling the “top-gap” length



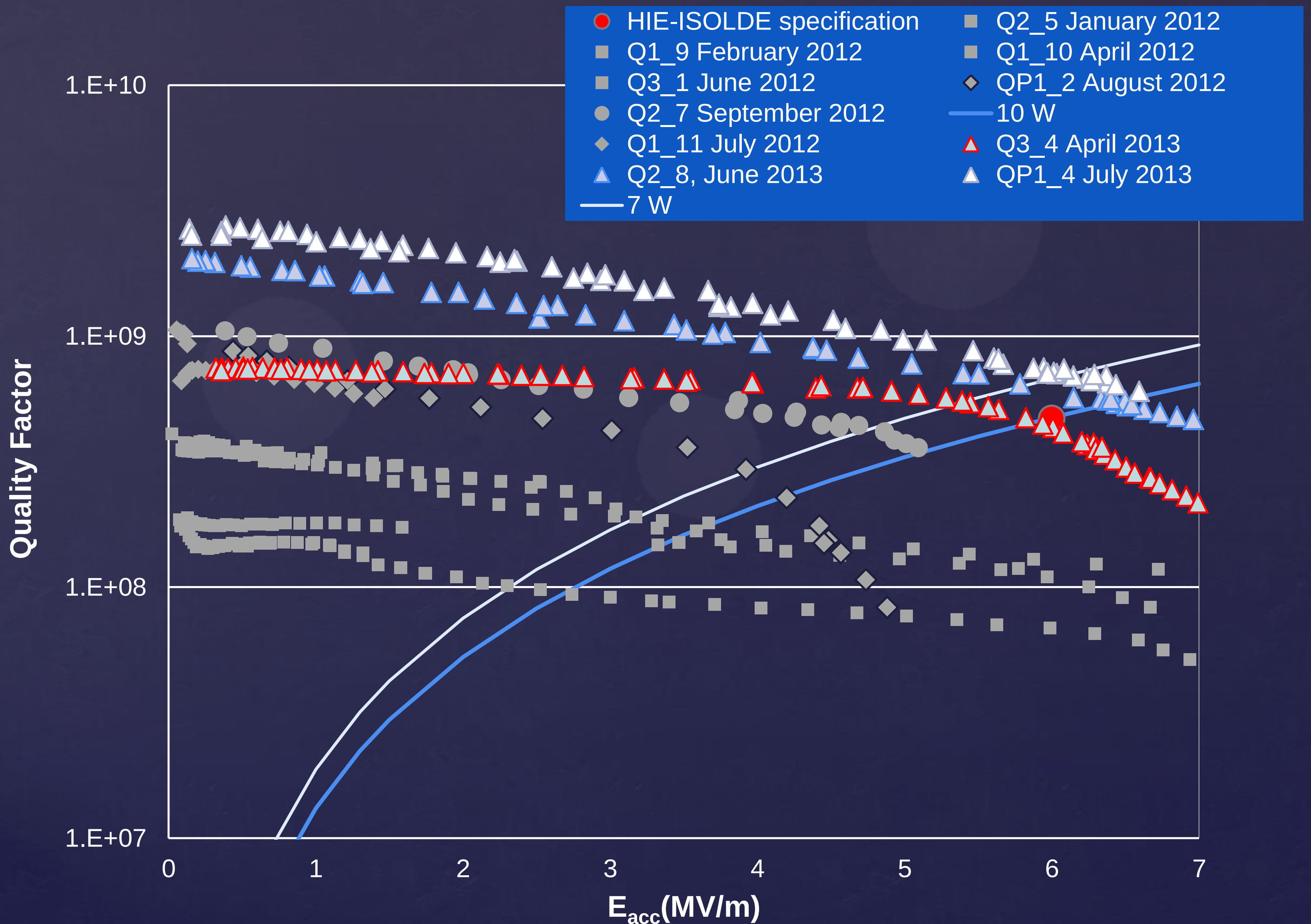
Reduced “top gap” length from 52 mm down to 32 mm



Same parameters on a 20 mm shorter substrate

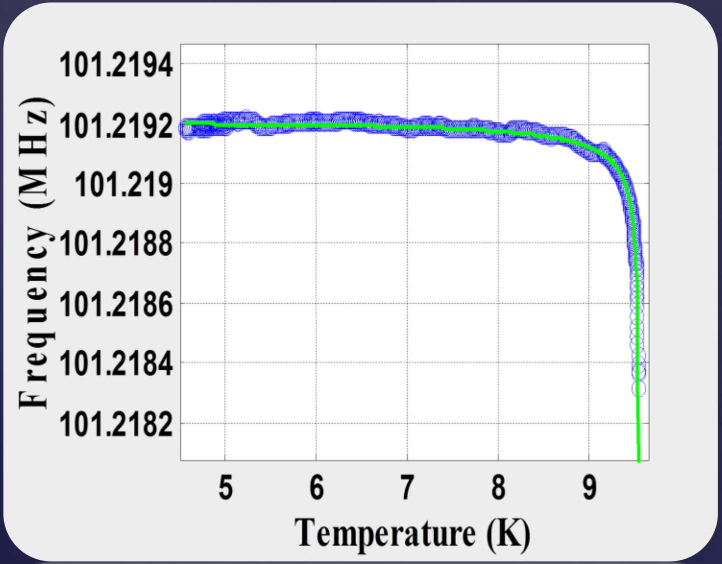


Top gap distance reduced to 22 mm



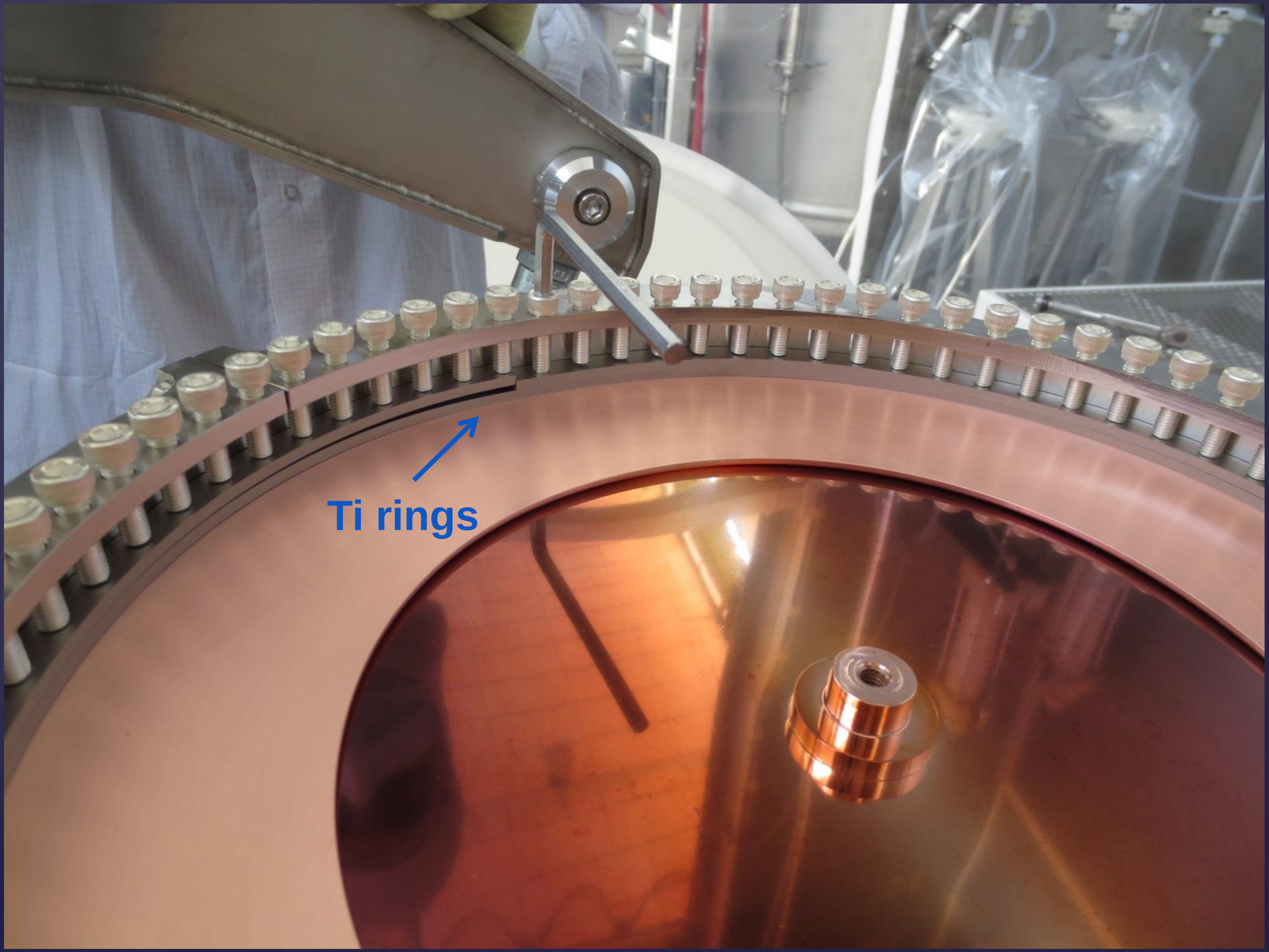
Average RRR extracted from $f_{res}(T)$ measurements

λ_0 =51±3 nm
T_c=9.55817±4e-5 K
Freq=101219201±3.5 Hz
mfp =64±14 nm
ρ = (0.6±0.1) μΩ*cm
RRR =26±5.5



Coating test	λ_0 (nm)	RRR
Q2_3 April 2011	188	1.9
Q1_5 June 2011	83	6.8
Q1_10 Feb. 2012	62.3	13.5
Q2_8 April 2013	50.7	26.4
Q3_4 March 2013	45.7	41. 8

Tuning plate is fixed with 72 M6 screws closed at 5 Nm and acting on Ti rings



Adhesion on the lower edge (RF contact) was improved using a longer cathode

with 840 mm cathode

length increased to 870 mm

RF tests in vertical cryostats

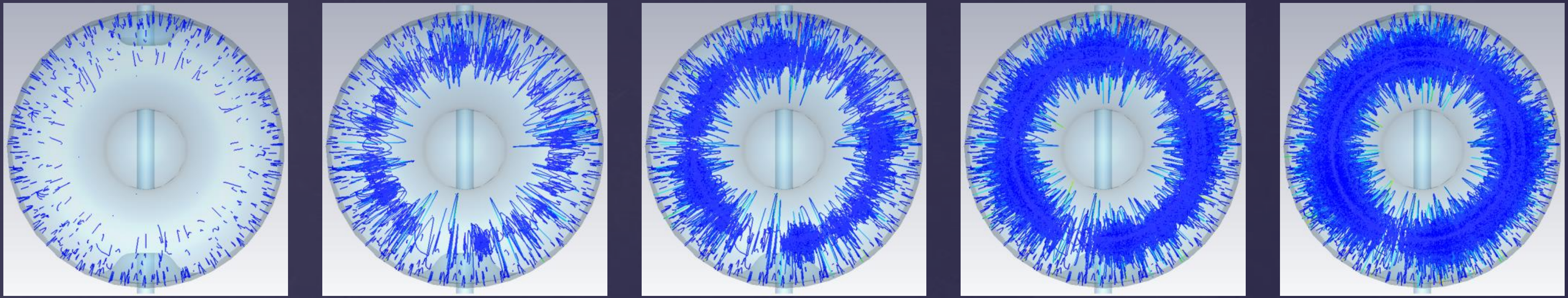
Quick turnaround (2 weeks) essential to feedback on coating

Two cryogenics inserts

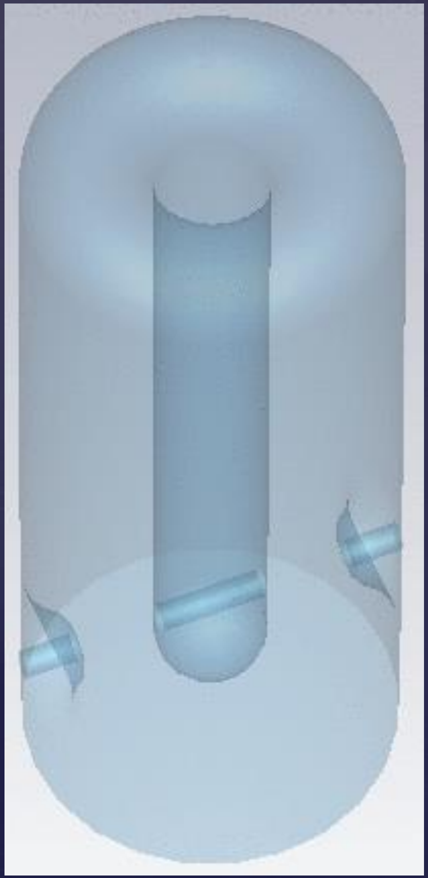
Thermal shield (50 K) and cavity circuit (4.5 K) cooled in parallel

Same cooling scheme as in the HIE-ISOLDE Linac

Multipacting (Cavity Top)



30ns 50ns 70ns 87.5ns



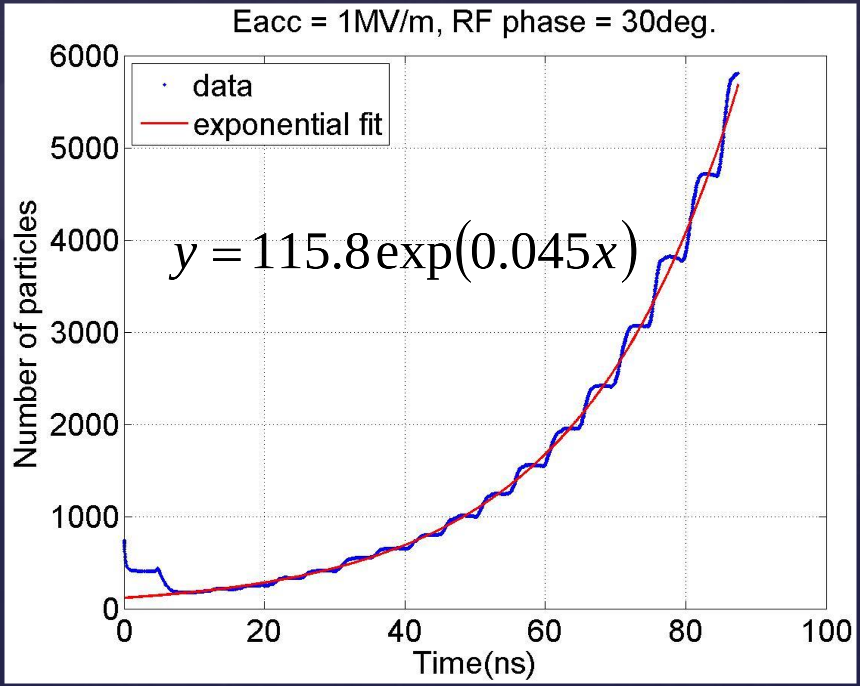
# of initial electrons: 742

Kinetic energy: 0-4eV (uniform)

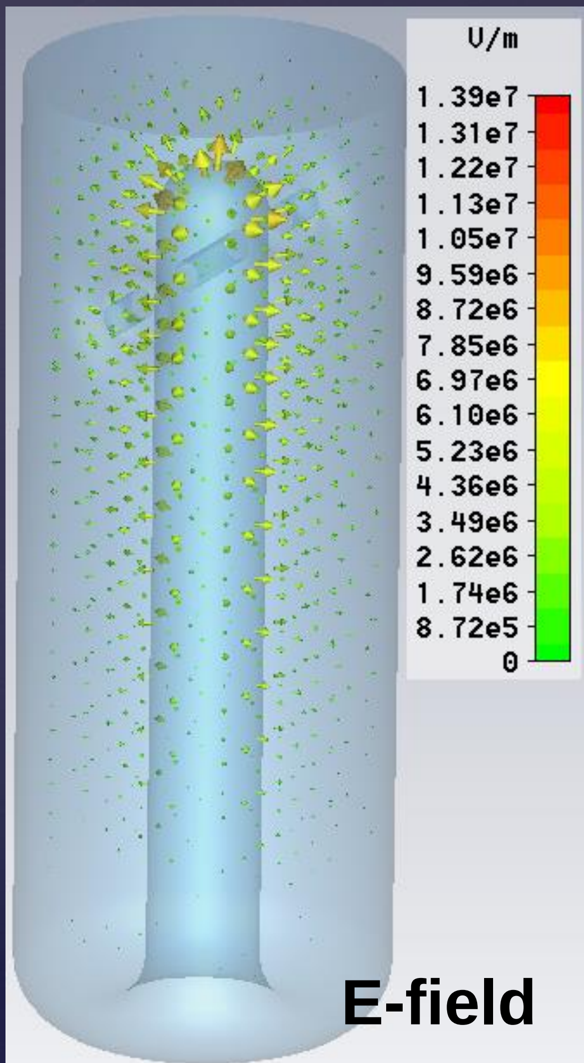
Emission angle: 0-180 deg. (random)

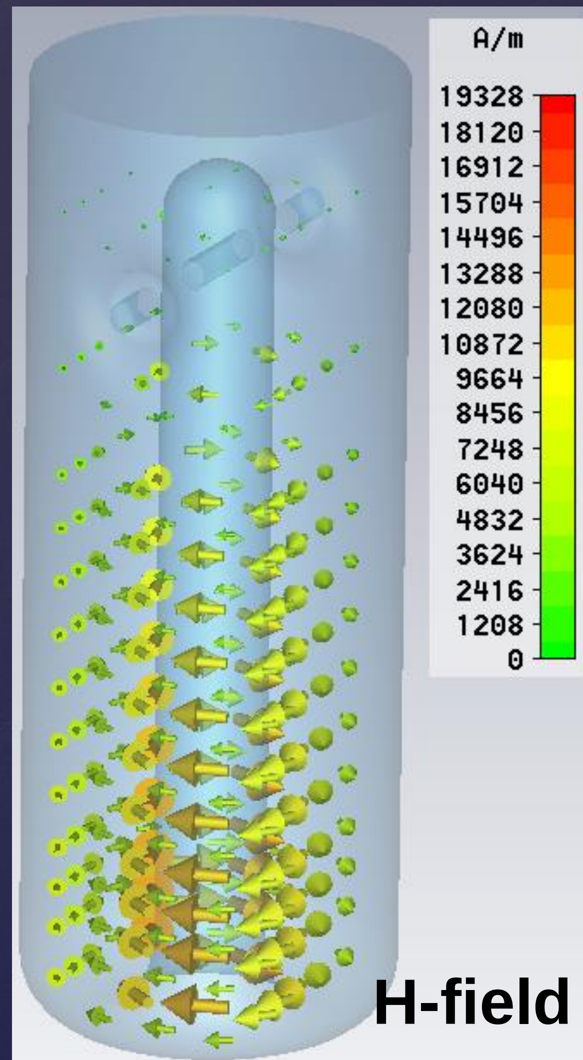
Max time steps: 4000

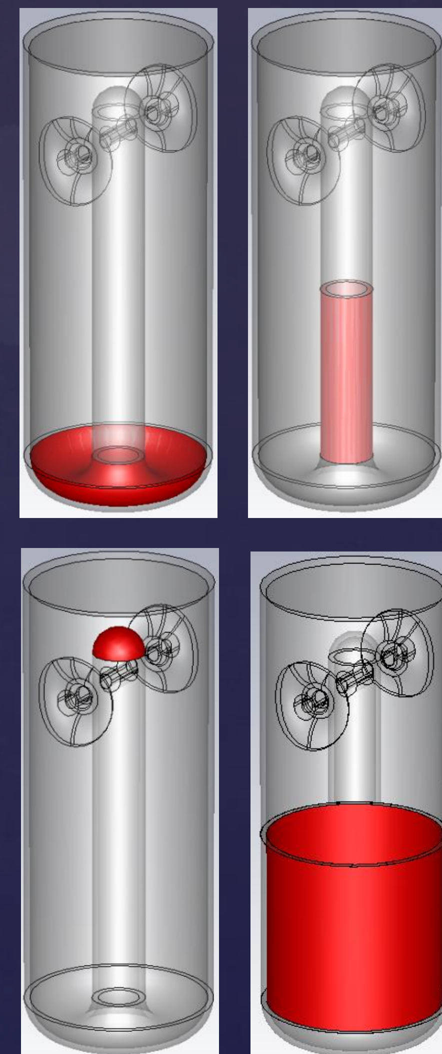
Eacc=1MV/m (30 deg)



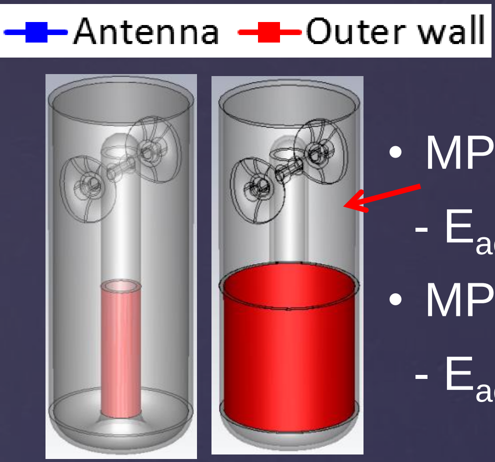
Regions of Potential Multipacting



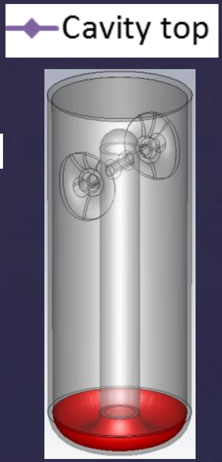


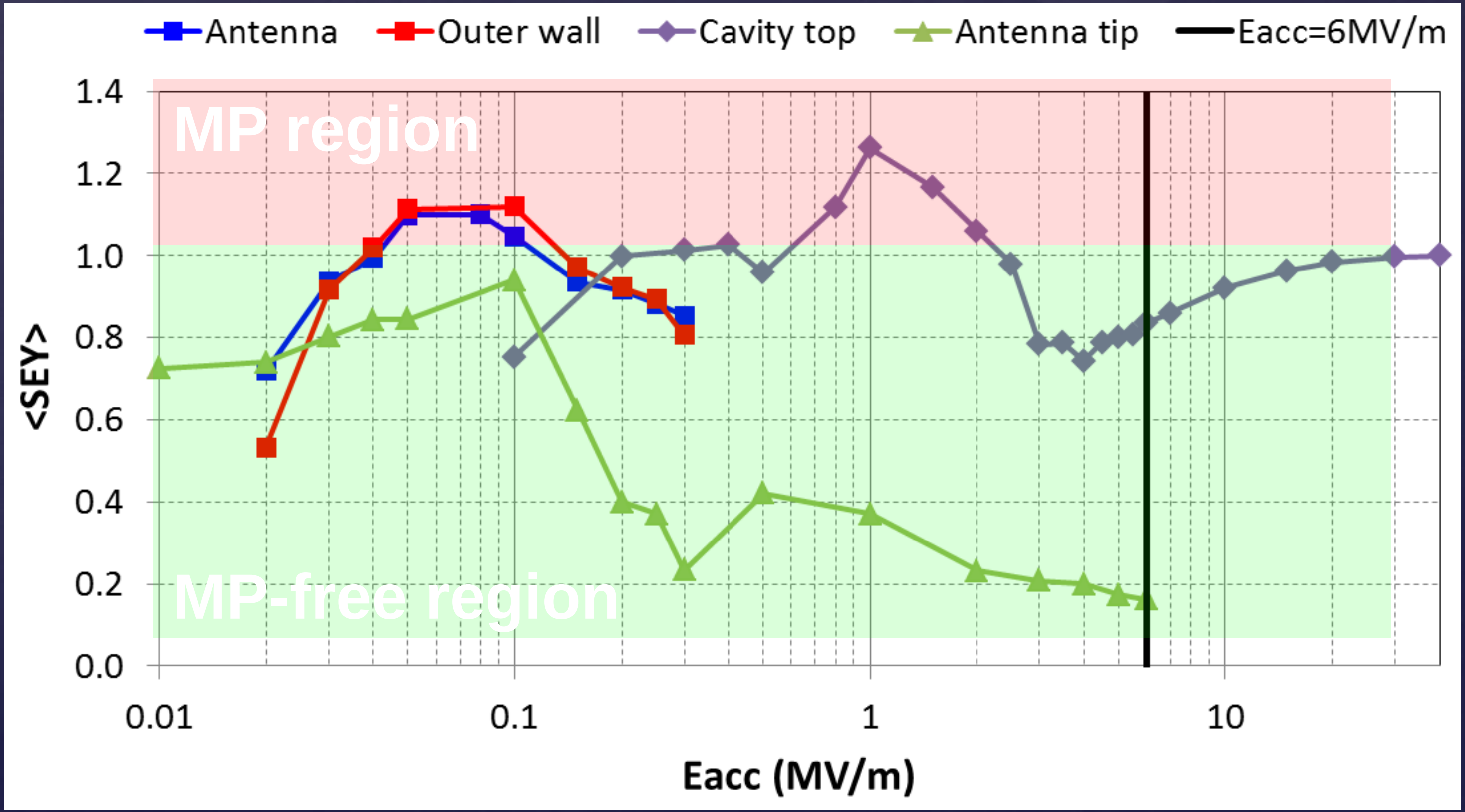


Multipacting Summary

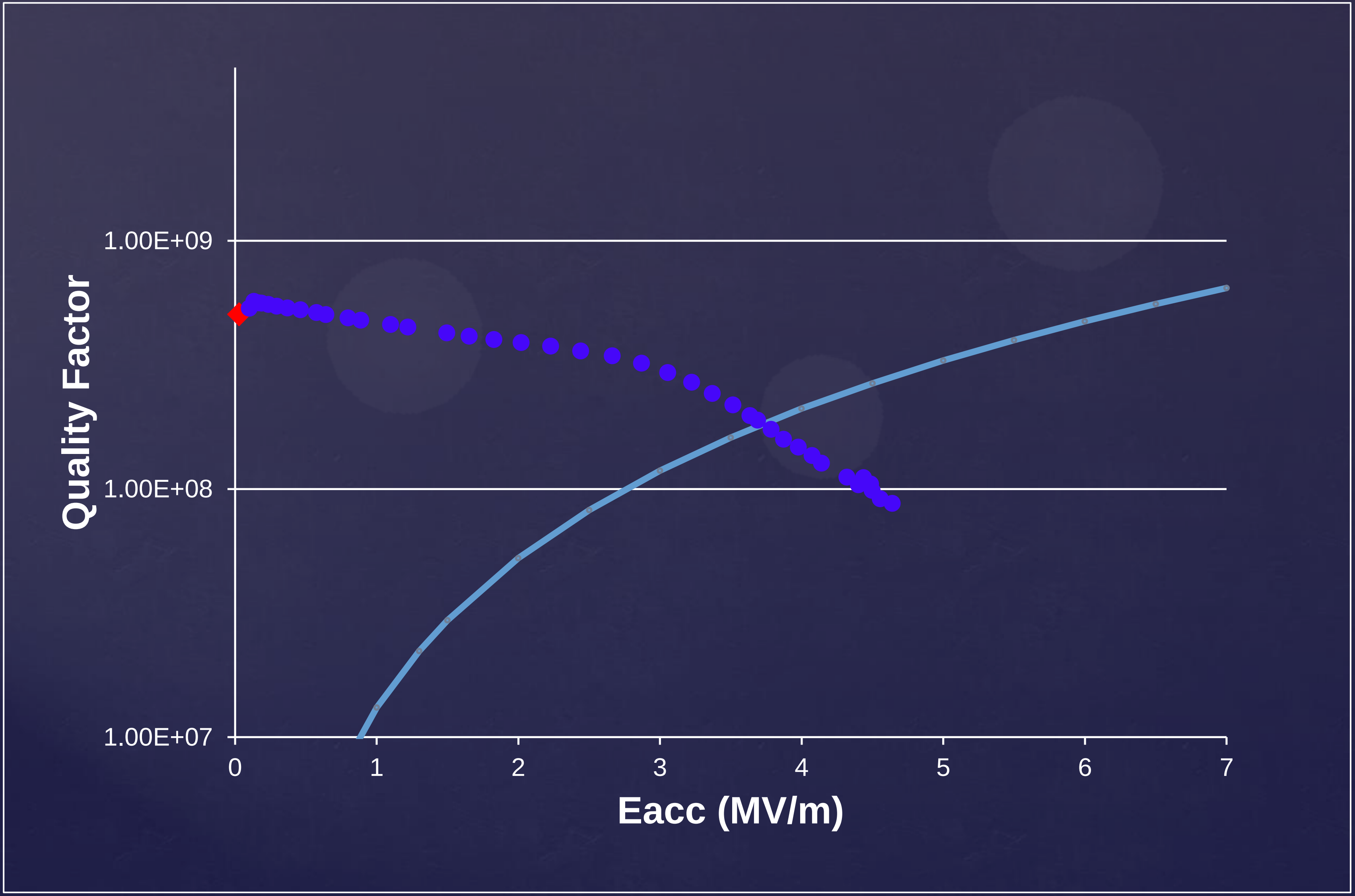


- MP happens at low fields for antenna region and outer wall
  - E_{acc} = 0.05-0.1MV/m
- MP happens at higher fields for cavity top region
  - E_{acc} = 0.8-2 MV/m



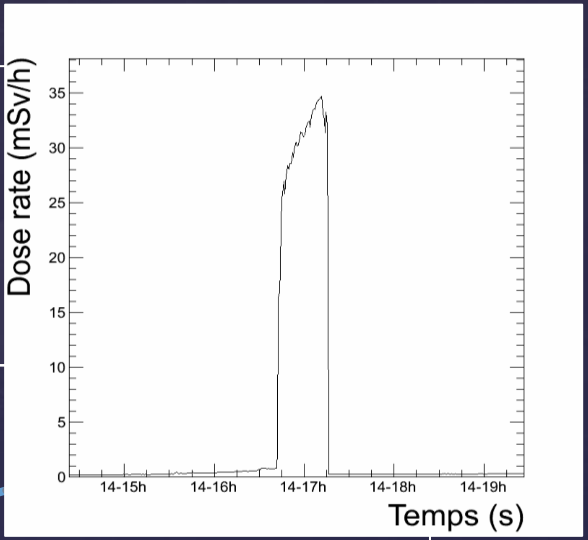


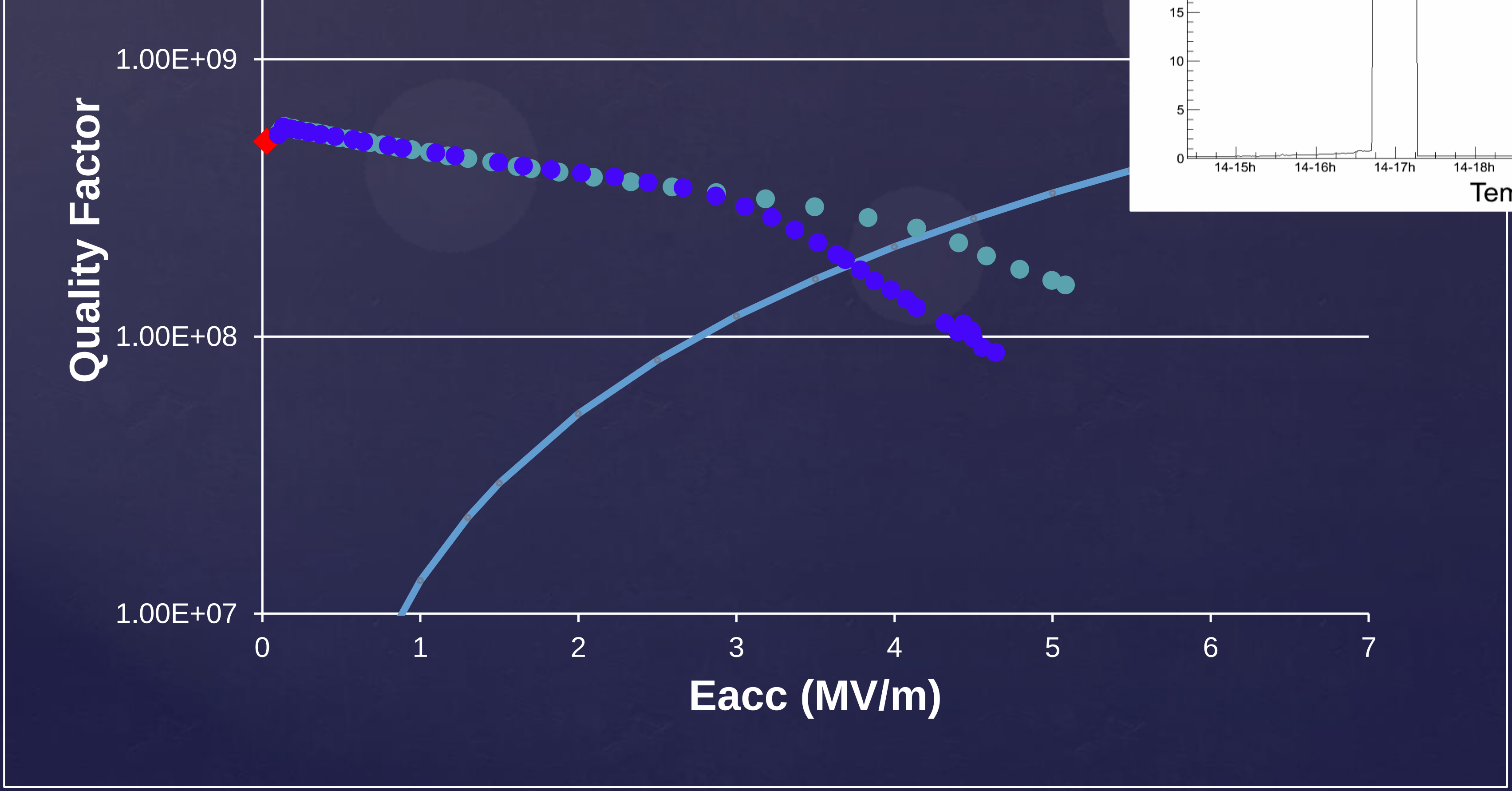
Field Emission



He processing

Dose rate data by S. Giron



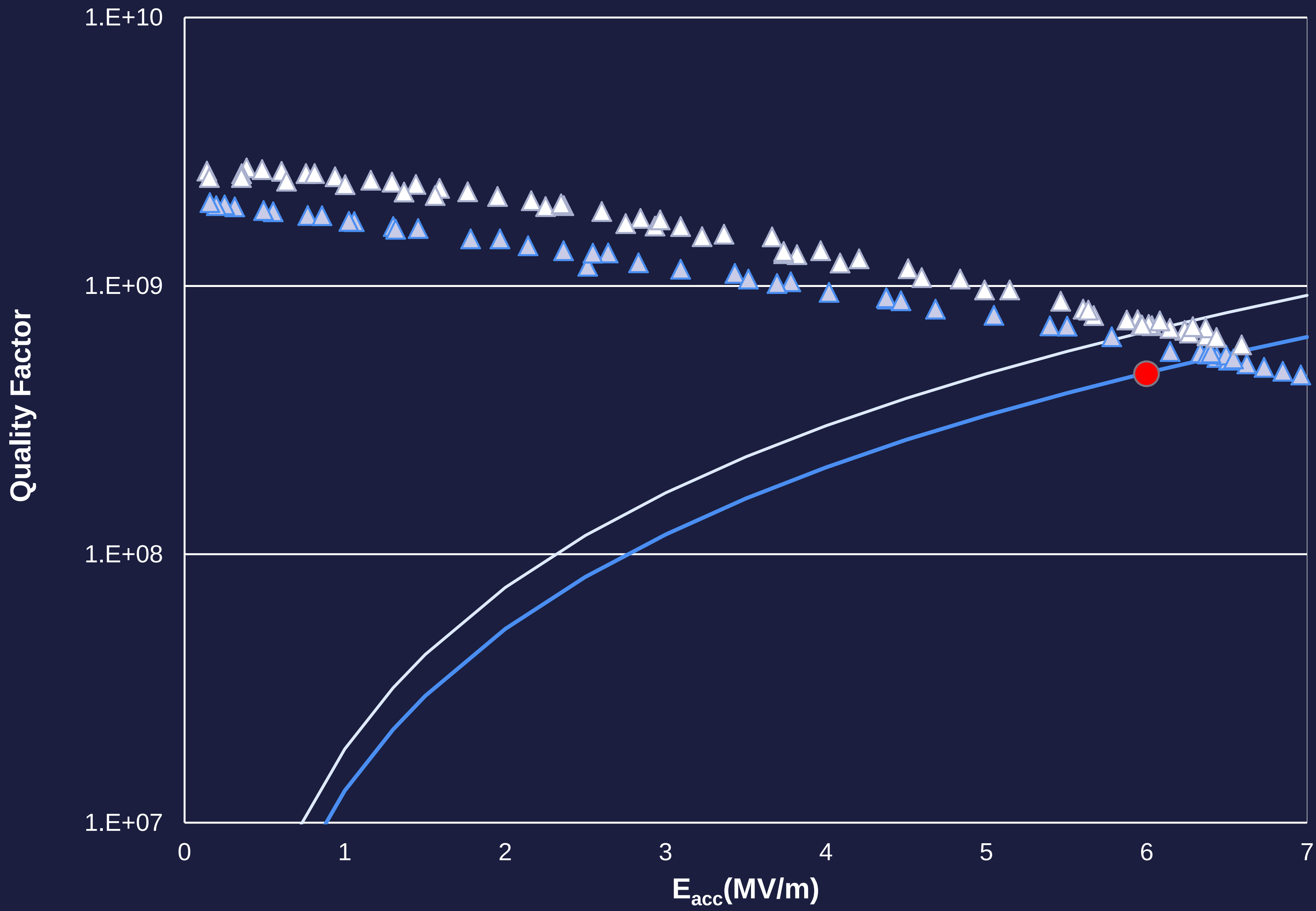


Surface quality of the inner conductor tip → source of field emission

Central electrode: 20 mm diameter, at earth potential

No counter electrode

Ready for production



Conclusions

HIE-ISOLDE will get its 39.6 MV from 32 independently phased QWR, based on Nb sputtering of copper technology

Project oriented R&D, several parameters changed at a time

HIE ISOLDE specifications were met in 2013, (with 30% margin in power)

We are starting now series production for the first phase up to 5 MeV/u

Project schedule is tight!

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M. Pasini

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number 264330.

The HIE ISOLDE International Advisory Panel

The CERN management

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