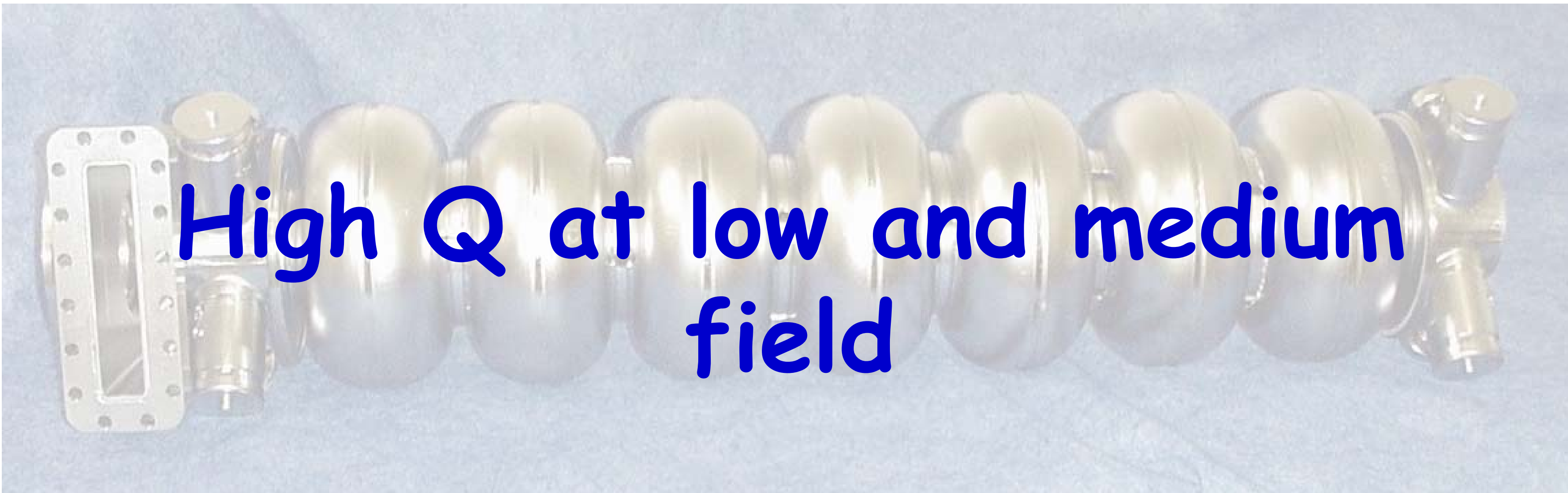
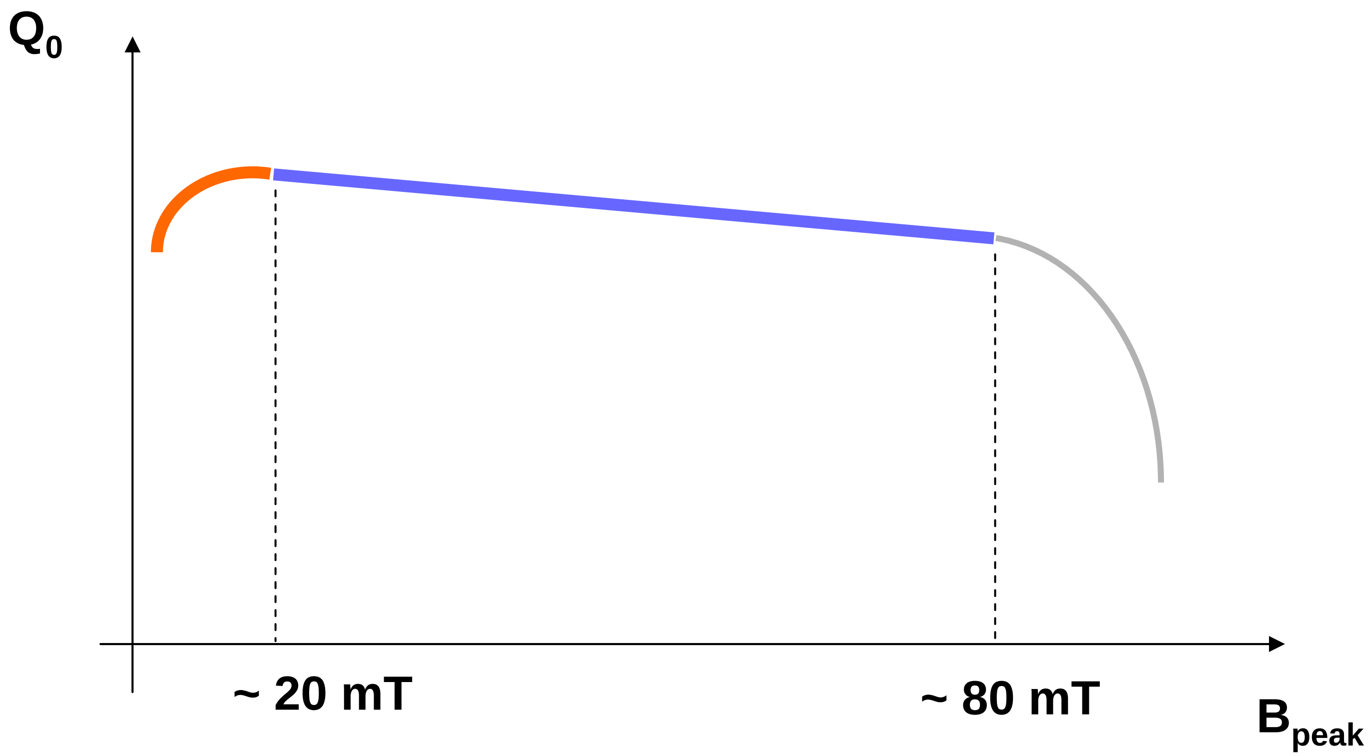
High Q at low and medium field



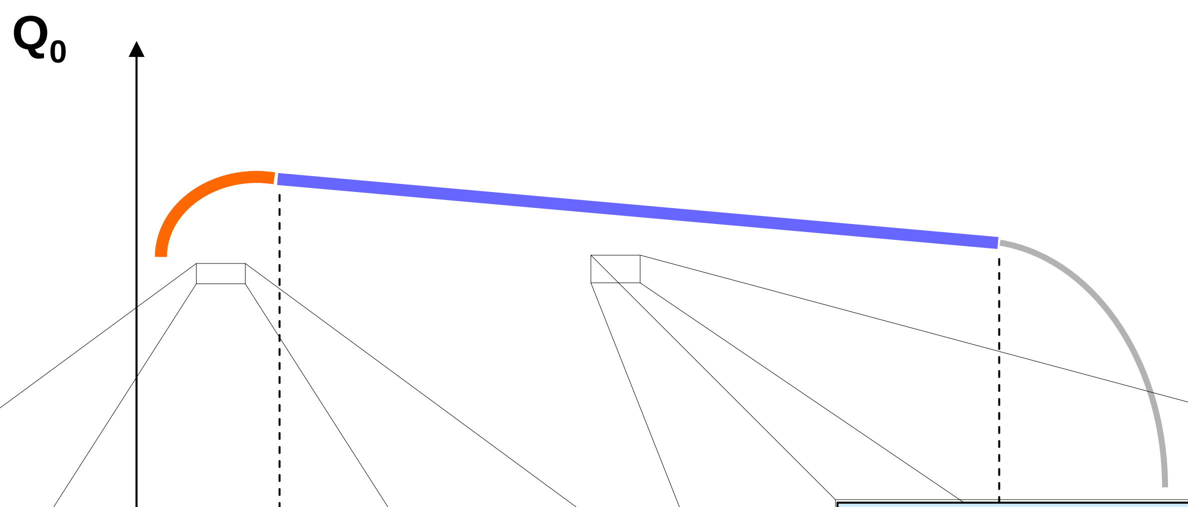
Gianluigi Ciovati

Jefferson Lab

Outline



Outline



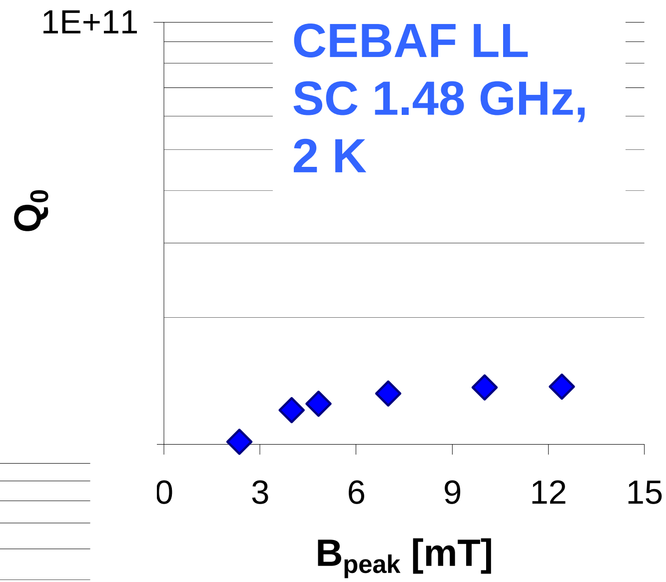
Low field Q-increase:

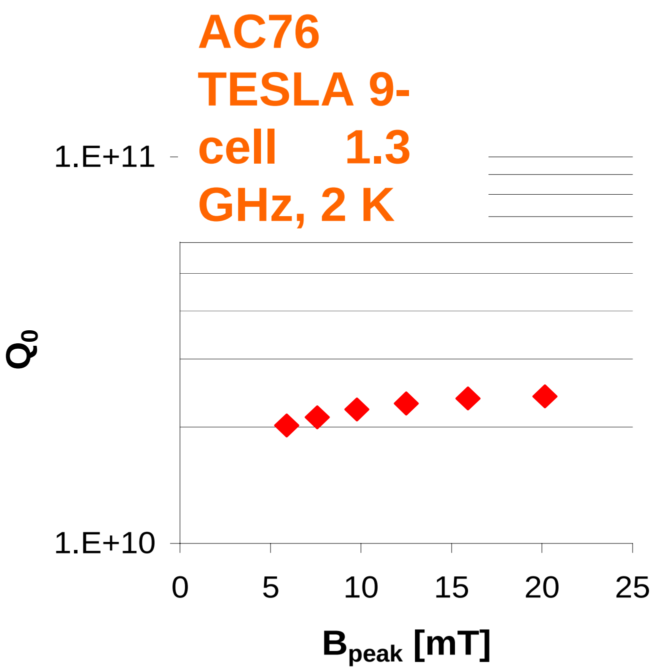
Review of model and measurements

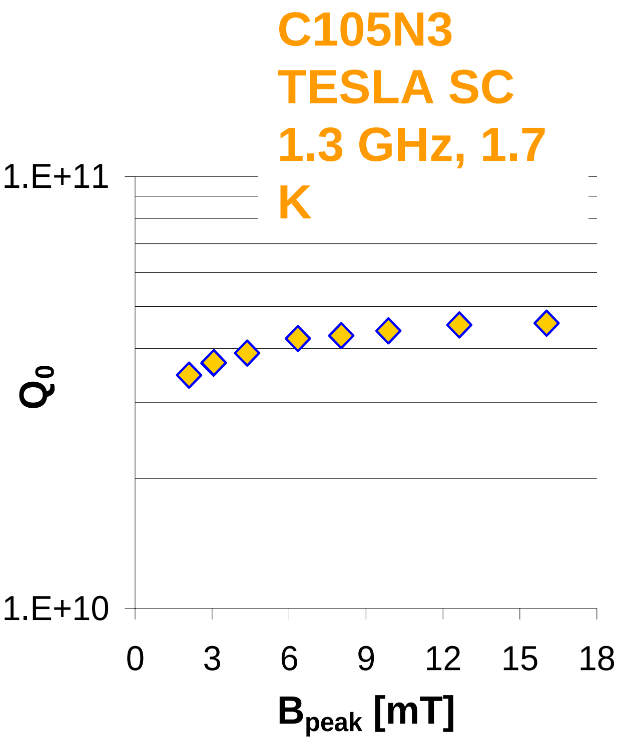
Medium field Q-slope:

- **definition and models**
- **Measurements at JLab and DESY**
- **Possible causes for Q-slope**

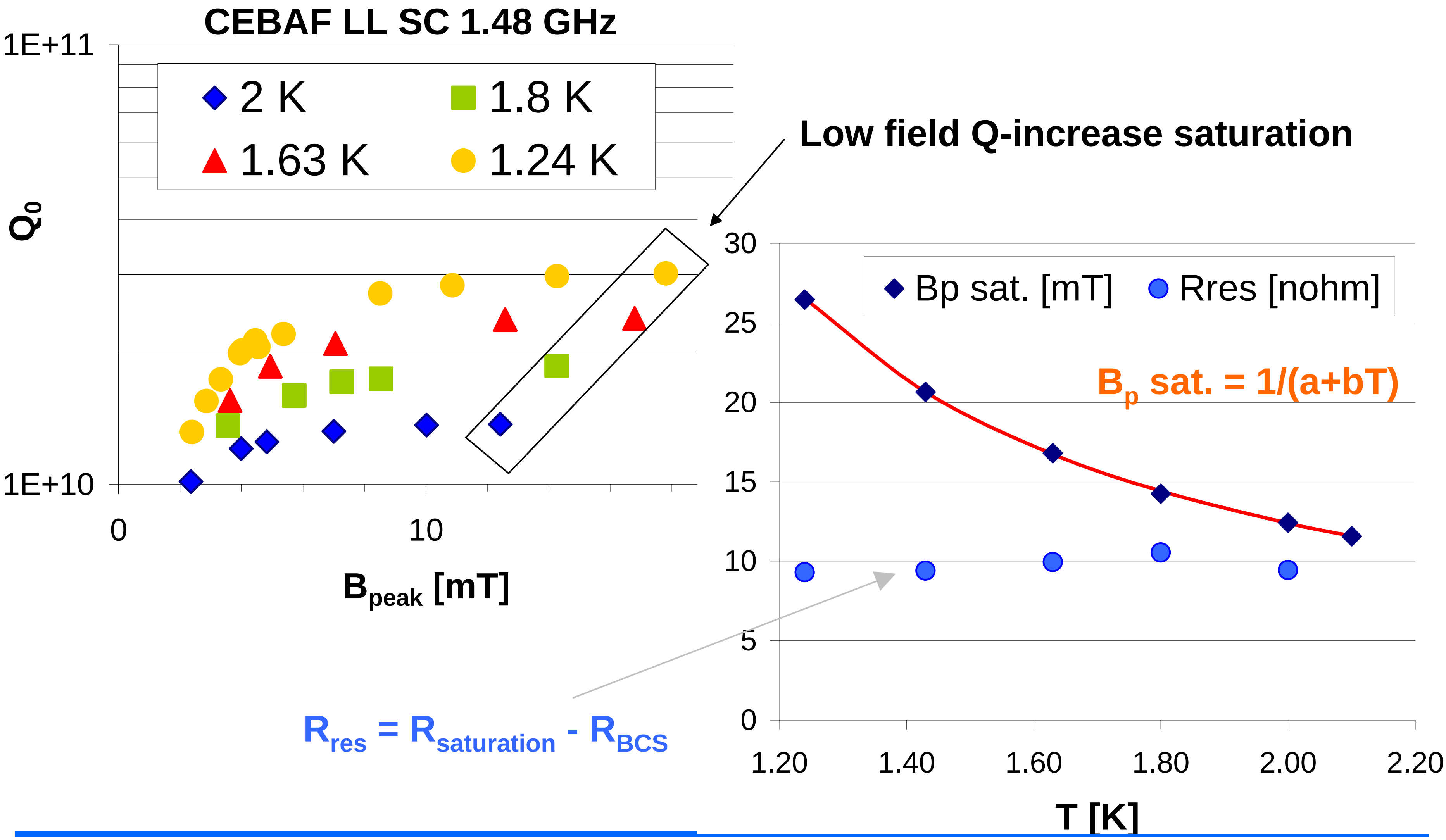
Low field Q-increase



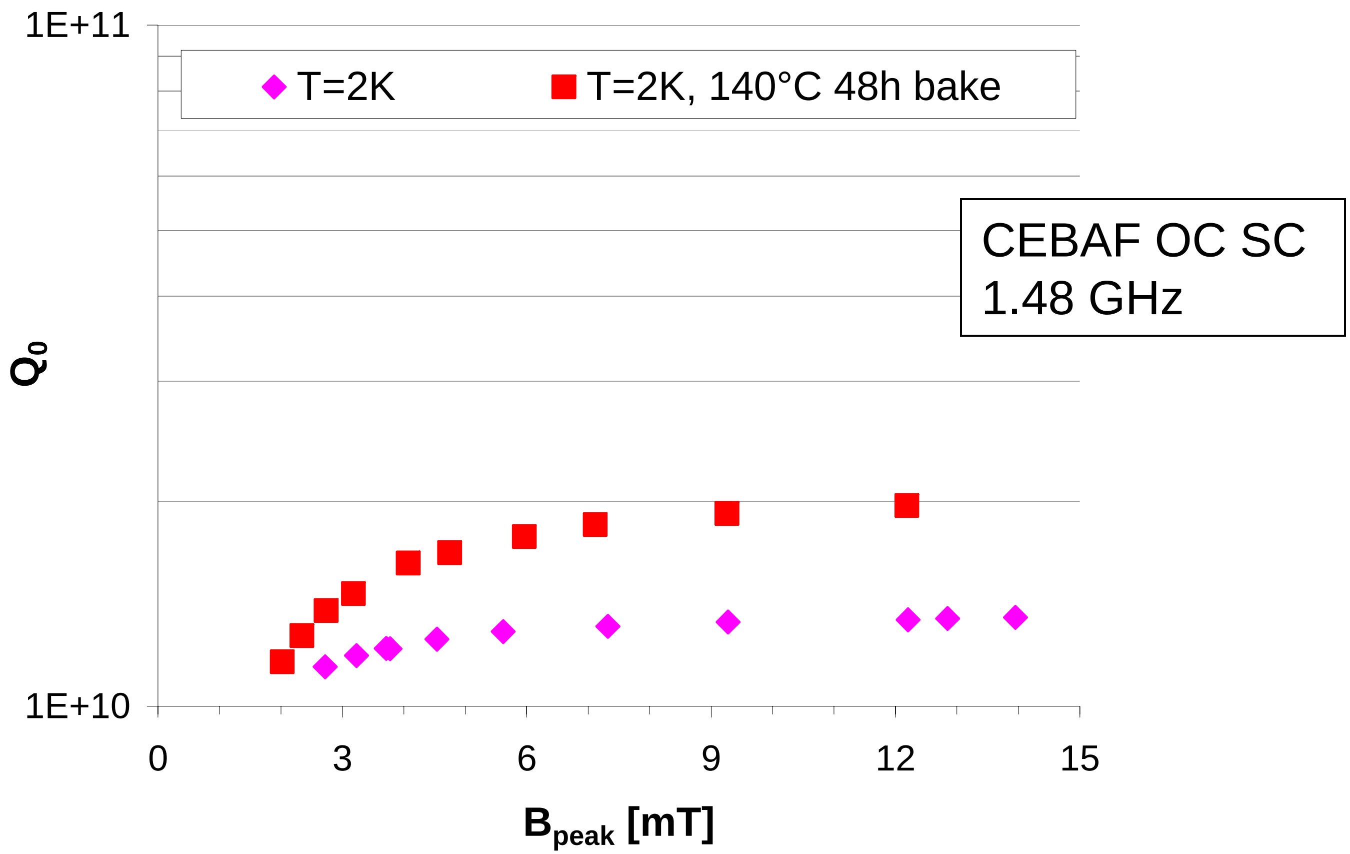




Experimental results: T dependence

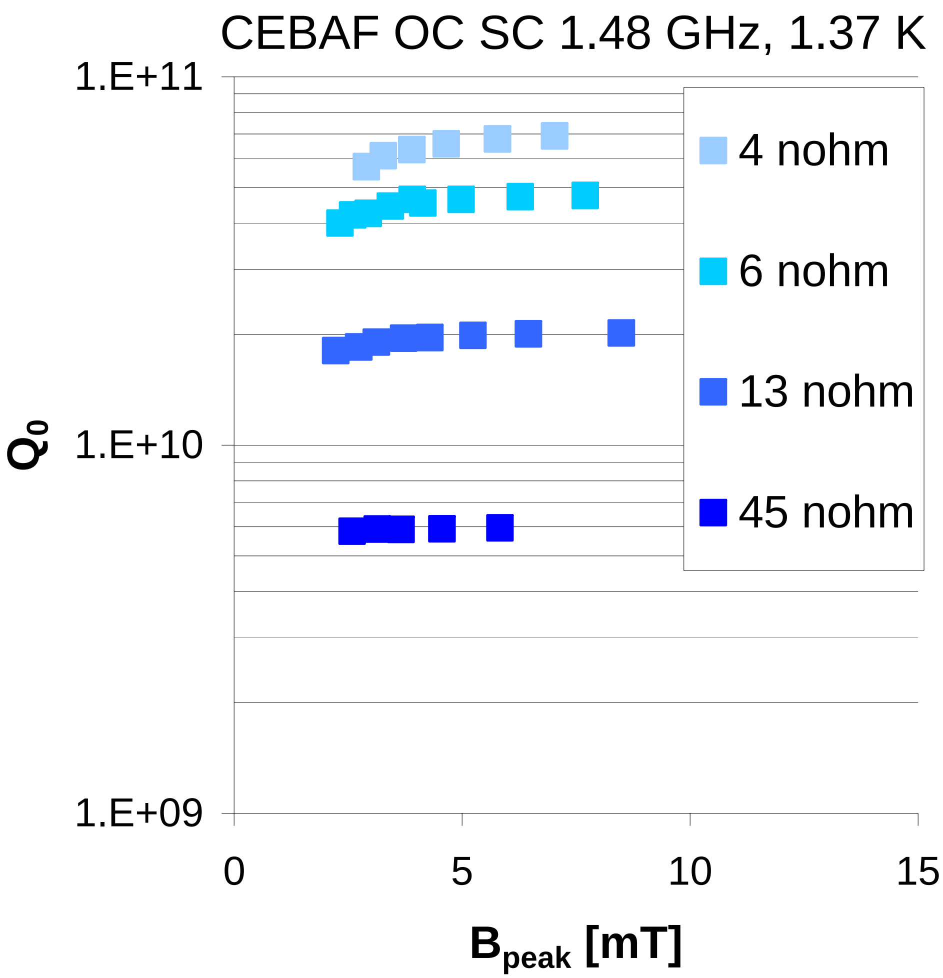


Experimental results: baking effect



Low temperature baking enhances the low field Q-increase

Experimental results: R_{res} effect



Residual resistance increased by increasing the residual DC magnetic field

- Low field Q-increase diminishes at higher residual resistance

Halbritter's model on low field Q-increase

- Quasiparticles driven out of thermal equilibrium with phonon bath

$T = 2$ K, $B_{peak} = 2$ mT, $f = 1.5$ GHz

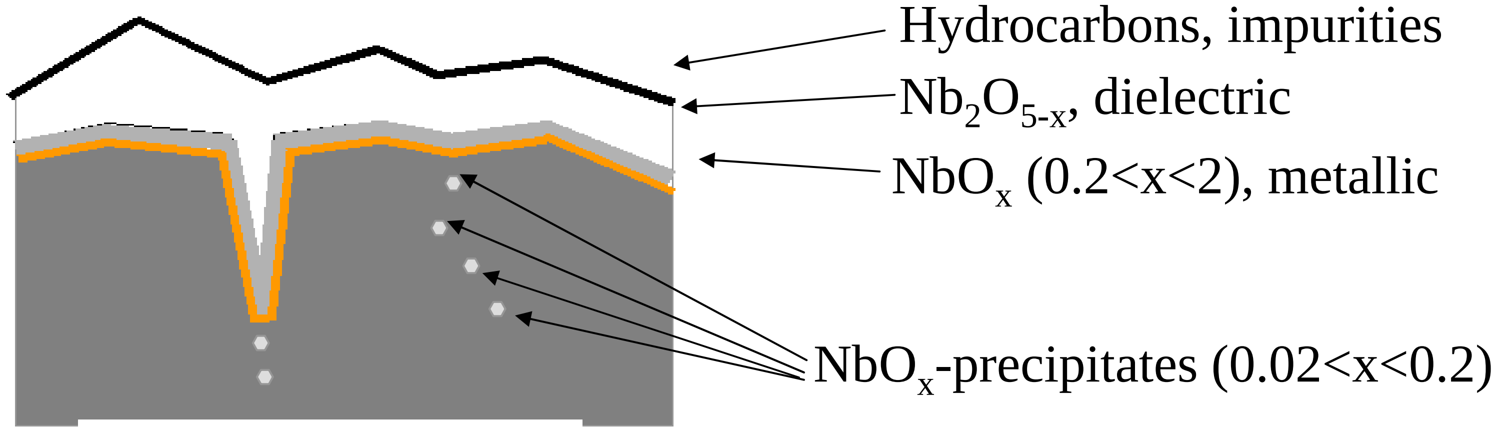
Quasiparticle absorption rate $1/\tau_{ab} \cong 2$ GHz

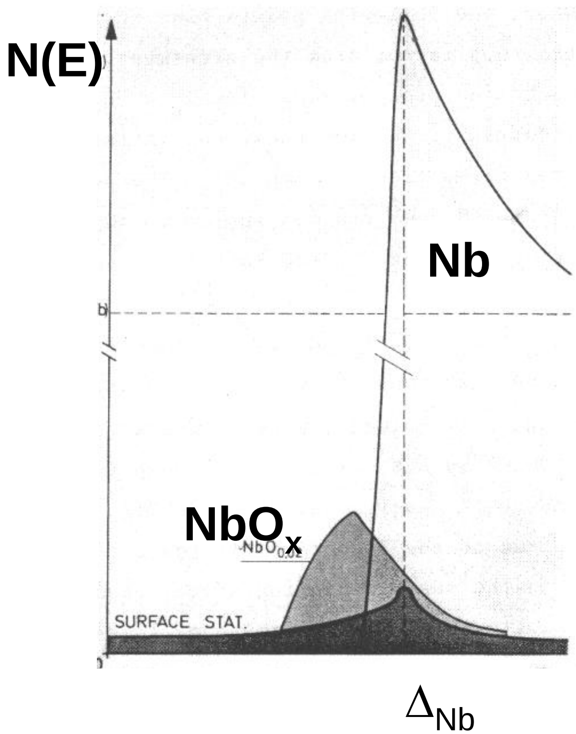
Quasiparticle relaxation time $1/\tau_r \cong 0.03$ GHz

→ $1/\tau_{ab} > 1/\tau_r$

J. Halbritter, *Proc. 10th Workshop on RF Superconductivity*, Tsukuba, Japan, (2001), p. 292

Niobium cavity surface





NbO_x introduces localized states inside the energy gap $\Delta < \Delta_{Nb}$

→ higher R_s

At higher fields the quasiparticles $\Delta < \Delta_{Nb}$

are driven out of the localized states restoring Δ_{Nb} and yielding a decrease of R_s.

- Absorbed rf power per unit area:

$$P = \frac{R_s}{2} H^2 = \underbrace{\int n_c \lambda I_r(\varepsilon) \hbar\omega d\varepsilon}$$

Quasiparticles inside the Nb gap are driven out of thermal equilibrium yielding **constant absorption** by local transfer of energy to phonons.

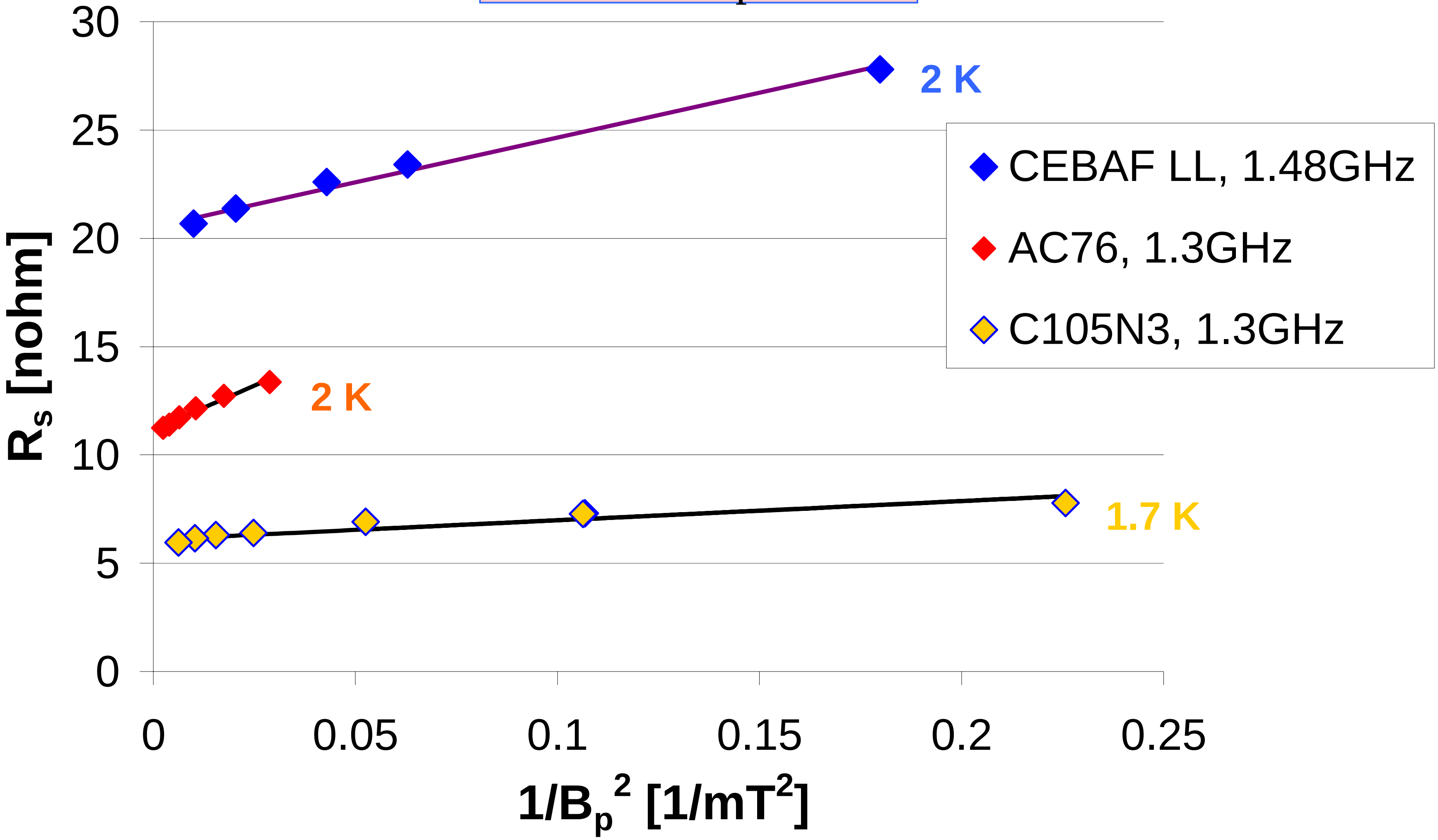
n_c = density of states

λ = penetration depth

I_r = quasiparticles relaxation rate

⇨ $R_s \propto 1/H^2$

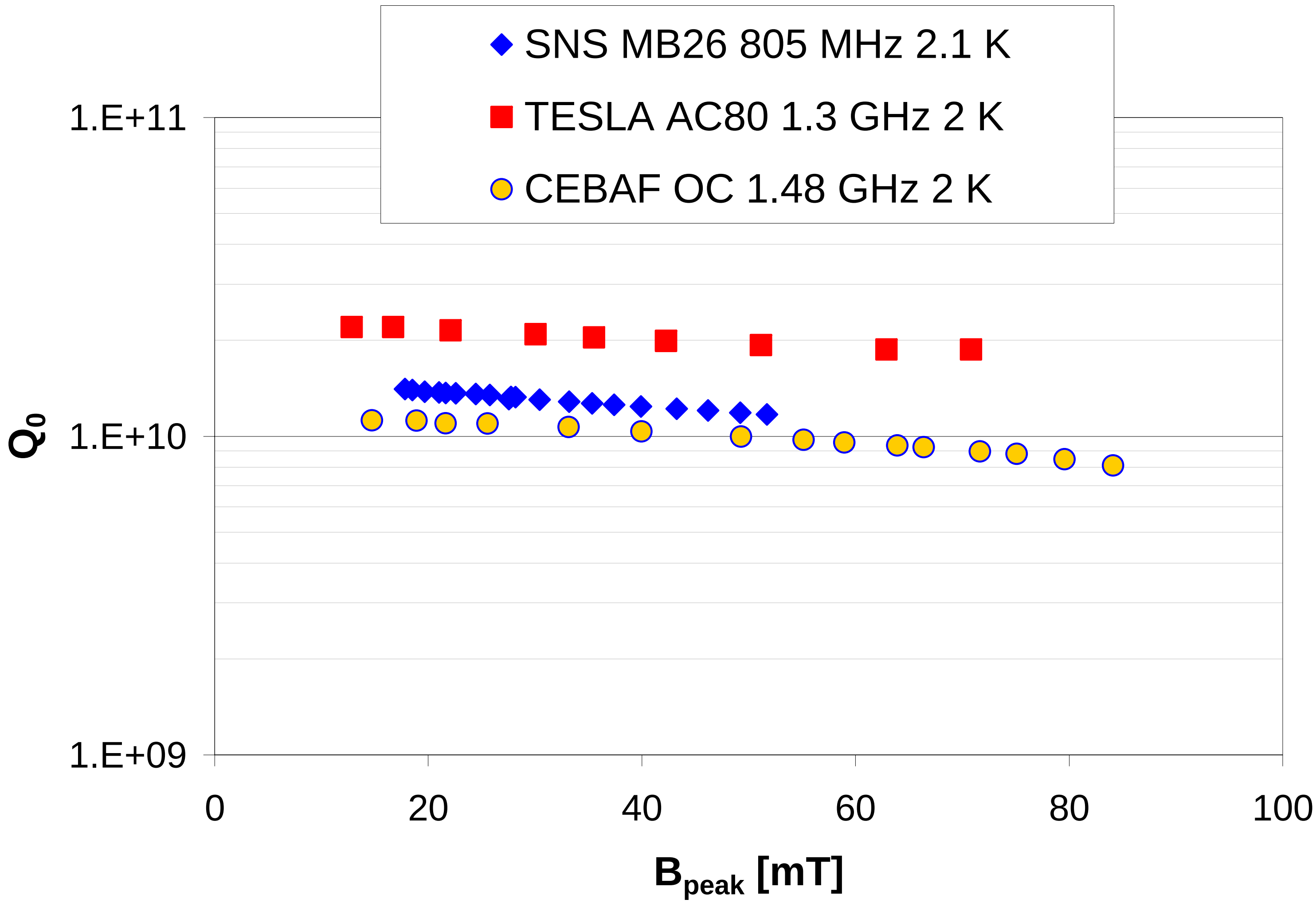
$$R_s = a/B_p^{\,2} + b$$



30
25
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
Rs [nohm]
1/Bp2 [1/mT2]
2 K
2 K
1.7 K
CEBAF LL, 1.48GHz
AC76, 1.3GHz
C105N3, 1.3GHz

- Quasiparticles with $E > \Delta_{Nb}$ are in thermal equilibrium with the phonons because they can easily transfer their energy to the He bath (l_{ph} >> wall thickness)
- $1/\tau_r \propto T^{3.5}$ ⟹ further absorption/relaxation rate mismatch at lower temperatures ⟹ low field Q-increase enhancement
- More NbO_x clusters are formed after baking
  ⟹ a/B_p^2 increases
- High residual resistance means strong quasiparticles-phonons coupling and therefore reduces the Q-increase effect

Medium field Q-slope



Models for medium field Q-slope

- Quadratic R_s vs. B_{peak}

$$R_s = R_s(15mT)[1 + \gamma(B_p/B_c)^2] \qquad B_c = 200mT$$

Medium field Q-slope

γ = 1 means 25% increase of surface resistance between 15 and 100 mT

$$\gamma(T) \cong R_{BCS}(T)B_c^2\Delta/2kT[d/\kappa(T) + R_K(T)]$$

d = wall thickness, κ = thermal conduc., R_K = Kapitza resistance

J. Halbritter, *Proc. 38th Eloisitron Workshop*, Erice, Italy, (1999), p. 59

- Linear R_s vs. B_{peak}

$$R_s = a + \mathbf{b} B_p$$

Medium field Q-slope

J. Halbritter: hysteresis losses due to Josephson fluxons penetrating weak links

$$R_{hys} \propto \omega B_{rf}$$

Weak links in the niobium due to oxide channels

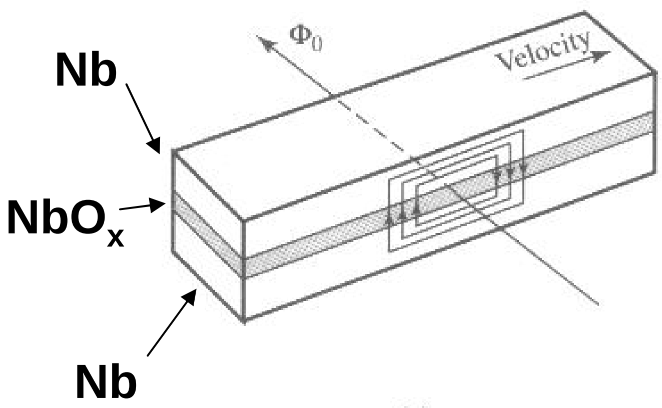
J. Halbritter, *J. of App. Phys.*, to be published, and *J. Supercond*. **8**, 691 (1995)

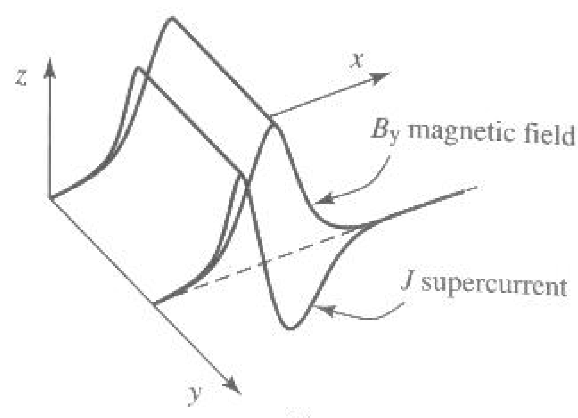
d_J = 82 nm length of RF penetration across the junction

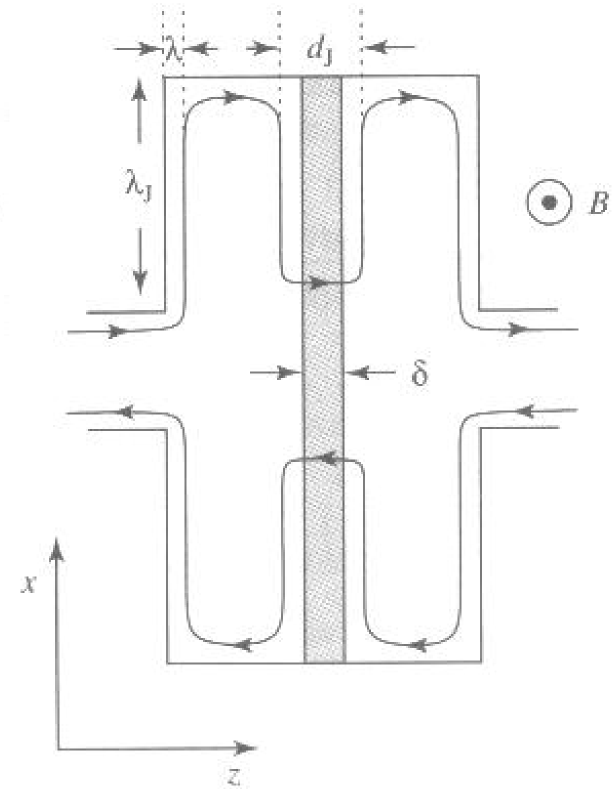
λ_J = 565 nm Josephson penetration depth

Φ_0 = h/2e unit quantum flux

$B_{cWL} = 2\Phi_0/\pi^2 d_J \lambda_J \cong 9$ mT Josephson fluxons start to penetrate at this field

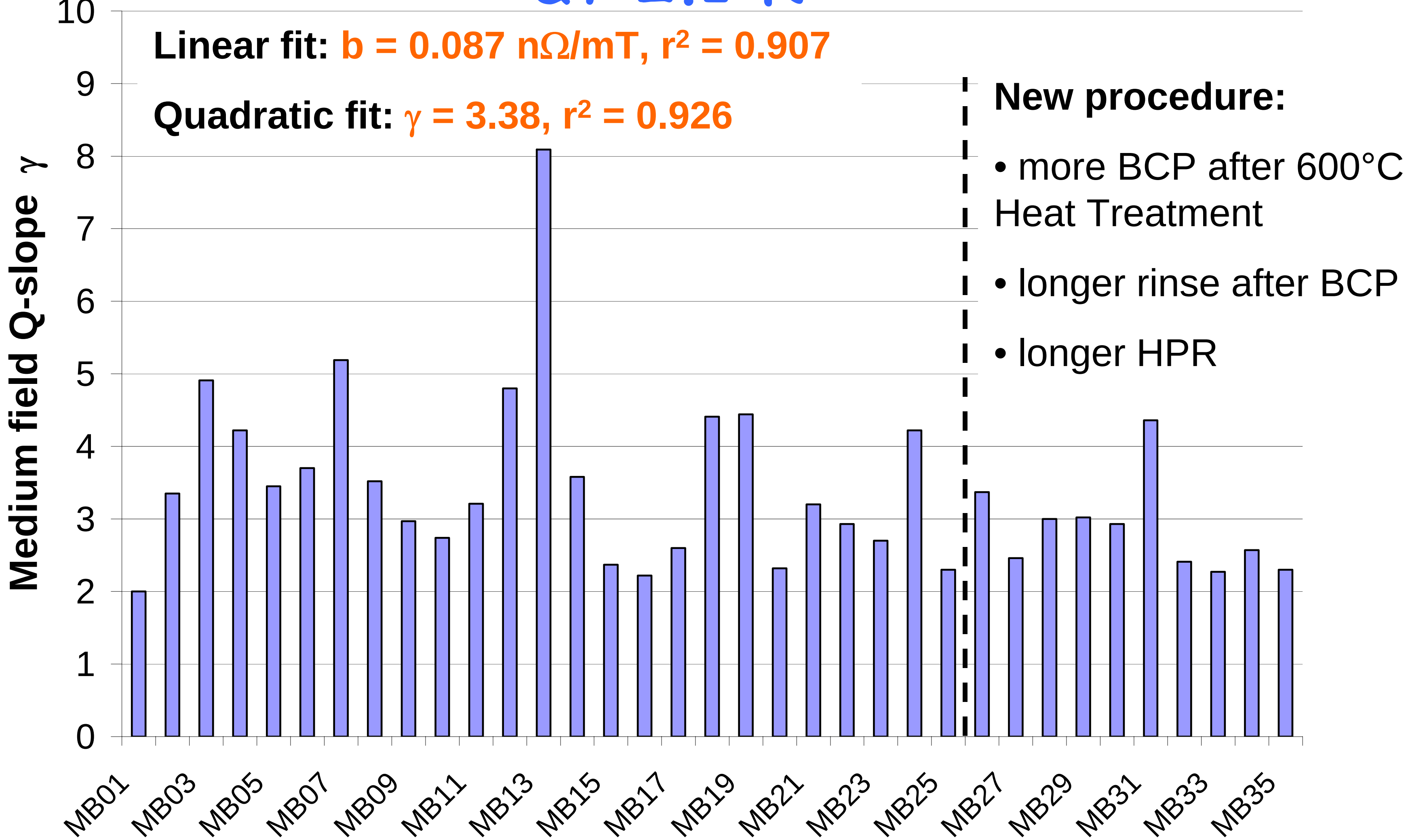




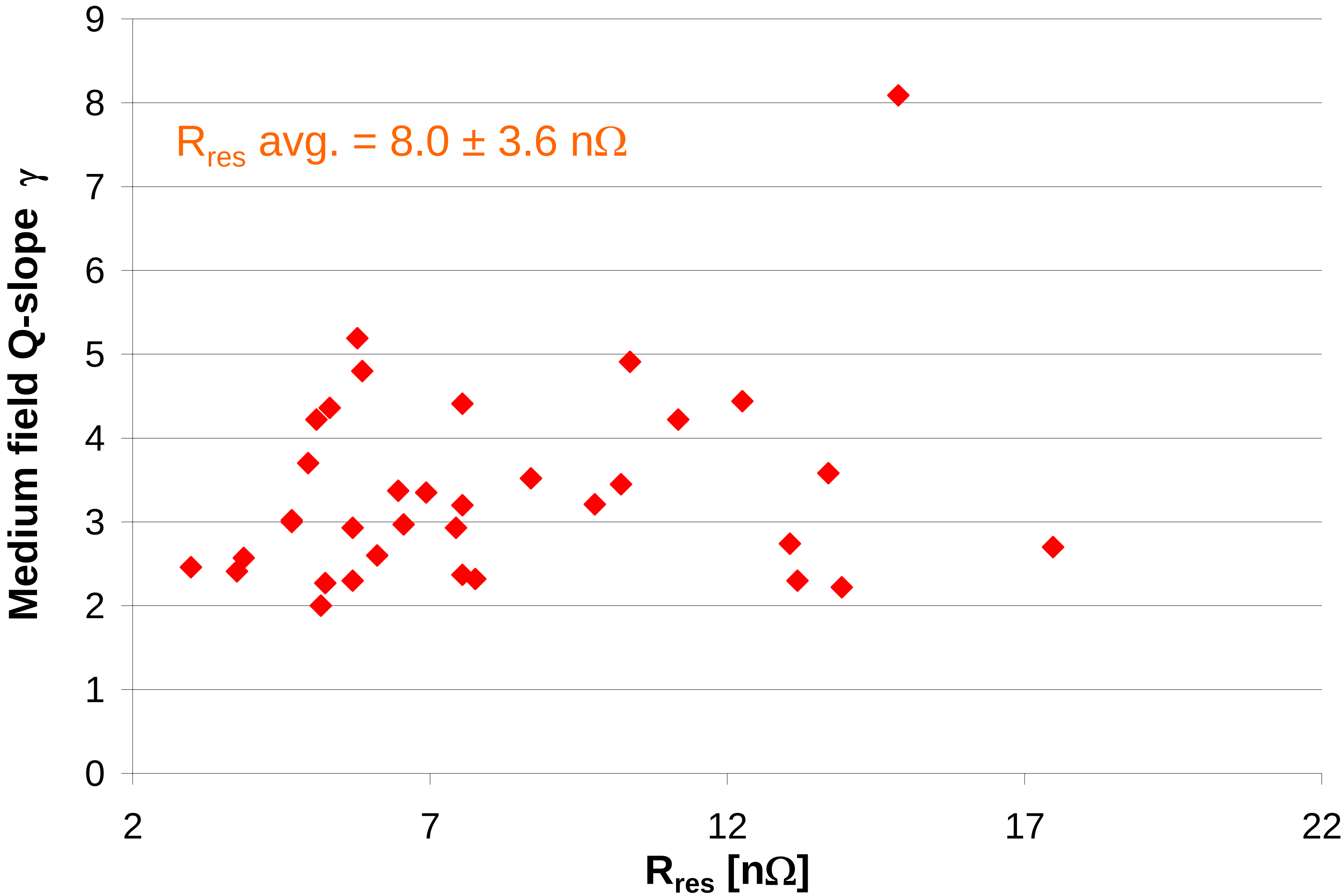


Josephson fluxons, differently from Abrikosov fluxons (SC mixed phase), do not have a normal conducting core

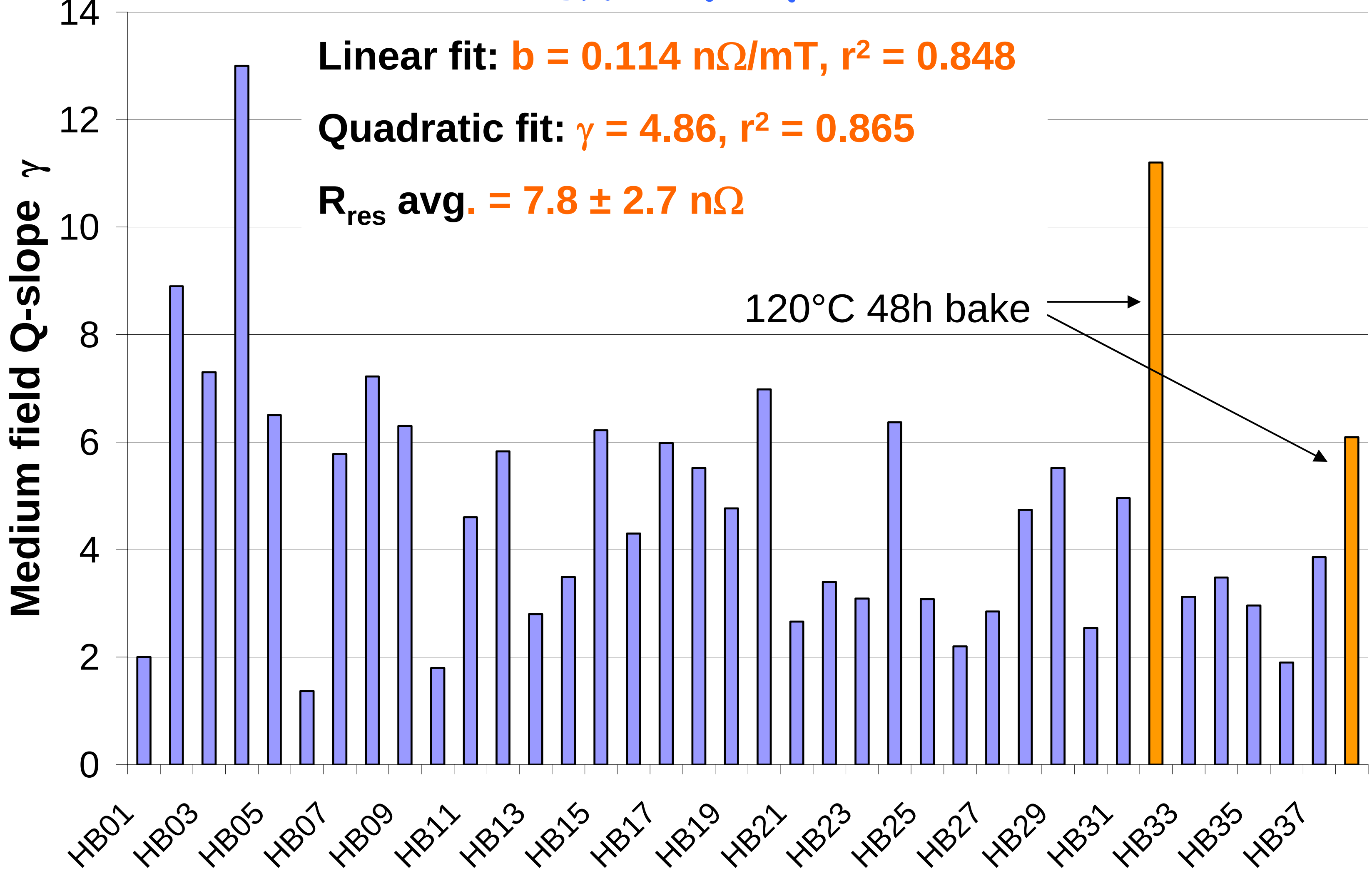
SNS β=0.61 6-cell 805 MHz cavities at 2.1 K



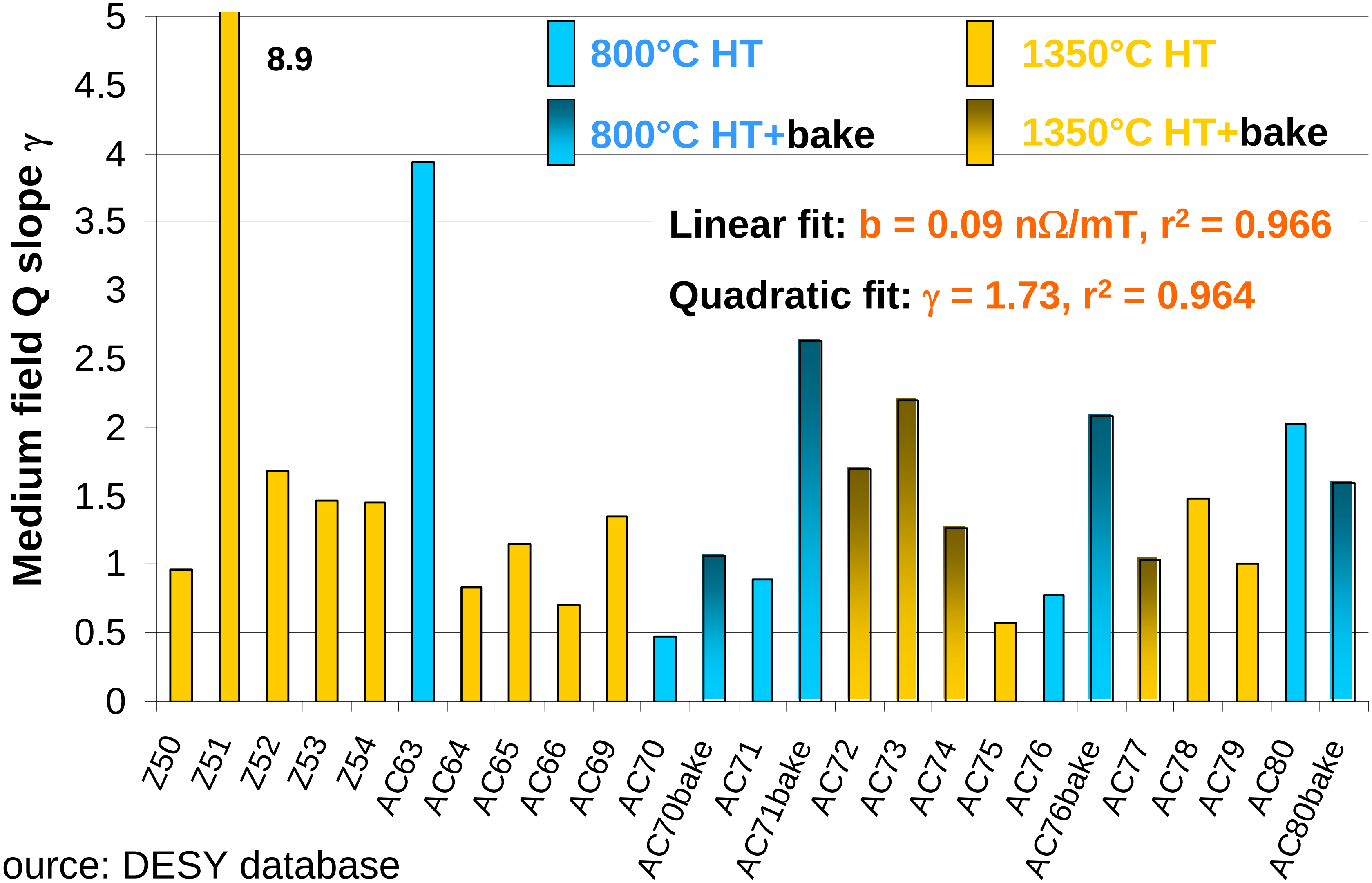
No correlation between medium field Q-slope and residual resistance



SNS β=0.81 6-cell 805 MHz cavities at 2.1 K

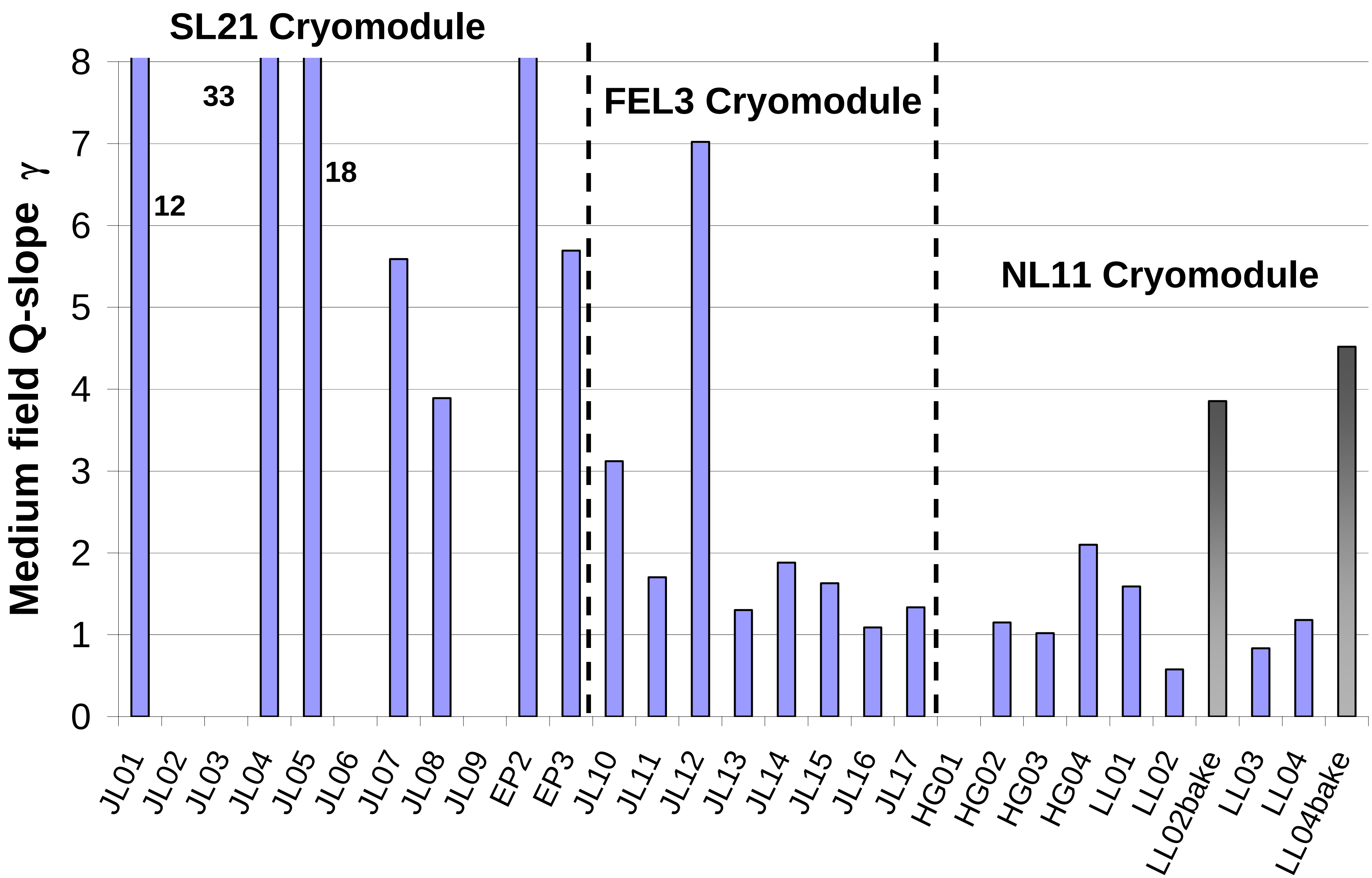


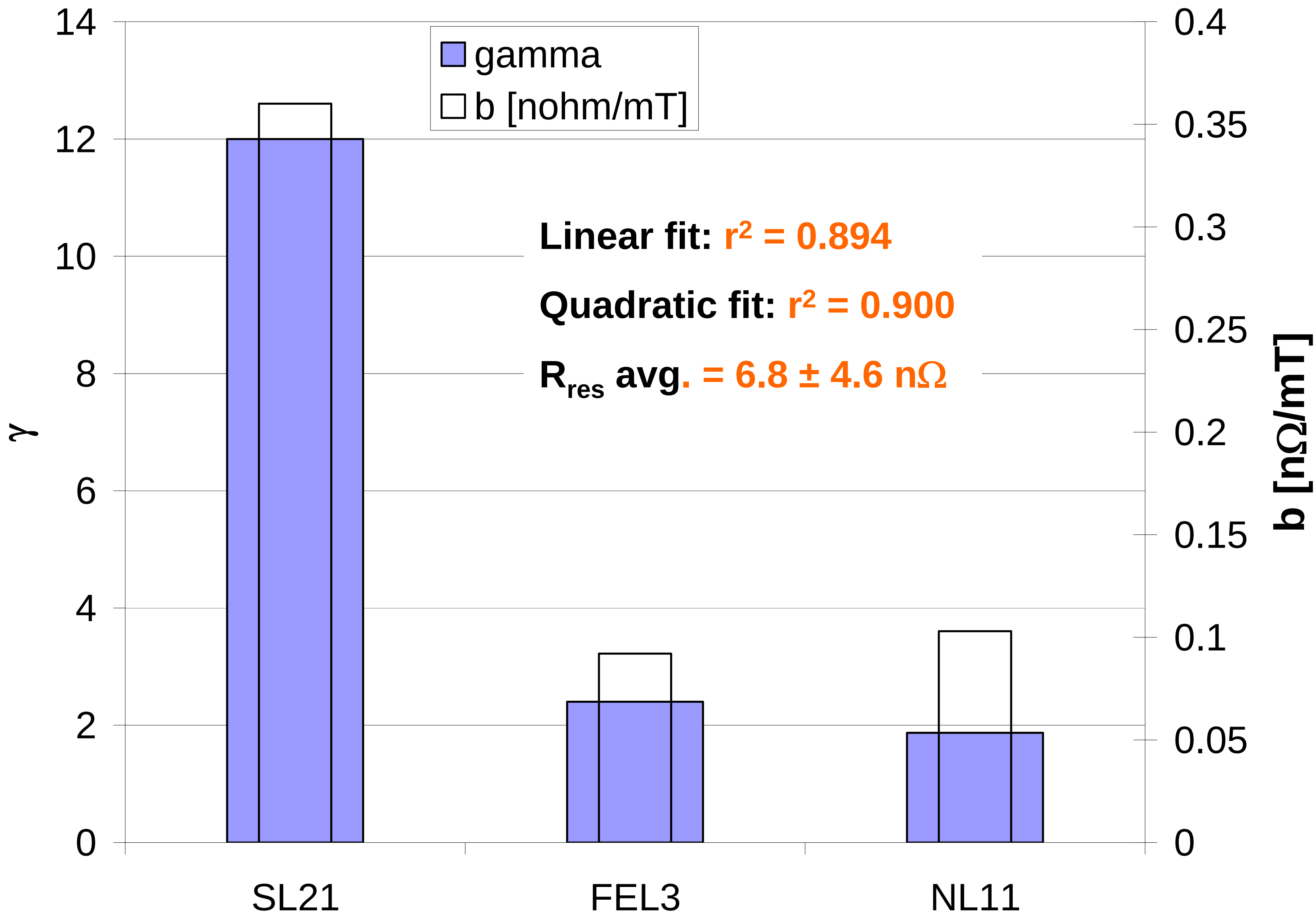
TESLA 9-cell 1.3 GHz cavities at 2 K



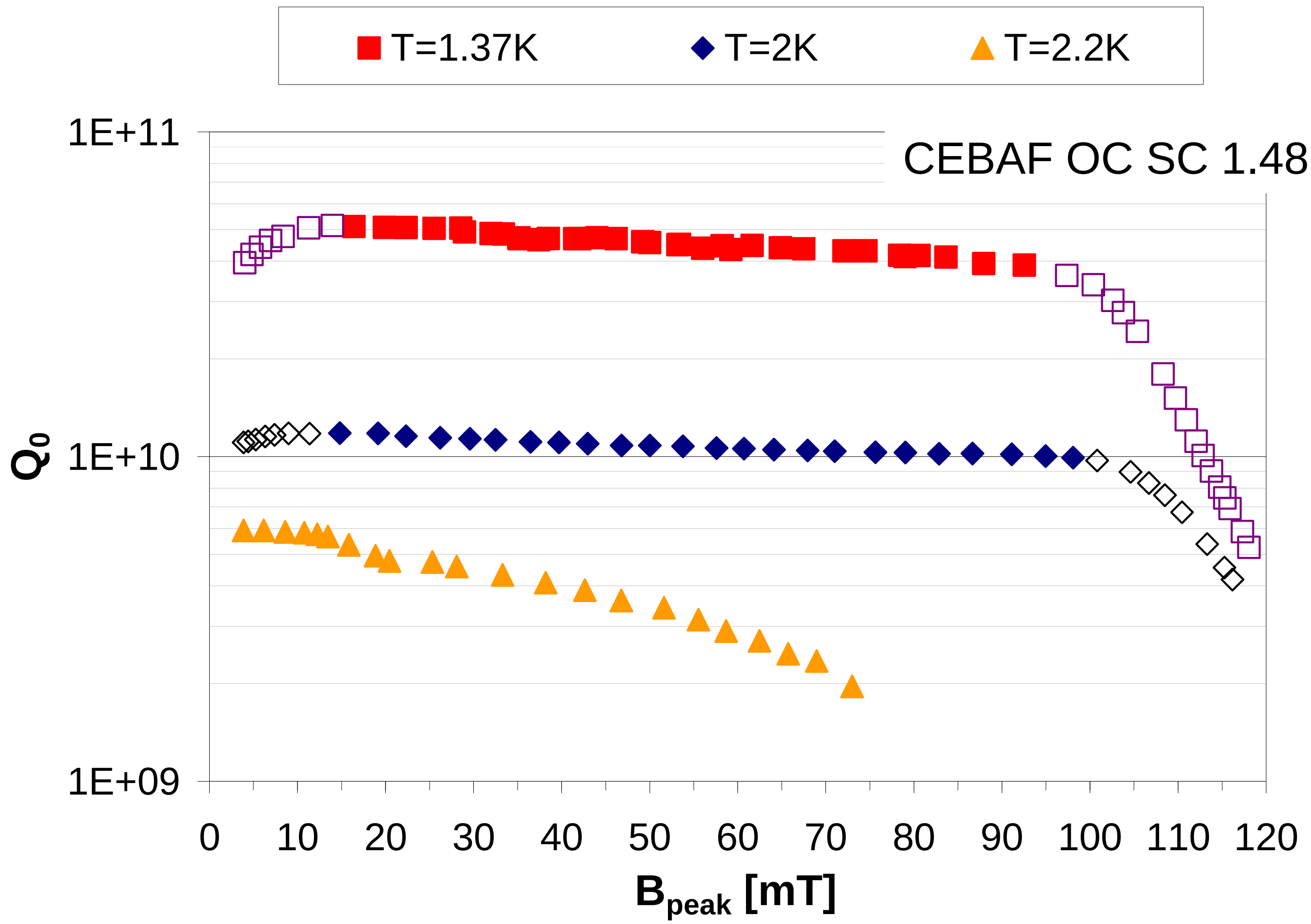
Source: DESY database

CEBAF 7-cell 1.5 GHz cavities at 2 K




14
12
10
8
6
4
2
0
γ
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
b [nΩ/mT]
gamma
b [nohm/mT]
Linear fit: r² = 0.894
Quadratic fit: r² = 0.900
R_res avg. = 6.8 ± 4.6 nΩ
SL21
FEL3
NL11

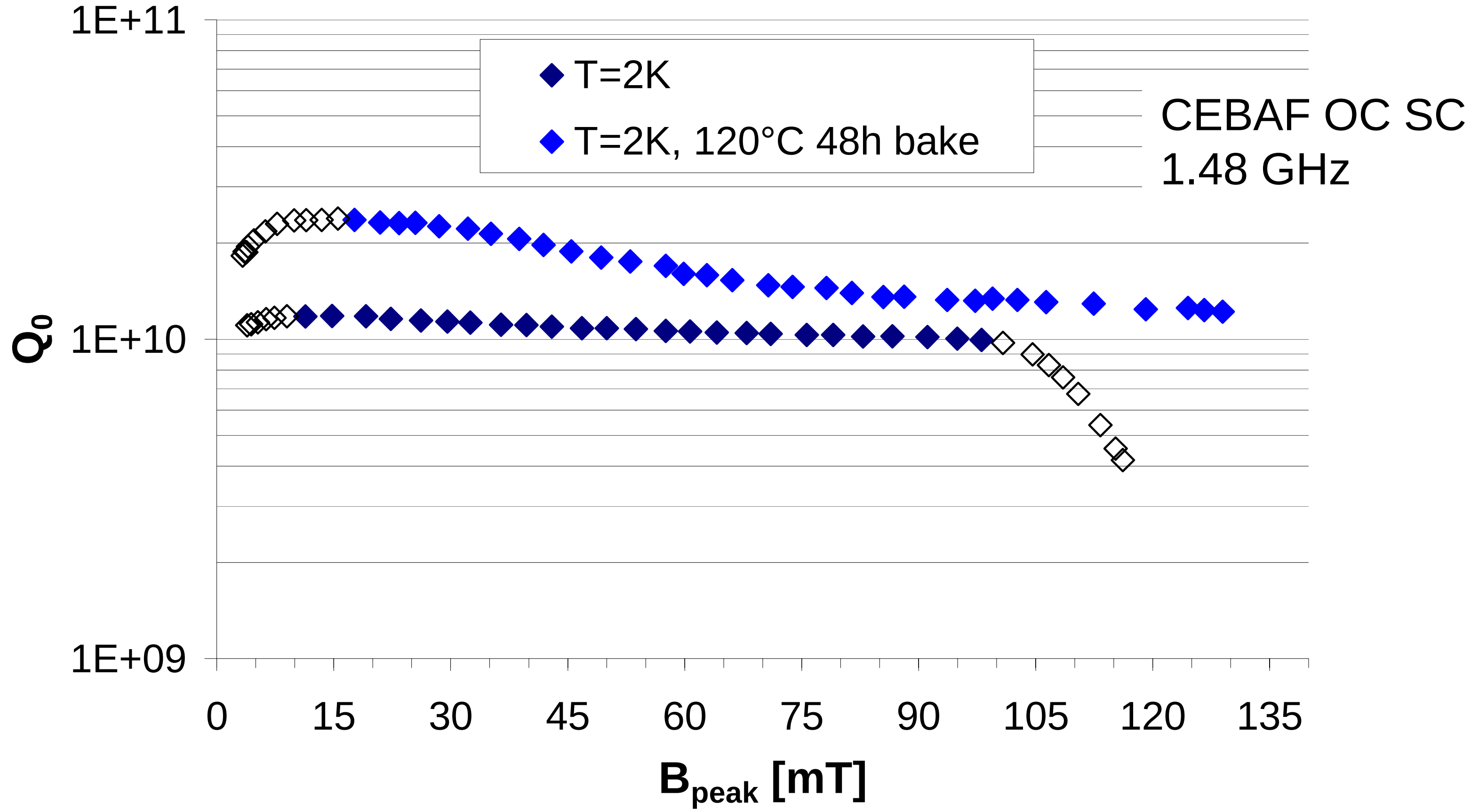
Medium field Q-slope: T dependent



	γ
1.37 K	1.85
2 K	0.94
2.2 K	13.7

G. Ciovati, *Journal of Applied Physics*, **96** No 3, 1591 (2004)

Medium field Q-slope: baking effect



- Increase of medium field Q-slope by baking
- Change from quadratic to linear R_s vs B_p dependence

Possible causes for Q-slope

- Heating of rf surface
  - Q-slope is T dependent
  - Higher Q-slope on SNS cavities (3.8mm thick, vs. TESLA and CEBAF 2.5-2.8mm thick)
  - Higher thermal conductivity (HT > 1200°C) reduces Q-slope
  - Thermal model (K. Saito, D. Retsche, G. Ciovati) does not account for all of the Q-slope

- Kapitza resistance effect:
  - Higher Q-slopes obtained when cavities are baked flowing hot N_2+air than He gas.
  - Outer surface of CEBAF cavities not etched, TESLA and SNS cavities are

- Extrinsic source of losses
  - Surface contamination
  - No correlation between Q-slope and R_{res}

- Hysteresis losses
  - Oxide channels deeper in the Nb after baking → more weak-links → hysteresis losses (linear R_s vs. B_p) prevail

Final remark

- Large scatter in medium field Q-slope values for the same cavity production

  ↳ all the sources for medium field Q-slope are not clear yet and the parameters that influence them are not under control