# Characterizing thin films by RF and DC methods

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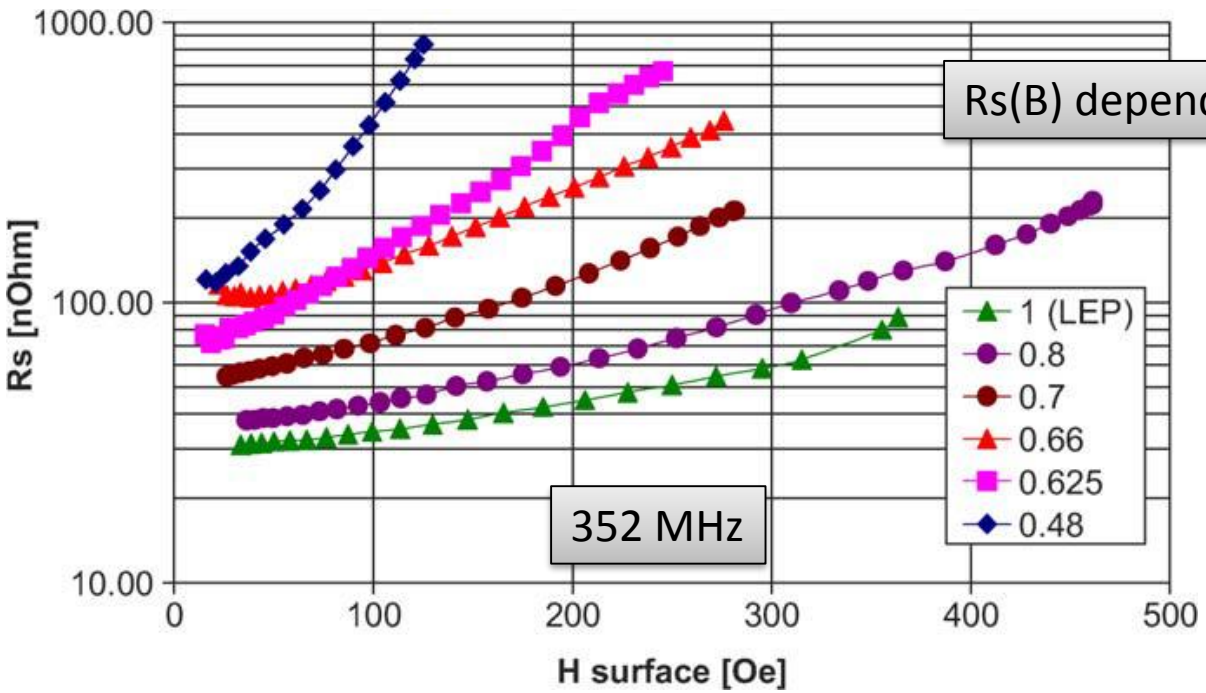
# Outline

- Cavity measurements
  - Example: Nb on Cu (HiPIMS)
- Sample measurements with the Quadrupole Resonator
  - Example: Nb on Cu (ECR)
- Point contact tunneling
  - Example: Nb on Cu (HiPIMS)
- Muon Spin Rotation
  - Example 1: Nb on Cu (HiPIMS)
  - Example 2: NbTiN/Nb

# Cavity measurements

- The *Q* vs *E* measurement of an accelerating cavity is a critical milestone for any thin film development
- Sputter coated Nb films on Cu cavities have been used in the past for LEP-II and currently for LHC and HIE-Isolde
- In the 1990 the dcMS technology has been investigated in depth for 1.5 GHz cavities
- More recently energetic condensatio techniques such as HiPIMS are investigated as an alternative approach to overcome the current limitation of this technology, i.e. the field dependent residual surface resistance

# HiPIMS: Motivation

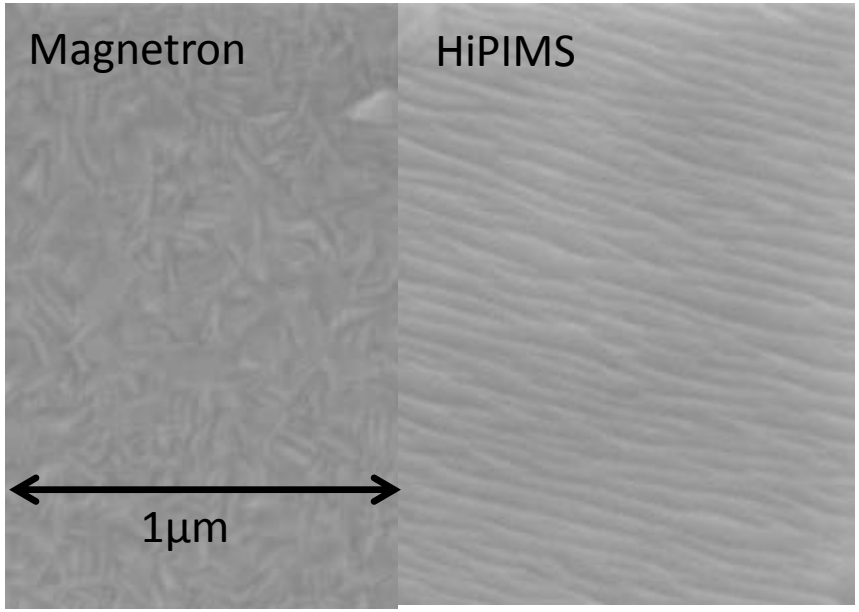


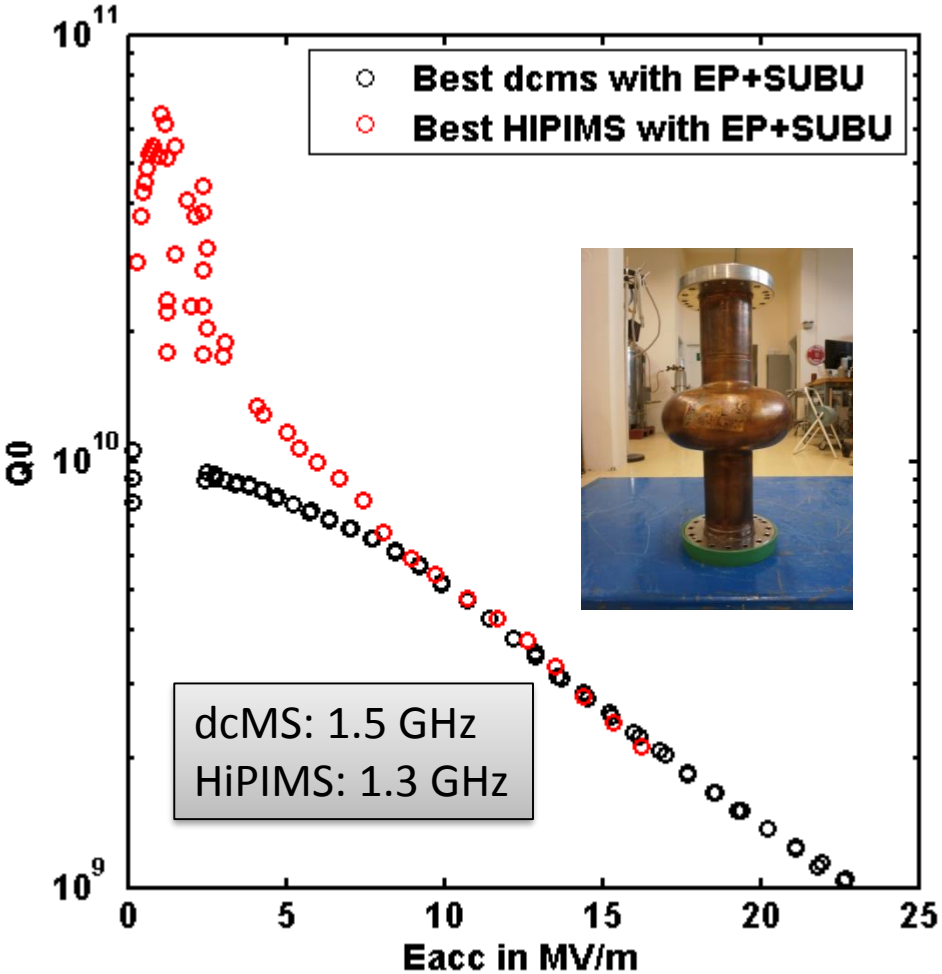

Rs(B) depends on the ion impact angle


By applying pulses of high power the sputtered target material atoms are ionized and applying biasing potential we can achieve:

- Target material ions can be accelerated towards the substrate, higher kinetic energy upon arrival
- Ions are directed to the surface, thus non-flat surfaces can be sputtered with good uniformity of the film

# HiPIMS: Status at CERN

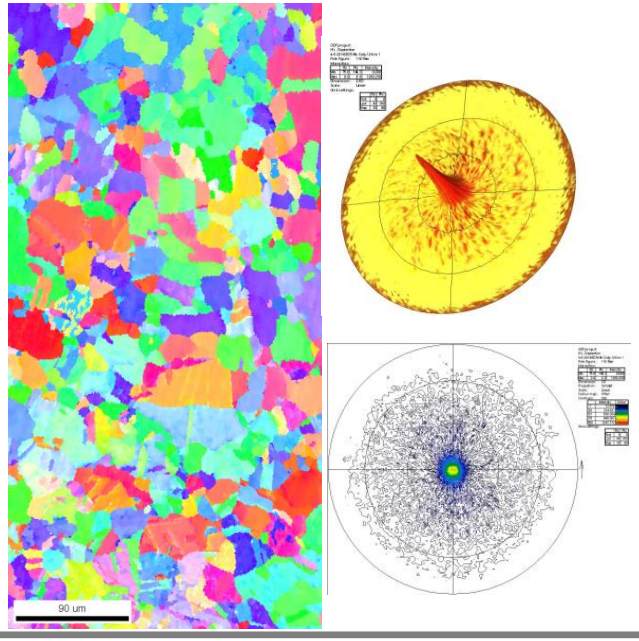


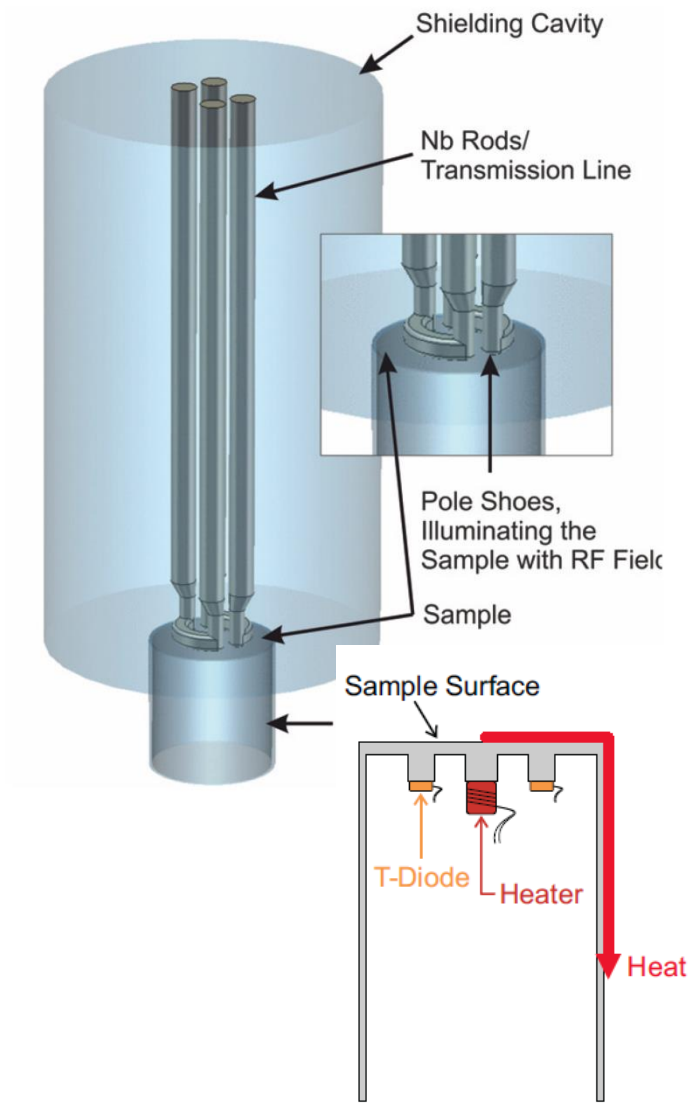

- So far only tests without biasing
- SEM images show more ordered surface structure
- RF performance equal to dcms with same surface preparation
  - Biasing could be the key
- RRR of about 20-30

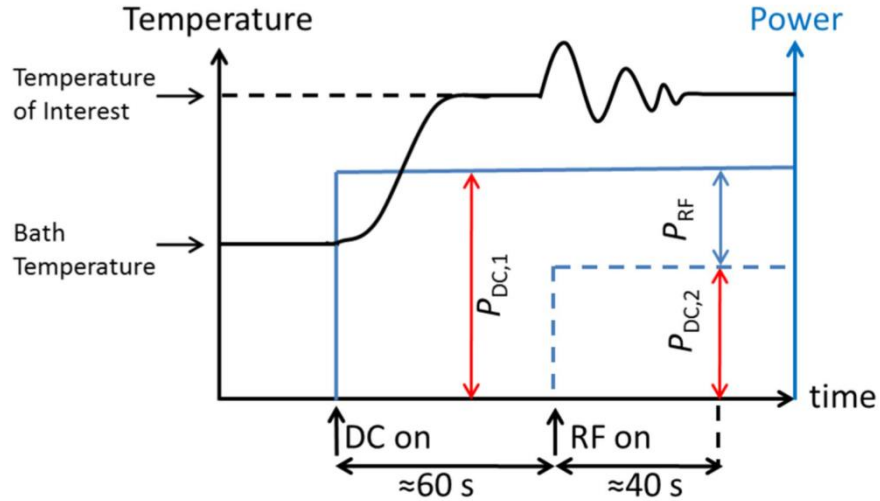
# Electron Cyclotron Resonance (ECR) at JLAB

- Another technique to create Nb films with high RRR and large grain size
- Deposition in vacuum with no sputter gas
- Deployement for deposition on cavities has just been initiated
- Tests on flat samples are necessary to probe the RF performance



# Quadrupole Resonator (CERN/HZB)




$$P_{RF} = P_{DC,1} - P_{DC,2} \approx 1/2\, R_{Surface} \int_{Sample} H^2 dS$$

$$R_{Surface} = \frac{2(P_{DC,1} - P_{DC,2})}{\int_{Sample} H^2 dS}$$

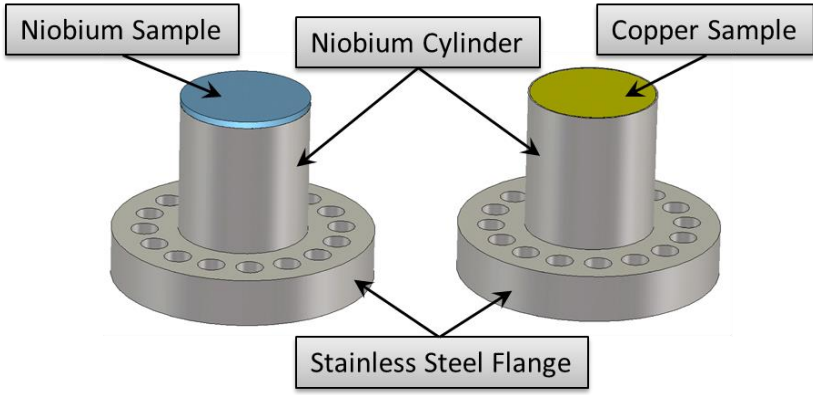
Measured directly

- Measurement of transmitted power $P_t$
- $P_t = c\int H^2 ds$, c from computer code

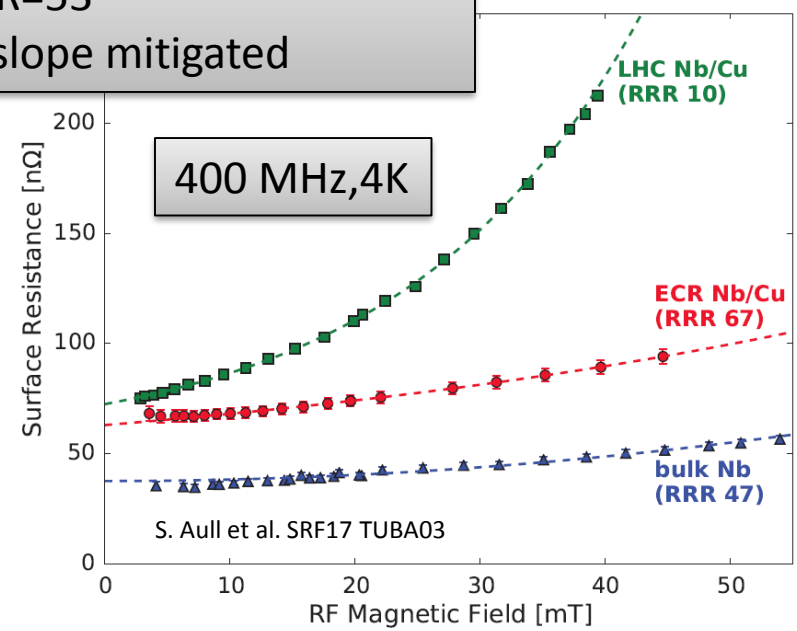
# Quadrupole Resonator (CERN)

**Features:**

- **Sample tests over a parameter range inaccessible to elliptical cavities**
- Niobium and copper substrates can be used
- Three different RF frequencies, with almost identical magnetic field configuration
- Wide temperature range (2-20K)
- Precise calorimetric measurement (Accuracy about 0.05 nΩ)




Results on an ECR sample
RRR=53
Q-slope mitigated

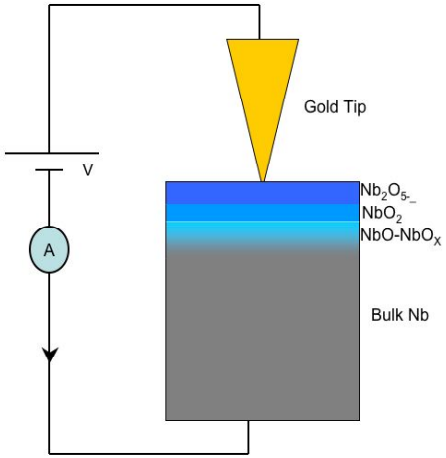


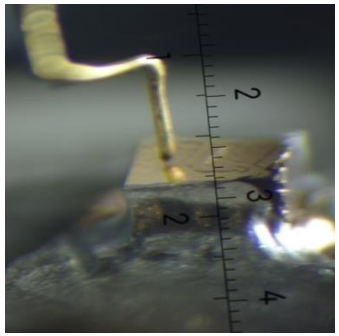

S. Aull et al. SRF17 TUBA03

# DC measurement techniques

- There are several thin film coatings which might be potentially interesting for SRF application but cannot yet be deposited on cavities
- Additional to RF sample tests there are several DC techniques, which can give invaluable information to optimize coating parameters and provide an understanding of loss mechanism
- Point contact tunneling can be used to measure the density of states directly
- Low energy muon spin rotation can be used to directly probe the field penetration

# Point contact tunneling

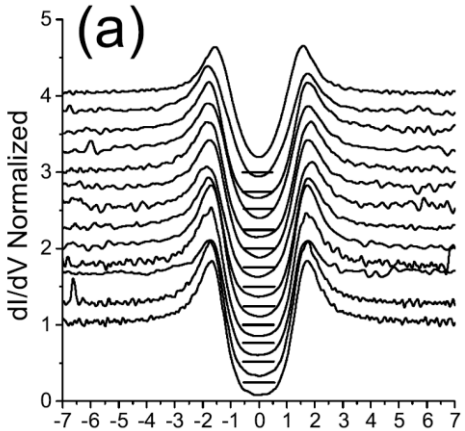


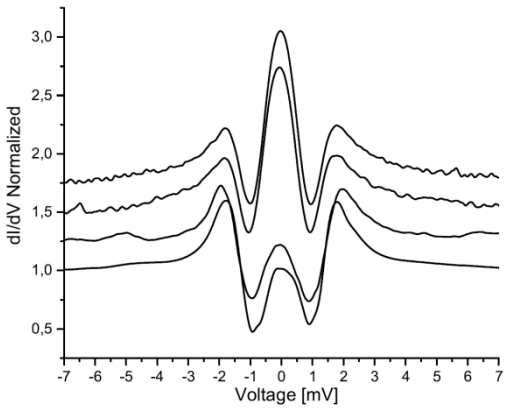
$$\frac{dI}{dV} = -\sigma_N \int N(E) \frac{\partial f(E+eV)}{\partial (eV)} dE$$

Smeared BCS DOS

$$N(E) = \mathrm{Re}\left[\frac{|E| - i\Gamma}{\sqrt{(|E| - i\Gamma)^2 - \Delta^2}}\right]$$

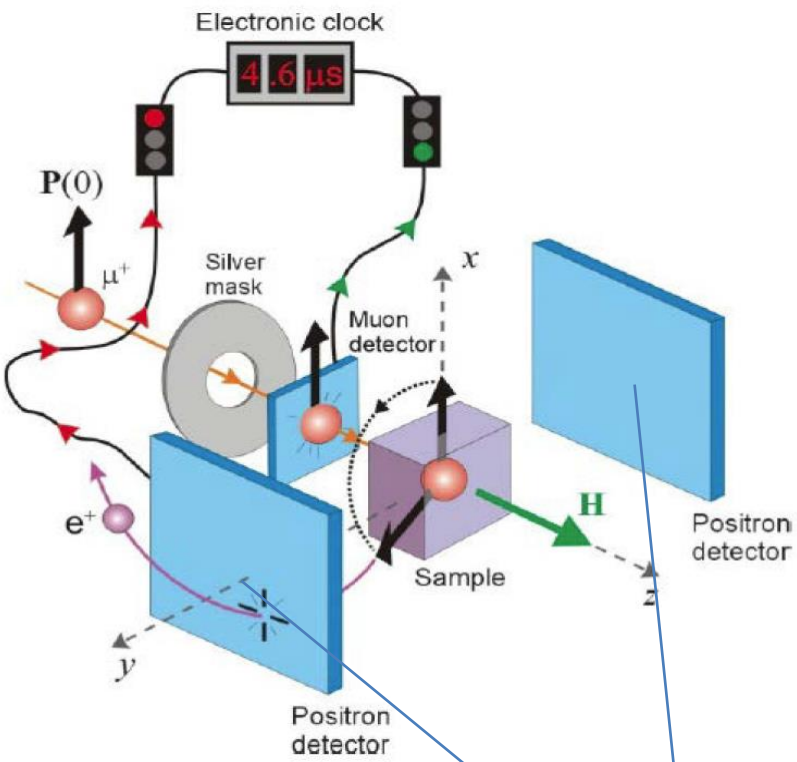



Measurement on a HiPIMS sample



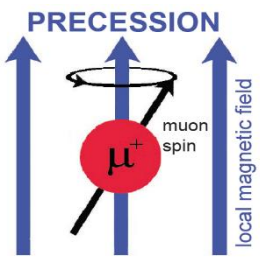

Some zero bias peaks: Magnetic impurities?

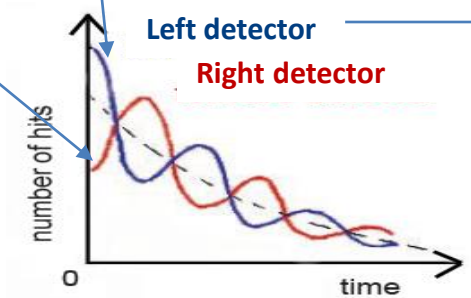
# Muon Spin Rotation (μSR)

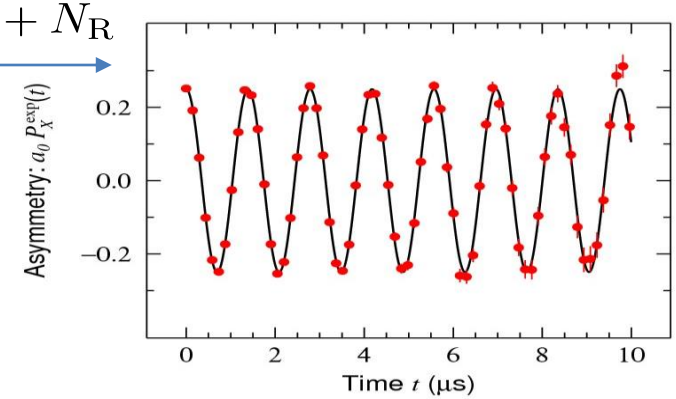



- Muons are deposited one at a time in a sample
- Muon decays emitting a positron preferentially aligned with the muon spin
- Right and left detectors record positron correlated with time of arrival
- The time evolution of the asymmetry in the two signals gives a measure of the local field in the sample

$$a_0 P_y(t) = \frac{N_L - N_R}{N_L + N_R}$$

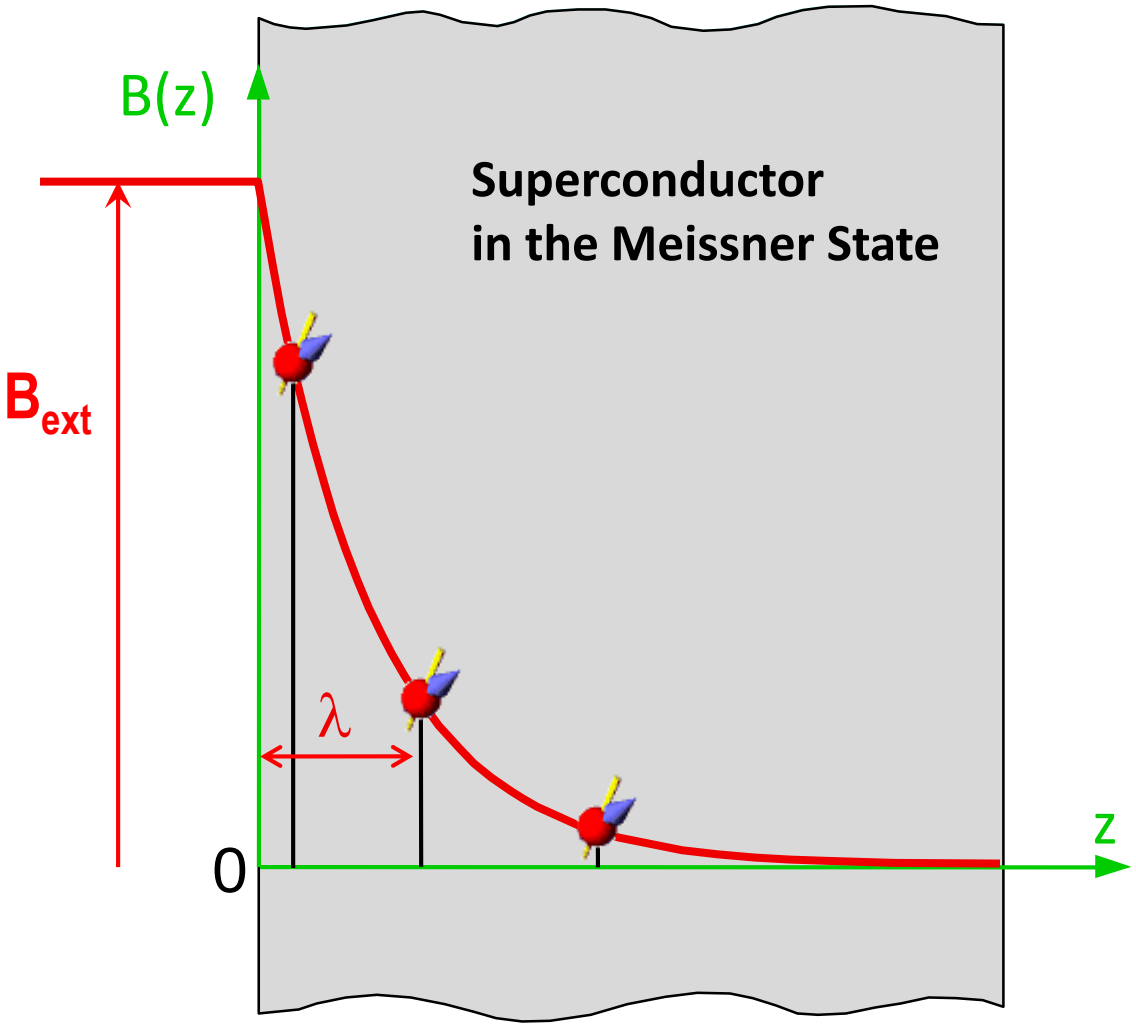


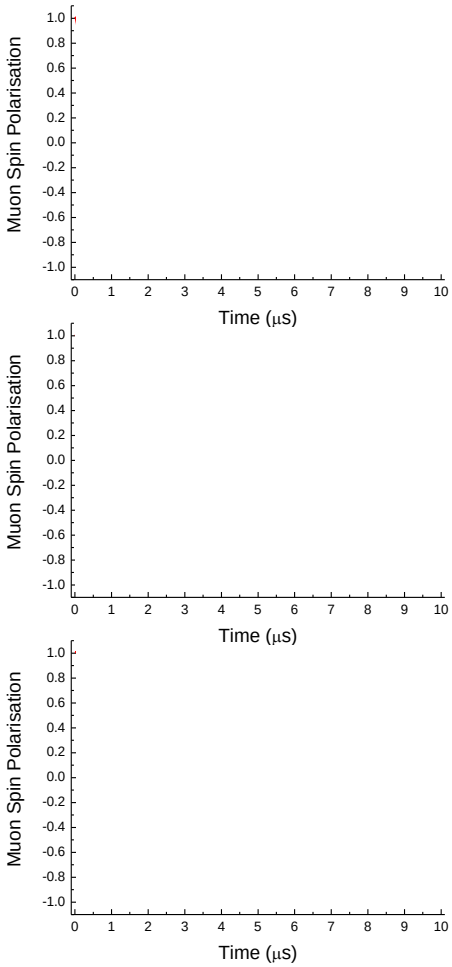




$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

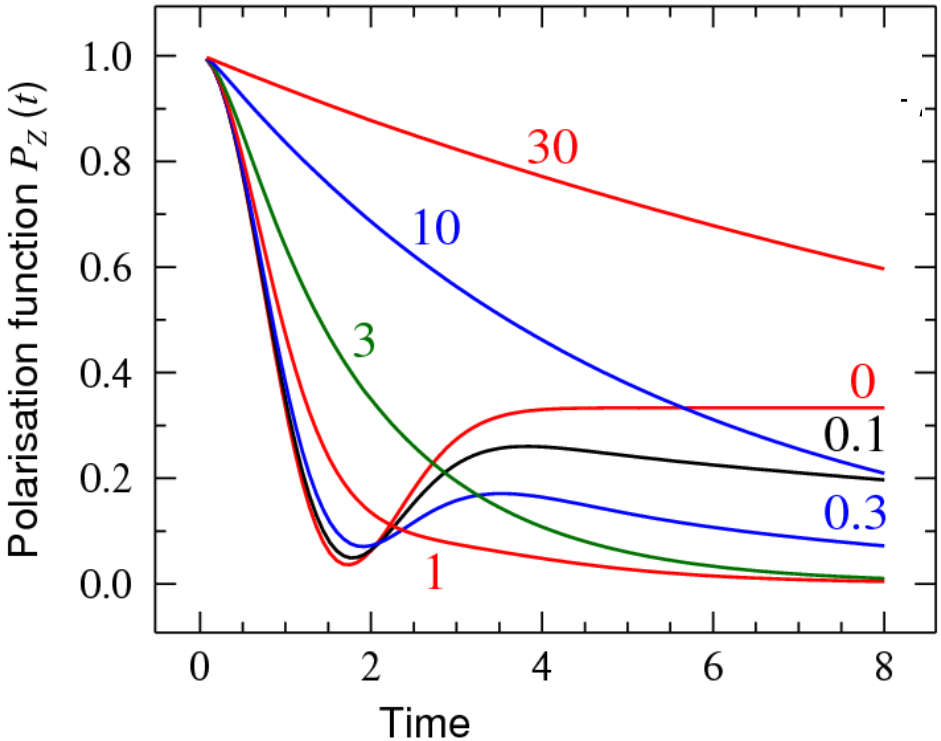
# Depth dependent (low energy) µSR




$$\omega_\mu(z) = \gamma_\mu B_{\mathrm{loc}}(z)$$

# Measuring fluctuating field




Polarization function for different fluctuation rates. The “0” function corresponds to a Gaussian distribution of random fields.

**Slow Fluctuations**

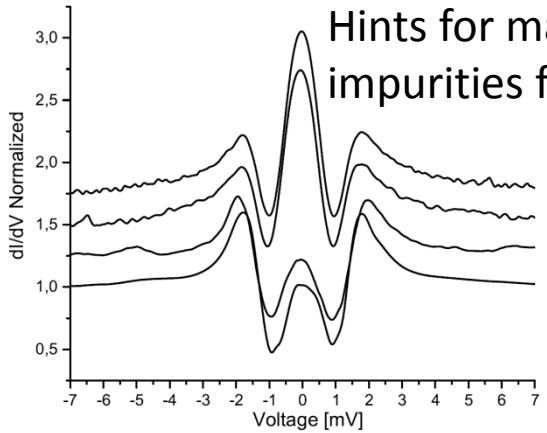
Main effect is relaxation of the ⅓ tail at long times, because 1/3 of the muons see a field in spin direction and do not process

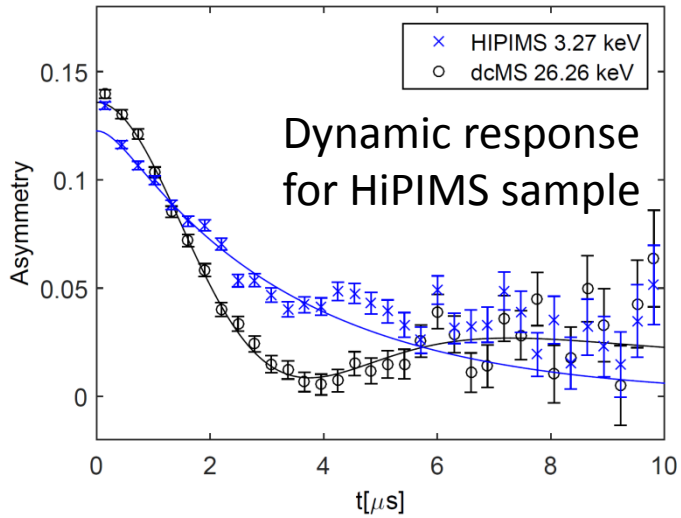
**Fast Fluctuations**

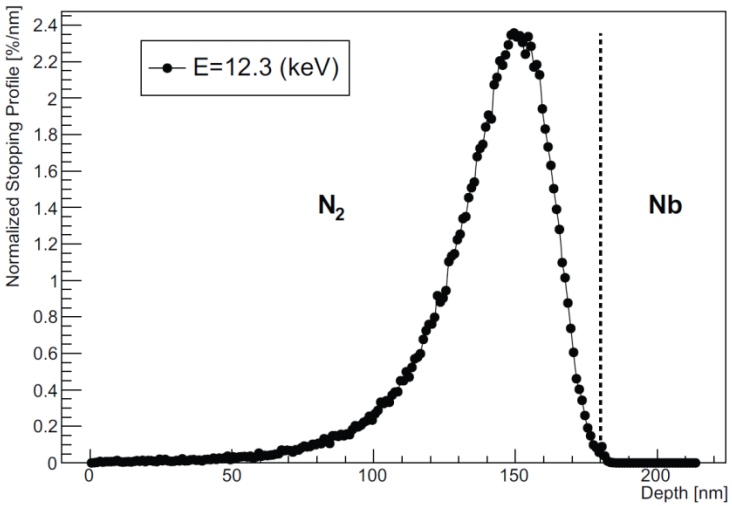
No recovery. For faster fluctuations slower depolarization (motional narrowing)

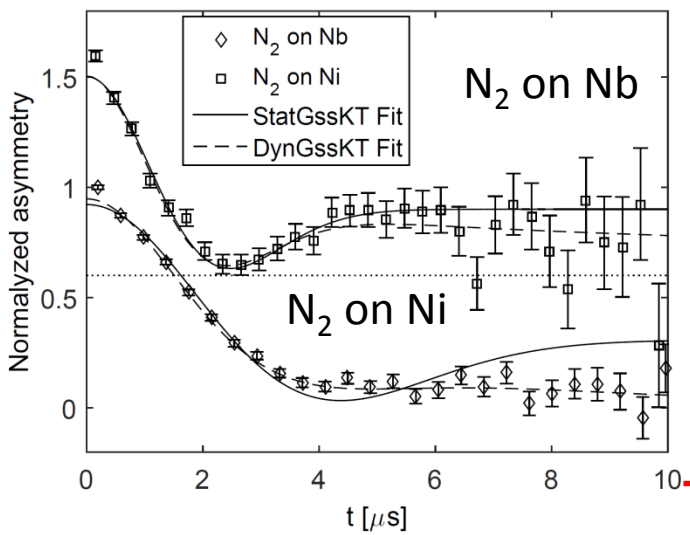
Can be due to muon diffusion or paramagnetism

# HiPIMS – PCT+muSR




Combined results strongly suggest paramagnetic impurities in HiPIMS sample
T. Junginger et al. arXiv:1703.08635

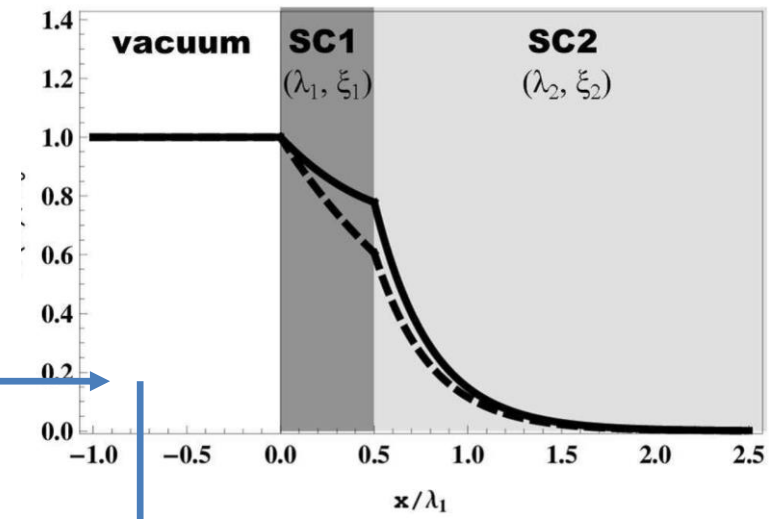
Growing a $N_2$ overlayer on top of Nb and stop muons close to Nb

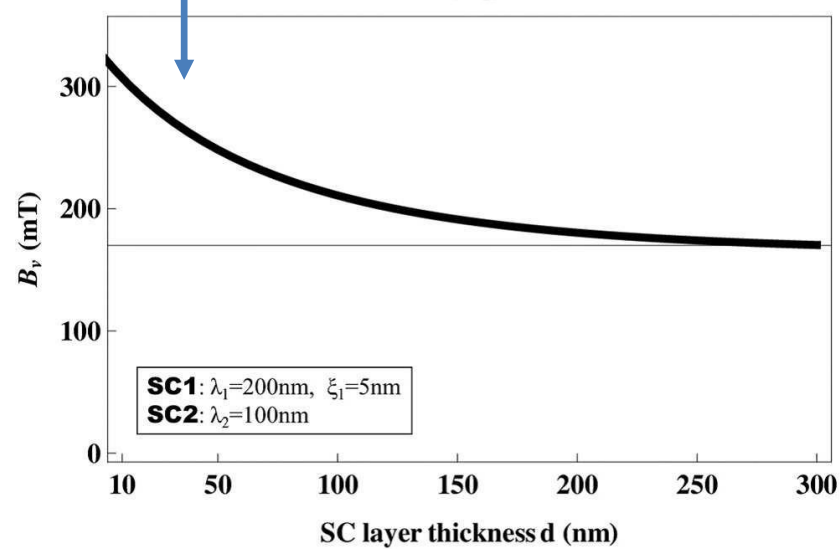
Dynamic response rules out diffusion
Crosscheck with Ni confirms that muon is static in $N_2$

# Depth dependent muSR on NbTiN/Nb

## MOTIVATION

- T. Kubo suggests the use of a bilayer system without insulator to reach high accelerating gradients
- He first calculates the penetration profile within London theory with appropriate boundary conditions
- He uses this result to calculate the forces acting on a vortex on the surface
- He concludes: **A boundary of two SCs introduces a force that pushes a vortex to the direction of the material with larger penetration depth**



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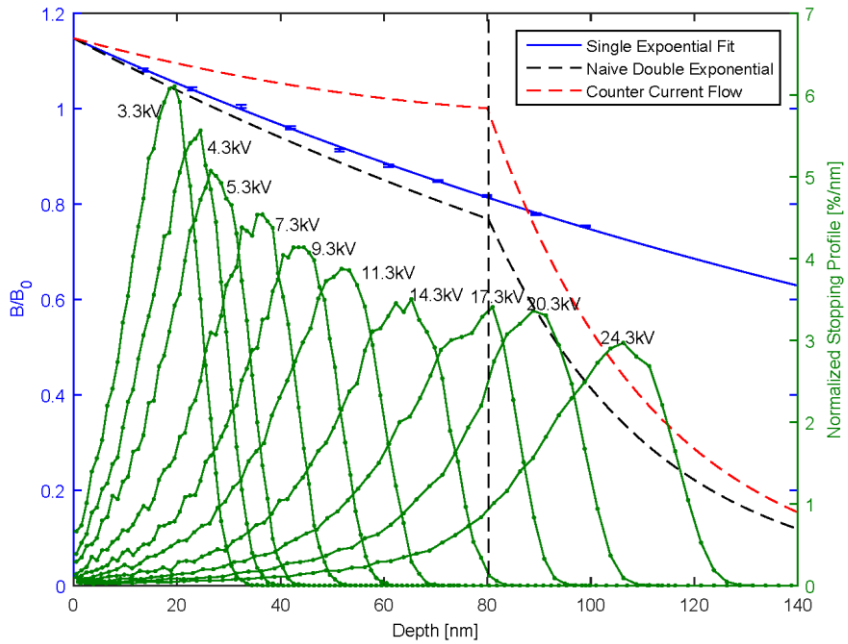
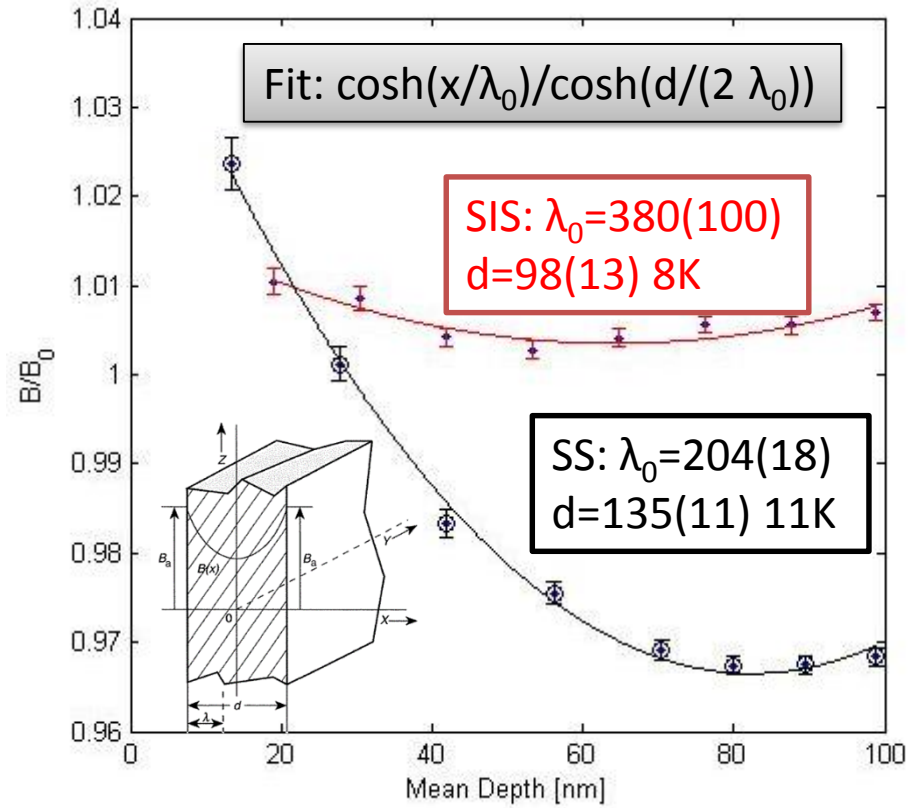



- We observe a single exponential dacay with $\lambda_0$=223(7)
- Proximity effect? Dirty Nb due to diffusion?

To benefit from the counter current flow an insulating layer is essential at least for the NbTiN/Nb system




- Measure above $T_c$ of Nb
  - Field enters from both sides
- Comparison with SIS sample (no proximity)
- **Significantly different $\lambda_0$ and *d* support proximity for SS**

# Conclusion

- RF sample tests enable
  - Testing materials which are not yet ready for deposition on cavities
  - Having a faster turnaround than cavity tests, providing feedback for coating optimization
  - Accessing a parameter space inaccessible to cavity tests
- DC methods
  - Can measure superconducting and material parameters
  - Provide information for coating parameter optimization
  - Can give insight which material/structures are potentially useful for SRF application