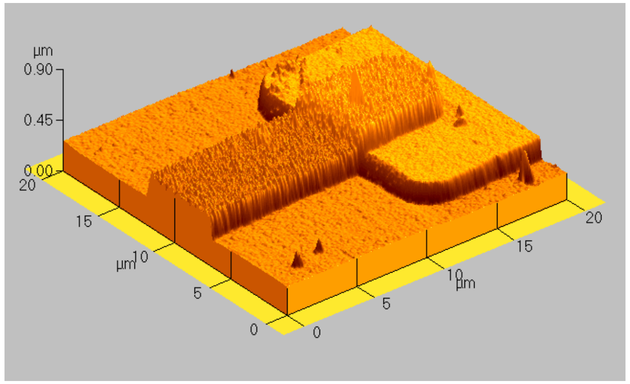

Nov. 21, 2010

Observation of two Andreev-like energy scales in LSCO S-N and S-N-S junctions

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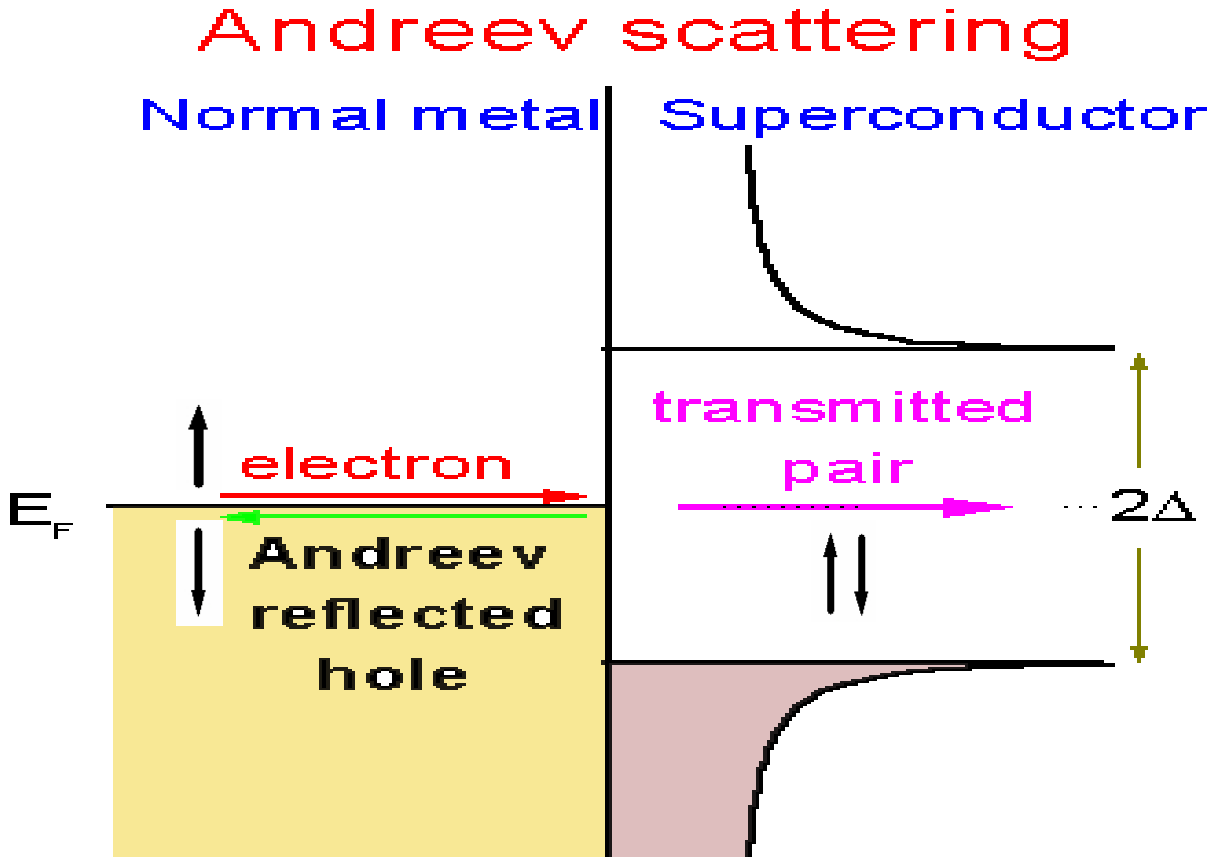
Outline

- Andreev spectroscopy: background and previous conductance results
- Ramp-type junctions: LSCOx-LSCO35 $(0.10<x<0.18)$ SN and SNS junctions
- Conductance results & Phase diagram
- Possible origin of the Δ_2 Andreev-like energy scale

Transport in SN junctions below the gap is via the Andreev scattering effect



Point contact spectroscopy on LSCO single crystals

Conductance at 4.2K

Deutscher, Achsaf, Goldschmidt & Revcolevschi Physica C, **282,** 140 (1997)

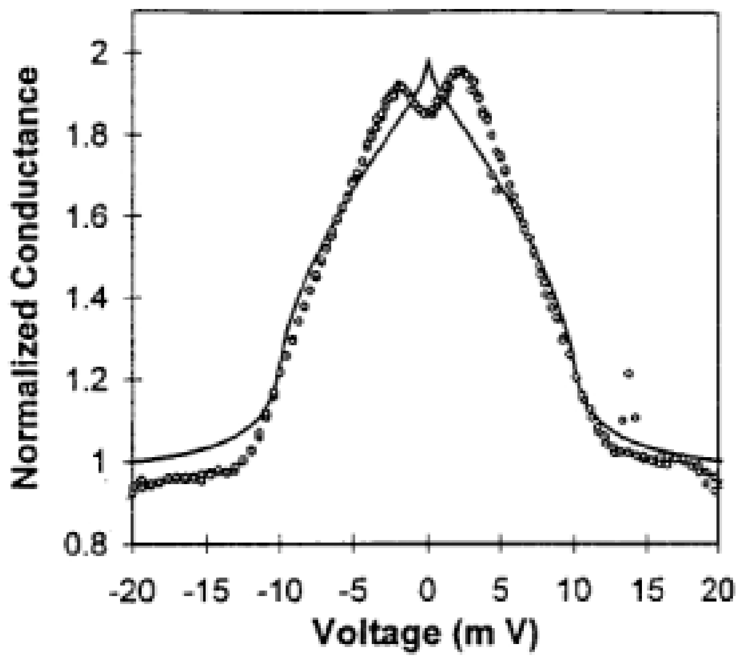
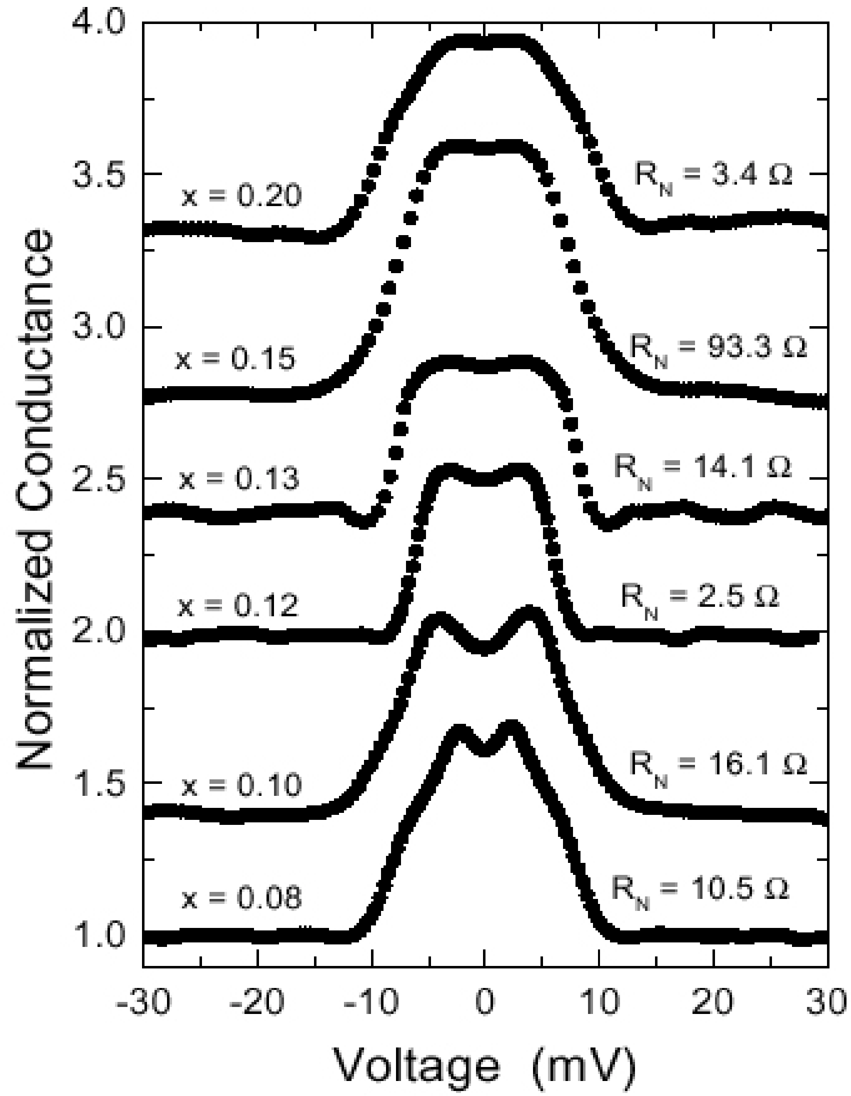
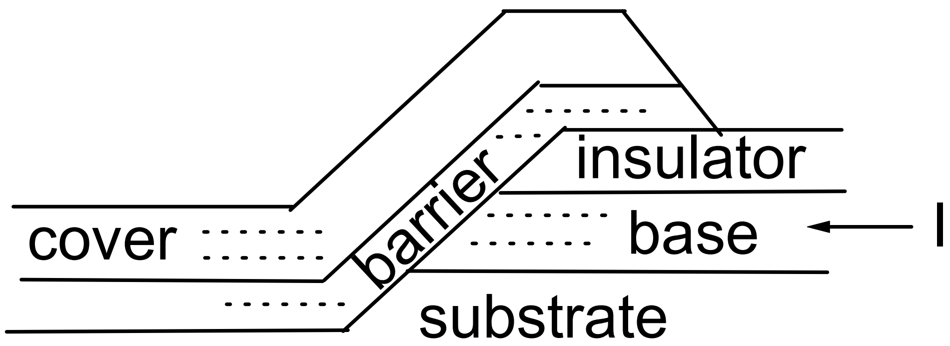


Fig.2 d-wave symmetry fit.

Gonneli et al. Eur. Phys. J. B**22**, 411 (2001)



Ramp-type junction cross-section



- Base – LSCOx; Barrier – LSCO35; Cover – LSCOx

Note: can't be done vs x with YBCO unless doped barrier

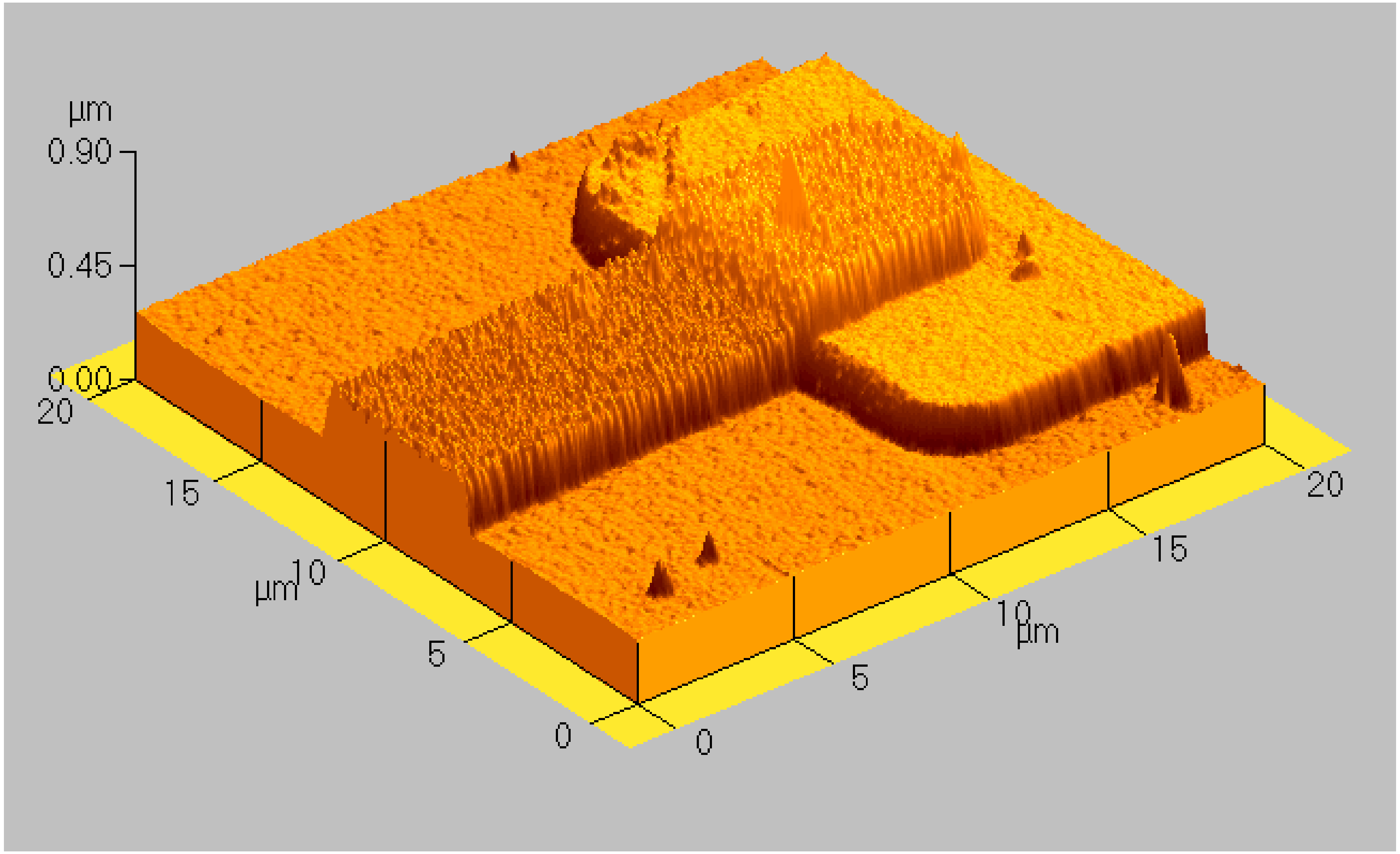
- All epitaxial structure (Laser ablation deposition, deep UV photolithography, and ion beam milling)

  avoids GBJ, and preserves structural orientation.

- *a*-*b* plane coupling

  with the longer coherence length ξ~4nm

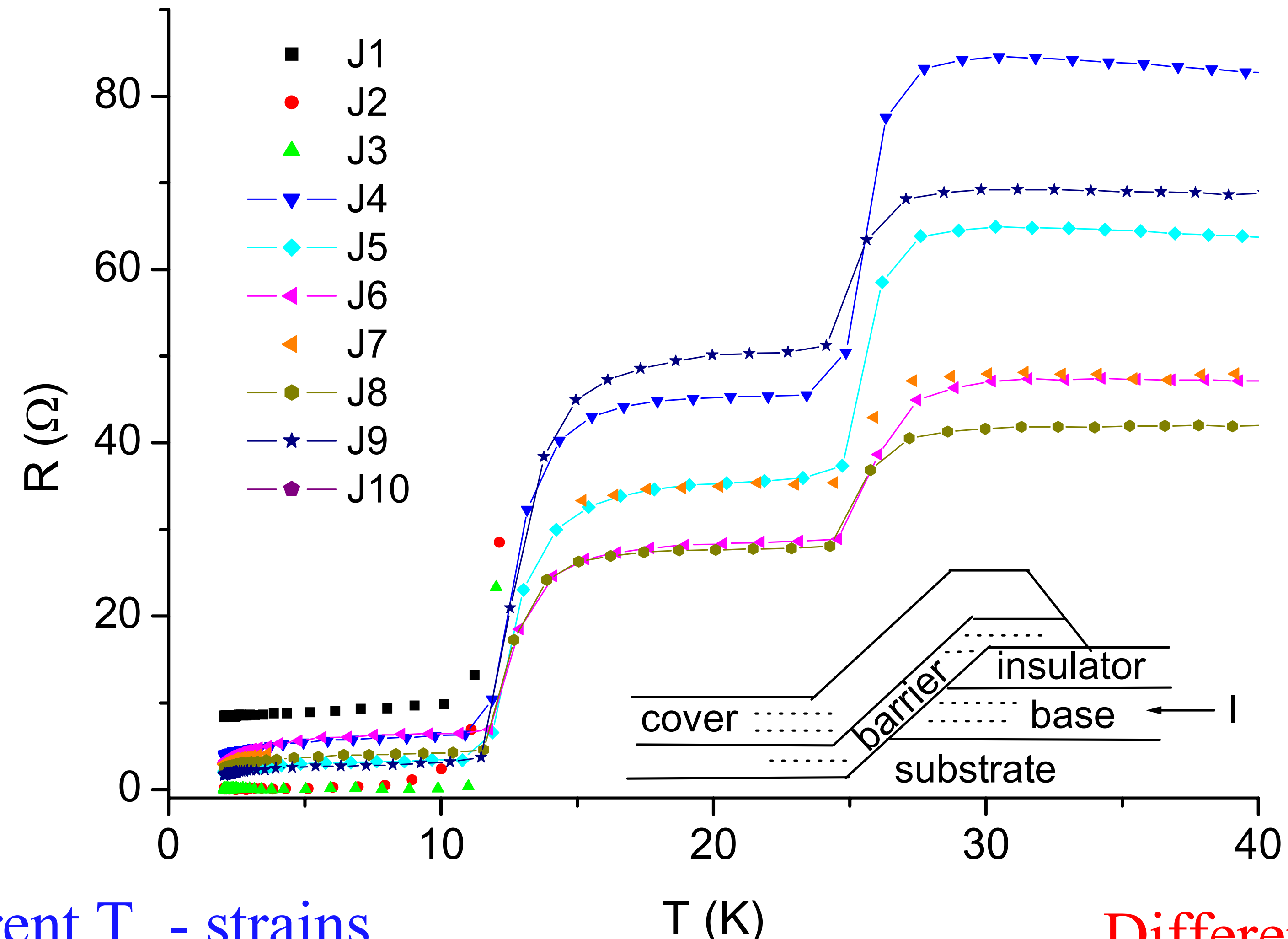
AFM of a ramp type junction



Base electrode: insulator (55 nm STO)/77nm LSCOx - S

Cover electrode: gold/77nm LSCOx/33nm barrier LSCO35 - N

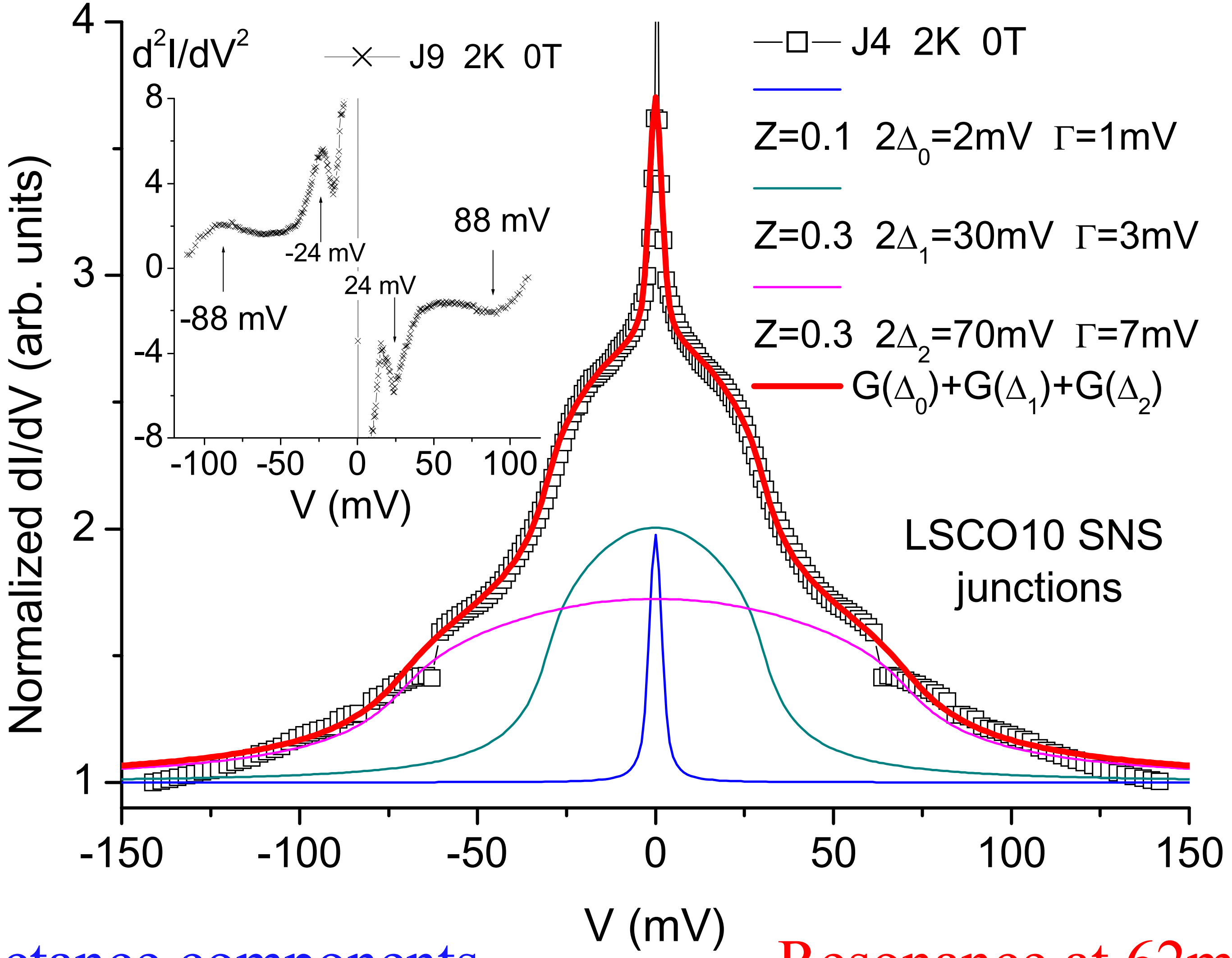
Resistance vs. Temperature of LSCO10-LSCO35-LSCO10 junction



Different T_c - strains

Different R_N

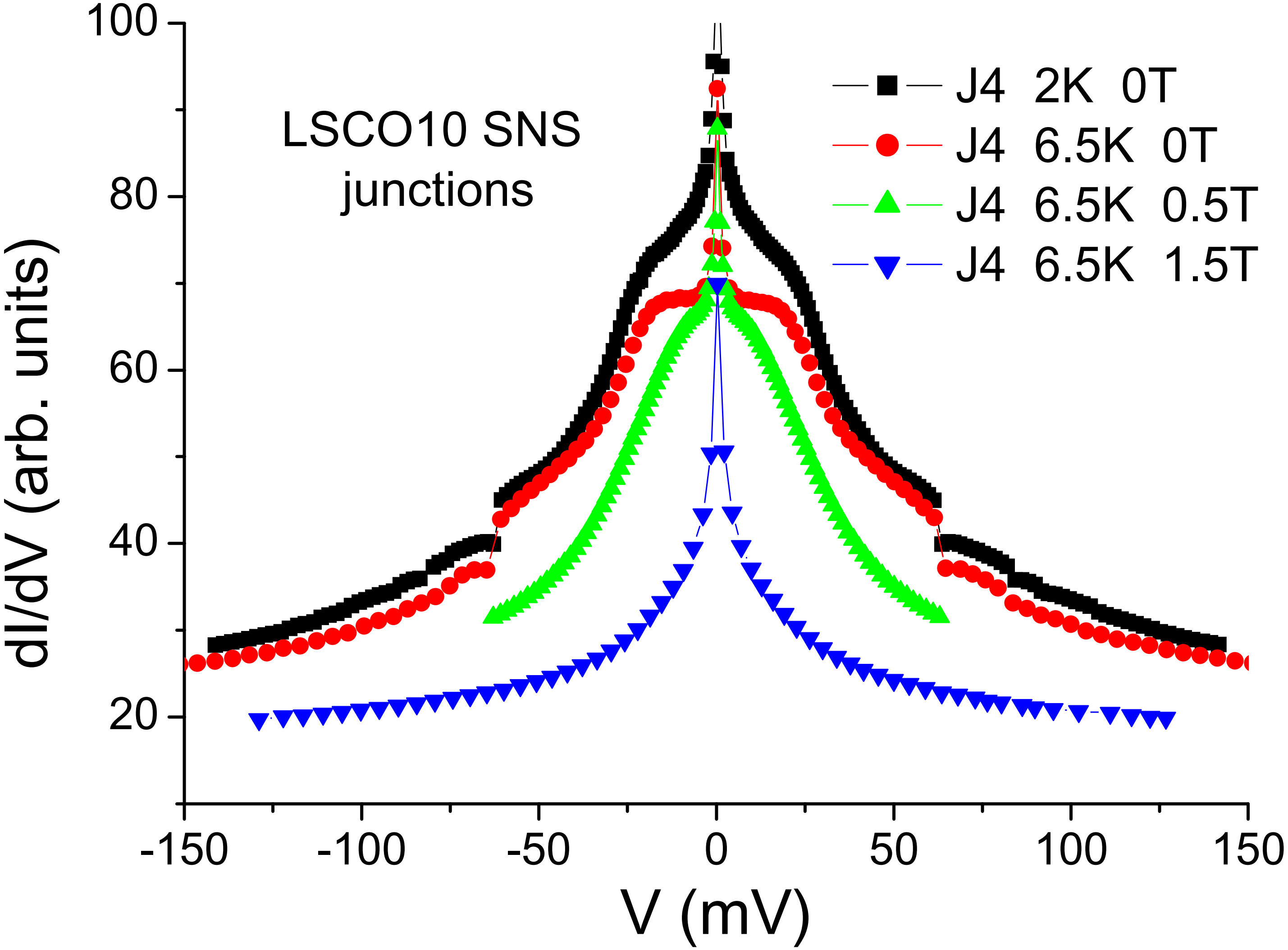
Conductance spectra of LSCO10-LSCO35-LSCO10 junctions



3 conductance components

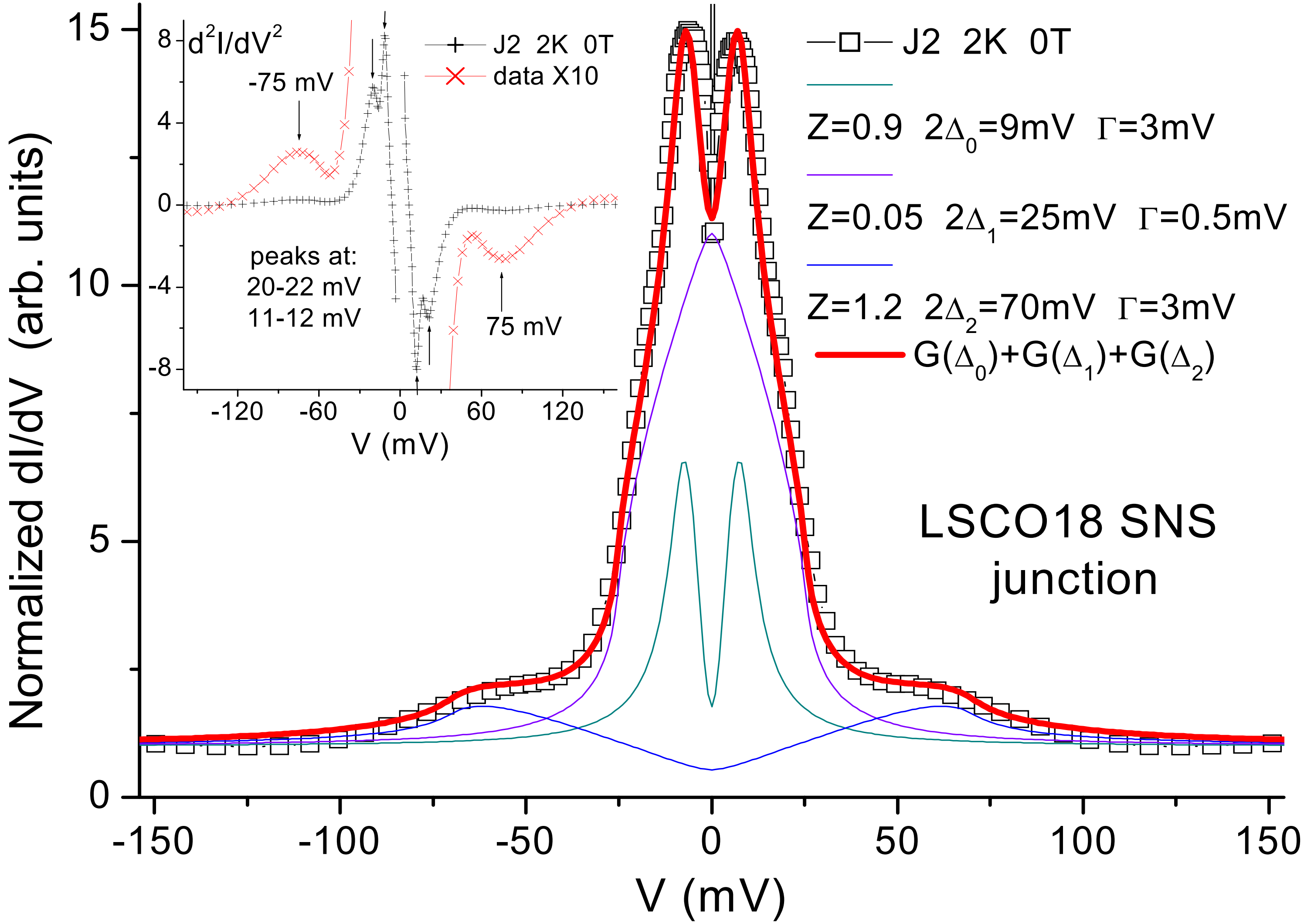
Resonance at 62mV - rare

Conductance spectra of LSCO10-LSCO35-LSCO10 junctions versus field H (& T)



Δ_2 is suppressed with H faster than Δ_1 (will show better data later)

Conductance spectrum of LSCO18 – LSCO35 – LSCO18 junction

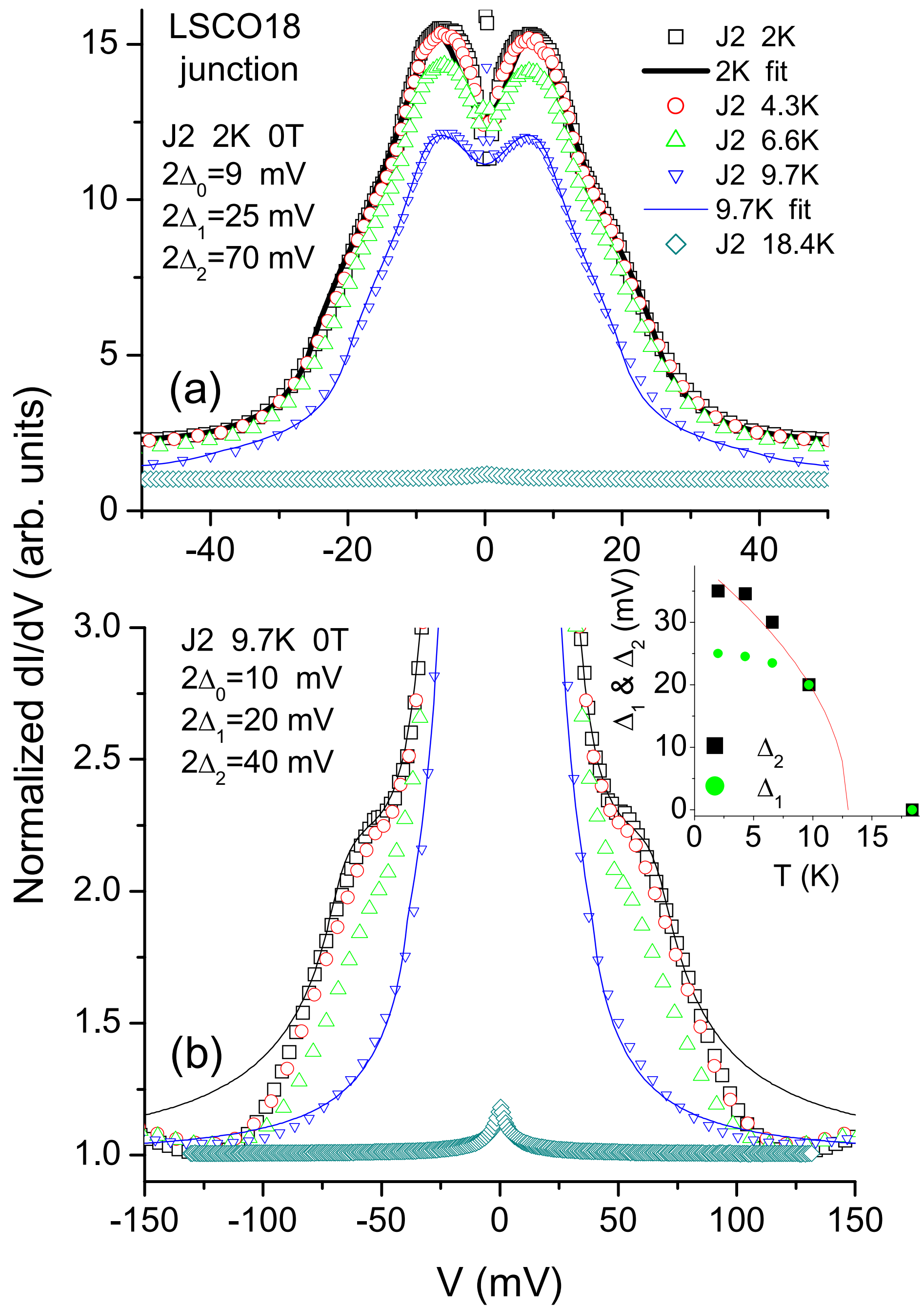


Main contribution from Δ_1 – very transparent! Δ_2 - tunneling

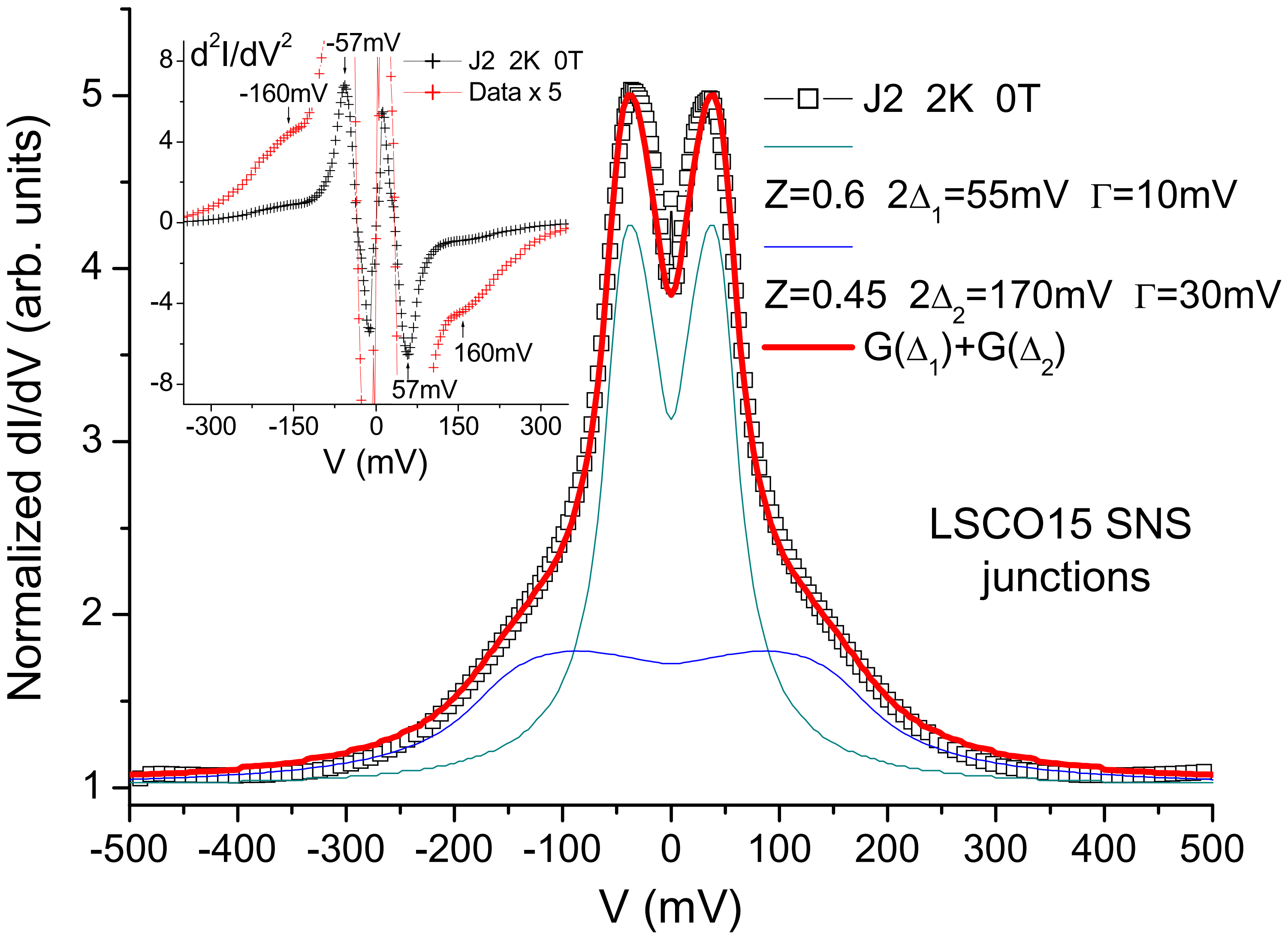
Conductance spectra of LSCO18 – LSCO35 – LSCO18 junction versus temperature

Δ_1 & Δ_2 behave like energy gaps

$$\Delta_2(T) = \Delta_2(0)\sqrt{(T_c - T)/T_c} \;\; fit$$



Conductance spectra of LSCO15 – LSCO35 – LSCO15 junction



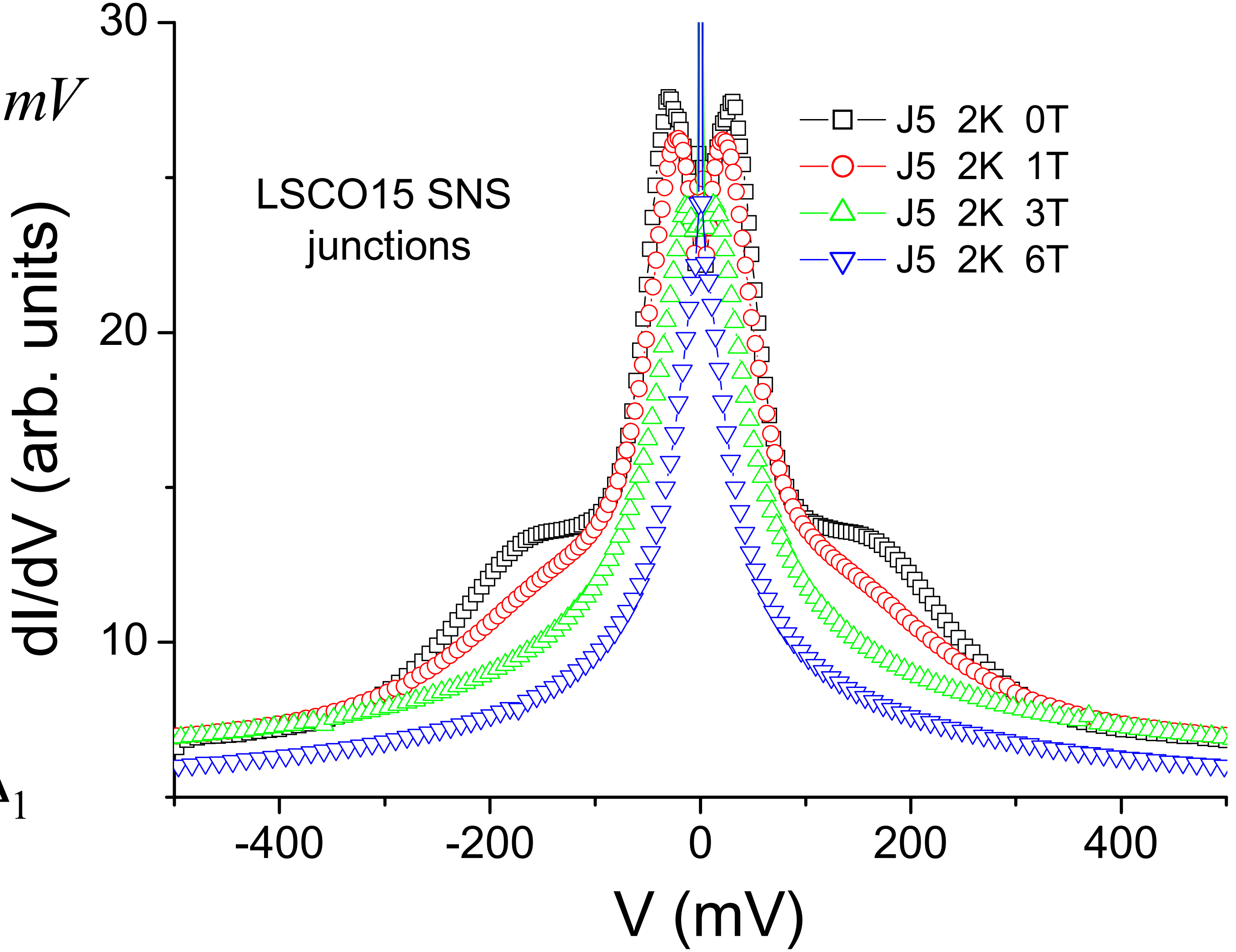
Conductance spectra of LSCO15 – LSCO35 – LSCO15 versus H

$2\Delta_2(2K, 0T) = 220\,mV$

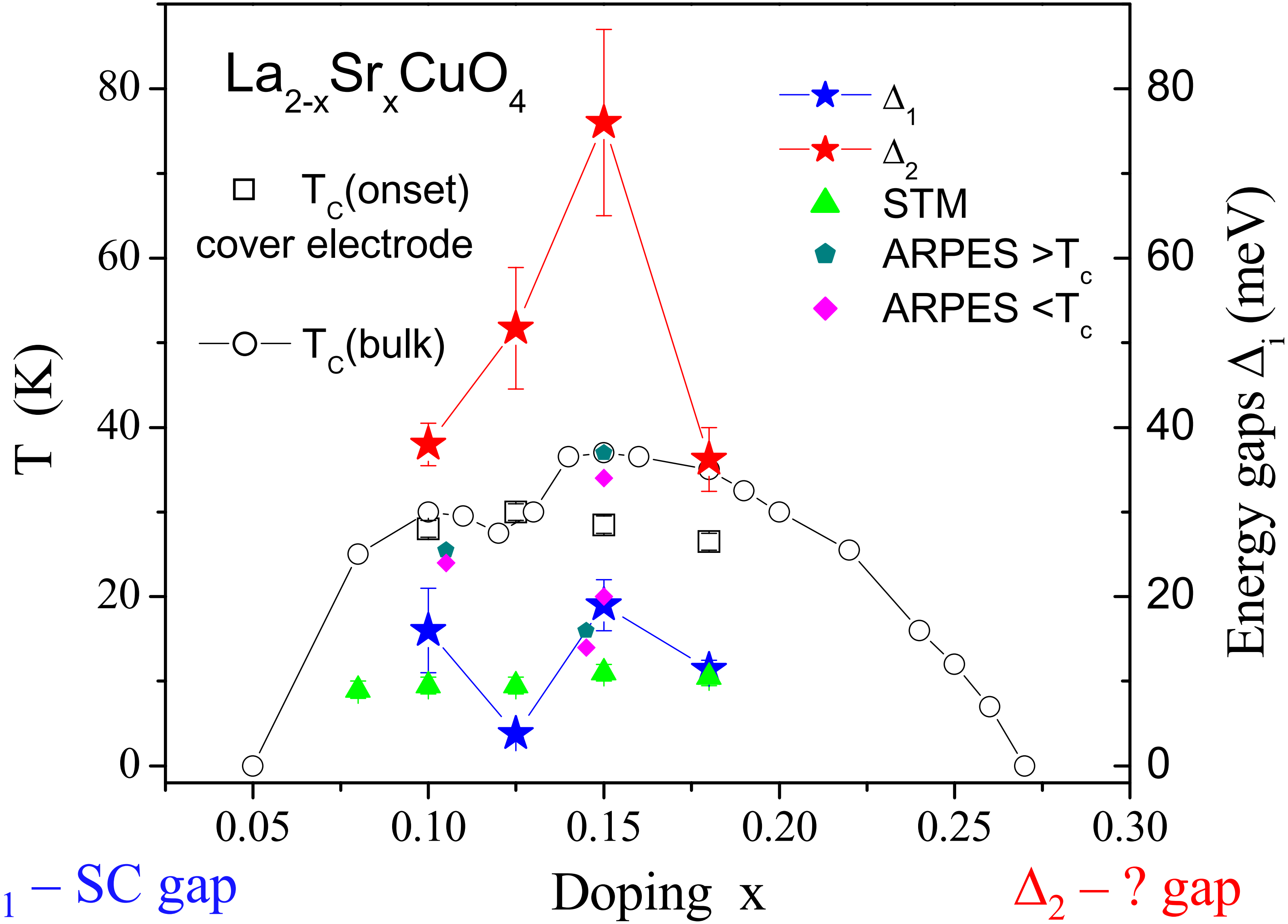
Largest Δ_2 on the wafer

Spread of Δ_2 values

Suppression versus H: Δ_2 faster than Δ_1



The phase diagram of LSCO



Δ_1 – SC gap

Δ_2 – ? gap

STM – Yuli et al., ARPES – Yohsida et al., Shi et al., Terashima et al.

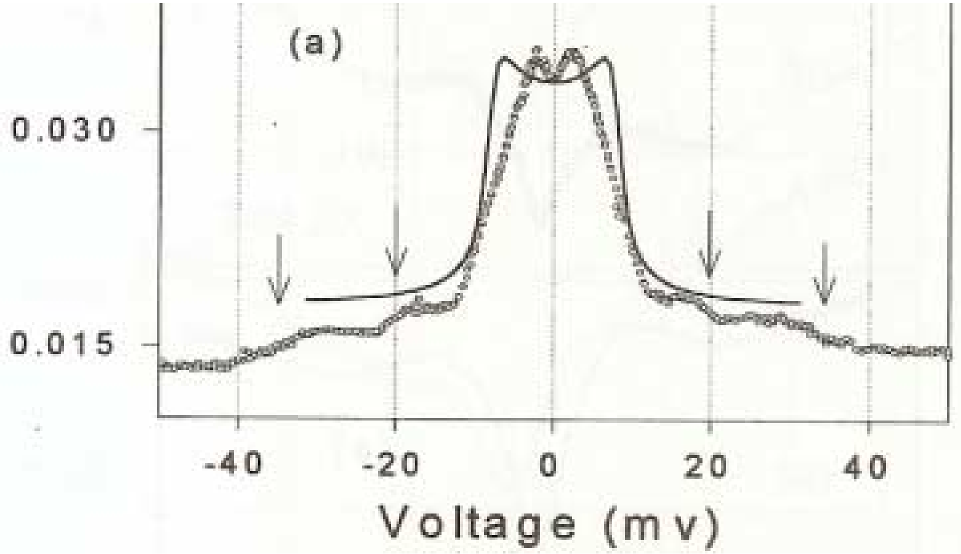
1 - What is the origin of Δ_2 ?

Δ_2 roughly follows the T_c dome – so that it should be related to superconductivity

- Can be due to a background "step down" at $eV = \hbar\omega - \Delta_1$ where $\hbar\omega$ is any excitation such as phonons, bosons, holons etc. If $\Delta_2 = eV$ the excitation $\hbar\omega$ can not be constant versus doping (?)

[Kirtley, inelastic transport, PRB **47**,11379 (1993)]

Achsaf & Deutscher
Coherence in HTSC 1996
(LSCO12, 4.2K)
– attributed high V peaks to Phonons emission thresholds



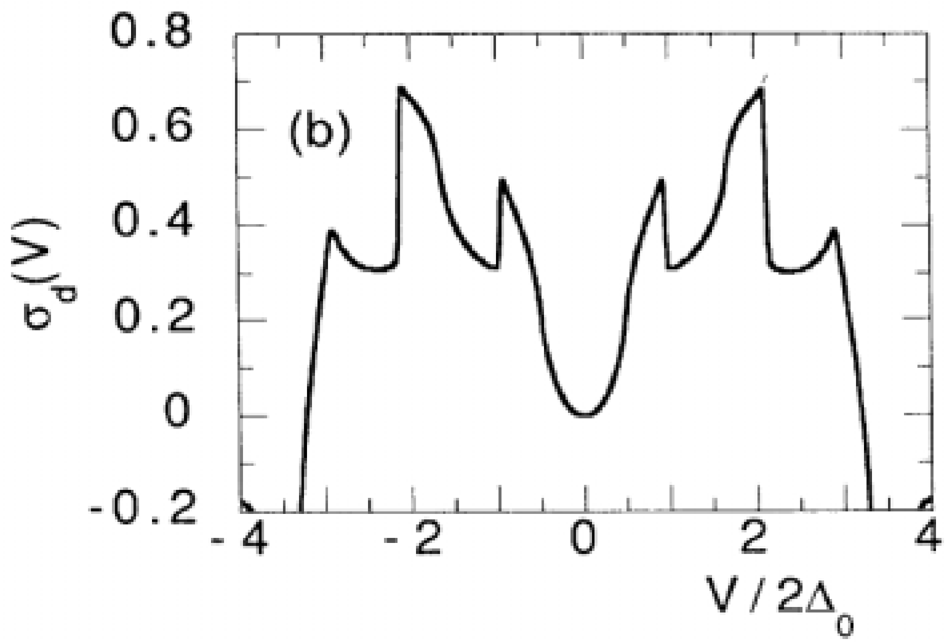
2- What is the origin of Δ_2 ?

- Another possibility is that Δ_2 is connected with the Van Hove singularity (VHS) of 2D LSCO.

Using a tt'J model for a d-wave SC for SIS junctions, Fedro & Koelling, PRB **47**, 14342 (1993) got:

Symmetric spectrum
(But tt't"J gives an asymmetric result)

Also, theory predicts that the gap vs doping is monotonous – unlike our results



3 - What is the origin of Δ_2 ?

Y. Wang & N. P. Ong
PRB **73**, 24510 (2006)→

- Similarity to the Nernst effect at $T > T_c$

- Possibly the same origin: 2K + current = breaking pairs correlations, equivalent to $T > T_c$

- Hence origin in SC-fluctuations or preformed pairs, but scaling is with SC dome, not the pseudogap

PHYSICAL REVIEW B **73**, 024510 (2006)

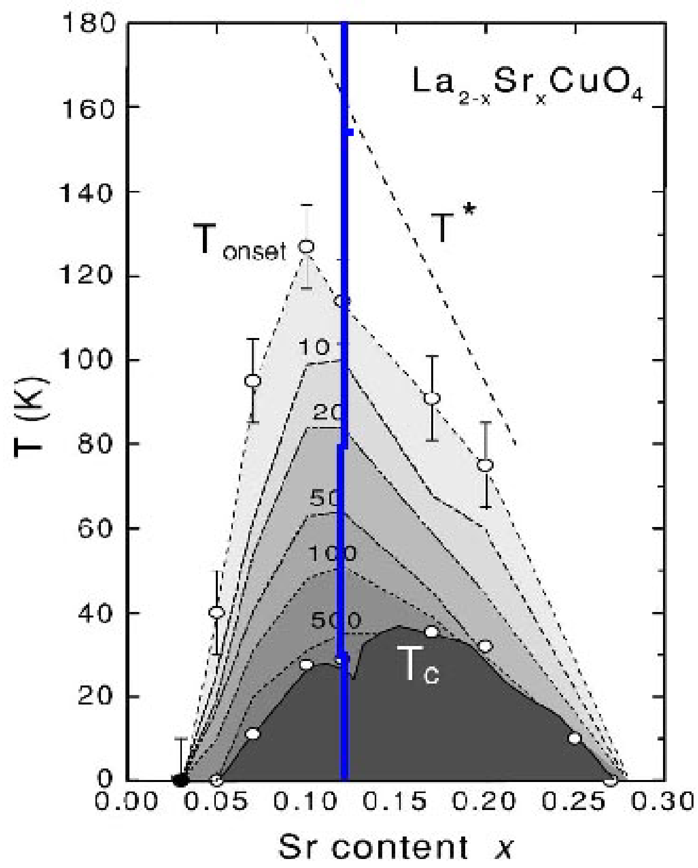


FIG. 20. The phase diagram of LSCO showing the Nernst region between T_c and T_{onset} (numbers on the contour curves indicate the value of the Nernst coefficient ν in nV/KT). The curve of T_{onset} vs x has end points at x=0.03 and x=0.26 and peaks conspicuously near 0.10. The dashed line is T^* estimated from heat-capacity measurements.

4 - What is the origin of Δ_2 ?

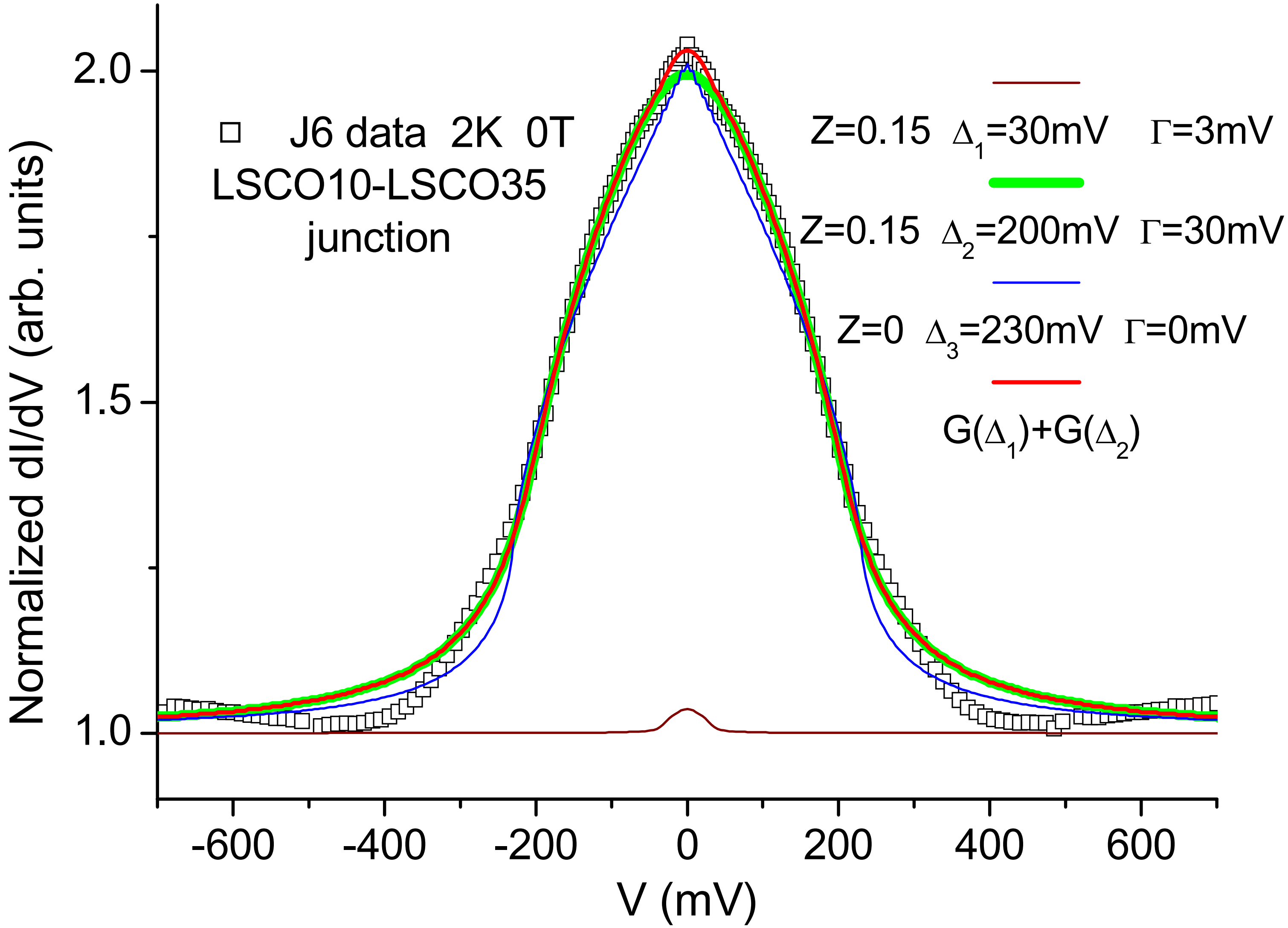
- And finally, why shouldn't Δ_2 be an Andreev gap?
- All the BTK fits for a d-wave SC look OK.
- But this implies the existence of pairs with a large condensation energy of Δ_2

-If so, theory of Δ_2 should account for the

fact that $\dfrac{\Delta_1(x=0.15)}{\Delta_1(x=0.10)} \approx 1$ while $\dfrac{\Delta_2(x=0.15)}{\Delta_2(x=0.10)} \approx 2$

- Well, theoretical modeling is certainly needed here.

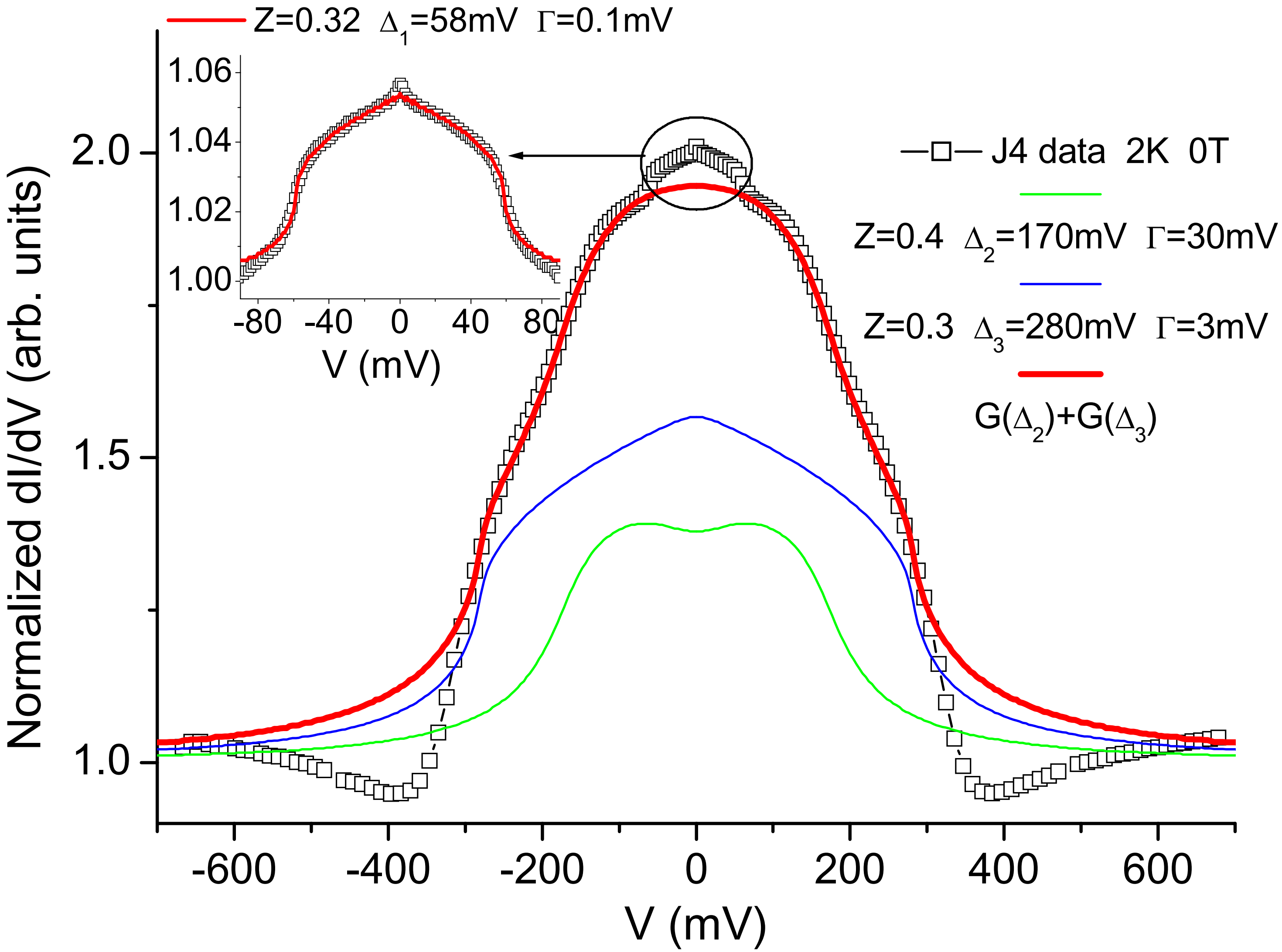
Some S-N results of LSCO10-35 RJ #1



Unphysically large Δ_i values

Will show solution later on

and more S-N results of LSCO10-35 RJ #2



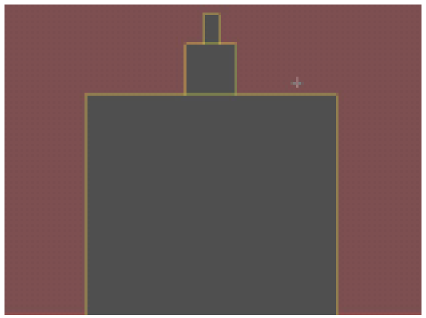
Large "gap" values due to lead resistance thus needs to subtract it

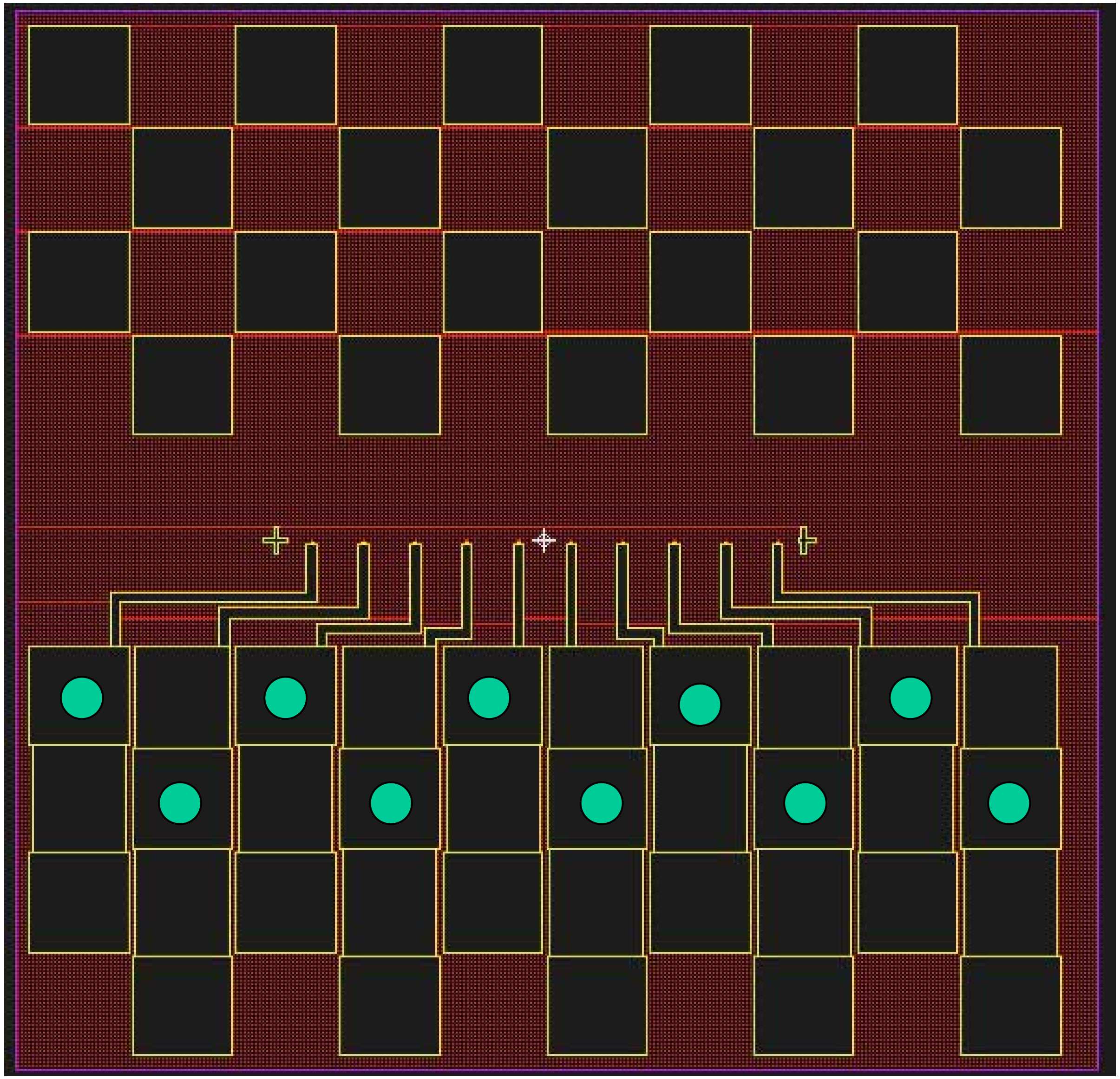
Cover electrode mask – leads resistance in S-N RJ

Base elect. is
a mirror image
but SC

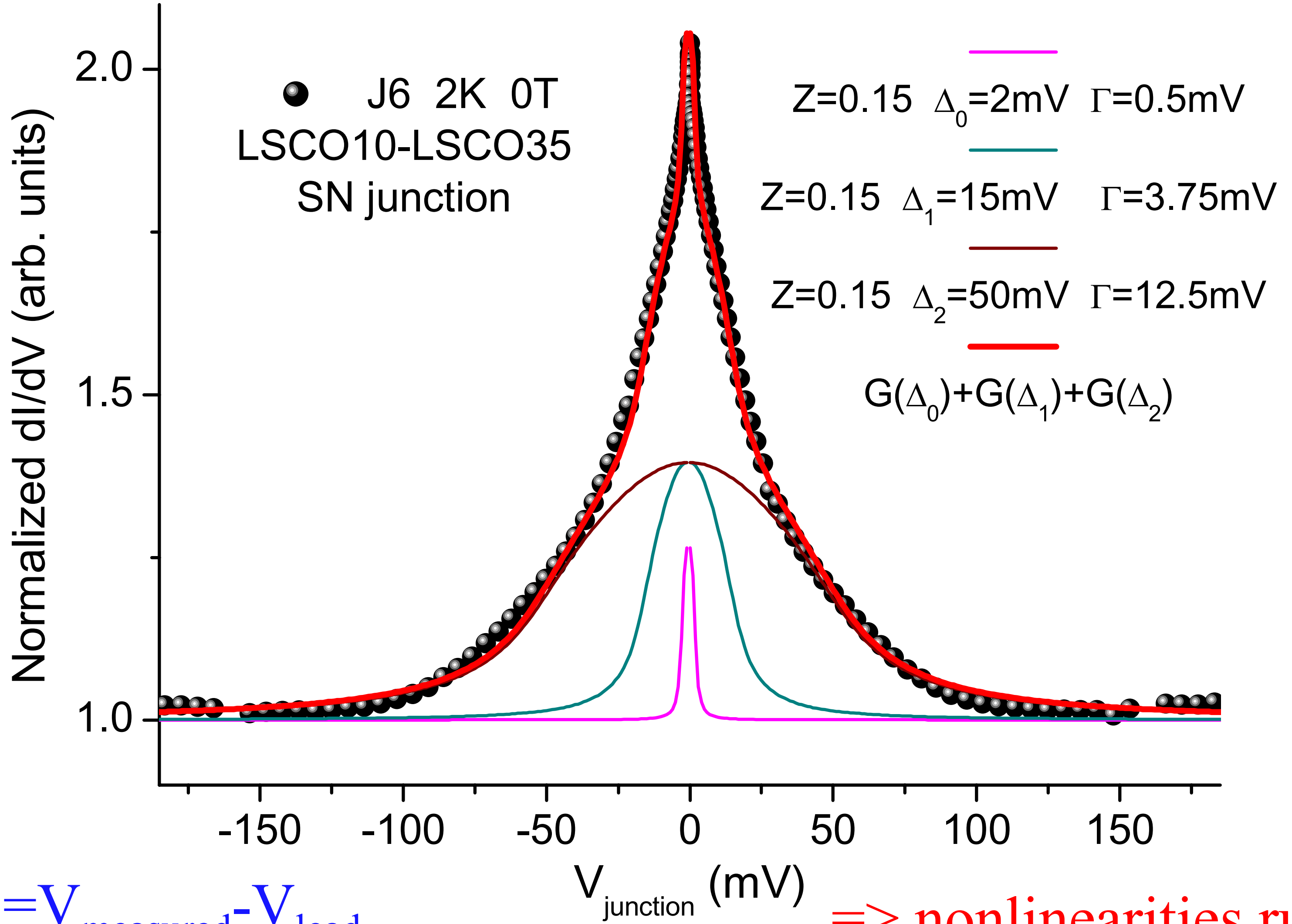
N - leads →

Voltage
contacts →





Calibrated S-N results of LSCO10-35 RJ #1



$V_{junction}=V_{measured}-V_{lead}$

=> nonlinearities ruled out

This should be compared with $2\Delta_i$ of 2, 24-30 & 70-88 mV (SNS)

Conclusions

- For reliable energy scales, have to use S-N-S rather than S-N junctions
- Both Δ_1 & Δ_2 mimic the SC dome vs doping
- Δ_1 is the superconducting energy gap
- Δ_2 can be a new Andreev-like energy scale
- Theoretical modeling of Δ_2 is needed