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Evidence for D-wave to S-wave Gap Symmetry Conversion in Ca and Ce Doped YBCO

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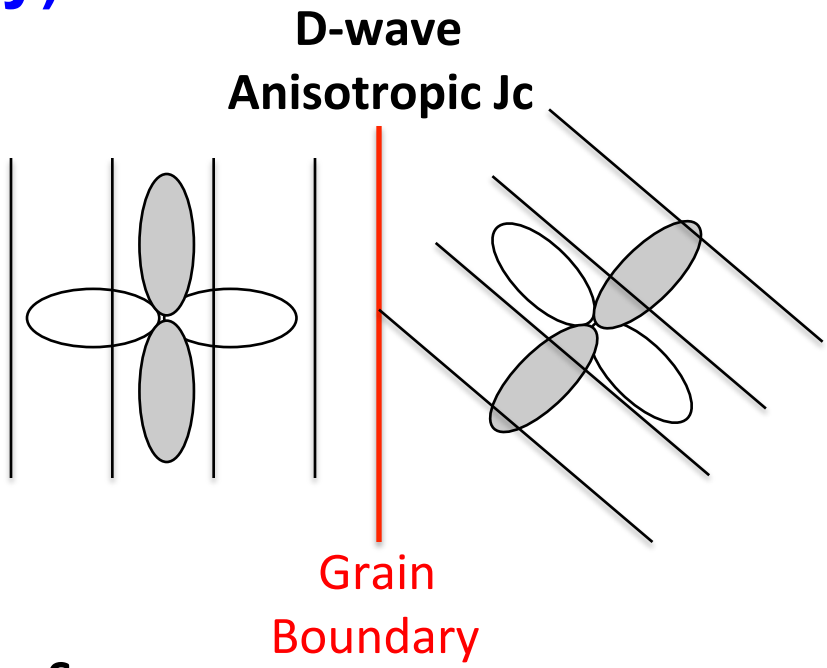
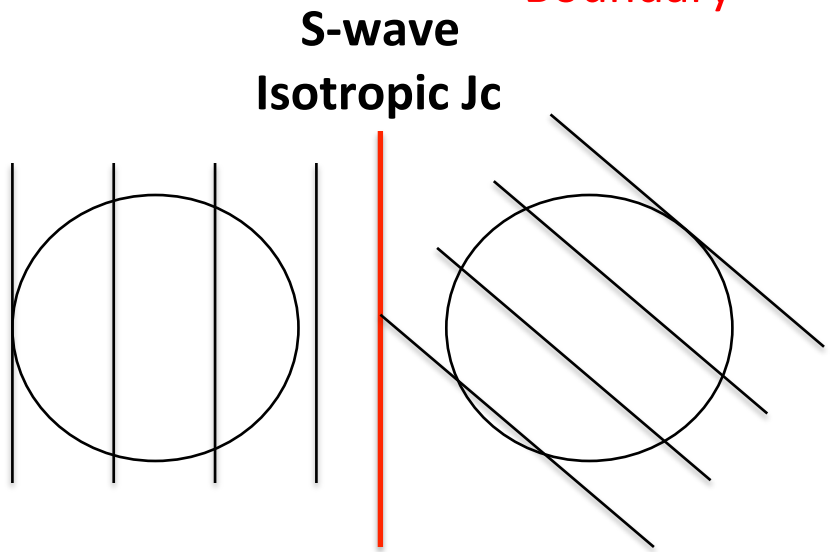
The YBCO D-wave Gap Symmetry Problem: Low Jc (Current Density) Across Grains

Mis-alignment of grains reduces Jc

➔ "Single-Crystal" tapes with < 4 degrees mismatch

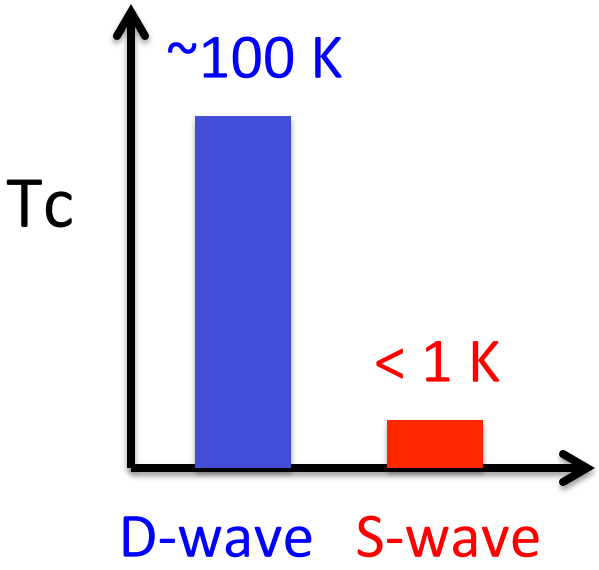


An S-wave gap is desired

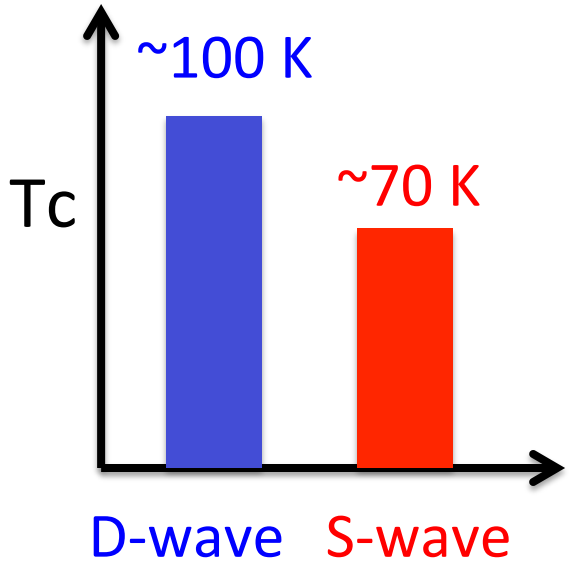


The Tc of a D-wave YBCO Phase versus an S-wave YBCO Phase

Most Theorist's "Guess"

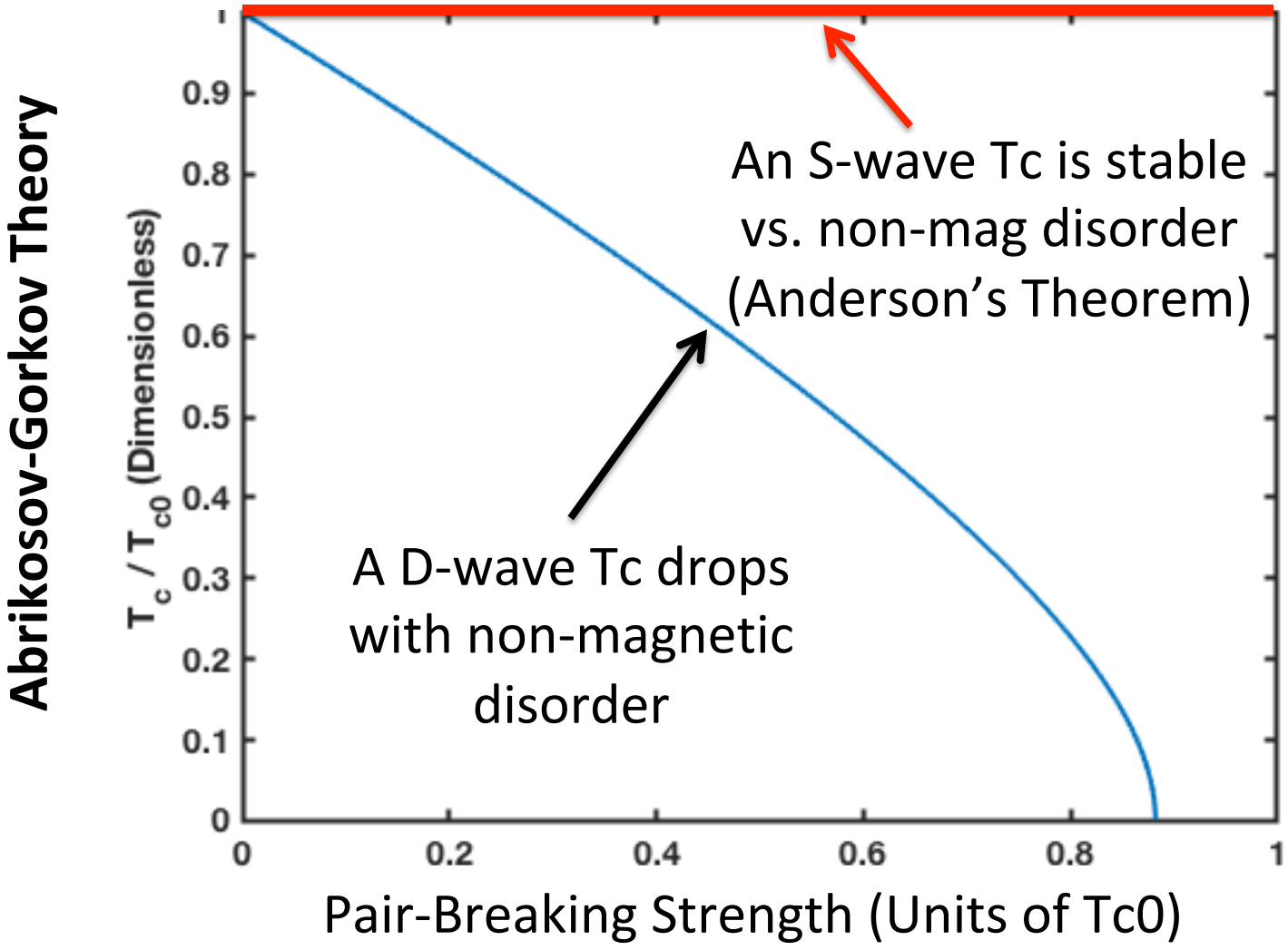


What We Believe



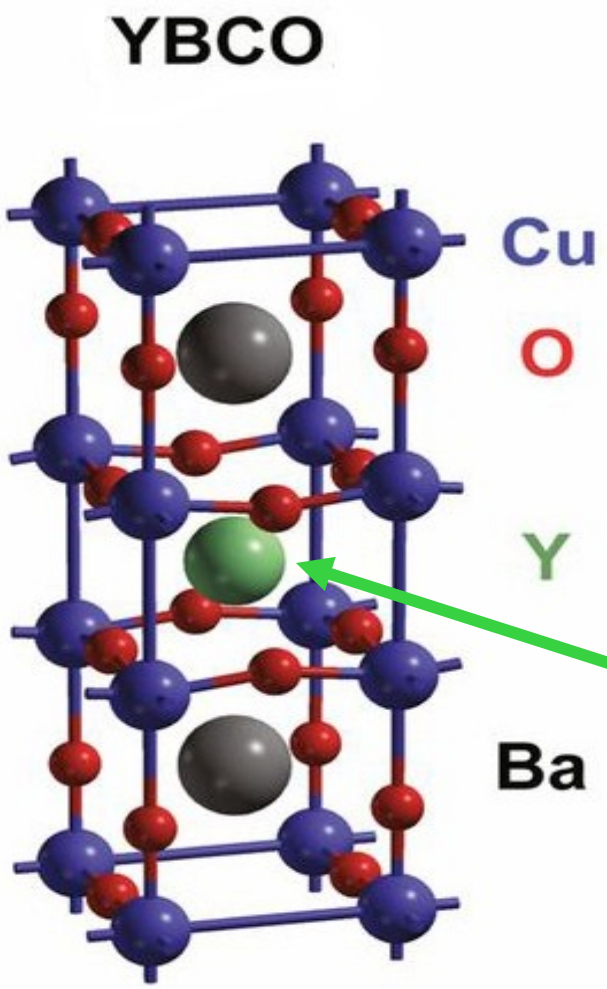
We try to "Push Down" the D-wave Tc in order to expose the S-wave phase

Pushing the D-wave Tc Down by "Pair-Breaking" with Non-Magnetic Disorder



Hence, we add Non-Magnetic Disorder to YBCO

Add Non-Magnetic Ca (+2) and Ce (+4) Disorder

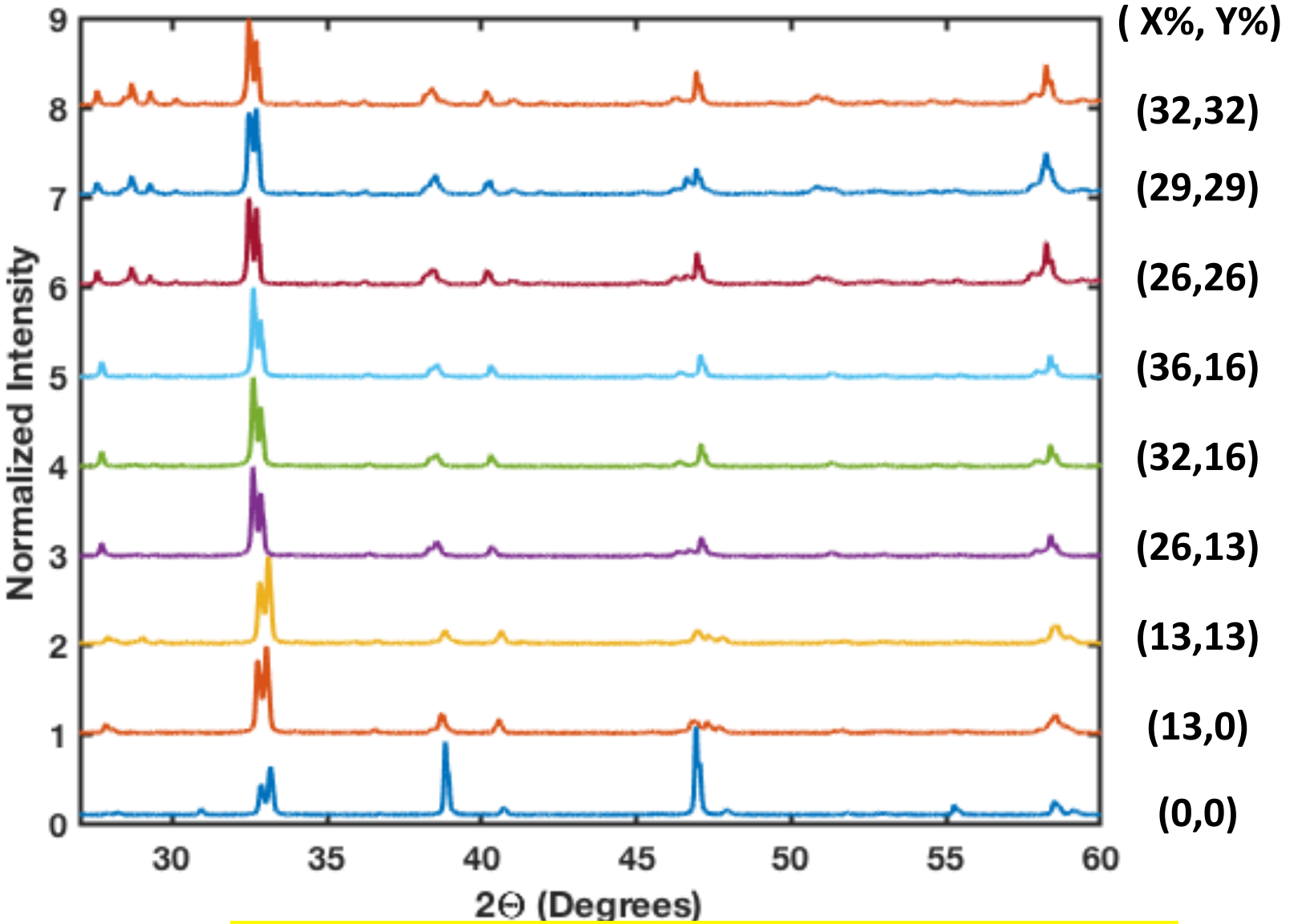


Substitute Ca (+2) and Ce (+4) for Y (+3) atoms

$(Y_{1-x-y}Ca_xCe_y)Ba_2Cu_3O_{7-\delta}$

Further discussion → Tahir-Kheli, arXiv 1702.05001

X-ray Diffraction (XRD) on $(Y_{1-x-y}Ca_xCe_y)Ba_2Cu_3O_{7-\delta}$



Synthesized by Tomas Hlasek,
CAN SUPERCONDUCTORS s.r.o., Czech Republic

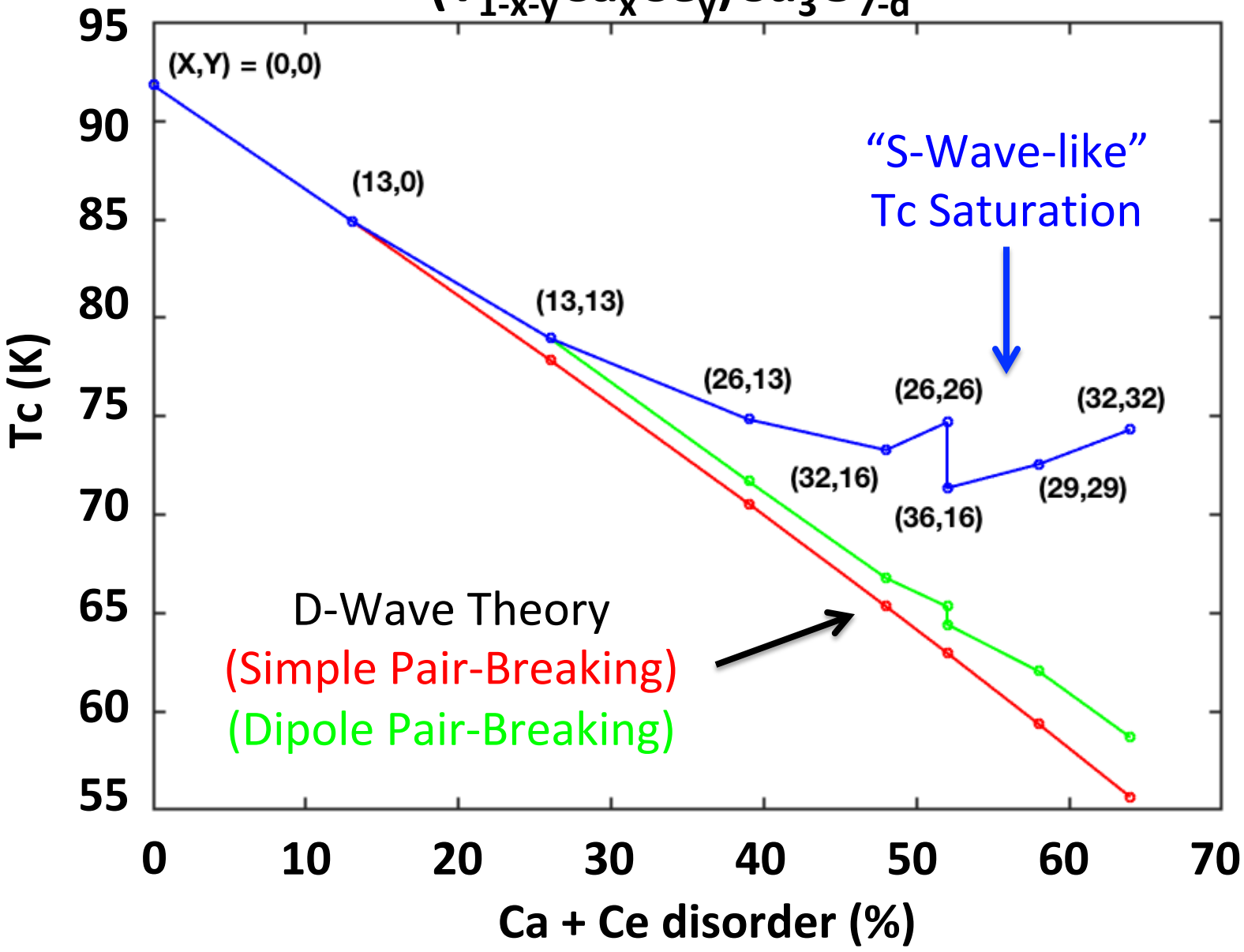
Good Single-Phase Poly-Crystalline Samples

D-Wave and S-Wave: The Three Differences

Experiment	D-Wave	S-Wave
Gap Magnitude Tc vs. Ca and Ce Disorder	Tc falls with increasing non-magnetic disorder	Tc weakly dependent on non-magnetic disorder
Gap Phase Point-Contact Andreev-Reflection (PCAR)	Has a Zero-Bias Conductance Peak (ZBCP)	No ZBCP
Gap Nodes Penetration Depth	Linear T dependence	~T^2 dependence

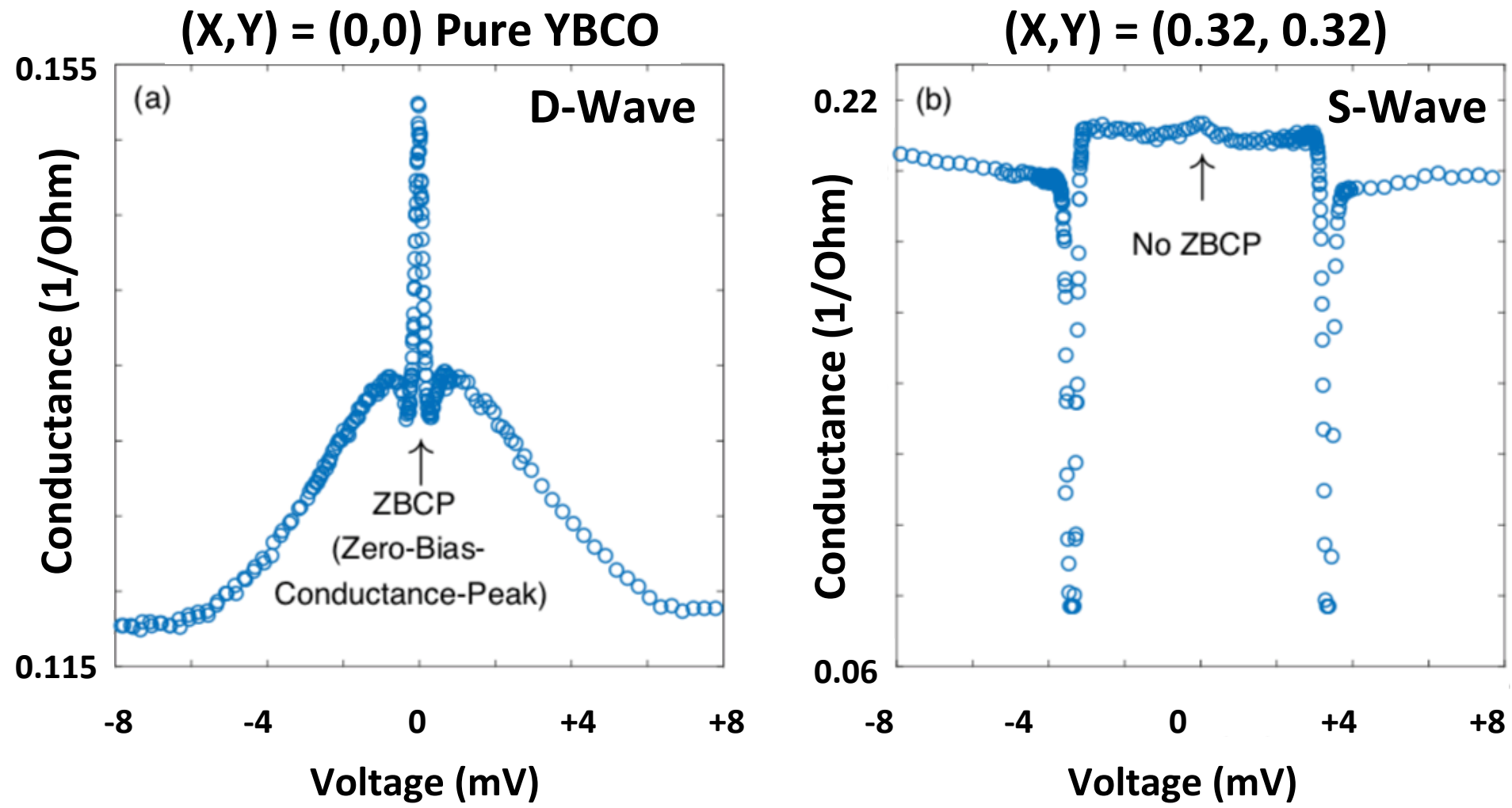
Expt #1: Gap Magnitude, Tc vs. Ca and Ce Disorder

$(Y_{1-x-y}Ca_xCe_y)Cu_3O_{7-d}$



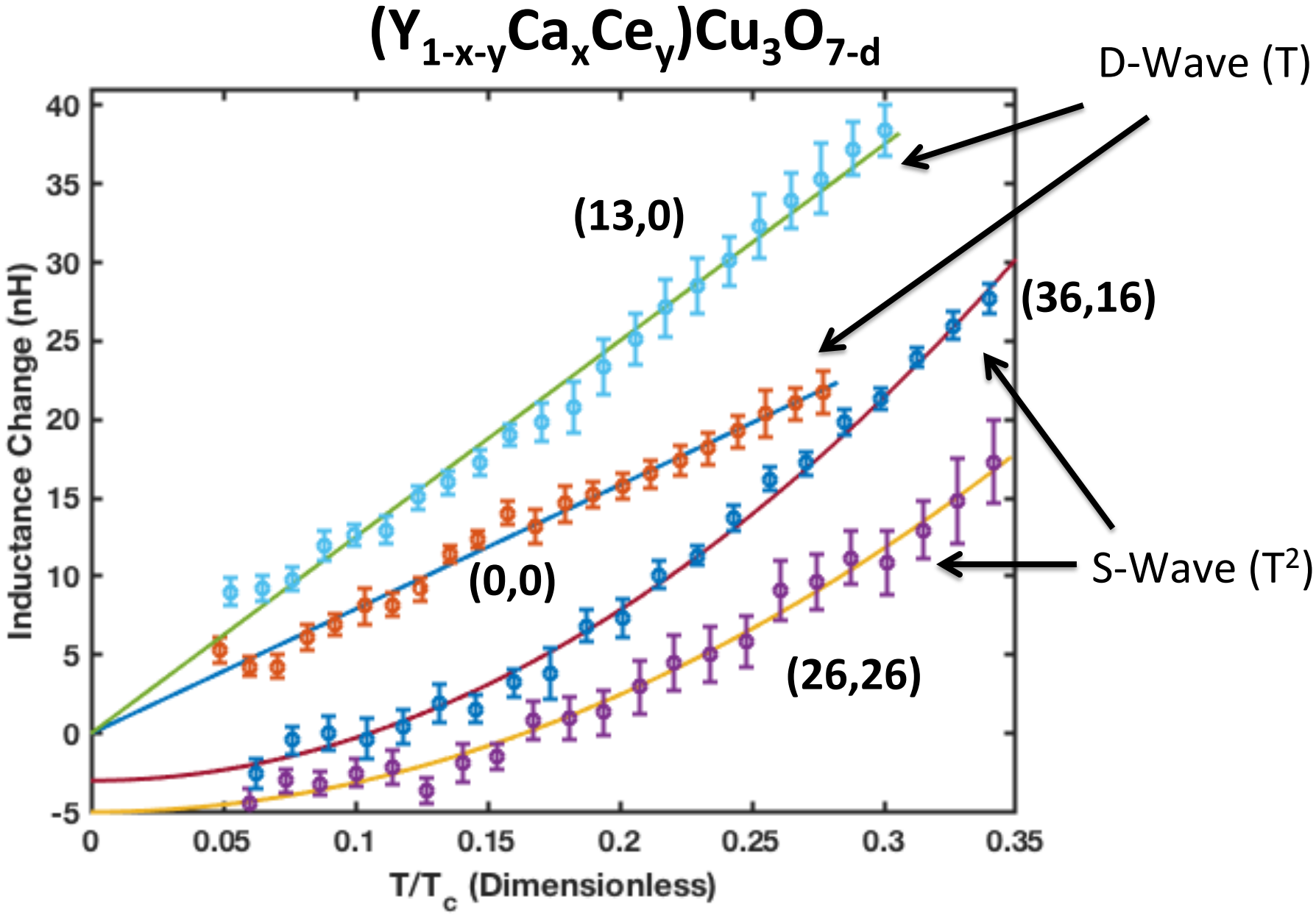
Expt #2: Gap Phase, PCAR (ZBCP Search)

$(Y_{1-x-y}Ca_xCe_y)Cu_3O_{7-d}$



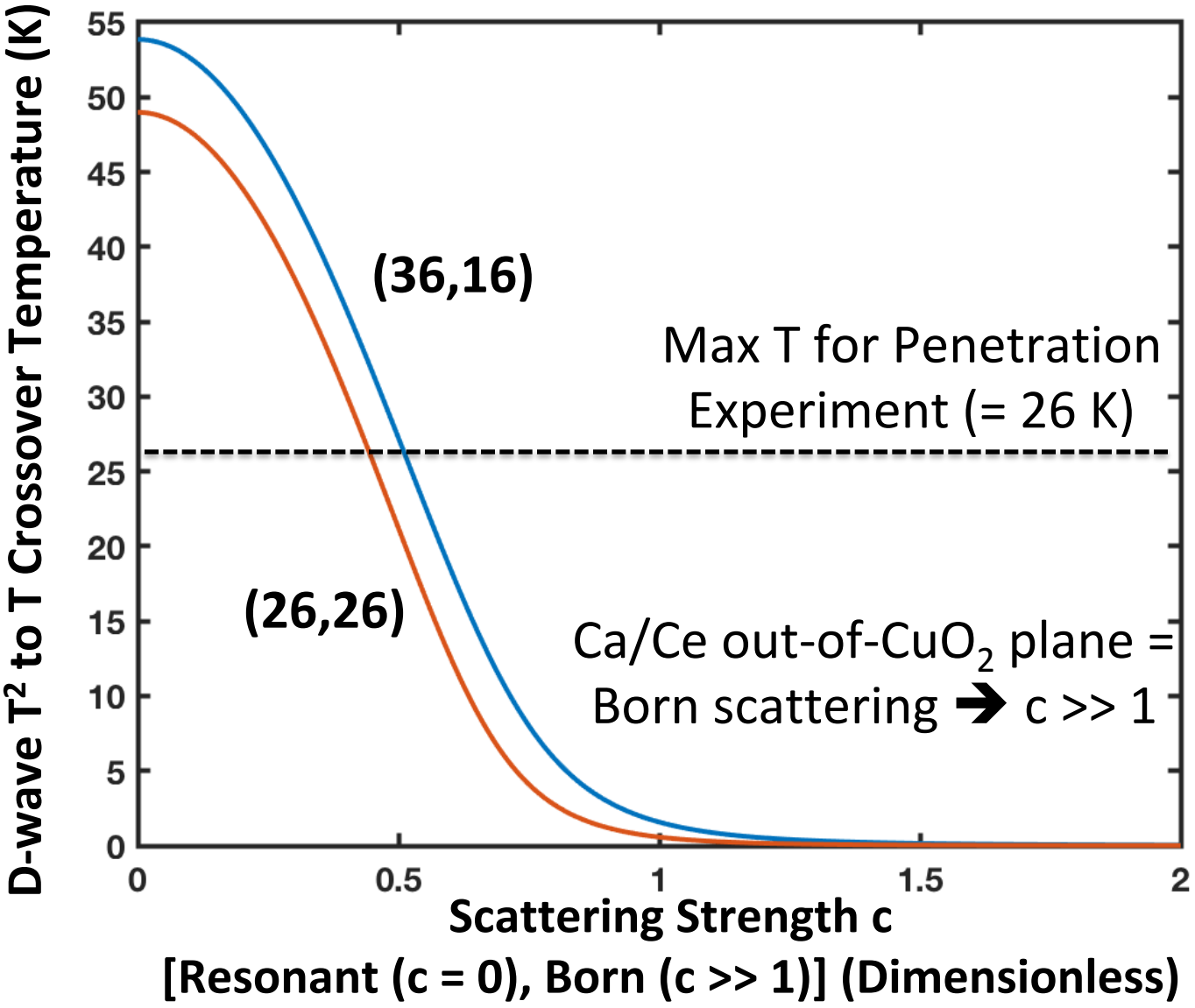
Experiment by Mike Osofsky, Naval Research Lab (NRL)

Expt #3: Gap Nodes, Penetration Depth vs. Temperature



A D-wave + Impurity Scattering Does NOT Explain the T^2

Peter Hirschfeld and Nigel Goldenfeld, PRB **48**, 4219 (1993)



What We Found

Experiment	D-Wave	S-Wave	Result
Gap Magnitude Tc vs. Ca and Ce Disorder	Tc falls with increasing non-magnetic disorder	Tc weakly dependent on non-magnetic disorder	S-Wave
Gap Phase Point-Contact Andreev-Reflection (PCAR)	Has a Zero-Bias Conductance Peak (ZBCP)	No ZBCP	S-Wave
Gap Nodes Penetration Depth	Linear T dependence	$\sim T^2$ dependence	S-Wave

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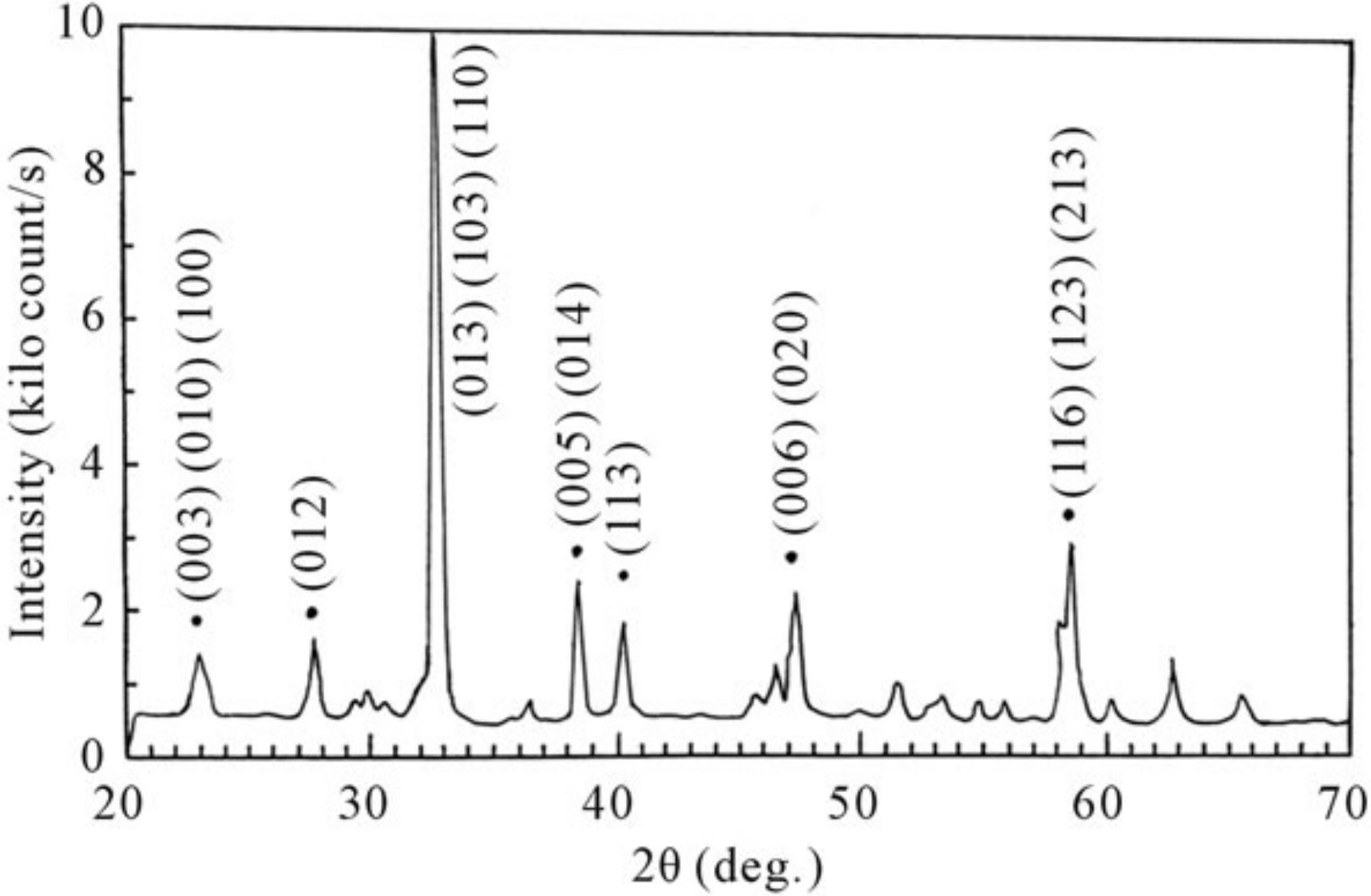
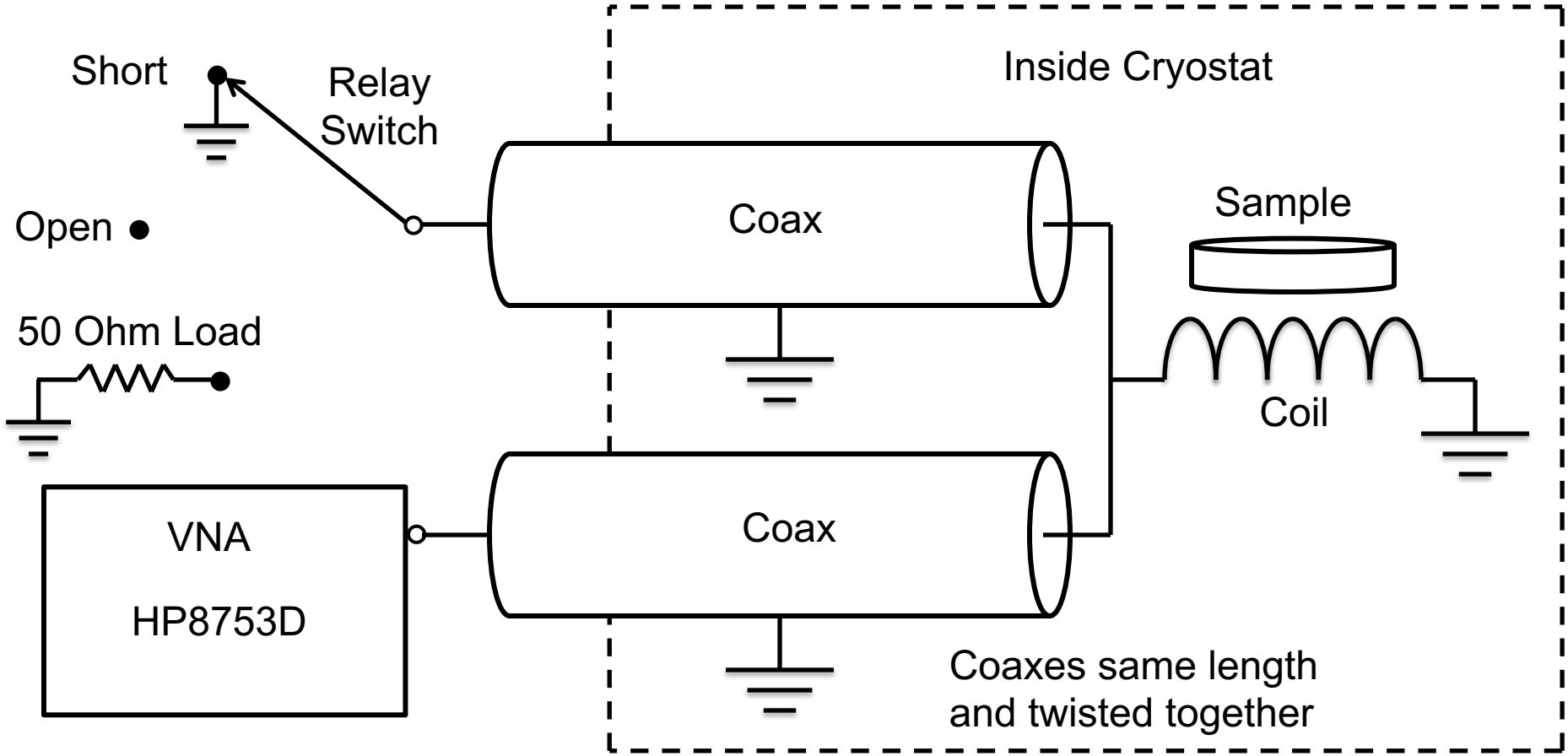
KILLER APP = FUSION MAGNETS

Wire can be made by the same production process used for Nb_3Sn

	(0.26, 0.13)		(0.32, 0.16)		(0.36, 0.16)	
Element	Expected	Refined	Expected	Refined	Expected	Refined
Y	0.61	0.61	0.52	0.52	0.48	0.48
Ca	0.26	0.255(4)	0.32	0.300(4)	0.36	0.348(3)
Ce	0.13	0.135(4)	0.16	0.180(4)	0.16	0.172(3)
Ba	2	2	2	2	2	2
Cu	3	3	3	3	3	3
O	7	7	7	7	7	7

	Phase Composition (weight %)		
	(0.26, 0.13)	(0.32, 0.16)	(0.36, 0.16)
$(YCaCe)Ba_2Cu_3O_{7-\delta}$	98.3(6)	98.3(6)	97.1(5)
$BaCuO_2$	1.66(6)	1.67(6)	2.85(5)


Intensity (kilo count/s)
10
8
6
4
2
0
20
30
40
50
60
70
2θ (deg.)
(003) (010) (100)
(012)
(013) (103) (110)
(005) (014)
(113)
(006) (020)
(116) (123) (213)


Short
Relay
Switch
Inside Cryostat
Open
Coax
Sample
50 Ohm Load
Coil
VNA
HP8753D
Coax
Coaxes same length
and twisted together