Challenging experiments for high-T_c superconductors

Kazuyoshi Yamada
WPI, Tohoku University

Final goal of the high-T_c research is to make clear answers to the following questions

What is the mechanism ?

How to lift up T_c ?

My task here is to propose challenging experiments towards the final goal
"Fish story(まゆつば話)" will be acceptable and better than no proposal

Three fundamental issues related with the mechanism

1) How do Mott insulators become metals by dilute carrier doping ?

doping-induced metal-insulator transition

2) How do the doped metals become superconductors in undedoped region?

pseudogap state

3) How do the superconductors degrade by overdoping?

doping dependence of pairing interaction

Search and study metallic antiferromagnets in dilute doped cuprates

Compare with insulating antiferromagnets induced by carrier localization

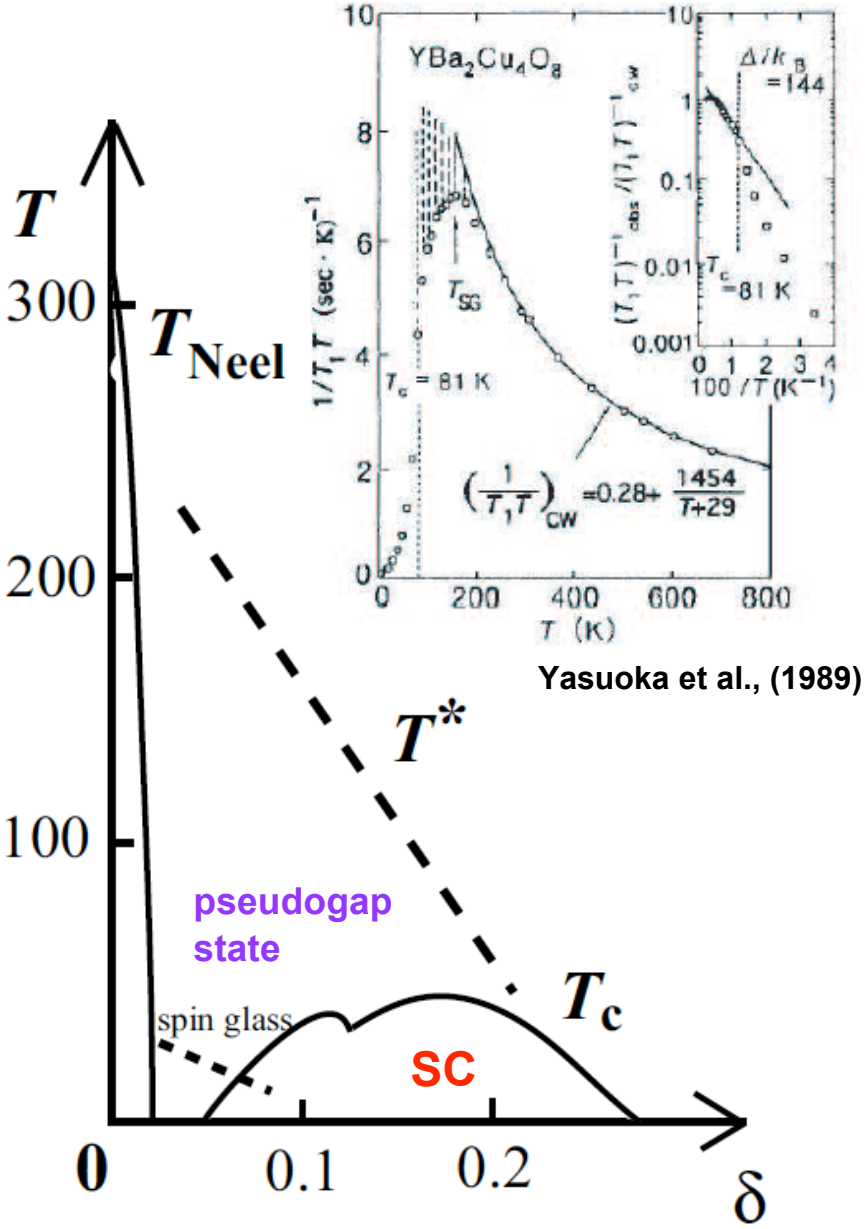
polarization analysis of spin fluctuaion

Search for dynamical vortexes in pseudogap state

polarized neutron small angle scattering

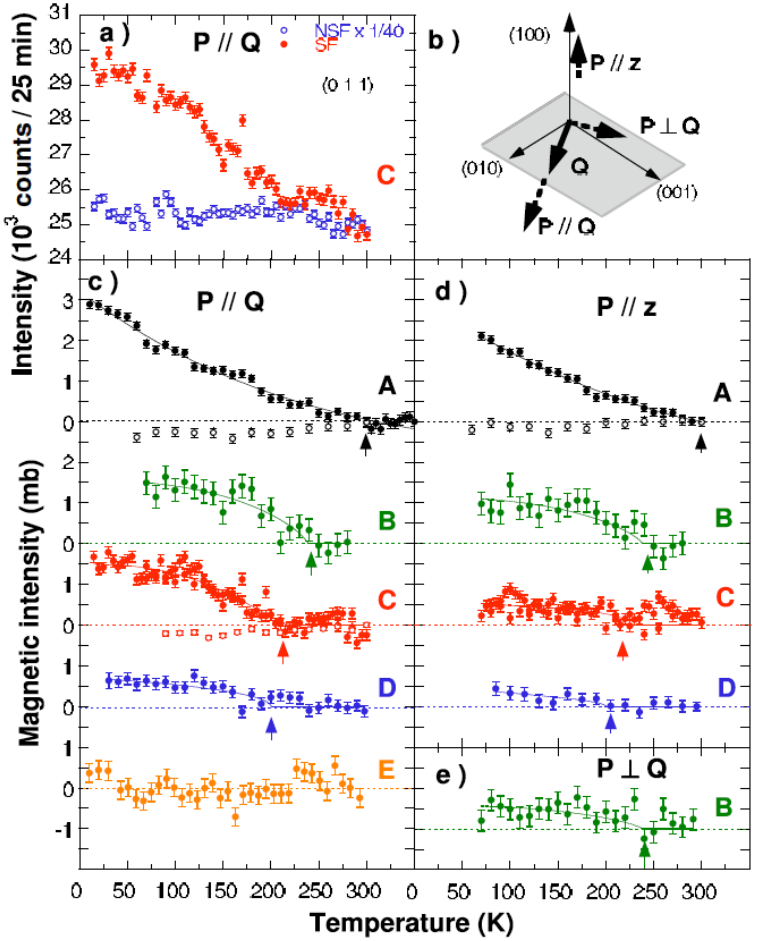
Determine orbital character of doped carriers in overdoped region

What happens in the pseudogap (PG) state ?



Yasuoka et al., (1989)

(I) magnetic order below T*
induced by spontaneous circular current?

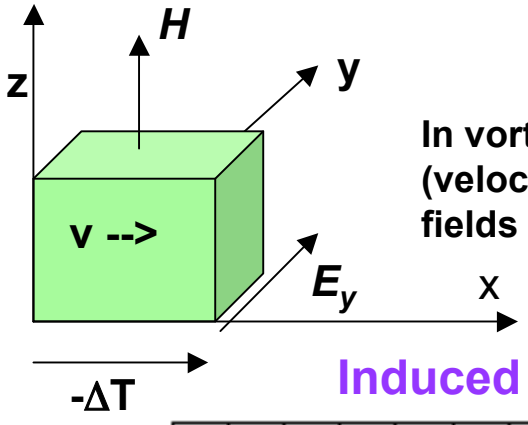


B. Fauqué et al., PRL96 (2006)

(II) Superconducting paring fluctuation below T* ?

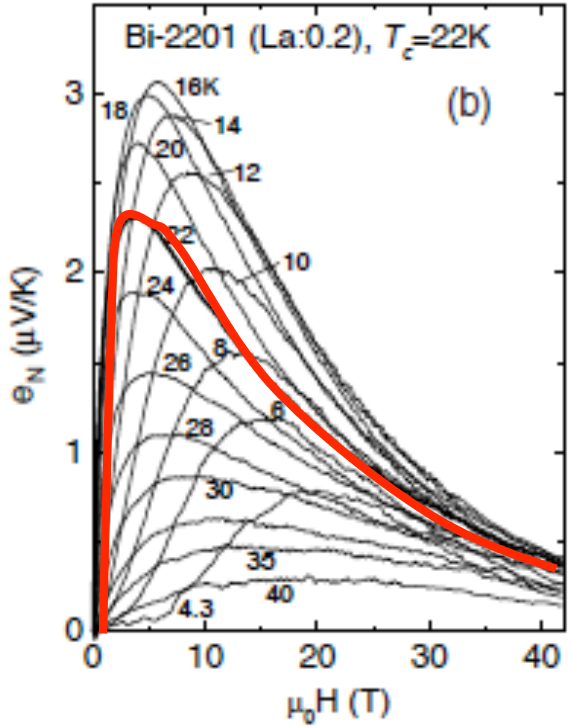
Nernst and diamagnetic signal above T_c

Lu Li et al., cond-mat 0611731



In vortex liquid phase, vortex flow (velocity *v*) occurs under magnetic fields towards cooler region:

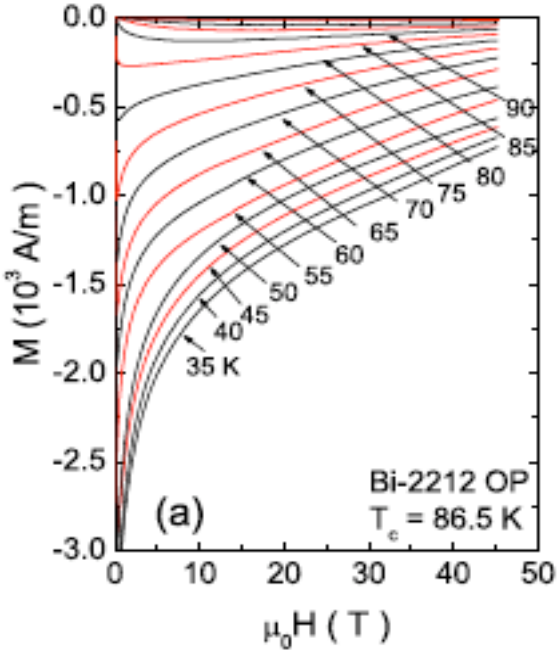
Induced electric field $E=Bxv$

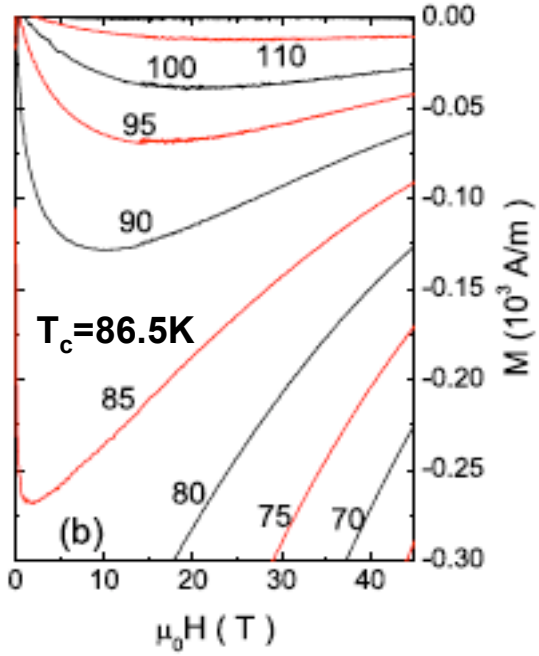


Nernst signal

$$e_N = E_y / |\Delta T|$$

diamagnetism above T_c

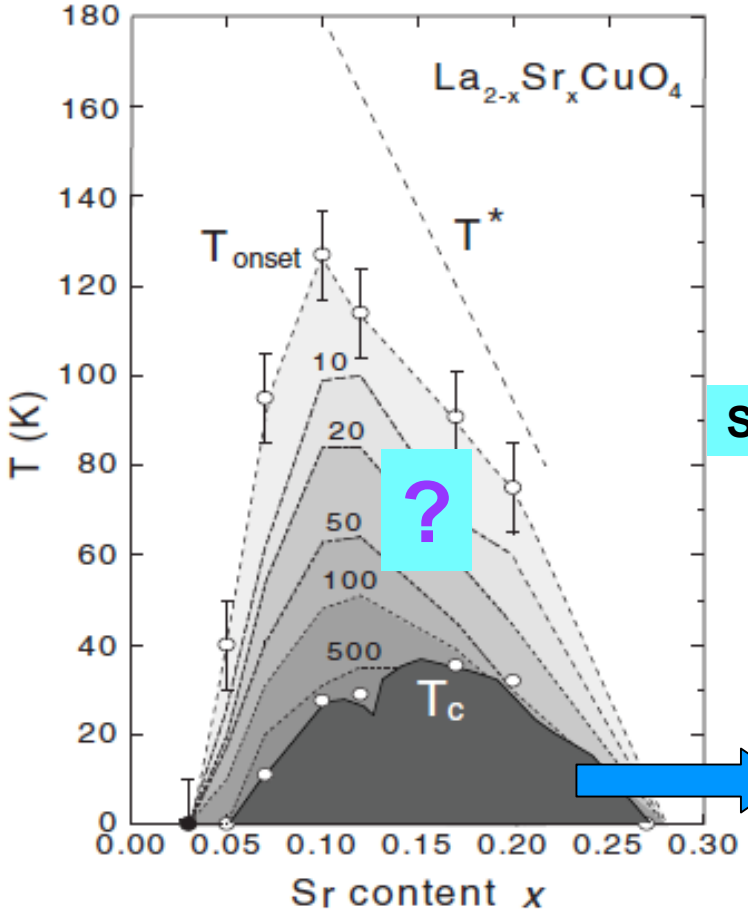


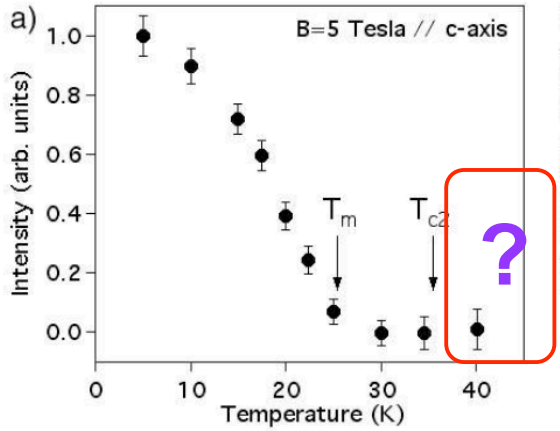


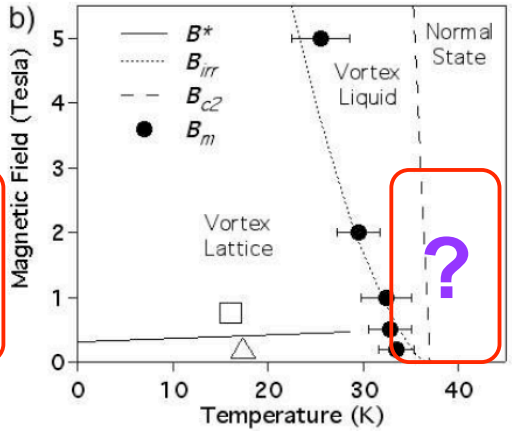
How to obtain direct evidence of vortex-like signal and its spatial correlation above T_c ?

Proposed experiment **Polarized small angle neutron scattering**

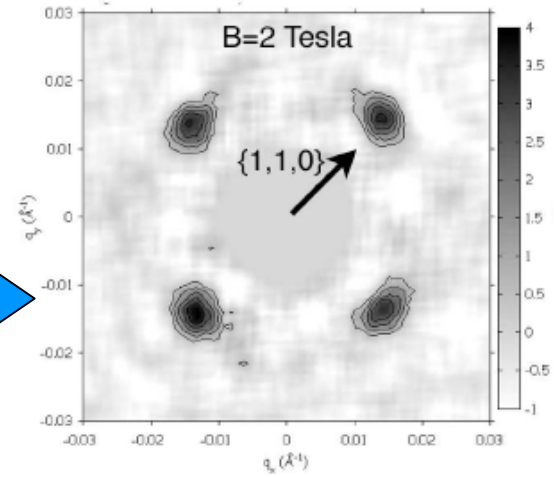
T_{onset} : onset temperature of Nernst signal







Small angle neutron scattering



vortex lattice(crystal)

vortex powder(powder like)

vortex liquid(liquid like)

Lu Li et al., cond-mat 0611731

R. GILARDI, S. STREULE and J. MESOT

dynamical vortex?

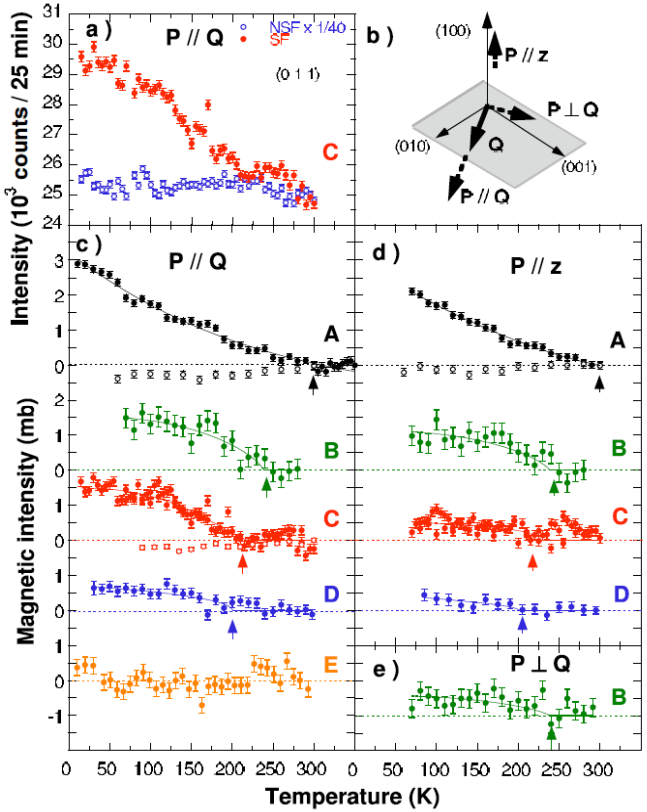
A fish story ?

How to merge two phenomena ?

Proposed experiment

Study magnetic field dependence of the magnetic order
-----> Collapse into the vortex-like state ????

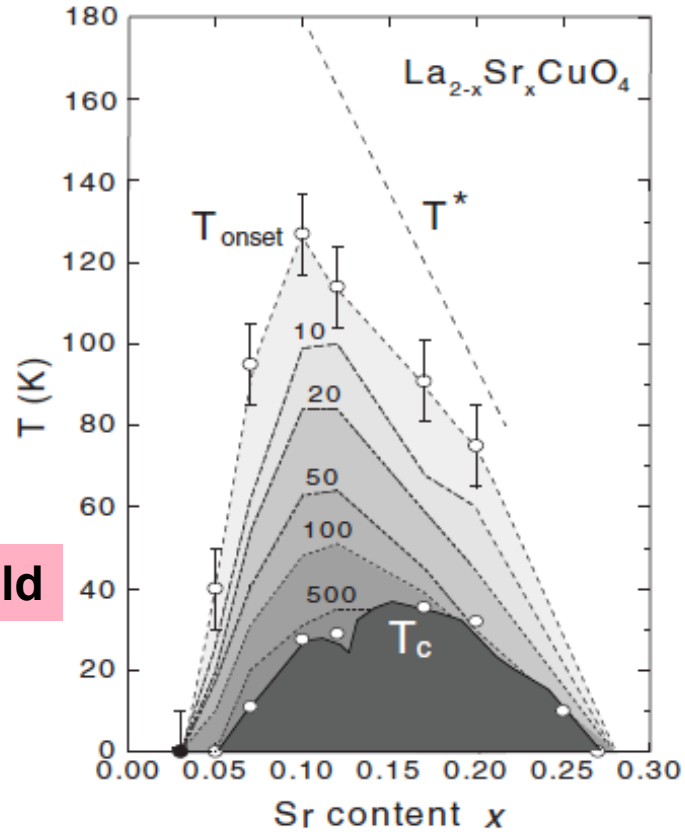
(I) Magnetic order ?



?

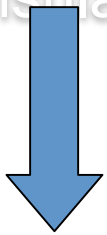
Magnetic field

(II) Superconducting fluctuation ?



1) How do Mott insulators become metals by dilute carriers doping ?

doping-induced metal-insulator transition

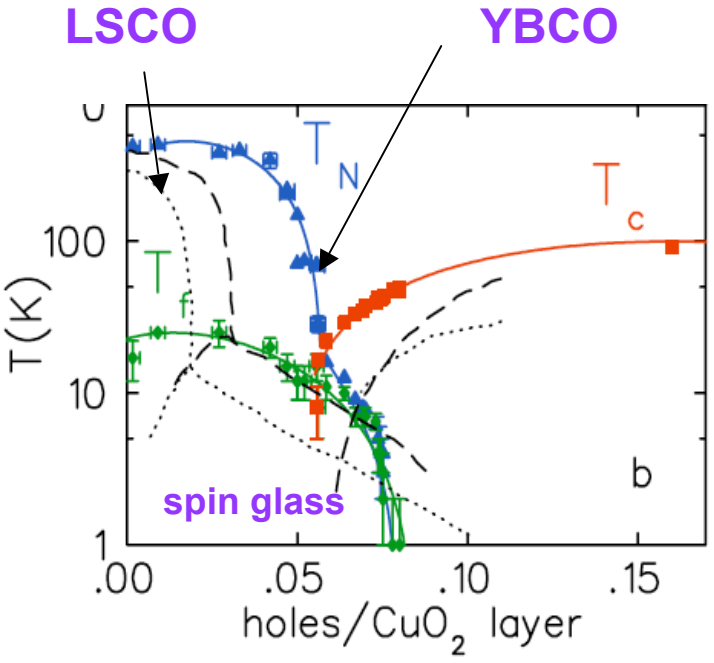


Origin of material dependence of phase diagram

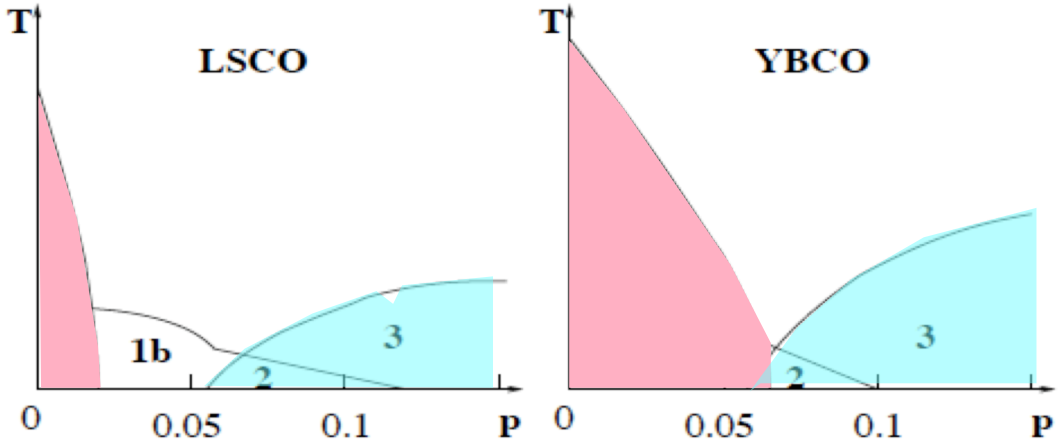
(a professional version of fish story)

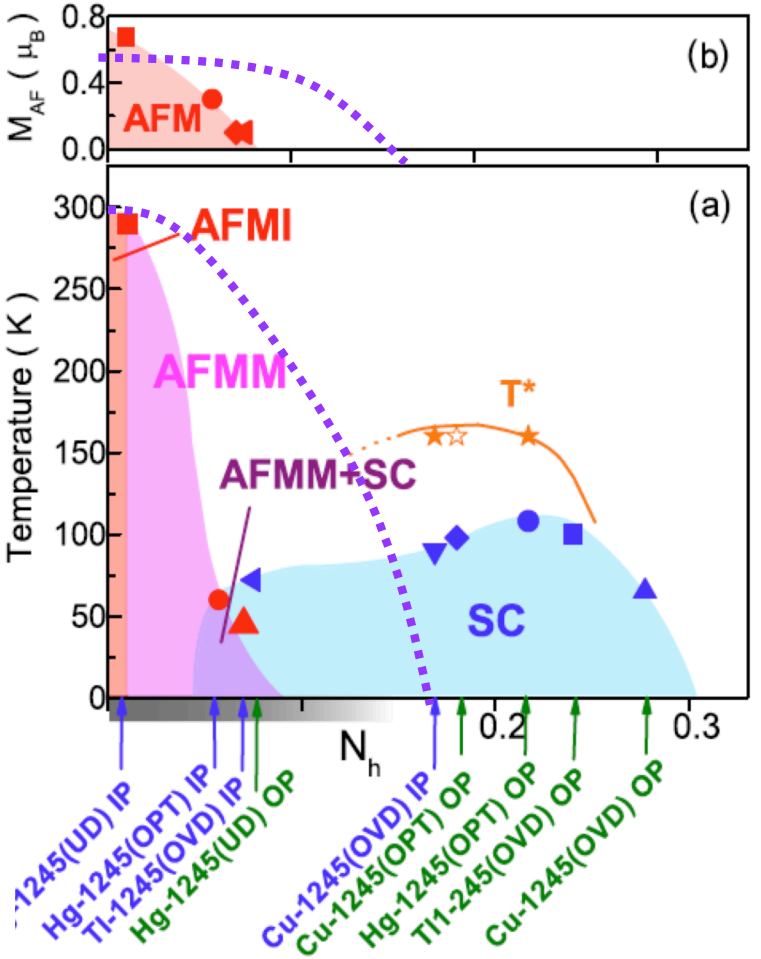
Material dependence of phase

How to obtain unified picture ?



Sanna et al., PRL 93('04)



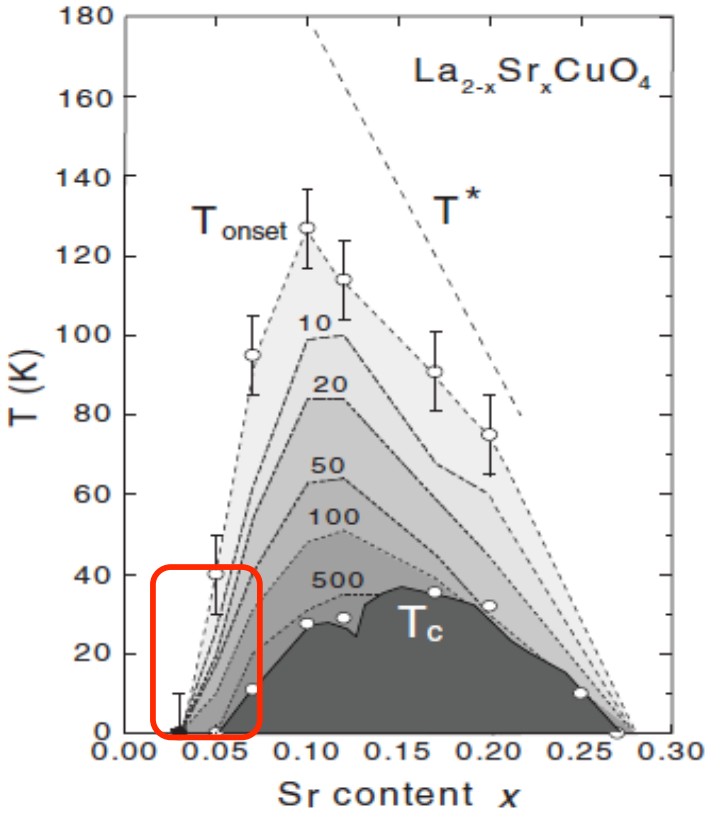


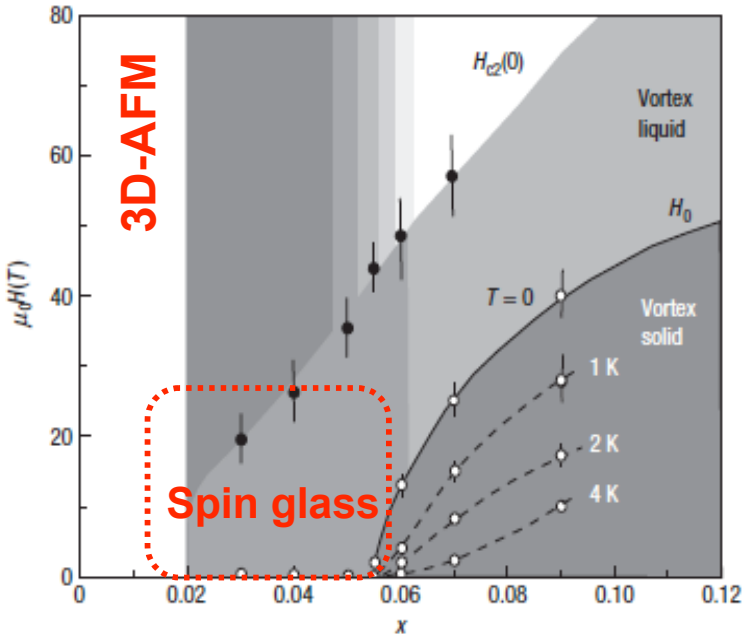
Mukuda et al. PRL 96(2006) and unpublished data

Sushkov cond-mat 2008

Nernst signal is also observed below X_c (lower critical concentration of SC)

Metallic properties already appear below X_c in LSCO?





X_c~0.055

Lu Li et al., cond-mat 0611731

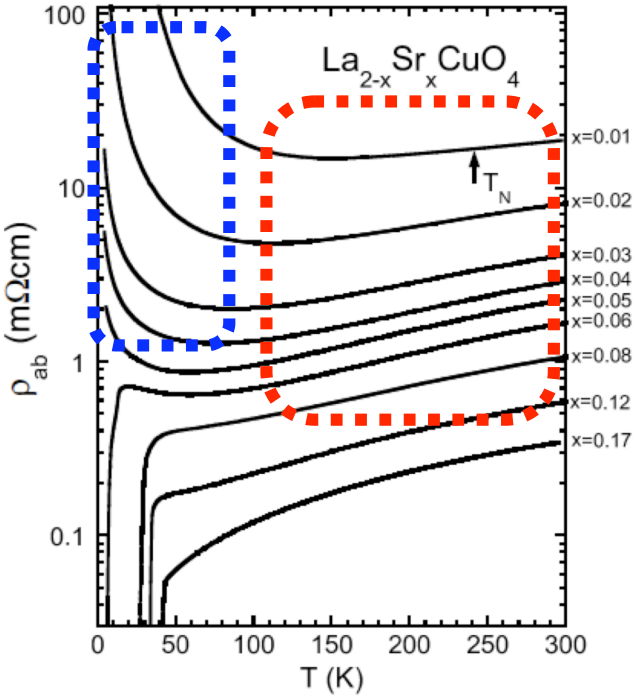
VOLUME 87, NUMBER 1 PHYSICAL REVIEW LETTERS 2 JULY 2001

Mobility of the Doped Holes and the Antiferromagnetic Correlations in Underdoped High-T_c Cuprates

Yoichi Ando, A. N. Lavrov, Seiki Komiya, Kouji Segawa, and X. F. Sun

Metallic transport already appears by dilute doping at high temperature

Carrier localization and hopping transport occur at low temperature



Variable range hopping conduction

$$\rho(T) \propto \exp((T_0/T)^{\alpha})$$

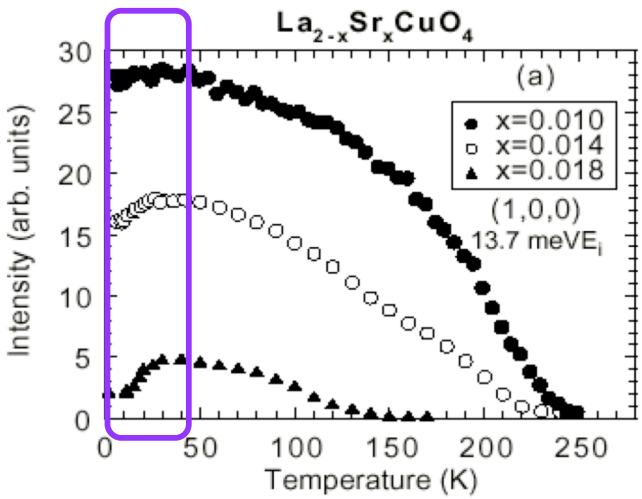
$$T_0 = \frac{13.8}{k_B N(\epsilon_F) r_{loc}^2}$$

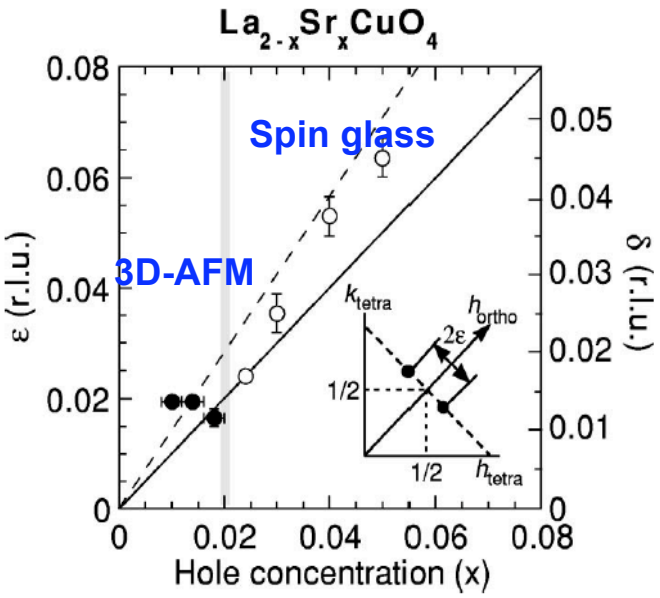
range of carrier hopping

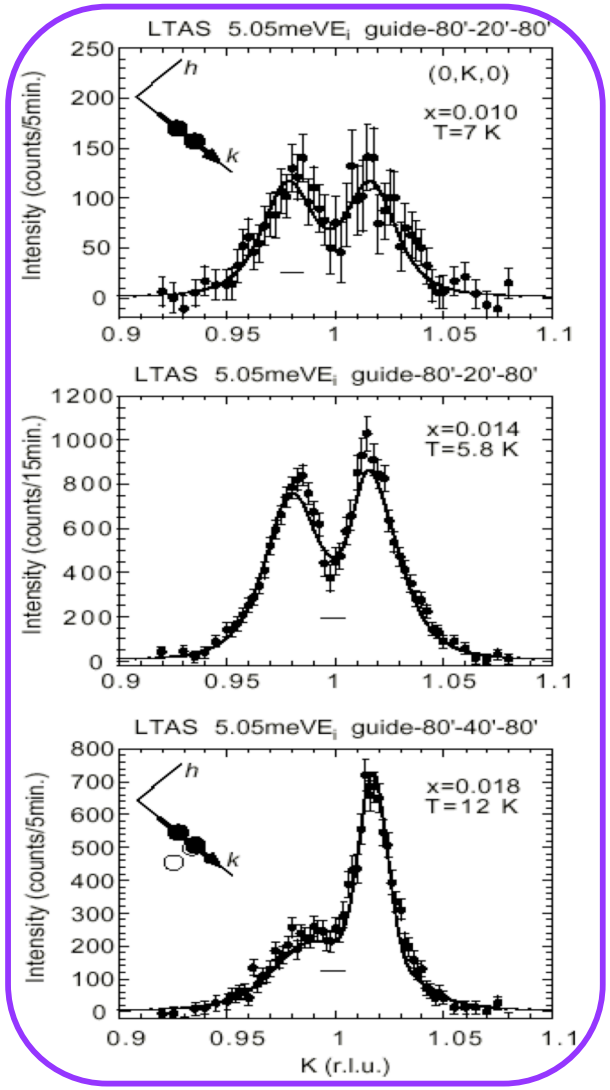
range of carrier localization

Incommensurate spin density modulation precipitates in AFM order by dilute hole-doping

Magnetic Bragg peak





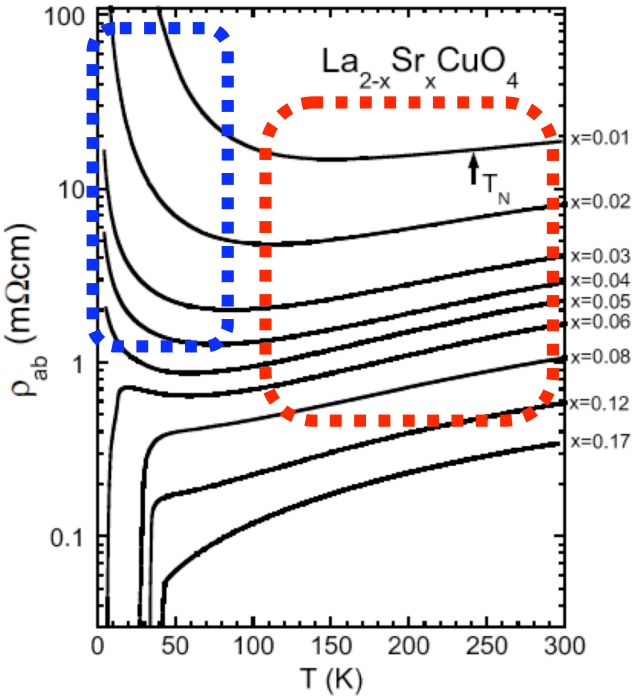


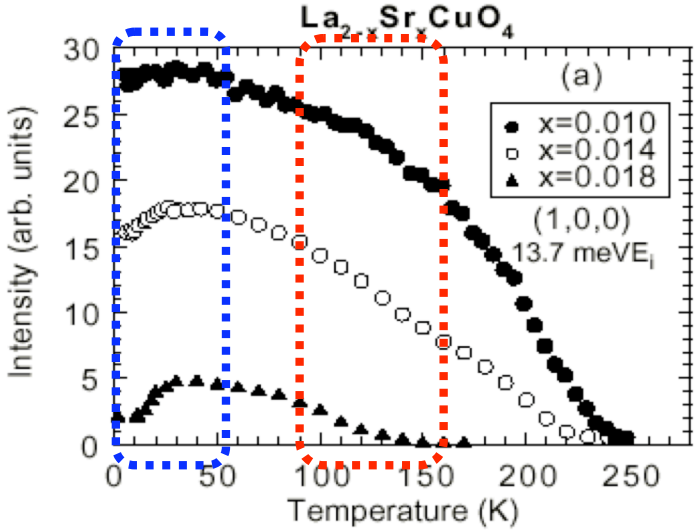
M.Matsuda et al. PRB65(‘02)

Proposed experiment

Precise measurement of spin excitation as a function of temperature

Carrier localization effect at low temperature and metallic character at high temperature ?

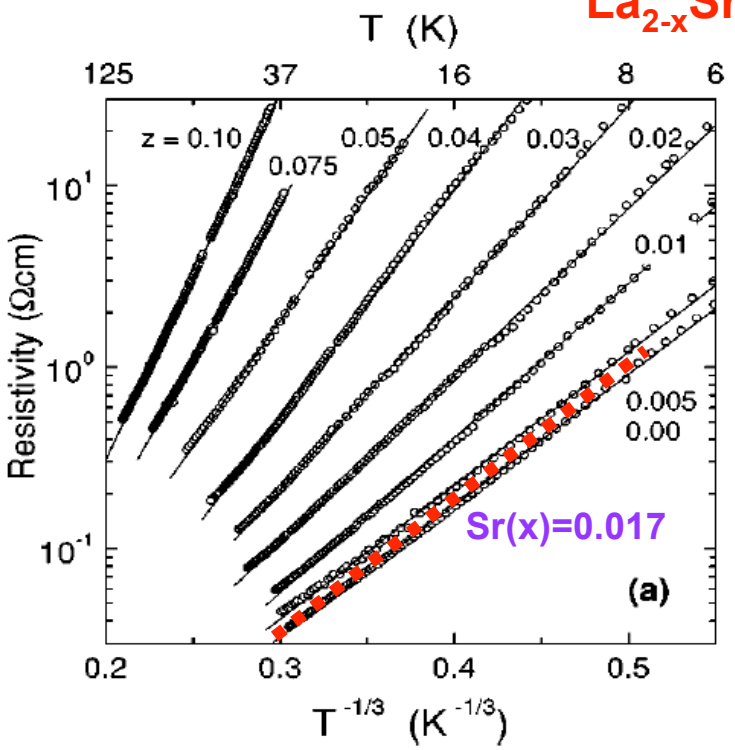


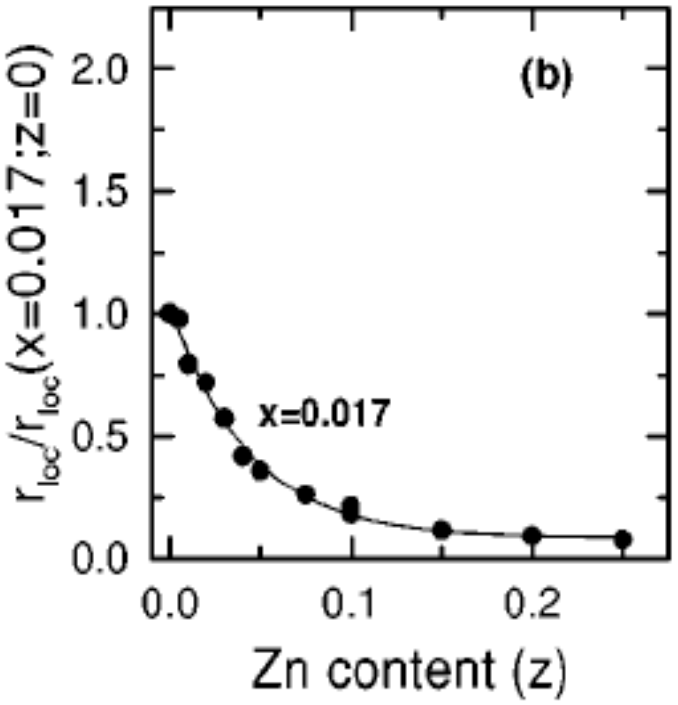


What happened by stronger carrier localization ?

Carrier localization is enhanced by impurity

$La_{2-x}Sr_xCu_{1-z}Zn_zO_4$

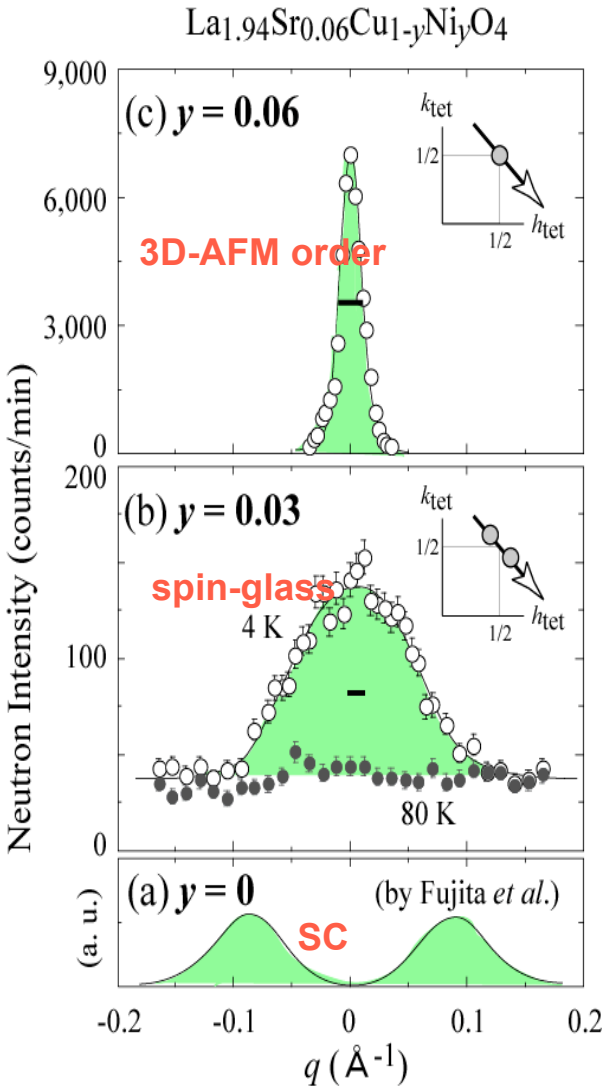




$$\rho(T) \propto \exp((T_0/T)^{\alpha})$$

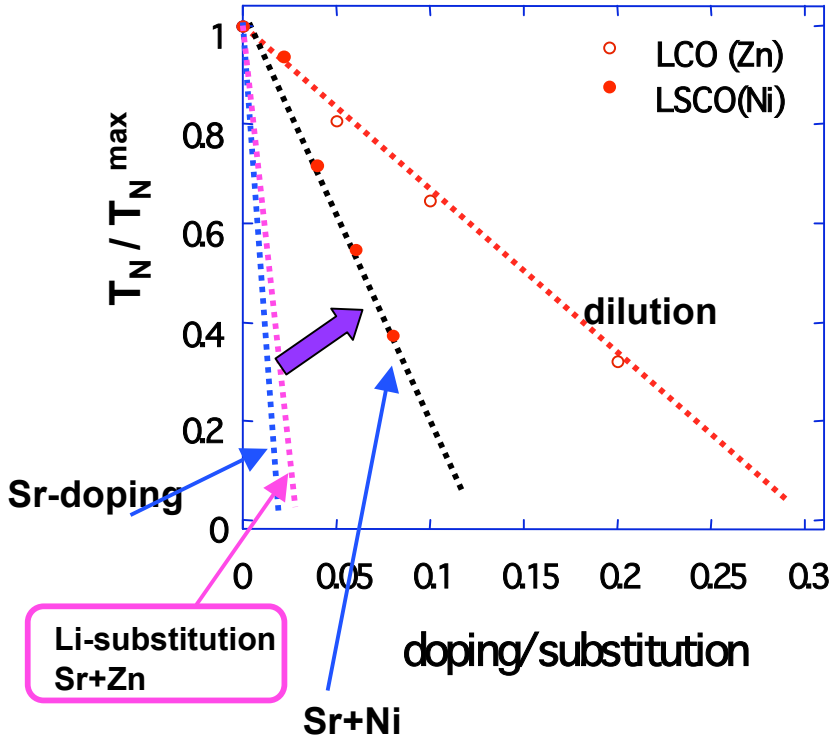
$$T_0 = \frac{13.8}{k_B N(\epsilon_F) r_{loc}^2}$$

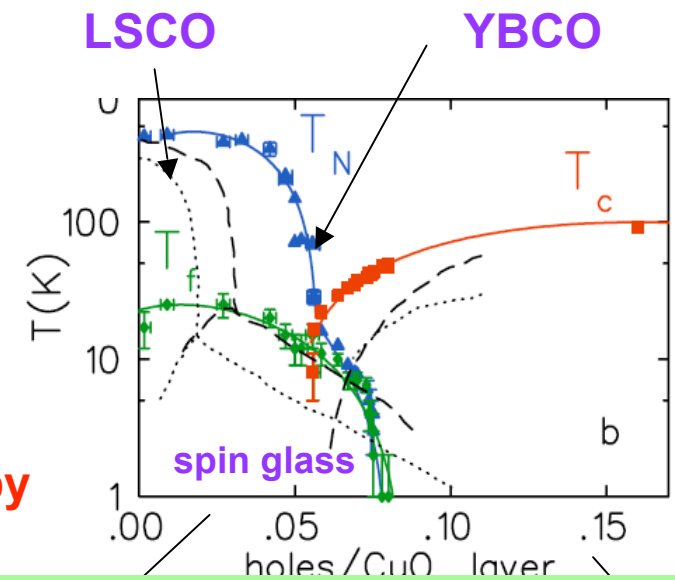
Hücker et al.
PRB59,(1999)



Hiraka et al., JPSJ(2007)

Strong carrier localization stabilizes 3D-AFM

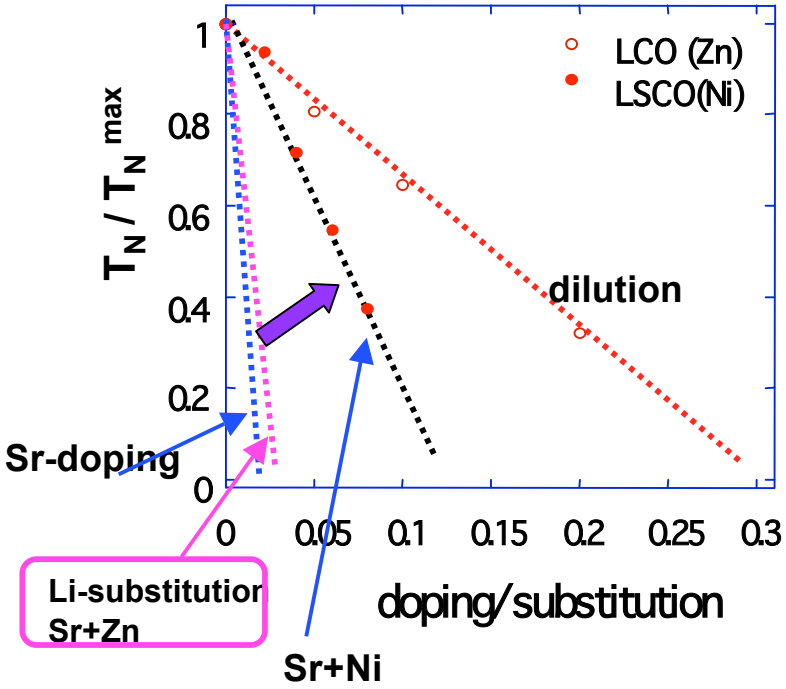


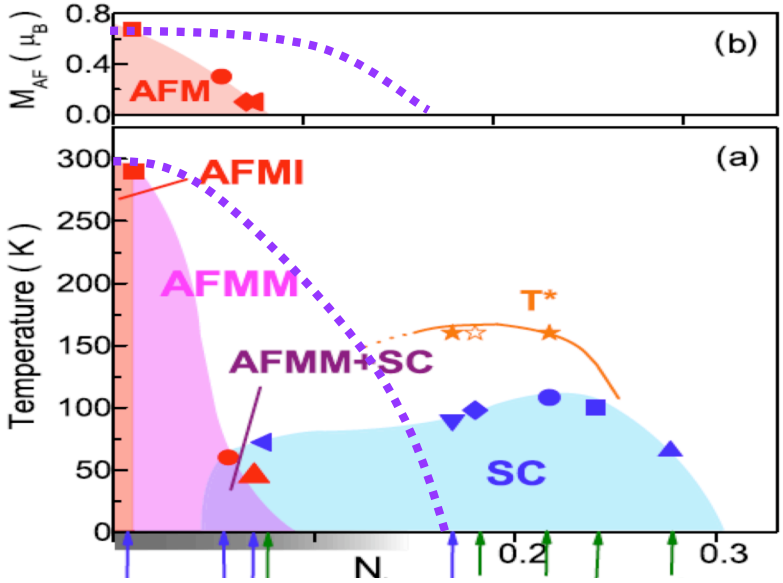


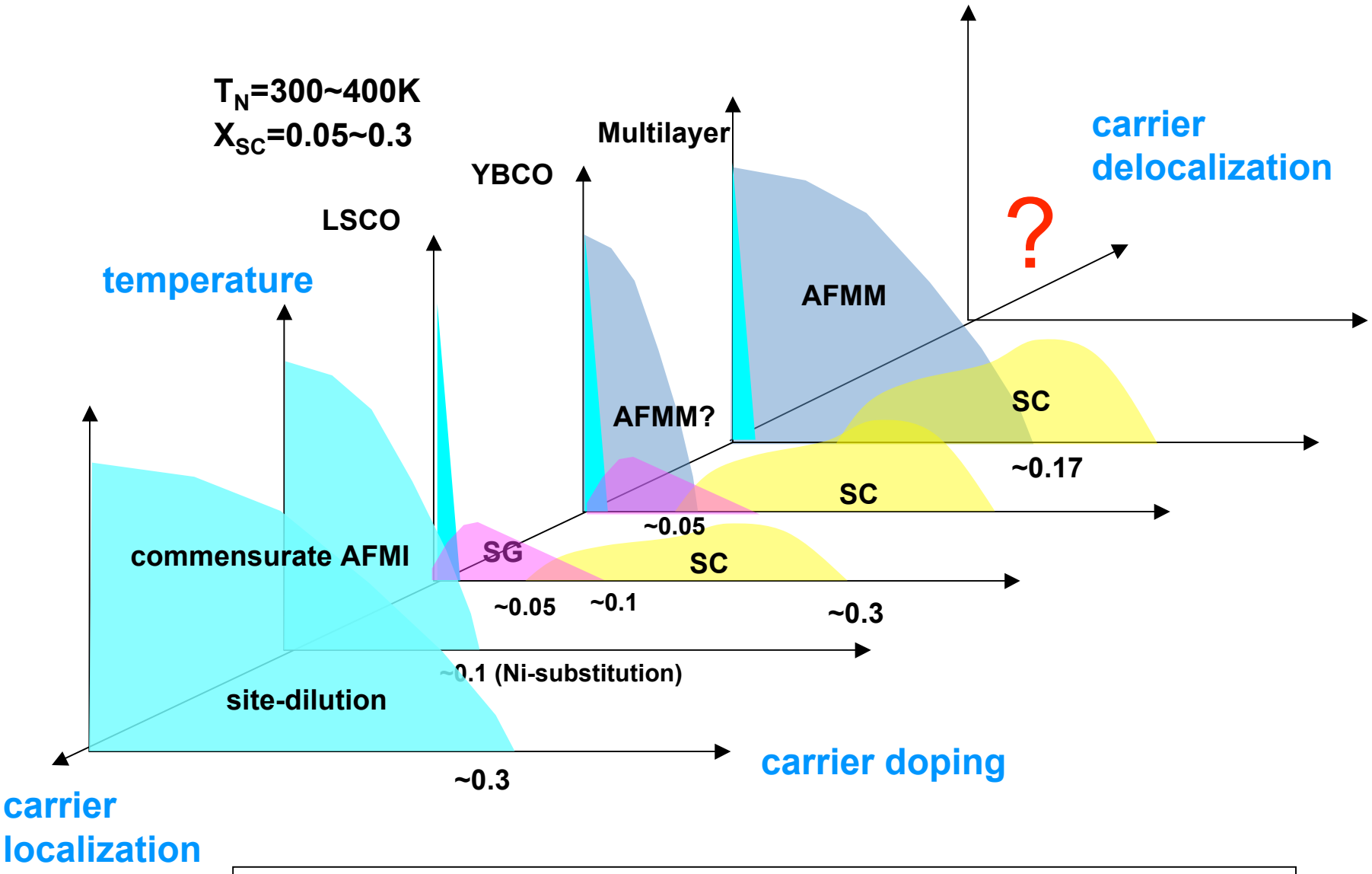
AFM region expands by carrier localization

AFM region expands by carrier delocalization

How to obtain unified picture of phase diagram ?



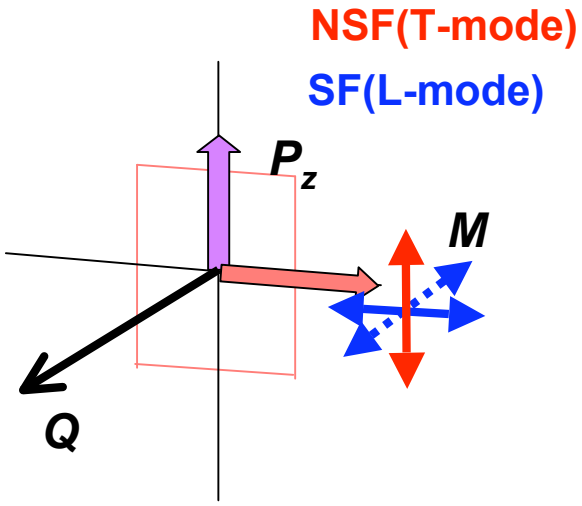



T_N=300~400K
X_{SC}=0.05~0.3
Multilayer
YBCO
LSCO
carrier delocalization
?
temperature
AFMM
AFMM?
SC
~0.17
SC
~0.05
commensurate AFMI
SG
SC
~0.05
~0.1
~0.3
~0.1 (Ni-substitution)
site-dilution
~0.3
carrier doping
carrier localization
AFM Insulator <----- Spin-glass phase -----> AFM Metal
strong
carrier localization
weak

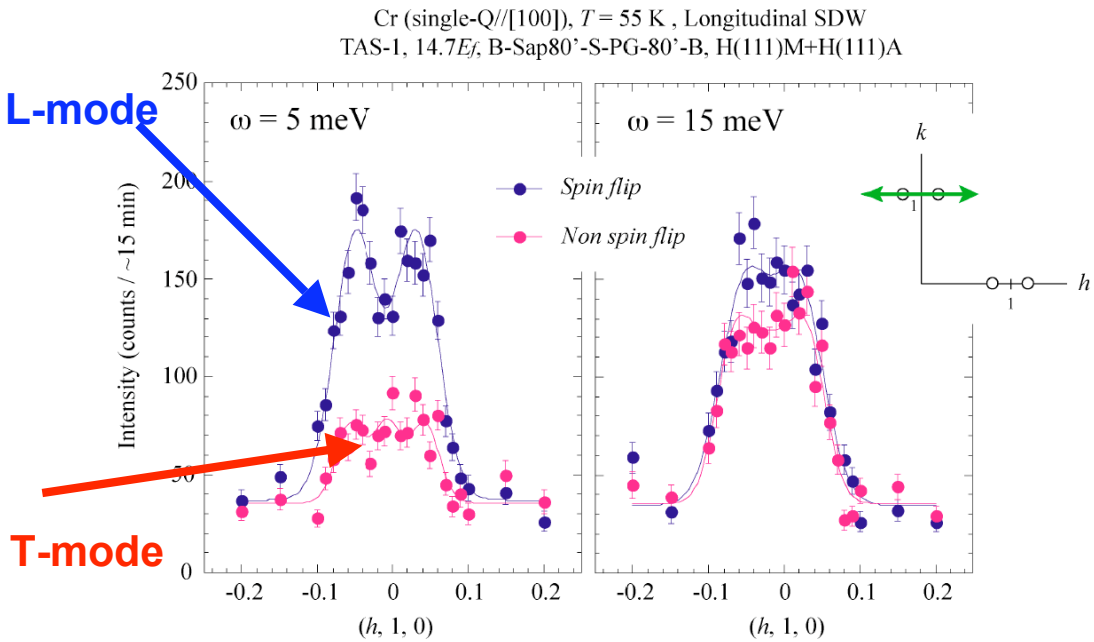
Proposed experiment

Detect metallic nature in spin fluctuations

Search for amplitude fluctuation of spins



Cr (Spin density wave)



S. Wakimoto et al., unpublished data

Y. Endoh et al., JPSJ ('97)

T. Fukuda et al., JPSJ('96)

Summary

(1) Pseudogap state

Direct evidence of superconducting fluctuation ?
Relation with magnetic order ?
---> polarized neutron small angle scattering
magnetic order under magnetic field

(2) Metallic transition by dilute doping

In LSCO metallic signature is seen even at dilute doping
---> precise temperature dependence of spin excitation in doped AFM

AFMI <----> spin-glass phase <---> AFMM

Clarify the relation between AFMM and spin-glass phases?
---> polarization analysis of spin fluctuation