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INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/1001-13

*IX TRIESTE WORKSHOP ON
OPEN PROBLEMS IN
STRONGLY CORRELATED SYSTEMS*

14 - 25 July 1997

DISSYMMETRY OF CRITICAL EXPONENTS IN UNTWINNED YBCO SINGLE CRYSTALS

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DISSYMETRY OF CRITICAL EXPONENTS IN UNTWINNED YBCO SINGLE CRYSTALS

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INTRODUCTION

- régime critique du composé YBCO
  par la mesure
  de Chaleur Spécifique.

  - bons échantillons
    m~ 10 µg, 2µj/K à 100 K

  - $\delta C \sim 10^{-2}$ (C_{el})

    $\delta C/C_{totale}=10^{-4}$.

    $\delta C \sim 0{,}1$ nj/K

  - $\Delta T \sim 0{,}2$K à T_c=92K.

    pas en température 5 mK.

    modulation T_{ac} de 5 mK.

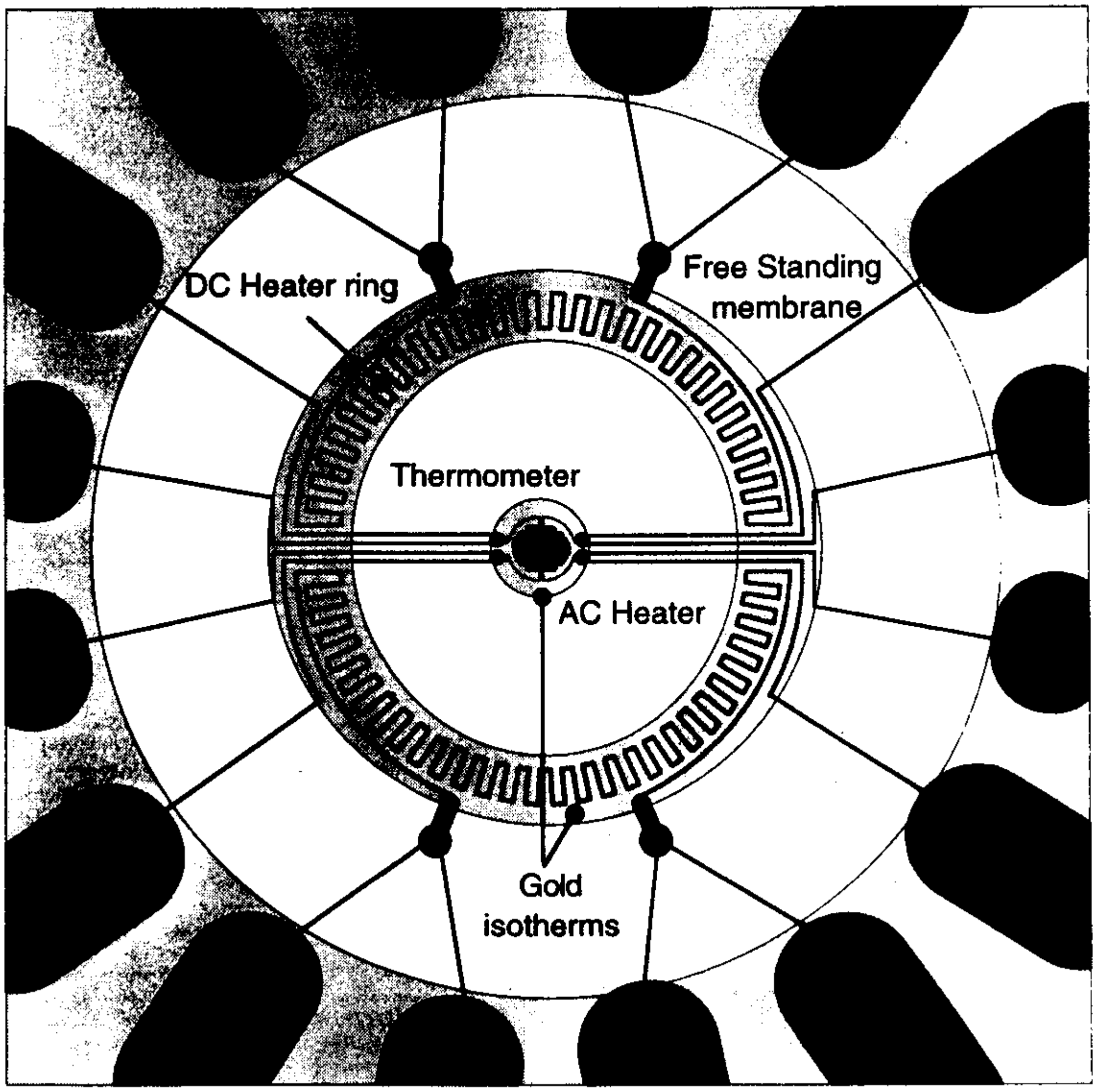
    δT_{ac}=1 µK à 100K

typical sample mass: 10 μg

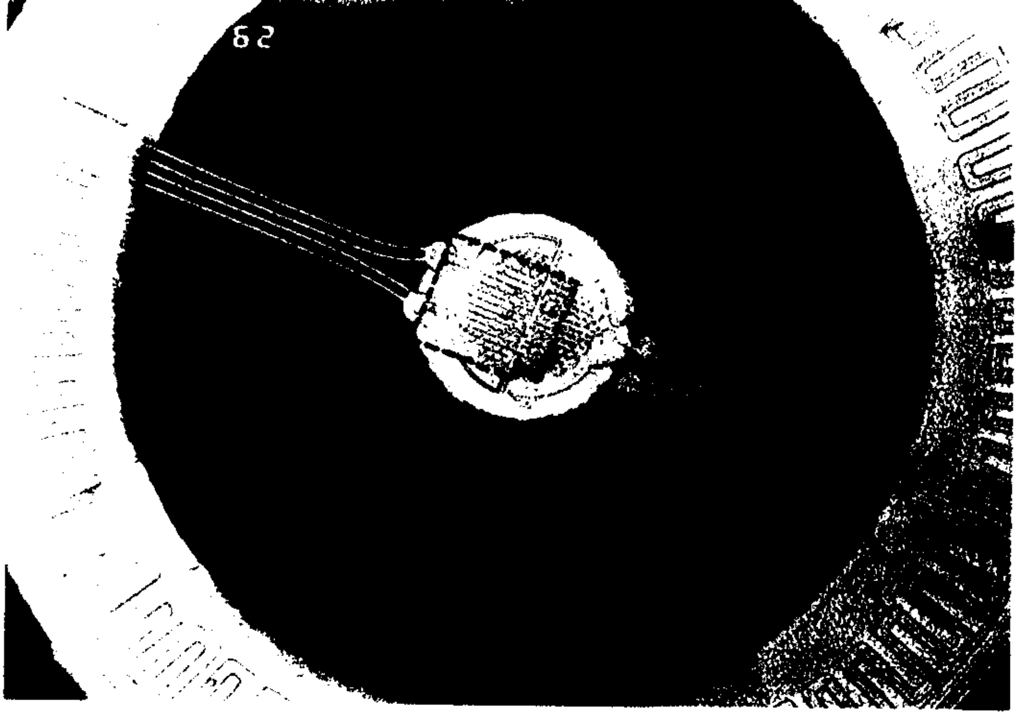
$C_{addendum} = 1 - 2\ \mu Joule/K$ 40 - 160 K

$\delta T_{AC} = 1\ \mu K$ $T_{AC} = 5\ mK$

steps in T_0: 5 mK drifts: < 1 mK/hr



$$\frac{dV}{dT} = 100\ \mu V / K$$

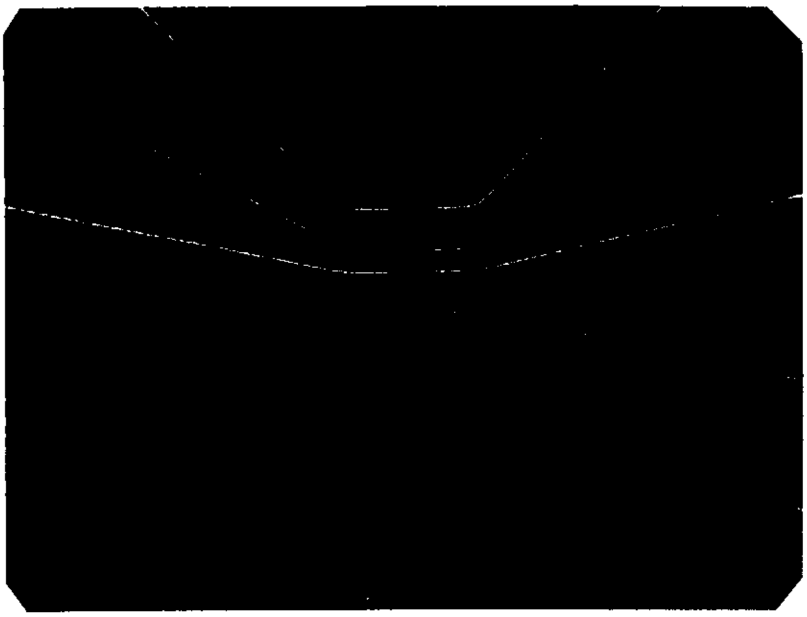


$K_{exch} = 1\ W/_{Kcm^2}$

$T_{sample} = 6$ msec

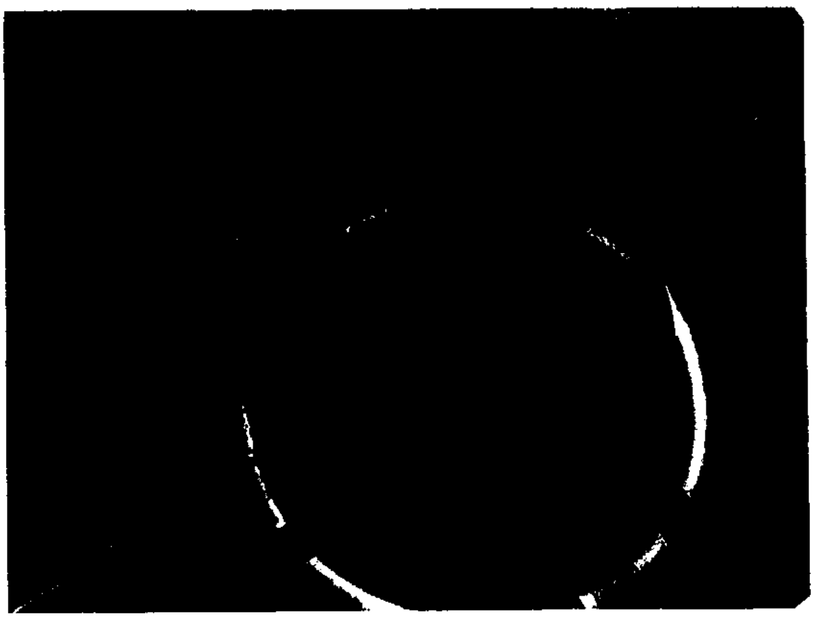
$f = 3-10$ Hz

Développements technologiques



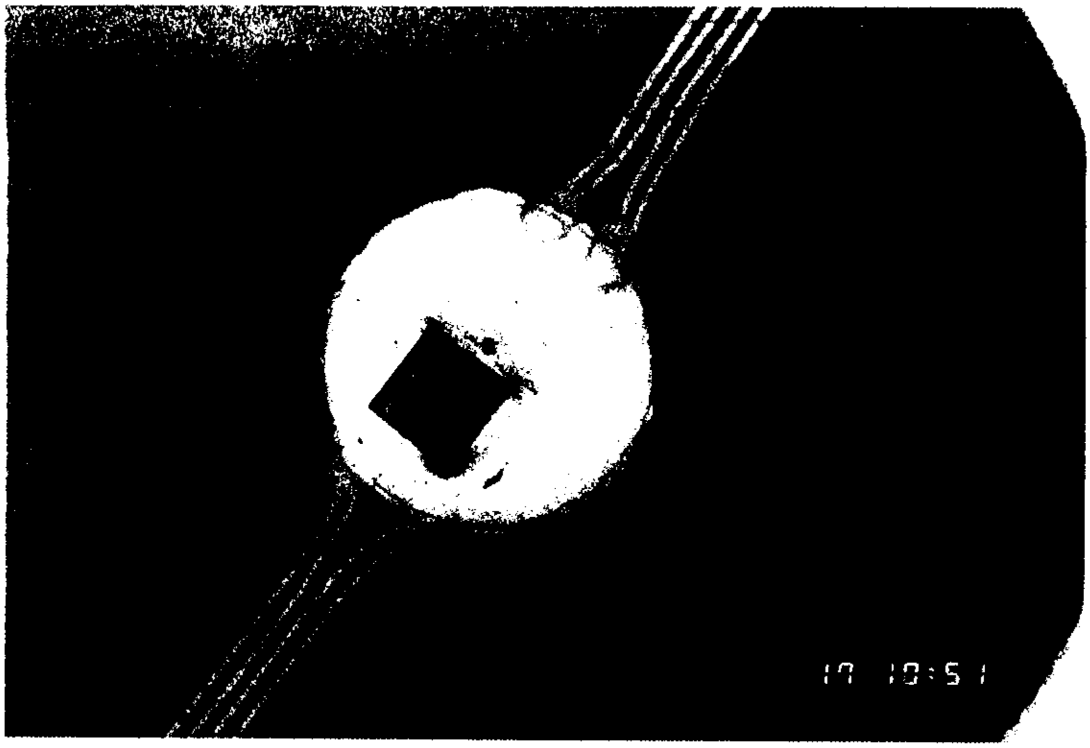
µ-sonde Hall
résolution:
10^{-9} emu

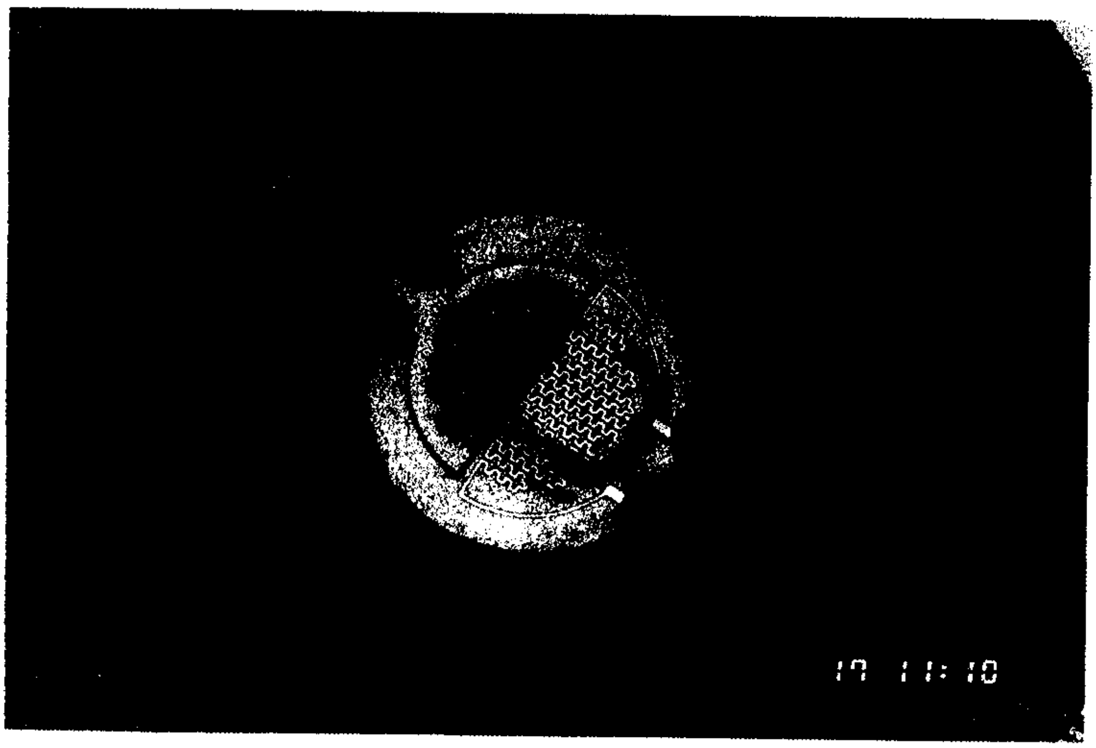
Fig.1 Barrette de Hall a couche mince de Bi lithographiée élaborée au CRTBT. Largeur de la µ-sonde: 1µm.



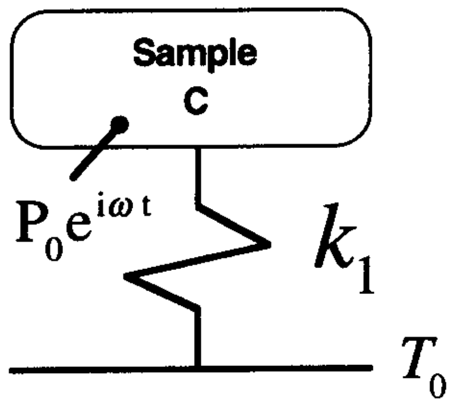
µ-sonde Hall
+
µ-calorimètre
sur le m̂ dispositif
Permet mesures simultanées
χ, C_p

Fig.6 Sonde de Bi de largeur 50µm, elaboree au CRTBT, lithographiée sur une membrane fine de polymère permettant d'effectuer des oscillations de température de 5mK a 80 K pour détecter dM/dT près de la fusion du réseau de vortex.


17 10:51


17 11:10

Principe de la mesure alternative



$$T = T_0 + \frac{P_0\, e^{i(\omega t + \varphi)}}{\omega C \sqrt{1 + \frac{1}{(\omega \tau_c)^2} + (\omega \tau_e)^2}}$$

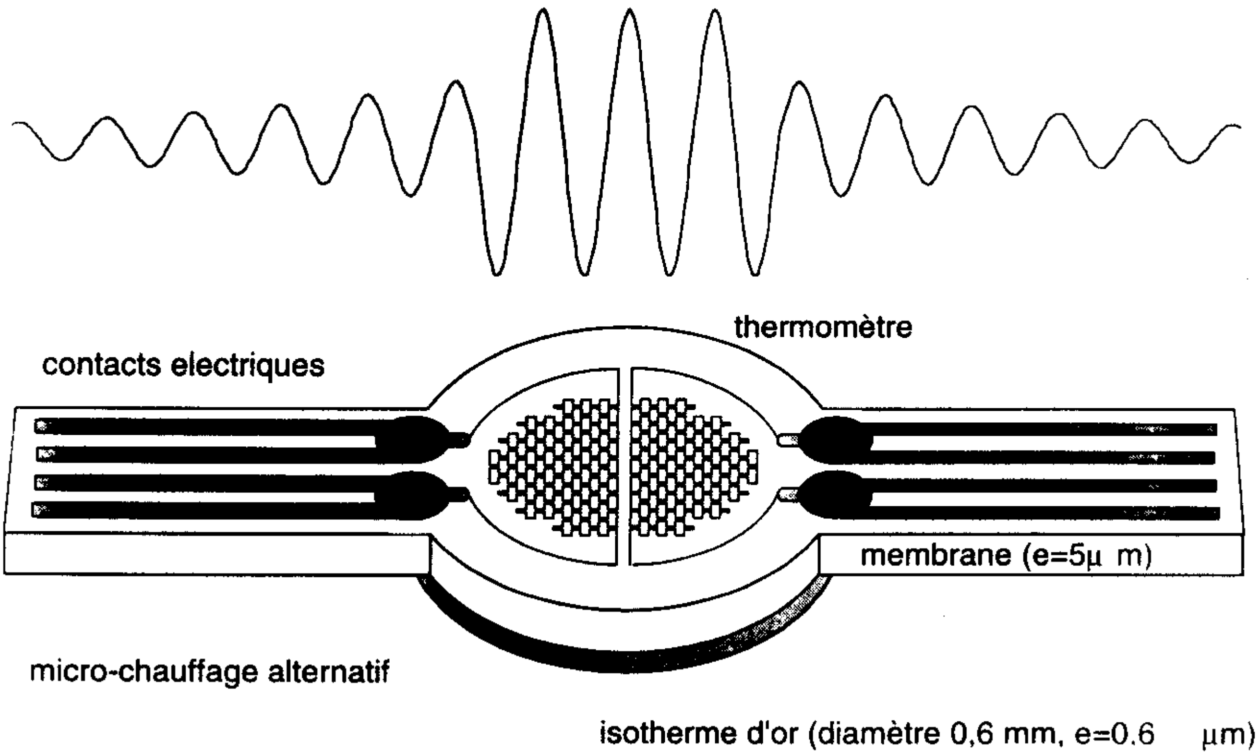
relaxation d'échange $\tau_c = \frac{C}{k_1}$

relaxtion interne $\tau_e \propto \frac{a^2}{D}$

$$\omega \tau_e << 1 << \omega \tau_c$$

$$T_{ac} = \frac{P_0}{\omega C(T_0)}$$

Contribution du porte-échantillon à la chaleur spécifique



$$C_{addenda} = C(\omega) + C_{spot}$$

Comportement intrinsèque
de l'YBaCuO

Différents types d'échantillons

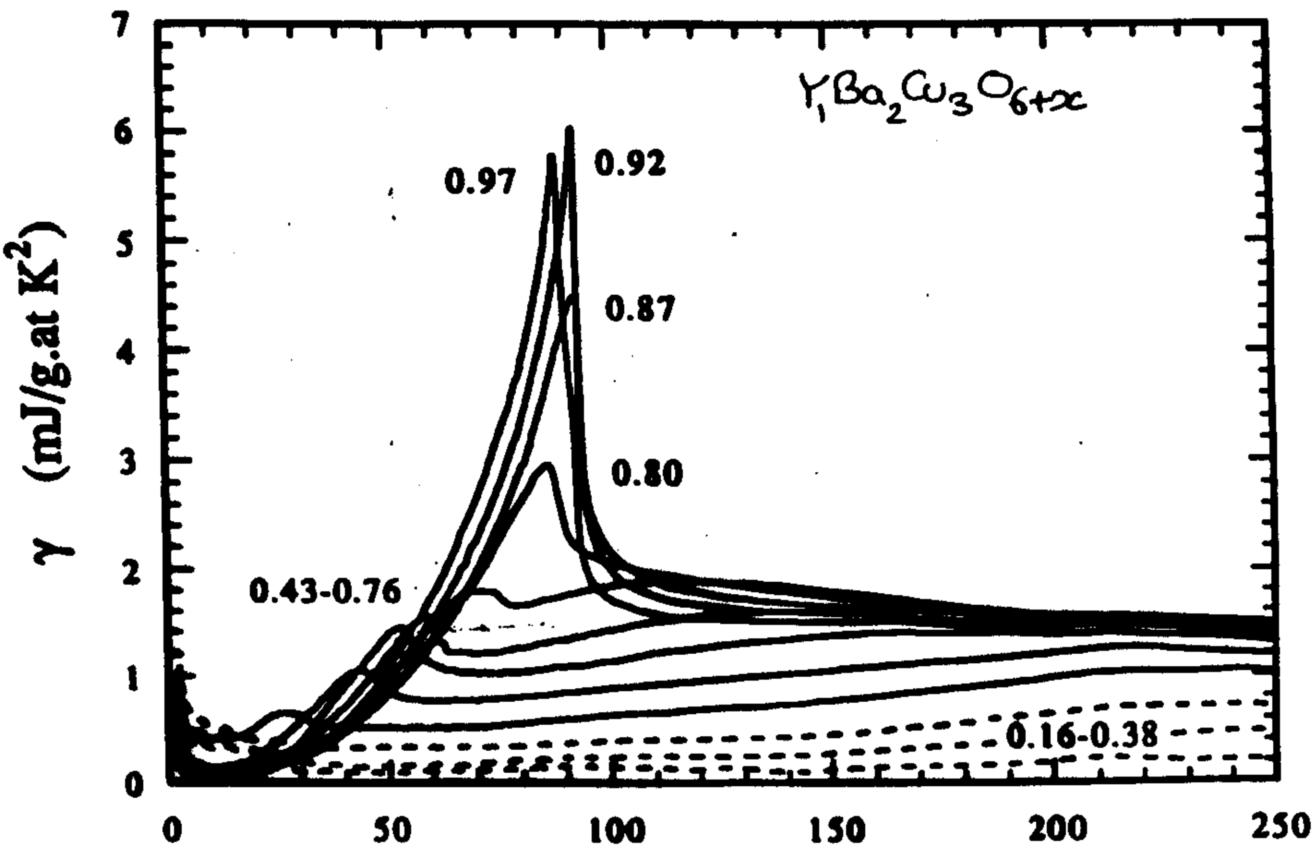
maclés-non maclés

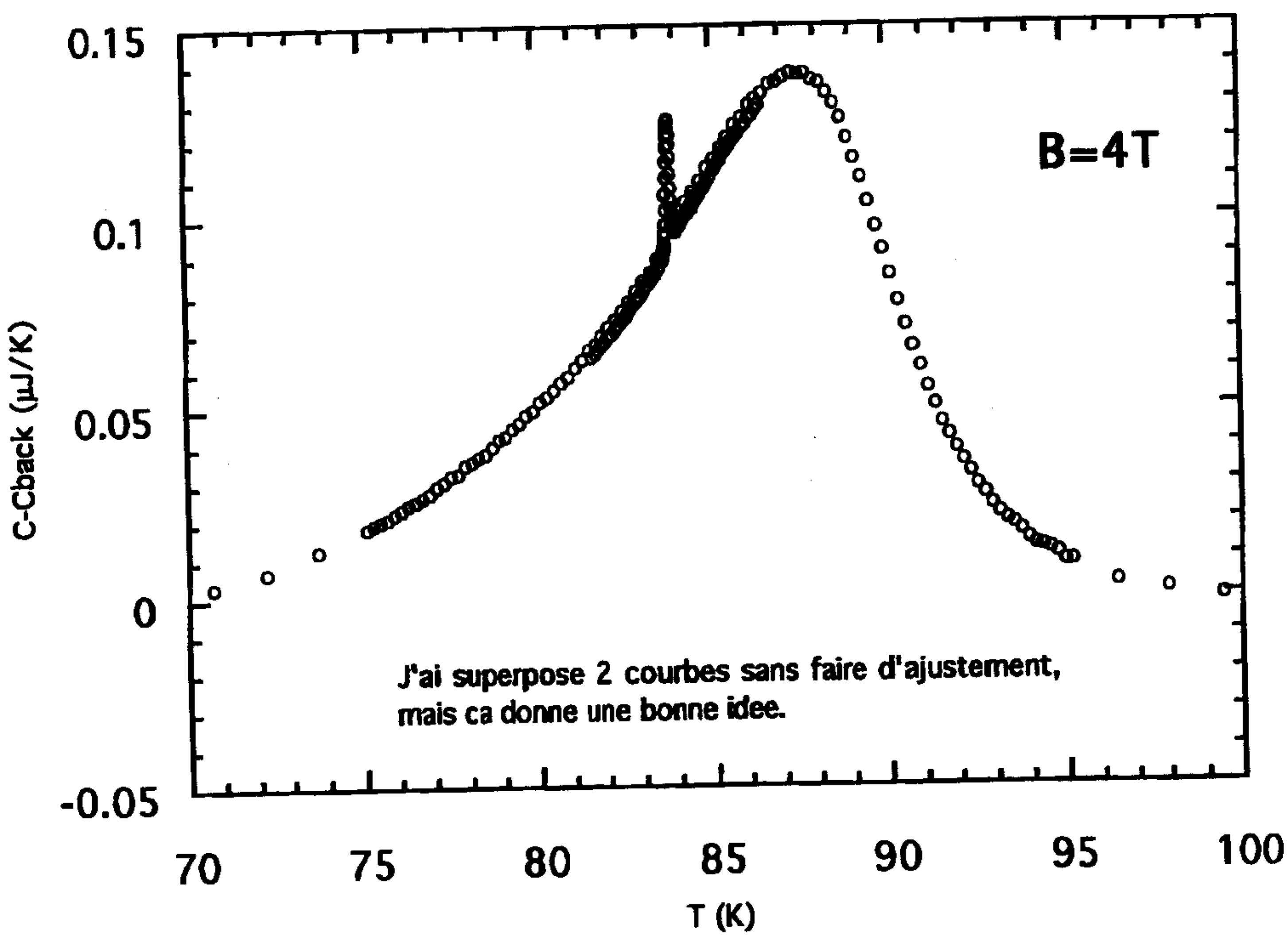
cristaux avec impuretés d'or
(CRTBT)

Cristaux à faible taux d'impureté
(UBC)

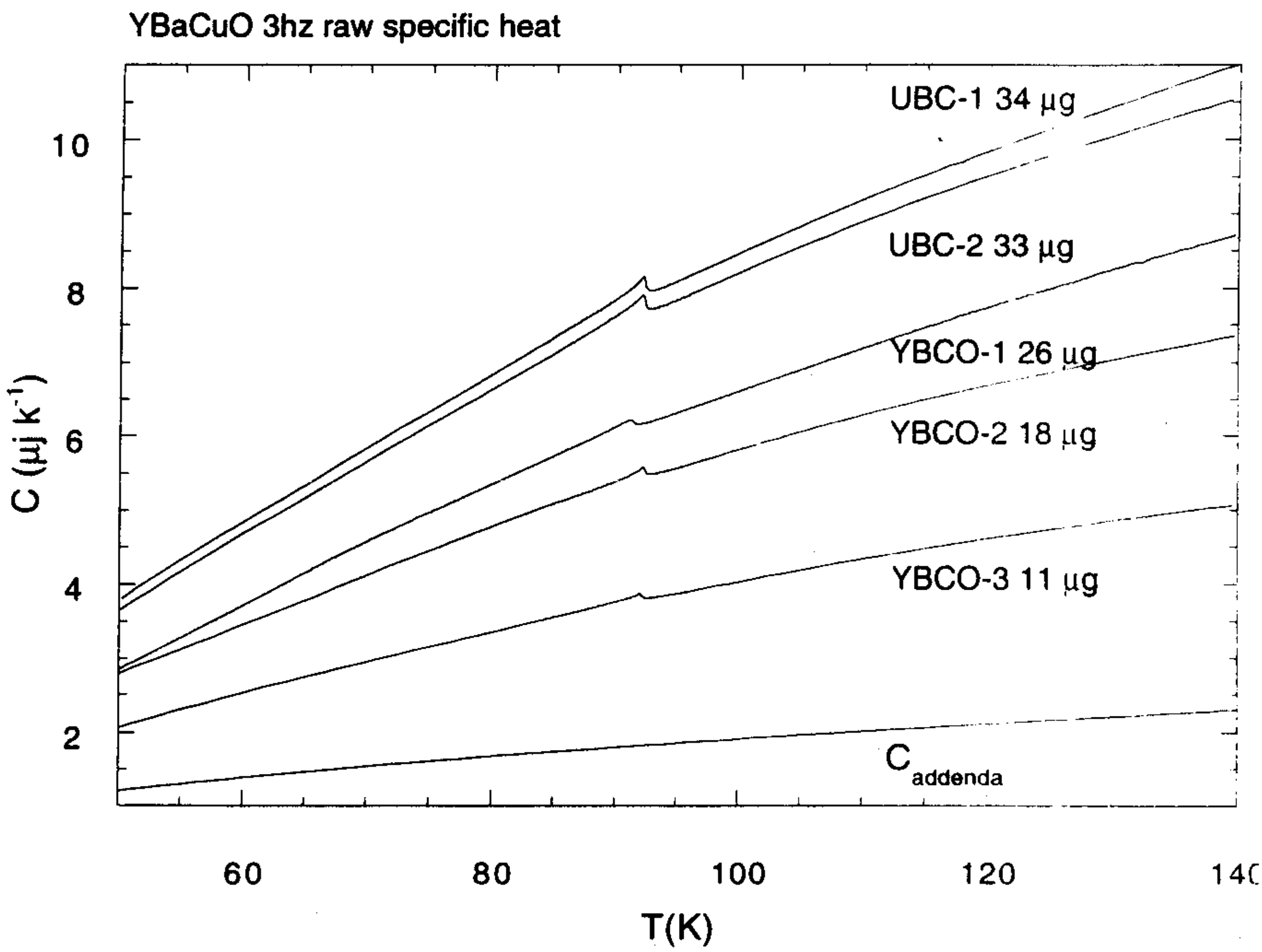
Sensibilité au taux d'oxygène.

LORAH PRL 71 (1993) 1740




B=4T
J'ai superpose 2 courbes sans faire d'ajustement,
mais ca donne une bonne idee.
0.15
0.1
0.05
0
-0.05
C-Cback (µJ/K)
70
75
80
85
90
95
100
T (K)

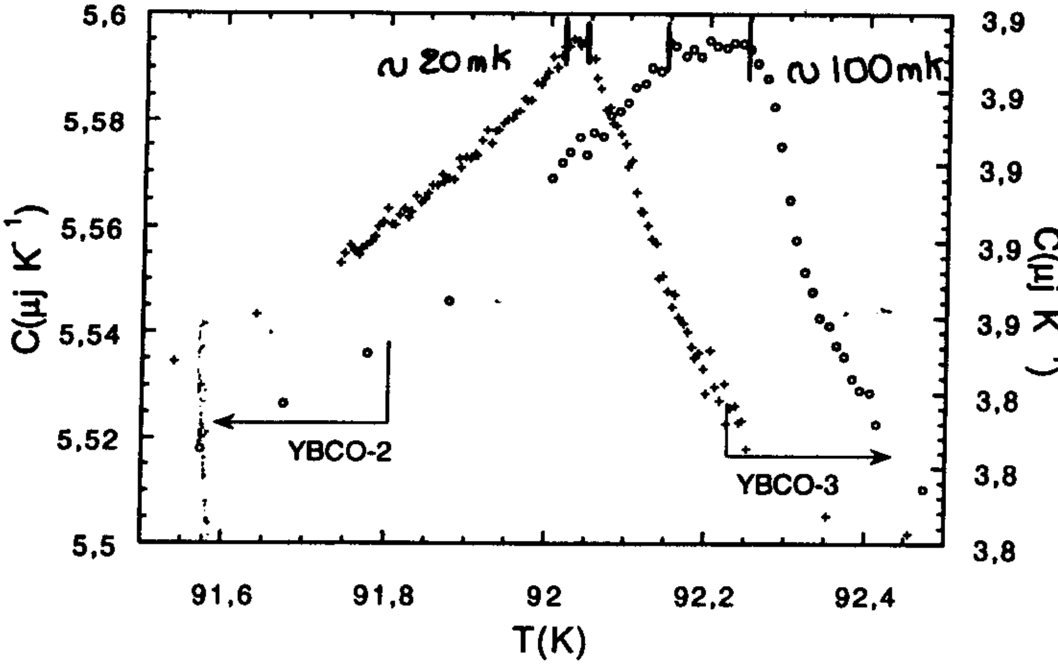
Application à la mesure de mono-cristaux d'YBaCuO



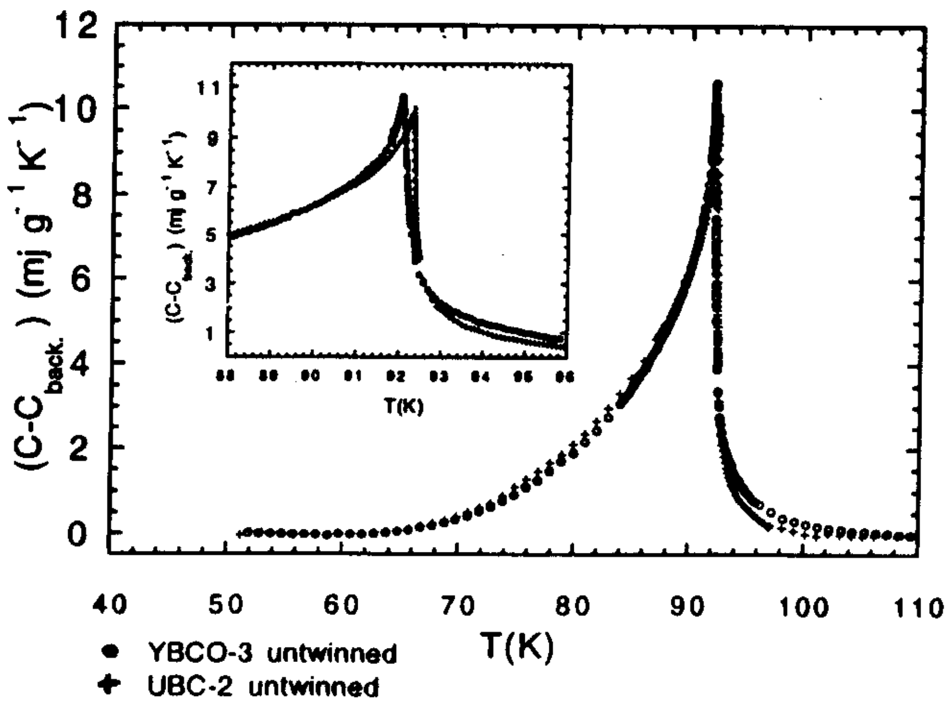
precision: 5%

	YBCO-1	YBCO-2	YBCO-3	UBC-1	UBC-2
Masse (µg)	27	19,6	11	35	34
Epaisseur	45	76	40	42	35
T_c (K)	91,20	92,20	92.02	92,24	92,28
ΔC (mj g^{-1} K^{-1})	6,53	8,92	10,8	11,2	10,6

Arrondis pour différents échantillons non maclés



Sensibilité aux impuretés d'or

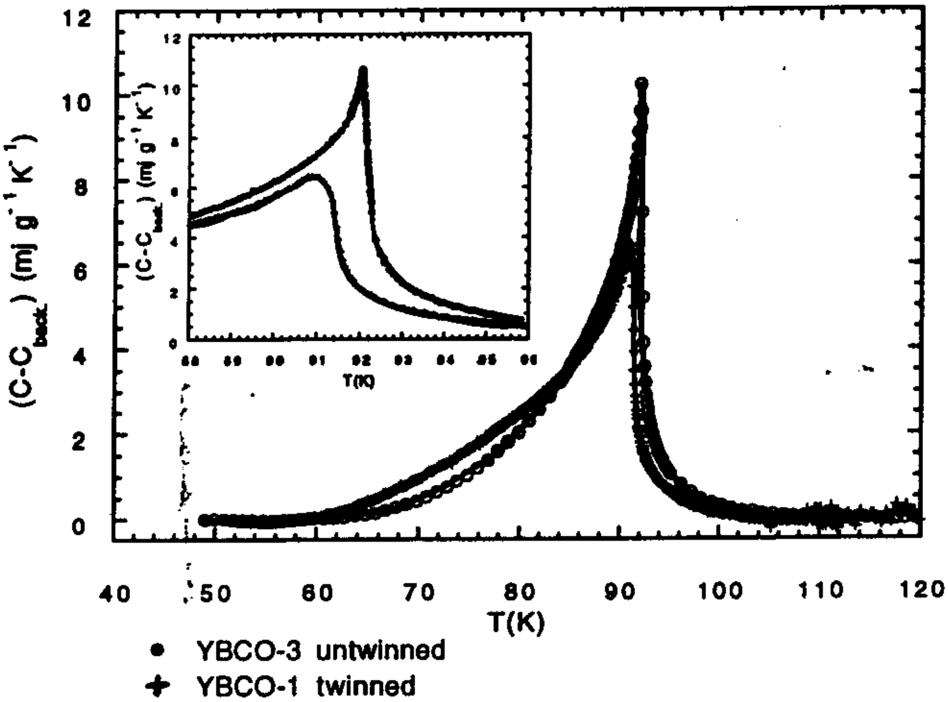


$\Delta C = 11 \pm 1 \ mJ\,g^{-1}K^{-1}$

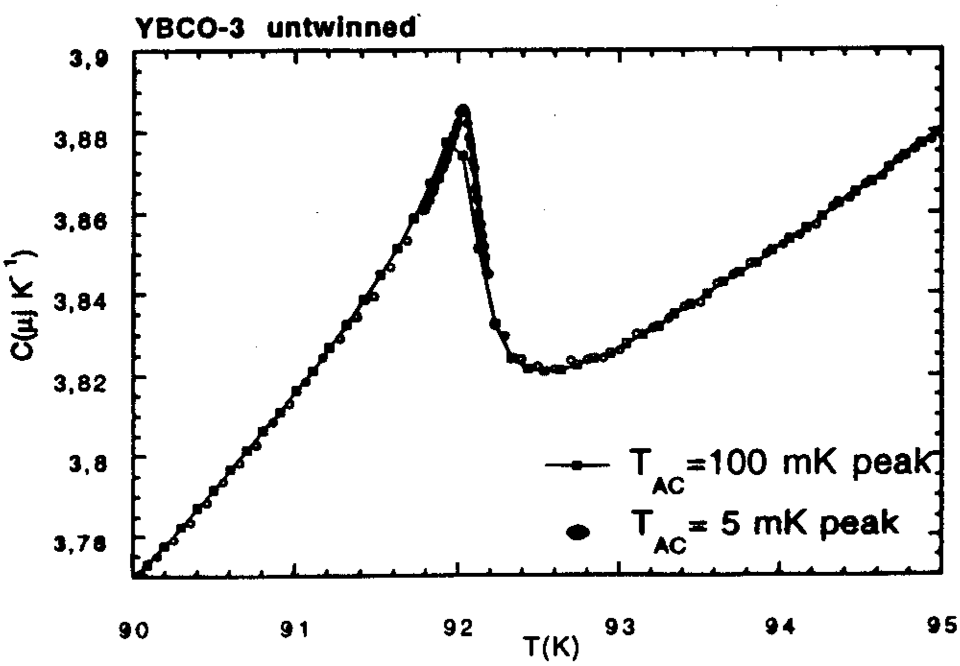
$\frac{\Delta C}{\gamma T_c} = 3.8 \pm 0.3$

(BCS : 1.43

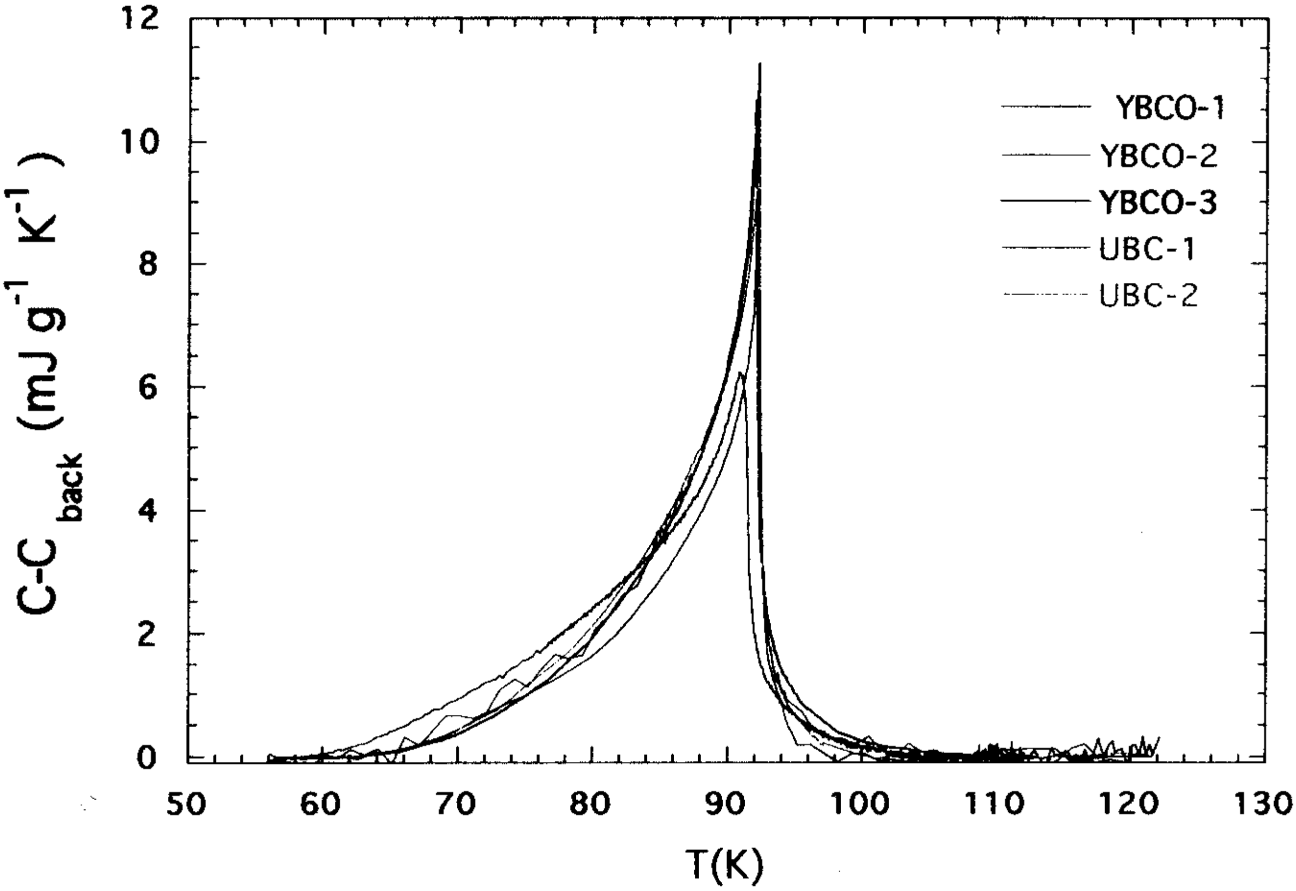
Comparaison maclés-non maclés:



Sensibilité au nombre de points et à la modulation Tac



Comportement intrinsèque de l'YBaCuO

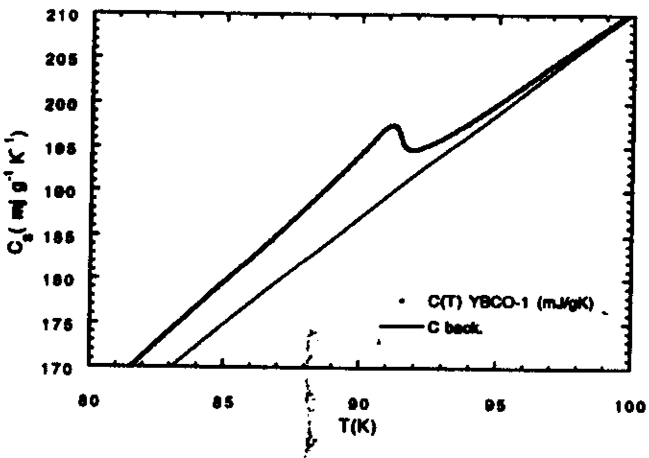


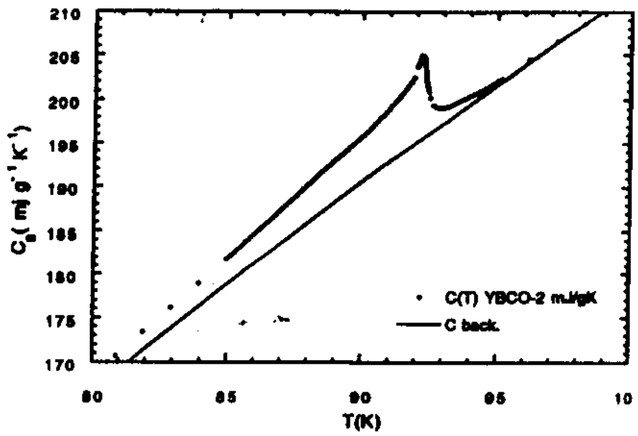
$$\Delta C = 11 \pm 1\, mJ\ g^{-1}\, K^{-1}$$

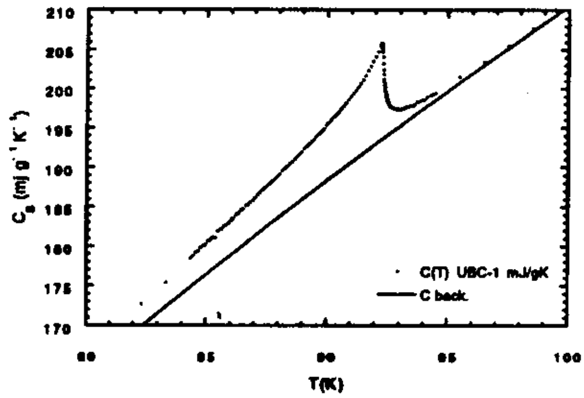
$$\frac{\Delta C}{\gamma T_c} = 3,8 \pm 0,3$$

$$(BCS:\quad 1,43)$$

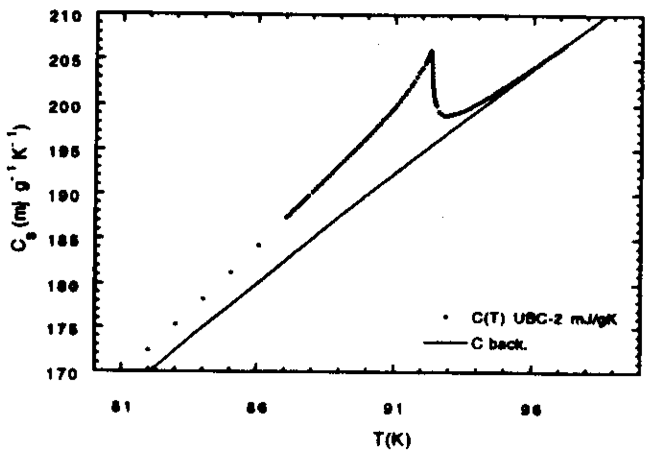
Soustraction du background

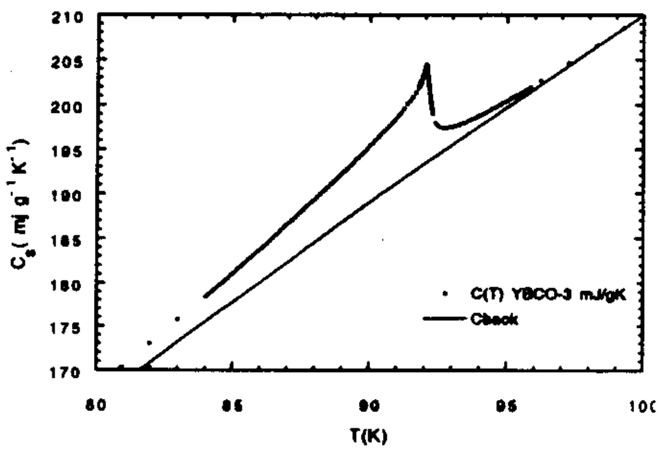


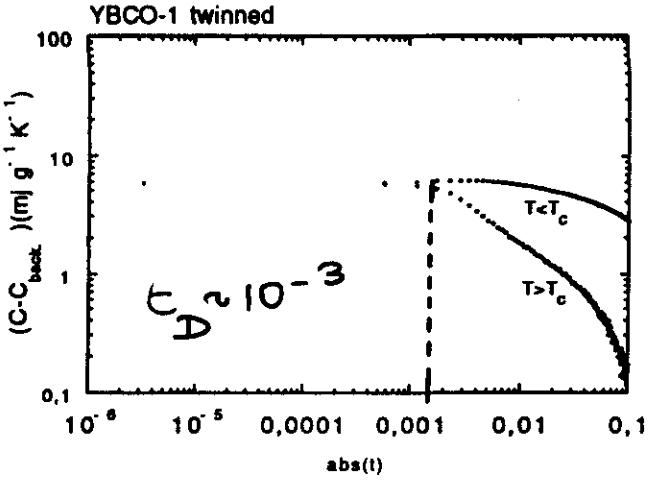


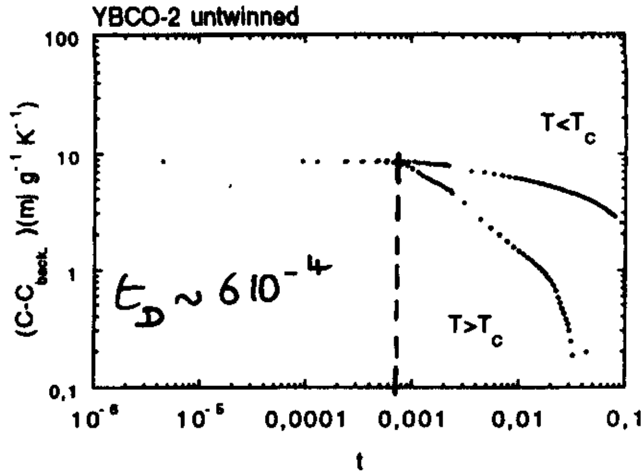


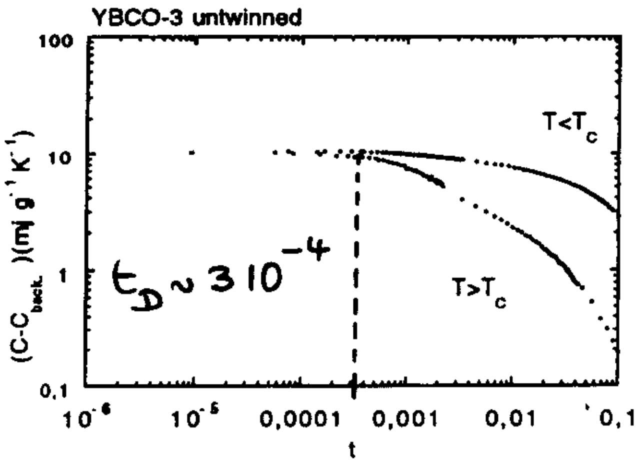
$$C_{back} = \sum_{i=1}^{2} \frac{(T/\theta_i)^2 \exp(-T/\theta_i)}{(\exp(-T/\theta_i)-1)^2} \cdot d_i$$

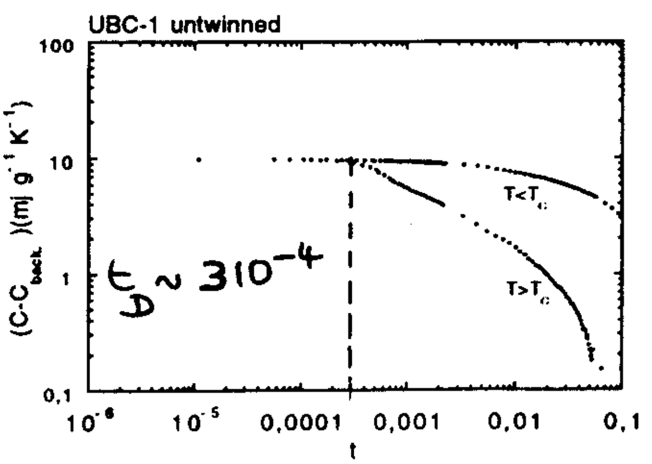


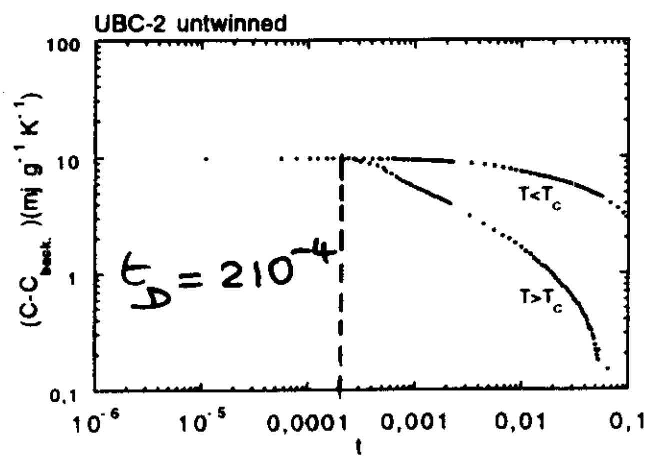








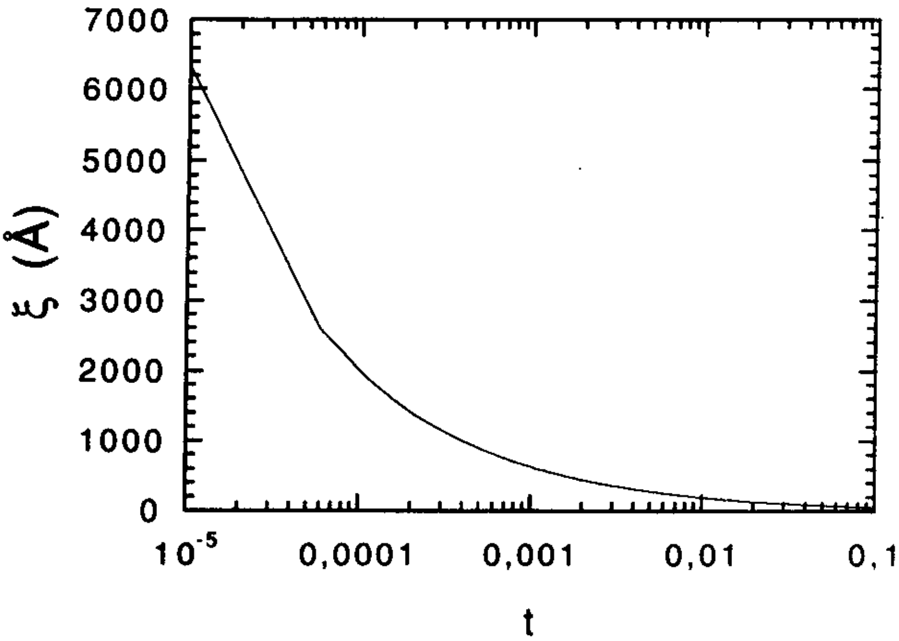


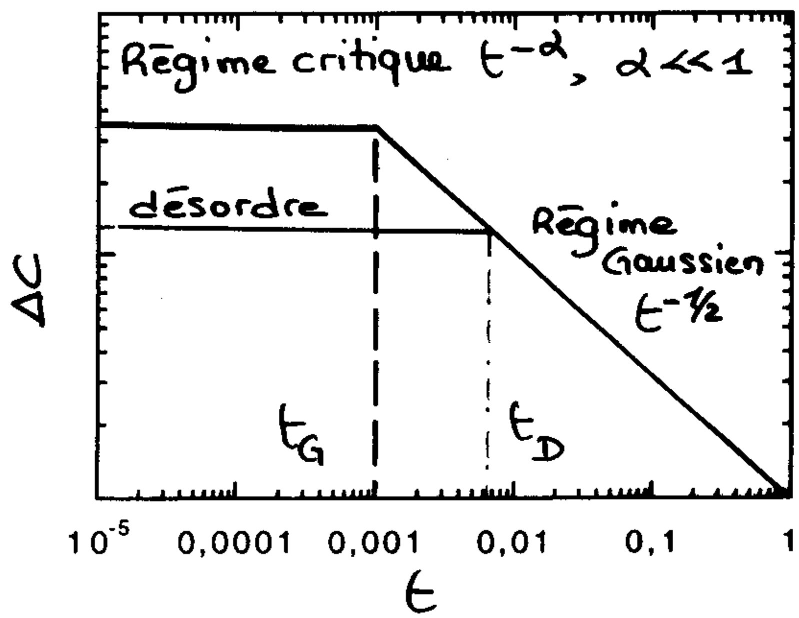


Taille caractéristique du désordre : $t_D \sim 2\,10^{-4}$

$\boxed{\xi \sim 0.2\ \mu m.}$

Coupure de divergence
due au désordre





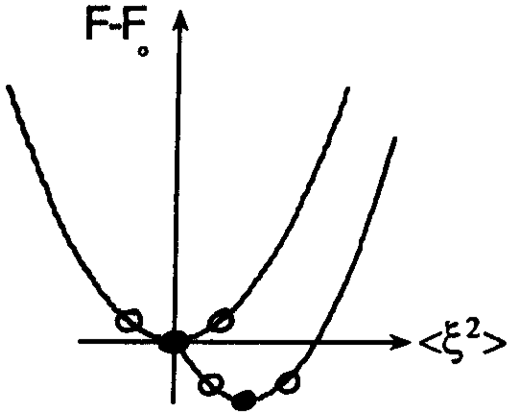
$\xi_d \sim 0.1 - 0.3\,\mu m \quad (\xi_0 = 8\text{-}20\,\text{Å})$

Contribution des fluctuations

$$F - F_0 = a(T)|\Psi|^2 + \frac{b}{2}|\Psi|^4 + \frac{\Gamma}{2}|\nabla\Psi|$$

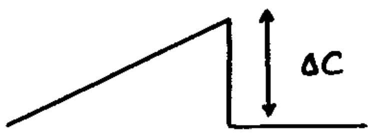
$$a(T) = \alpha(T - T_c)$$

Transition du second ordre:



Saut champ moyen $\Delta C = \dfrac{H_c^2}{\mu_0 T_c}$

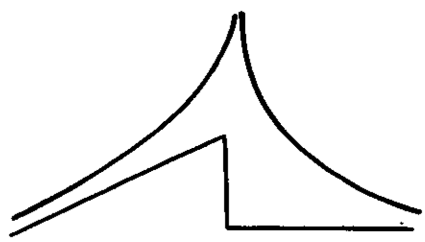
$$H_c(0) \sim 2.5T$$



fluctuation Gaussienne

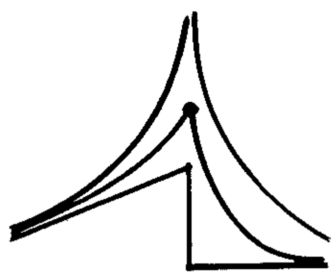
$$C_{fl} = \frac{k_b}{32\pi}\left[\frac{\alpha}{\Gamma}\right]^{3/2}|t|^{-1/2}$$

$$t = \frac{T}{T_c} - 1$$



gaussian $\alpha = 0.5$

fluctuation critique

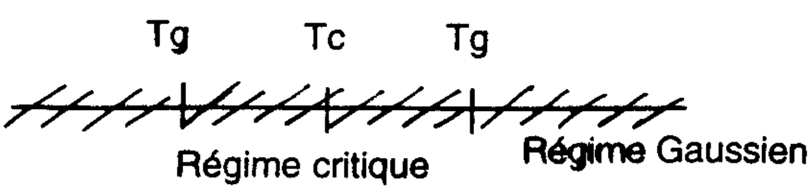


$$C_{critique} = C^{\pm}|t|^{-\alpha} \qquad \alpha\begin{cases} >0 & divergence \\ <0 & "cusp" \end{cases}$$

uncharged superfluid 3DXY $\alpha \simeq 0.0$

charged superfluid ?

Critère de Ginsburg

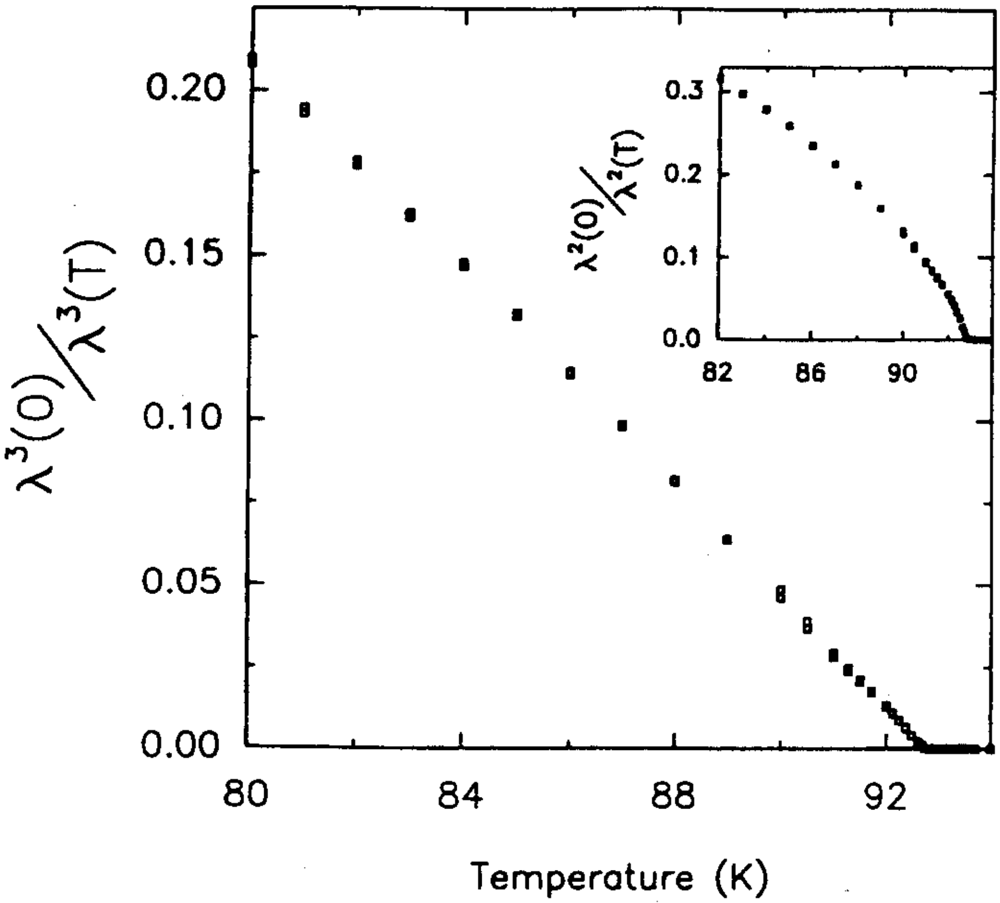


$$t_G = 10^{-2}$$

Measurements of $\lambda(T)$ close to T_c

$$\lambda^2 \sim \frac{1}{\rho_s} \qquad \rho_s \sim \xi^{2-D} \sim \frac{1}{\xi} \quad 3D$$

$$\lambda^2 \sim \xi \sim t^{-\nu}$$



S. Kamal et al
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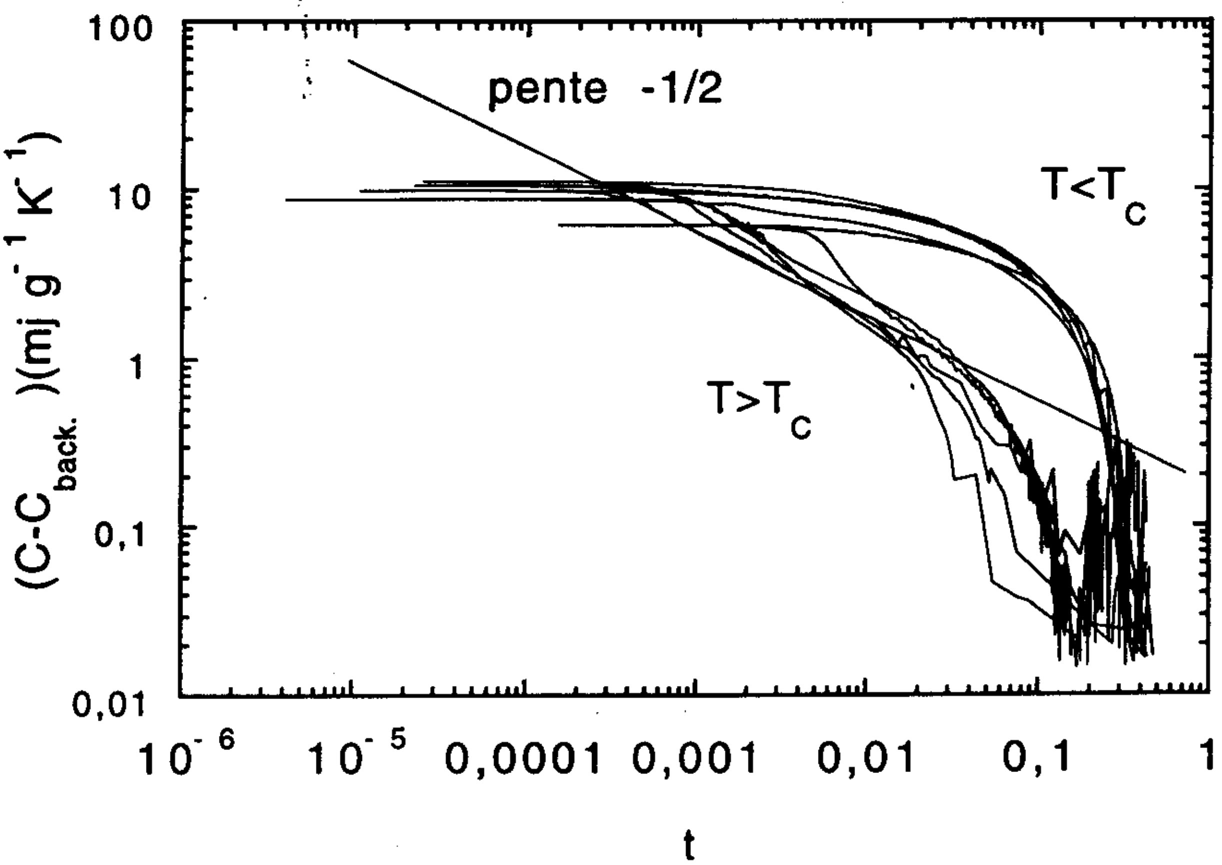
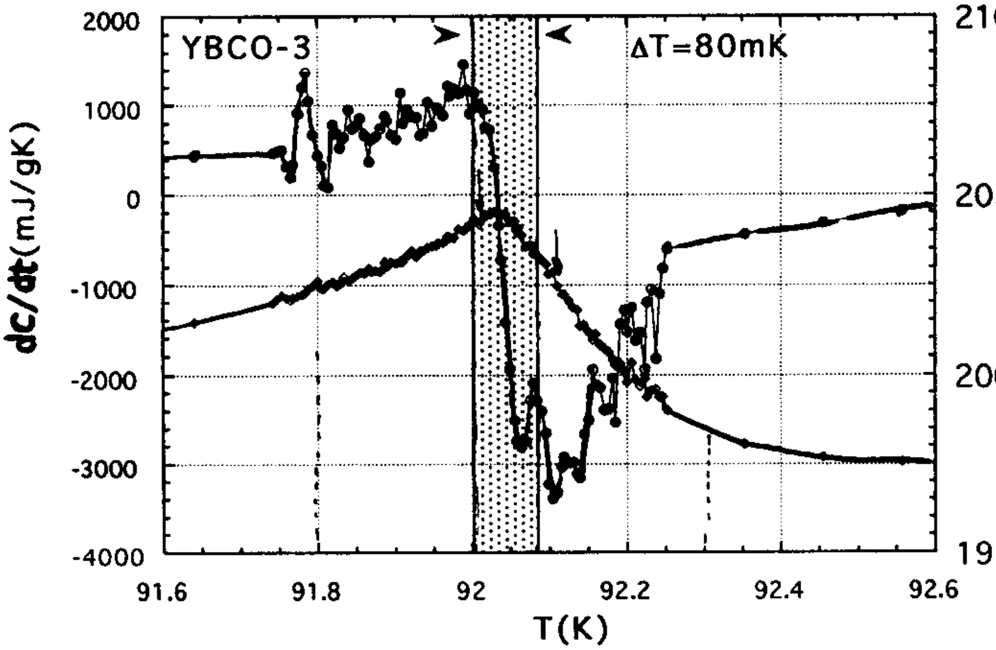
$\nu = 2/3$

Hyperscaling relation

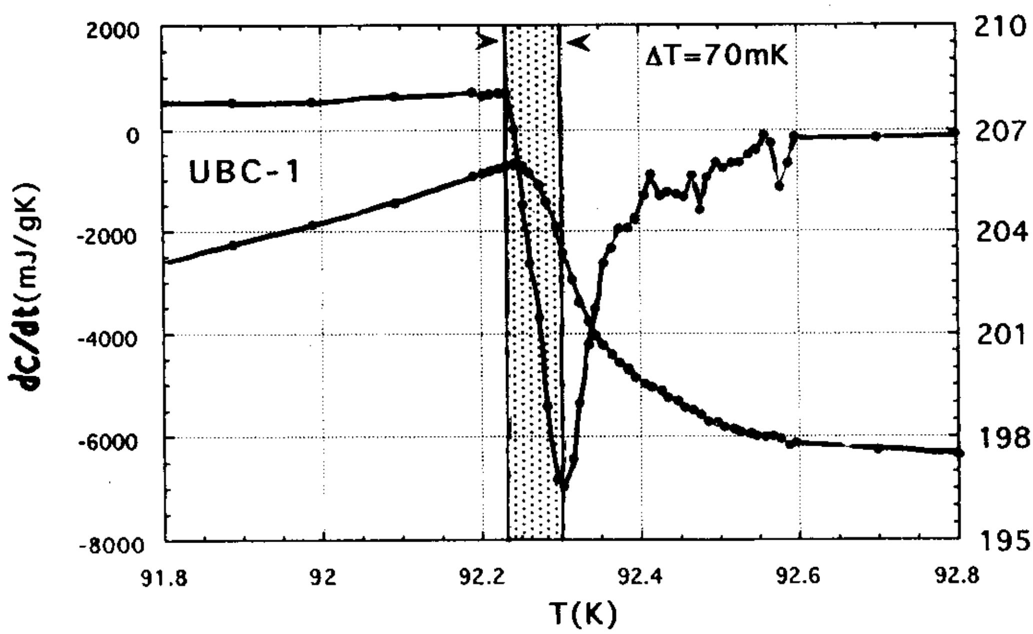
$$2 - \alpha = d \cdot \nu \Rightarrow \alpha = 0$$

Analyse mathématique
des fluctuations

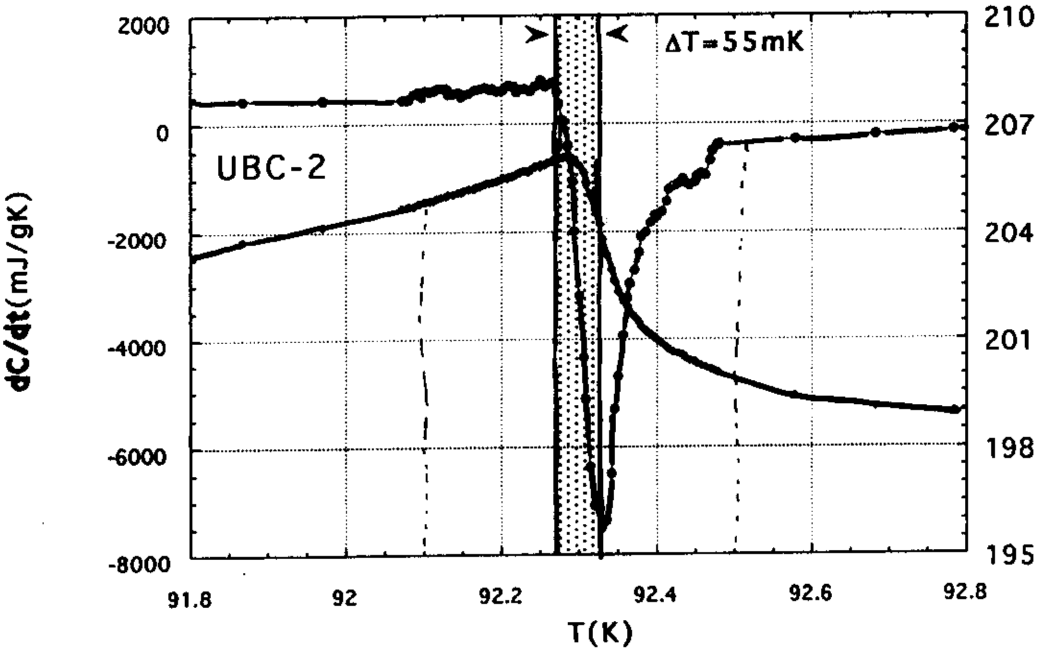




plot 6a



plot 6b



plot 6c → plot 21

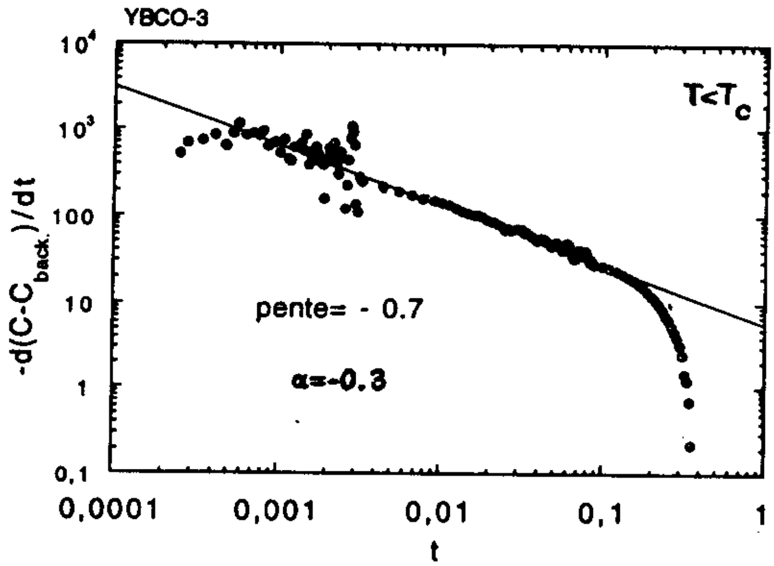
Dérivée $\frac{d}{dt}[C - C_{back}]$

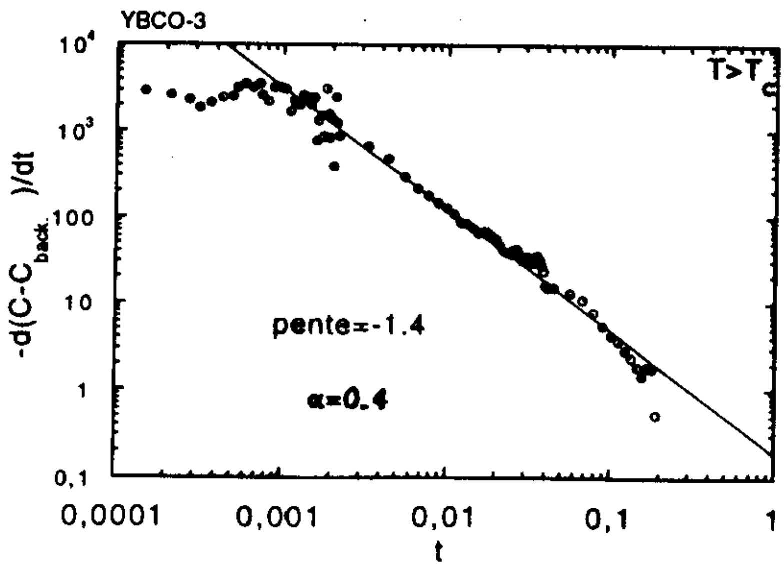
- divergence: $C_{fluct.} = A|t|^{-\alpha}\ (\alpha > 0) \Rightarrow -\frac{dC_{fluct.}}{d|t|} = A\alpha|t|^{-(\alpha+1)}\ \ (\alpha + 1 \geq 1)$

  exposant gaussien 0.5

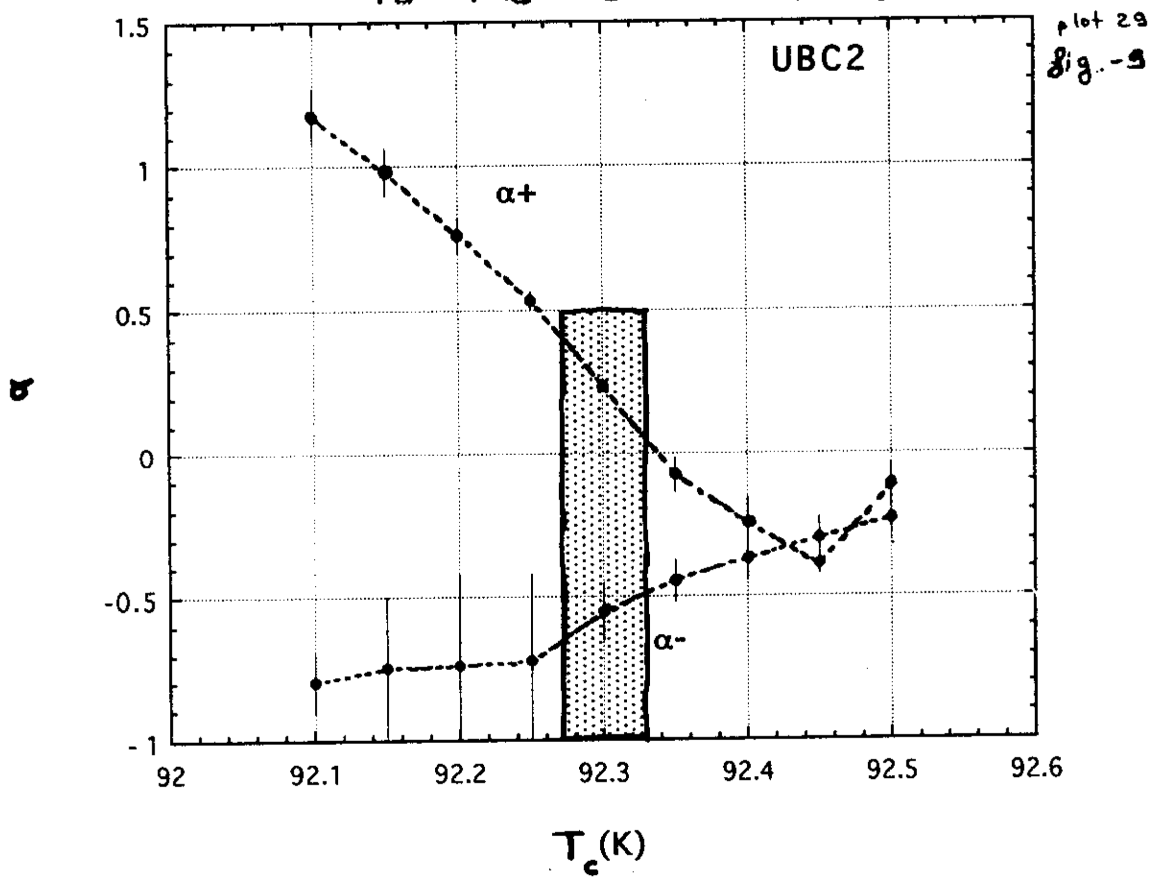
- Cusp:

$$C_{fluct.} = C_0 - A|t|^{-\alpha}\ (\alpha < 0) \Rightarrow -\frac{dC_{fluct.}}{d|t|} = A\alpha|t|^{-(\alpha+1)}\ \ (\alpha + 1 \leq 1)$$



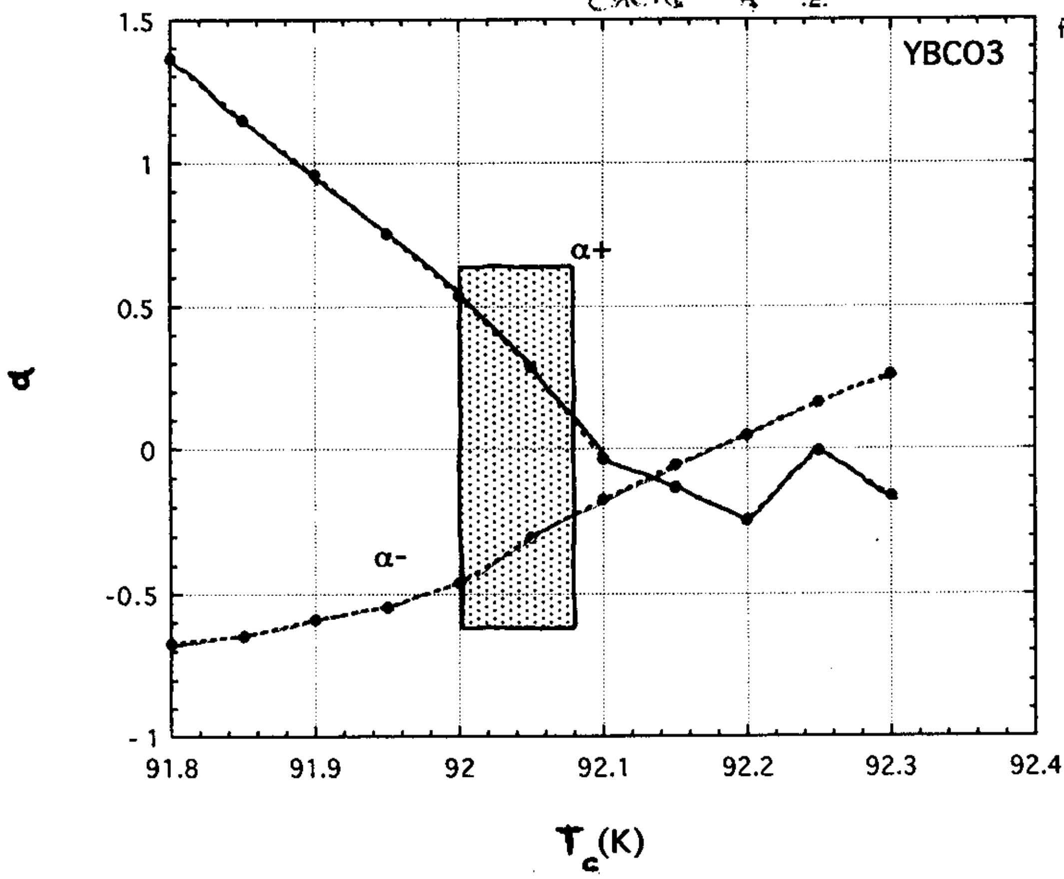


Sensitivity of the exponent to the choice of T_c

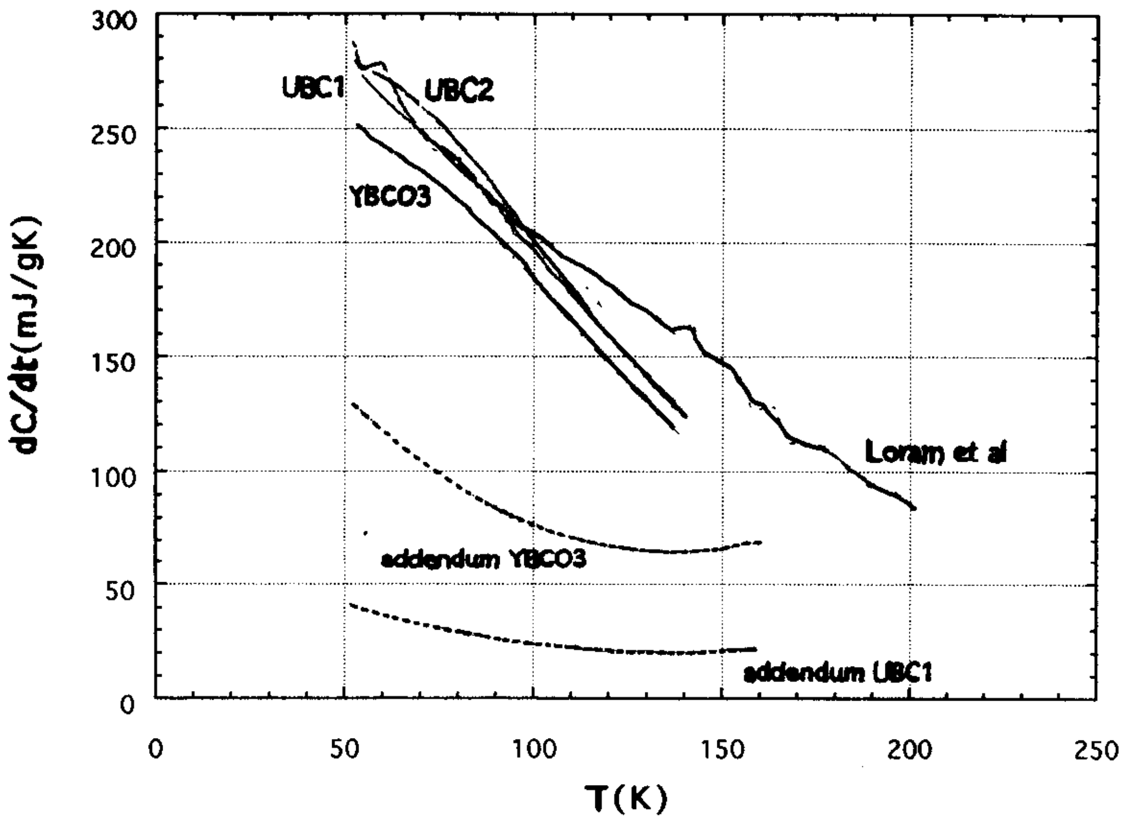


Sensitivity of the exponent to the choice of T_c

plot 33
fig-10



Estimation of backgroud slope



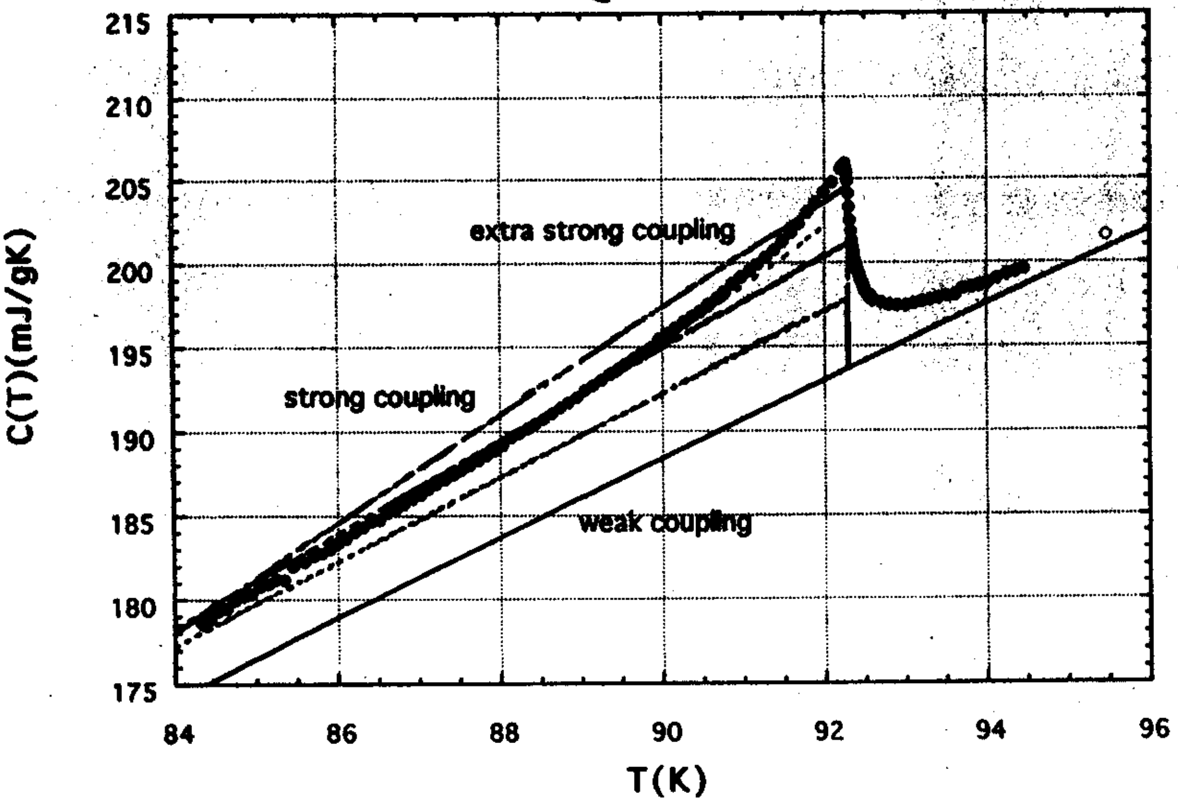
<u>110K</u> $b_{Loram} = 192$ mJ/gK → discrepancy of 7%
$b_{UBC2} = 179$ mJ/gK

<u>Addendum</u> $b_{UBC2} = 26$ mJ/gK → discrepancy of 3%
30% precision

$b_{YBCO} = 83$ mJ/gK → discrepancy of 10%
30% precision

Overall uncertainty in background slope: $0.9b_0 \rightarrow 1.1\ b_0$

Mean field step



weak coupling slope $b = 10 \frac{mJ}{gK}$ → 5% of total

strong coupling slope $b = 36 \frac{mJ}{gK}$ → 20% of total

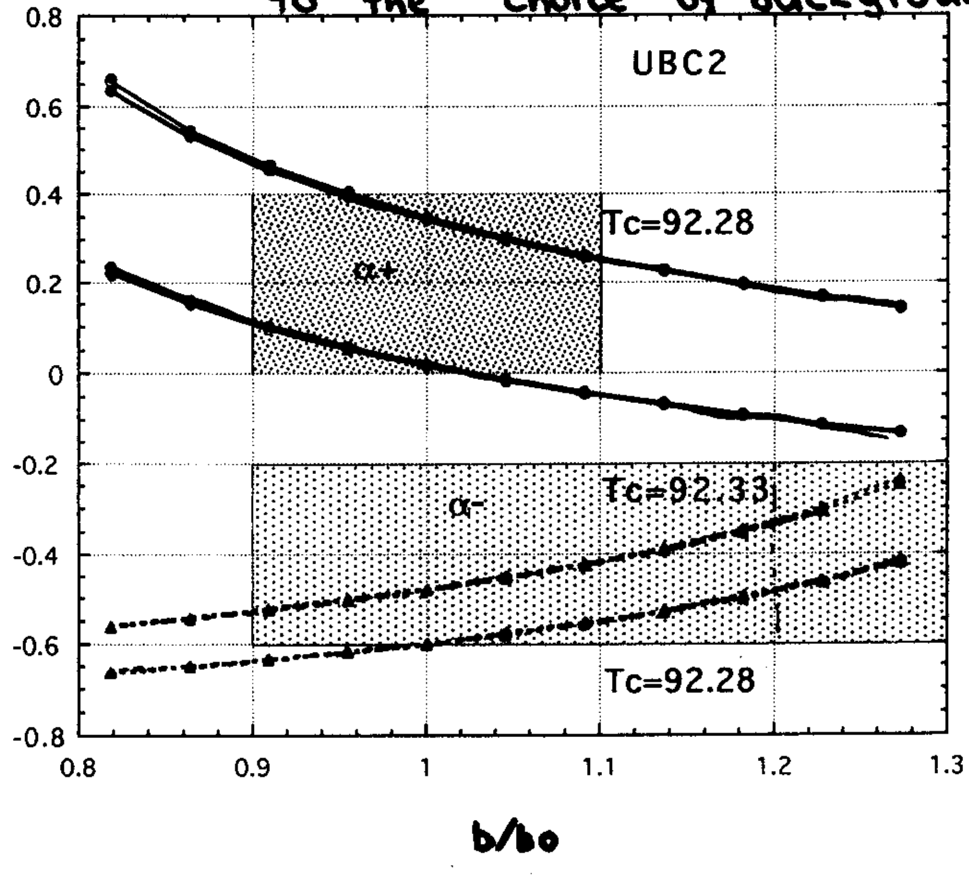
Overall window in background slope:

$T > T_c$ $0.8\, b_c \rightarrow 1.1\, b_c$

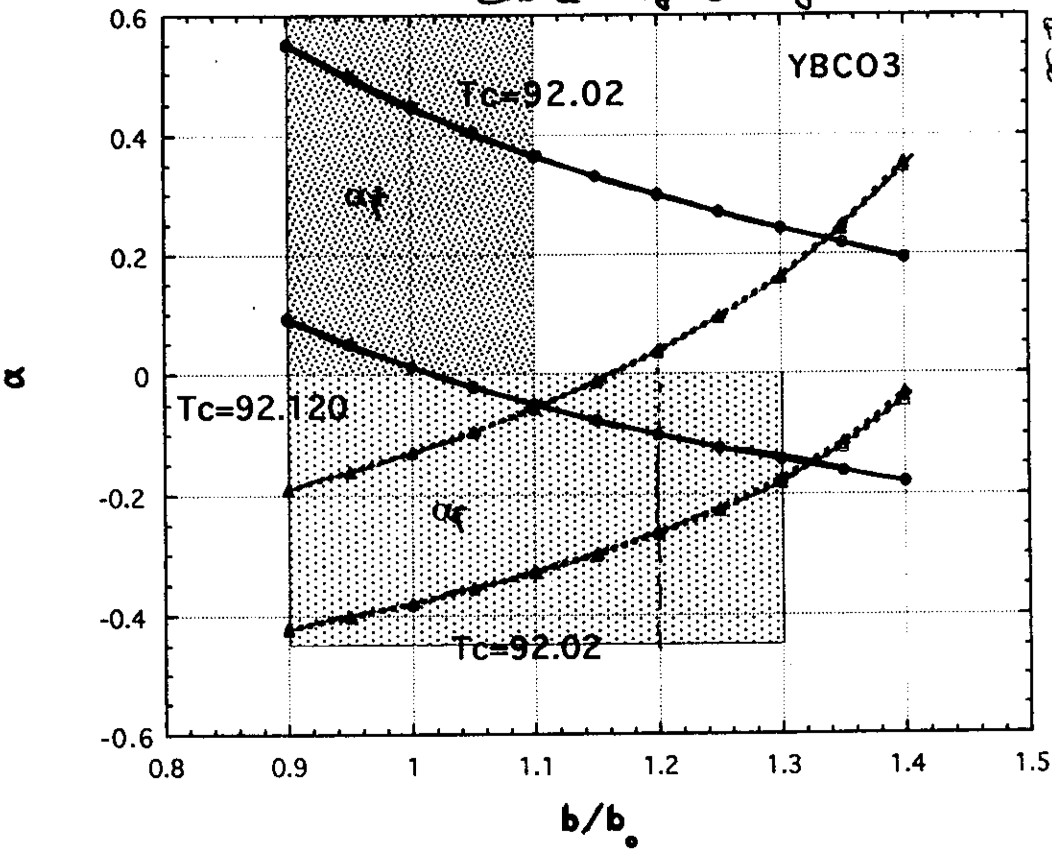
$T < T_c$ $0.9\, b_c \rightarrow 1.3\, b_c$

Sensitivity of the exponent to the choice of background

plot 18
fig. 14.

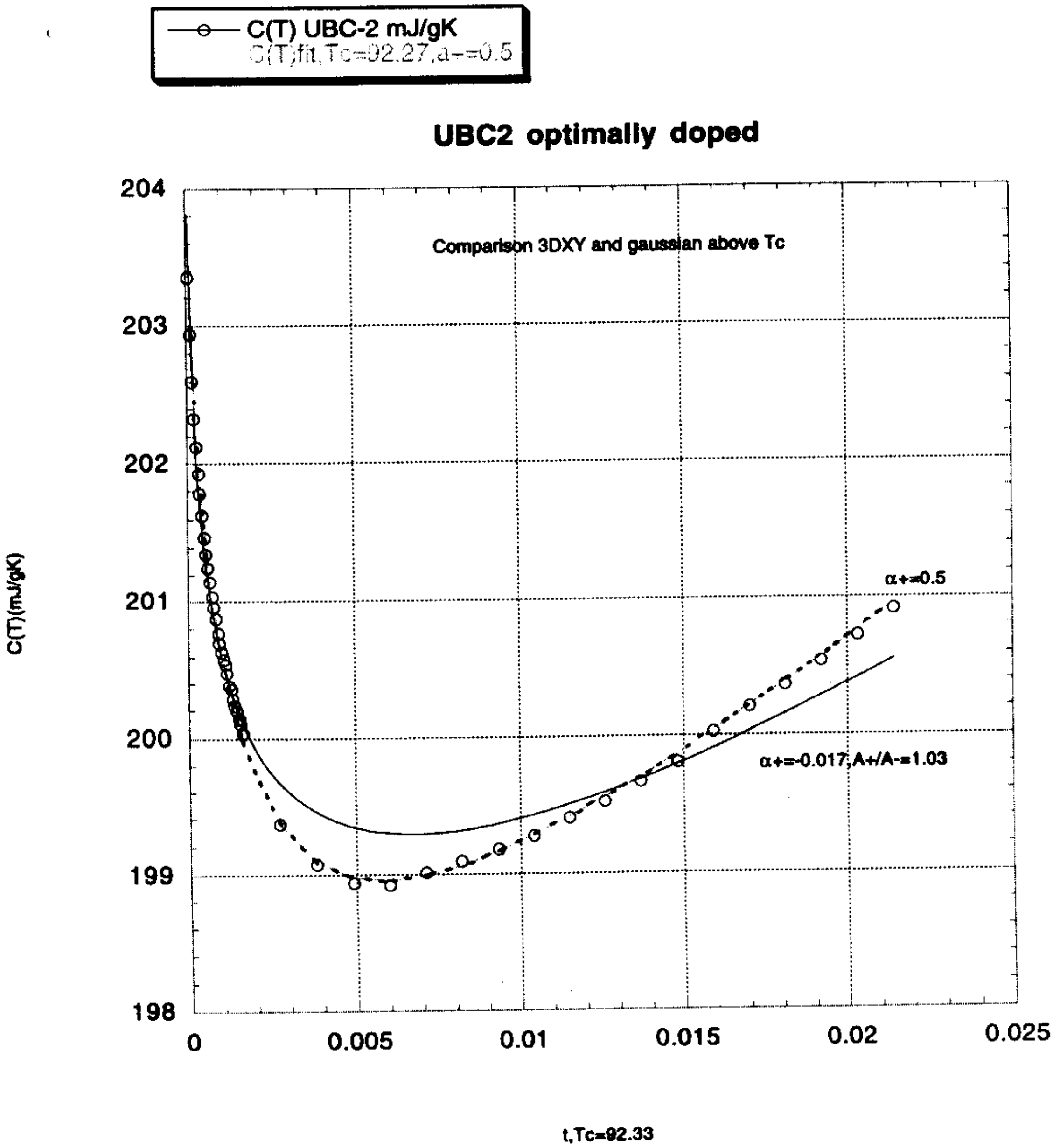


Sensitivity of the exponent to the choice of background

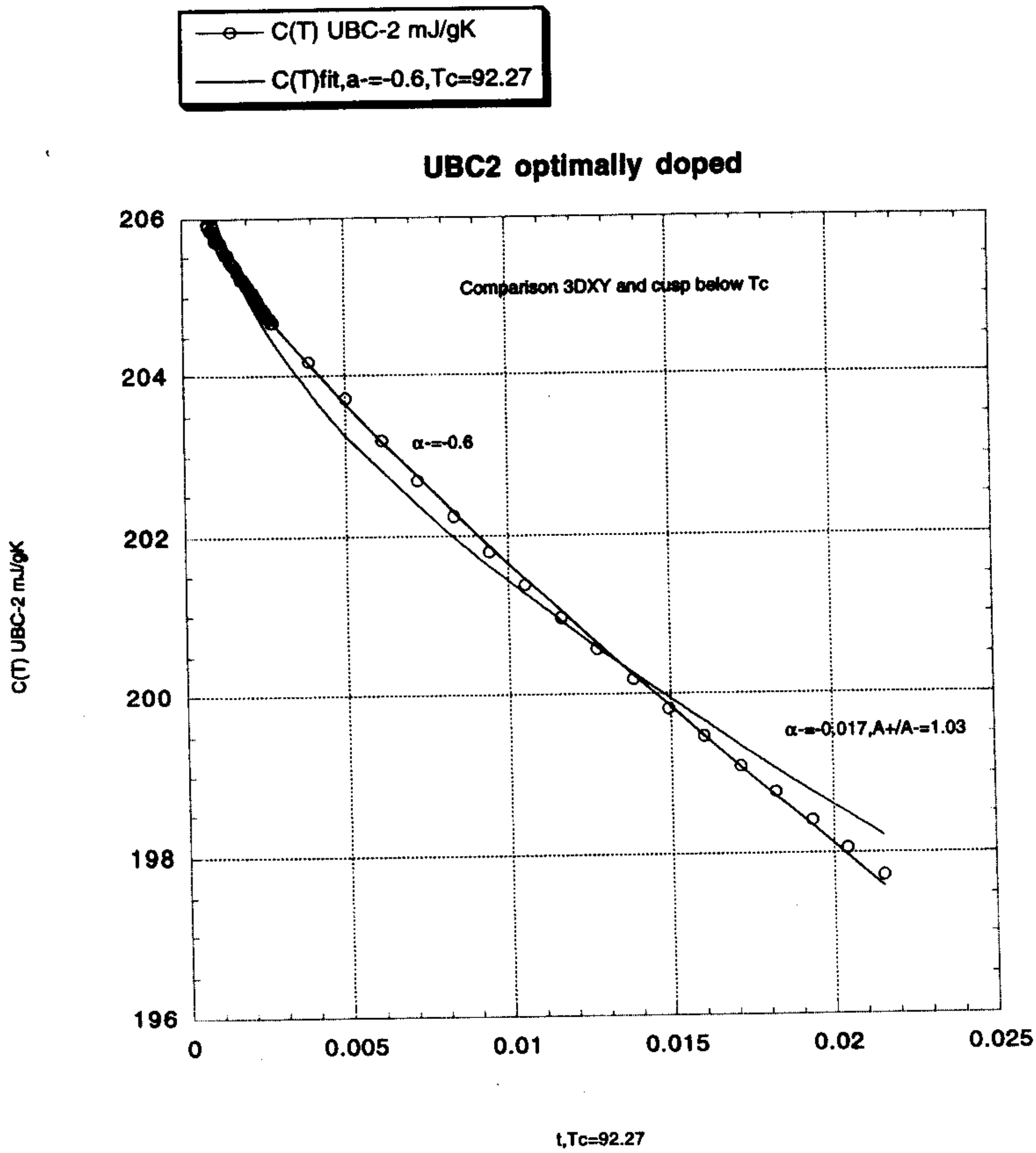


plot 10
γ_δ -1.3

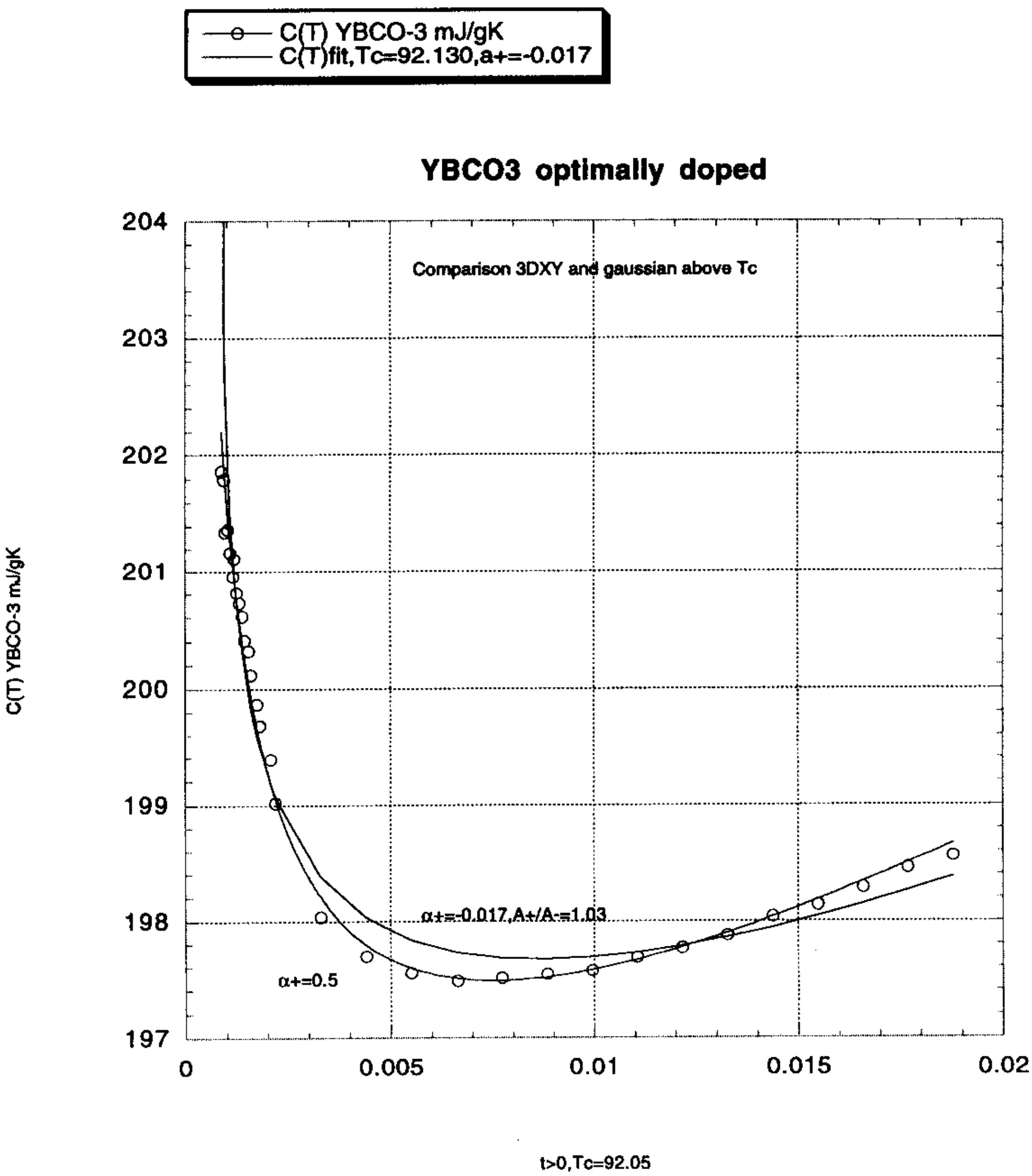
plot6


C(T) UBC-2 mJ/gK
C(T)fit,Tc=92.27,a-=0.5
UBC2 optimally doped
Comparison 3DXY and gaussian above Tc
α+=0.5
α+=-0.017,A+/A-=1.03
204
203
202
201
200
199
198
C(T)(mJ/gK)
0
0.005
0.01
0.015
0.02
0.025
t,Tc=92.33

plot 8

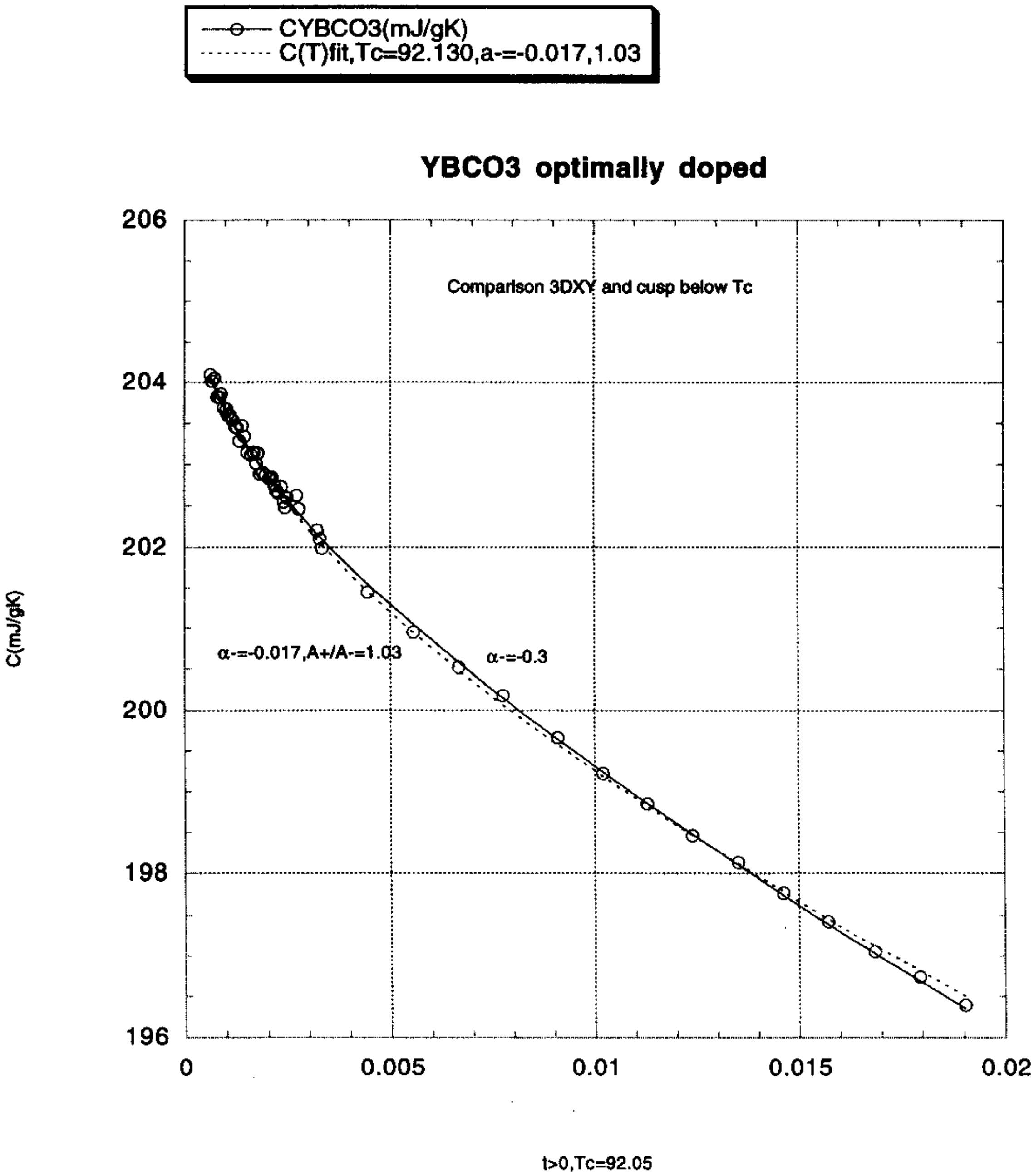

C(T) UBC-2 mJ/gK
C(T)fit,a-=-0.6,Tc=92.27
UBC2 optimally doped
Comparison 3DXY and cusp below Tc
α-=-0.6
α-=-0.017,A+/A-=1.03
206
204
202
200
198
196
0
0.005
0.01
0.015
0.02
0.025
C(T) UBC-2 mJ/gK
t,Tc=92.27

plot10

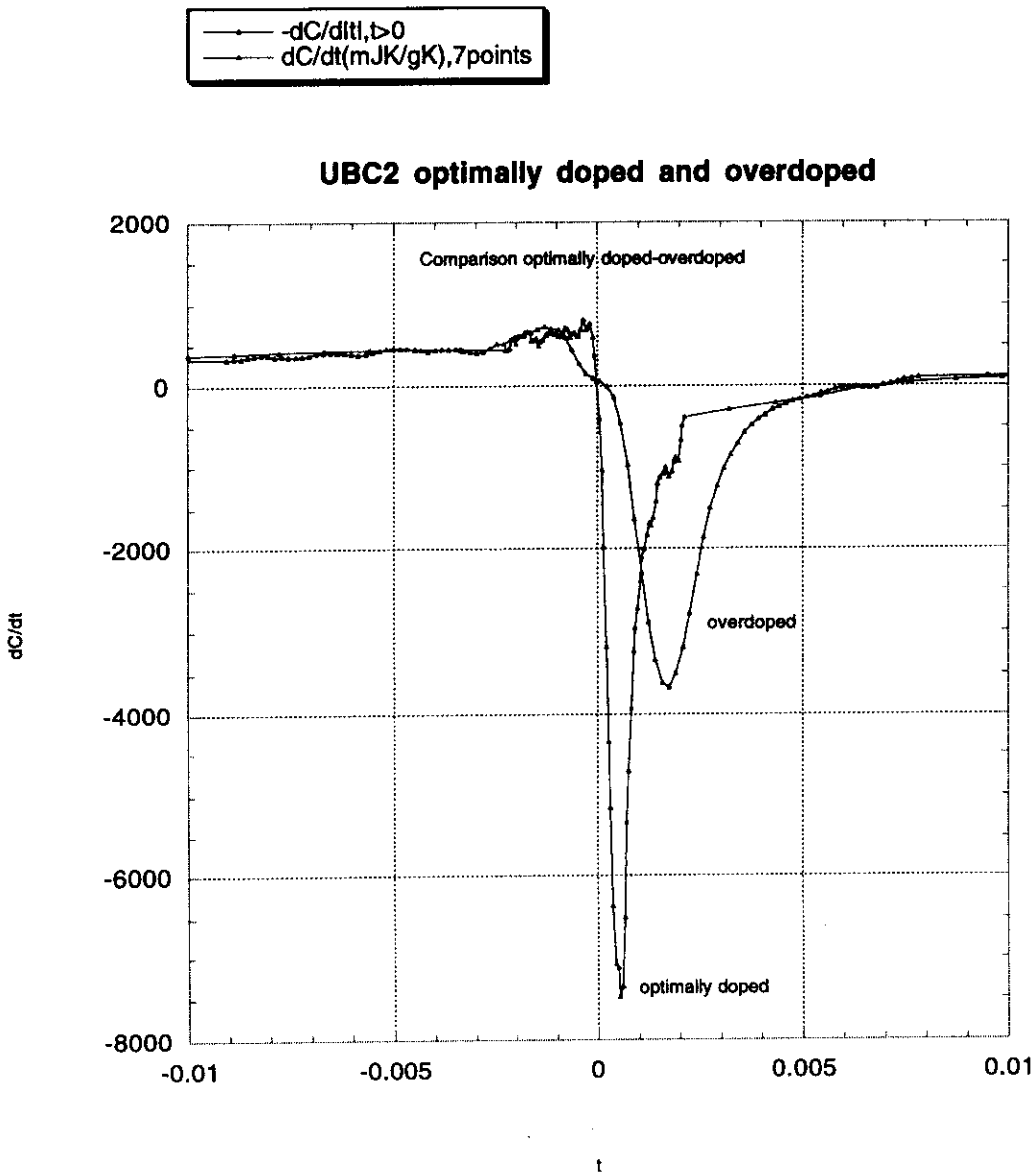


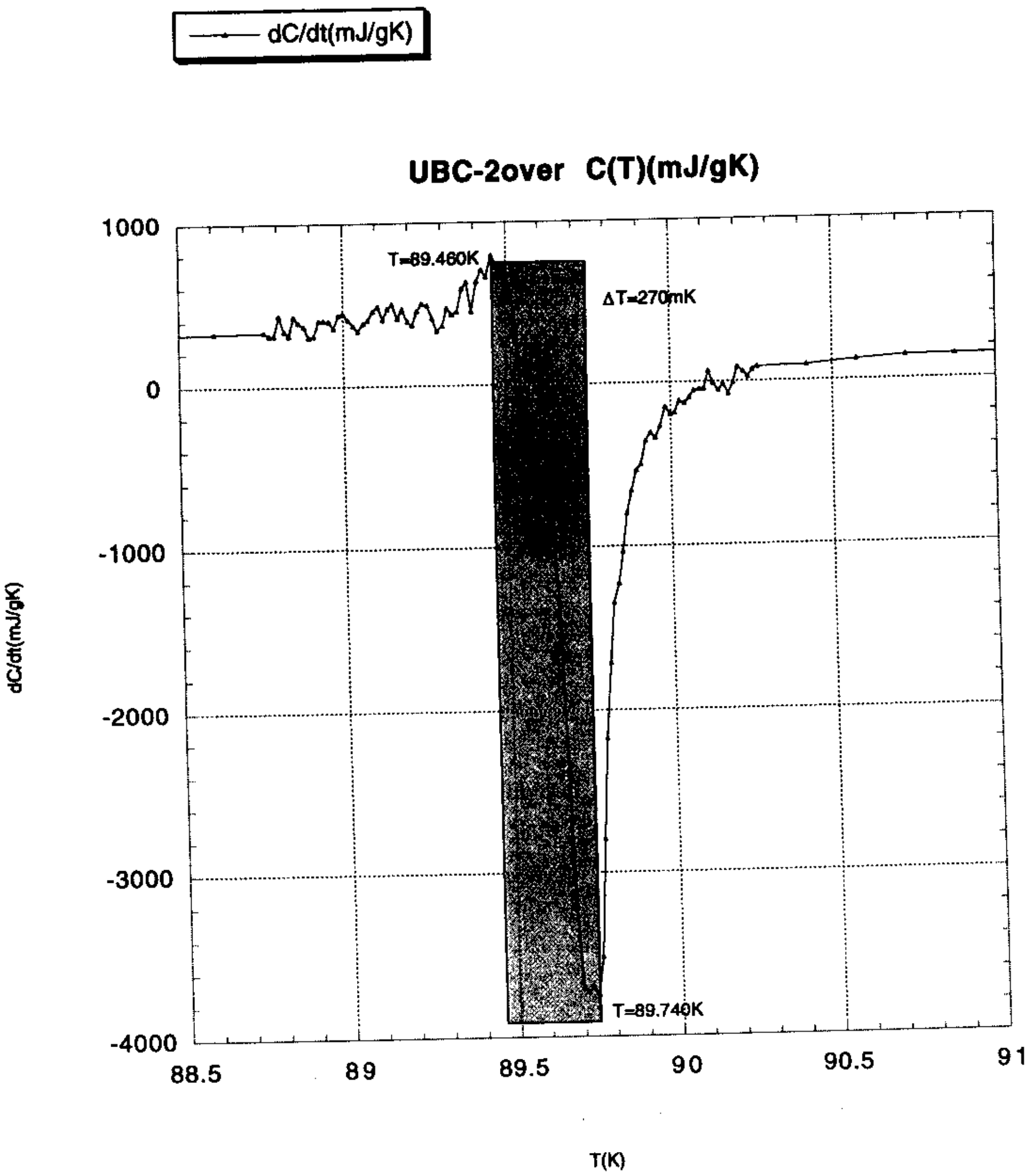
C(T) YBCO-3 mJ/gK
C(T)fit,Tc=92.130,a+=-0.017
YBCO3 optimally doped
Comparison 3DXY and gaussian above Tc
α+=-0.017,A+/A-=1.03
α+=0.5
204
203
202
201
200
199
198
197
0
0.005
0.01
0.015
0.02
C(T) YBCO-3 mJ/gK
t>0,Tc=92.05

p.6+12

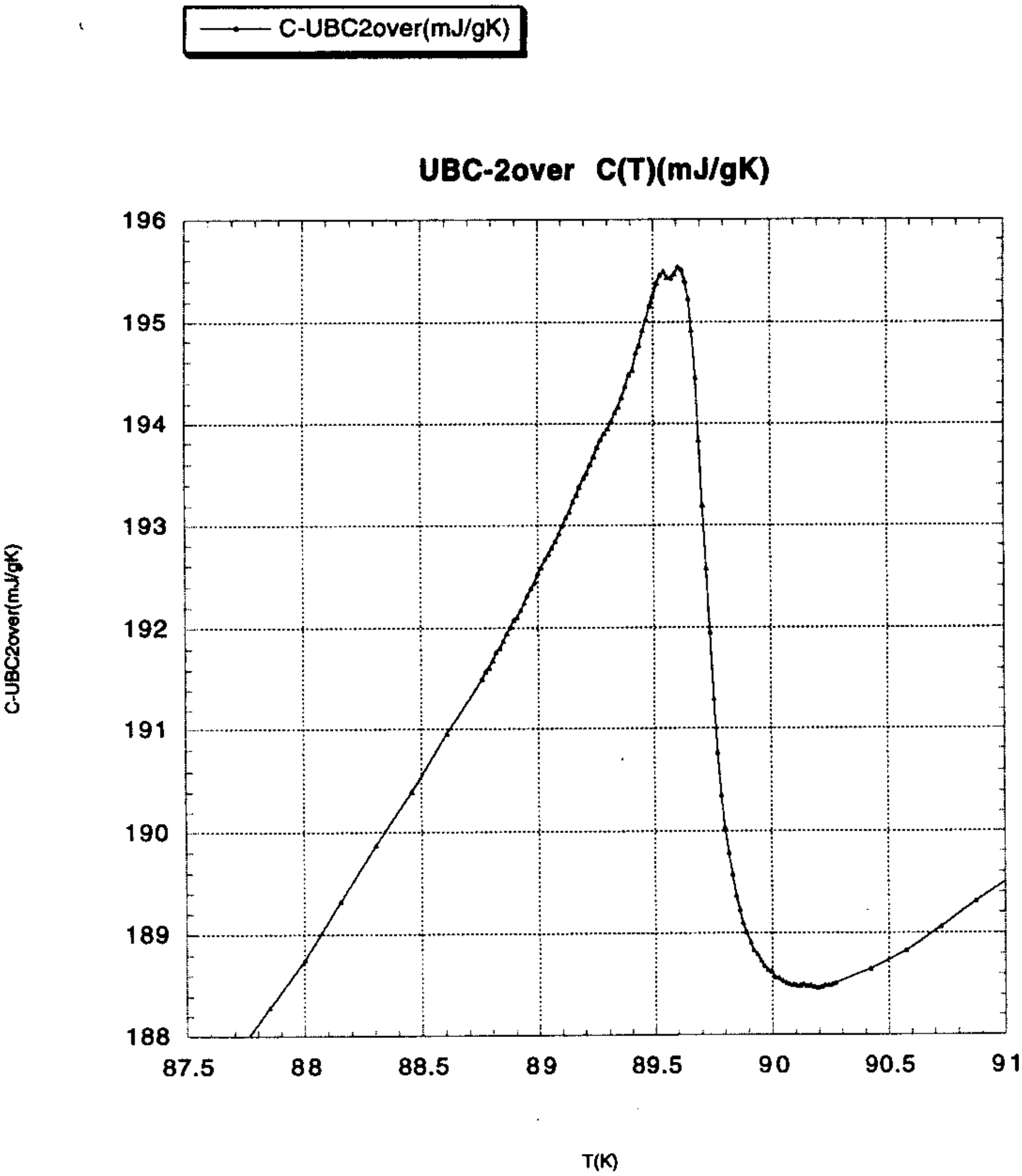


CYBCO3(mJ/gK)
C(T)fit,Tc=92.130,a-=-0.017,1.03
YBCO3 optimally doped
Comparison 3DXY and cusp below Tc
α-=-0.017,A+/A-=1.03
α-=-0.3
C(mJ/gK)
t>0,Tc=92.05
206
204
202
200
198
196
0
0.005
0.01
0.015
0.02


-dC/dtl,t>0
dC/dt(mJK/gK),7points
UBC2 optimally doped and overdoped
Comparison optimally doped-overdoped
overdoped
optimally doped
dC/dt
2000
0
-2000
-4000
-6000
-8000
-0.01
-0.005
0
0.005
0.01
t

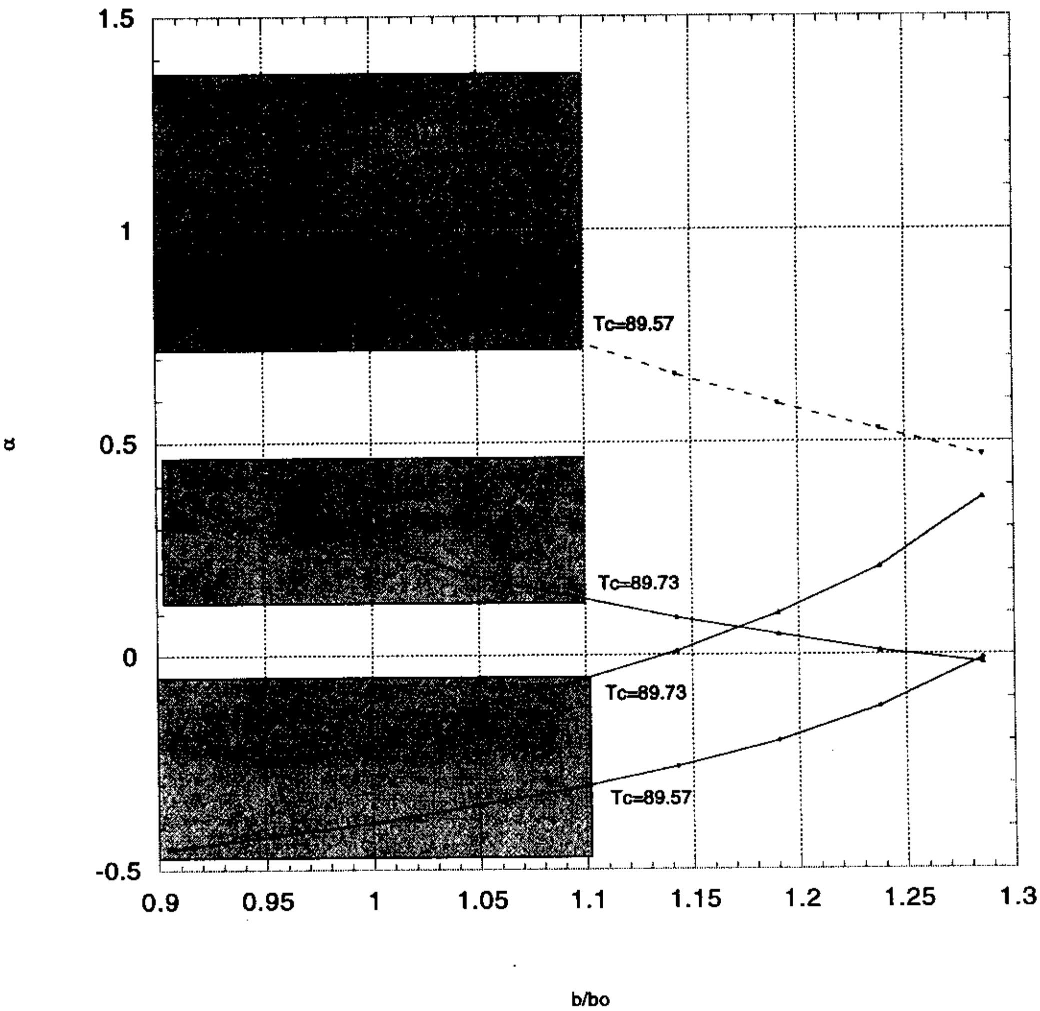


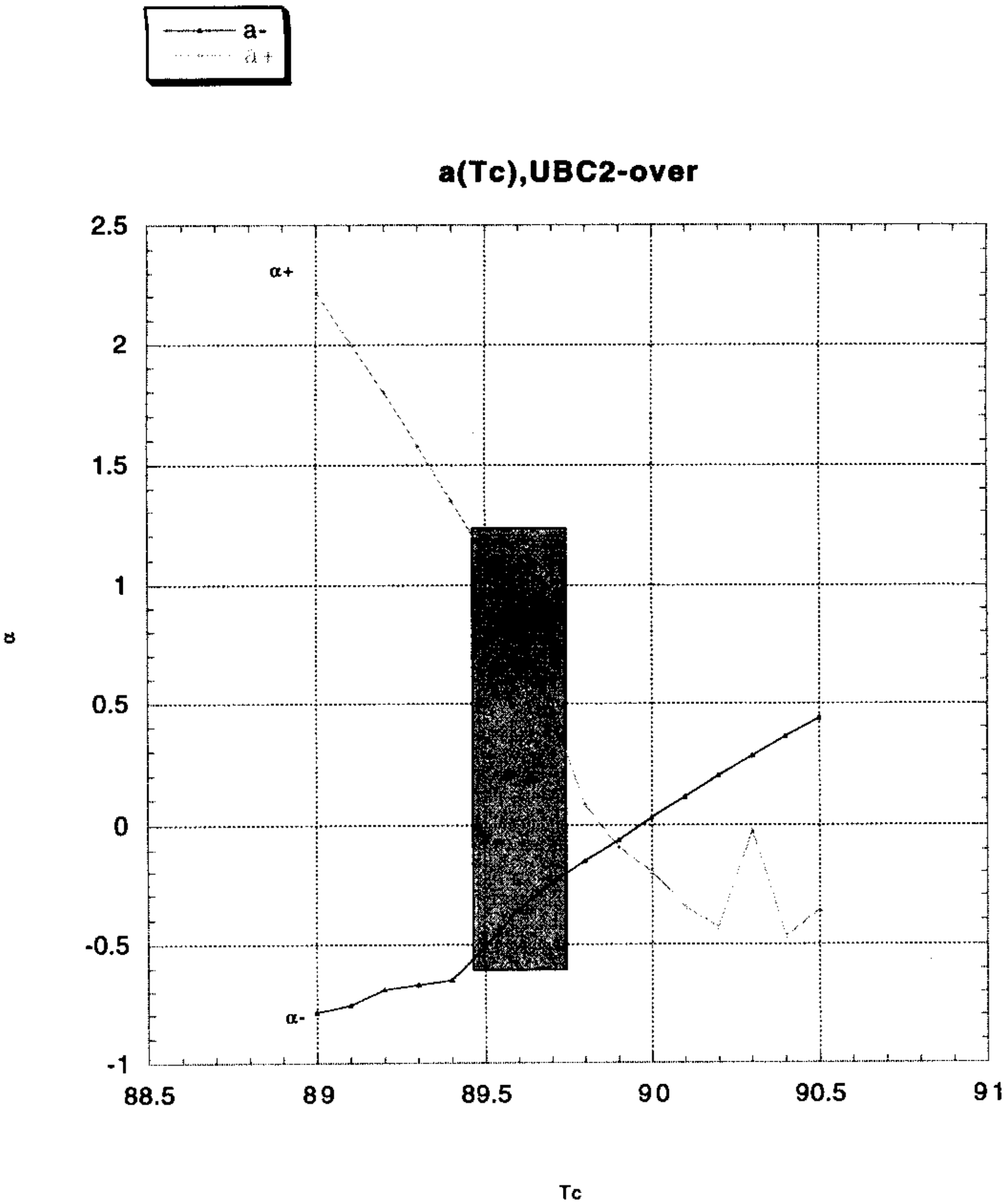
dC/dt(mJ/gK)
UBC-2over C(T)(mJ/gK)
T=89.460K
ΔT=270mK
T=89.740K
1000
0
-1000
-2000
-3000
-4000
88.5
89
89.5
90
90.5
91
dC/dt(mJ/gK)
T(K)



89 → 90.5 = 1.5K every 100 mK

a(b),UBC2over,Tc=89.73

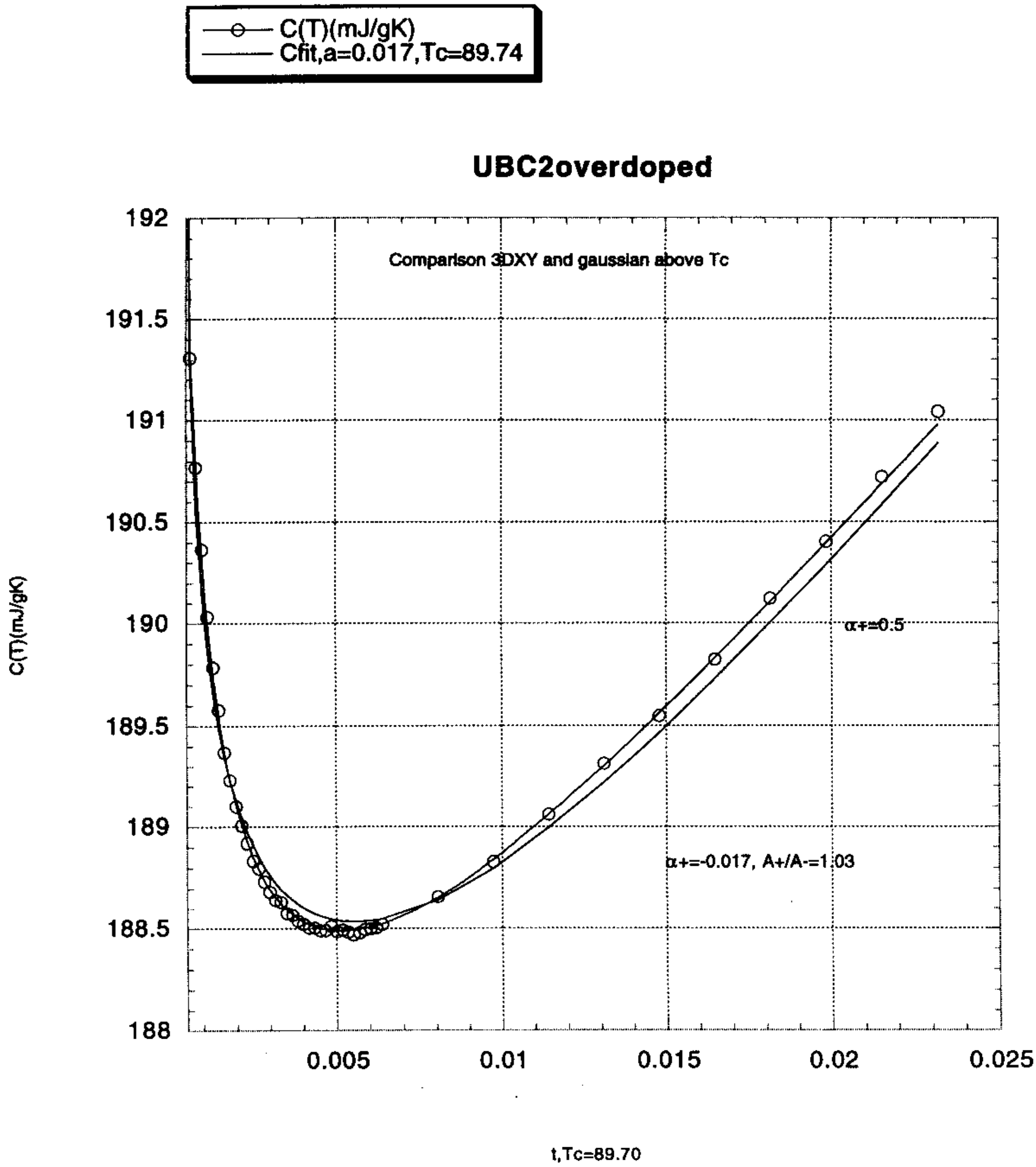




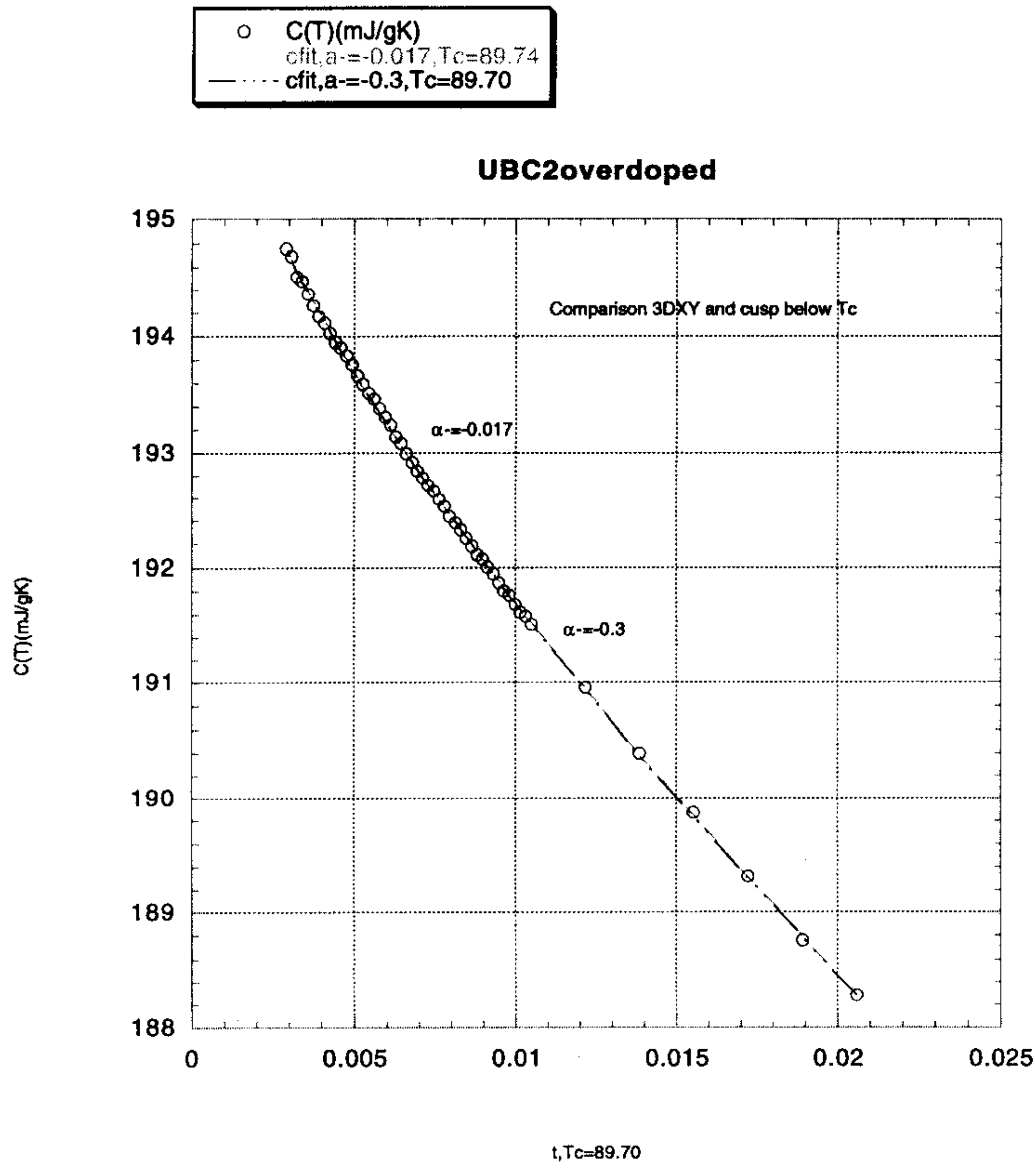
try 8970

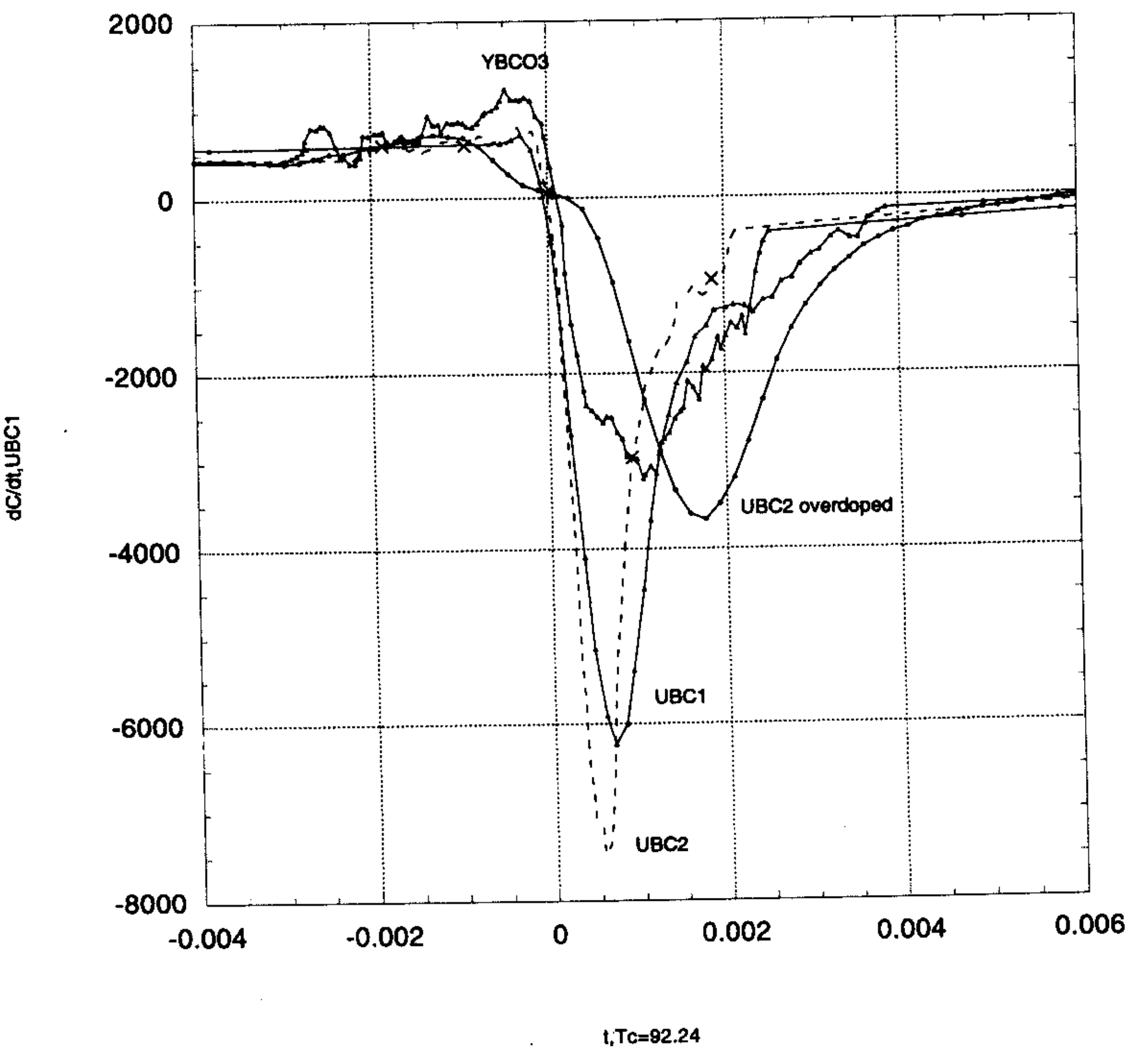
$\alpha- = -0.\overset{\text{best}}{\downarrow}3 \rightarrow -0.2$

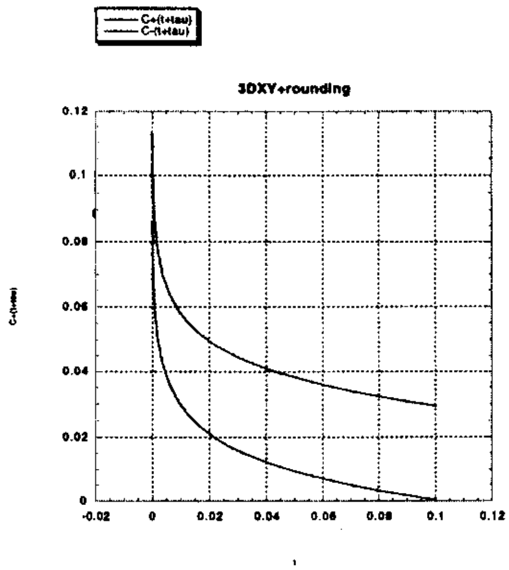
$\alpha+ = 0.5$



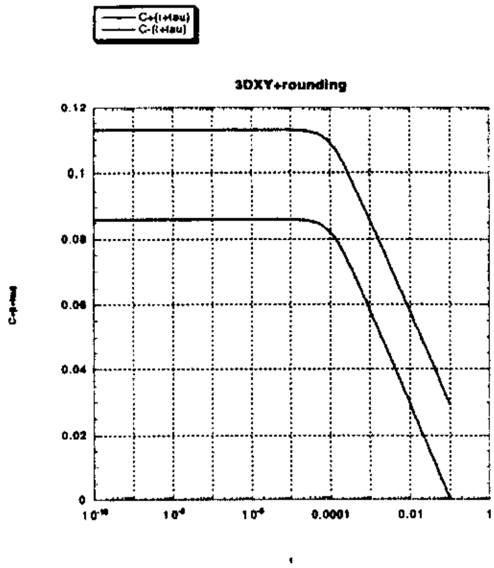
C(T)(mJ/gK)
Cfit,a=0.017,Tc=89.74
UBC2overdoped
Comparison 3DXY and gaussian above Tc
α+=0.5
α+=-0.017, A+/A-=1.03
192
191.5
191
190.5
190
189.5
189
188.5
188
0.005
0.01
0.015
0.02
0.025
C(T)(mJ/gK)
t,Tc=89.70


C(T)(mJ/gK)
cfit,a-=-0.017,Tc=89.74
cfit,a-=-0.3,Tc=89.70
UBC2overdoped
Comparison 3DXY and cusp below Tc
α-=-0.017
α-=-0.3
195
194
193
192
191
190
189
188
0
0.005
0.01
0.015
0.02
0.025
C(T)(mJ/gK)
t,Tc=89.70

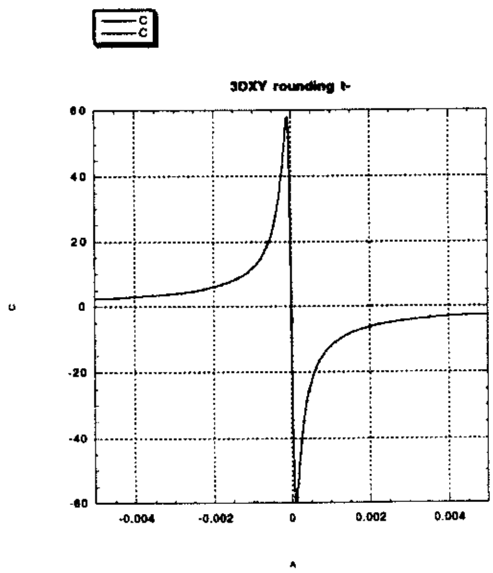

2000
0
-2000
-4000
-6000
-8000
-0.004
-0.002
0
0.002
0.004
0.006
YBCO3
UBC2 overdoped
UBC1
UBC2
dC/dt,UBC1
t,Tc=92.24



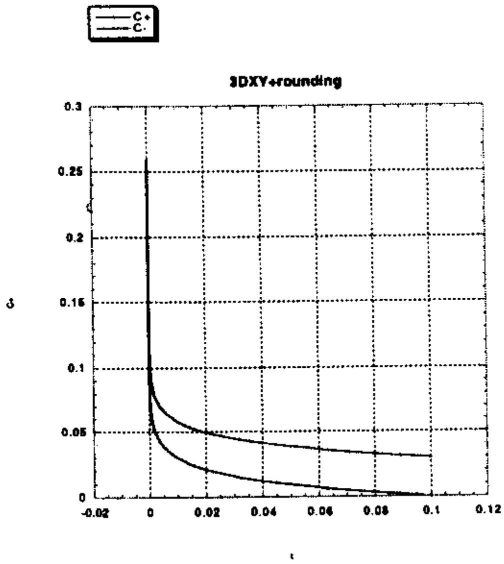
C+(t+tau)
C-(t+tau)
3DXY+rounding
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12

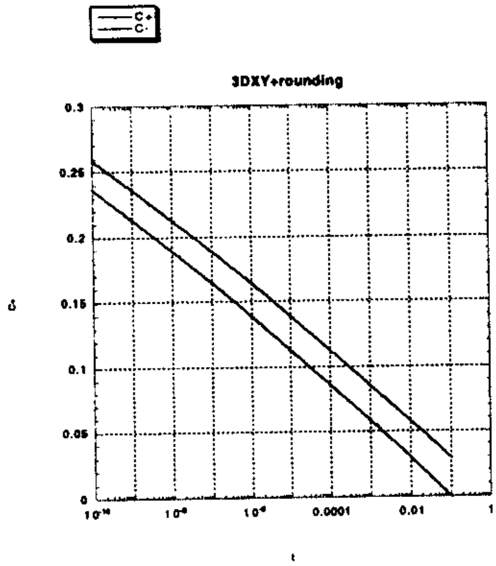


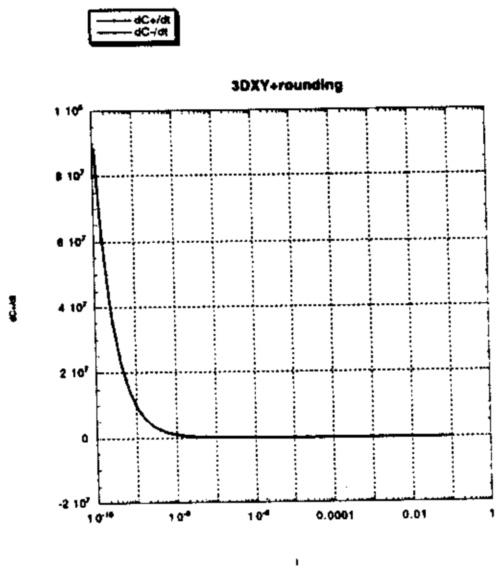
C+(t+tau)
C-(t+tau)
3DXY+rounding
0.12
0.1
0.08
0.06
0.04
0.02
0
0.0001
0.01
1

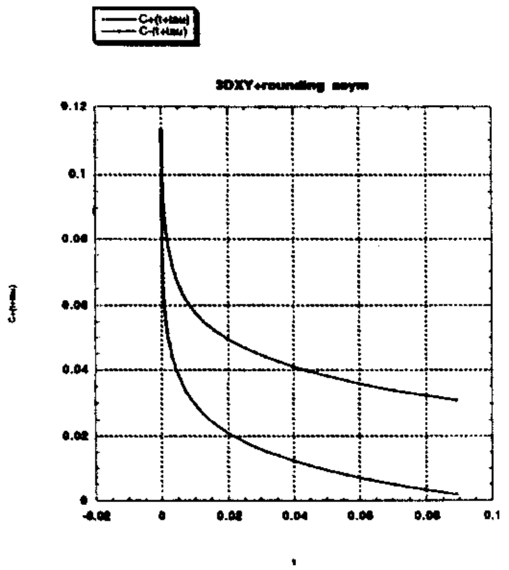


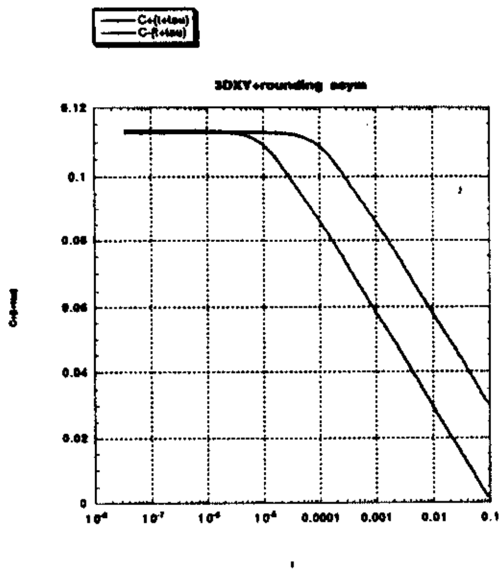
C
C
3DXY rounding t-
60
40
20
0
-20
-40
-60
-0.004
-0.002
0
0.002
0.004

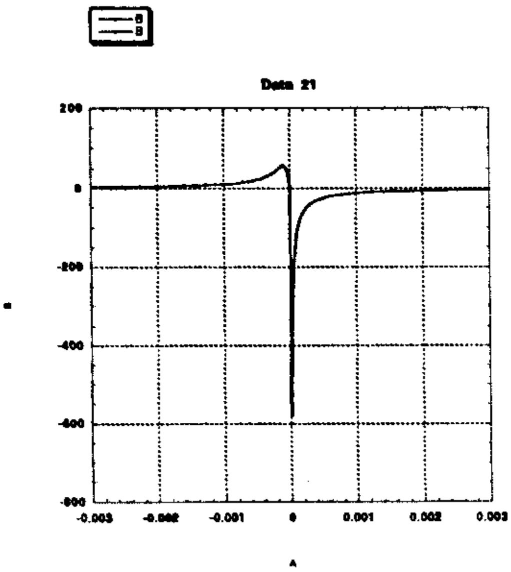

C+
C-
3DXY+rounding
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
t

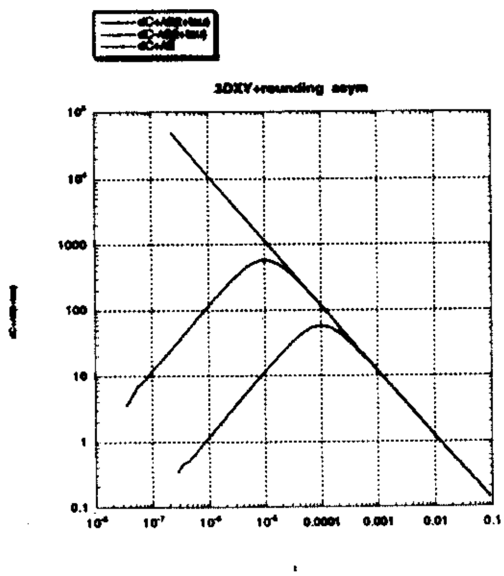

C+
C-
3DXY+rounding
0.3
0.25
0.2
0.15
0.1
0.05
0
0.0001
0.01
1
t

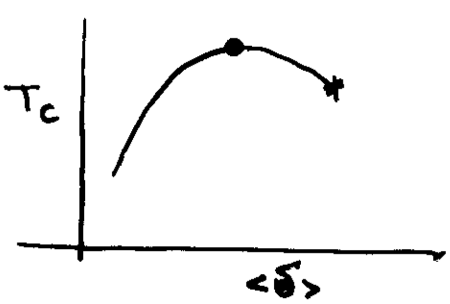

dC+/dt
dC-/dt
3DXY+rounding
0
0.0001
0.01
1

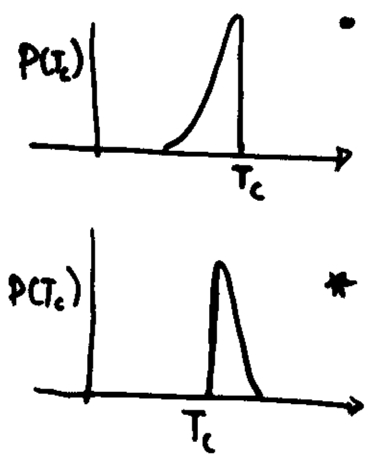

C+(t+tau)
C-(t+tau)
3DXY+rounding asym
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0
0.02
0.04
0.06
0.08
0.1


C+(t+tau)
C-(t+tau)
3DXY+rounding asym
0.12
0.1
0.08
0.06
0.04
0.02
0
0.0001
0.001
0.01
0.1

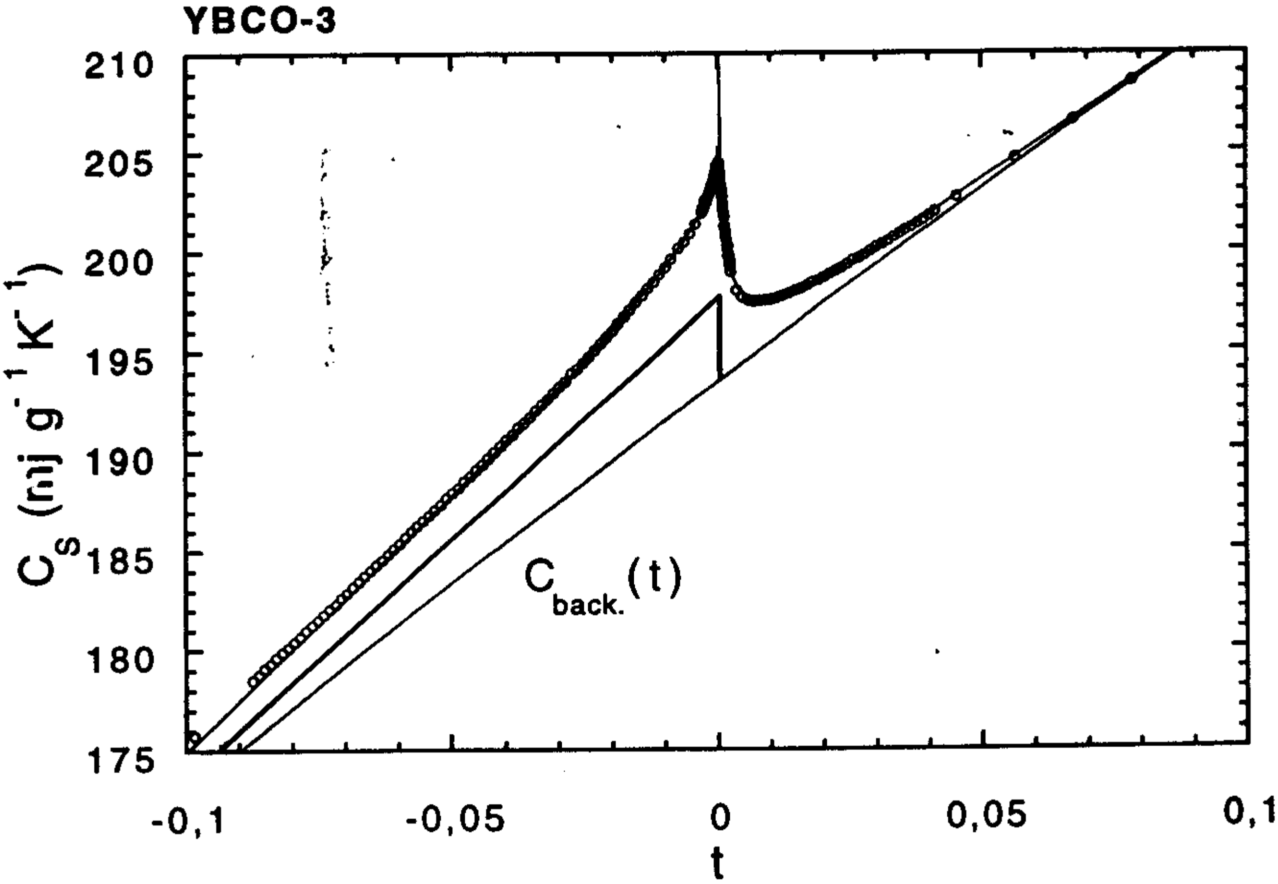

B
B
Data 21
200
0
-200
-400
-600
-800
-0.003
-0.002
-0.001
0
0.001
0.002
0.003
A


3DXY+rounding asym
1000
100
10
1
0.1
0.0001
0.001
0.01
0.1


Tc
<δ>


P(Tc)
Tc
P(Tc)
Tc

Conclusion sur les exposants
pour le composé YBaCuO



$$en\ dessus\ \ de\ T_c: C(t) = C_{back}(t) + C^{+}(t)^{-\alpha^{+}} \quad \alpha^{+}=0.5$$

$$en\ dessous\ de\ T_c: C(t) = C_{back}(t) + C_0 - C^{-}(-t)^{-\alpha^{-}} \quad \alpha^{-}=-0.3$$

	YBCO-1	YBCO-2	YBC3-3	UBC-1	UBC-2
$T_c(K)$	91.2	92.2	92.02	92.24	92.28
α^-	-0.4	-0.23	-0.29	-0.35	-0.35
C_0 $\left(mJ\,g^{-1}\,K^{-1}\right)$	9.6	11.3	12.6	12.44	12.8
α^+	0.56	0.65	0.5	0.52	0.44
C^+ $\left(mJ\,g^{-1}\,K^{-1}\right)$	0.38	0.33	0.31	0.23	0.25

$$C_0 = 12{,}6\ mJ\ g^{-1}\ K^{-1}$$

$$\alpha^- = -0{,}3 \pm 0.05$$
$$\alpha^+ = 0{,}5 \pm 0.1$$

$$C^+ = 0.26\ mJ\ g^{-1}\ K^{-1}$$

$$\xi_0 = (\xi_{ab}^2 \xi_c)^{1/3} = n^{1/3}\left(\frac{k_b}{16\pi\rho C^+}\right)^{1/3} \approx n^{1/3}.5{,}5\mathring{A}$$

$$n = 2 \quad \xi_0 = 6.3\mathring{A}$$
$$n = 4 \quad \xi_0 = 8.7\mathring{A}$$

Conclusion

Réalisation d'un dispositif de micro-calorimétrie très performant

$m \sim 10\ \mu g$, $2 \mu J/K$

Résolution en C: 0.1 nJ/K
$\delta T_{ac} = 1\ \mu K$ à 100K

Résolution en T: 1 mK

Précision sur Cs < 10%
(définition de la masse)

Etude de la transition de l'YBCO

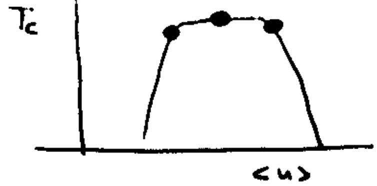
Comportement intrinsèque
$\Delta C = 11$ mJ/gK

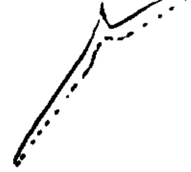
Effet des mâcles sur la transition

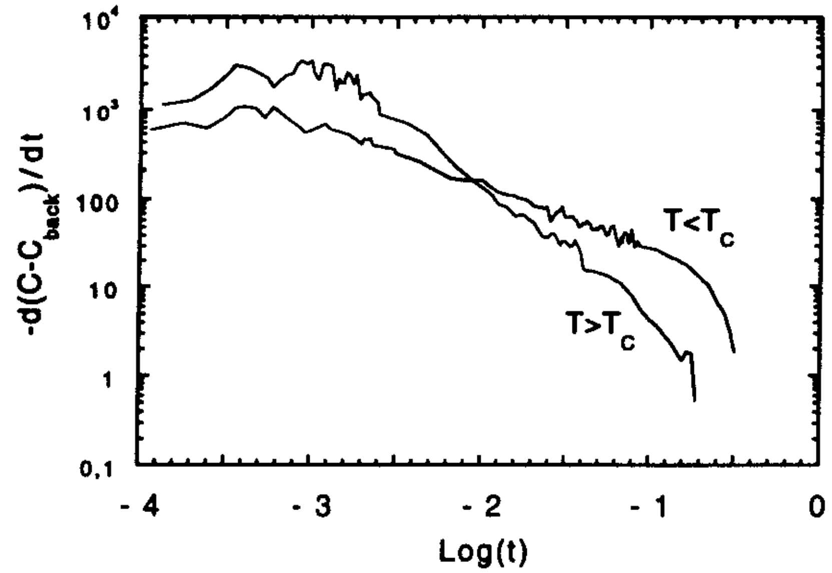
Largeur du désordre dans les meilleurs échantillons
0.2 µm

Dissymétrie du régime des fluctuations
30 mK < T-Tc < 10K

T<Tc: cusp $\alpha^{-} = -0.30 \pm 0.05$
T>Tc: divergence $\alpha^{+} = 0.5 \pm 0.1$



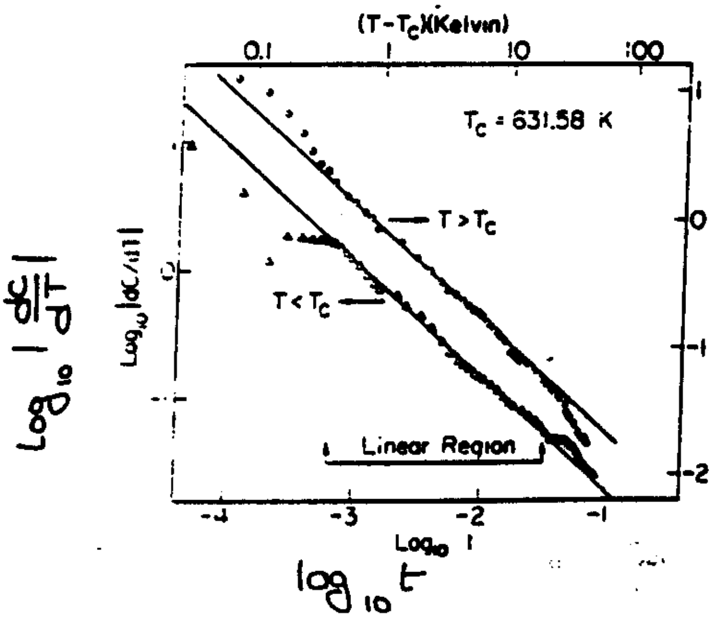




Transition supraconductrice YBaCuO

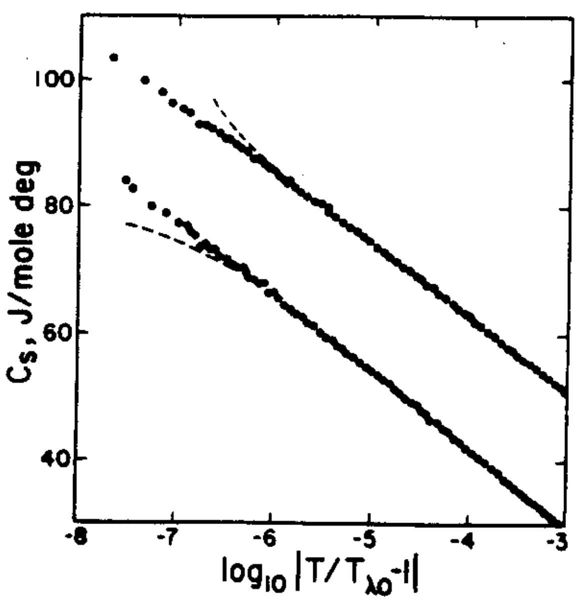
$\alpha^- = -0.3$

$\alpha^+ = 0.5$



Transition magnétique du Nickel

$\alpha^- = \alpha^+ = -0.1$



Transition superfluide ^4He

$\alpha^- = \alpha^+ = -0.013$