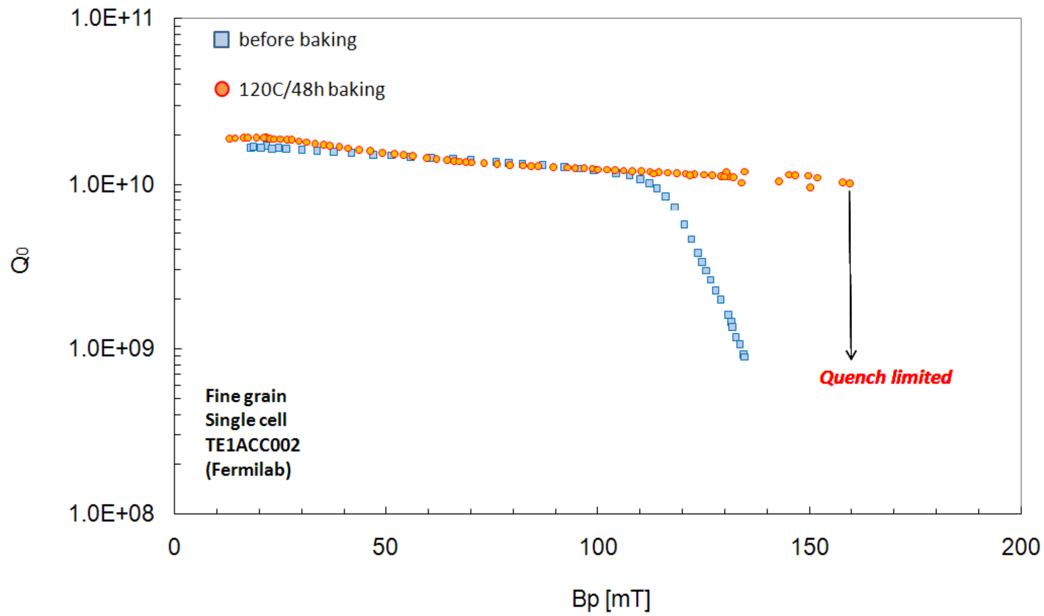
Vortex dissipation as an origin of Q-Slope and Quench

Alexander Dzyuba

Fermilab

2010

Q-Slope and Quench Review



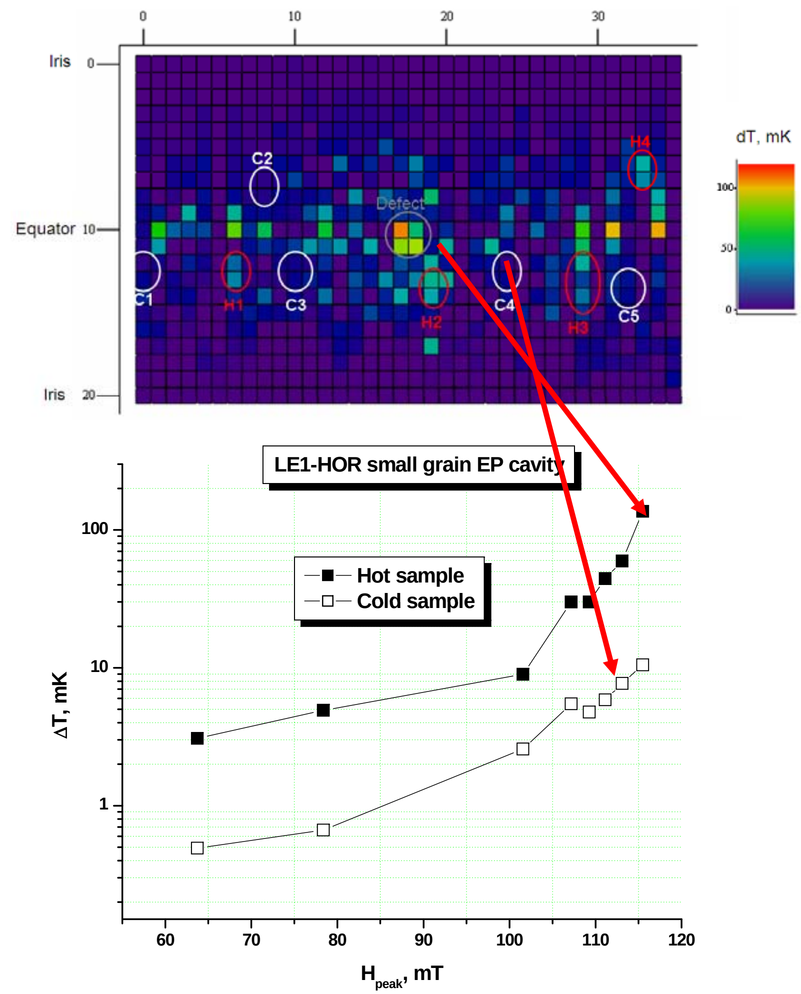
Facts:

1) EP + Baking better than BCP + Baking for FG Nb.
   Without baking 10% difference in onset field.

2) EP + Baking = BCP + Baking for SG Nb.
   Without baking 20% difference in onset field.

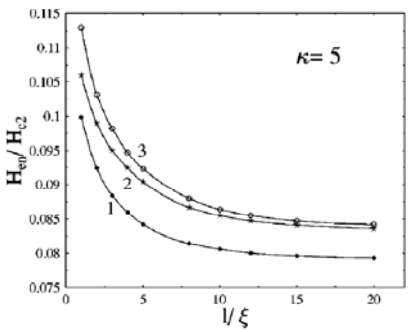
3) SG Nb (no Grain Boundaries) shows Q-Slope

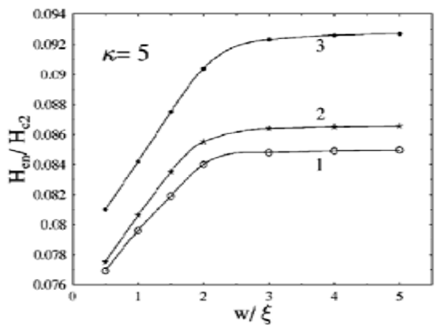
4) Macro roughness after EP and BCP : < 0.5 microns
   and > 2 microns respectively

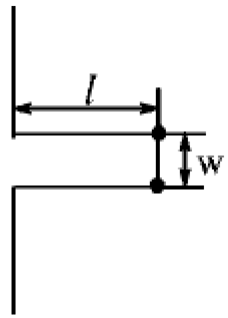


T-map data source: Alexander Romanenko

H_{pen} Review



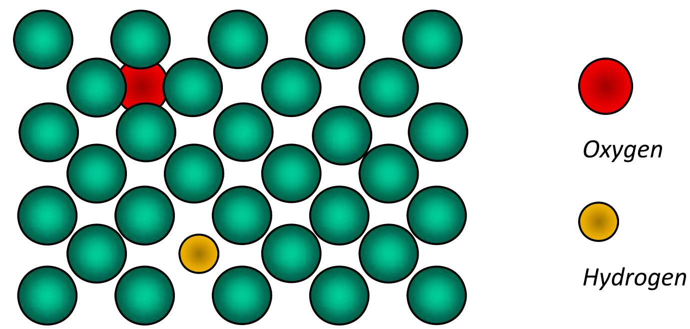


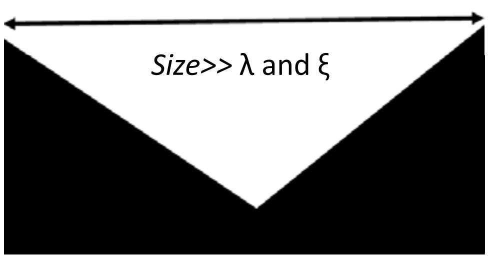


$$H_{\mathrm{en}}^{\mathrm{min}} \simeq \begin{cases} \dfrac{1}{(4\kappa/3)^{4/3}} & 1/\sqrt{2} \leqslant \kappa \leqslant 5, \\ \dfrac{1.03}{\kappa^{3/2}}(1-0.63/\kappa) & 5 \leqslant \kappa \leqslant 20, \end{cases}$$

Pictures 1-2 (from D.Yu. Vodolazov, *Phys.Rev.B, v.62, 8691 (2000)). Penetration field dependence on rectangular defect length (left) and width (right).*

k (kappa) = λ/ξ= Function(mean free path) = Function (dislocation density, impurities, e.t.c.)



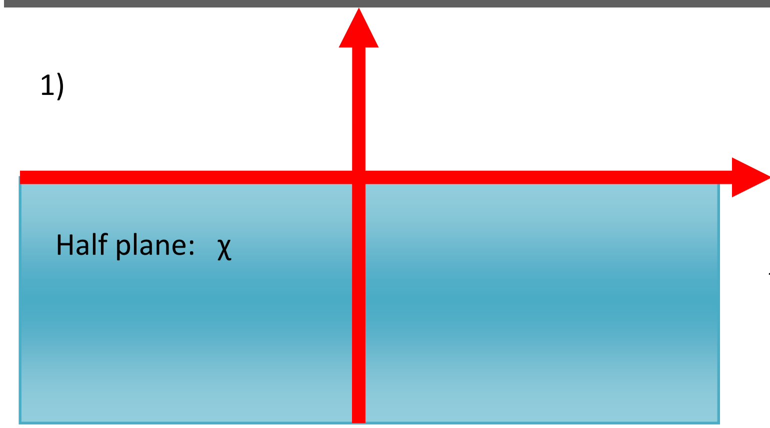


$$H_{pen} = \frac{\sqrt{\pi}}{\sqrt{k}} H_{crit}$$

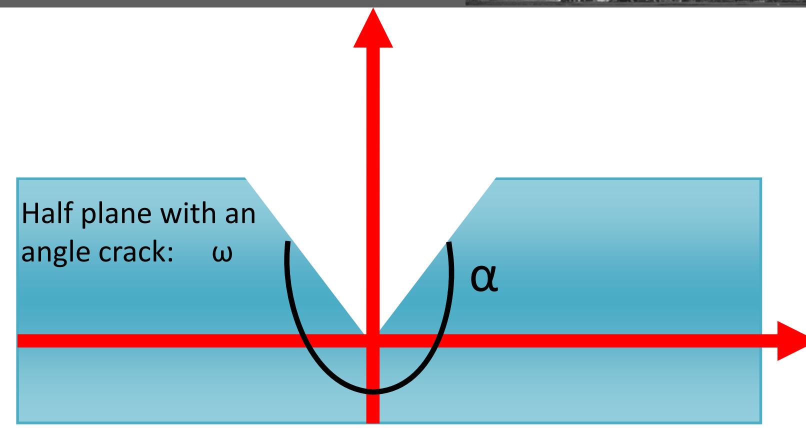
A.Yu.Aladyshkin et.al., cond-mat/9911430 (unpublished).

Conformal mapping

1)



$$w = (\chi^{\alpha/\pi})$$

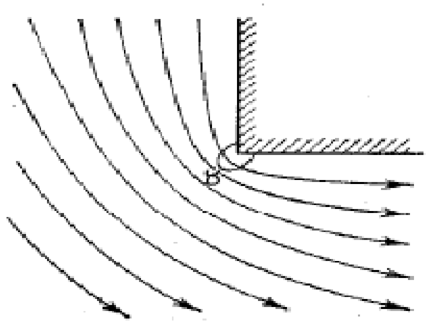


$$E_{att} = -(\frac{\phi_0}{4\pi\lambda})^2 \ln\frac{\lambda}{2x_0}; \quad f_{att} = -(\frac{\phi_0}{4\pi\lambda})^2 \frac{1}{x_0}$$

$$E_{att} = -(\frac{\phi_0}{4\pi\lambda})^2 \ln\frac{\lambda}{2u_0^{\pi/\alpha}}; \quad f_{att} = -(\frac{\phi_0}{4\pi\lambda})^2 \frac{\pi}{\alpha u_0}$$

2)

$$\begin{cases} f_{rep} = \frac{\phi_0}{c} j \\ j = \frac{c}{4\pi}(rot \quad h) \end{cases}$$



Picture3. from L.D.Landau, E.M.Livshitz "Hydrodynamics".

$$\Delta\varphi = 0, \quad bound.cond \quad for \ v$$
$$\Delta h = 0, \quad bound.cond. \ for \ j$$

3)

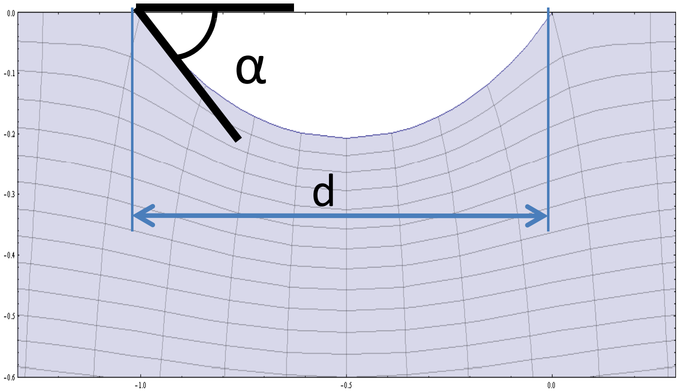
$$f_{rep} = f_{att}, \quad depth_{\min} = \xi$$

➡

$$H_{pen} = \left(\frac{\zeta}{\lambda}\right)^{1-(\pi/\alpha)} H_{crit}$$

(A.Buzdin, M.Daumens, Phys.C 294, 257(1998).)

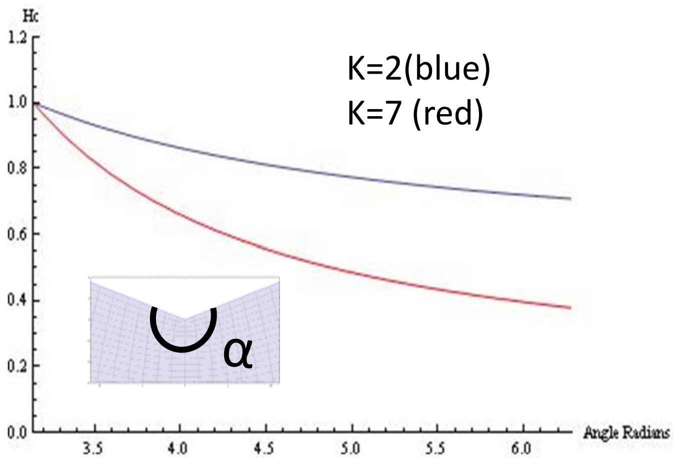
Entrance Field

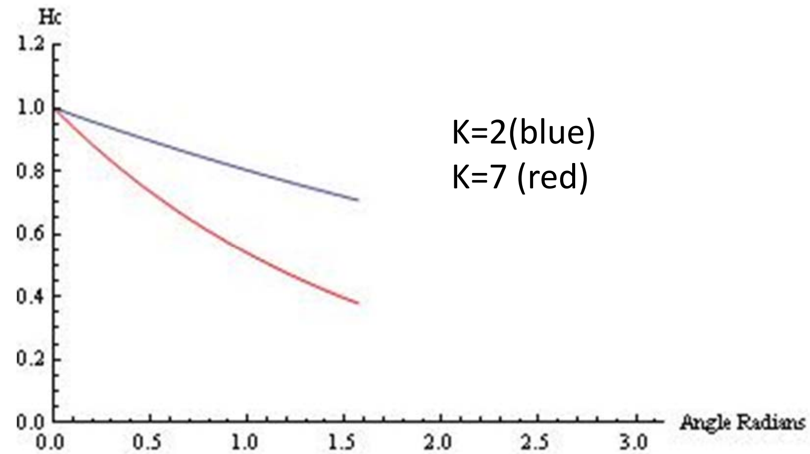


$$w = \frac{d\pi}{\pi - \alpha}\left\{1 - \left(1 - \frac{d}{\chi}\right)^{\pi/\pi-\alpha}\right\}^{-1}$$

Formula from M.A.Lavrientev, B.V.Shabat "Theory of Functions of Complex Variable".

$$H_{pen} = \left(\frac{\lambda}{\xi}\right)^{-\alpha/\pi} H_{crit}$$





Plots 1-2.Penetration field (in units Hc) versus defect angle (1rad~57 degrees, 3.14~180degrees).

Implications. Quench

1) Interplay between purity and geometry determines entrance field

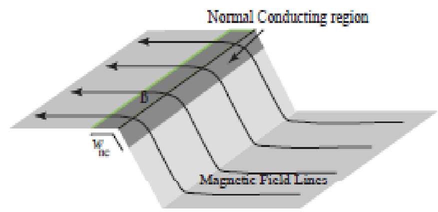
2) Defect size (when >> λ and ξ) doesn’t influence on flux penetration

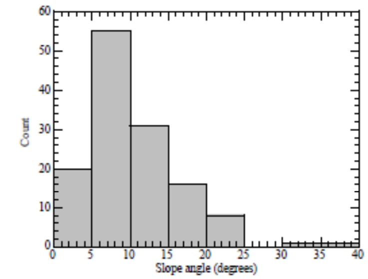
3) Worse points of the pit surface (bad kappa or/and geometry) govern dissipation

Q-Slope approach

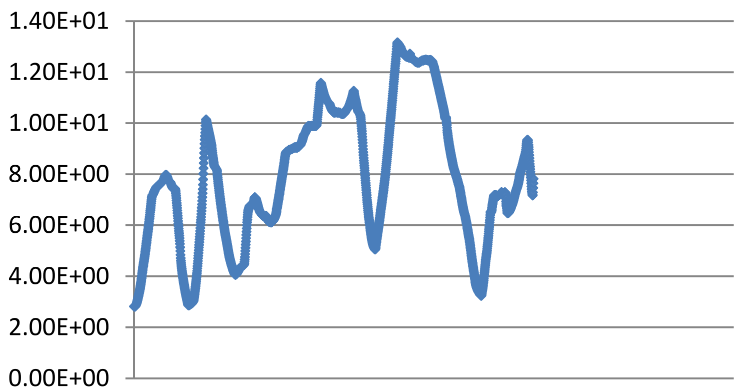
J.Knobloch's et al. model of magnetic field enhancement

« High-Field Q-Slope in SC Due to Magnetic Field Enhancement », 9th Workshop on RF Superconductivity





Difficulties : G.Eremeev's experiment, Q-Slope in SG cavity



$$\begin{cases} n(\alpha_m)d\alpha_m = \dfrac{1}{N}\exp\left(-\dfrac{|\alpha_m-\alpha_0|^{0.5}}{\sigma^{0.5}}\right) \\ H_{pen} = \kappa^{\frac{\pi}{\alpha}-1} \\ R_s = \dfrac{H}{H_c}\rho \end{cases}$$

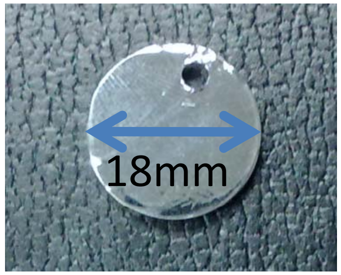
$$R_s^{total} = \int R_s^{local}\cdot n(\alpha)d\alpha = const\cdot\int H\cdot e^{-\left(\frac{\alpha(H)-\alpha_0}{\sigma}\right)^{0.5}} dH$$

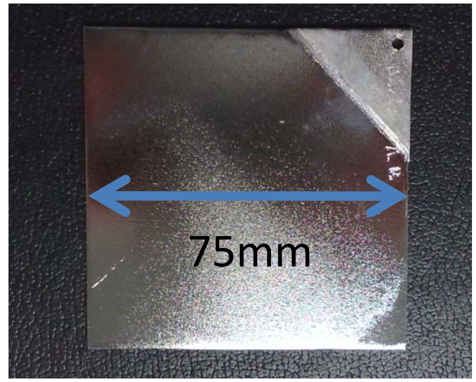
Rs formula source: M.Rabinowitz, J.App.Phys. 42(1), (1971).

Direct connection between surface parameters and Q-Slope.

Description of an experiment

1. Samples



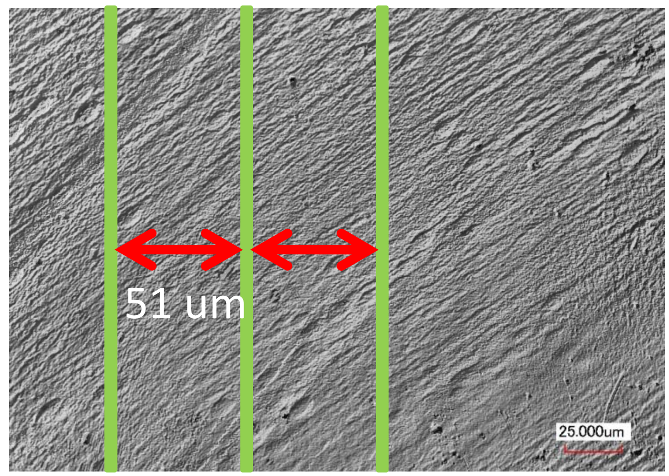


2. Treatment

SG (100um BCP, 137um EP)

FG (100um BCP, 115um EP)

3. Profilometry

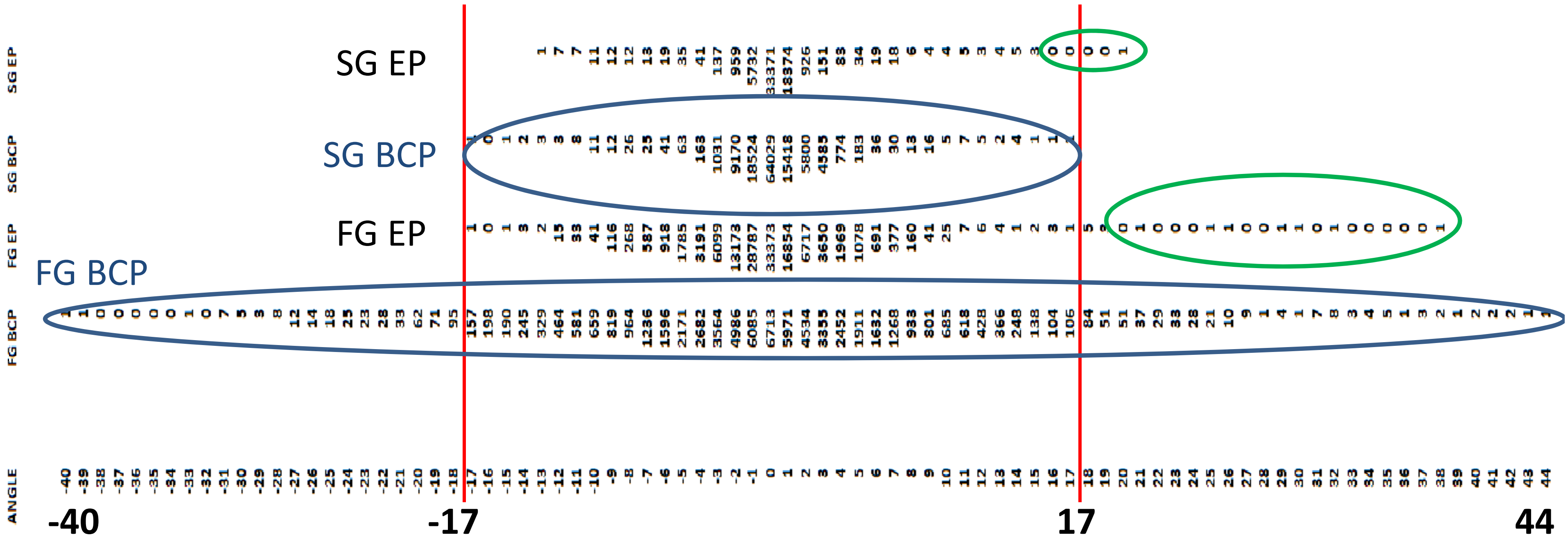


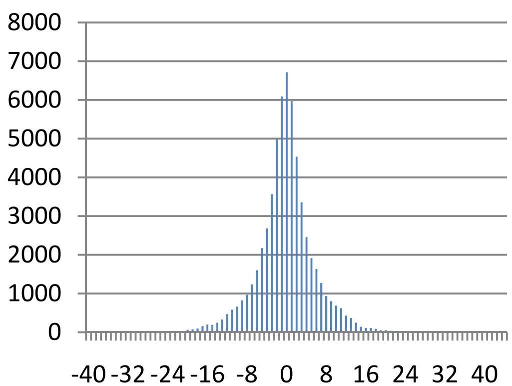
Three 1cm lines on each side.
Totally 24 cm of profiles.
3 lines cover ~ 0.01cm * 1 cm area
Step Size – 0.5 um

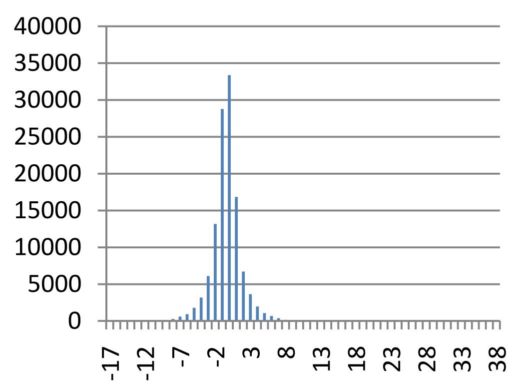
4. Data analysis

Profiles -> Software (written on Mathematica 7.0) -> Angles Distribution -> Sum of 6 lines for each sample/treatment (statistics)

Angles distribution







Plot 6,7. Angles distribution: FG BCP(left), FG EP(right)

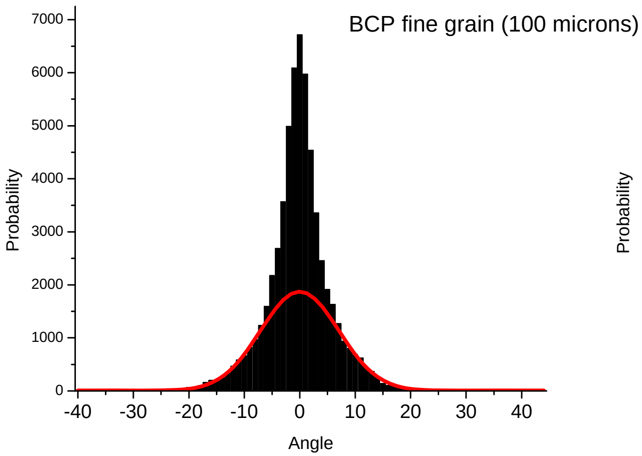
1) BCP – symmetric, EP - no

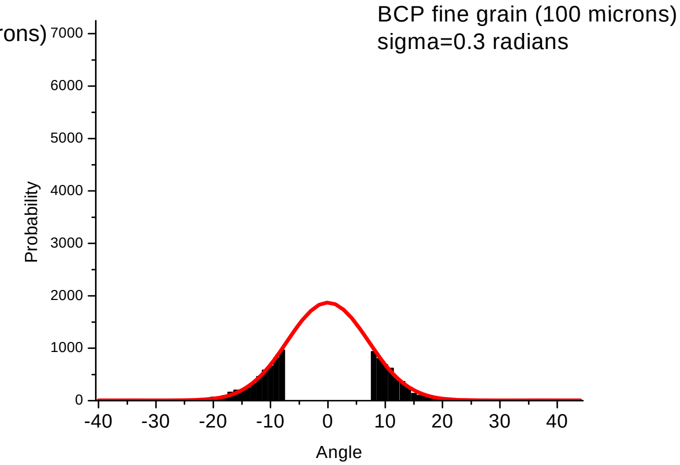
2) EP and BCP close in both SG and FG cases

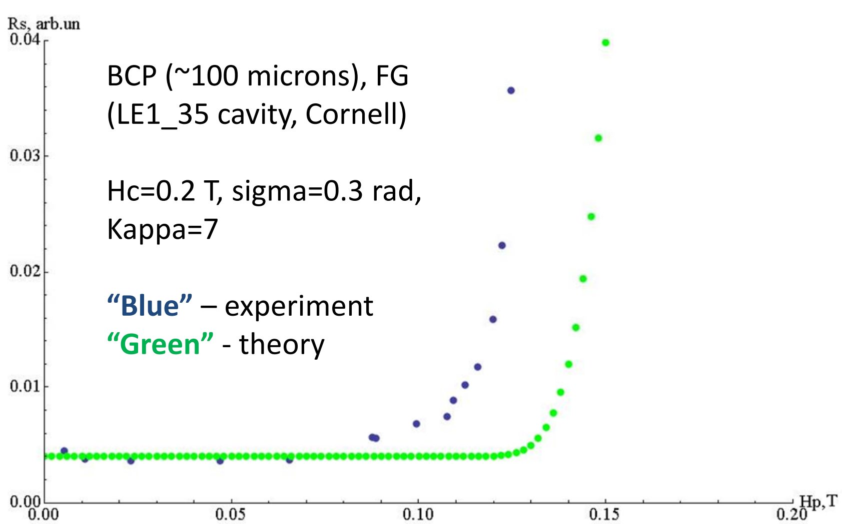
3) SG has big angles (34deg -> 140 mT, k=7) for Q-Slope

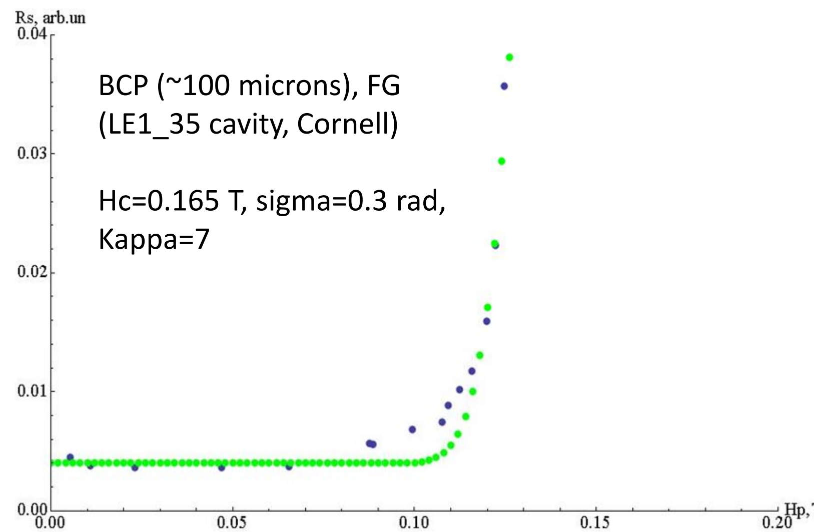
4) EP samples have long tales of “small intensity”, BCP - solid

Q-Slope modeling









Good fit for "before baking" physics. To go further kappa after baking should be determined.

Implications. Q-Slope

1) “Before baking ” Q-Slope successfully modeled with 3 fitting parameters (sigma, kappa, Hc)

2) Surface kappa should be understood (before/after baking and after polishing)

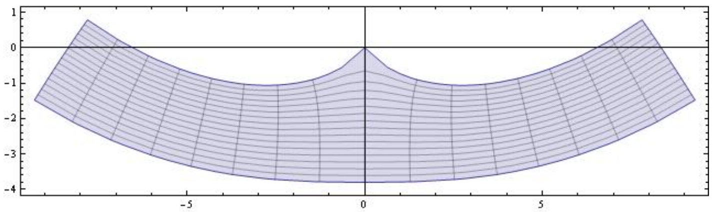
Acknowledgments

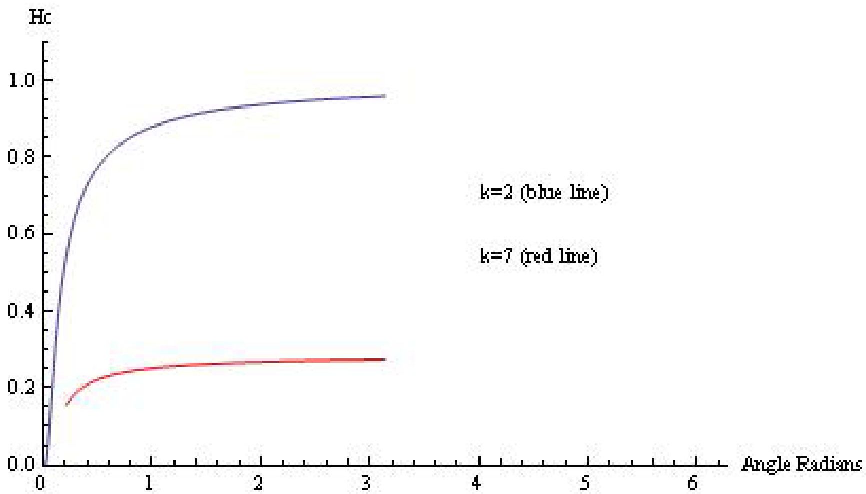
Thanks for polishing:
C. Thompson, D.Hicks, R. Schuessler

Thanks for discussion:
A. Romanenko, L.Cooley, H.Padamsee, G. Wu, M.Ge

Thank you for your attention

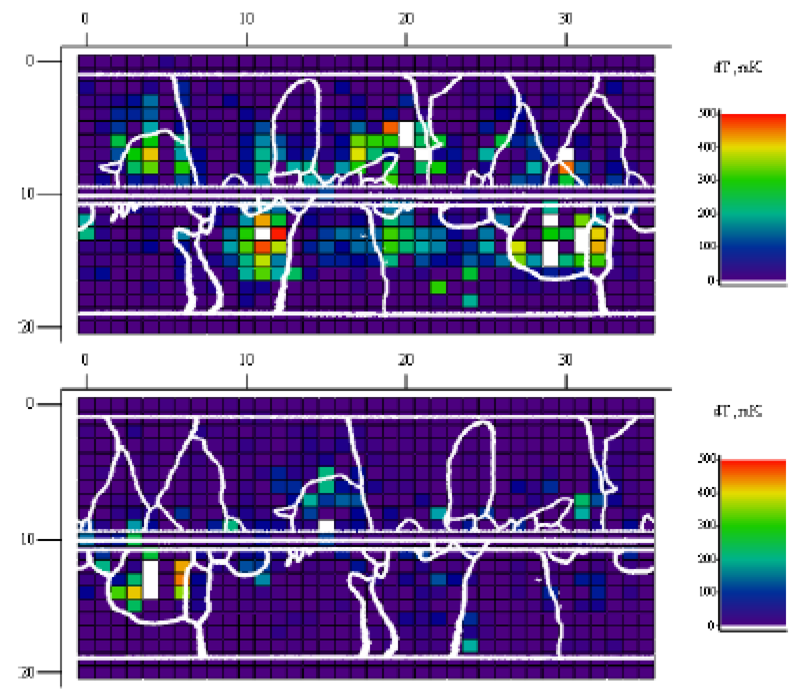
Appendix 1





$$H_{pen} = A \cdot \left(\frac{\zeta}{\lambda} \right) \cdot \left(\frac{\ln \lambda}{\ln \zeta} \right)^{\pi / \alpha} H_{crit}$$

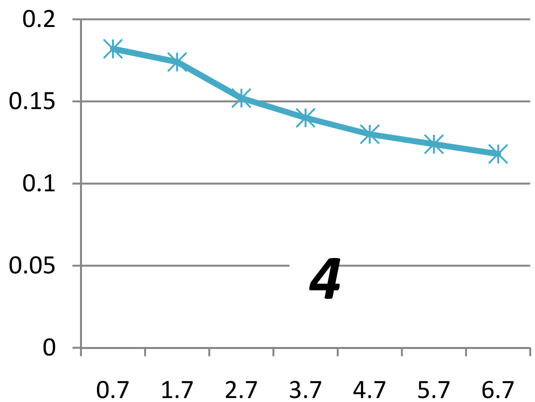
H_{pen}=0.7Hc (or 0.25 Hc for k=7)

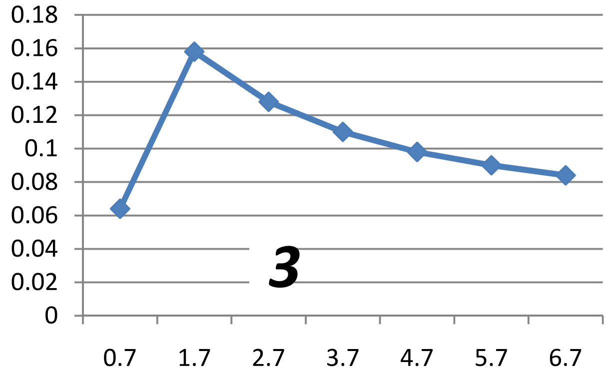


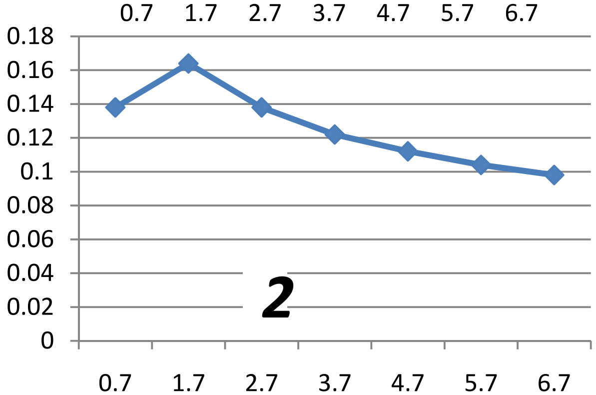
From "Thesis Work" by G.Eremeev. Cornell University,2008

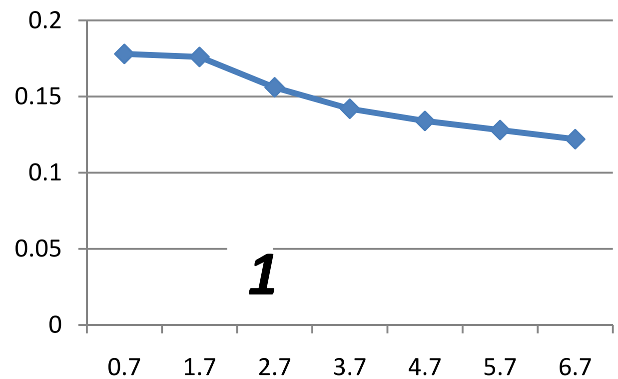
Appendix 2

k	Hp(s=0.12,a0=0.15) "1"	Hp(s=0.22,a0=0.15) "2"	Hp(s=0.32,a0=0.15) "3"	Hp(s=0.12,a0=0.25) "4"
0.7	0.178	0.138	0.064	0.182
1.7	0.176	0.164	0.158	0.174
2.7	0.156	0.138	0.128	0.152
3.7	0.142	0.122	0.11	0.14
4.7	0.134	0.112	0.098	0.13
5.7	0.128	0.104	0.09	0.124
6.7	0.122	0.098	0.084	0.118

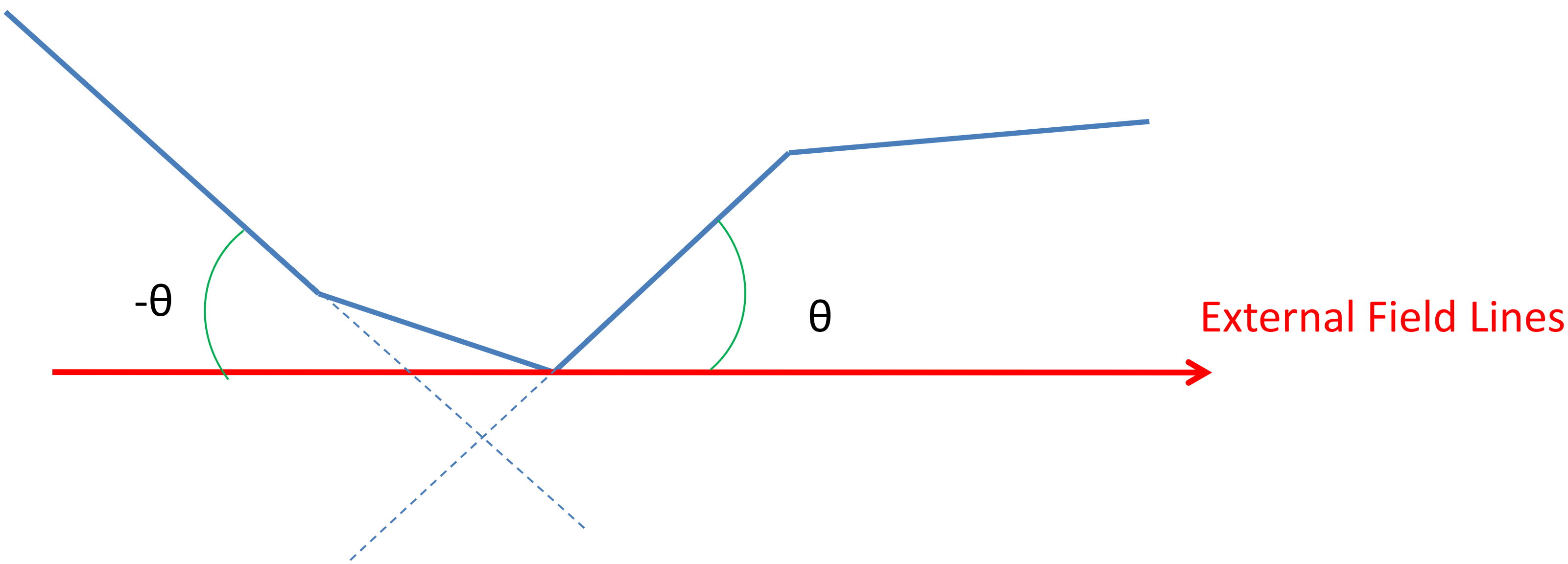


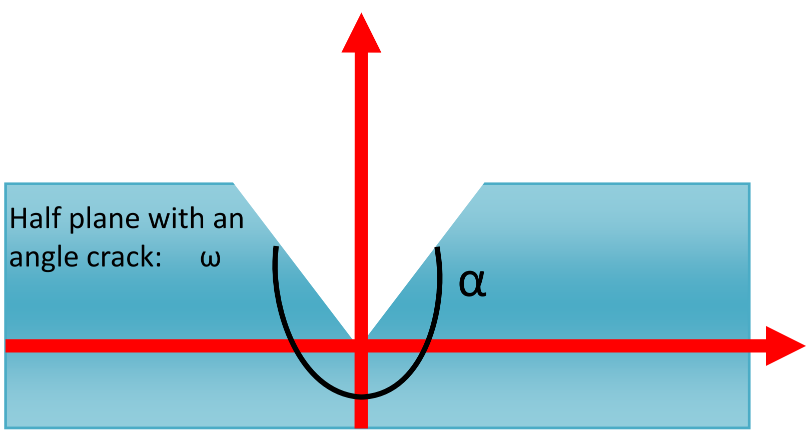




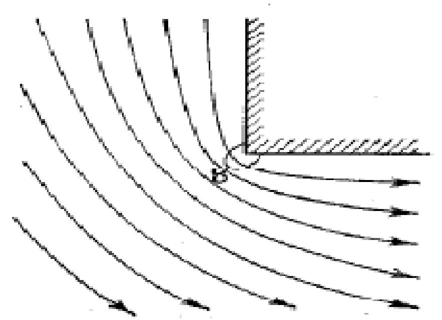


Appendix 3

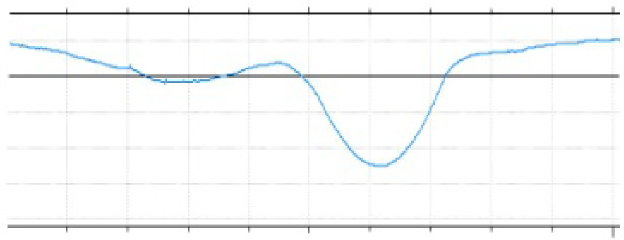




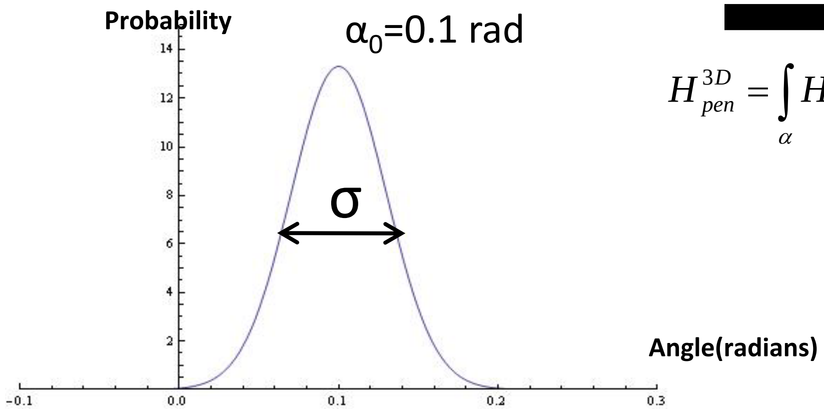
$$\alpha = 2\theta + 180^0$$



3D Penetration



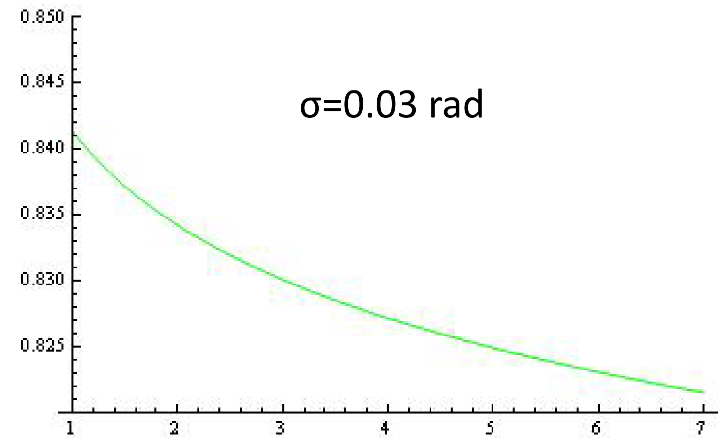
Picture 4. Profile of the pit in the cavity TE1ACC003(Fermilab, by M.Ge)



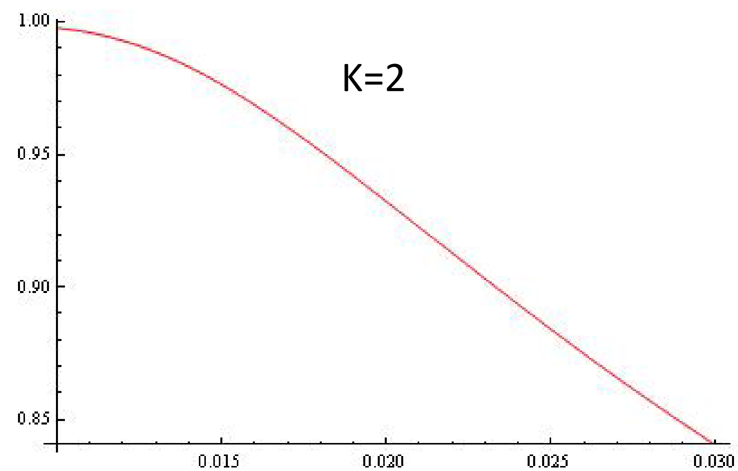
Plot3. Gaussian distribution of angles in different profiles (arb. units)

slices

$$H^{3D}_{pen}=\int_{\alpha} H^{2D}_{pen}(\alpha,k)\cdot\rho(\alpha)d\alpha$$



Plot 4.Penetration field (in Hc) versus kappa



Plot 5.Penetration field (in Hc) versus sigma(radians)

Surface defects decrease H_{pen}(purity, geometry).

3D penetration model designed.