Quadruple R&D
Conductor and Cable R&D

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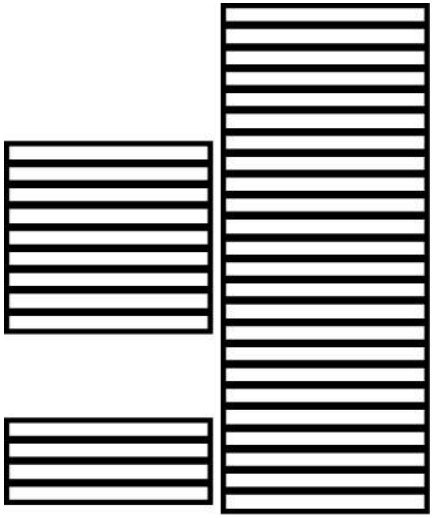
LARP Workshop
Port Jefferson, NY

Objective of LARP – Increase Luminosity

- Pay for performance, costs a lesser concern
- Increase magnet aperture: 70mm to 90mm or greater
- Gradient same or greater: ~205 T/m
  - Nb_3Sn designs for 230-290 T/m
    - With J_c of 2,400 A/mm^2 (12T, 4.2)
    - New conductor 3,000 A/mm^2 (12T, 4.2)
- Cabling issues
  - Racetrack coils – Cable not an issue
  - Cosine 2Θcoils
    - 4 layer or 2 layer design

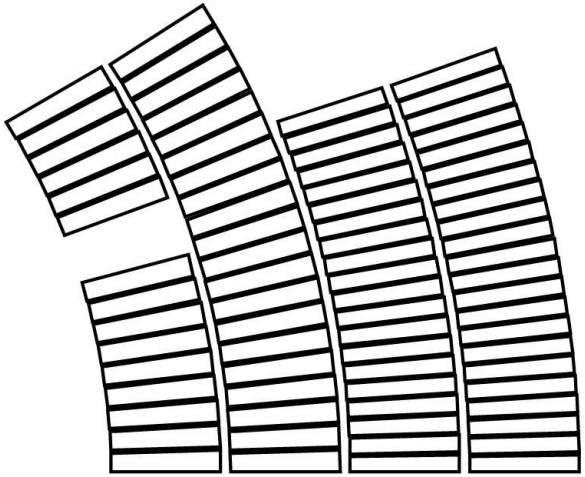
Quad Coil Sections

Racetrack



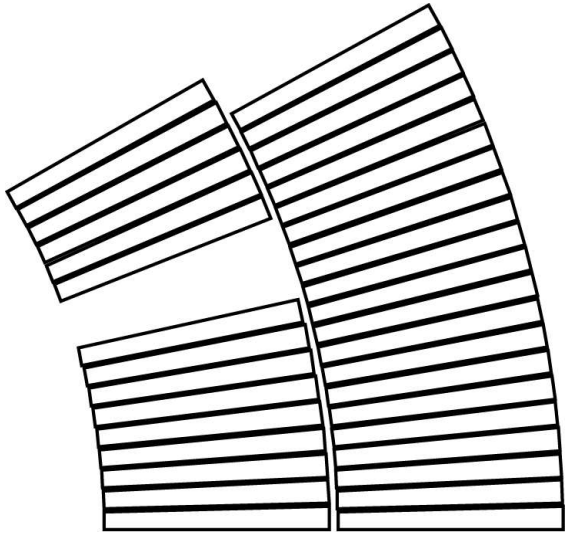
- Rectangular Cable
  - High Jc
  - No degradation
  - More compaction

4-layer



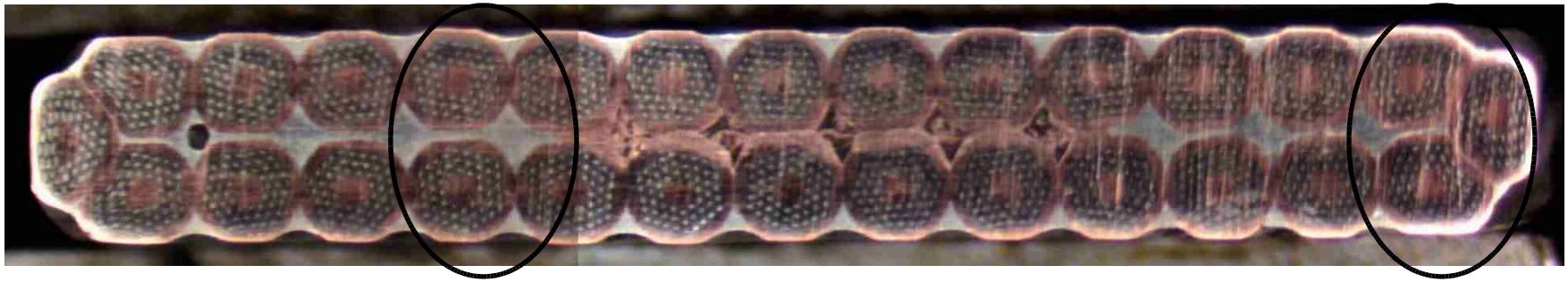
- Fully Keystoned Cable
  - Use rect. cable from Sub-size magnet program
  - Need to establish keystone cable limits

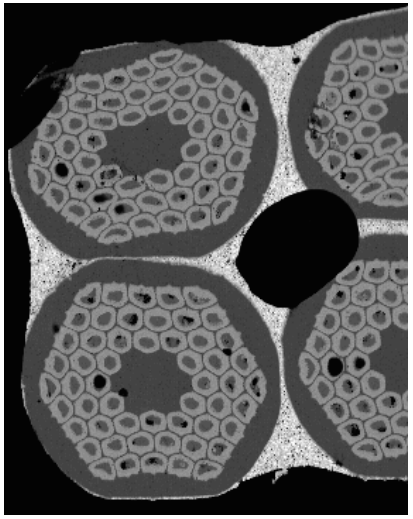
2-layer

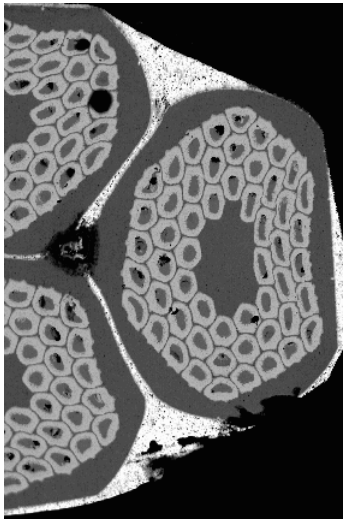


- Fully Keystoned Cable
  - Need core for mechanically stable cable
  - Need to establish keystone cable limits

Rutherford Cable







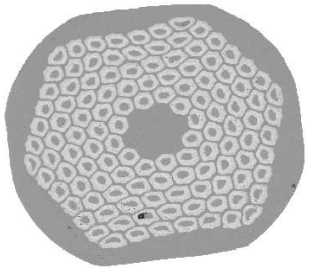
Deformation Definitions

- Thickness deformation
  - Final cable thickness divided by 2 times the wire diameter

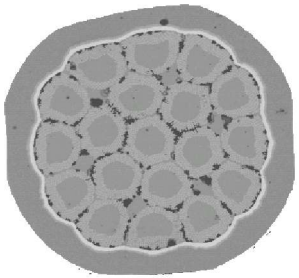
- Width deformation
  - [Final cable width – (# strands/2) x (strand diameter*)] divided by final cable width
    - *strand diameter is corrected for cable pitch angle (14.5-17.5^{o}).

Cables for D-20, RD-3, and HD-1

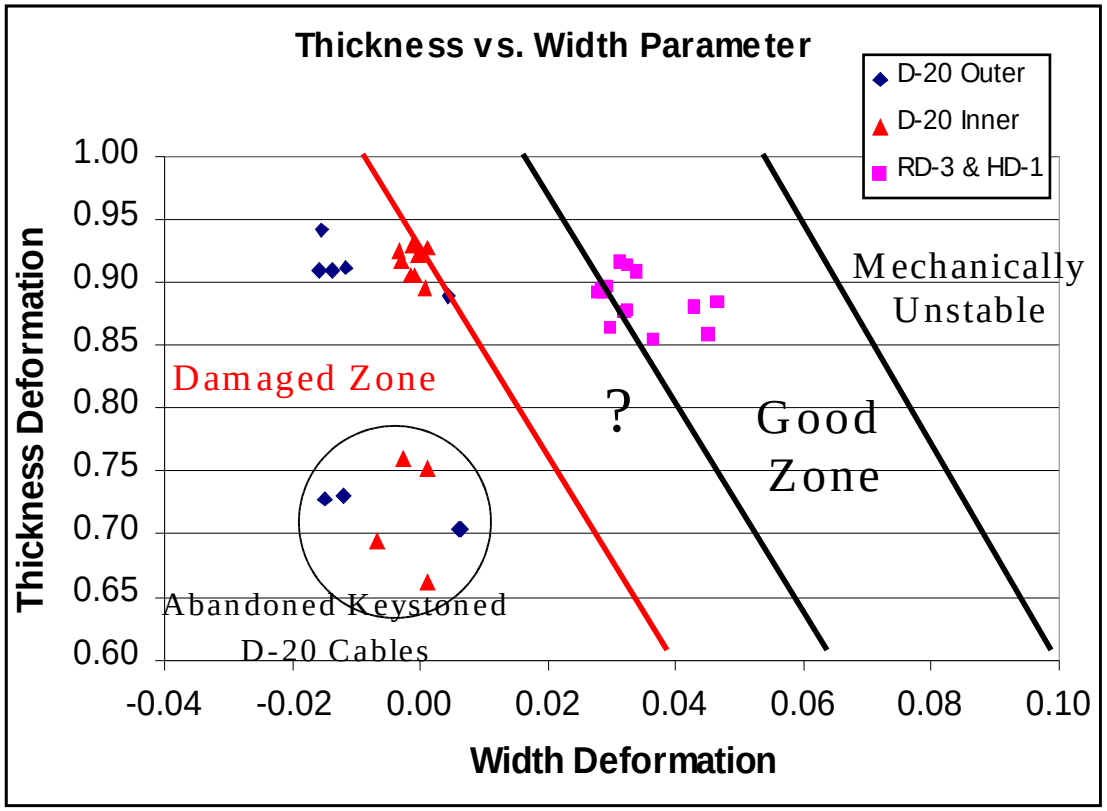
D-20



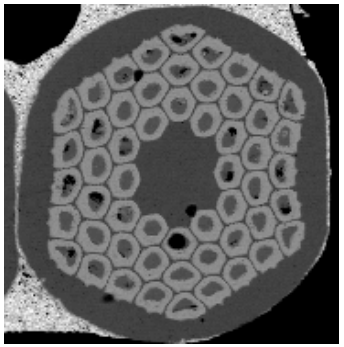
LBL Cable # 523
MJR-TWCA



LBL Cable # 522
IGC-Int. Tin

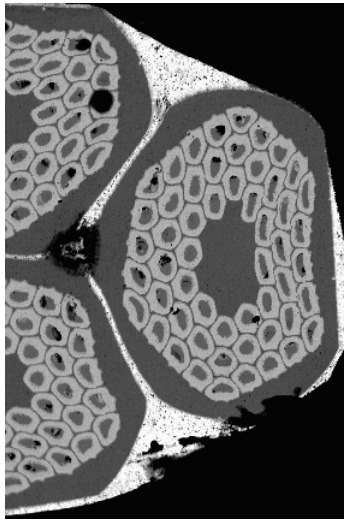


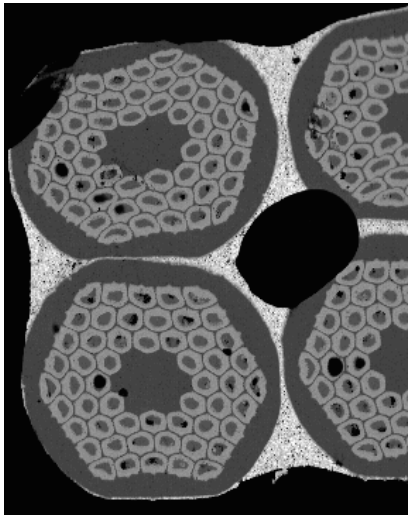
RD-3



LBL Cable # 805R
Oxford-ORe

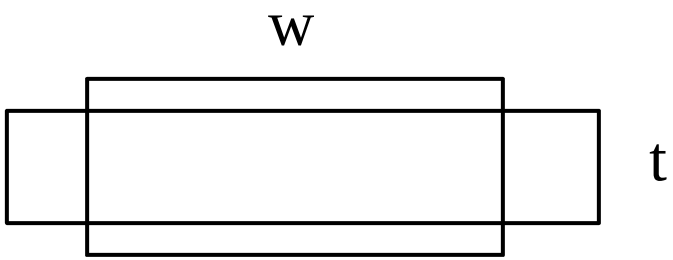
Cable Compaction





0.8 mm strand diameter
40 Strands
Area = 20.11 mm^2
87.57% Compaction

Problem with Compaction

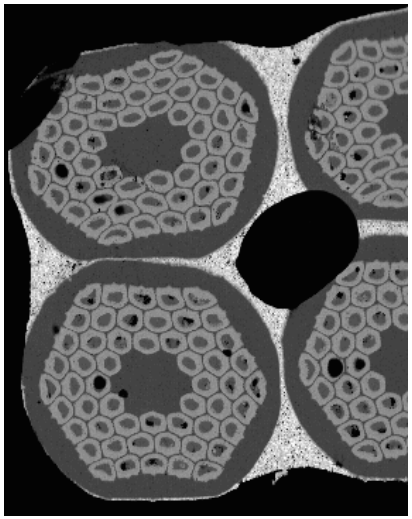


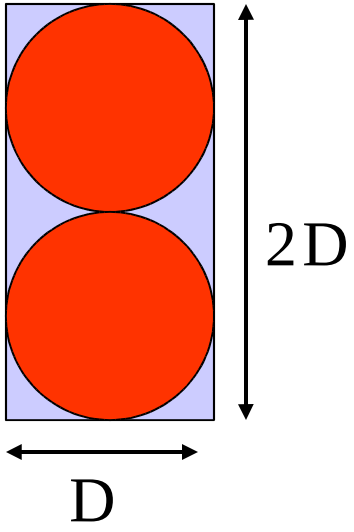
2 Cables: Same compaction

16.4 mm x 1.400 mm = 22.96 mm2

16.0 mm x 1.435 mm = 22.96 mm2

Cable Compaction





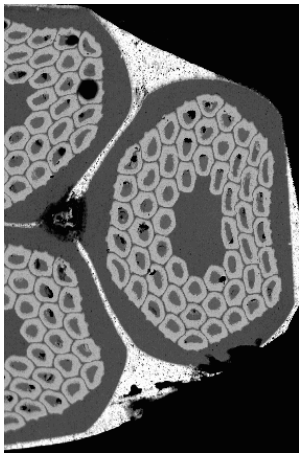
$$\frac{2\left(\frac{\pi D^2}{4}\right)}{} = \text{Area of 2 wires}$$

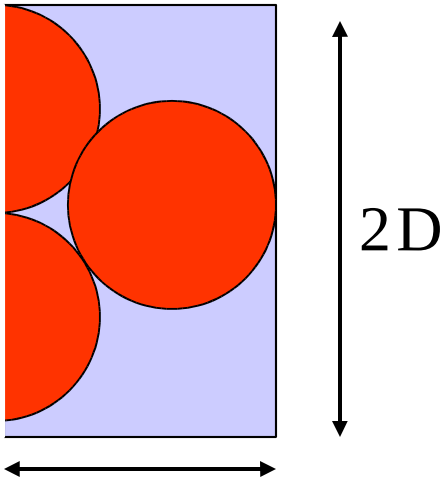
t x D = Area of box after cabling

$$\frac{t}{2D} = \frac{\pi}{4} \qquad 0.78$$

5

Edge Compaction





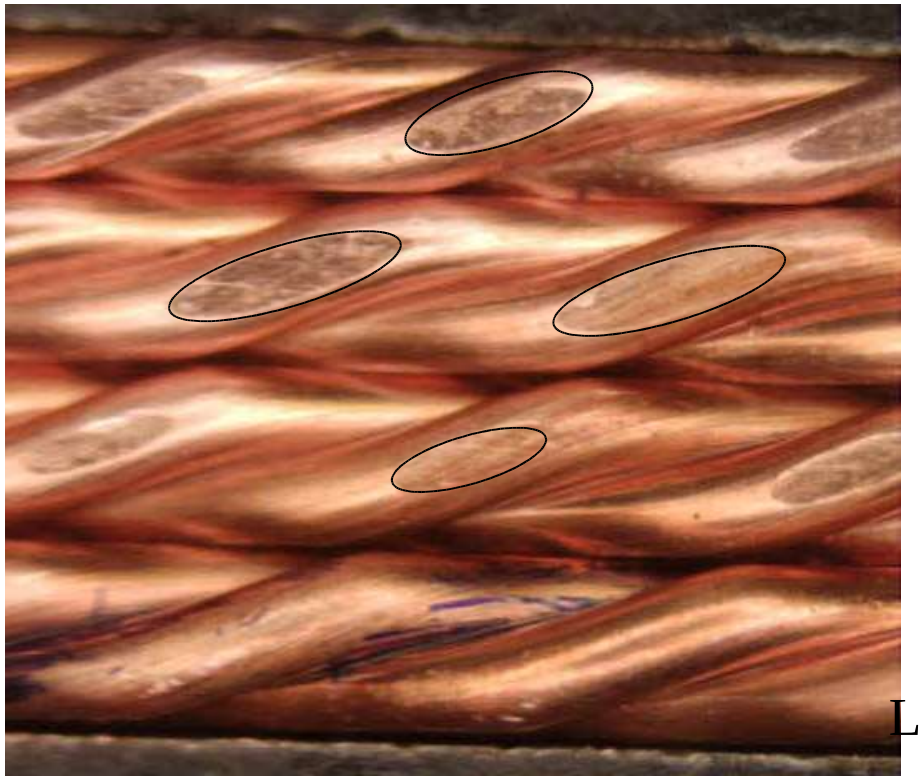
$D/2[\ 1 + (2)^{1/2}]$

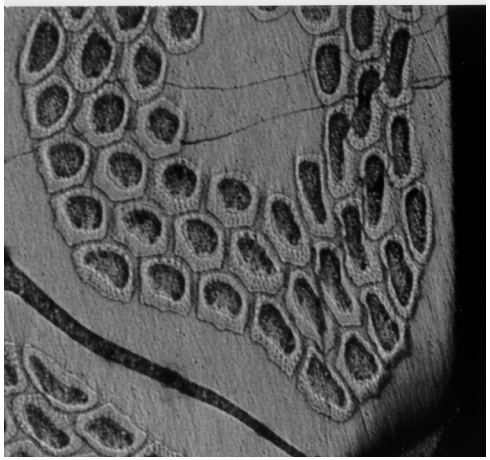
0.65 space filling

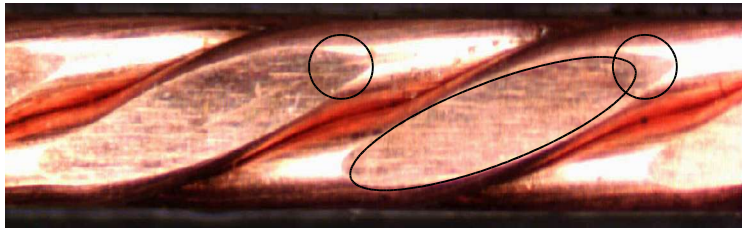
- More void space near edge of cable
- Must balance thickness reduction and width reduction

Quantify Cable Deformation

- Area of edge facet



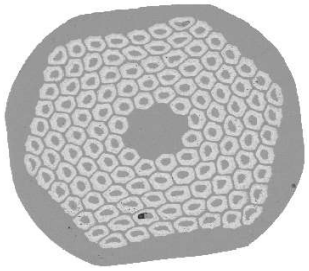




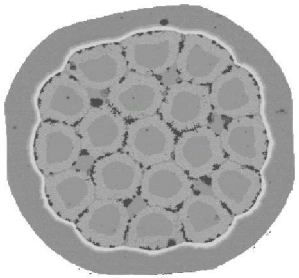
Large facets: deformation too high

Cables for D-20, RD-3, and HD-1

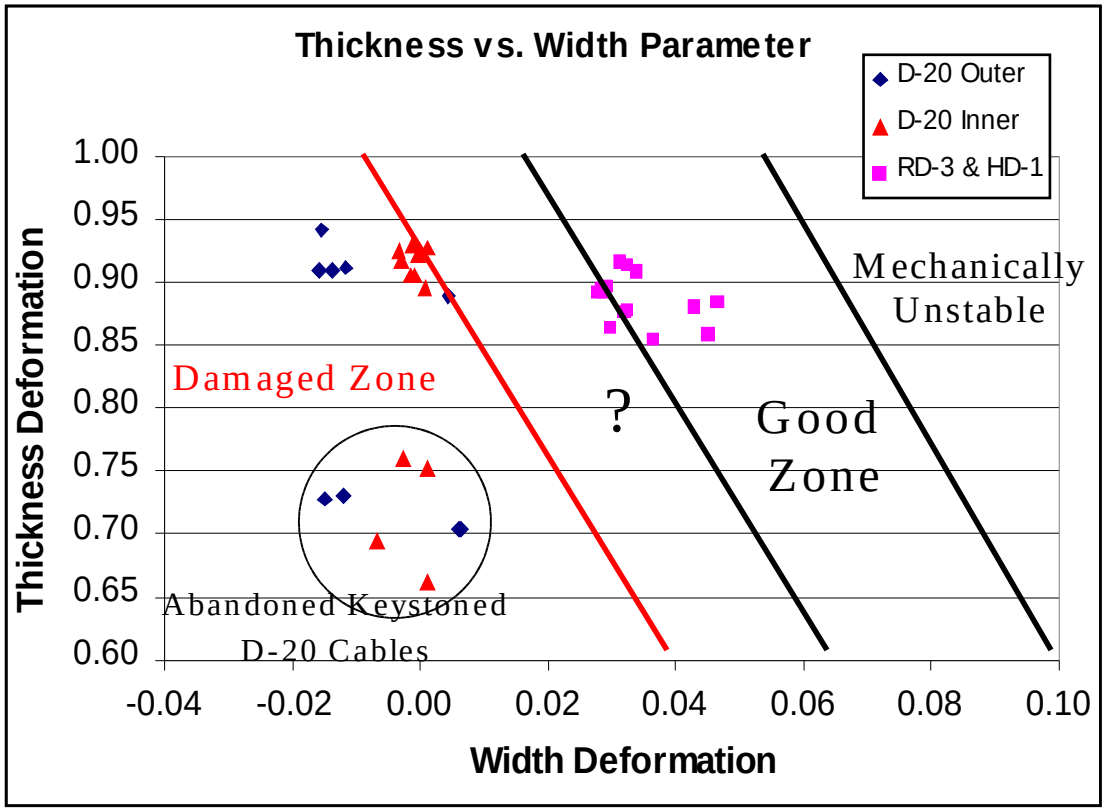
D-20



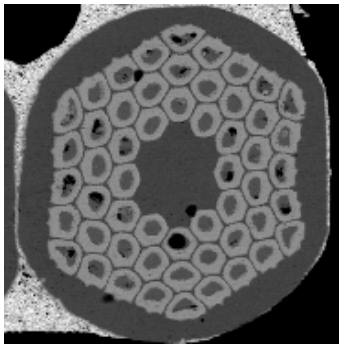
LBL Cable # 523
MJR-TWCA



LBL Cable # 522
IGC-Int. Tin



RD-3

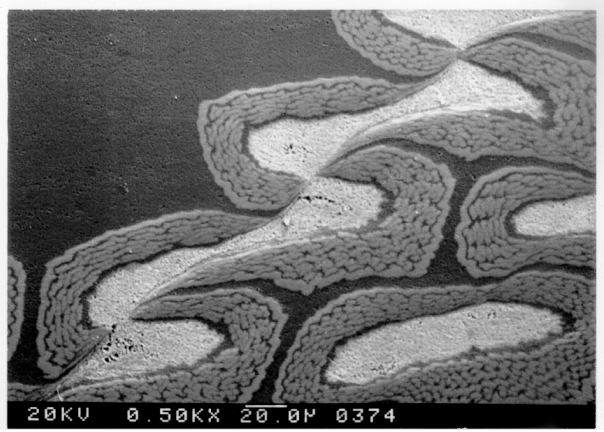


LBL Cable # 805R
Oxford-ORe

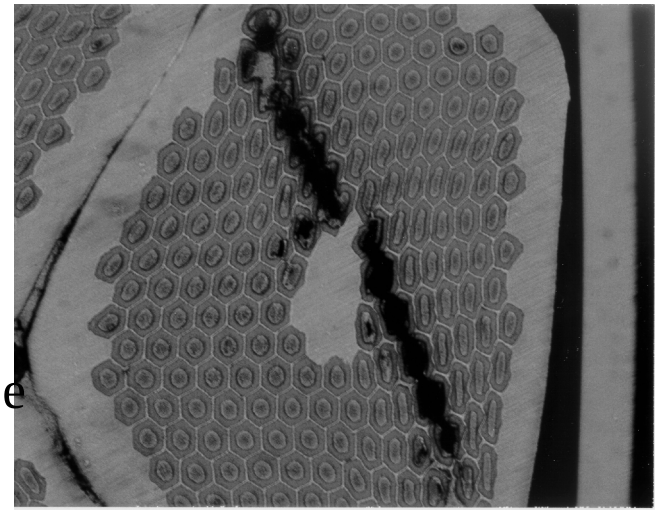
Quantify Cable Deformation

- Polished cross-section of cable: Edge stands

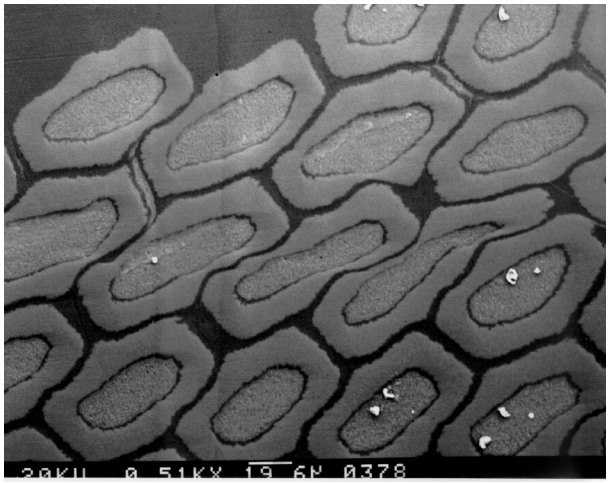
Oxford MJR



SMI PIT Keystone



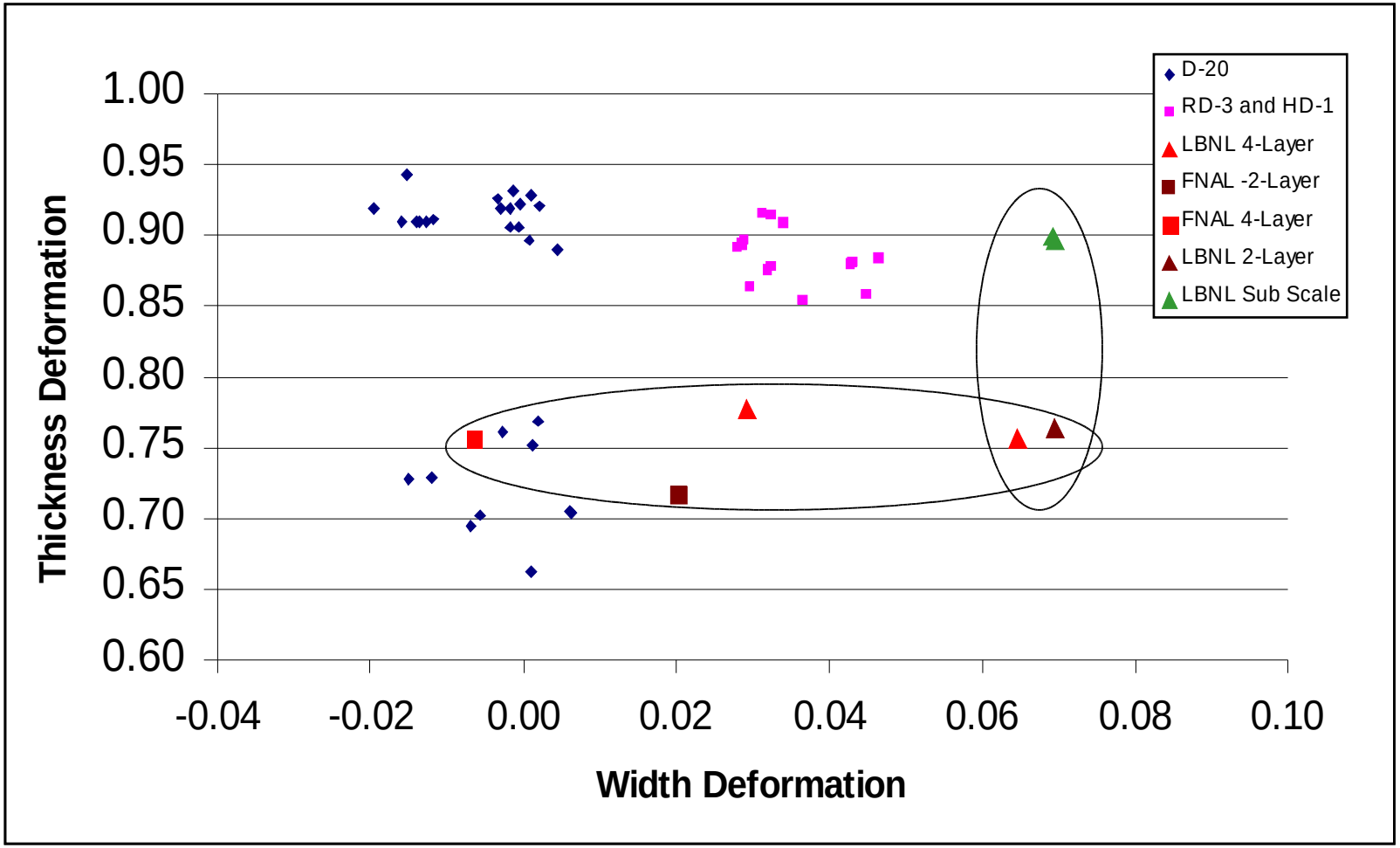
SMI PIT Rect.



LBNL Quad Parameters

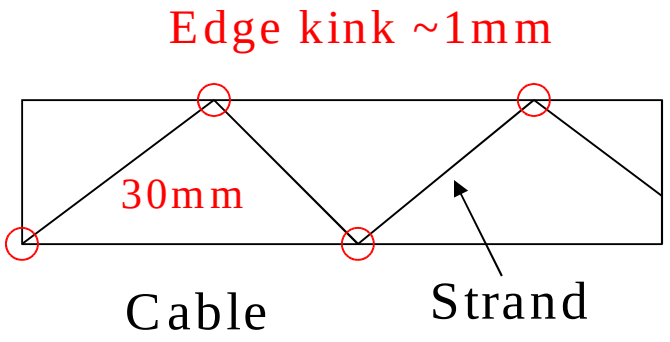
Parameter	Unit	2-layer	4-layer	
			Inner	Outer
Strand diameter	mm	**0.7**	**0.8**	**0.65**
Cu/Sc ratio		1.5	1.2	1.6
No. strands		**42**	**17**	**22**
Cable width	mm	**15.8**	**7.7**	**7.7**
Cable mid-thickness	mm	1.45	1.43	1.13
Keystone angle	deg	**1.38**	**1.63**	**0.89**
Insulation thickness	mm	0.1	0.1	0.1
No. turns/octant		36	35	42

Keystoned Cables for LARP



Jc of Extracted Strands

- Kink resistance should be large enough to observe damage



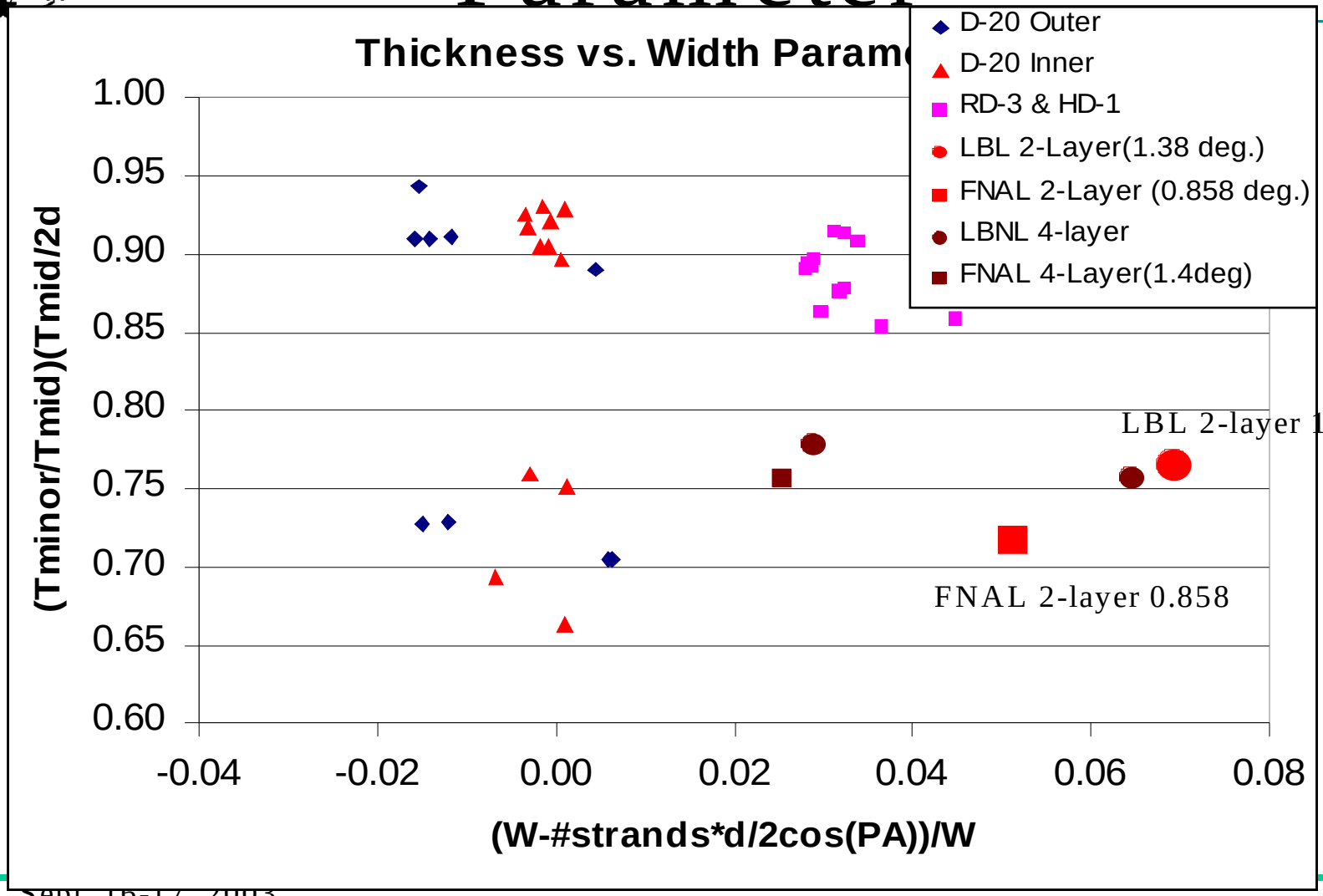
RRR	ρ-273 ohm-cm	Kink Length Lk (cm)	Dia (cm)	Rkink ohm (4.2K)	Rkink micro-ohm (4.2K)
3	1.55E-06	0.1	0.08	2.06E-05	20.56
10	1.55E-06	0.1	0.08	6.17E-06	6.17
30	1.55E-06	0.1	0.08	2.06E-06	2.06
100	1.55E-06	0.1	0.08	6.17E-07	0.62

Objective of Quad R&D - 04

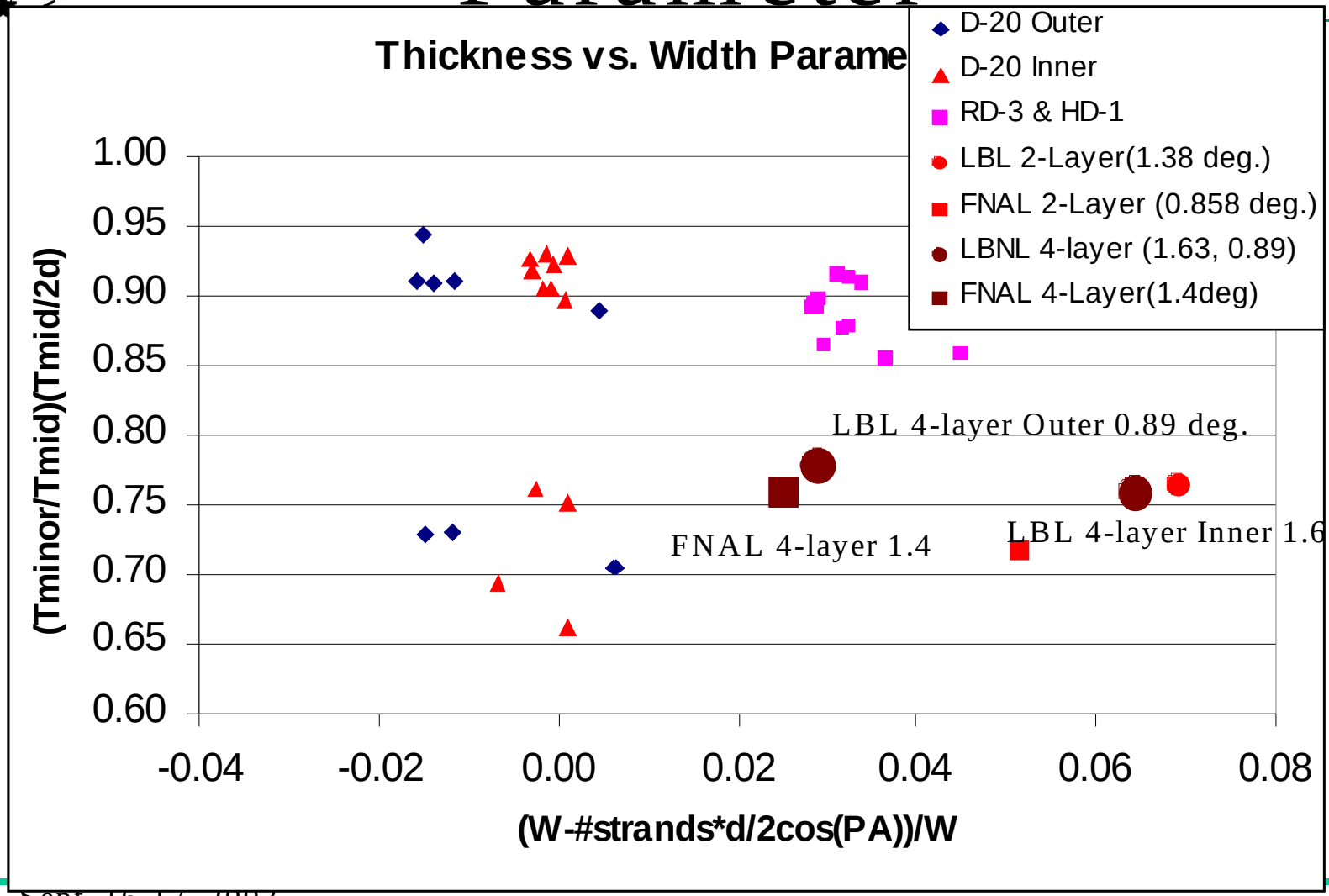
- Establish parameters for cable of 4-layer design
  - Extend LBNL's rectangular cable used for sub-size coils
    - 20 Strands and 0.7mm diameter
- Develop Cu keystoned-cable
  - Core for wide cables of 2-layer design
- Establish that extracted strands and metallography are consistent

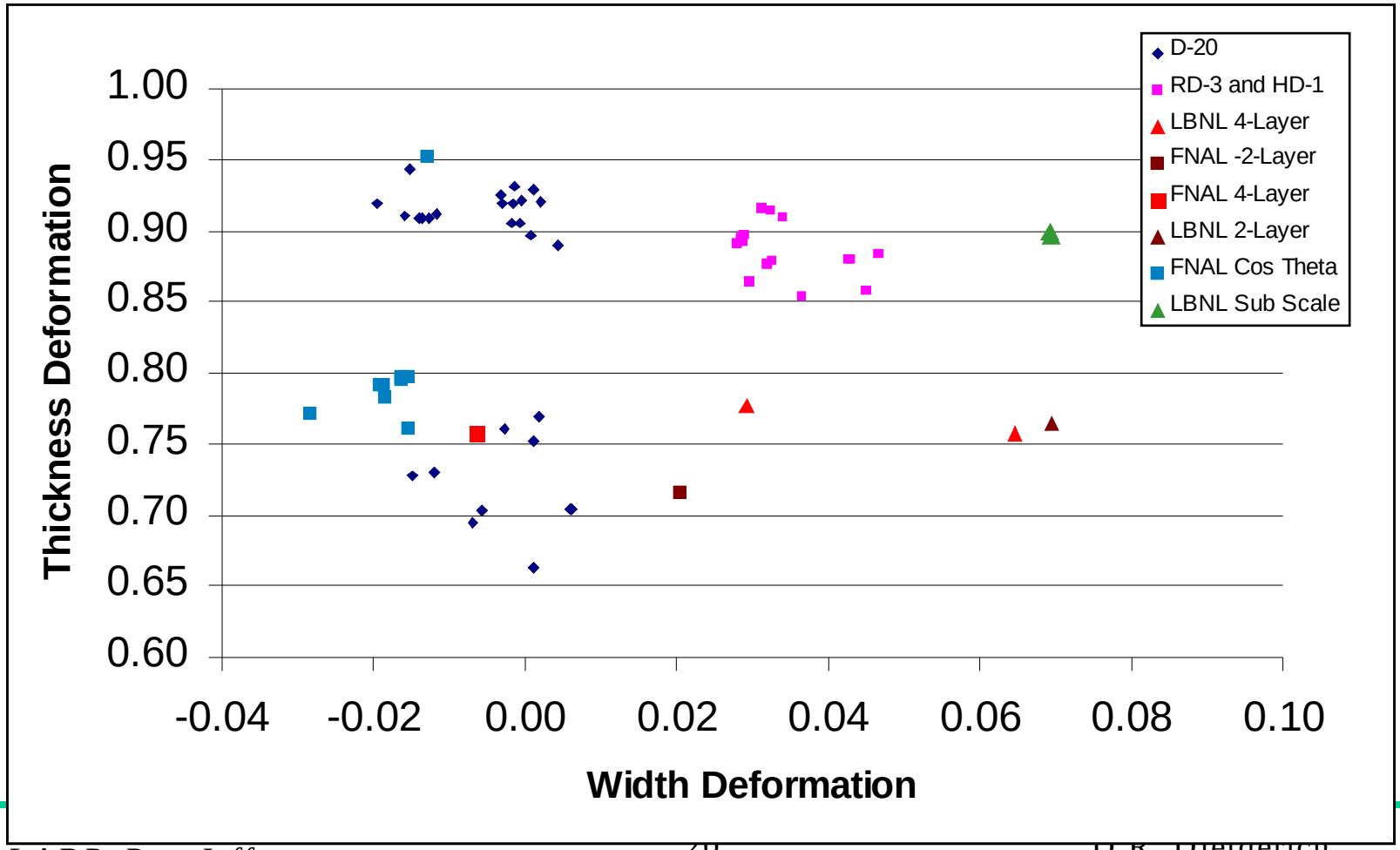
end

Thickness vs. Width Parameter



Thickness vs. Width Parameter




D-20
RD-3 and HD-1
LBNL 4-Layer
FNAL -2-Layer
FNAL 4-Layer
LBNL 2-Layer
FNAL Cos Theta
LBNL Sub Scale
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
Thickness Deformation
-0.04
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
Width Deformation

LARP Cable R&D Tasks

1. **Keystoned core for cos(2θ) to remove (redcue) the high compaction of the Nb_3Sn strands.**

   - **Make a core from Cu strands around a stainless steel core.**
   - **Determine the limits on compaction and keystone angle of different strands that are difficult to cable or that behave differently. (PIT, Internal-tin, MJR, and HER).**

2. Determine the deformation and compaction limits of cable after low temperature heat treatments **(210°C for 10-100h and 340°C 10-48h**)

   - Reduce dimensional changes during coil heat treatment by doing low temperature heat treatments prior to coil winding.
   - Shorten heat treatment time of the final coil by doing low temperature heat treatments prior to coil winding.

3. Evaluate the performance and cost effectiveness of adding Cu as strands or as a core in a Rutherford cable.

   - Determine the effects on heat transfer and eddy currents.

4. **Evaluate new insulations and epoxies and new potting schemes.**

   - **Ceramic and radiation hard insulations**
   - High pressure potting of epoxy.

Quantify Cable Deformation

- Pattern surface of strand before cabling
  - Blue axial
  - Red circumferential
- Measure local distortion of grid on surface of wire
- Determine local strain

Surface of strand