Stellarator magnet conductors

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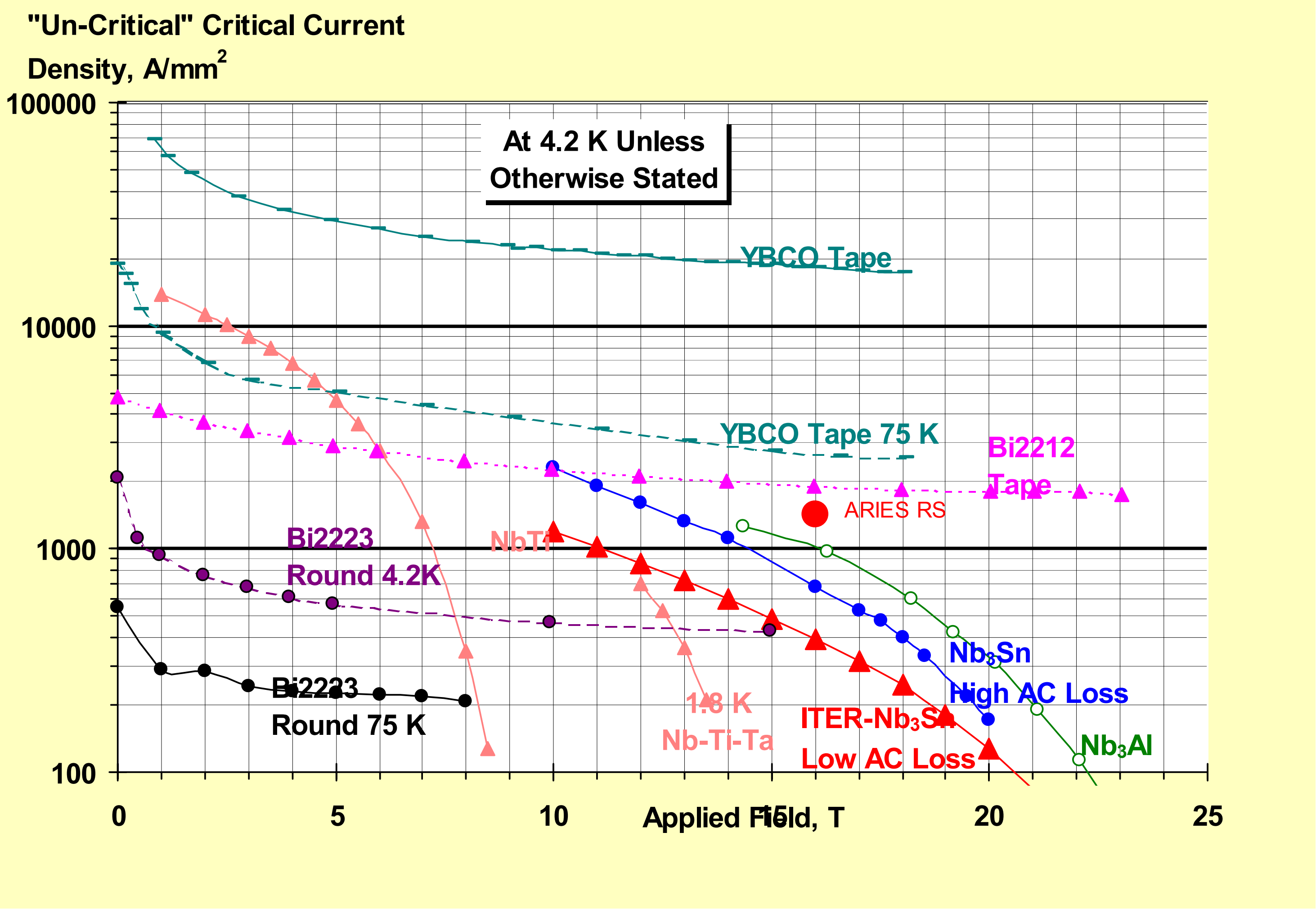
Organization of talk

- Status of HTS/comparison with LTS
- Design optimization of LTS
- Cost comparison

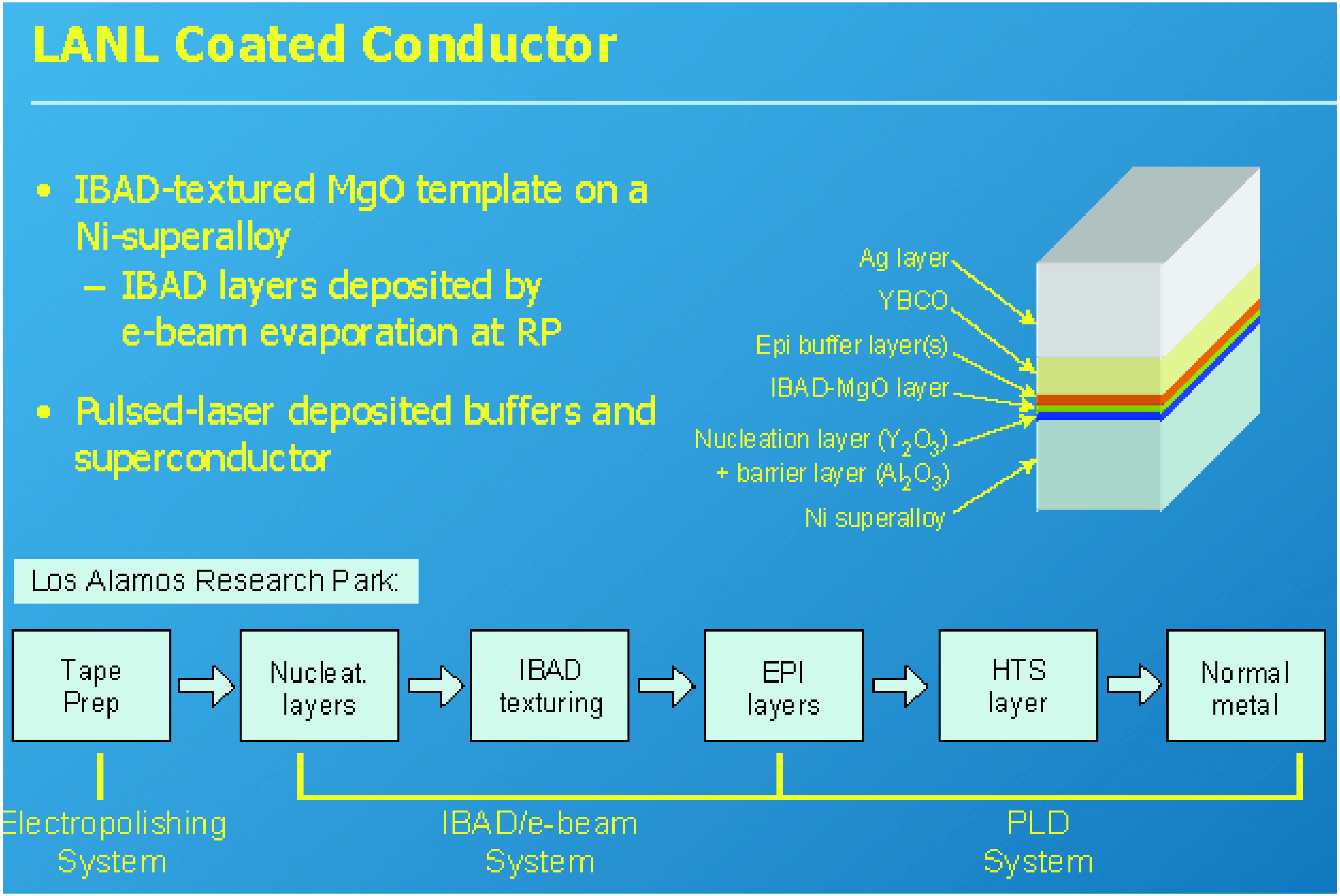
HTS Superconductor options and comparison with LTS (YBCO tape at 4 K and at 75 K)



Courtesy of Lee, UW Madison

Status of industry

- Japan/US/EU continue to support industry
  - In US, mainly for power applications (motors, generators, fault limiters, transmission lines)
- In the US, American Superconductor
  - Dropping all but YBCO
  - Hopes to hit 10-20 $/kA m (competitive with copper)
- Japan, Europe supporting others (2212)



LANL Coated Conductor

- IBAD-textured MgO template on a Ni-superalloy
  - IBAD layers deposited by e-beam evaporation at RP
- Pulsed-laser deposited buffers and superconductor

Ag layer
YBCO
Epi buffer layer(s)
IBAD-MgO layer
Nucleation layer (Y_2O_3)
+ barrier layer (Al_2O_3)
Ni superalloy

Los Alamos Research Park:

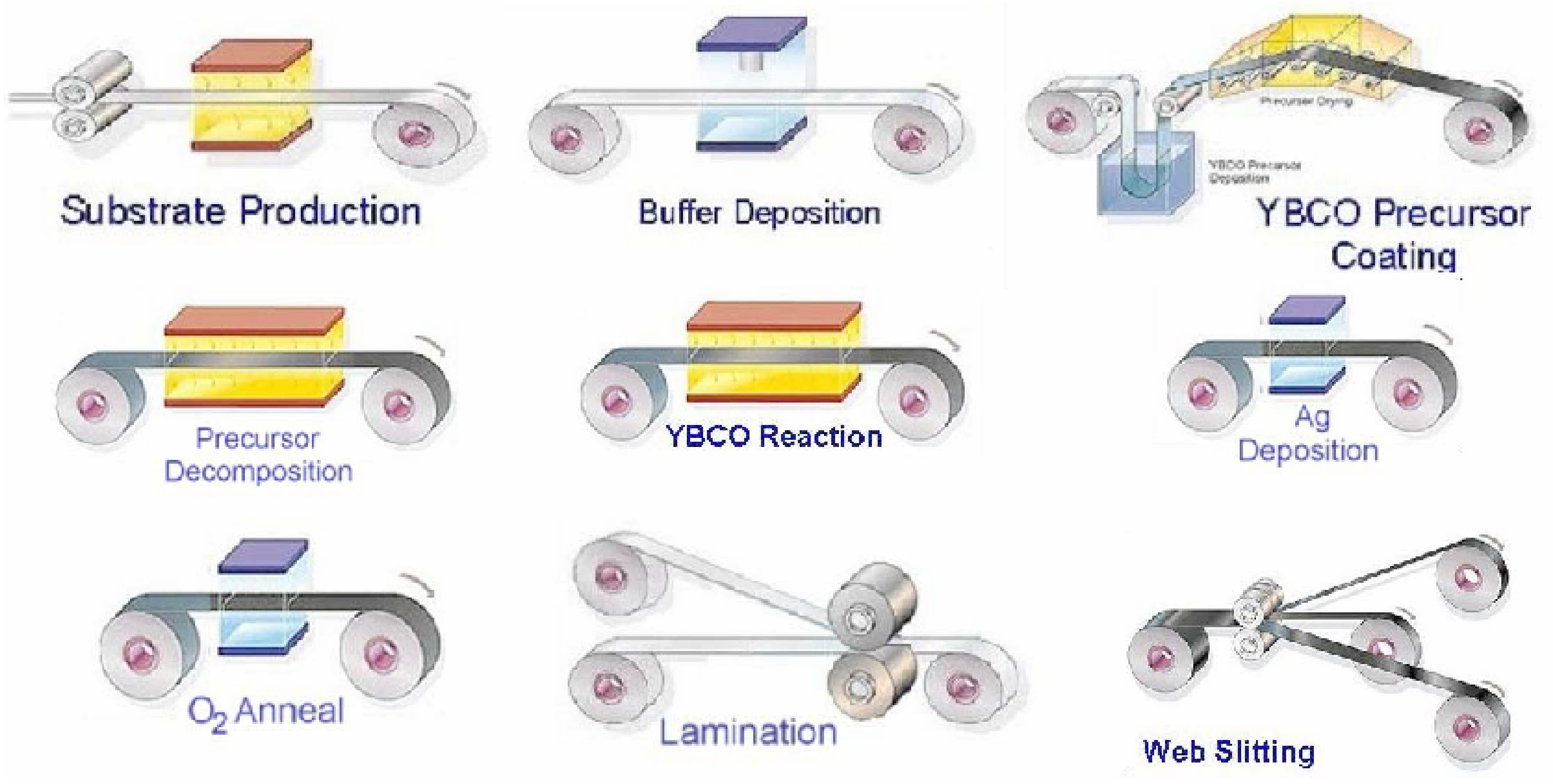
Tape Prep → Nucleat. layers → IBAD texturing → EPI layers → HTS layer → Normal metal

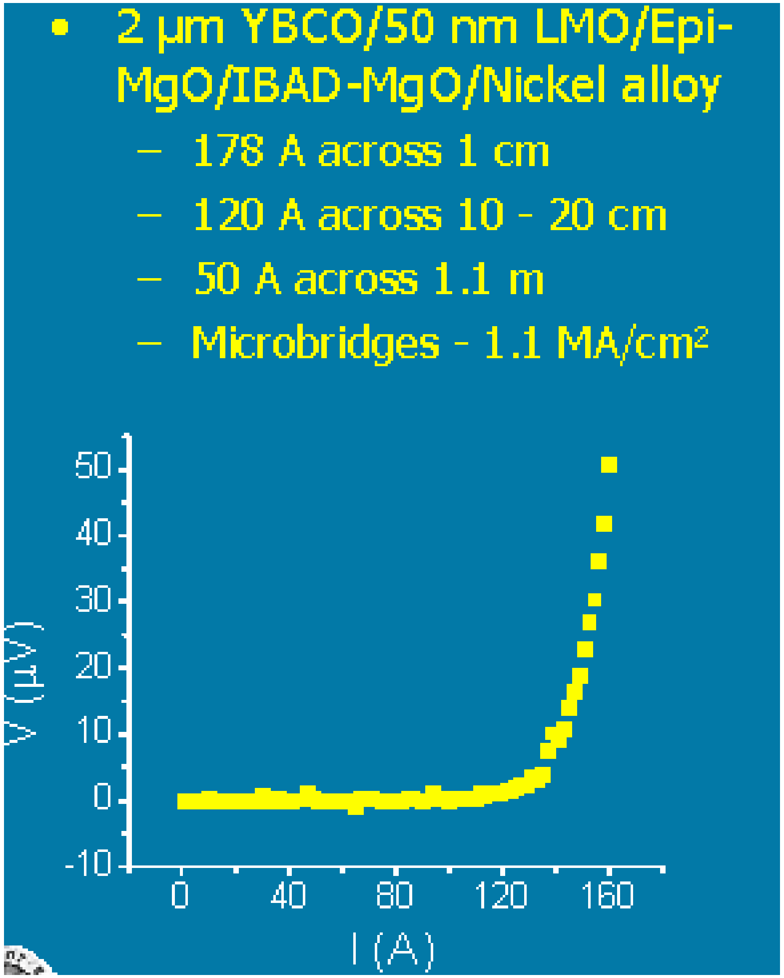
Electropolishing System
IBAD/e-beam System
PLD System

LANL IBAD, Peer review 7/03

AMSC current 2G wire process

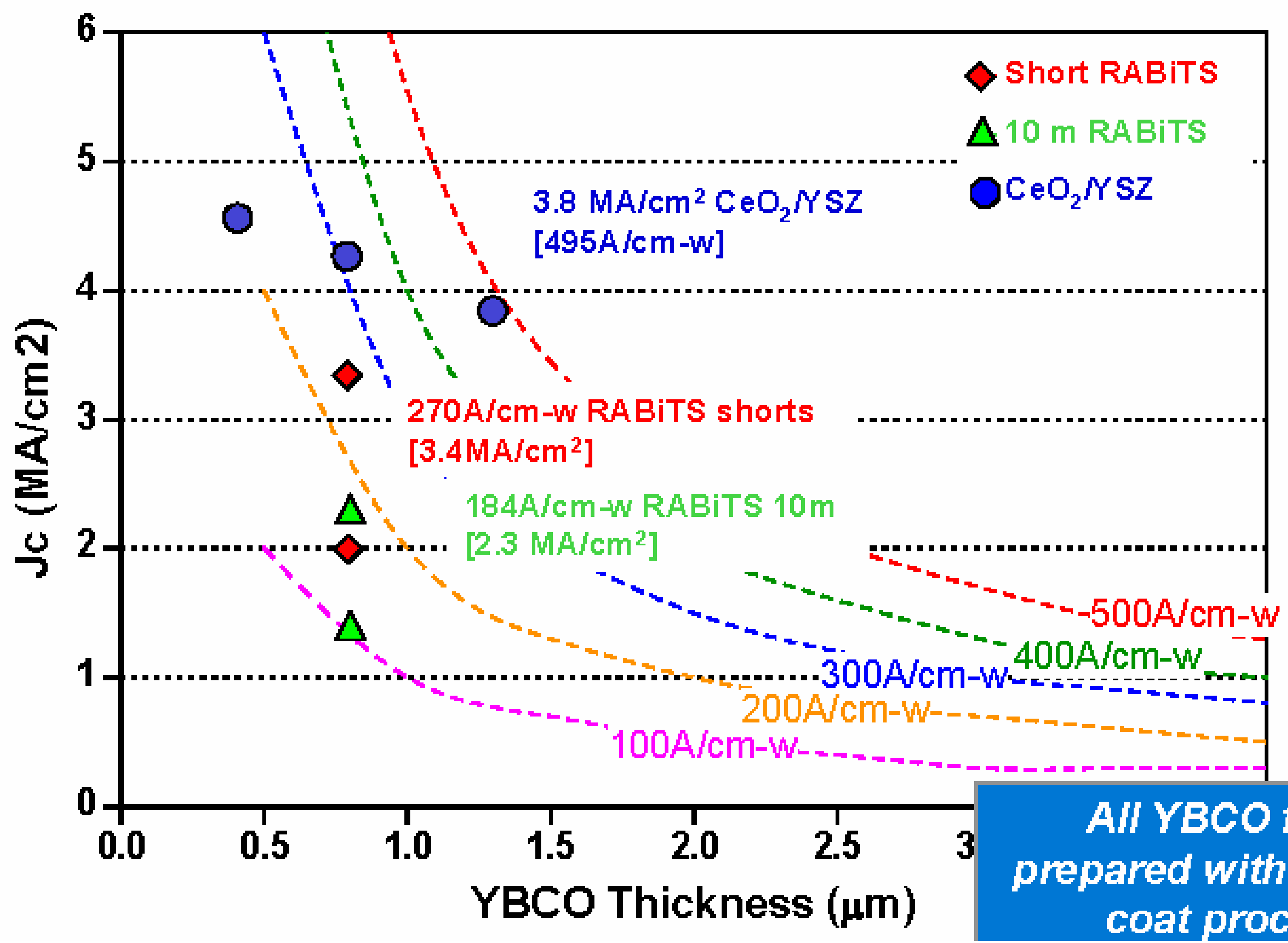
(scaleable to 10cm wide web which yields 20 4mm wires)



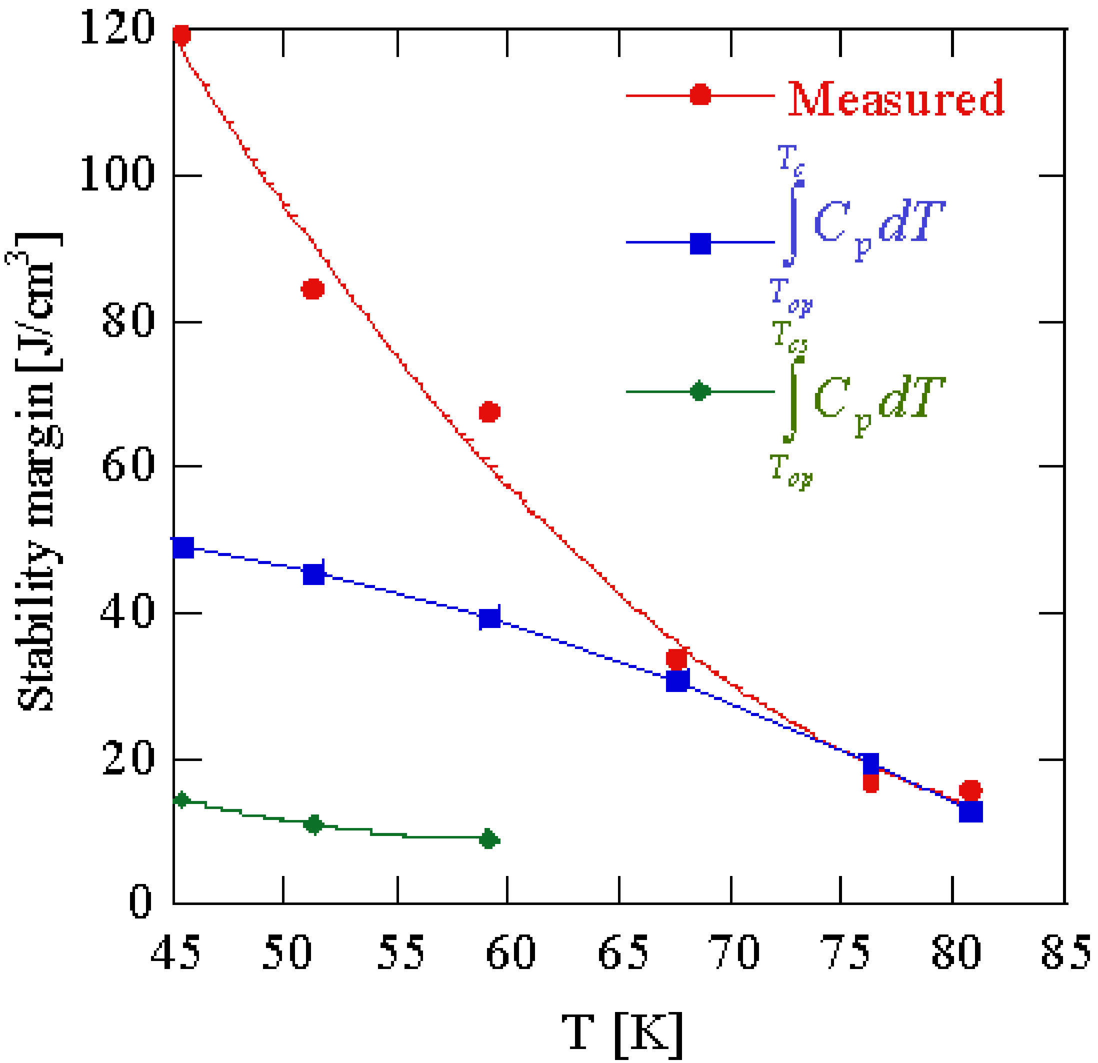


- 2 µm YBCO/50 nm LMO/Epi-MgO/IBAD-MgO/Nickel alloy
  - 178 A across 1 cm
  - 120 A across 10 - 20 cm
  - 50 A across 1.1 m
  - Microbridges - 1.1 MA/cm^2

AMSC, ORNL conductor development



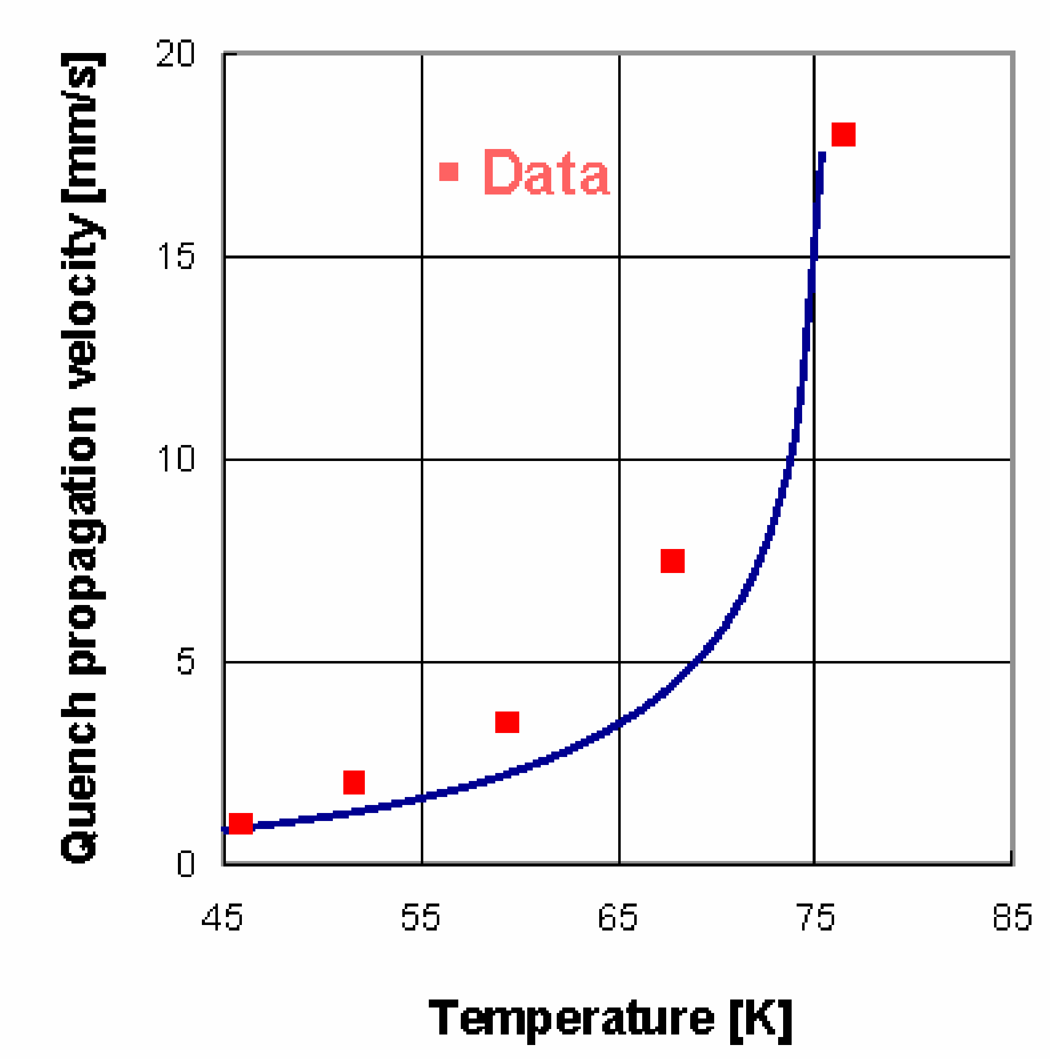
All YBCO films prepared with a single coat process



Stability margin for low Tc superconductors ~ 100’s mJ/cm^3 (3 orders of magnitude smaller)

Y. Iwasa, MIT

Quench propagation



For low Tc, quench propagation velocity is ~10 m/s (3 orders of magnitude larger)

M. Gouge, ORNL

Stabilizer

- In order to allow for proper cooling of HTS in region of poor superconductivity, M. Gouge recommends 5 mΩ/m resistive shunt (7/03)
- This decreases substantially the current density

Desired minimum resistivity	5.00E-03 Ohm/m
Copper resistivity @ 77 K	2.57E-09 Ohm m
Width	0.01 m
Thickness	5.14E-05 m

- For ARIES-stellerator: no shunt material, beyond that required for manufacturing

HTS conductor current density

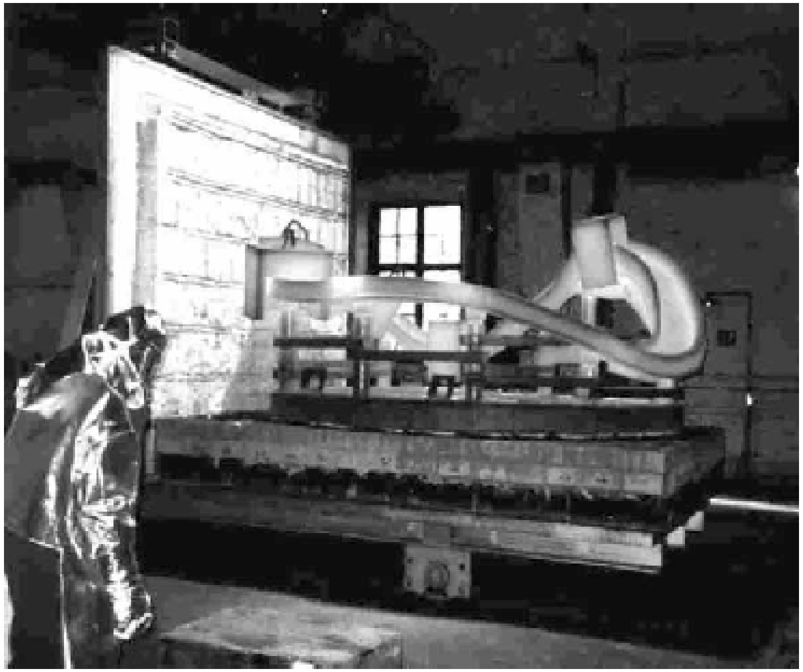
- YBCO and related 123 materials have texturing issues that decrease current density with thickness.
- Thickness of superconductor is ~ 1-2 microns
- Thickness of structure (Ni-based materials, either Ni, NiW or Hastelloy) is ~ 400-500 microns.
- Current density in conductor is 2 orders of magnitude smaller than superconductor
- But
  - Likely that SC can be deposited in much thinner substrates
  - If 50 microns, drop in current density only 1 order of magnitude

HTS as of 7/03

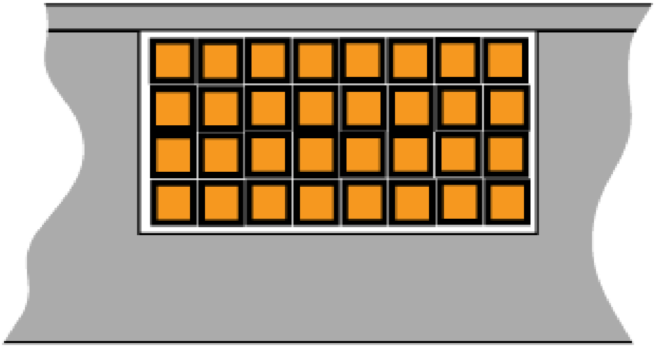
- Dependence of properties on YBCO thickness
  - $Jc \sim 1/d^{1/2}$
  - $Ic \sim d^{1/2}$
- The best YBCO result to date (77 K)
  - for thick(2.9 μm) on IBAD-YSZ $I_c \sim$ 270 A/cm
  - reel-to-reel RABiTS, 188 A/cm is for a 2.4-μm-thick coating, although one 1.37-μm-thick film exhibited an I_c = 219 A/cm, in 10 m long section
- Best properties for YBCO at 77K:
  - $J_c \sim 2$ MA/cm^2 in 0.35-μm-thick for IBAD-MgO.
  - $J_c \sim 3$ MA/cm^2 in 0.9μm for RABiTS

ARIES-Stellarator magnet concept

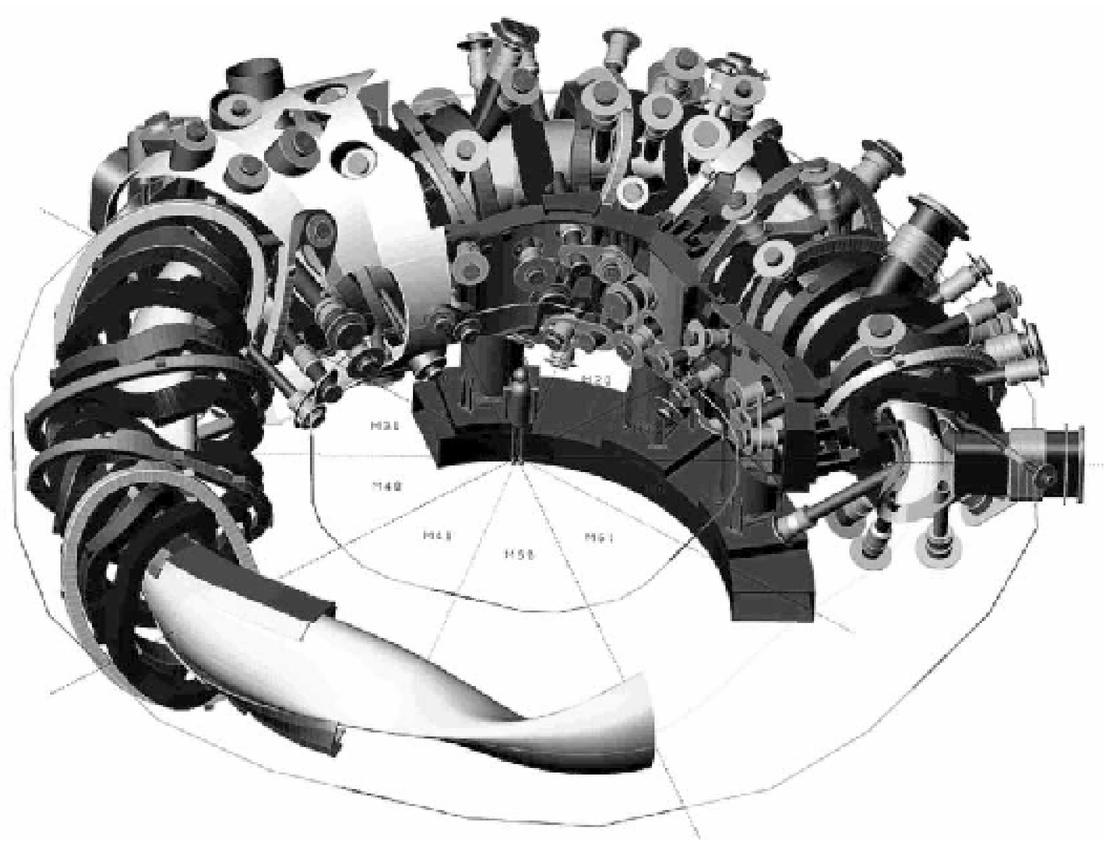
- For assembly/maintenance, Mallang proposes structural trenches where conductor is inserted



Wendelstain 7X



Magnet structure concept



Instead of individual forms for magnet structure, shells with trenches used for structure

Wendelstein 7-X

Low temperature magnet

- Use grading to decrease cost
  - Use NbTi in regions of low field (< 7 T)
  - In regions of higher field, use Nb_3Sn or equivalent
- Problem:
  - To wind stellerator magnets with Nb_3Sn, it is needed to use react and wind method
  - Magnets too complicated for applying insulation/bonding after winding (wind & react)
- Solution: Use high Tc material at low Tc

High Tc (at low temperature)

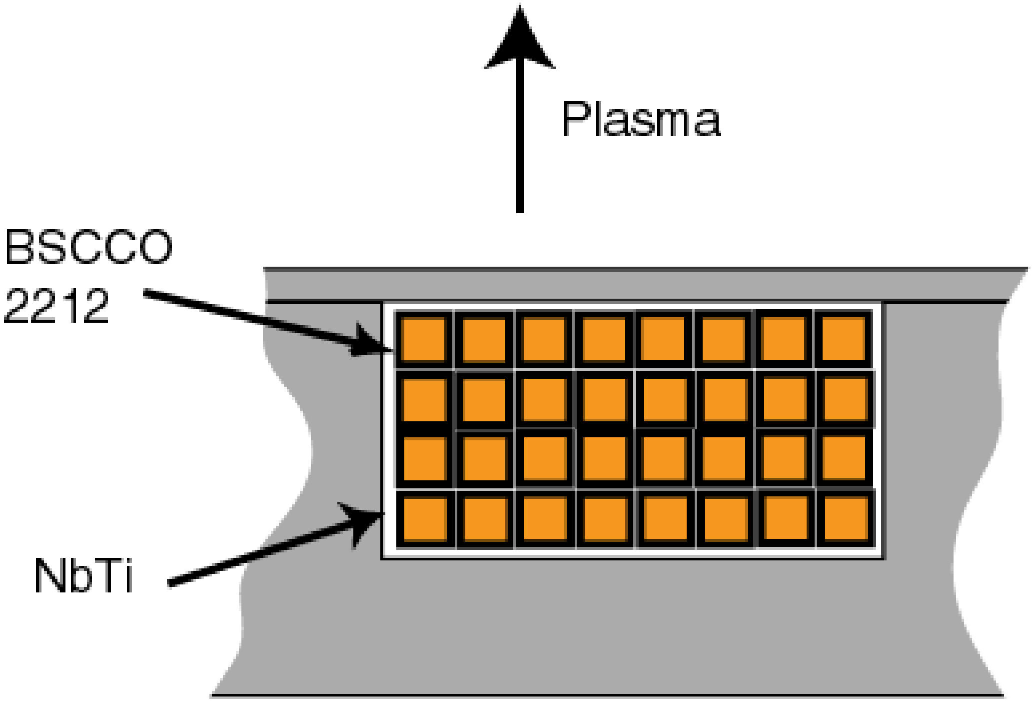
- Justin Schwartz (ARIES-1), now at FSU HFNML (Tallahassee, FL)
  - **It all started here (actually, in UCLA)!!!**
- Record field, energy, number of turns
  - BSCCO 2212

HTS insert	Background	Total
5.19	18	23.19
5.13	19	24.13
5.08	19.94	25.02

Oxford/NHMFL HTS insert BSCCO 2212

"Fusion should not have to wait for High Temperature Superconductor"

Comment made by a leader of the magnet fusion technology activity to Justin Schwartz


Plasma
BSCCO
2212
NbTi

LTS design of conductor

Magnetic field	T	10	12
SC current density	A/m^2	4.00E+09	3.00E+09
J2 tau	(A/m^2)s	5.00E+16	5.00E+16
tau	s	2.00E+00	2.00E+00
Current density in Copper	A/m^2	2.24E+08	2.24E+08
Helium fraction		0.25	0.25
Sheathing thickness			
B^2/2mu0	Pa	3.98E+07	5.73E+07
Stress in sheath	Pa	8.00E+08	8.00E+08
Fractional thickness of sheath		4.97E-02	7.16E-02
Sheath fraction in conductor		9.70E-02	1.38E-01
Current density	A/m^2		
Current density in strands	Conductor	2.12E+08	2.08E+08
Strands + Helium	Conductor + helium	1.59E+08	1.56E+08
Strands+helium+sheath	Conductor + Helium + sheath	1.43E+08	1.35E+08

LTS conductor design

Current density in LTS

- In 5/7 meeting, I mentioned that winding pack current density could be as high as 300 MA/m^2
- More careful investigation (*i.e.*, inclusion of quench protection), reduces current density to about 100 MA/m^2

Cost comparison

- NbTi
  - Presently: 1-2 $/kA m
- Nb_3Sn
  - Today: 10-20 $/kA m
  - Expected: 2-4 $/kA m
- YBCO
  - Presently: 200 $/kA m
  - Guessed: 10-20 $/kA m
  - Expert opinion: 50$/kA m

Magnet design algorithms

- This presentation provides algorithm for LTS design, modified for stellerator applications
  - Winding of conductor in trench, with substantial strains (Nb_3Sn can not be used)
  - Conductor grading: NbTi in low field region, BSCCO 2212 in high field region
  - Costing for LTS and HTS
- Model for HTS in January presentation:

  aries.ucsd.edu/ARIES/meeting/0106/bromberg.pdf
- Model for structure in May meeting:

  aries.ucsd.edu/ARIES/meetings/0507/bromberg.pdf