Iron based superconductors at FNAL: ultra high-field superconductor at low-cost

T. Spina

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Introduction and motivation

The high energy physics community has been asking for a strong push towards the energy frontier beyond the LHC. Unfortunately, large rings are very expensive and with the current state-of-the-art magnet technology (NbTi, Nb_3Sn and Cuprates), the costs are prohibitive. An emerging technology that has a great potential to provide **low-cost** conductor with **ultra-high-field** performance (>20 T) is based on a new class of HTS materials discovered in 2008: Iron-Based-Superconductors (IBSs or pnictides).

In view of future High Field Magnet (HFM) applications (Figure 1), this project is intended to the development of *inexpensive* high-T_c Iron-Based-Superconductor (IBS) wire with high critical current density (J_c>10^5A/cm^2 at >20T/4.2K).

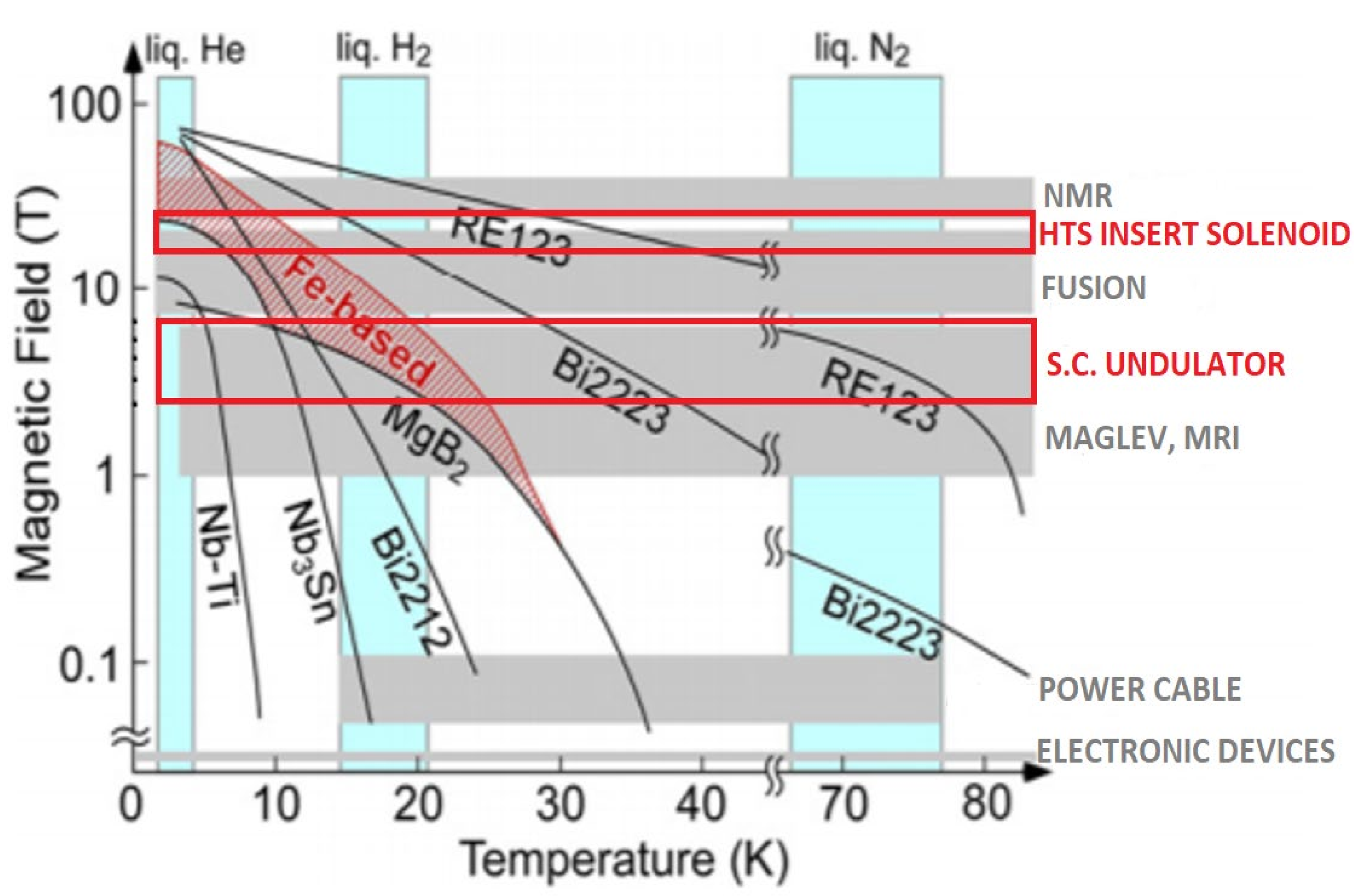

Figure 1: Applicable conditions for J_e>10^4 A/cm^2 for various superconducting tapes and wires.

Main goals

The major goal to pursue is to address the extrinsic J_c limitations uncovered in pioneering work and develop an optimized *production-ready PIT doped-122 monofilament* wire at FNAL.

In order to improve J_c, the limits due to the flux pinning defects landscape and granularity must be overcome. To this aim:

- ***Charged particle irradiations experiment*** on bulk and wire samples with different chemical additions to engineering the defects pinning landscape;
- **Optimized *mechanical deformation* and *heat treatment*** procedures to improve grain connectivity and texture.

Specific studies will be also devoted to the ***improvement of sheath*** composite materials for cost reduction and to increase the mechanical performances under bending.

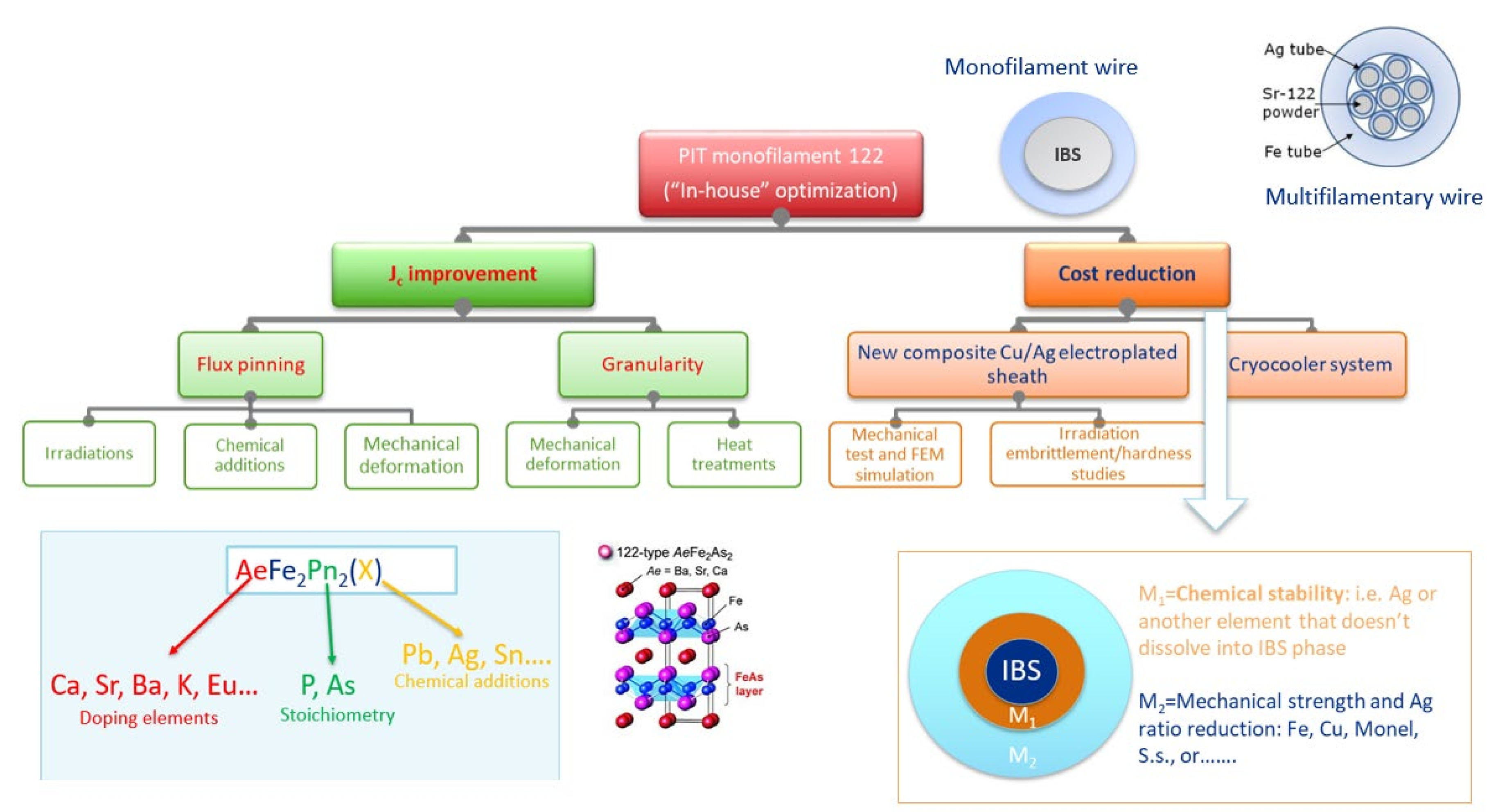

Figure 3: PIT IBS-122 monofilament optimization plan at FNAL: improvement of J_c and cost reduction will be the major tasks to achieve in the present proposal.

State-of-the-art

A recent proof-of-principle demonstration by Y. Ma et al. [1] showed that Powder-In-Tube (PIT) technique is a feasible method to produce 100m-long IBS wires with good values of J_c (up to 1.3x10^4A/cm^2 at 4.2/10T) but, as shown in Figure 2, still below the practical level (>10^5A/cm^2).

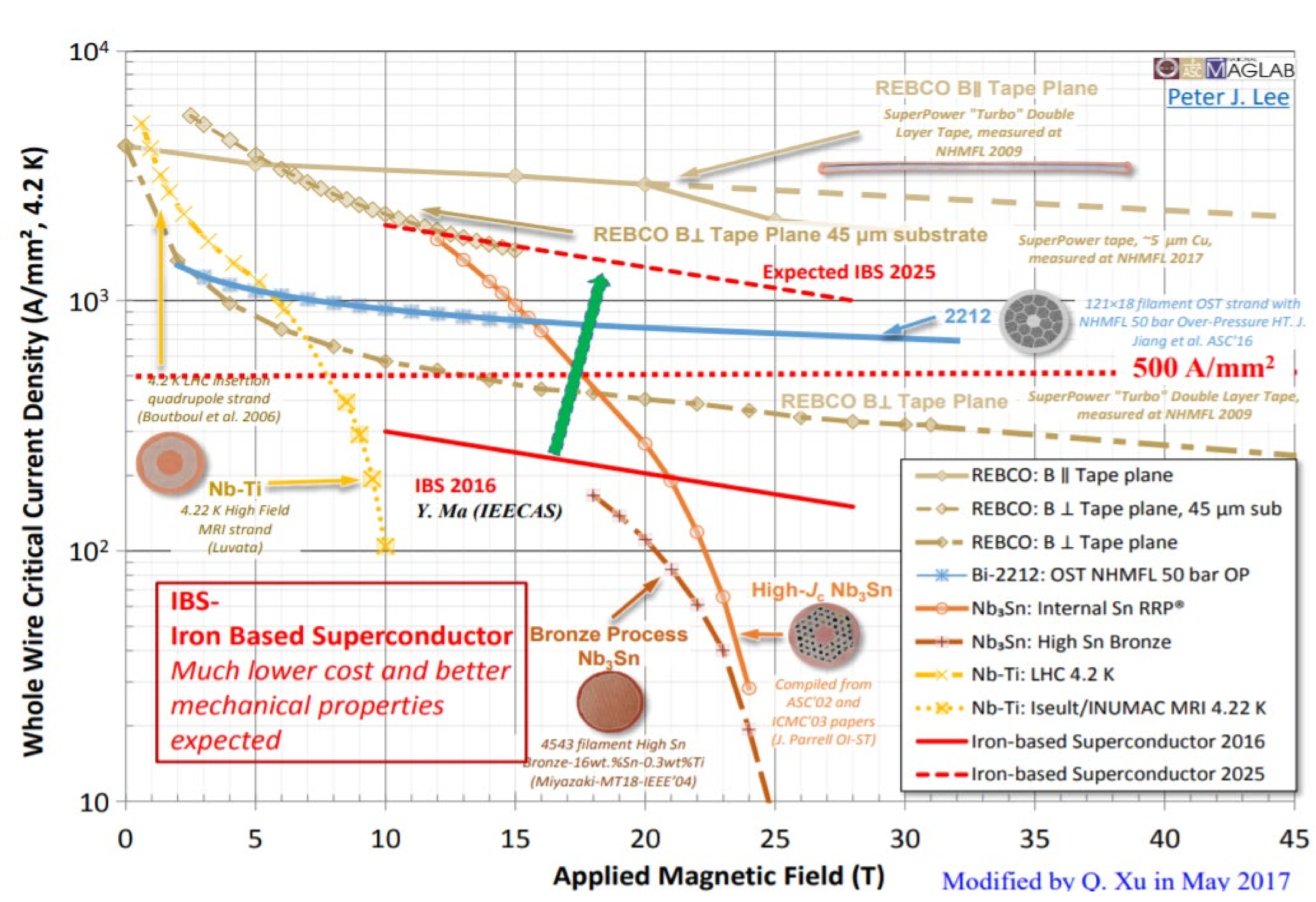

Figure 2: State-of-the-art of J_c for practical conductors – In red: Expected IBS 2025 J_c value above the practical level, i.e. 500A/mm^2 [1].

Ex-situ Powder-In-Tube method at FNAL

In this project the ***ex-situ* PIT** process will be adopted (Figure 4).
The precursors powders are reacted before being packed into metal tube Different 122-IBS bulk samples produce by **Spark Plasma Sintering (SPS)** technique in Japan will be the source for reacted precursors in this study.

Phase	I: Powdering	II: Mechanical Deformation	III: Sealing and Sintering
	Starting powders; Metal tube	Swaging and drawing; Flat rolling	Wire or tape; Arc welding; HT: 800-900°C Under vacuum or Ar atmosphere
Possible Defects	✓ Low density ✓ Oxidation ✓ Impurities	✓ Cracks and strain induced in IBS phase	✓ Loss of volatile elements ✓ Pores ✓ Second phase ✓ Chemical reaction with metal sheath

Figure 4: PIT process for wires and tapes fabrication. The typical material defects are shown. The mechanisms that limit current flow at the grain boundaries are still lacking a well-founded explanation, but the results achieved so far seem to indicate that among the key targets to pursue are improving densification and inducing a certain degree of texture. [2].

[1] Chao Yao and Yanwei Ma, Supercond. Sci. Technol. **32** 023002 (29pp) (2019)
[2] I. Pallecchi et al., Supercond. Sci. Technol. 28 114005 (12pp) (2015)

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