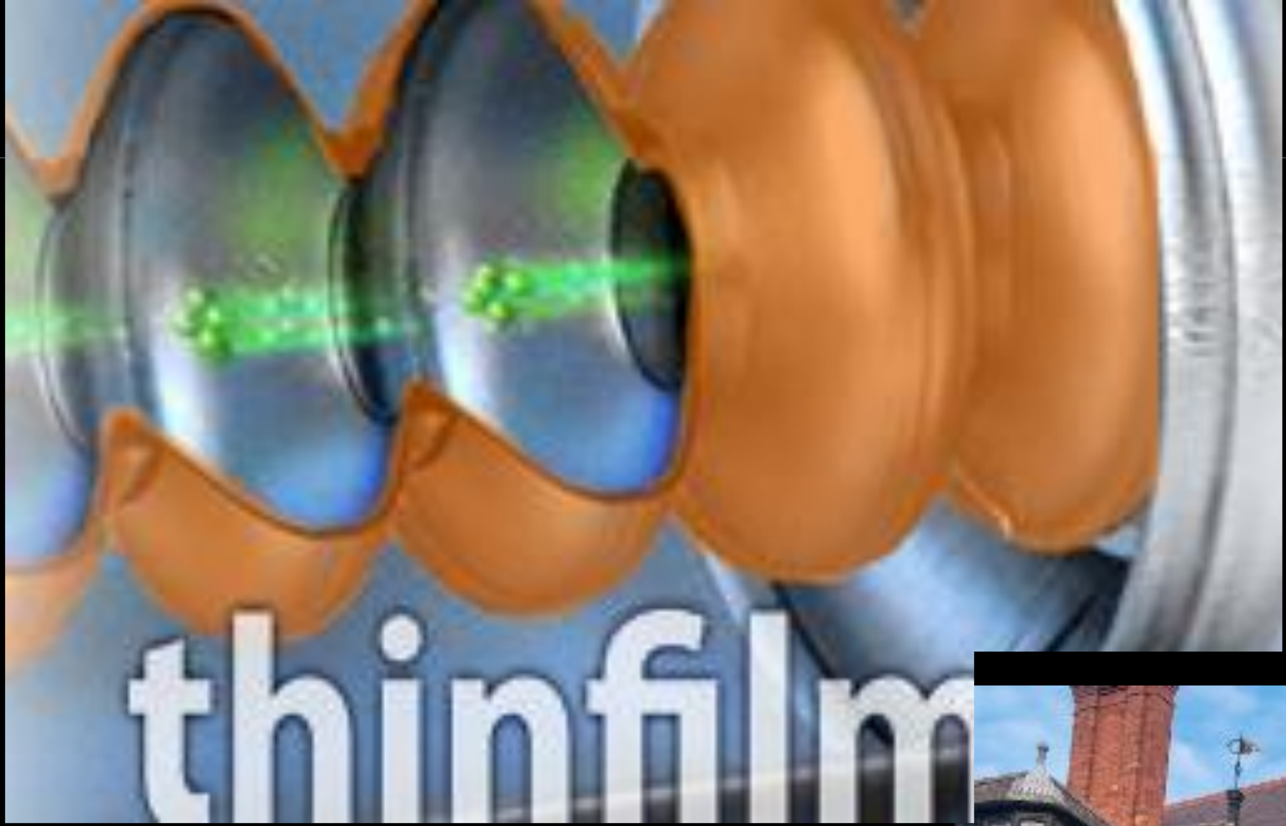

WELCOME

TFSRF 2026- 12th EDITION

THIN FILM AND NEW IDEAS FOR PUSHING THE LIMITS OF RF SUPERCONDUCTIVITY

International Organising Committee:
Anne- Marie Valente
Alex Gurevich
Reza Valizadeh - Chair
Cristian Pira
Thomas Proslier
Walter Venturini Delsolaro
Takayuki Saeki

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The TFSRF Started in 2005 at JLab

- Has been alternatively every 2 years by Jlab and INFN Legnaro (except 2020)
- From 2024 edition
  - It is organized to be shared among other community
  - We propose to work at International level combining various road maps.
  - Intensify R&D and accelerate the progress in TF SRF field.

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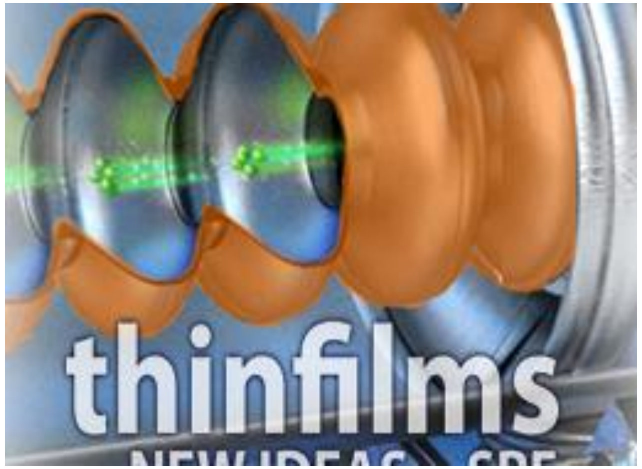

Sharing Ideas to create Synergy

The primary aim of the workshop is to provide a collaborative environment as open, inclusive and diverse as possible, to foster discussion and new ideas.

- **Setting the Horizon: Global Perspectives & Technical Roadmaps**
- **Pushing SRF Thin Films Limits: Theoretical Advances, Deposition Modeling & DFT**
- **Latest Advances in Nb Thin Film Technology**
- **Conventional PVD, energetic condensation from highly ionized plasmas**
- **Nb3Sn Technology: Recent Technical Advances & Scaling Horizons**
- **Beyond Nb & Nb3Sn: Alternate materials, multilayer SIS structures and functional layers**
- **Tailored Substrates for Advanced Film Growth**
- **Emerging Frontlines in Characterization Methods: Advanced Imaging & Novel Probes**
- **Emerging Frontiers & Synergies in SRF Thin Films: From Quantum Sensing to AI-Driven Material**

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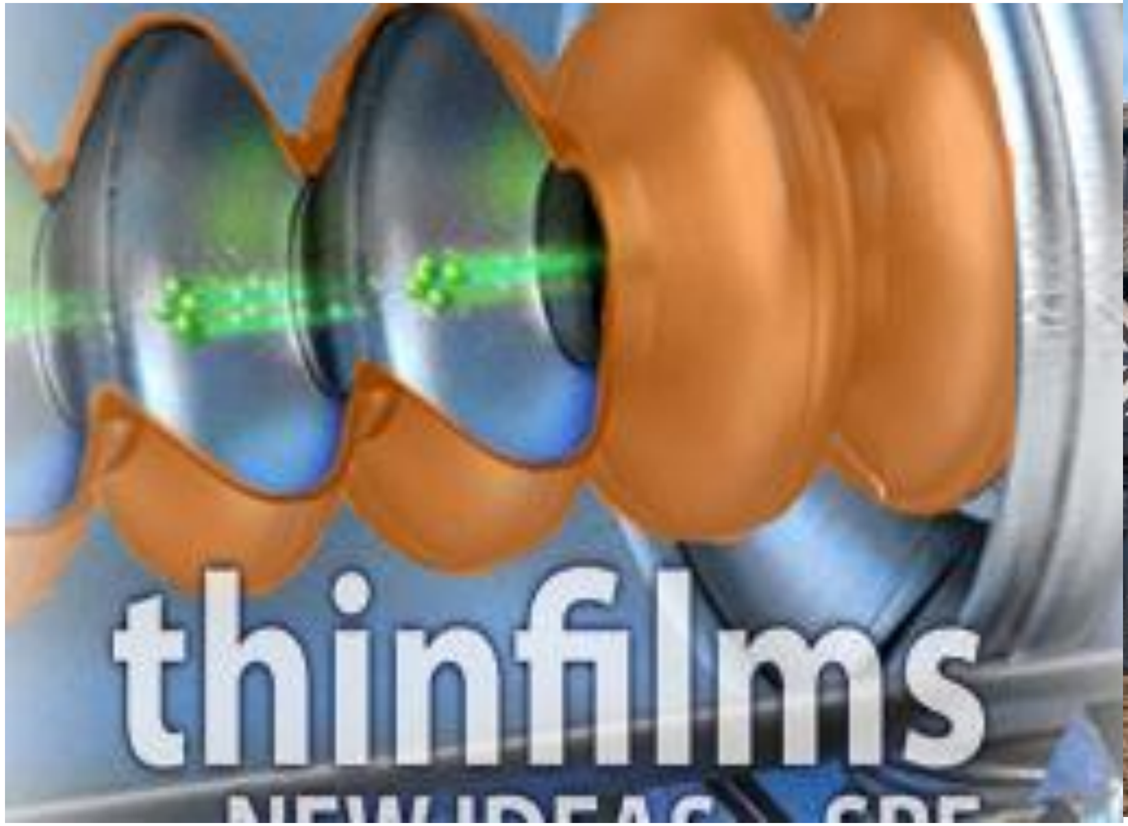

Speakers

Please upload your slides the day BEFORE your talk, we need to download them in order to verify them and show on ZOOM if needed

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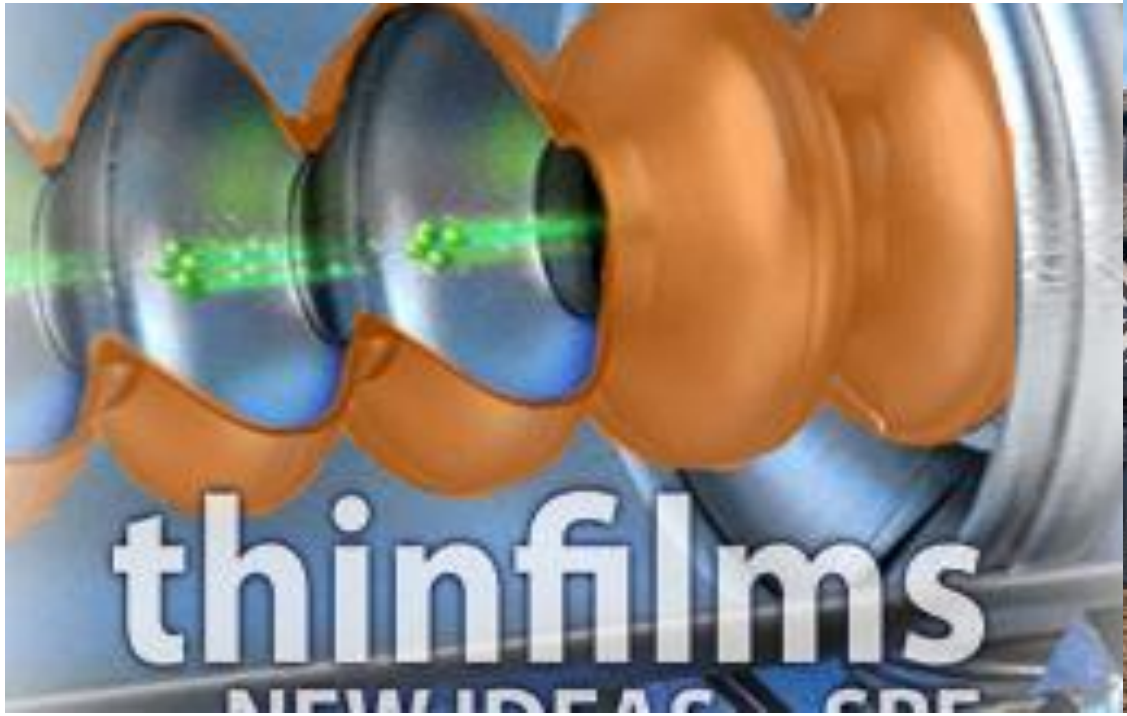

For those who are staying at the Plaza Hotel

Breakfast is included

Lunch is served at restaurant adjacent .

For Dinner there will be plenty of choices in city centre

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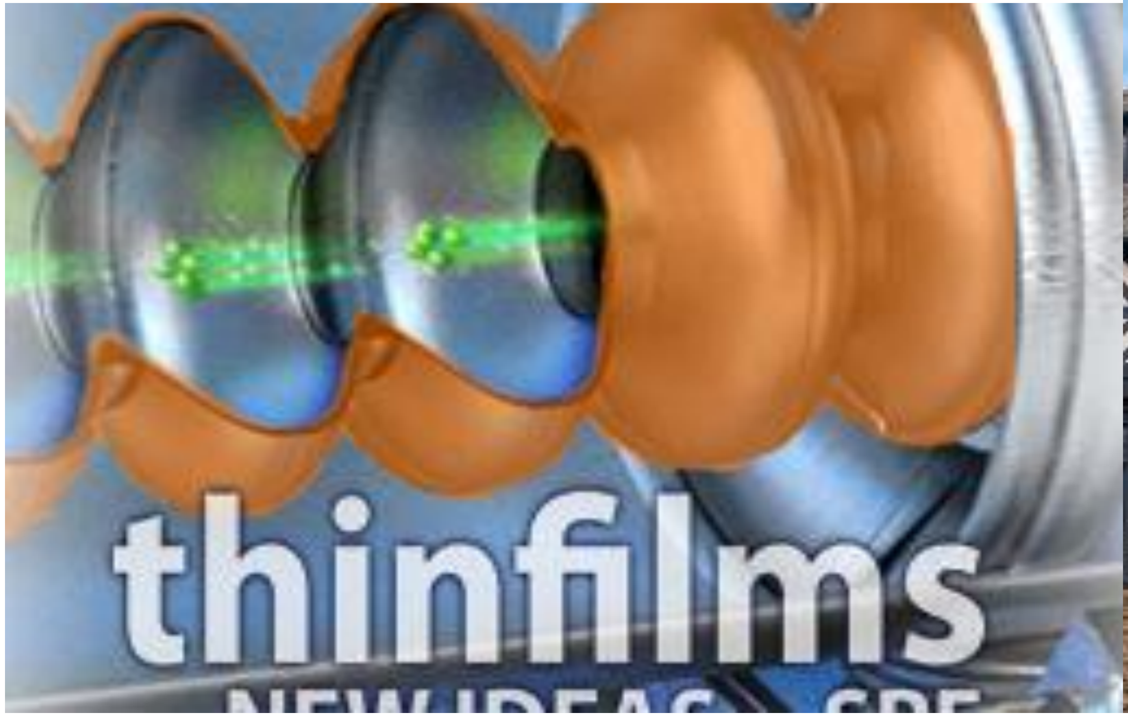

Visit to Daresbury Laboratory:

- A dedicated bus is arranged to take all the delegates to Lab and back.
- The bus will leave from the Hotel at 2:00 pm just after the lunch on Wednesday

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Workshop Dinner

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Date: 23rd September 2026
Time: 7pm
Chester Cathedral

Direction:
5 minutes walk from the Plaza Hotel,
Signed Posted.

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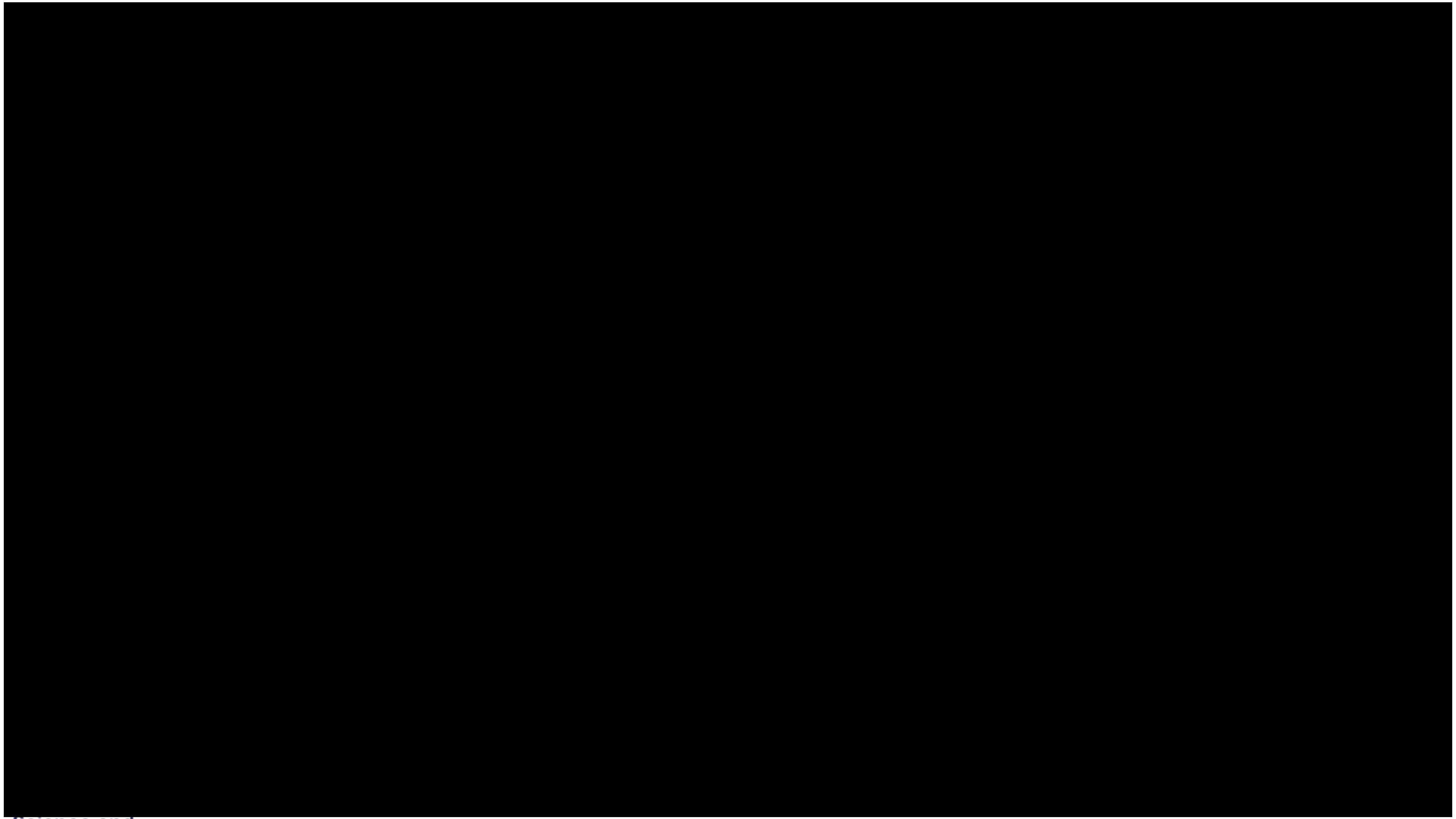
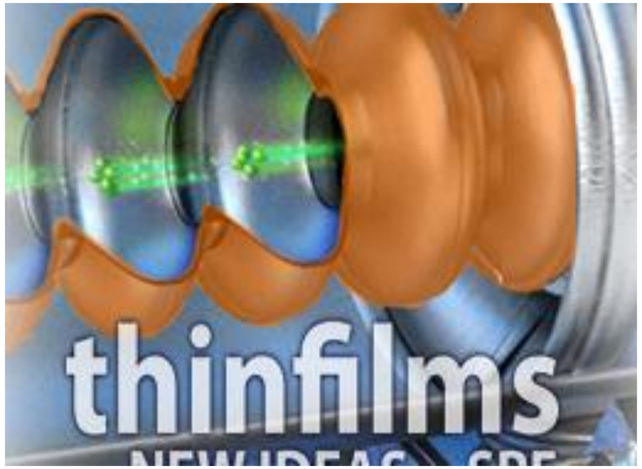
Remebering Abscent Colleagues





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Thin-Film Superconductivity for SRF Cavities

Current Status & Future Challenges

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Why Thin Films for SRF?

- SRF performance is a SURFACE phenomenon — RF penetrates only ~40 nm (Nb) to ~350 nm (NbN)
- Bulk Nb is near its intrinsic limit (~50 MV/m) after decades of N-doping & processing

Thin films offer:

  - Higher gradient potential (Nb3Sn, multilayers)
  - Operation at 4.2 K (vs 2 K for Nb) -> cheaper cryogenics
  - Lower material cost (less Nb, Cu substrate)
  - Better thermal stability (Cu's high thermal conductivity)

- Only the first few hundred nm 'matter' — the bulk is redundant

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The Materials Landscape

Nb (sputtered on Cu) — Tc 9.2 K — Deployed (HIE-ISOLDE) — Mature

Nb3Sn (A15) — Tc 18 K — Prototype cavities — Most optimised alternative

- NbN / NbTiN — Tc 16-17 K — Sample + small cavity — Mid-stage
- MgB2 — Tc 39 K — Sample only — Exploratory
- Nb3Al, V3Si, Mo-Re — Tc 11-19 K — Sample studies — Exploratory
- SIS multilayers — Concept + samples — Early R&D
- Nb remains the benchmark. Nb3Sn is the clear frontrunner among alternatives.

Status: Sputtered Nb on Cu

ACHIEVEMENTS

- CERN HIE-ISOLDE quarter-wave cavities: >60 MV/m surface peak field, Q ~ 1e9 at 2.3 K
- First production thin-film cavity to match bulk-Nb performance
- Seamless spun-Cu substrates eliminated weld-seam limitations
- 4 cryomodules (20 cavities) installed and operational

REMAINING LIMITS

- Voids, impurities, non-uniformity, adhesion issues
- Large elliptical cavities still trail bulk Nb

Status: Nb_3Sn — The Leading Alternative

- **Tc ~ 18 K -> can operate at 4.2 K (no superfluid helium)**
- Theoretical gradient ~2x Nb
- Single-cell: Q0 ~ 1e10 at ~10 MV/m; up to 3e10 at 2 MV/m (4.2 K)
- Coating methods: tin vapour diffusion, magnetron sputtering (DCMS, HiPIMS)

KNOWN PROBLEMS

- Sn deficiency / non-stoichiometric A15 phase
- Cu interdiffusion (on Cu substrate)
- Surface roughness -> major gradient limiter (Cornell)
- Film cracking under mechanical strain (brittle)
- Q-slope at high field

Status: Other Materials

Nitrides (NbN, NbTiN):

- Higher Hc than Nb, but high-field Q-slope & impurity incorporation limit performance

MgB2:

- Highest Tc (~39 K) -> could operate at 15-20 K; but unstable, oxygen-sensitive

SIS multilayers (Superconductor-Insulator-Superconductor):

- Theoretical path to exceed Nb superheating field (>50 MV/m)
- Requires pinhole-free insulating layers — not yet at cavity scale

Key Achievements Summary

WHAT WORKS TODAY

- Thin-film Nb-on-Cu deployed in HIE-ISOLDE (production)
- Nb3Sn demonstrates high Q at 4.2 K (prototype)
- Sample-level characterisation infrastructure mature
- European Thin-Film SRF Roadmap published (2025)
- Active international collaboration (CERN, Fermilab, Cornell, JLab, KEK, STFC)

WHAT DOES NOT YET WORK

- Reproducible high-gradient Nb3Sn at production scale
- Thin films matching bulk-Nb gradient on large elliptical cavities
- Multilayer/SIS at cavity scale
- Stable MgB2 coatings

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Challenge 1: Reproducibility & Yield

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THE CHALLENGE

- Prototype cavities hit target performance; production runs do not
- Coating uniformity over complex cavity geometry is inconsistent
- Defect statistics not yet controlled enough for accelerator-grade yield

IMPACT

- Thin films cannot be specified for future machines (FCC, ILC) until yield is predictable
- *'A single great cavity is a paper. A hundred great cavities is a technology.'*

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Challenge 2: Defects, Stoichiometry & Interface

Nb3Sn-specific:

- A15 phase requires exact 3:1 Sn:Nb stoichiometry — deviations kill performance
- Sn-poor regions, voids, Cu interdiffusion create weak spots
- Surface roughness nucleates vortex entry -> premature quench

General:

- Particulates and pinholes -> field emission
- Film-substrate adhesion & thermal interface resistance -> hot spots, quench
- Impurity incorporation during sputtering (O, N, Ar)

- Coating chemistry & microstructure must be controlled to nm precision over m^2 of surface

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Challenge 3: Mechanical & Operational Robustness

MECHANICAL

- Nb3Sn is brittle — cracks under handling, cooldown thermal contraction, tuning stress
- Safe strain range is narrow (~ -2.3% to +0.9%)
- Recoating/healing degraded cavities is an active research area

OPERATIONAL

- Q-slope at high field limits useful gradient
- Flux pinning and trapped flux losses (especially at 4.2 K)
- Long-term field emission & gradient degradation in operation (LEP-II experience)

Challenge 4: Scaling & New Architectures

SCALING TO REAL CAVITIES

- Most data is from sample-level or single-cell tests
- Multi-cell, full-size elliptical cavities remain rare
- Cryomodule integration largely unproven for alternatives

NEW ARCHITECTURES NEEDED

- HiPIMS / energetic sputtering -> denser, void-free films
- Multilayer SIS -> break the Nb superheating-field limit
- In-situ surface preparation compatible with coating

Coordinated Programs & Roadmaps

EUROPEAN PROGRAMME CHAIN (Horizon 2020 / Europe)

- ARIES (2017-2021) WP15: substrate prep & TF quality (Nb, NbN, NbTiN, Nb3Sn, SIS) — TRL 3
- IFAST (2021-2025) WP9: 6 & 1.3 GHz cavities; first bulk-Nb cavity PVD-coated with Nb3Sn; EU TF-SRF roadmap; laser & FLA annealing — TRL 4-5
- iSAS (2024-2028) WP3: Cu cavities + Nb3Sn coating & RF testing; flux trapping & mitigation; tunability
- EPITA (2027-2031) WP4: industrialise Nb3Sn cavity production; vertical & horizontal cryostat tests; conduction cooling — TRL 6
- *Industrial partners: 0 (ARIES) -> 3-5 (EPITA); goal: transfer Nb3Sn production to industry*

SNOWMASS 2023 (US strategy)

- Next-Gen SRF via advanced thin films & innovative materials (Valente-Feliciano et al.)
- Nb3Sn: maturing tech for accelerators + dark-matter / GW / quantum-sensing detectors (Posen et al.)

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EXAMPLE

- *Aug 2025: first bulk-Nb cavity coated with Nb3Sn (Cockcroft/ASTeC), RF-tested at HZB*

Roadmap & Outlook

NEAR-TERM (1-3 yrs):

- Improve Nb3Sn reproducibility via HiPIMS & process control
- Multi-cell Nb3Sn cavity demonstrations
- Recoating/healing protocols

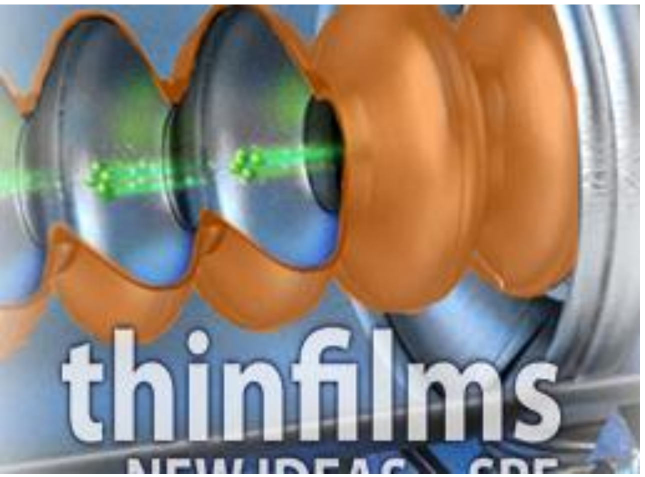
MID-TERM (3-7 yrs):

- Nb3Sn production qualification for a real accelerator
- SIS multilayer cavity-scale proof-of-principle

LONG-TERM (7+ yrs):

- Thin-film baseline for FCC, muon colliders, ILC upgrades
- 4.2 K operation as standard -> major cryogenic cost reduction

- Milestone: 12th Int'l Workshop on Thin Films & RF Superconductivity — Chester UK, Sept 2026



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Take-Home Message

Thin-film SRF has moved from concept to demonstrated prototype. The science works. The remaining battle is engineering: reproducibility, defect control, mechanical robustness, and scaling to production cavities. Nb3Sn is the material to watch; the next 3-5 years will decide whether thin films become the future of SRF.

Thank you

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