IFAST kick-off meeting 04/05/2021

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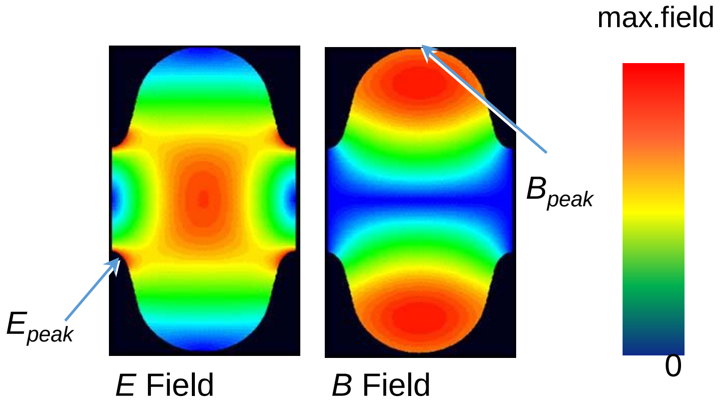
WP9 coordinators

Introduction

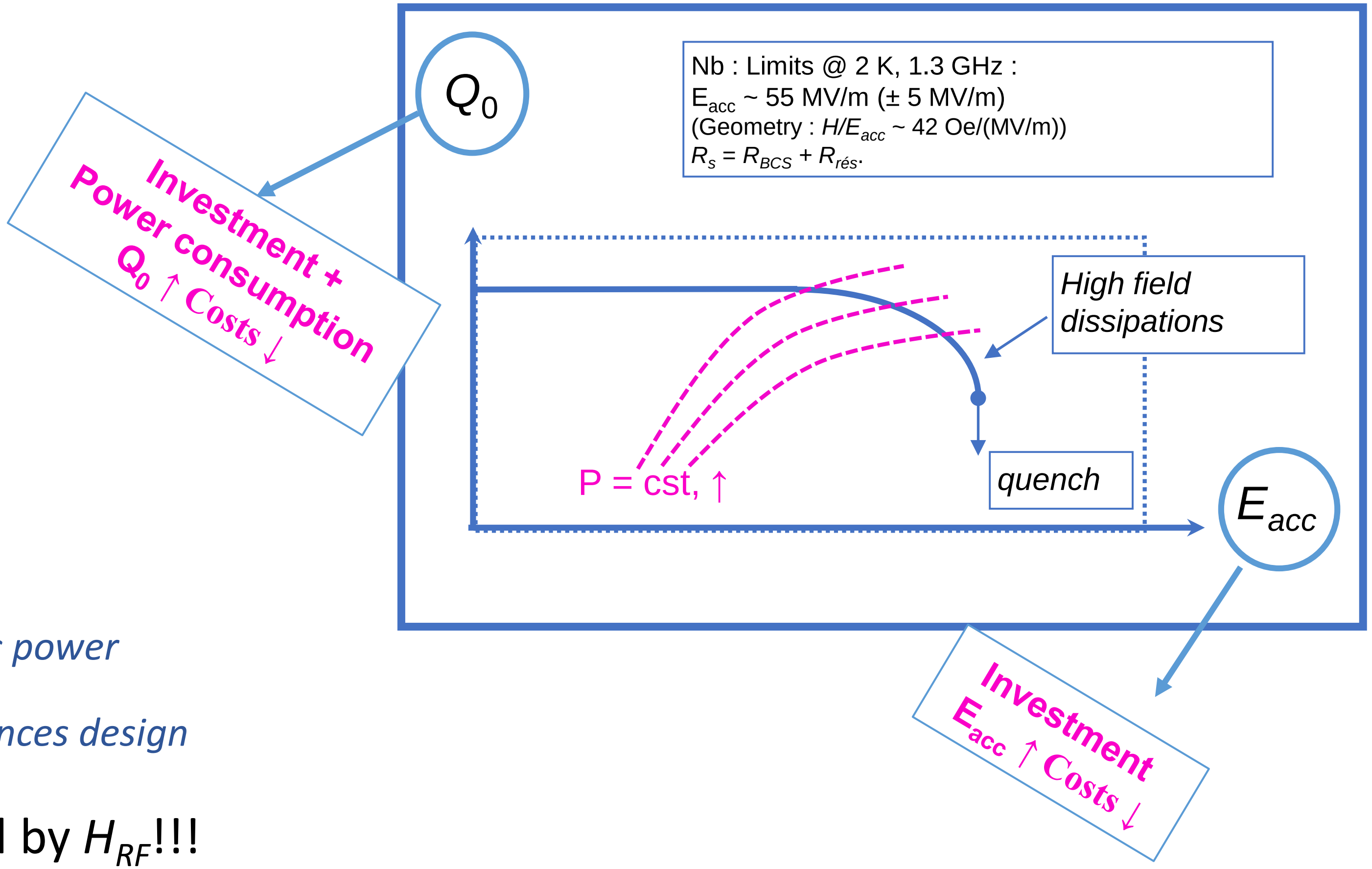
Recalls on SRF cavities

Bulk Nb: monopoly since > 50 years

- Nb/Cu applications at low accelerating field only until recently



- Figures of merit:
    - $E_{acc} \propto H_{RF}$ *limitation = magnetic transition*
    - $Q_0 \propto 1/R_S$ *limitation = thermal transition*
    - Duty cycle (=> 100%): *limitation = cryogenic power*
    - $\beta = \frac{v}{c}$ (particle speed /light speed): *influences design*
- At $f < 3$ GHz: cavities are mainly limited by H_{RF}!!!



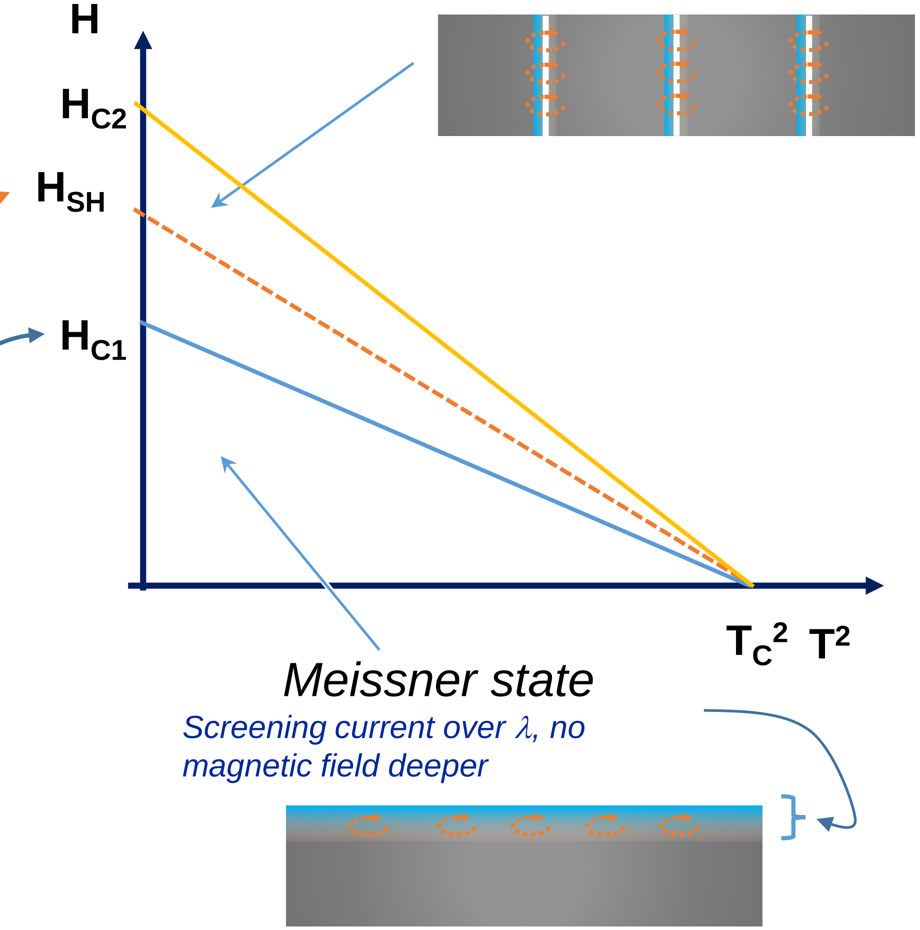
Nb : Limits @ 2 K, 1.3 GHz :
E_{acc} ~ 55 MV/m (± 5 MV/m)
(Geometry : H/E_{acc} ~ 42 Oe/(MV/m))
$R_s = R_{BCS} + R_{rés}$.

Ultimate limits in SRF

- SC phase diagram
  - All SC applications except SRF: mixed state w. vortex
    - Vortices dissipate in RF !
  - SRF => Meissner state mandatory !
  - H_{C1} = limit Meissner/mixed state
    - Nb highest H_{C1} (180 mT)
  - "Superheating field" (H_{SH}) : Metastable state favored by $H//$ to surface
    - Difficult to get in real life

Mixed state *w.Vortex*

(i.e. N. cond. flux line + screening currents)



Meissner state

Screening current over λ, no magnetic field deeper

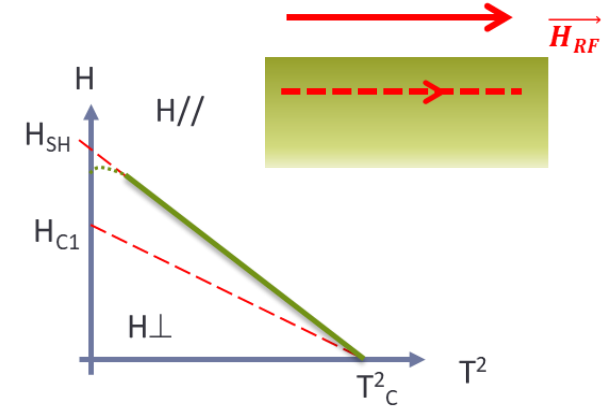
Superconductors for SRF

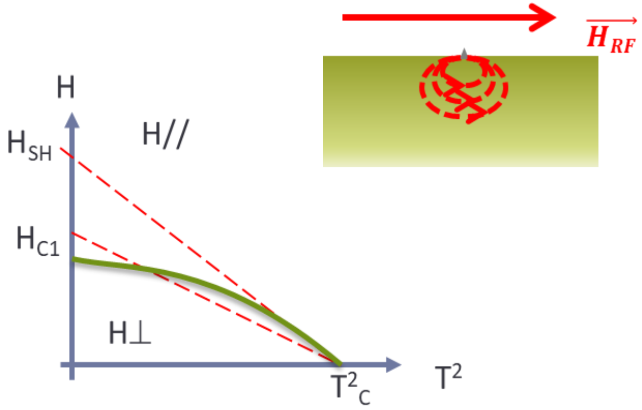
Material	T_C (K)	$\mu_0 H_{SH}$ (mT)@ 0 K
Pb	7,1	100
Nb	**9,2**	**219,0**
NbN	**17,1**	**214,0**
Nb_3Sn	**18,3**	**425,0**
MgB_2	**39,0**	**170,0**
Pnictides **$Ba_{0.6}K_{0.4}Fe_2As_2$**	**38,0**	**756,0**
~~**Cuprates**~~ ~~**YBaCuO**~~	**93,0**	**1050,0**

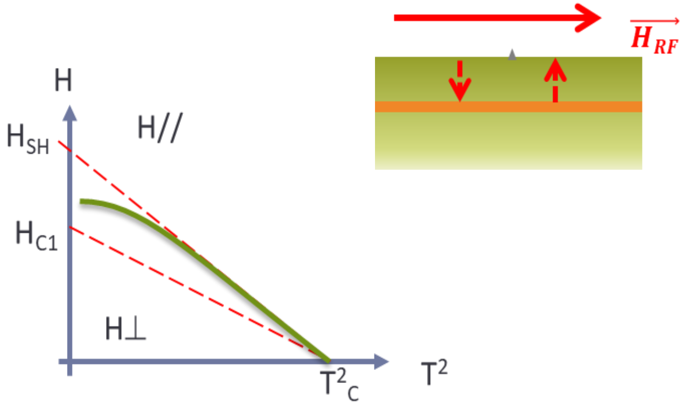
High H_{SH} => High E_{acc}… in theory

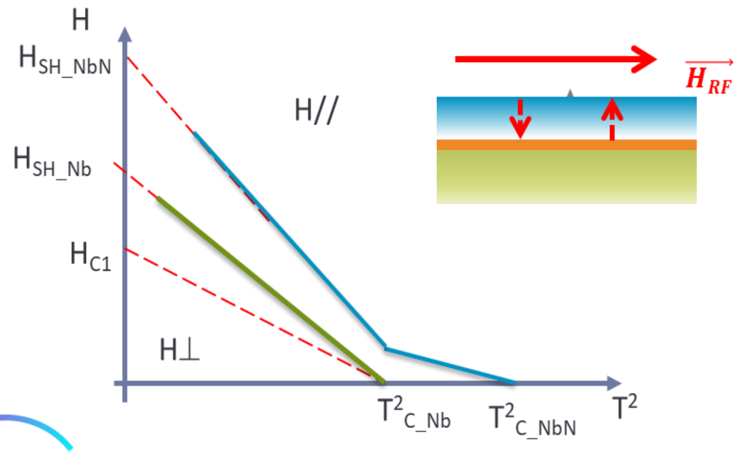
High T_C => High Q_0

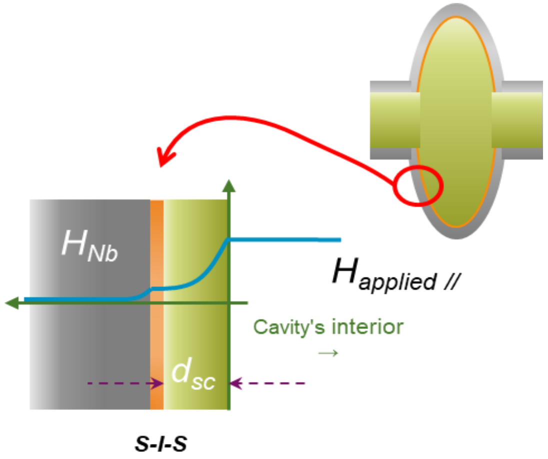
Multilayers concept,
or how to make theory face reality

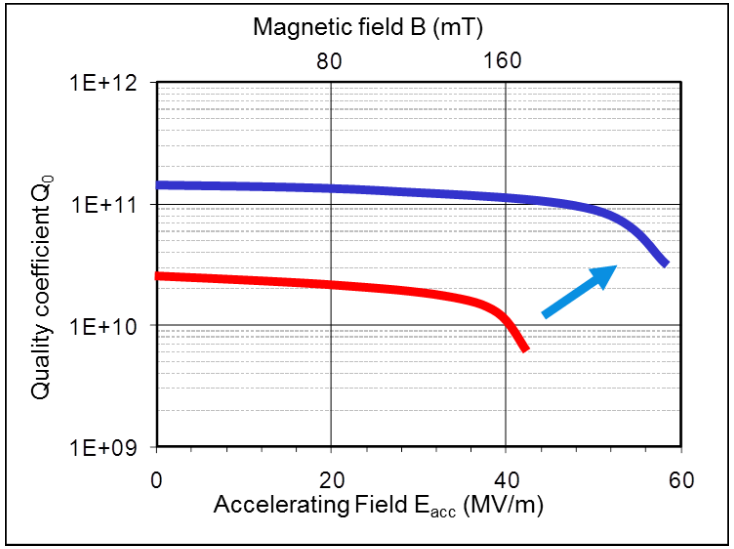












What past has taught us ?

- Huge number of parameter have to be explored
  - Not achievable without cooperation and work sharing
  - Still relatively few research teams and resources
- Paramount importance of substrate quality (pre/post treatments)
  - We knew it, but there is still room for improvement
- Thick and thin films are very sensitive to crystalline defects, but not all defects are troublesome.
  - Need for characterisation: structural, superconducting, RF.
  - For now still no overlapping with techniques => predictions are difficult

IFAST WP9

WP9 objectives

- Define a strategy for innovative superconducting RF (SRF) cavities coated with a superconducting film.
  - Deposition techniques: PVD and ALD
  - Superconducting films: Nb, NbN, Nb_3Sn, V_3Si (and others) and SIS
  - Optimization of flat SRF thin films production procedure
- Optimise and industrialise the production of seamless copper cavities and of the deposition techniques.
- Produce and test prototypes of SRF (single-cell elliptical) cavities:
  - Initially with pre-prototypes with f = 6 and 3 GHz
  - Scaling up for f = 1.3 GHz.
- Test a new laser treatment of Nb coated cavity.

➢ **Main goal**:

- Improving the performance and reducing the cost of acceleration systems
  - both production and operation

Transition from ARIES WP15 to IFAST WP9

ARIES WP15

The main emphasis was on a systematic study of correlation between

Surface preparation
- Cleaning, etching,
- Polishing, passivating

Thin film deposition
- **PVD**: DC, pulsed, HIPIMS…
- **Nb, NbN, $\mathbf{Nb_3Sn}$**, MgB_2, etc.
- Laser treatment of Nb film

Film characterisation
- SEM, FIB, AFM,
- XPS, XRD, RBS, TEM…

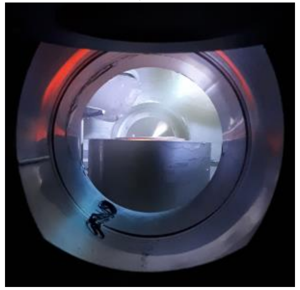
Superconducting properties measurement
- DC magnetic susceptibility,
- RRR, H_c, H_{fp}, H_{sh},
- Field penetration

Superconducting RF properties evaluation
- QPR at CERN
- QPR at HZF
- HW cavity at ASTeC

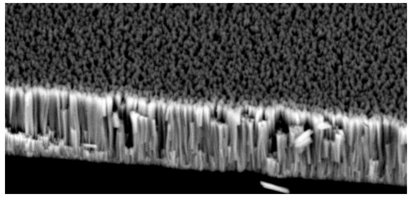
~~Re y mea nt~~
- Cavity deposition

Cu sample polishing

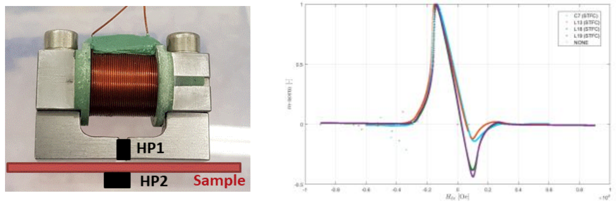
Film deposition



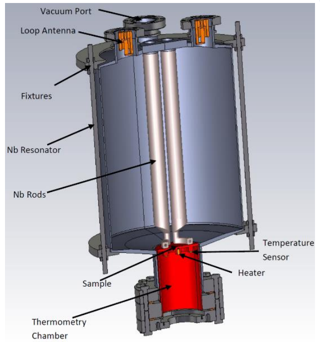
SEM image of a NbN thin film



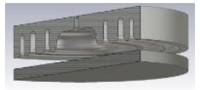
DC magnetisation



QPR



HW test cavity



Main results of ARIES WP15

Key results: better understanding of a correlation between

- substrate preparation,
- deposition process, thin film characteristic,
- the DC and AC SC evaluation results and
- the TF behaviour at the RF conditions

- Five polishing techniques for Cu have been tested with Nb films
  - SUBU5 and EP demonstrate best results
- Development of non-Nb superconducting films on small samples:
  - NbN, Nb_3Sn, NbTiN films as well as SIS structures deposited and characterised,
  - Small sample evaluation on SC properties with VSM and MFPF;

- Evaluation of Nb films at the RF conditions:
  - New QPR sample design, transport case,
  - QRR sample polishing developed and applied to the samples at INFN,
  - Deposition of 10 QPR samples
    - at INFN, Siegen and STFC
    - *with Nb and SIS: Nb/AlN/NbN and Nb/AlN/Nb_3Sn*,
  - First QPR results for SIS structures,
  - Comparative testing of QPR facilities at CERN and HZB with the samples produced by WP15 team;
- Developing of new technologies:
  - Laser treatment of Cu substrate and Nb films,
  - Magnetic field penetration facility (MFPF);
- Strong collaborating team, enhancing a capability of every partner, frequent discussions, joint publications.

Main result:

enabling progressing to the next stage: developing a real cavity prototype coated with non-Nb superconducting TF and SIS structures within I.FAST WP9

I.FAST WP9

The main emphasis is on applying the result of ARIES to RF cavity deposition and testing

Surface preparation

- Cleaning, etching,
- Polishing, passivating

Thin film deposition

- **PVD**: DC, pulsed, HIPIMS…
- (PE)CVD, (PE)ALD
- **Nb, NbN, Nb_3Sn**, MgB_2, etc.
- Laser treatment of Nb films

Film characterisation

- SEM, FIB, AFM,
- XPS, XRD, RBS, TEM…

Superconducting properties measurement

- DC magnetic susceptibility,
- *RRR*, H_c, H_{fp}, H_{sh},
- Field penetration

Superconducting RF properties evaluation

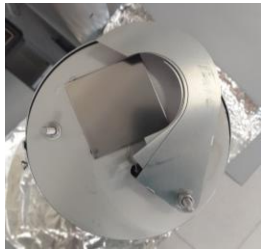
- QPR at CERN
- QPR at HZF
- HW cavity at ASTeC

Real cavity measurement

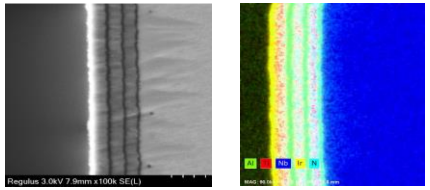
- Cavity deposition and testing

Cu sample polishing

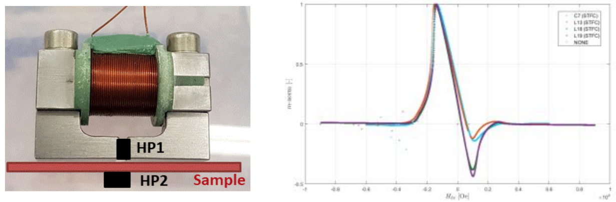
Film deposition



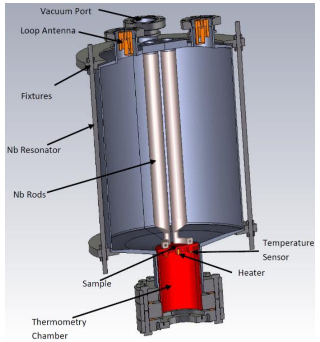
SEM and EDS images of SIS film



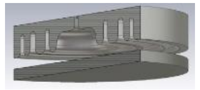
DC magnetisation



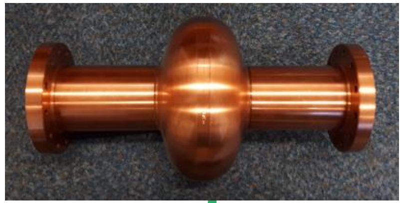
QPR



HW test cavity



1.3 GHz cavity for STF deposition



WP9 tasks

- **Task 9.1**: Coordination and strategy for innovative superconducting accelerating cavities
  - *CEA, INFN, HZB, UKRI, USI, JLab MEPHI, PTI.*
- **Task 9.2**: Innovative SC accelerating cavity prototype
  - *INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB, PTI, MEPHI*
- **Task 9.3** : Optimisation of process parameters and target development for SRF cavity coating with A15 material
  - *UKRI, INFN, IEE, USI, HZB, MEPHI*
- **Task 9.4**: Surface engineering by atomic layer deposition (ALD)
  - *CEA, CNRS*
- **Task 9.5**: Improvement of mechanical and superconducting properties of RF resonator by laser radiation
  - *RTU, UKRI, INFN, IEE, HZB*
- **Task 9.6**: Optimization of flat SRF thin films production procedure
  - *HZB, INFN, UKRI, USI, CEA*

	IFAST WP9 Partners	Leading	Participating
1	CEA (Saclay, France)	WP, Tasks 1 and 4	Task **1**, 2, **4**, 6
3	IEE-SAS (Bratislava, Slovakia)		Tasks 2-6
4	INFN/LNL (Legnaro, Italy)	Task 2	Tasks 1, **2**, 3, 5, 6
5	*INFN/LASA (Milano, Italy)*		Tasks 2, 3
6	*Piccoli S.r.l. (Noale (VE), Italy)*		Tasks 2, 3
7	Helmholtz-Zentrum Berlin (Berlin, Germany)	Task 6	Tasks 1 and **6**
8	RTU (Riga, Latvia)	Task 5	Task **5**
9	University Siegen, (Siegen, Germany)		Tasks 2, 3, 6
10	UKRI/STFC/ASTeC (Daresbury, UK)	WP, Tasks 1 and 3	Tasks 1, 2, **3**, 5, 6
11	*Lancaster University (Lancaster, UK)*		Tasks 1 - 3
12	*Jlab (Newport News, Virginia, USA)*		Tasks 1, 2
13	*PTI (Physics-Polytechnic Institute, Minsk, Belarus)*		Tasks 1, 2
14	*MEPHI (National Research Nuclear University, Moscow, Russia)*		Tasks 1 - 3
15	*Helmholtz-Zentrum Dresden-Rossendorf (Dresden, Germany)*		Tasks 1 – 3, 5

WP9 Tasks

Task 9.1 (Coordination and strategy)

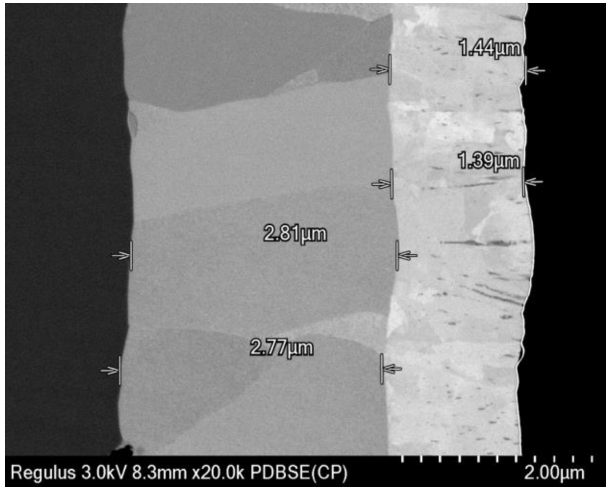
- **Task 9.1**: Coordination and strategy for innovative superconducting thin film coated superconducting RF cavities (TF-SRF)
  - *CEA, INFN, HZB, UKRI, USI, JLab MEPHI, PTI.*
    - *Coordinated by Claire Antoine (CEA) and Oleg B. Malyshev (UKRI)*

1. Coordination of the overall activities of the WP
2. Strategy:
   - Overview existing and explore future directions in development of TF-SRF.
   - The ultimate goal is to obtain TF-SRF cavities with enhanced RF performances:
     - higher E_{acc}
     - with lower cryogenic power consumption
     - at lower production costs in comparison to bulk Nb.
     - Various high T_c materials (Nb_3Sn, V_3Si, NbN, NbTiN, MgB_2, and multilayer structures) to be explored.
   - Bring together the experts from EU and overseas institutions involved in R&D, production and operation of TF-SRF accelerating cavities organising
     - regular video-conferencing, satellite meetings at conferences, and dedicated workshops, etc.

MS37: International thin film workshop organization (web site)	M28	**D9.1:** Thin-Film SRF roadmap report. *Summaries of the results obtained within the workpackage and prospective inspired from WP advances as well as discussions at TF-SRF 2022.*	M35

Task 9.3 (Development)

- **Task 9.3** : Optimisation of process parameters and target development for SRF cavity coating with A15 material
  - *UKRI, INFN, IEE, USI, HZB, MEPHI*
    - *Coordinated by Reza Valizadeh (UKRI)*
  - *Seamless (INFN - Piccoli) or split (UKRI) cavities made of OFHC copper,*
  - *f = 6 GHz*
    - *Coated with non-Nb and SIS thin films and tested at INFN and/or UKRI*
  - *Planar copper samples*
    - *Coated with non-Nb and SIS thin films and characterised at INFN, UKRI and USI*
    - *Tested at IEE, MEPHI and UKRI*
  - *QPR samples (in coordination with Task 9.6)*
    - *Polished at INFN,*
    - *Deposited at INFN, UKRI and USI*
    - *Tested at HZB*



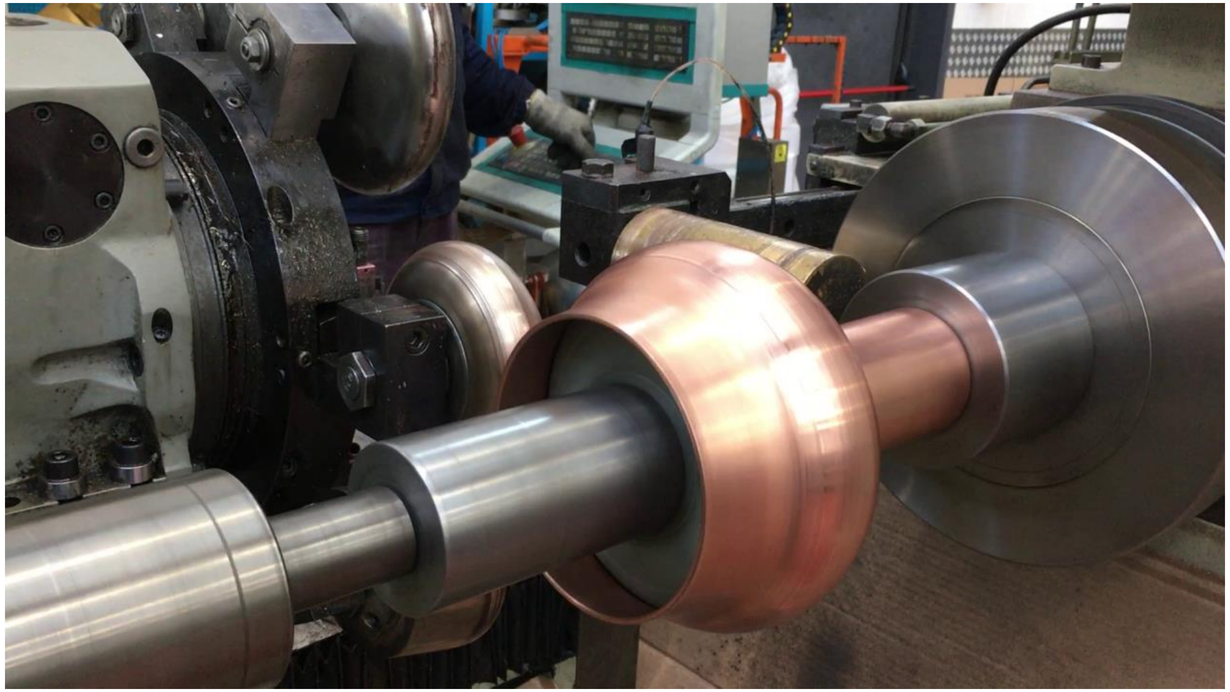
X-section SEM of Nb_3Sn with a Nb underlayer as double structure on copper. Courtesy to R. Valizadeh (UKRI)

MS39: Coating facility built and tested at STFC, USI and INFN (Report)	M12	**D9.3:** First 6 GHz cavity coated and characterised. *Results from the morphological and SC characterisation of first coated cavity with an alternative material to Niobium.*	M36

Task 9.2 (Prototype)

- **Task 9.2**: Innovative SC accelerating cavity prototype
  - *INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB, PTI, MEPHI*
    - *Coordinated by Cristian Pira (INFN-LNL)*
  - *Seamless (INFN - Piccoli) and EB welded (PTI) cavities made of OFHC copper*
  - *f = 1.3 GHz*
  - *Coated with non-Nb and SIS thin films at CEA, JLab, INFN, UKRI and USI*
  - *Tested at INFN, UKRI, CEA, HZB and JLab*

Production of a seamless cavity from OFHC copper. Courtesy to Cristian Pira (INFN)



MS38: First seamless copper 1.3 GHz cavity produced as substrate for the coating of the SC film (Report)	**M12**	**D9.2:** RF test on coated resonant cavity. *Resonant cavity coated and tested with an alternative material to Niobium with a $Q_0 > 10^9$ at 4.2 K and 1.3 GHz.*	M46

Task 9.4 (Development)

- **Task 9.4**: Surface engineering by atomic layer deposition (ALD)
  - *CEA, CNRS*
    - *Coordinated by Thomas Proslier (CEA)*
  - *Cavities made of OFHC copper or niobium*
  - *f = 3 and 1.3 GHz*
  - *Nb cavity coated with SIS thin film by ALD.*
  - *Cu cavity coated with Nb or non-Nb and SIS thin films by ALD*
  - *Tested at CEA*

MS40: Construction and operation of the cavity dedicated ALD system (Report)	**M24**	**D9.4:** Deposition of superconducting multilayers on cavities. *1.3 and 3 GHz Nb and Cu cavities coated and tested with multilayers.*	M46

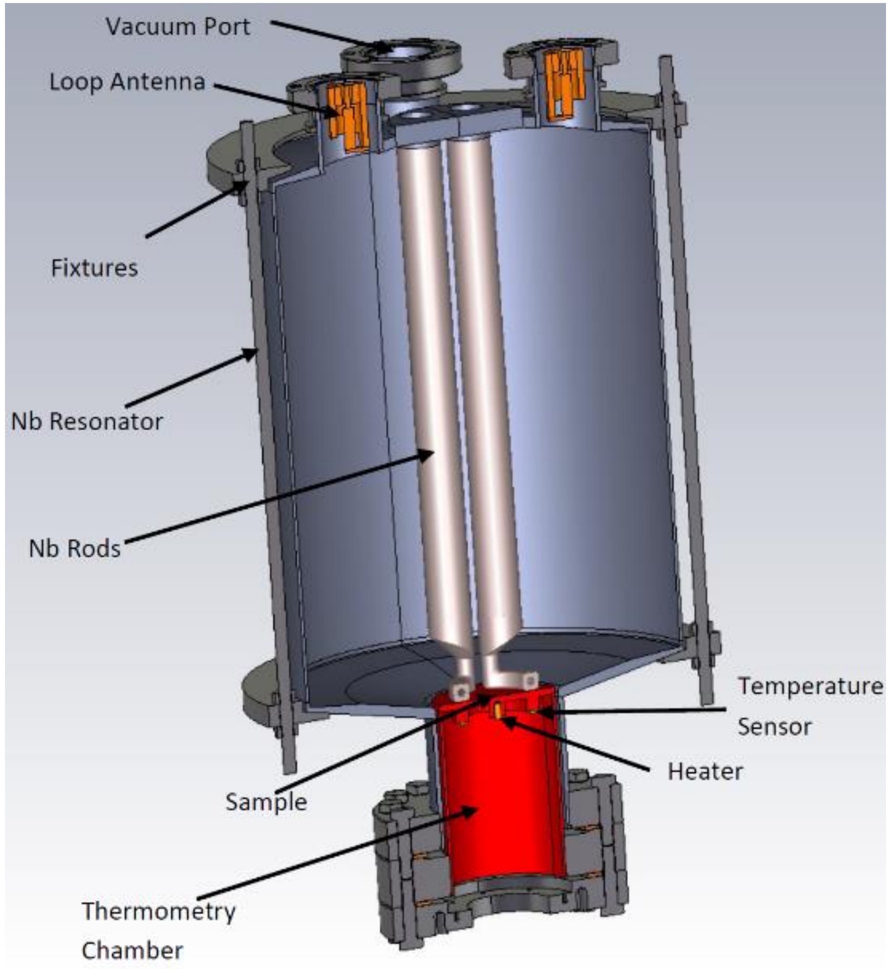
Task 9.5 (Development)

- **Task 9.5**: Improvement of mechanical and superconducting properties of RF resonator by laser radiation
  - *RTU, UKRI, INFN, IEE, HZB*
    - *Coordinated by Arturs Medvids (RTU)*
  - *Continue further development of laser treatment of Nb films on planar samples made of OFHC copper*
    - *Deposited at INFN or UKRI*
    - *Laser treated at RTU*
    - *Tested at IEE and UKRI*
  - *Development of a facility at RTU for laser treatment of Nb films deposited on*
    - *Copper tubes deposited with Nb (from INFN or UKRI)*
    - *1.3 GHz copper cavities made of OFHC copper and deposited with Nb (INFN)*
    - *RF tested at INFN or UKRI*

MS41: A facility for laser operation for complex 3D treatment is tested on 1.3 GHz cavity **(Report)**	M36	**D9.5:** 1.3 GHz Nb-coated cavity irradiated by laser in Ar atmosphere and RF tested. *Increasing of the field of magnetic flux entry in Nb coated 1.3 GHz cavity irradiated by laser in argon atmosphere. Standard RF testing.*	M45

Task 9.6 (Development)

- **Task 9.6**: Optimization of flat SRF thin films production procedure
  - *HZB, INFN, UKRI, USI, CEA*
    - *Coordinated by Oliver Kugeler*
  - *Continue further development of non-Nb and SIS films on planar QPR samples made of OFHC copper*
    - *Deposited at CEA, INFN, UKRI and USI*
    - *Tested at HZB*

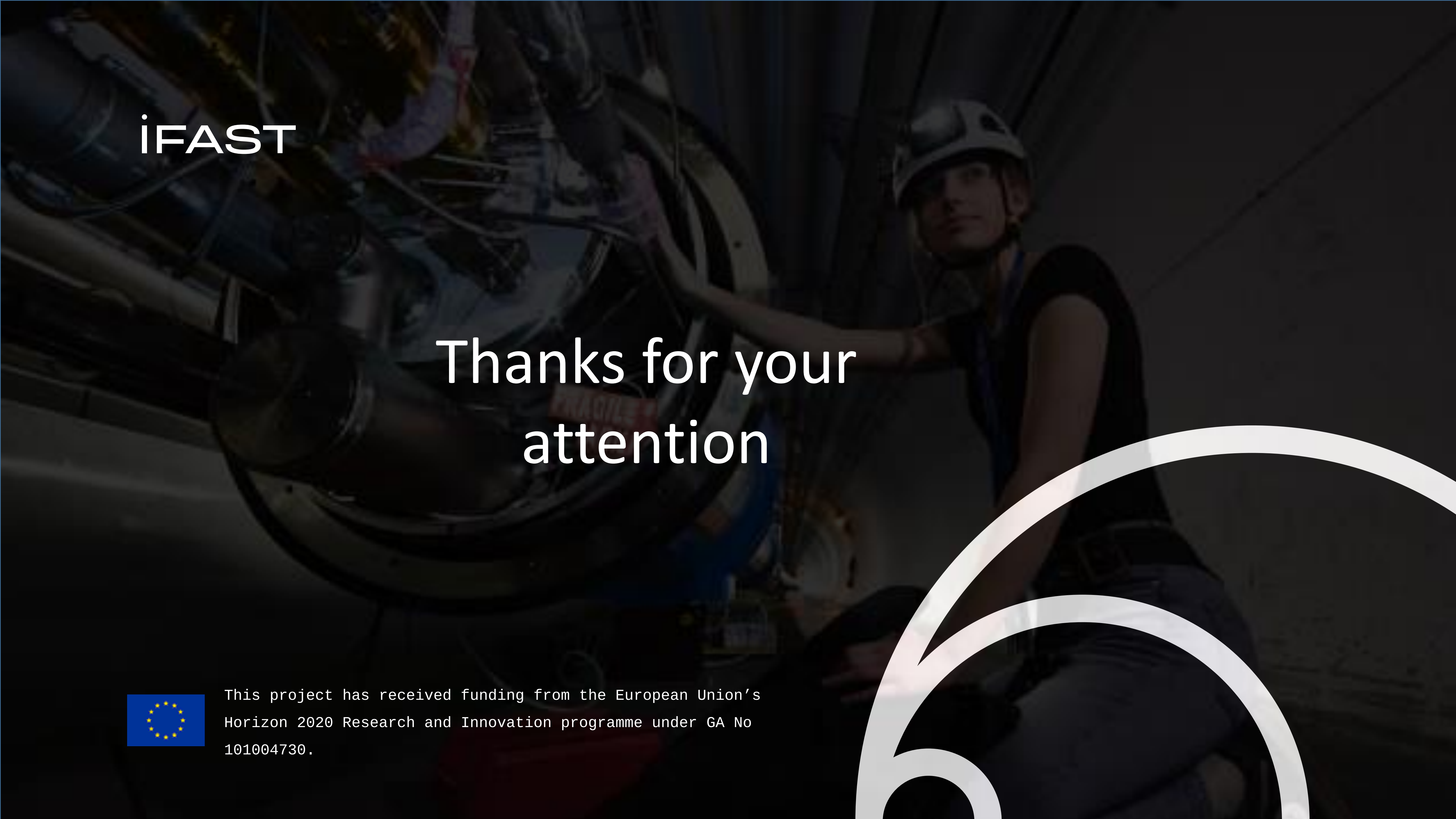


MS42: ARIES samples prepared for renewed SC film deposition	**M6**	**D9.6:** Test of thin-film samples. *Four thin film samples reprocessed by 4 different techniques and tested with QPR.*	M46

WP9 ongoing activities

WP9 has already started:

- IFAST WP9 preparatory meeting – 17th April 2021
  - A transition from ARIES WP15 to IFAST WP9:
    - Emphasis shifts
      - from the thin film development on small planar samples
      - to **the RF cavity prototype production and testing**
      - **based on non-Nb films**
  - A few task meetings took place in April 2021
- IFAST WP9 kick-off meeting – 5th May 2021



iFAST

Thanks for your attention

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