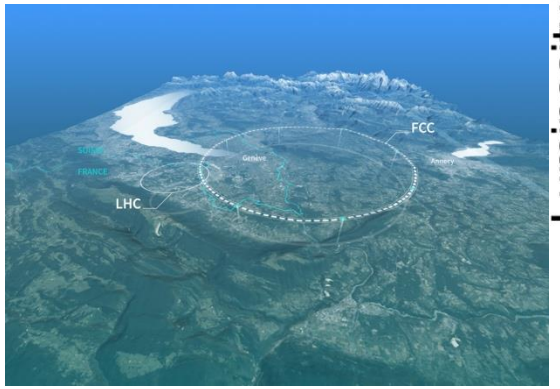
SRF material R&D for FCCee:

high-Q niobium and high-tanδ ceramic

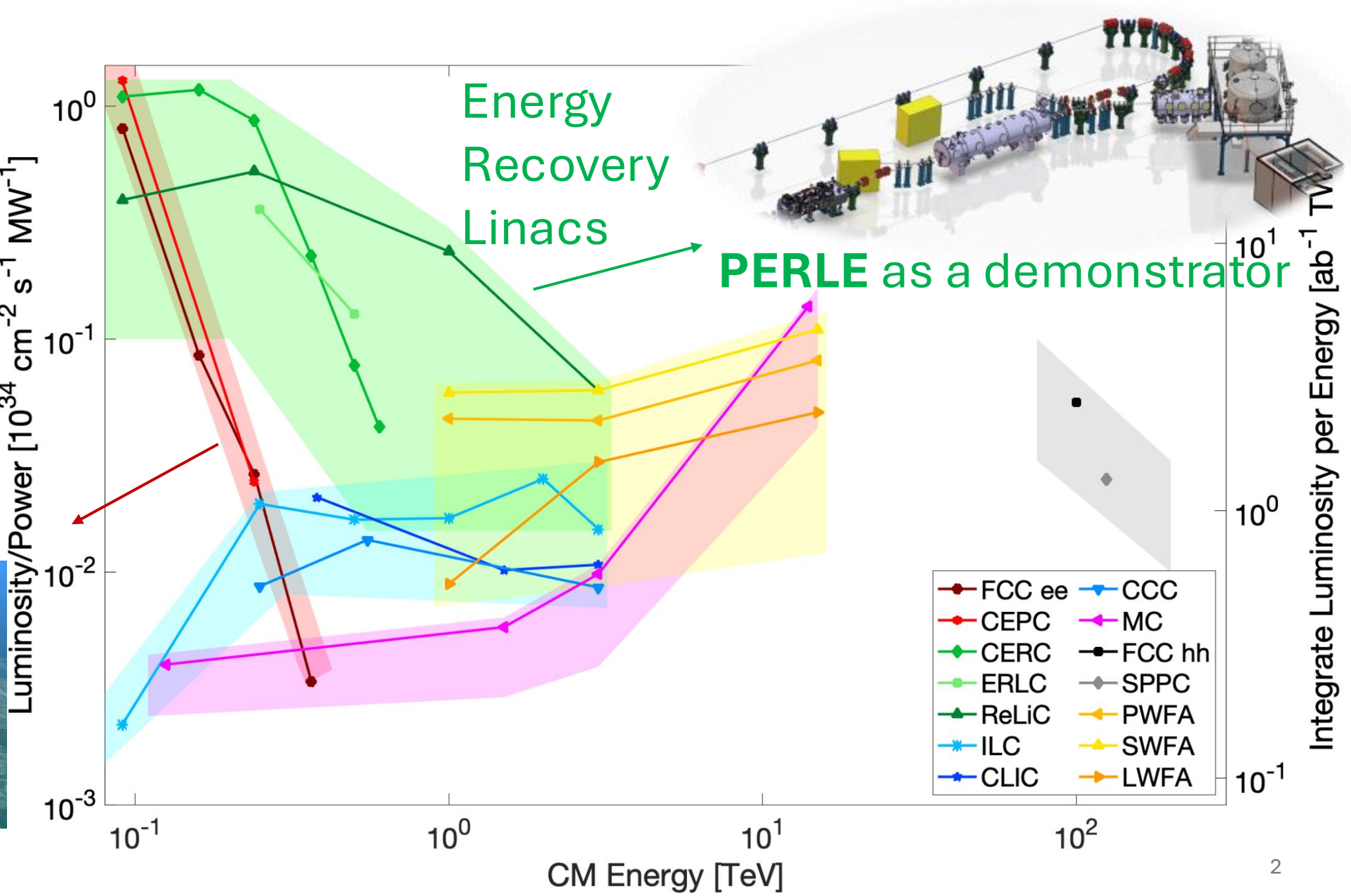
CNRS/IN2P3/IJCLab

Akira Miyazaki on behalf of IJCLab team

Luminosity over power: case study in Snowmass



FCCee



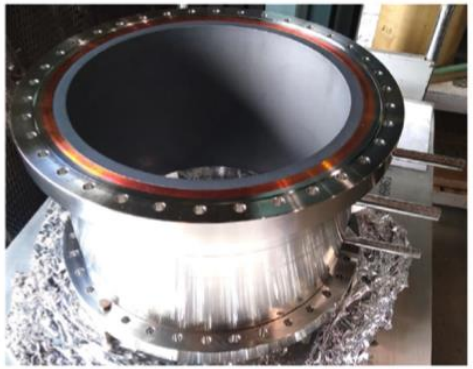
JINST 18 P05018 (2023)

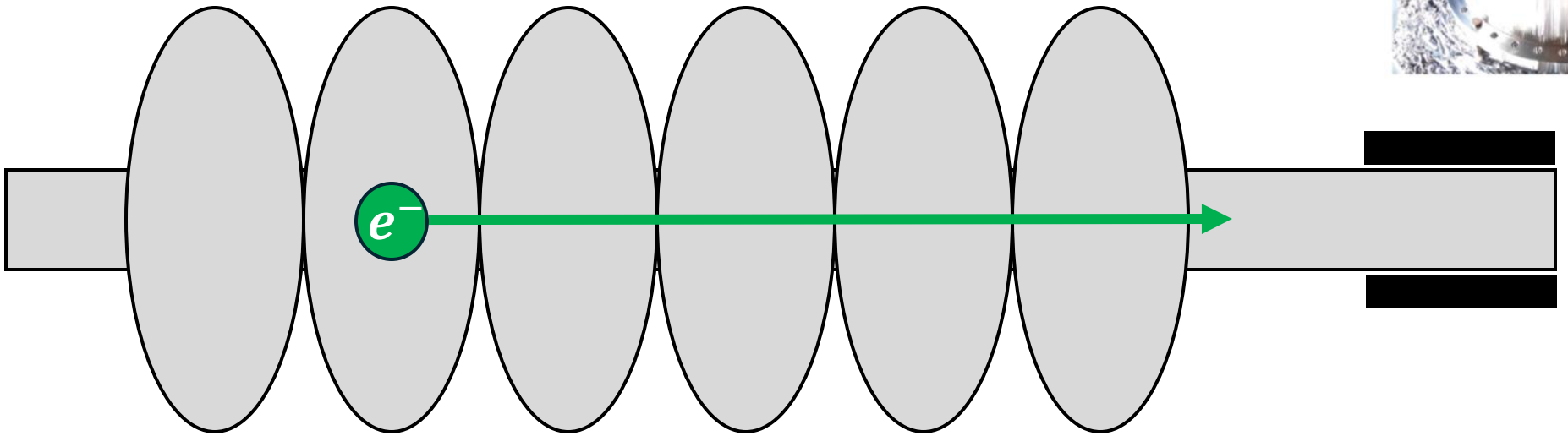
Two *contradicting* SRF materials for FCC/PERLE

Phys. Rev. Accel. Beams **27**, 031601 (2024)

800 MHz
bulk niobium

SiC



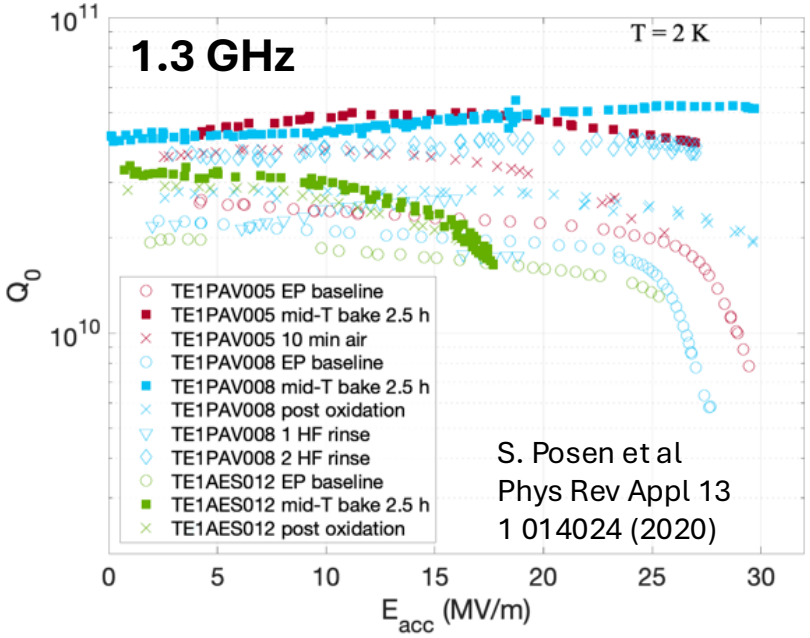


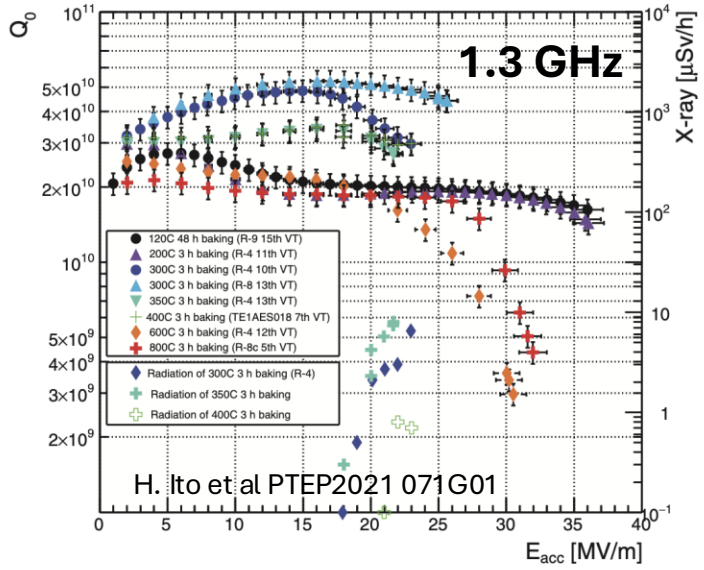
<u>High CW current machine for high luminosity</u>

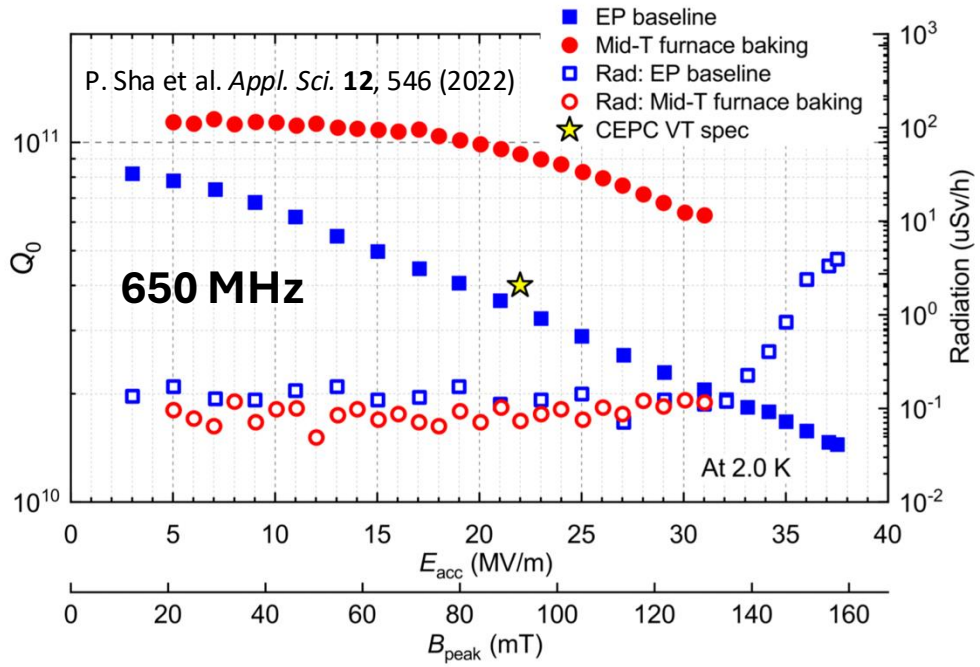
- Extremely high-Q (lossless) **superconducting** cavities to accelerate beam
  - Mid-T baking for $Q_0 > 3 \times 10^{10}$ around $20\ \mathrm{MV/m}$ (FCC/PERLE)
- Very high-tanδ (lossy) **dielectric** beam line absorbers to eliminate higher-order modes
  - 100W at 40 K (PERLE) and >1 kW at 300 K (FCC)

Mid-T bake: literature

Discovery by FNAL → detail R&D at KEK, DESY, JLAB → impressive success in IHEP







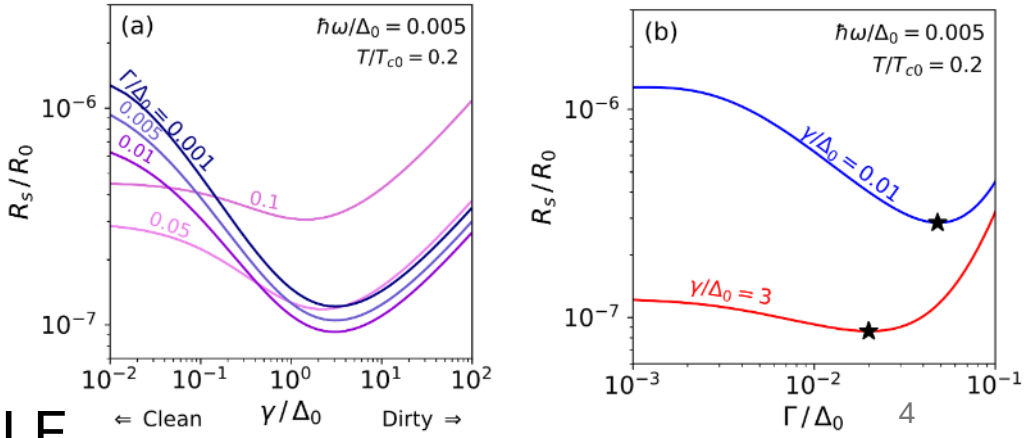
Recent standard in CW machines

- CEPC (650 MHz)
- PIP-II MB650 (650 MHz)

Physics: uniform oxygen diffusion

- Magnetic & non-magnetic scattering (?)
- Robust process

→ Natural candidate for 800 MHz FCC/PERLE

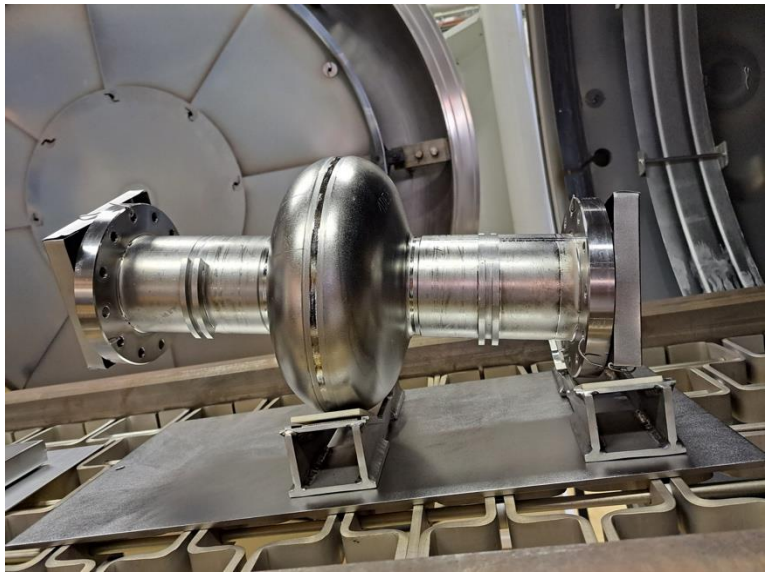


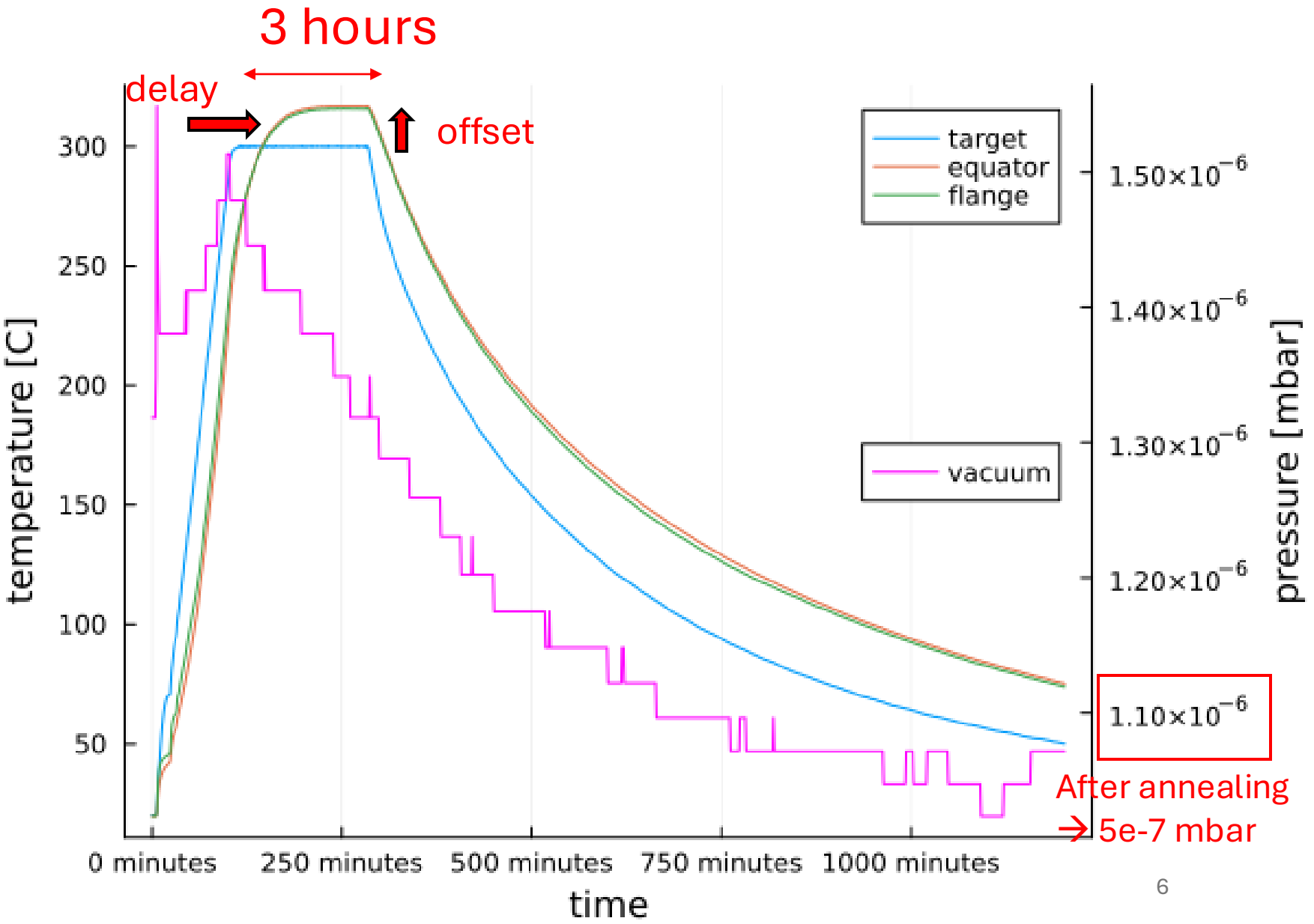
Takayuki Kubo, Phys. Rev. Applied 17, 014018, 2022

Clean vacuum furnace is the key for mid-T bake

- CERN does not have a furnace
- DESY's new furnace is for 1.3 GHz cavities only
- The furnace in IJCLab is perfect for prototyping 800 MHz in Europe

1st demonstration of mid-T bake with a 1.3 GHz cavity

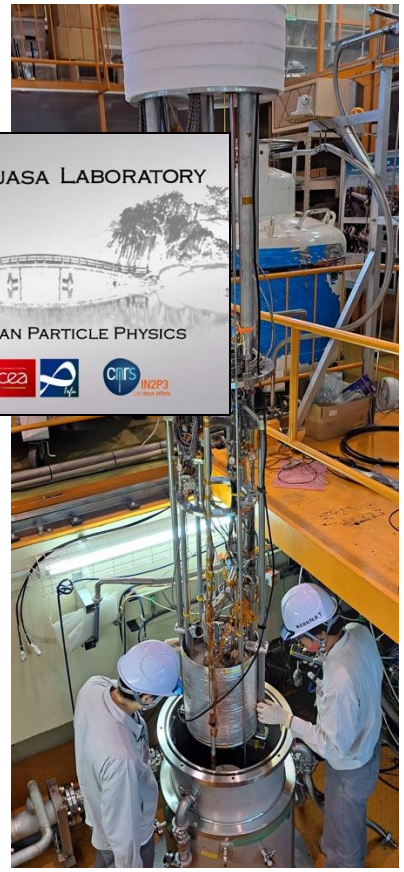




Cavity measurement in collaboration

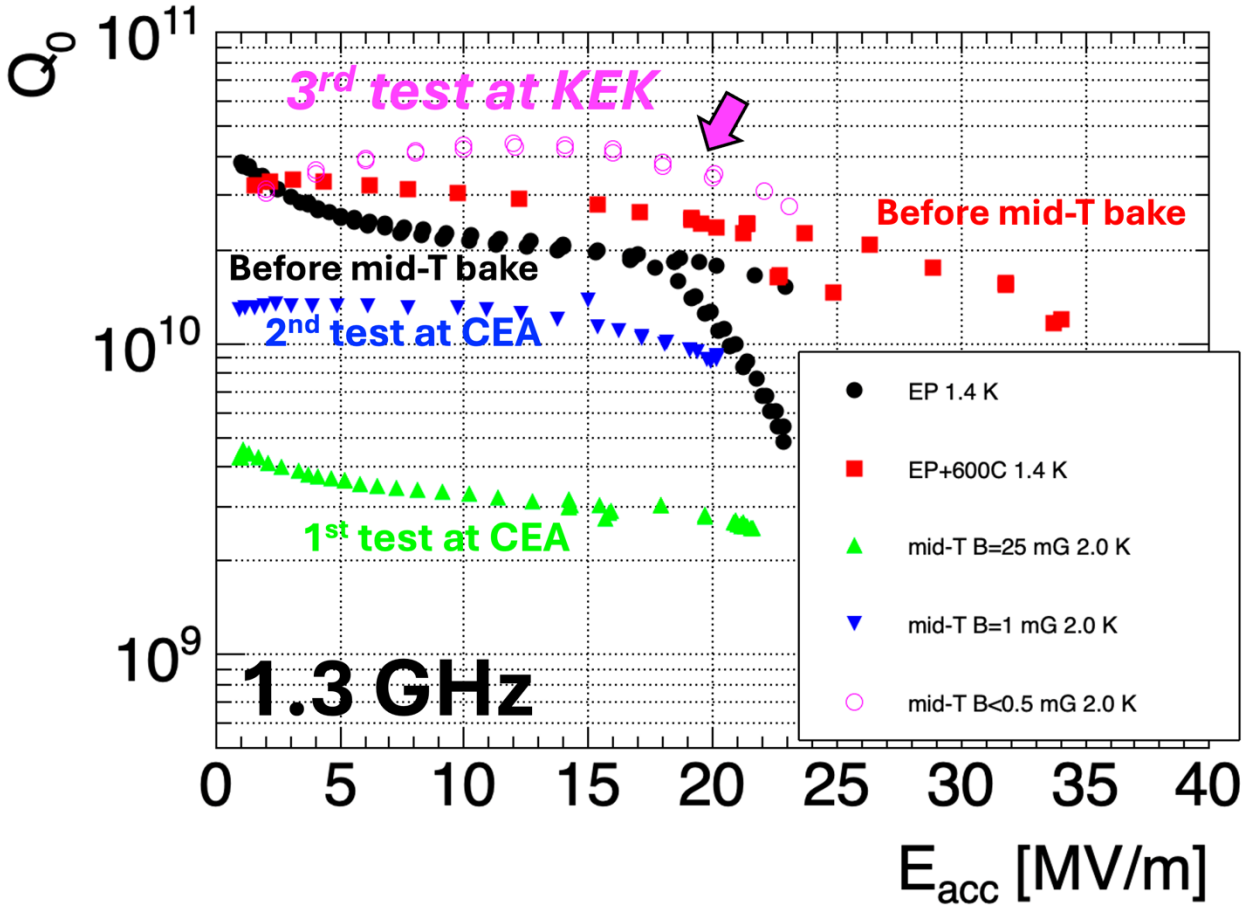
1st (June) and 2nd (July) tests at CEA Saclay

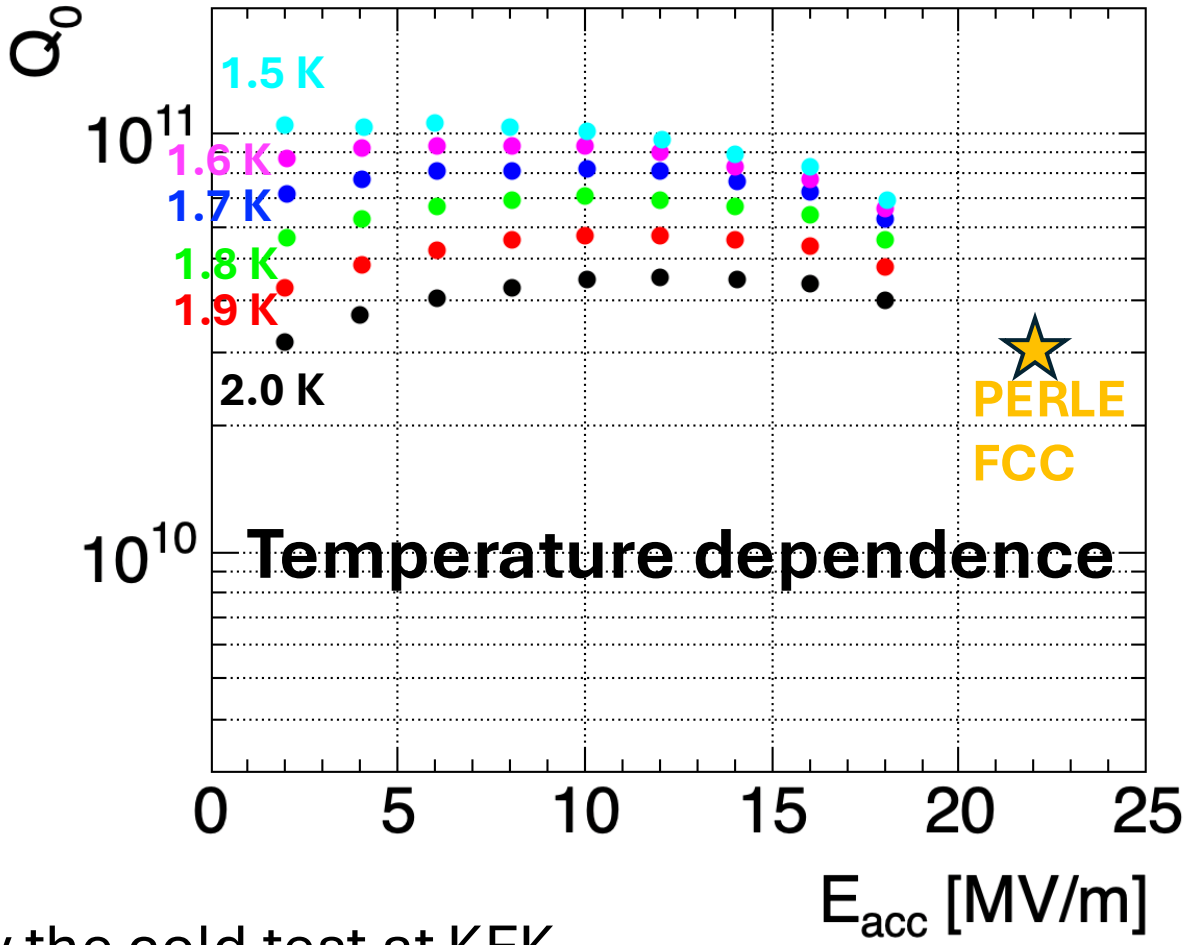
3rd test at KEK-STF: Sep 30 – Oct 11



TESLA TECHNOLOGY
T T C
COLLABORATION

1st mid-T baked cavity result treated at IJCLab

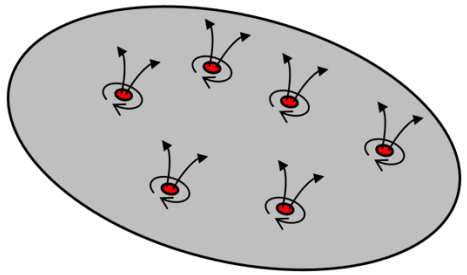


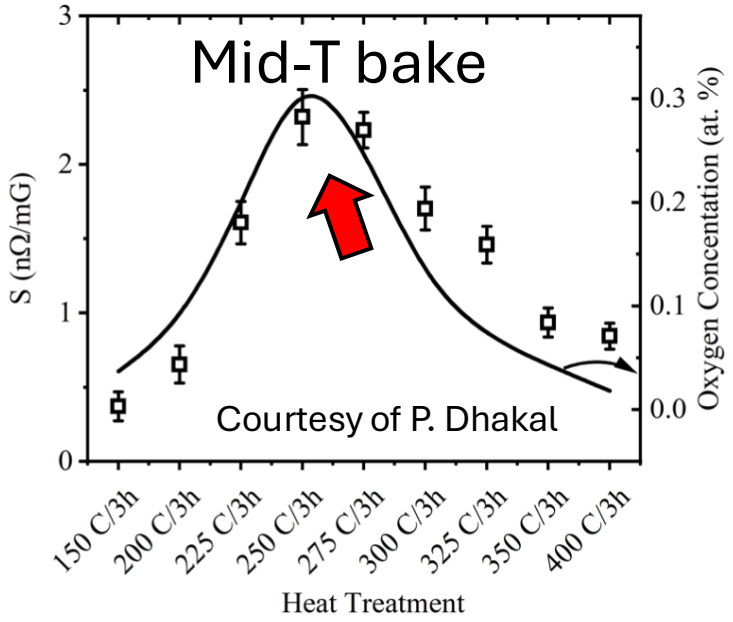


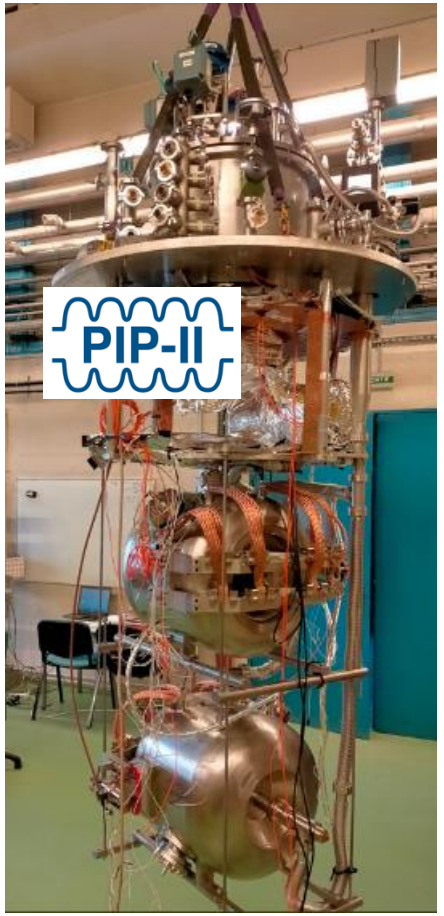
- A successful mid-T baking was proven by the cold test at KEK
  - IJCLab's vacuum furnace is good for mid-T bake
- 1.3 GHz → 800 MHz would further improve the Q vs T to go beyond PERLE/FCC
- Technical challenge: unifying data from different labs for systematic study

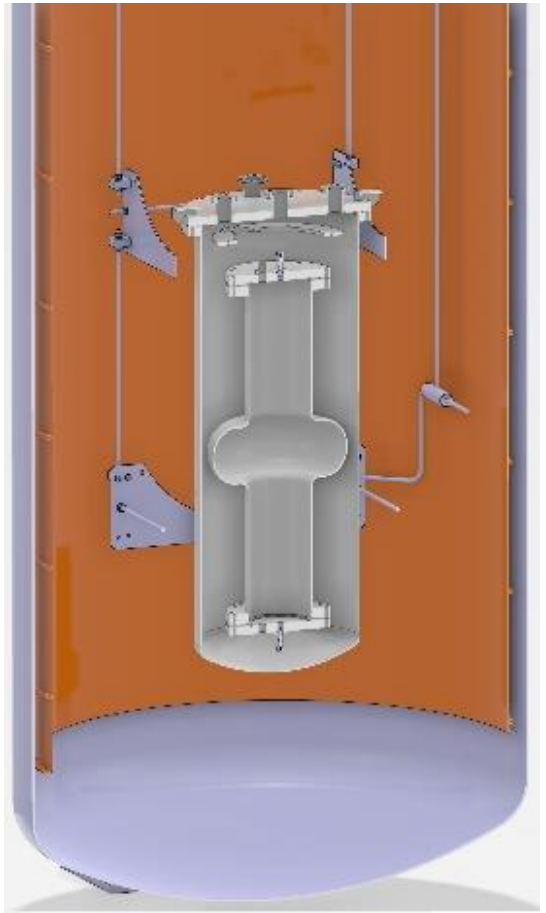
Issue: cold tests in excellent residual magnetic field

$$S = R_{\mathrm{fl}}/H_{\mathrm{trap}}$$









$$R_{\mathrm{s}} = R'_{\mathrm{BCS}} + R_{\mathrm{fl}} \rightarrow R'_{\mathrm{BCS}} \downarrow + S \uparrow \times H_{\mathrm{trap}}$$

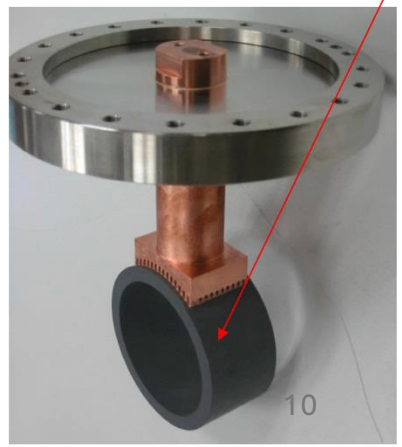
- IJCLab' test-stand is dedicated to jacketed spoke cavities (PIPII, ESS, MYRRHA)
- The cavities after mid-T bake becomes factor 5 more sensitive to the residual magnetic field

→ We will upgrade our test stand to have excellent cold magnetic shield + demountable helium jacket
(In mean time, CERN's SM18-V3 or V4 or V6 will be suitable for cavity testing)

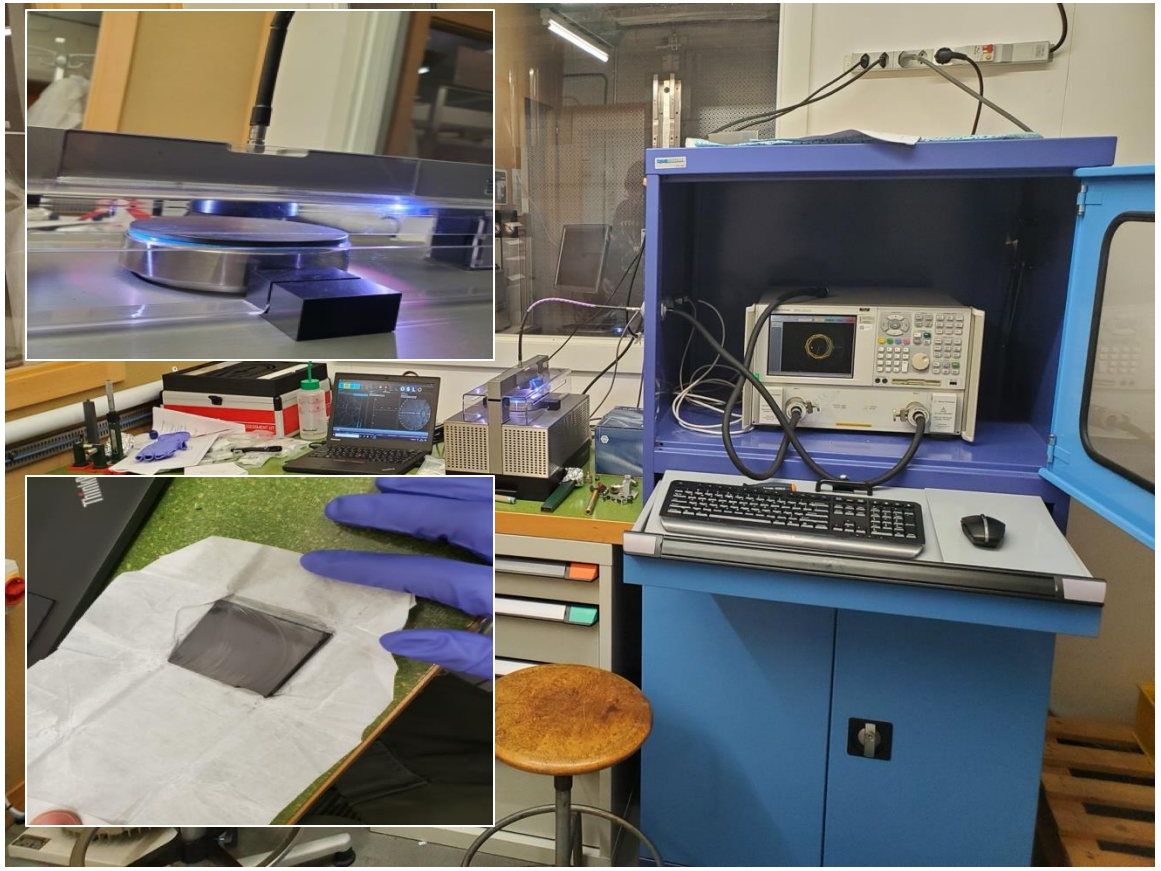
High loss ceramic: literature

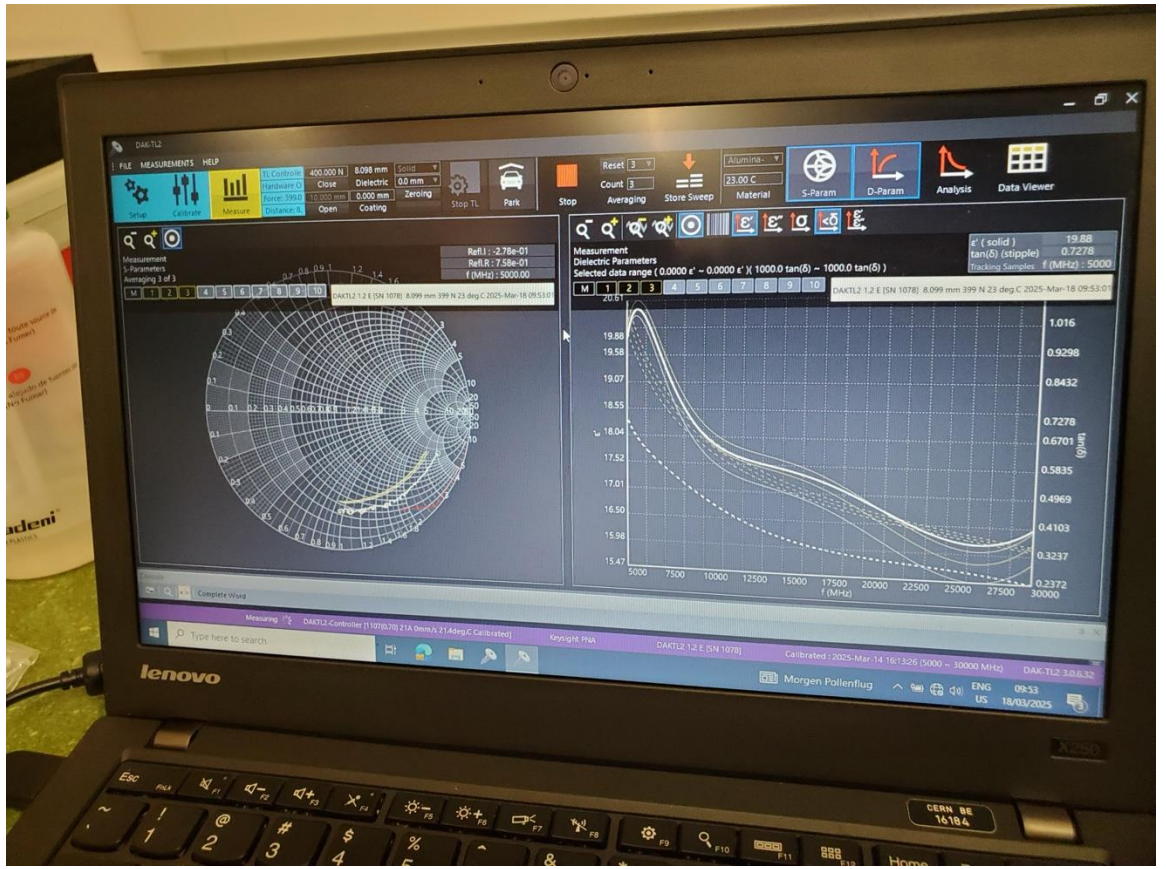
Type	Company	Product	T [K]	projects	tanδ	σ [S/m]	P [W]
SiC	Coorstek	CERASIC-B → Hexoloy	300	KEKB, KEK-PF, SKEKB	0.4		
SiC	Coorstek	SC-30/SC-35	80-300	APS, CBETA	-	-	-
SiC	Kyocera	SC1000	300	EIC	-	1e-10	200
SiC	ECM	Cesic	50	ARIEL	-	1.5e4	30
AlN	Ceradyne	Ceralloy 137CD1	70	LCLS-II, EuXFEL	-	-	-
AlN	Sienna	STL-150D14	40	LCLS-II, CEBAF	0.4	-	120
AlN	Sienna	STL 100HTC	300	BESSY, BERLinPro	0.2	-	120

- Previously ferrite (dusty) → either SiC or AlN recently
  - Most of them absorbs RF via dielectric loss
  - Cesic exceptionally eliminates RF via Ohmic loss
- Limited market (Coorstek SC-30/35 & Ceradyne no longer available)
- Some materials loses tanδ at cold (→ problem for PERLE)
- Some materials are very expensive



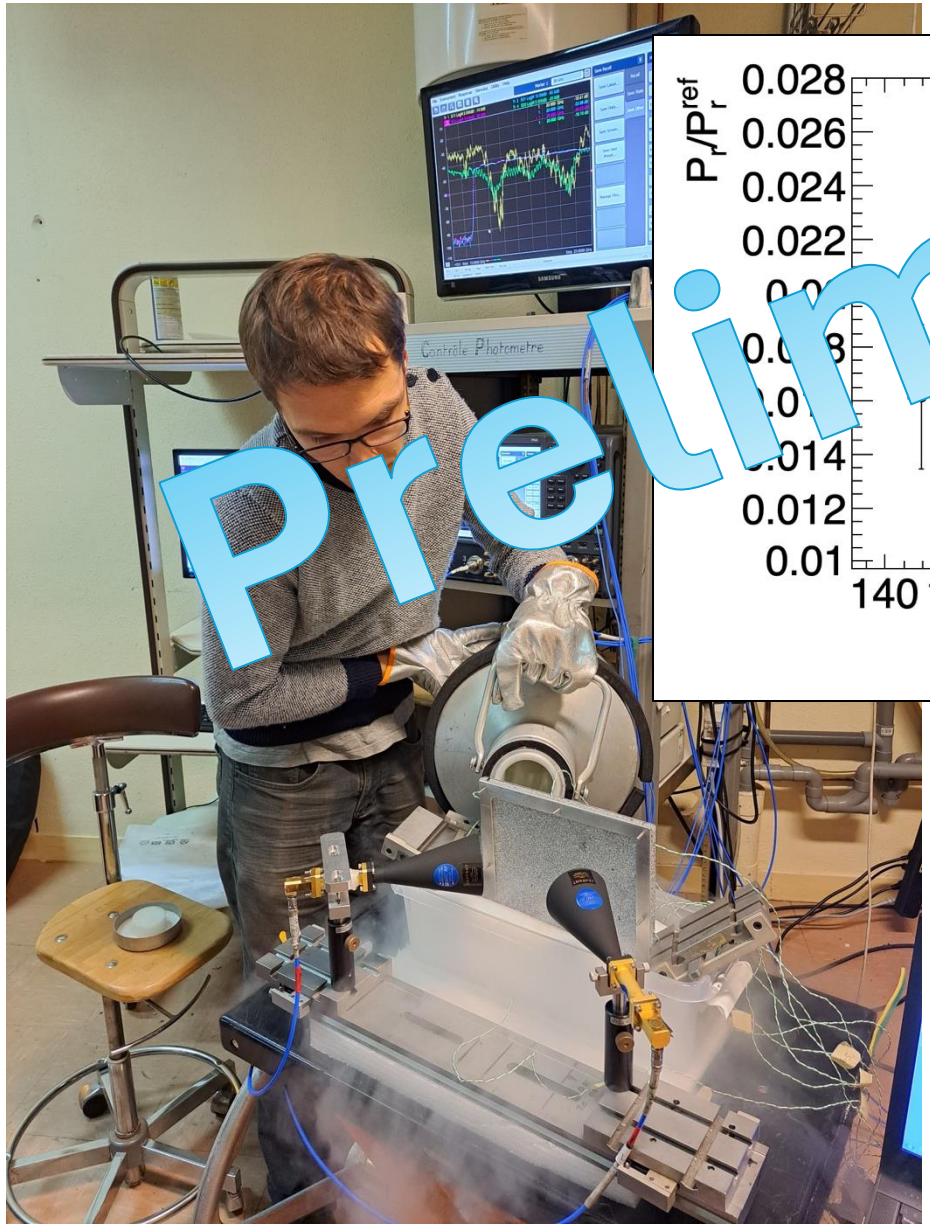
Test stand at CERN CLIC RF measurement bench

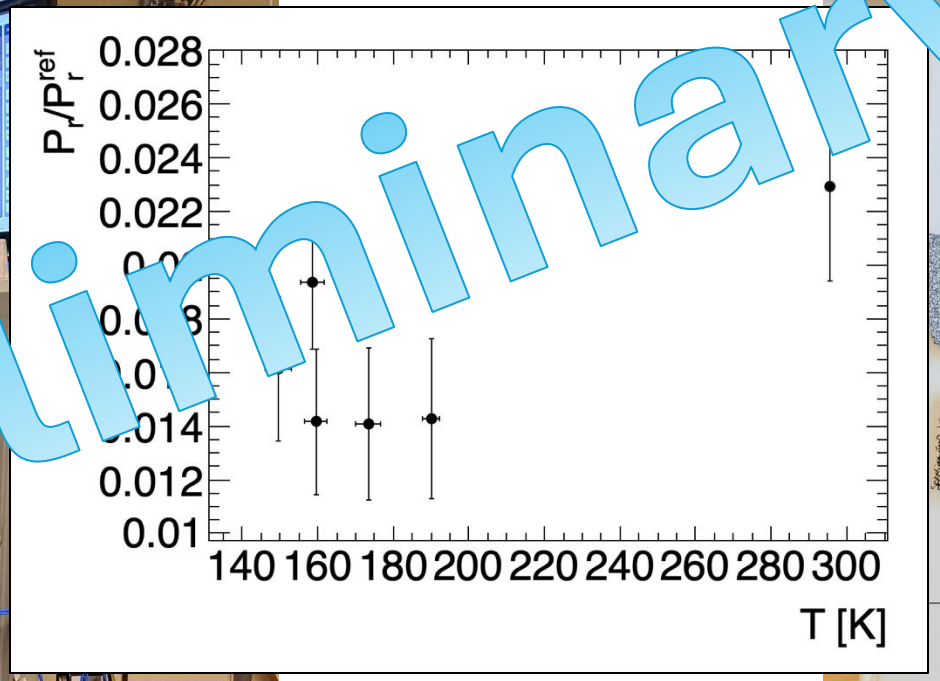




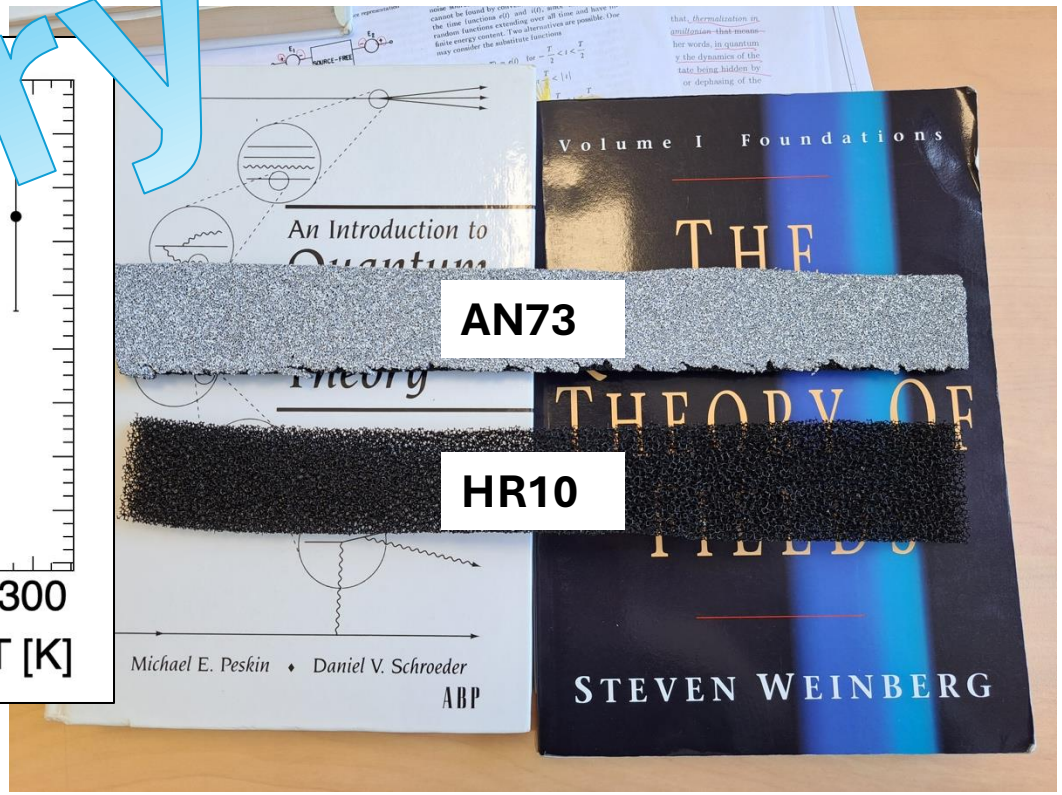
- Commercial device for dielectric measurement (ϵ', ϵ'') DAK-TL2 (5-67 GHz) with VNA E8364B
- **Warm & low power** measurement → CLIC X-band
- Sample size: 5 cm x 5 cm x 1 cm
- Calibration (5-30 GHz) with the dedicated probe seems like the key → cryogenic application is non-trivial

Test stand development at Université Paris Saclay





Preliminary



- Collaboration with particle physics (dark matter axion) and astrophysics (CMB)
  - Cryogenic compatibility of ECOSORB is studied
  - ECOSORB is NOT for particle free applications
- One PhD starts working on cryogenic RF setup

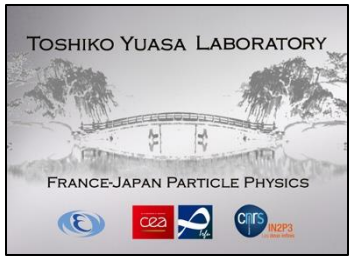
Conclusion

- Two materials are crucial for high-current machines (FCC/PERLE)
  - High-Q superconducting cavities
  - High-tanδ dielectric beam line absorbers
- High-Q SRF cavities are enabled by mid-T bake
  - Clean vacuum furnace is the key
  - Recently IJCLab's furnace was demonstrated for mid-T bake
  - Perfect magnetic environment is necessary for proper qualification
- High-tanδ dielectrics are made of special ceramics
  - Market survey has been done → dedicated experiments are necessary
  - Low power and warm setup exists at CERN → for CLIC (→ FCC)
  - Cryogenic setup will be developed at IJCLab (→ PERLE)
- Financial support
  - The research leading to these results has received funding from the European Union's Horizon Europe MSCA under grant agreement no. 101086276 (EAJADE), 101004730 (I.FAST)
  - The project was supported by FJPPN and IN2P3/CNRS

Funded by the European Union

EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

iFAST



PhD job opening for high-Q cavity study

INSPIRE HEP jobs ...

Fundamental studies of superconducting radiofrequency cavities [CNRS-UChicago joint-PhD program]

U. Paris-Saclay • Europe

physics.acc-ph | cond-mat | physics | PhD • Experiments: CERN-FCC

Deadline on Jun 30, 2025

- Systematic data analysis of SRF cavity data over the world
- Comparison to nonequilibrium superconductivity theories
- Contact: Akira.Miyazaki@ijcalb.in2p3.fr