SRF programs towards High-Q/High-G cavities in IJCLab

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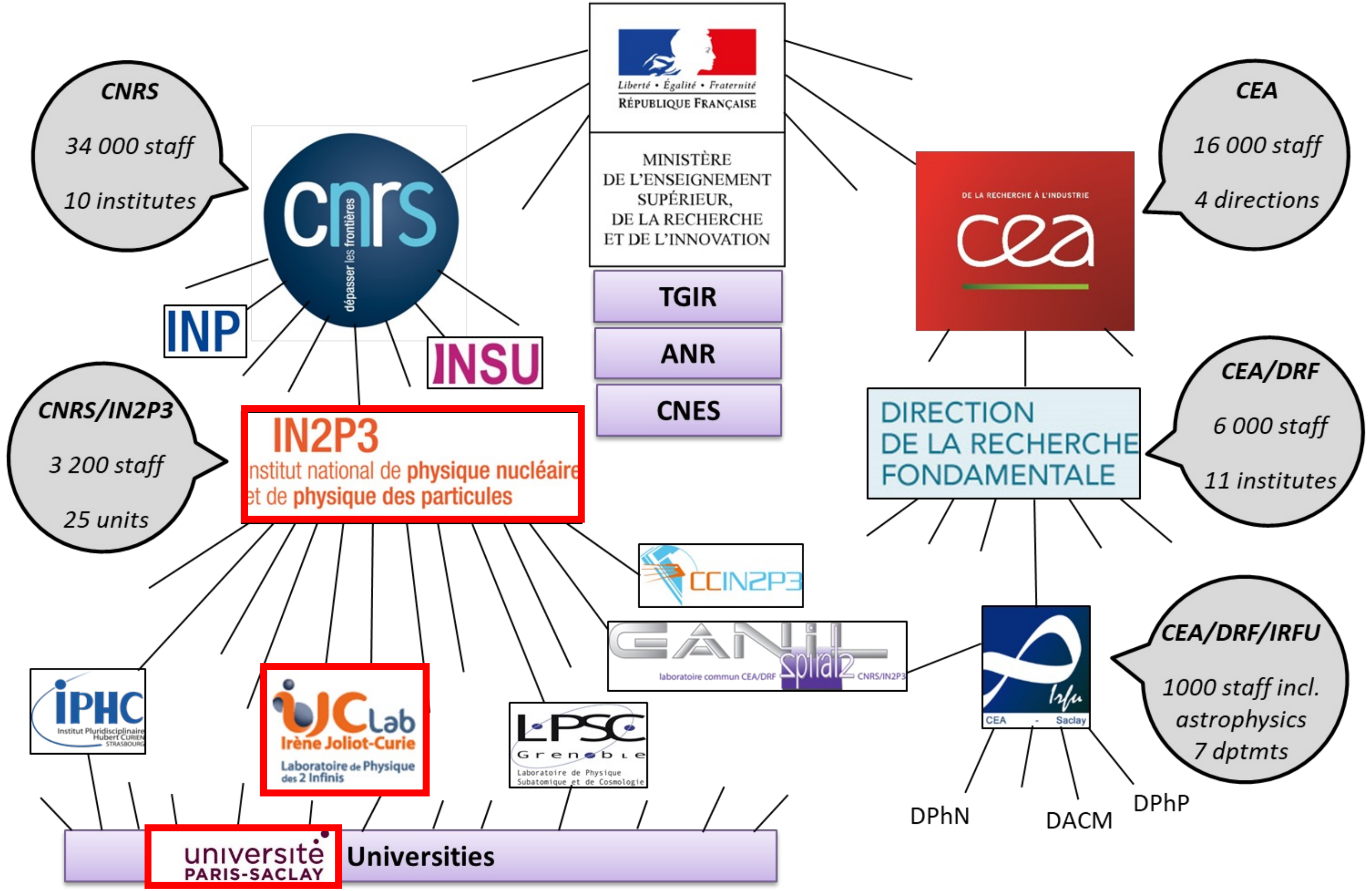
LCWS2024 International Workshop on Future Linear Colliders

Introduction : Instances around SUPRATech



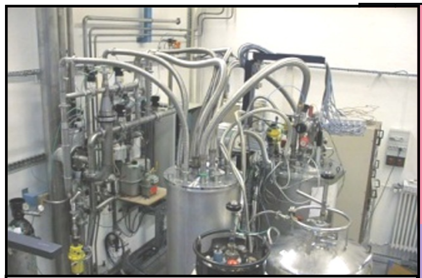
Credits :
J.L. Biarrotte

Introduction : History summary and series production

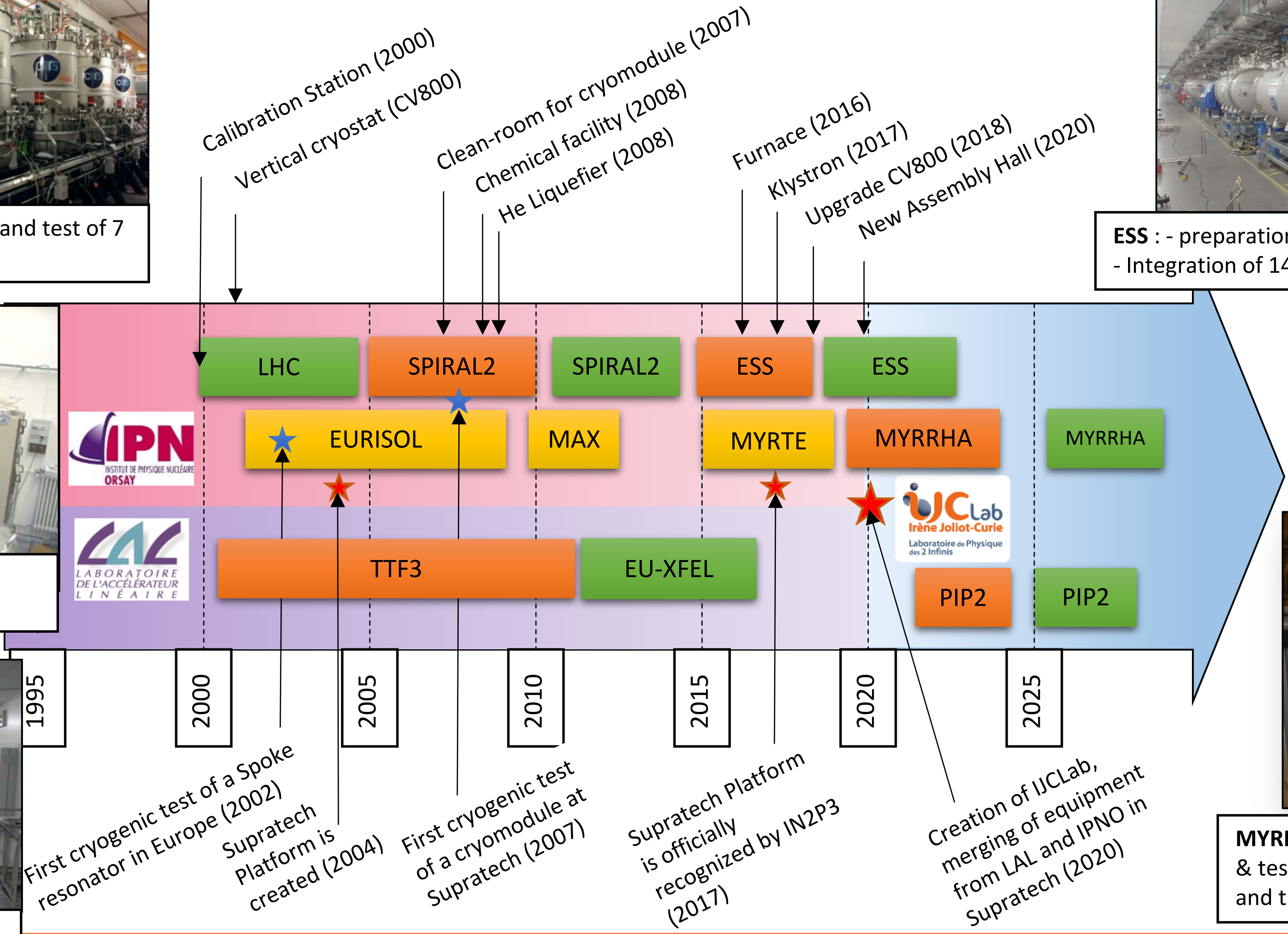
Prototyping Phase | Series production | R&D

Spiral2 : Integration and test of 7 cryomodules

ESS : - preparation & testing of cavities, couplers and tuners
- Integration of 14 cryomodules

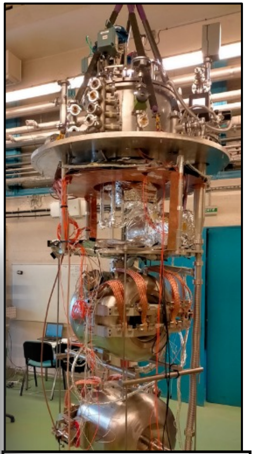


LHC : Calibration of all Cernox thermal sensors (> 6000 units)



EU-XFEL : Preparation and power testing of 800 couplers

MYRRHA : - preparation & testing of 60 couplers and tuners

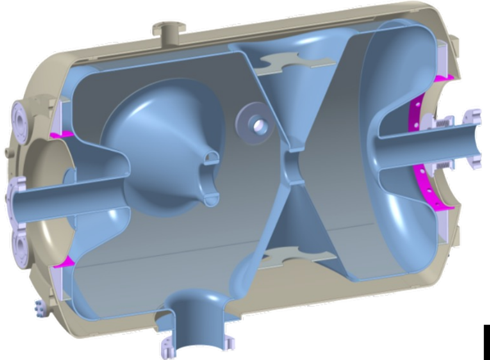


PIP-II : Testing of 33 Spoke cavities

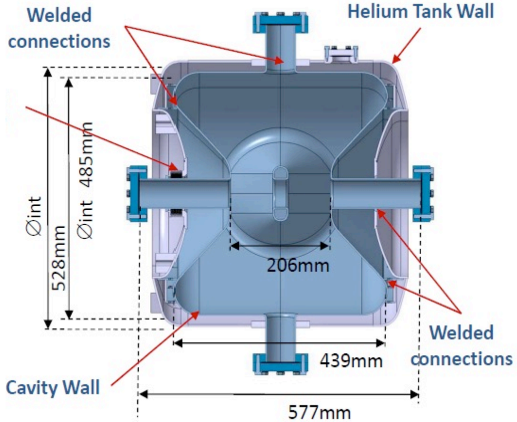
Low-β cavities for protons & heavy ions→ collider cavities

88 MHz

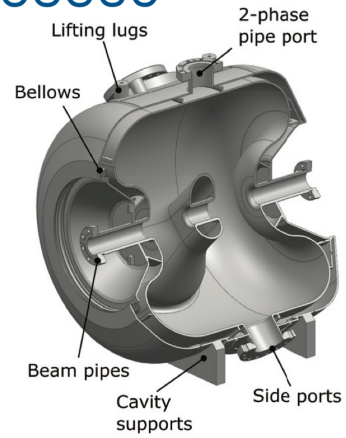
352 MHz



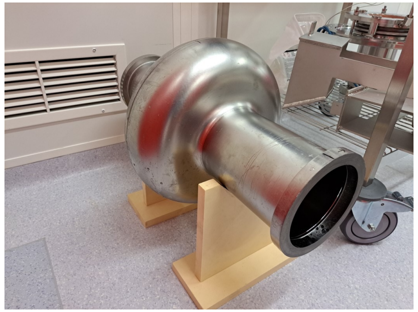
352 MHz

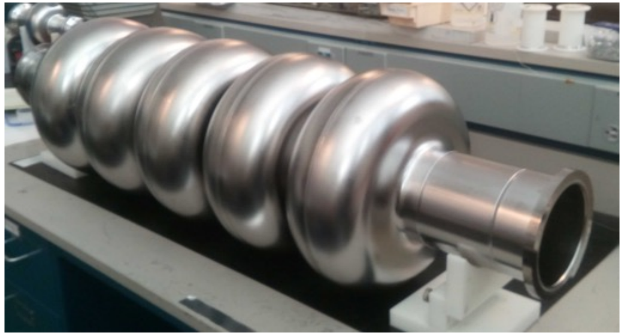


325 MHz

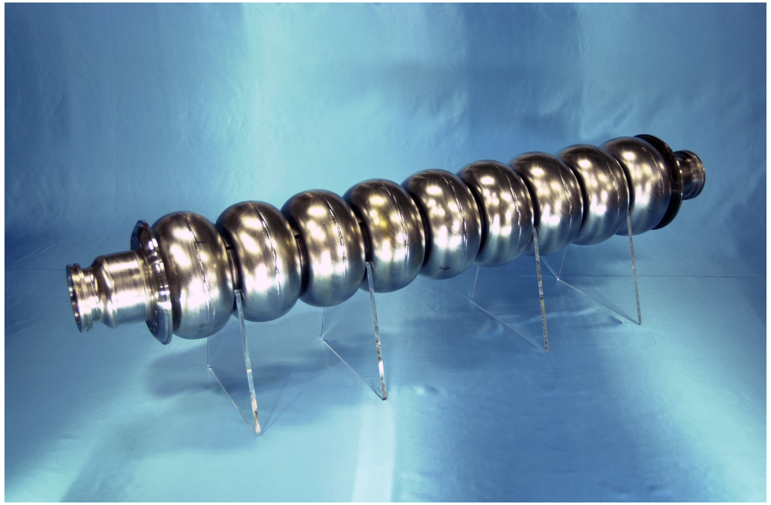


FCC/PERLE cavities (800 MHz)

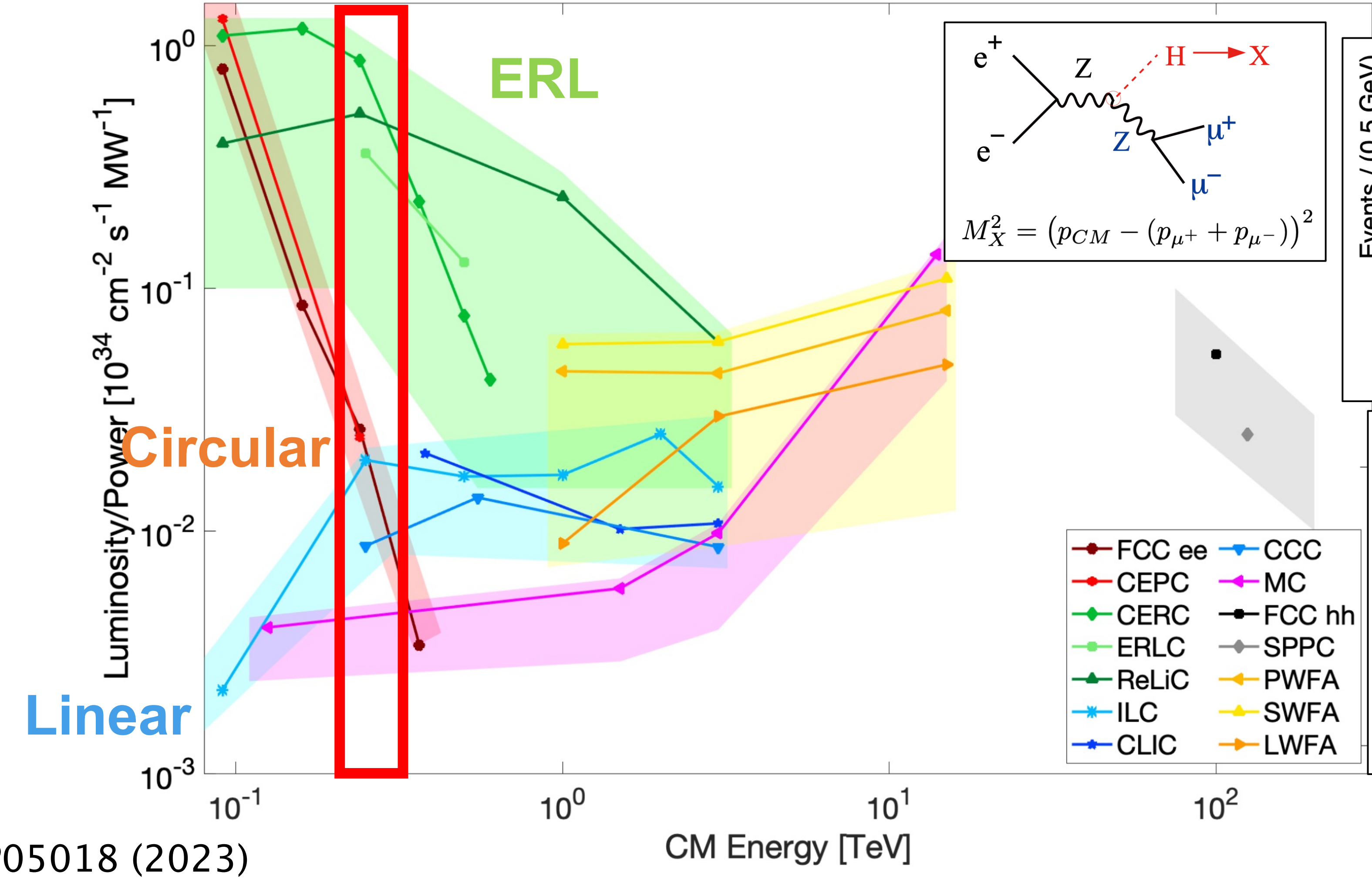




ILC cavities (1.3 GHz)

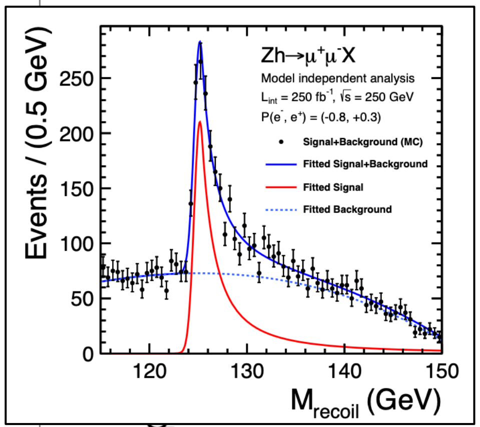


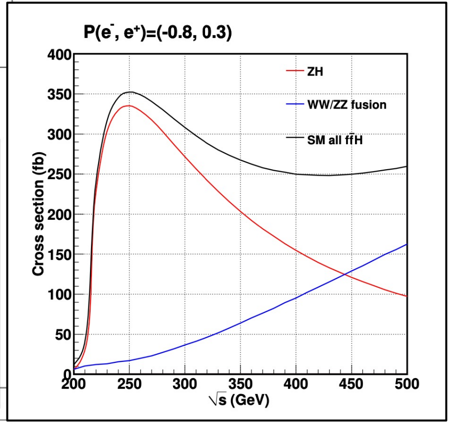
Next future colliders: priority in Higgs boson



JINST 18 P05018 (2023)

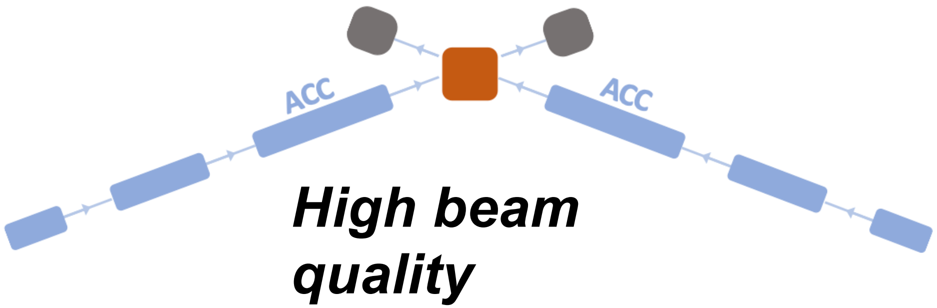
arXiv:1407.2133



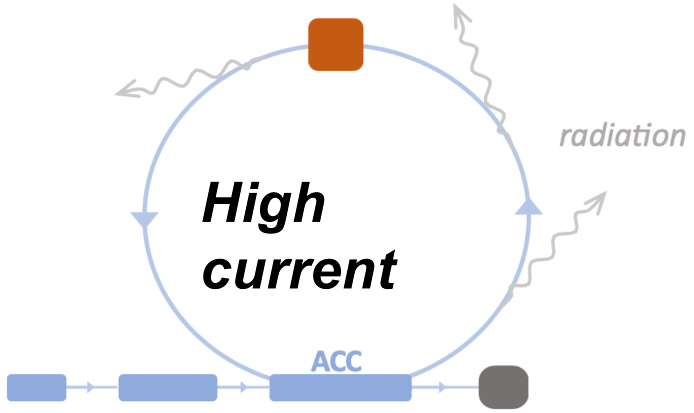


Energy Recovery Linac (ERL)

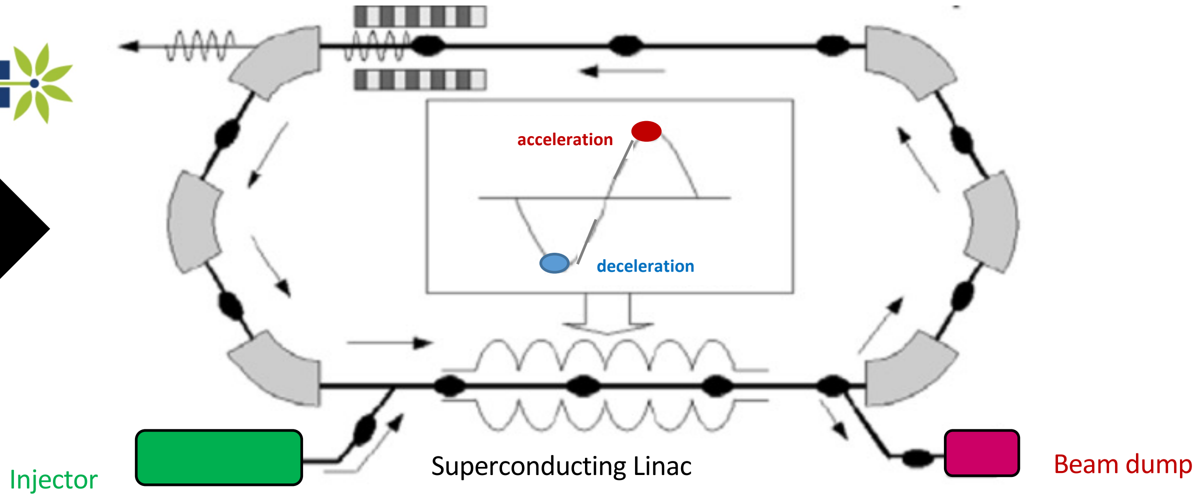
Linear colliders

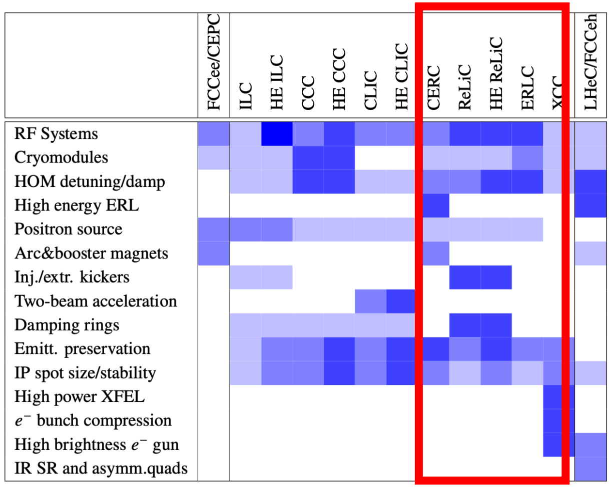


Circular colliders



ERL Loop





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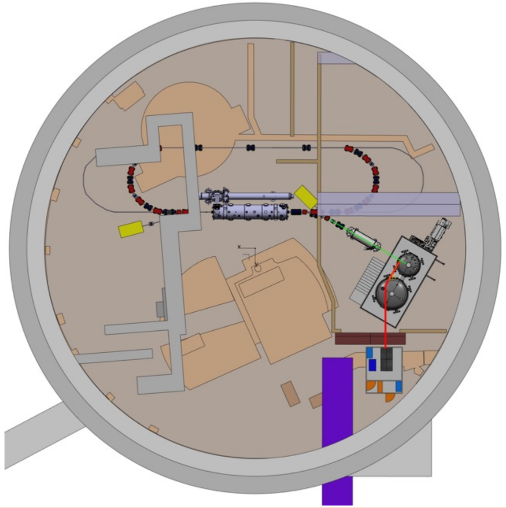
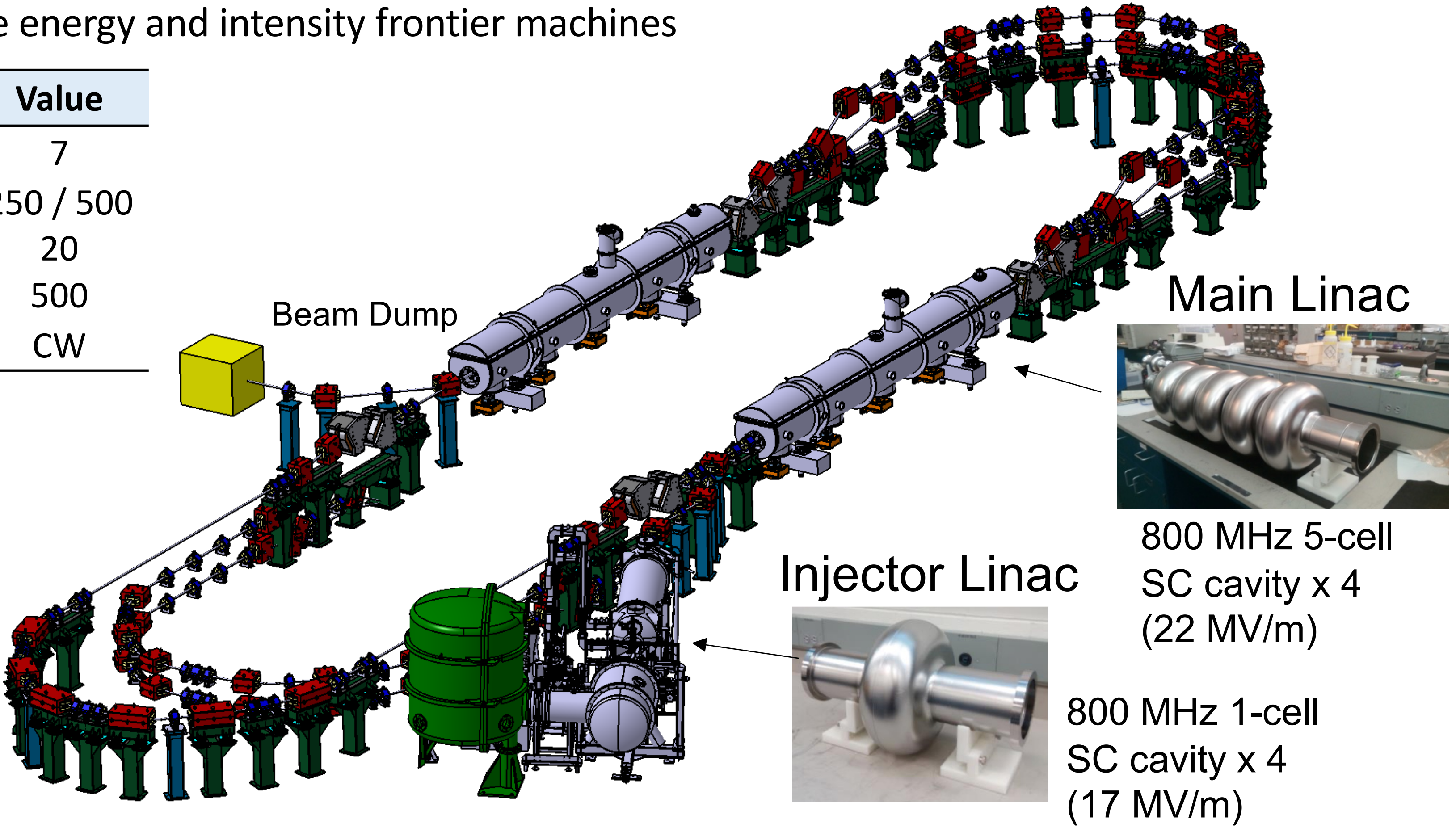
PERLE project at IN2P3/IJCLab

Ultimate goal of PERLE: first multi-turn ERL designed to operate at 10 MW (20 mA, 87→250→500 MeV)

→ A hub to explore a broad range of accelerator phenomena and to validate technical choices improving accelerators for future energy and intensity frontier machines

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	250 / 500
Average beam current	mA	20
Bunch charge	pC	500
Duty factor		CW

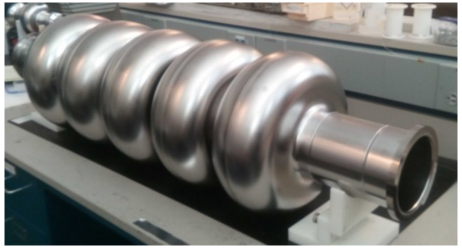




R &D targets

For FCC/PERLE

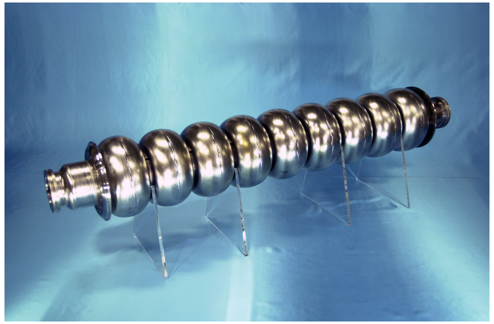
Duty cycle =100%



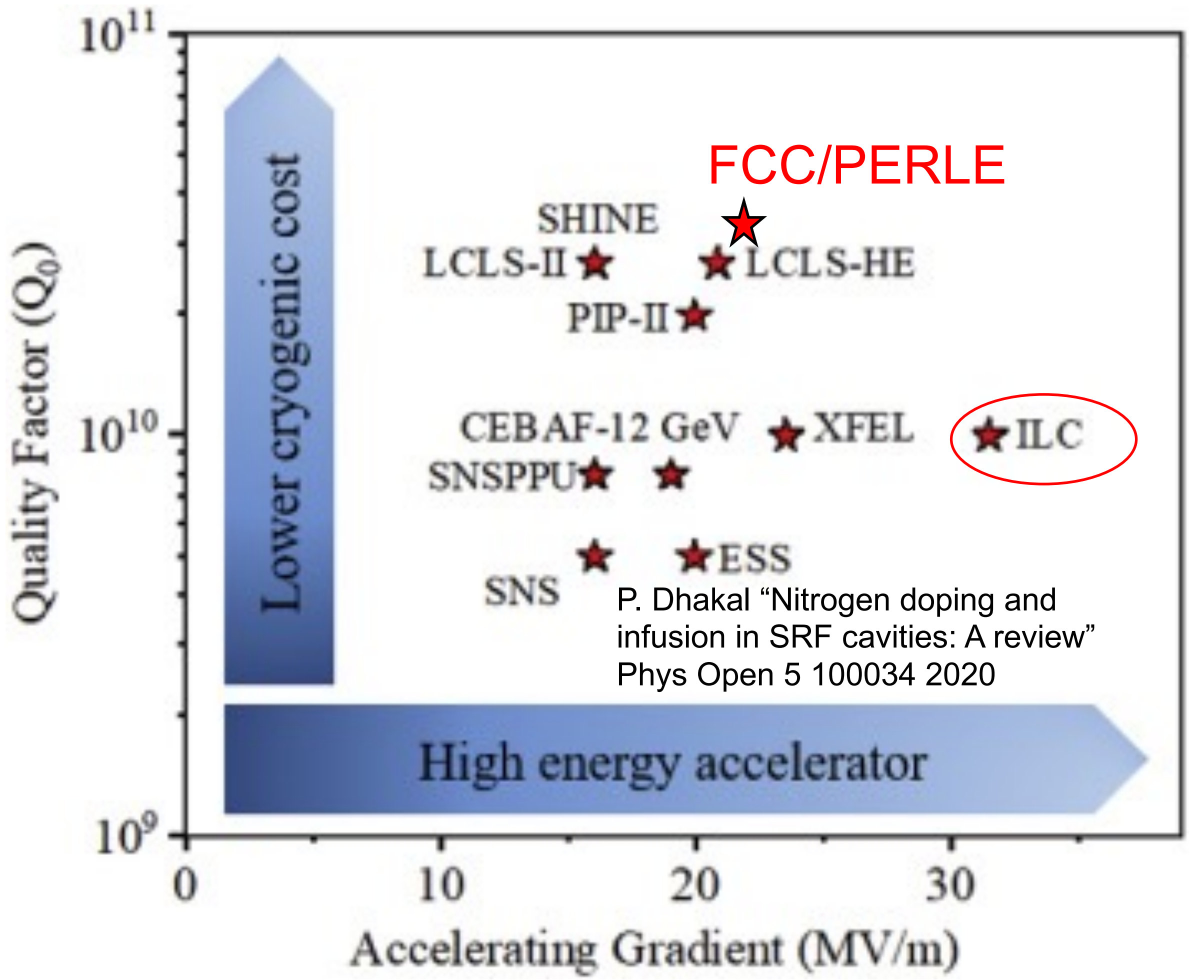
Extremely high-Q at relatively high gradient in large cavities (800 MHz)

For ILC250

Duty cycle <1%

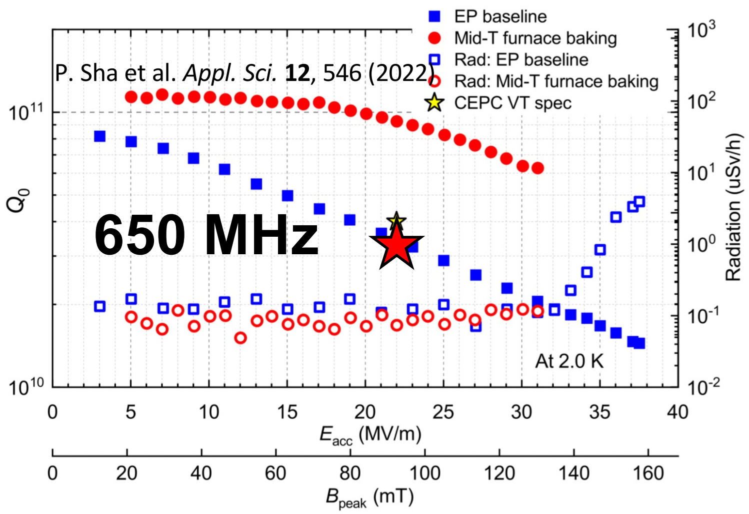


Extremely high gradient with relatively high-Q in a large # of cavities (~8000)

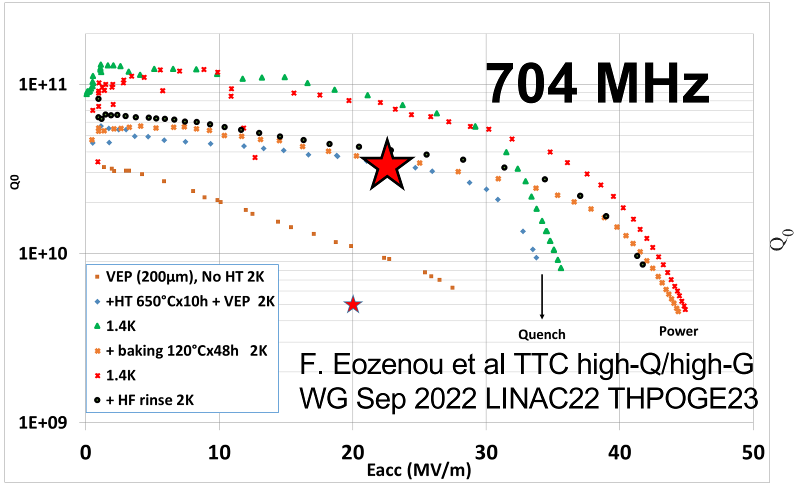


P. Dhakal "Nitrogen doping and infusion in SRF cavities: A review" Phys Open 5 100034 2020

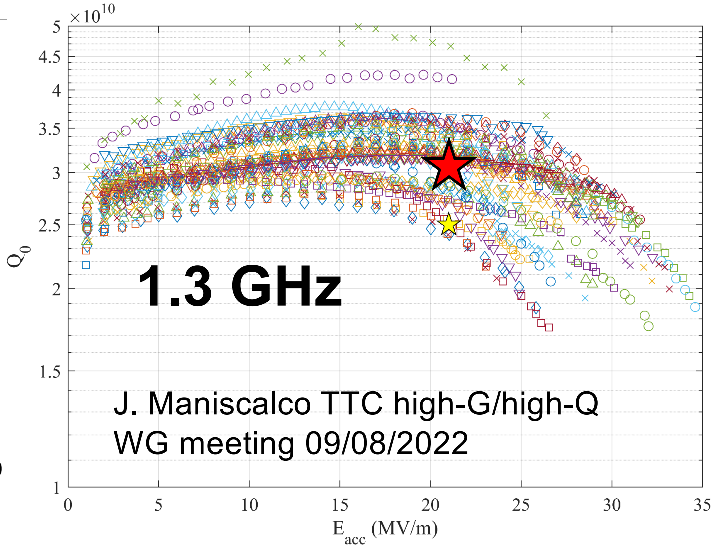
300C baking @ IHEP



120C baking @ CEA-Saclay



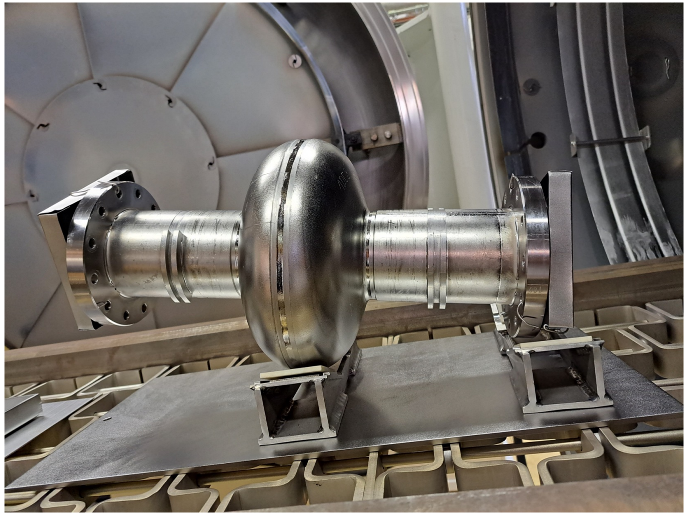
2N0 doping at 800C @ LCLSII



- 300C baking or N-doping seems like the best option for FCC/PERLE
- 120C or 2-step baking for higher gradient → ILC

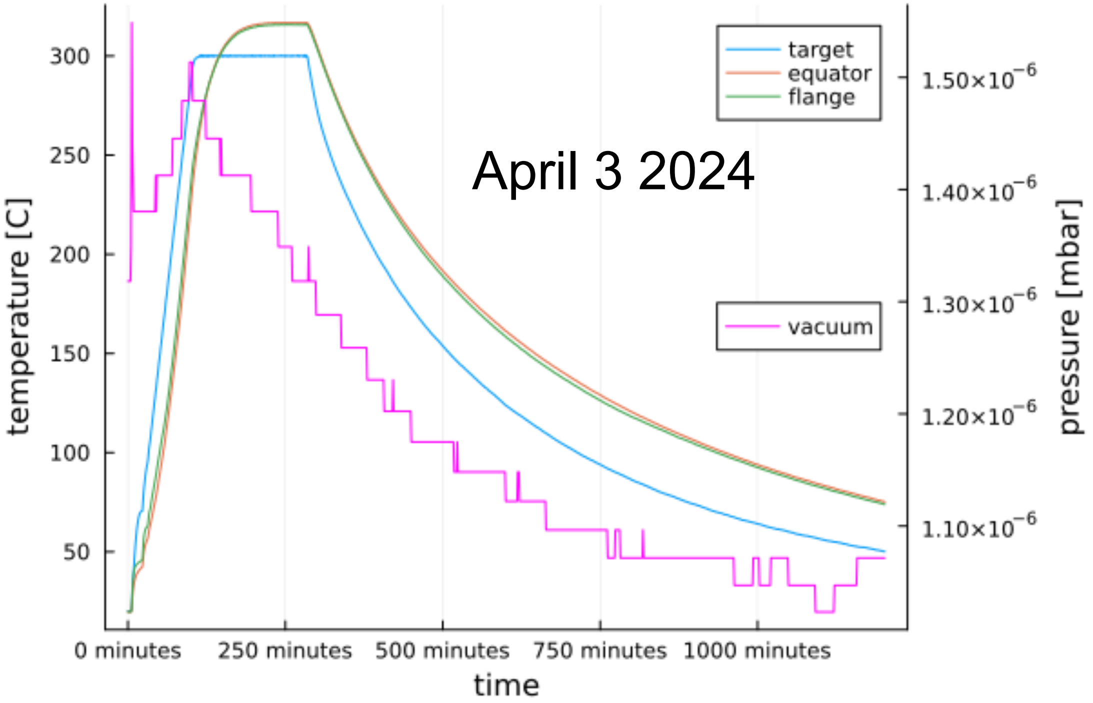
- **Clean vacuum baking furnace** is key in this research domain

300C baking in IN2P3/IJCLab

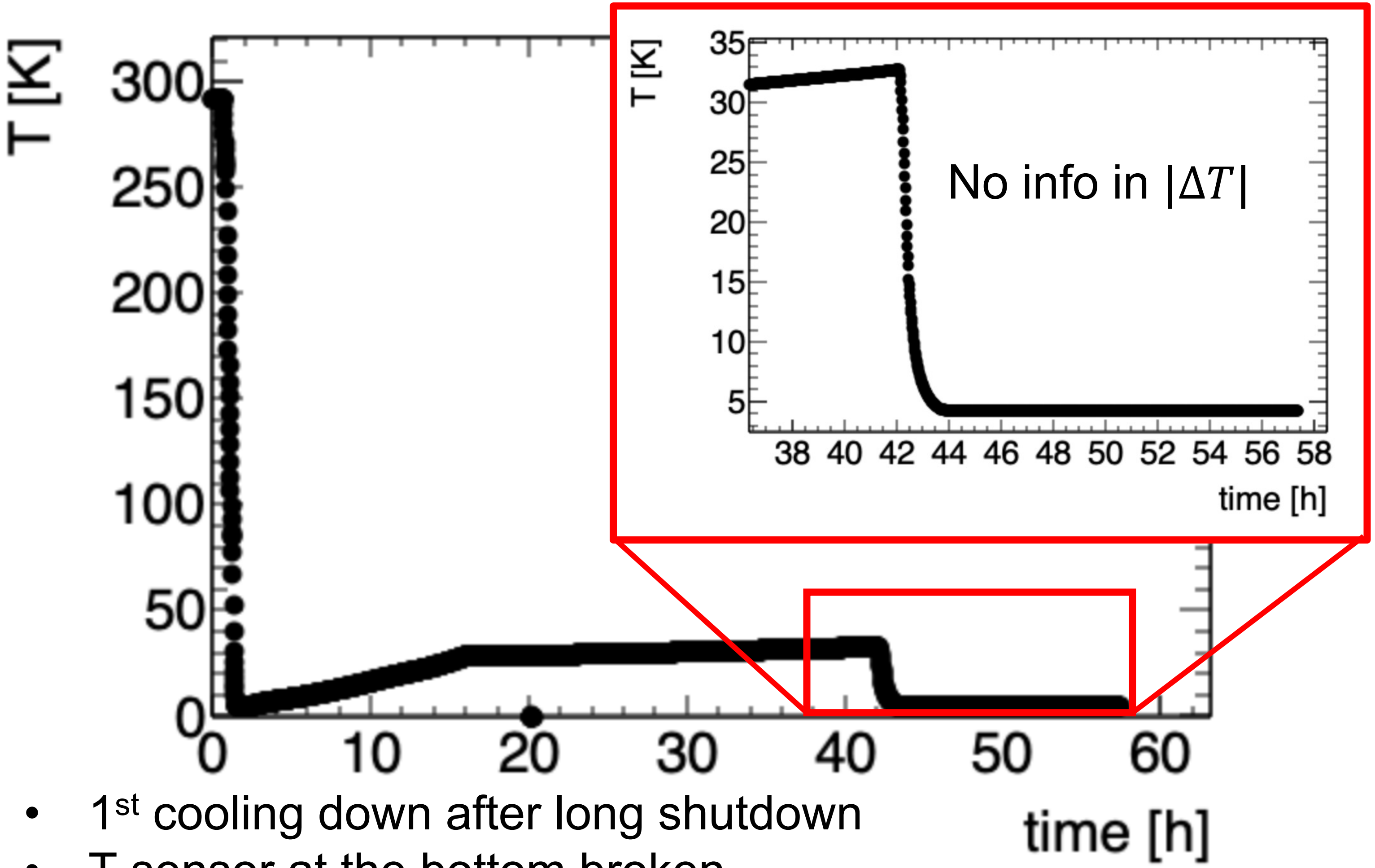


- Vacuum furnace originally used for 600C annealing of ESS spoke cavities
- A cryogenic pump, pure Ar for purging etc
- New R&D with DESY 1.3 GHz cavities

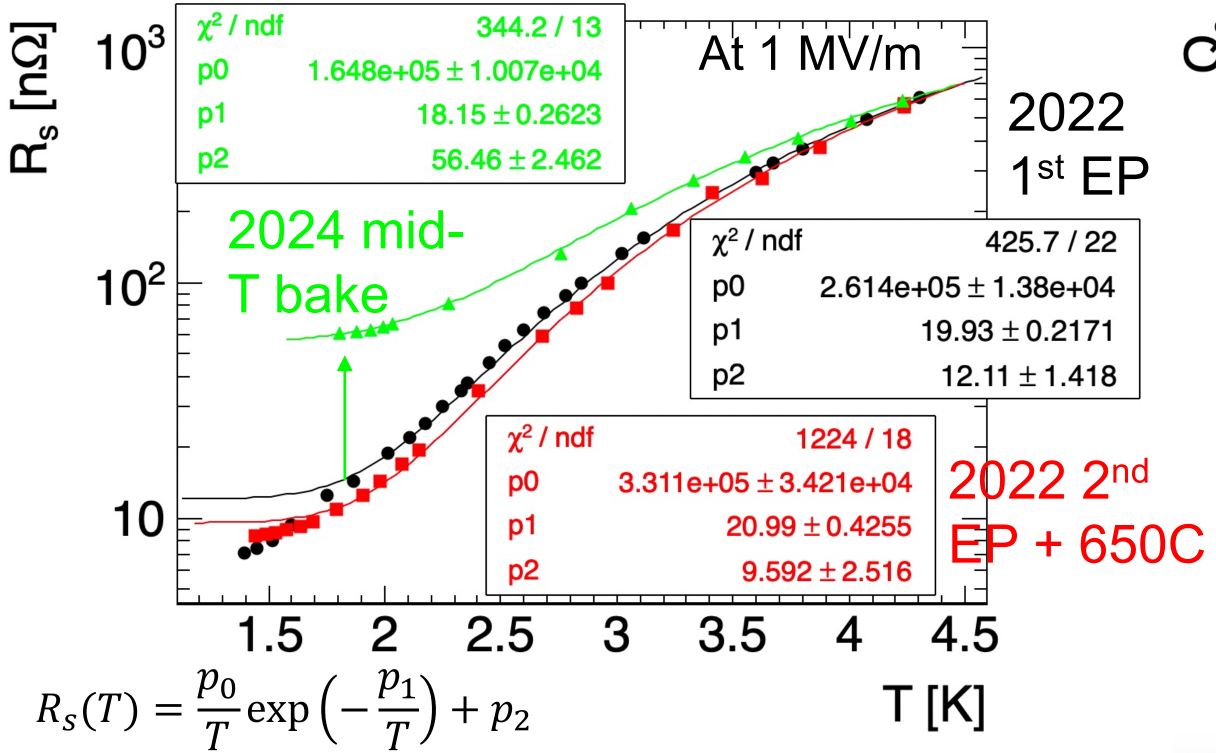
M. Fouaidy et al., IEEE Transactions on Applied Superconductivity, vol. 28, no. 4, pp. 1-6 (2018)



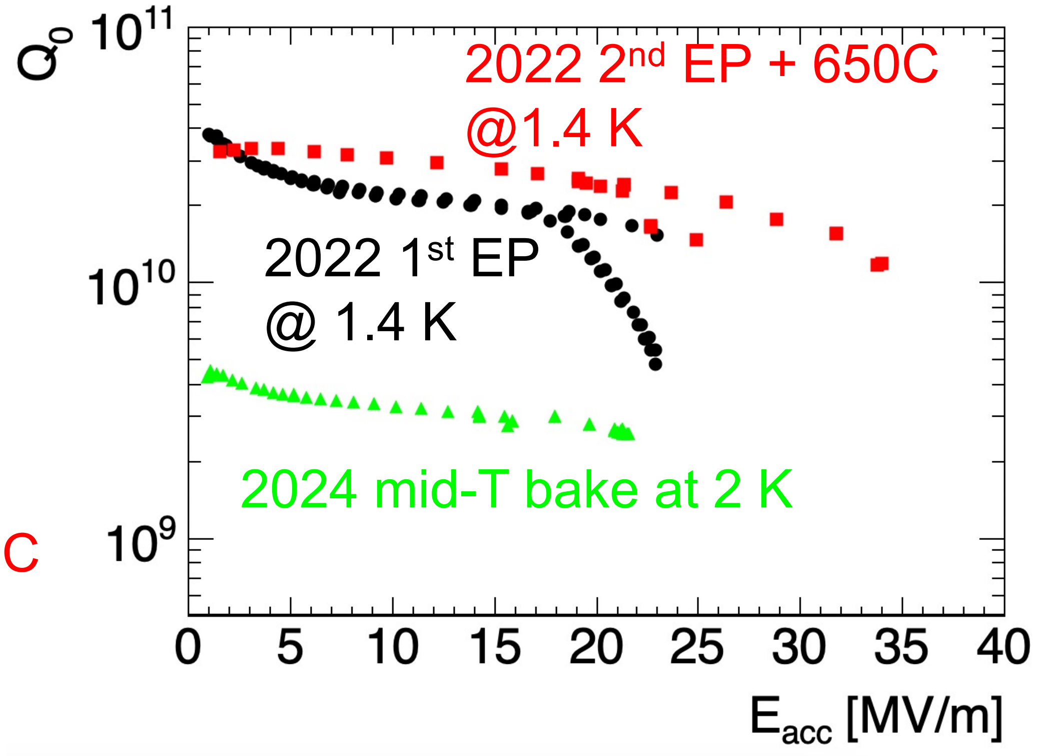
1st test is always far from ideal (CV1 at CEA Saclay on June 18 2024)



- 1st cooling down after long shutdown
- T-sensor at the bottom broken



$$R_s(T) = \frac{p_0}{T}\exp\left(-\frac{p_1}{T}\right) + p_2$$



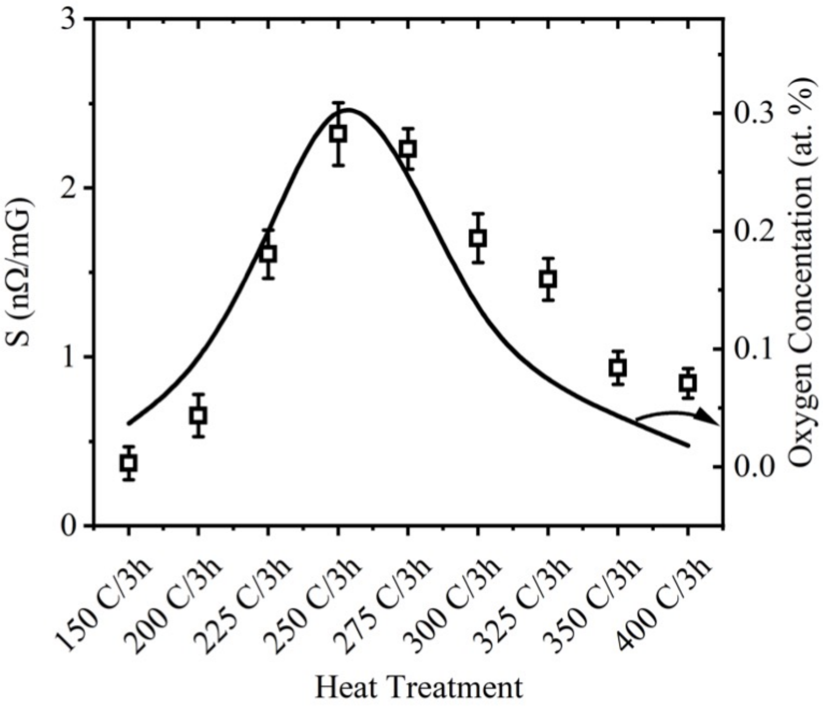
- The mid-T baked cavity showed significantly high residual resistance $\Delta R_{res} > 46\ n\Omega$
→ Is it due to contamination of furnace/cavity or magnetic field effect?

Magnetic field sensitivity (1.3 GHz cavities)

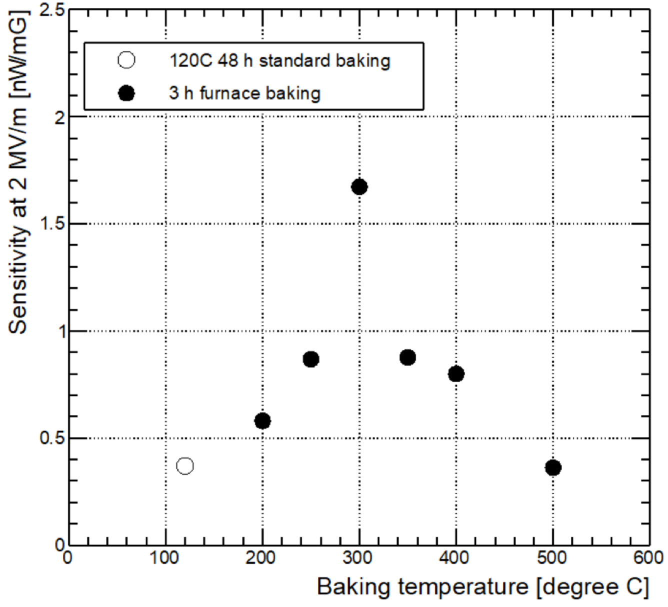
$H_{ext} \sim 25\ \mathrm{mG} = 2.5\ \mu\mathrm{T}$

Not yet optimized

JLab

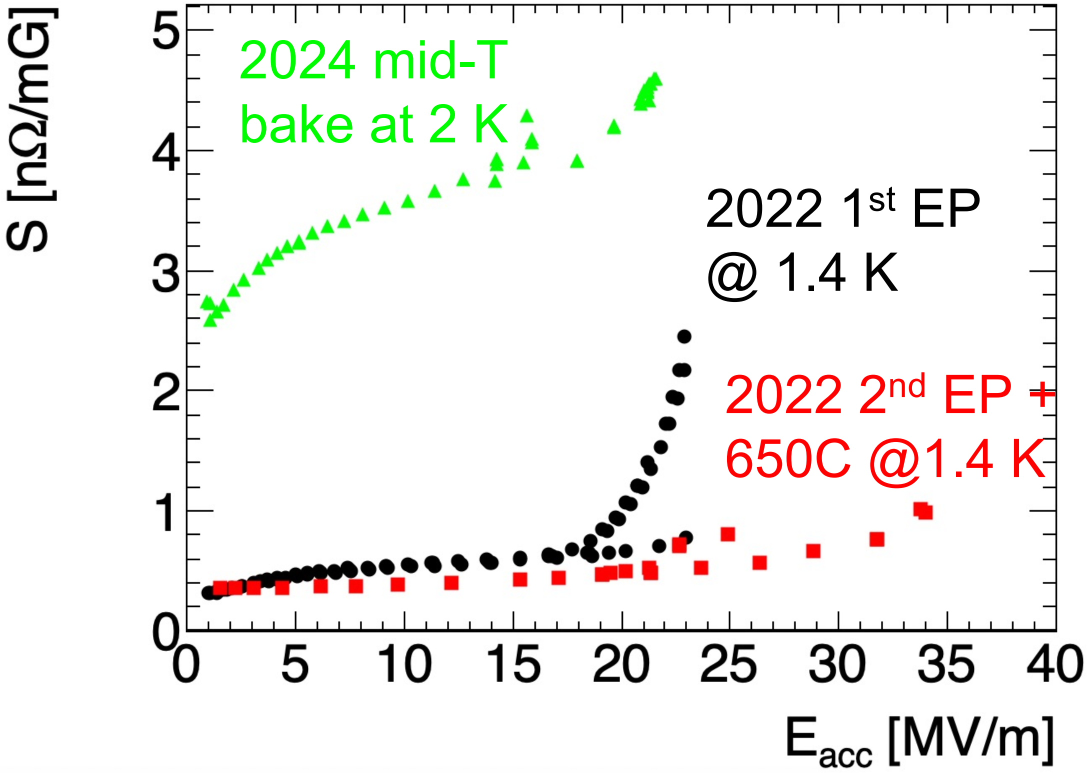


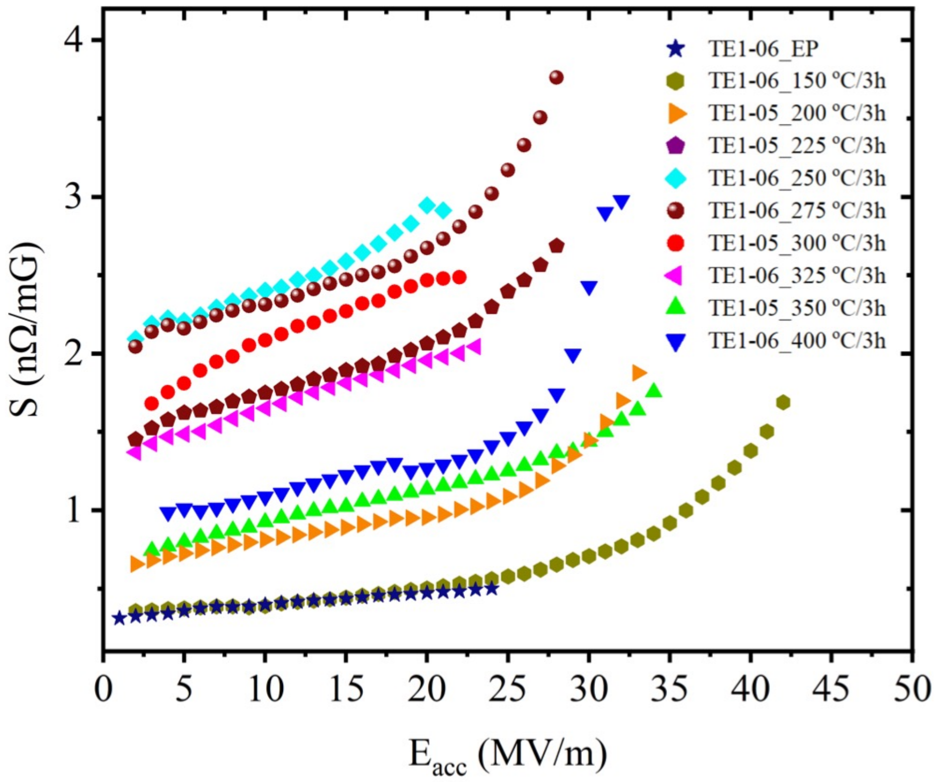
KEK



$S \sim 2\ \mathrm{n\Omega/mG}$

$$\rightarrow \Delta R_{res} \sim S H_{ext} = 50\ n\Omega$$



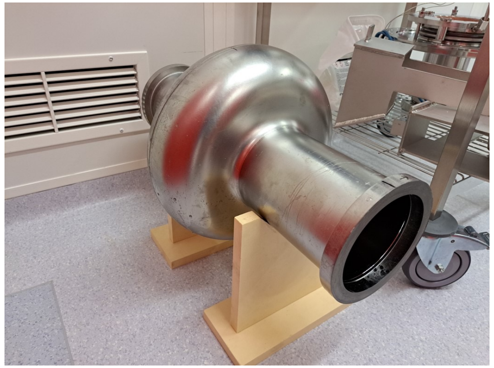


- We could explain the degradation of Q due to non-optimized magnetic shield and high sensitivity to trapped flux in mid-T baked cavities

→ Improving magnetic shield and installing magnetic field mapping at CEA after summer

Conclusions

- IJCLab has been a world-leading laboratory of SRF cavities for proton / heavy ion linear accelerators
  - R&D of Spiral2, ESS, MYRRHA, PIPII cavities are coming to the final phase
  - Contributions to collider projects has been in beam dynamics and nanobeams (ATF), RF couplers (Eu-XFEL), temperature sensors (LHC), etc
- IJCLab is expanding R&D activities of SRF cavities towards future colliders
  - FCC / PERLE 800 MHz cavities: super high-Q
  - ILC 1.3 GHz cavities: super high-G
- Advanced heat treatment is the key R&D subject
  - IJCLab is equipped with a clean vacuum furnace originally used for the ESS spoke cavity project
  - Mid-T baking for super high-Q
  - 1st mid-T baked results in 1.3 GHz cavity → studies on-going
- Future prospects
  - 2nd test with improved magnetic field at CEA (July 18), test at STF in KEK (October)
  - Heat treatment of the 800 MHz prototype cavity
- Collaborations
  - ERL collaboration with KEK via FJPPL
  - FCC: collaboration with CERN/FNAL
  - PERLE: collaboration with CERN/JLAB



backup

Open questions

- Magnetic field sensitivity
  - N-doping/mid-T bake makes cavities sensitive to trapped magnetic fields
  - Factor 10 better magnetic shield may be necessary
  - Flux expulsion technique with higher thermal gradient
  - Advantage of mid-T baking is based on a compromise between ultimately high-Q and realistic trapped flux level in a cryomodule
- EP vs BCP
  - EP + mid-T bake has been studied intensively
  - EP is mandatory for very high gradient but may not be for high-Q at decent field
  - BCP is simpler and less expensive
  - The limited number of tests have been performed for BCP + mid-T baking → results are somewhat contradictory
- Low-T bake could also be an option for FCC/PERLE
  - Not enough margin even in the best case but probably more conservative

List of the different recipes

xNy doping

1. High temperature degassing 800 °C (~ 3hours) in UHV
2. Nitrogen injection at the end of process (~ 25 mTorr) hold for 'x' mins
3. Evacuate furnace and temperature hold for 'y' mins
4. Furnace cooldown to room temperature in UHV
5. Electropolishing (5-10 µm)
6. High Pressure Rinse (HPR), clean room asselbly and rf test

N-infusion

1. HPR and Nb caps installed in clean room
2. High temperature degassing 800 °C (~ 3hours) in UHV
3. Furnace cooldown to (120-200 °C) in UHV
4. Nitrogen injection ~ 25 mTorr hold for 24-48 hours
5. Furnace cooldown to room temperature in UHV
6. High Pressure Rinse (HPR), clean room asselbly and rf test

2-step baking (1.3 GHz)

1. HPR and Nb caps installed in clean room
2. High temperature degassing 800 °C (~ 3hours) in UHV
3. 75C for a few hours in UHV
4. 120C for 48 hours in UHV
5. Furnace cooldown to room temperature in UHV
6. High Pressure Rinse (HPR), clean room asselbly and rf test

Mid-T baking

1. HPR and Nb caps installed in clean room
2. High temperature degassing 800 °C (~ 3hours) in UHV
3. Exposed to air for oxidation on purpose
4. 250-400 C for a few hours in UHV
5. Furnace cooldown to room temperature in UHV
6. High Pressure Rinse (HPR), clean room asselbly and rf test

P. Dhakal "Nitrogen doping and infusion in SRF cavities: A review" Phys Open 5 100034 2020

P. Sha et al. *Appl. Sci.* **12**, 546 (2022)