Erk Jensen/CERN

K. Aulenbacher (JG|U), O. Brüning, R. Calaga, A. Hutton (TJNAF), M. Klein, K. Schirm, R. Torres-Sanchez, A. Valloni

THE LHEC ERL CAVITY DEVELOPMENT & TEST FACILITY

Many thanks to O. Brunner, E. Ciapala, S. Calatroni, T. Junginger, D. Schulte, E. Shaposhnikova, J. Tückmantel †, W. Venturini, W. Weingarten and many more …

17–21 March 2014,

Thomas Jefferson National Accelerator Facility

EIC14

Relation to other presentations

- **Overview of LHeC Project** – covered this morning by Oliver Brüning
- **Design of the ERL Test Facility** – covered later by Alessandra Valloni

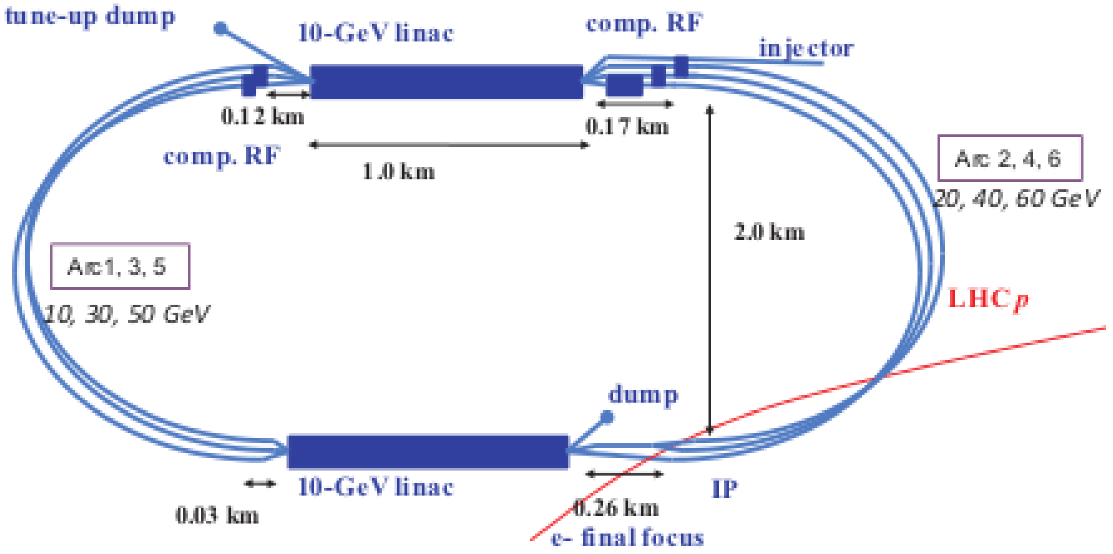
- In order to minimize the overlap with these presentations, I decided to significantly deviate from the title and focus on ***Superconducting Cavity R&D*** and put this in the context of ***SRF R&D at CERN*** in general.

CERN

THE ERL-TF

Motivation: ERL based e- Linac for LHeC

- LHeC CDR published: arxiv.org/abs/1206.2913
- Goal: Collide LHC proton beam with e^- or e^+ for DIS.
- Power consumption ≤ 100 MW!
- 60 GeV ERL with two 10 GeV Linacs
- Frequency choice:
  $f = 801.58$ MHz
- Same as SPS and LHC harmonic systems!



Goals of a CERN ERL-Test Facility

- In this decade, CERN is exploiting and upgrading the LHC – but not constructing "the next big machine".
- CERN is mandated to study and develop the technologies to prepare for a possible next energy-frontier machine.
- This R&D focuses on high field magnets and high gradient acceleration.
- Superconducting RF is a key area – this is where this planned facility comes in.

Study real SCRF cavities with beam (not interfering with HEP)

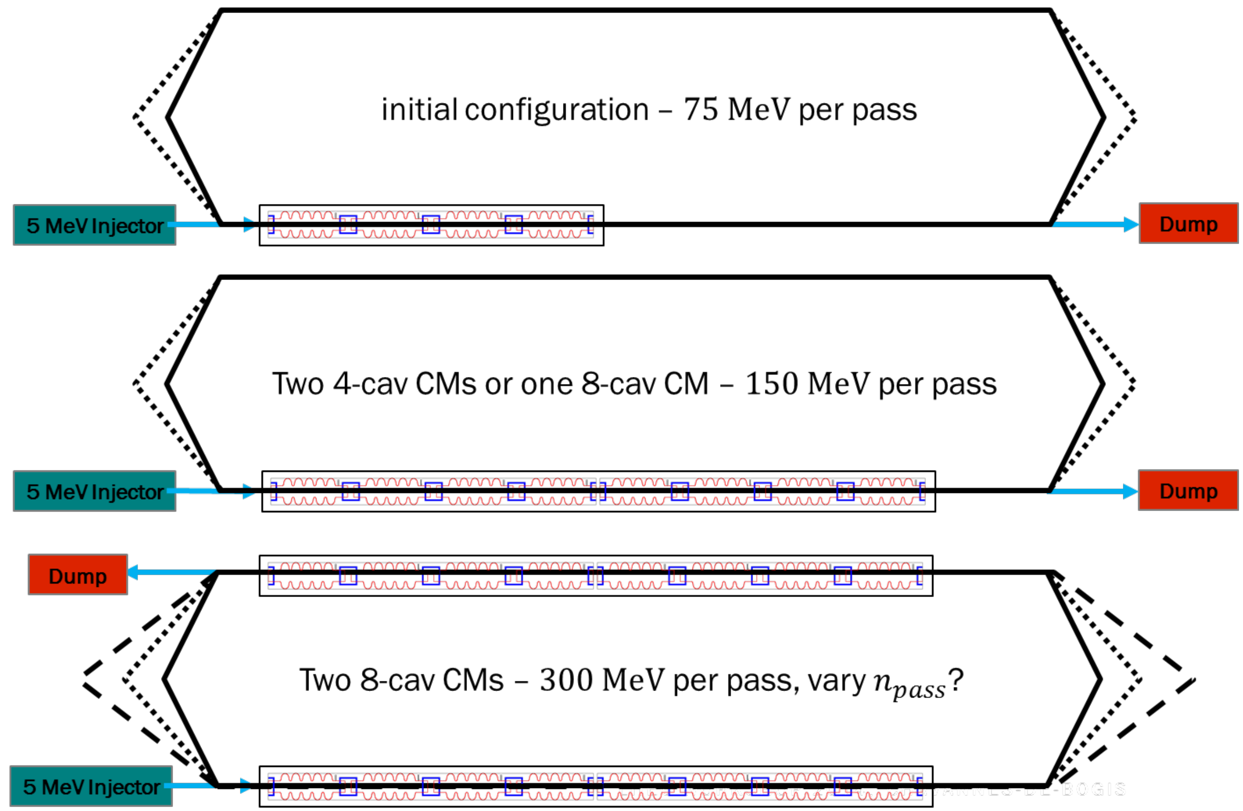
- In addition, it would allow to study beam dynamics & operational aspects of the advanced concept of the recovery of otherwise wasted beam energy!
- Additional goals:
  - test beams for detector R&D,
  - beam induced quench test of SC magnets
  - … (see Alessandra Valloni's talk later today)
- At the same time, it will be fostering international collaboration (JG|U Mainz and TJNAF collaborations being formalized)

What are we talking about?

- The ERL test facility would be conceived to be built in stages;
- It would allow for instrumentation and it would have built-in flexibility.

A. Valloni

- More details on this later by Alessandra!



ERL CAVITY/CRYOMODULE DEVELOPMENT

… only just starting (R. Calaga, K. Schirm, R. Torres-Sanchez)

Goals of the 800 MHz Cavity R&D

- Design, develop, build and test cavities/cryomodules for the ERL-TF!

- Parameters (ball park):

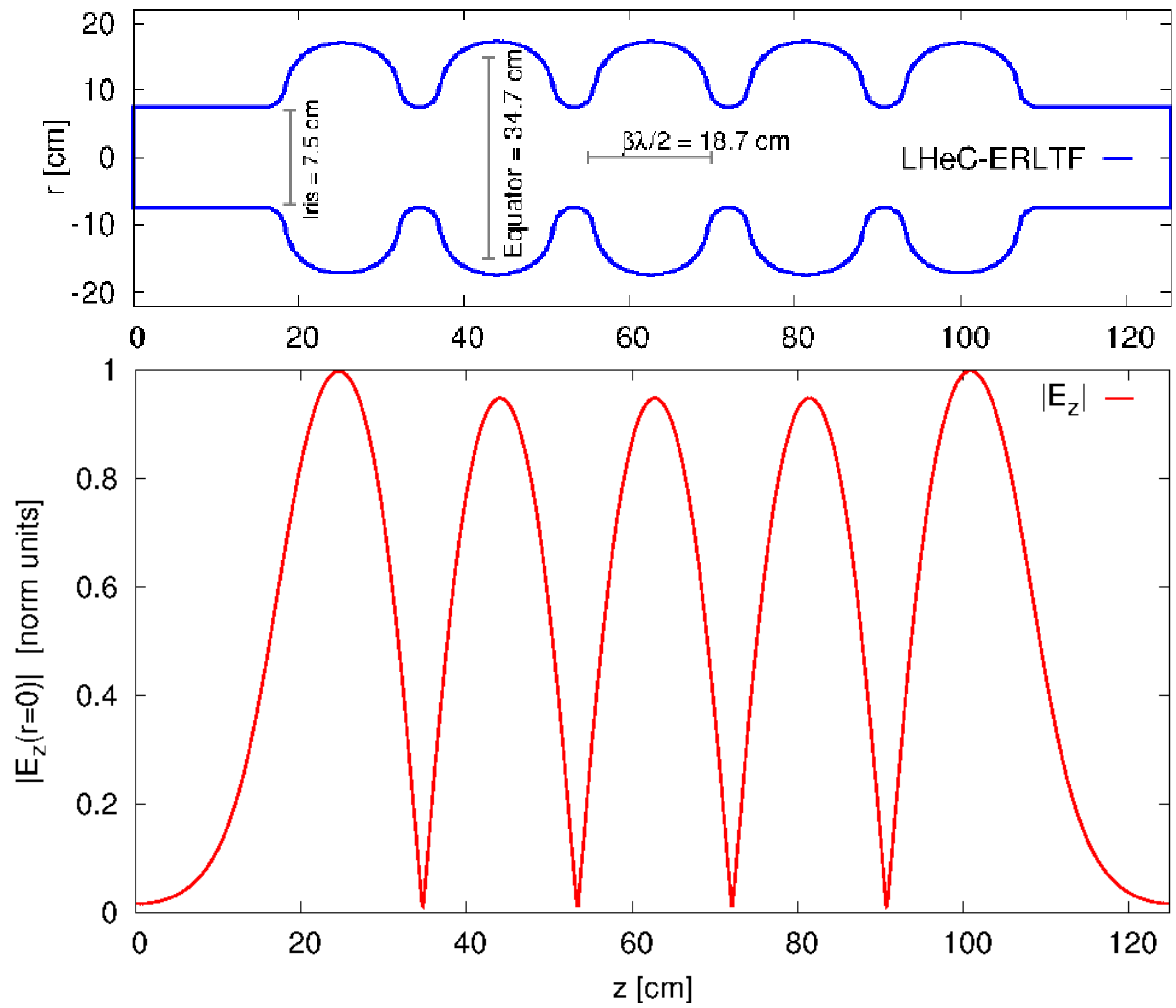
R. Calaga

Parameter	Value
Acceleration gradient	$< 20\ \mathrm{MV/m}$
# cells/cavity · cavities/CM · CMs	$5 \cdot 4 \cdot 2\ (4)$
Accelerating voltage/cavity	$18\ \mathrm{MV}$
$5 \cdot \lambda/2$, total cavity length	$935\ \mathrm{mm},\ 1.2\ \mathrm{m}$
Operation frequency	$801.58\ \mathrm{MHz}$
RF power/CM	$< 50\ \mathrm{kW}$
Bunch charge	$2 \cdot 10^9\ e = 320\ \mathrm{pC}$
Beam current	$4 \cdot \frac{320\ \mathrm{pC}}{25\ \mathrm{ns}} \approx 50\ \mathrm{mA}$
Duty factor	CW

800 MHz cavity: Some first choices

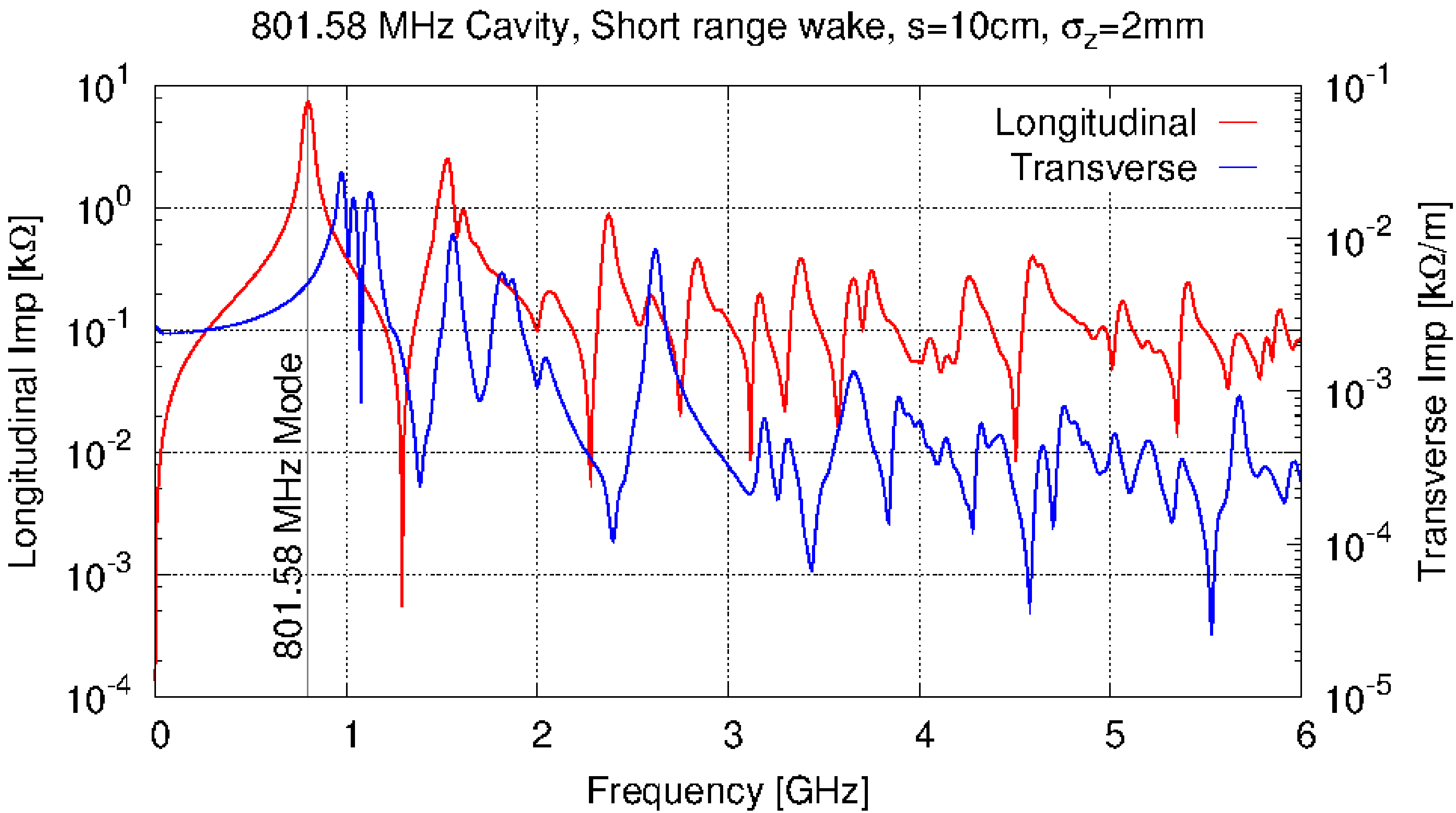
R. Calaga

Parameter	Value
n_{cell}	5
V_{acc}	18 MV
f_0	801.58 MHz
W	131 J
aperture Ø	75 mm
equator Ø	347 mm
R/Q	462 Ω
G	276 Ω
E_{peak}	41 MV/m
B_{peak}	86 mT
$P_{diss}\big\|_{2K}$	< 28 W



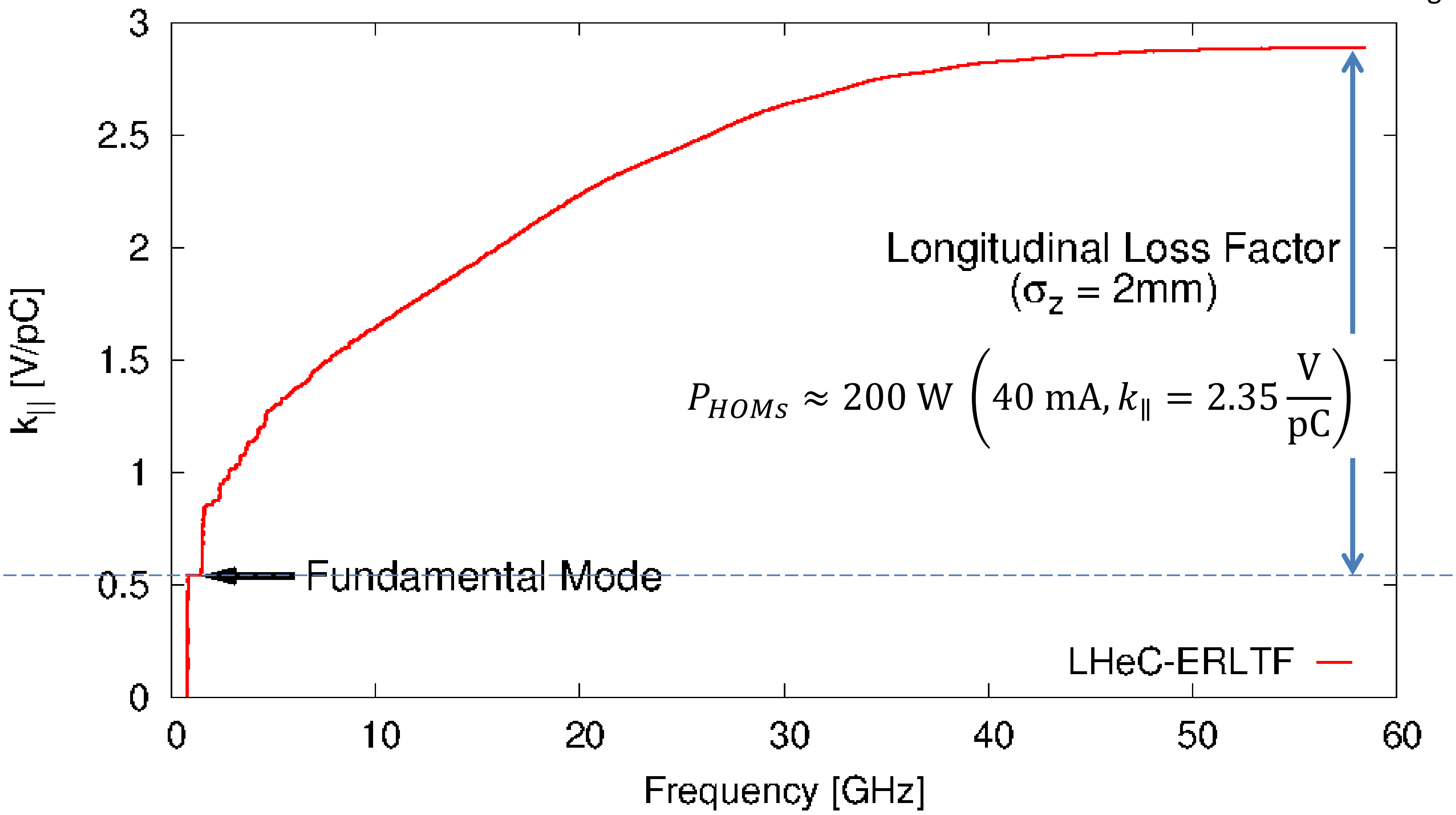
Impedance spectra

R. Calaga



HOM power estimate (short bunches)

R. Calaga

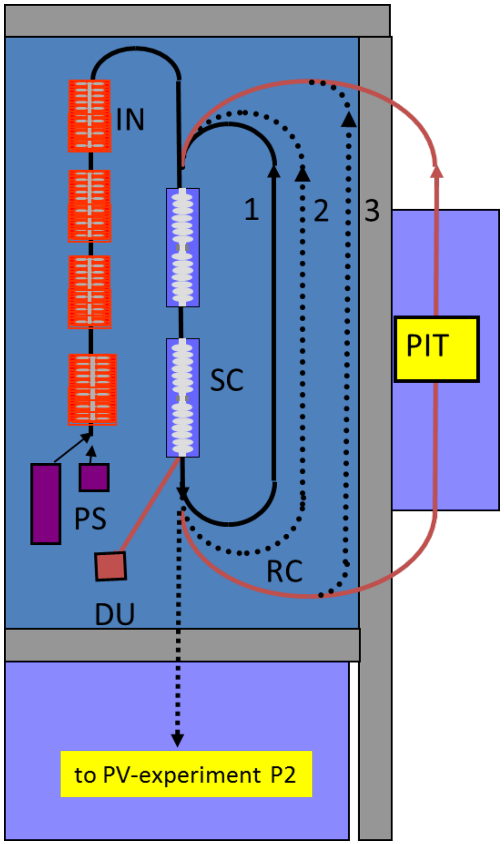


The planned collaboration:

- We are now formalizing collaboration with JG|U Mainz and JLAB to build prototype 802 MHz cavities/CMs together!
  - JG|U to provide infrastructure (MESA and HIM) manpower and resources
  - CERN to design/engineer cavities, HOM dampers, FPCs, tuners, He vessel, ancillaries…
  - JLAB to design/engineer the CM (based on SNS 805 MHz concept)
- 1st prototype cavities can serve in MESA.

K. Aulenbacher

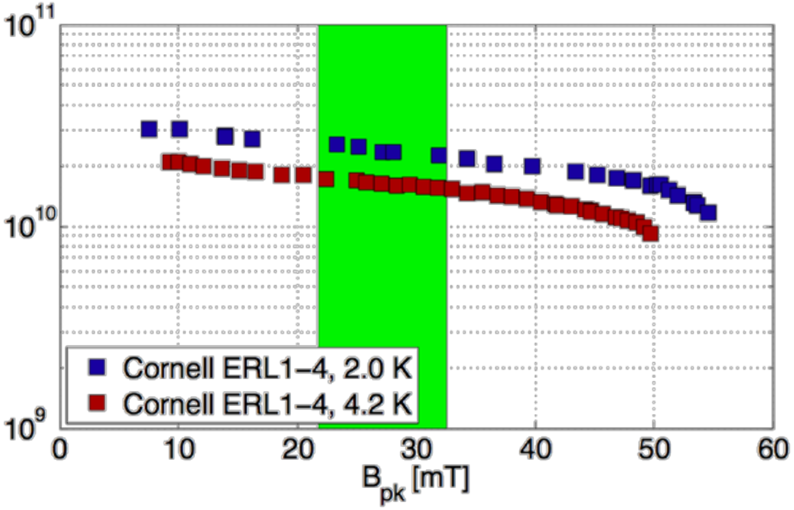
MESA Concept:



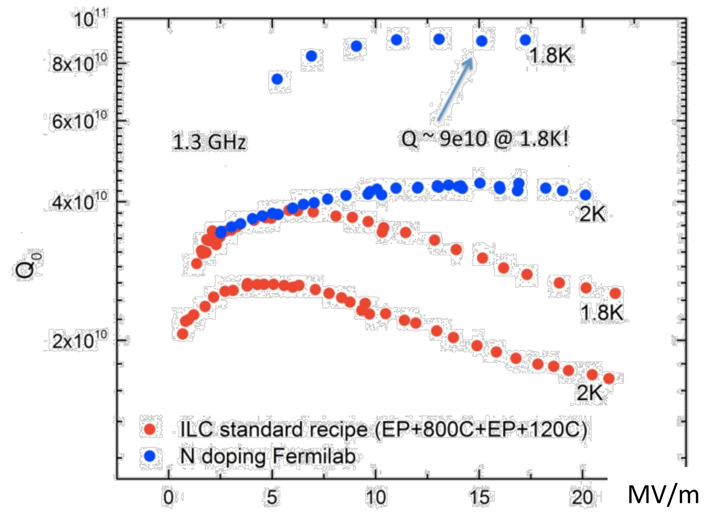
MESA: **M**ainz **E**nergy recovering **S**uperconducting **A**ccelerator
HIM: **H**elmholtz-**I**nstitut **M**ainz

SRF ACTIVITIES @ CERN

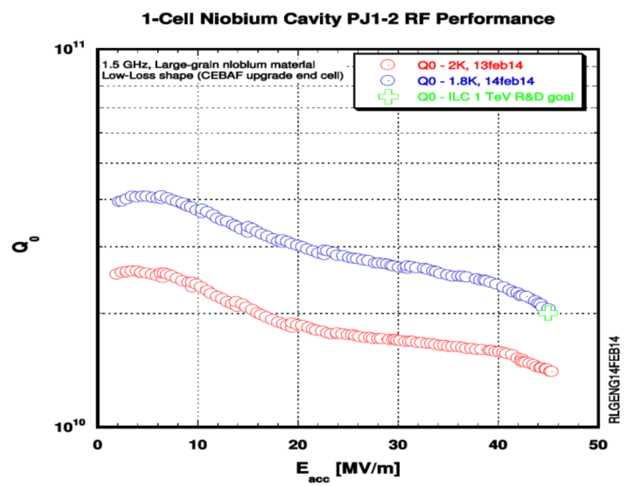
Elsewhere: recent progress in SRF



Sam Posen et al. (Cornell): “Theoretical Field Limits for Multi-Layer Superconductors”, SRF 2013



Anna Grasselino et al. (FNAL): “New Insights on the Physics of RF Surface Resistance and a Cure for the Medium Field Q-Slope”, SRF 2013



Andrew Hutton (JLAB), private communication: recent results with large-grain Nb in low-loss shape (CEBAF upgrade end cell)

Overview SRF Activities at CERN

- At the times of LEP II (1990s), CERN was at the forefront of SRF Technology
  - Key technology: Nb sputtered on Cu!
- Then came TESLA/ILC and technology progressed tremendously – CERN lagging behind … (see previous page)

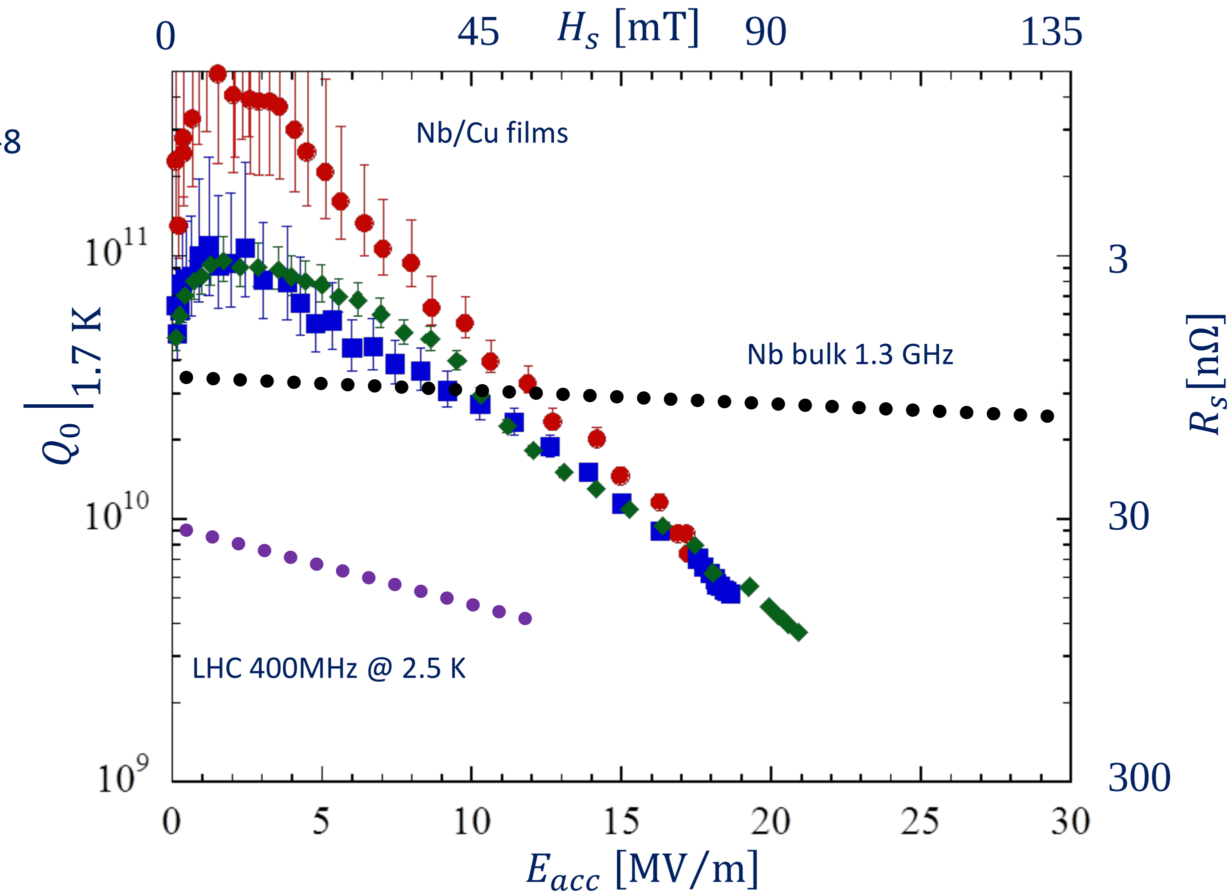
- Recently, CERN is involved in the following SRF projects/studies:
  - LHC — operational, 16 cavities in 4 CMs, 2 MV/cavity, Nb/Cu
  - HIE-ISOLDE — construction (20 + 12) QWR cavities, Nb/Cu
  - HL-LHC Crab Cavities — CERN coordinating; 3 different designs, bulk Nb
  - SPL — study, with CEA, IPNO and ESS, 4 cavity CM, bulk Nb
  - LHeC — design study, ERL, ERL-TF
  - FCC — design study – about starting now.
- Today CERN is trying to ***re-establish know-how*** and ***upgrade its facilities*** to be able to perform relevant R&D and help prepare SRF technology for the future.
- In the centre of attention (but not exclusively) are again the thin-film techniques

State of the art in magnetron sputtered Nb/Cu films

S. Calatroni

NIM A463 (2001) 1-8

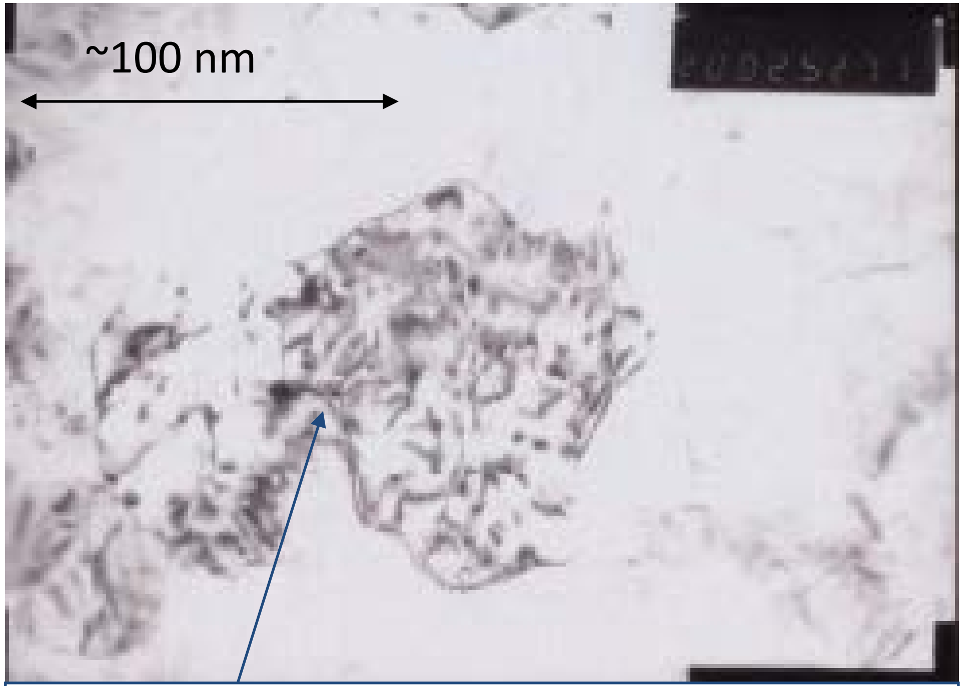
1.5 GHz Nb/Cu cavities, sputtered with Kr @ 1.7 K ($Q_0 = 295\,\Omega/R_s$)



$\boldsymbol{Q_0 = 1 \cdot 10^{10}}$ **@** $\mathbf{15\,MV/m}$ is a value that would make film cavities a competitive option in several future projects.
Current R&D is focussed on improving the “slope”, applying films to new geometries, new materials

Possible origin of Q-slope: film defects

S. Calatroni



Crystallographic defects can be at the origin of reduced H_{c1} compared to bulk Nb

$$\frac{1}{l_{total}} = \frac{1}{l_{intra-grain}} + \frac{1}{D}$$

RRR of films: $10 \div 30$

$\Rightarrow$

mfp of films $(30 \div 100)$ nm

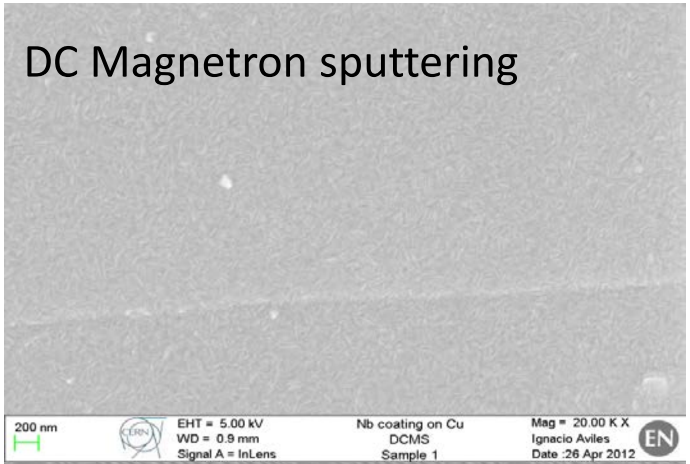
Grain size of films $> \ 100$ nm

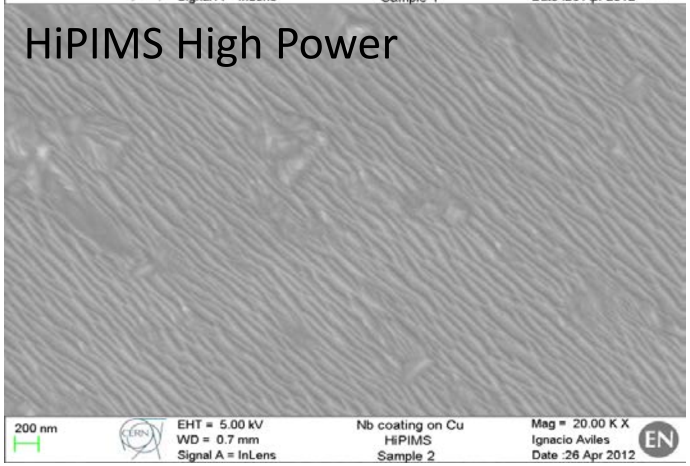
$\Rightarrow$

RRR limited by intra-grain defects in most cases

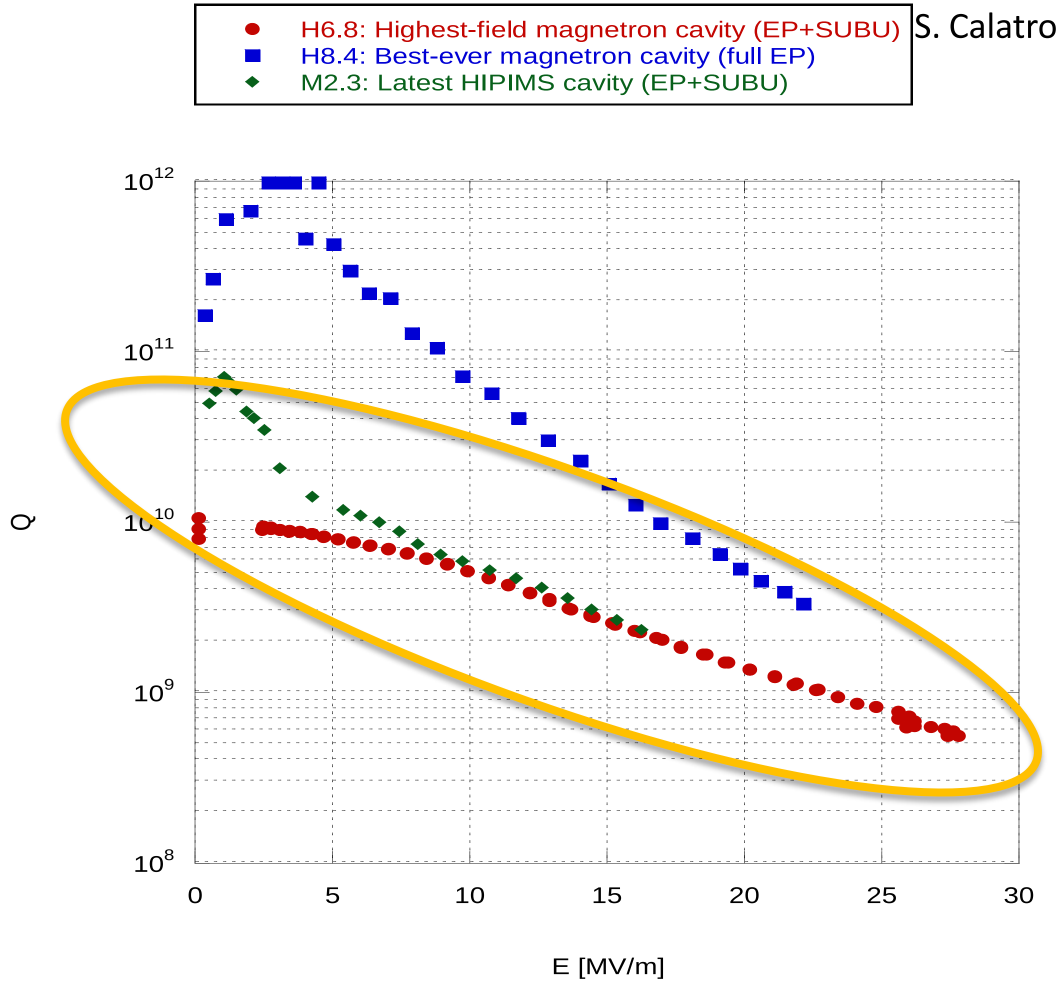
The goal is to make films as bulk-like as possible in terms of microstructure. The grain size does not seem to be a major issue

HiPIMS: a way to produce Nb ions for coating





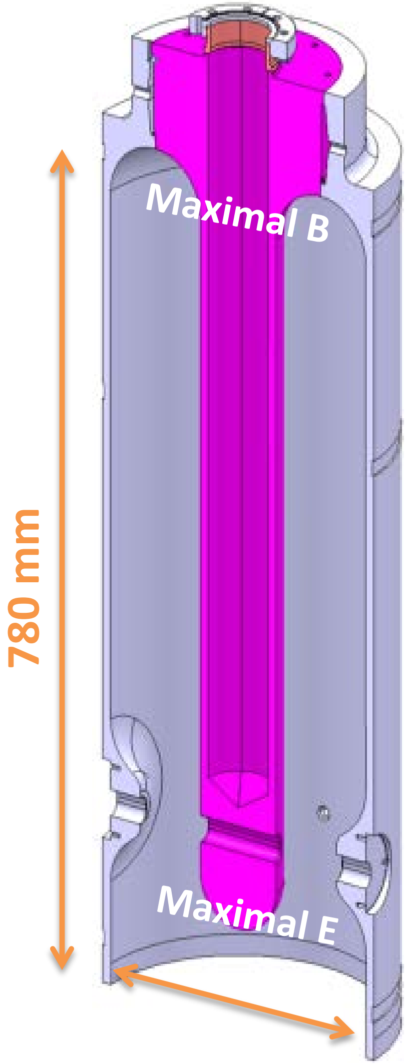
S. Calatroni

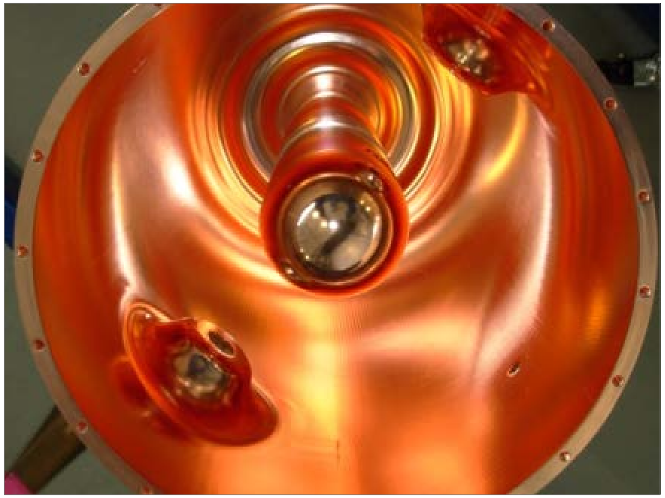


With HIPIMS at this early stage we are currently **at the level of the best performing magnetron sputtering coatings**, for an equivalent surface preparation (SUBU vs EP)

HIE ISOLDE QWR Coatings

S. Calatroni, I. Mondino, W. Venturini Delsolaro



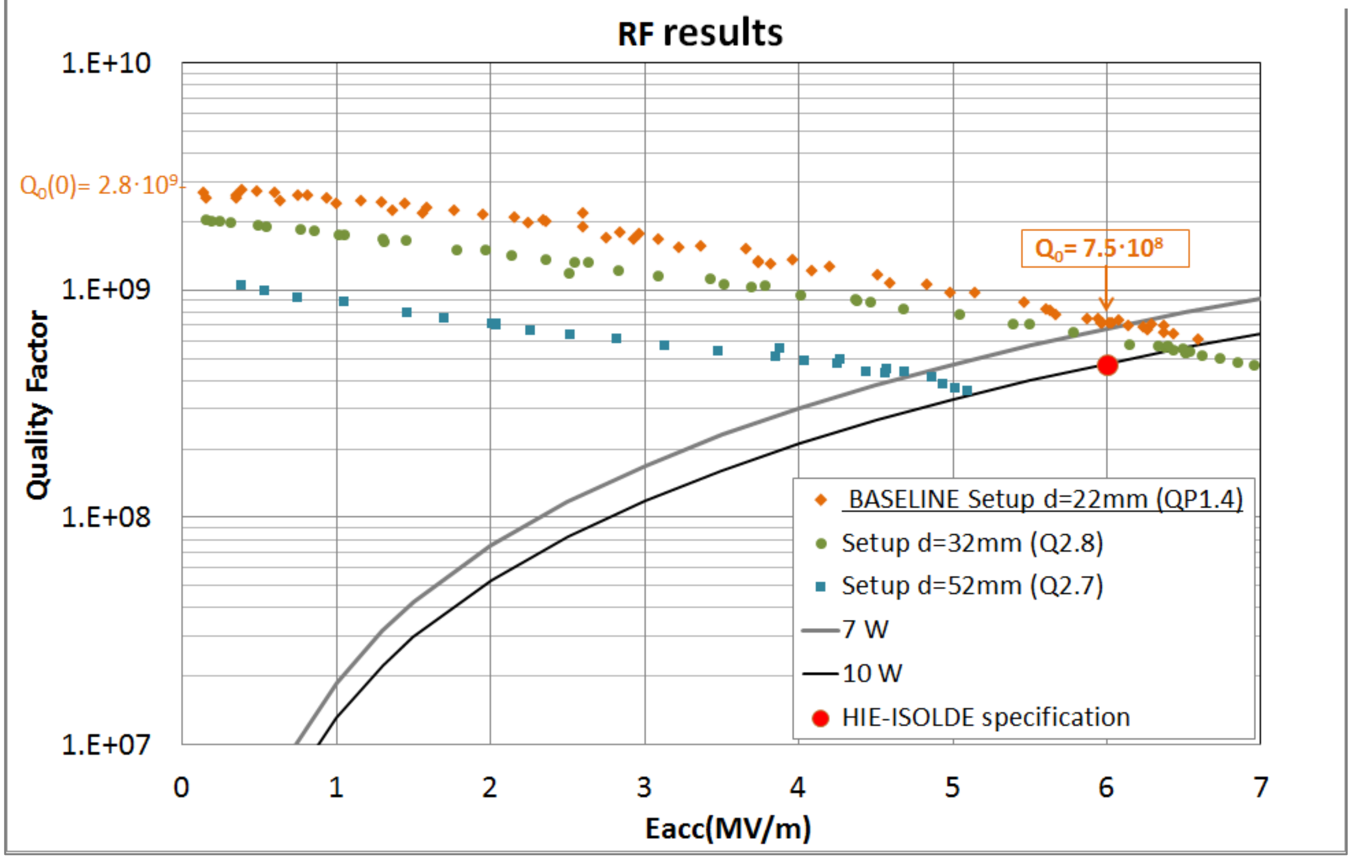


HIE ISOLDE

- Specifications **6 MV/m** for 10 W RF power (30 MV/m peak) were exceeded after initial development phase; series production starting

Nb-Coating

S. Calatroni, I. Mondino, W. Venturini Delsolaro

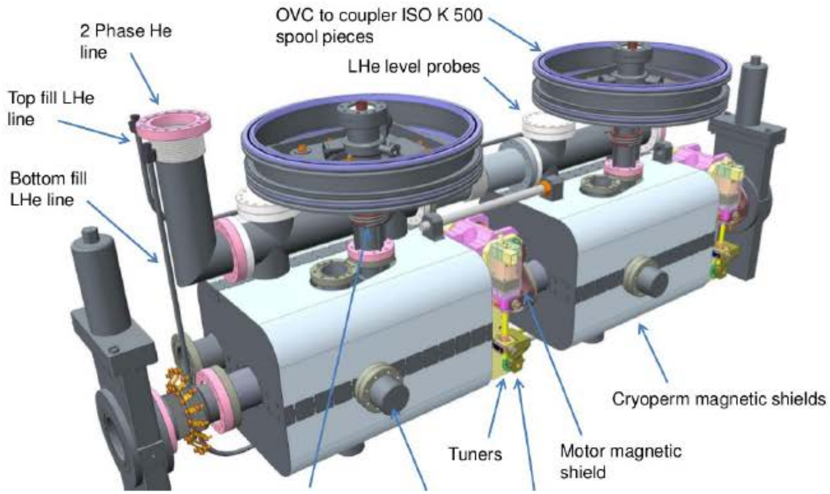


Cavities performances progress

LHC Luminosity upgrade: Crab Cavities

Three compact cavity prototypes constructed & tested

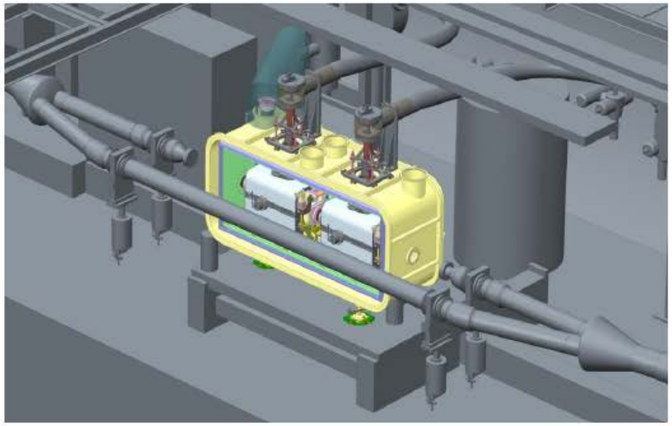
- 1 cavity with x2 performance
- 2 other cavities with moderate performance



Cryomodule concepts in advanced stage

SPS-BA4 test preparation advancing well

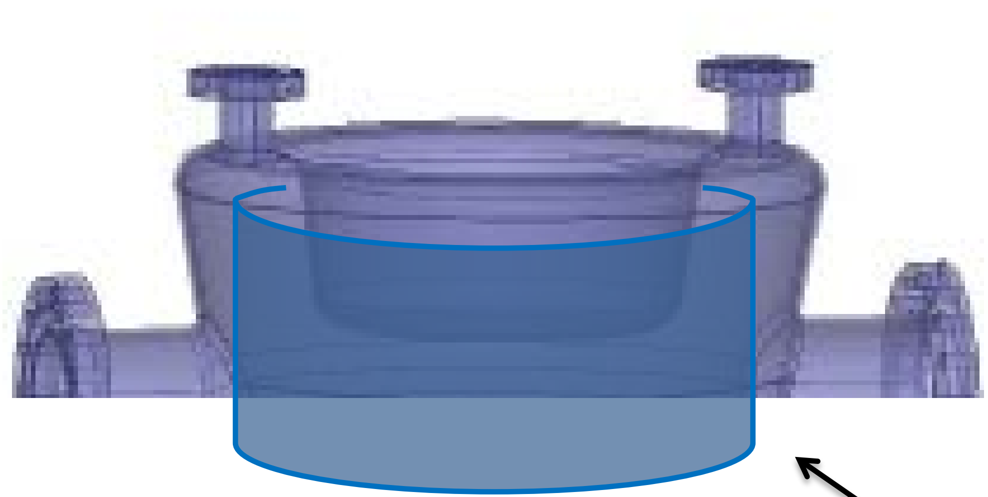
International collaboration:
BNL, FNAL, JLAB, ODU, SLAC,U-Lanc, …



Coating Crab Cavities???

S. Calatroni

A topological configuration similar to HIE-Isolde QWR is possible



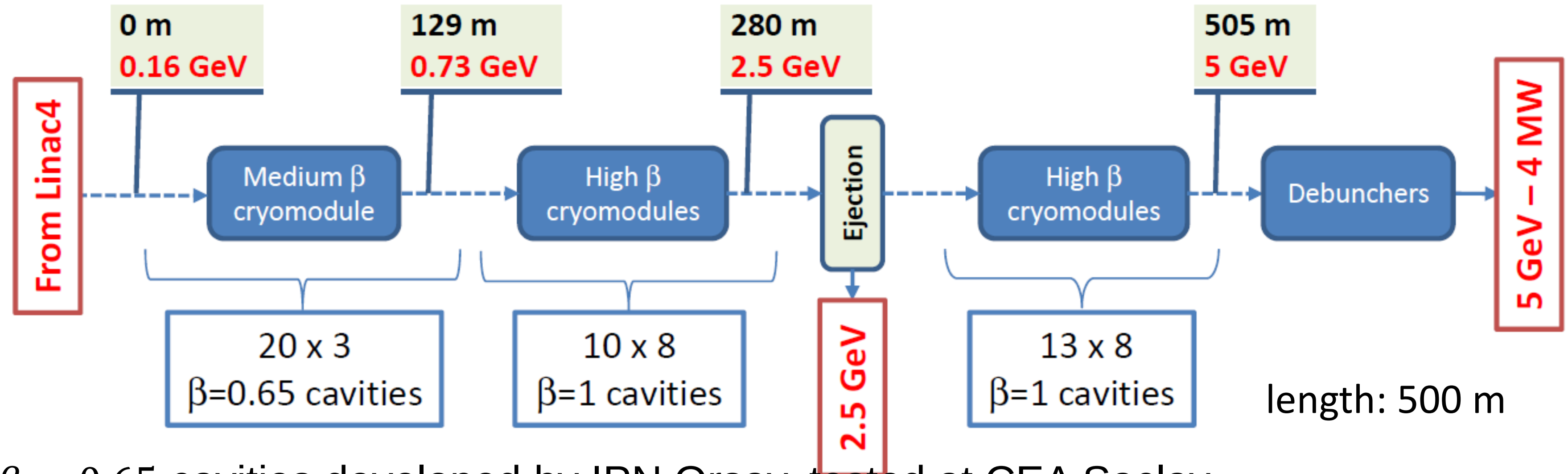
Cylindrical niobium cathode

Coat, then clamp onto the other symmetric half

A performance equivalent to HIE-ISOLDE QRWs (and in line with HL-LHC expectations) could be expected. Intrinsically quench-free

Superconducting Proton Linac - SPL

O. Capatina

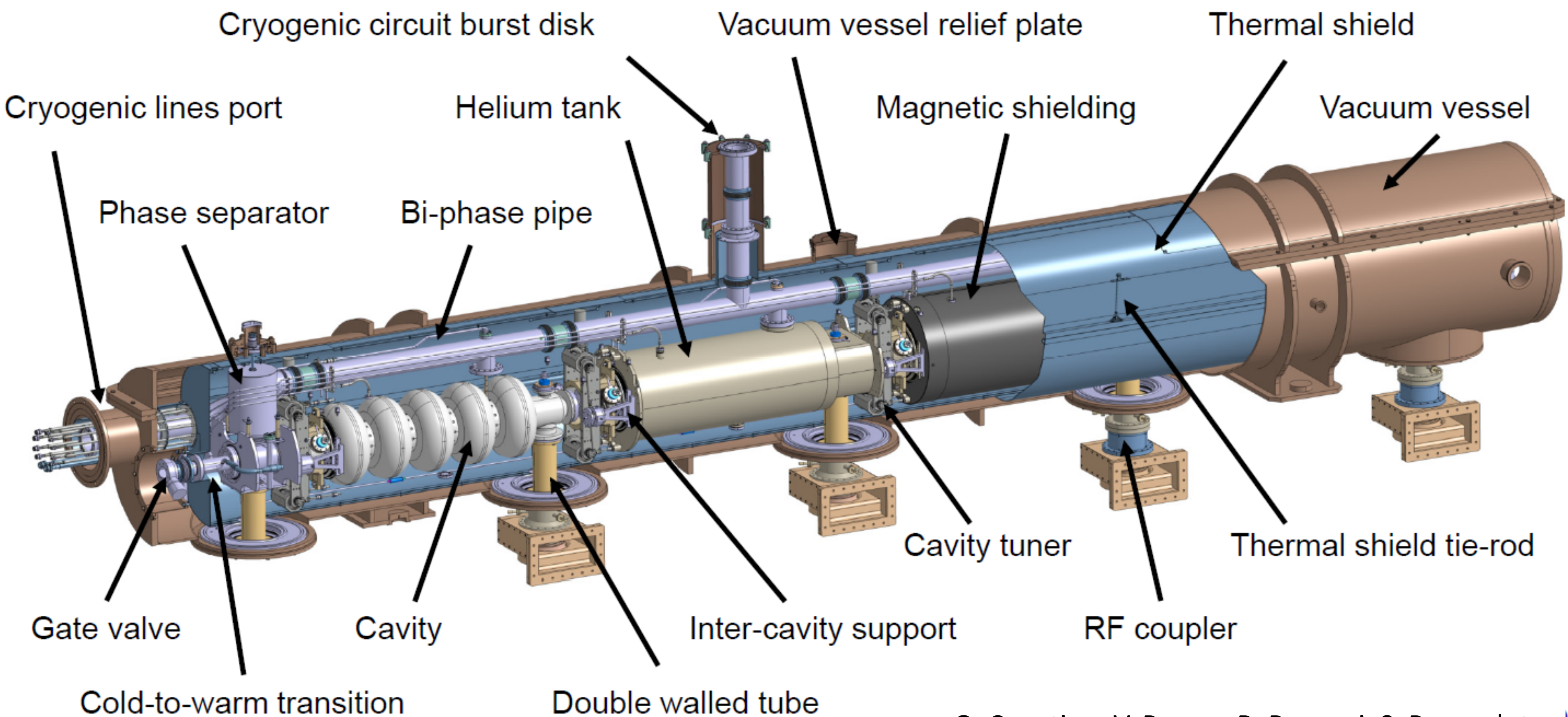


- $\beta = 0.65$ cavities developed by IPN Orsay, tested at CEA Saclay
- $\beta = 1$ cavities developed and tested by CEA Saclay and (short CM) by CERN.
- Strong Synergy and collaboration established with the European Spallation Source

EUROPEAN SPALLATION SOURCE

For more details: http://ipnweb.in2p3.fr/srf2013/papers/friob04.pdf

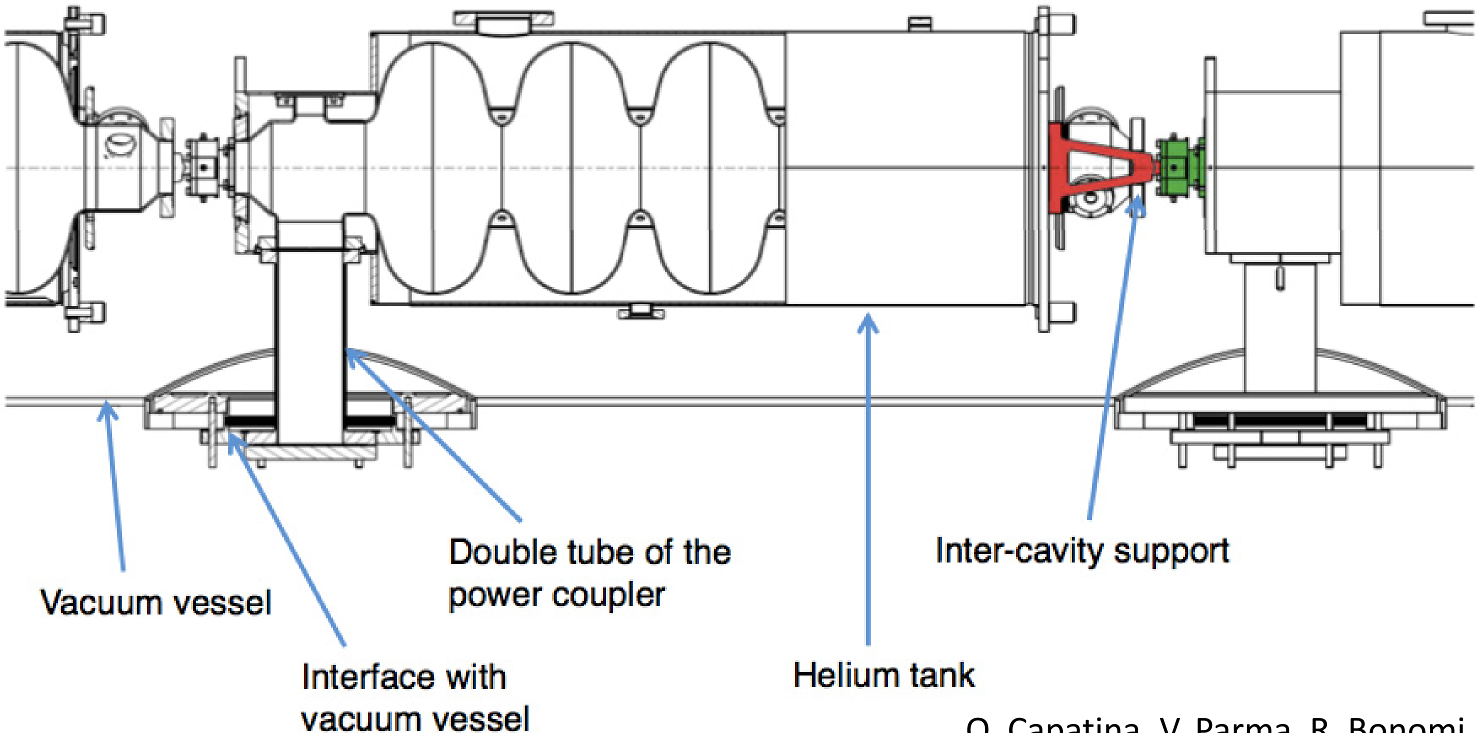
SPL Short Cryomodule



O. Capatina, V. Parma, R. Bonomi, S. Rousselot

SPL Short Cryomodule

New supporting system (by double-walled tube) could minimize heat load to 2 K bath



O. Capatina, V. Parma, R. Bonomi, S. Rousselot

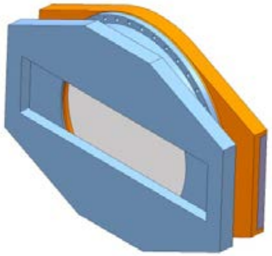
Recent SPL progress in pictures

RF Power Couplers

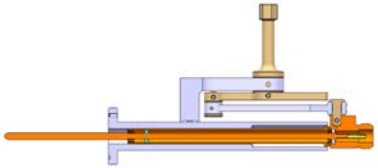
E. Montesinos

Machine	Design	Construction	Operation
SPS 200	✓	✓	2001
LHC 400	✓	✓	2006
SPL cylindrical	✓	✓	**1 MW TW** **550 kW SW**
SPL disk	✓	✓	**1 MW TW** **1 MW SW**
ESRF	✓	✓	**300 kW CW**
ANL-APS	✓	✓	**100 kW CW**
Linac 4	✓	✓	**750 kW SW**
HIE-Isolde	To be improved		
LIU- SPS 200	To come		
SPS 800	To come		
SOLEIL	To come		
Crab Cav x 3	To come		

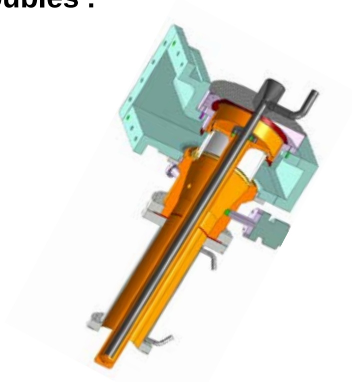
- **Some good results this year :**
  - **ESRF**
  - **APS (tests still on-going)**
  - **SPL coaxial disk**
- **Some still to be improved :**
  - **SPL cylindrical**
  - **HIE-Isolde**
- **Some still operating without troubles :**
  - **SPS 200**
  - **LHC 400**
- **Some additional to come**



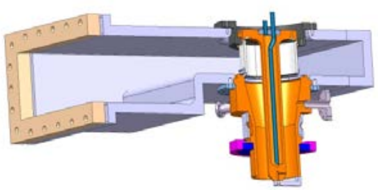
Linac 4



HIE-Isolde



SPL cylindrical



ESRF & APS

SPL disk

Cryolab Activities

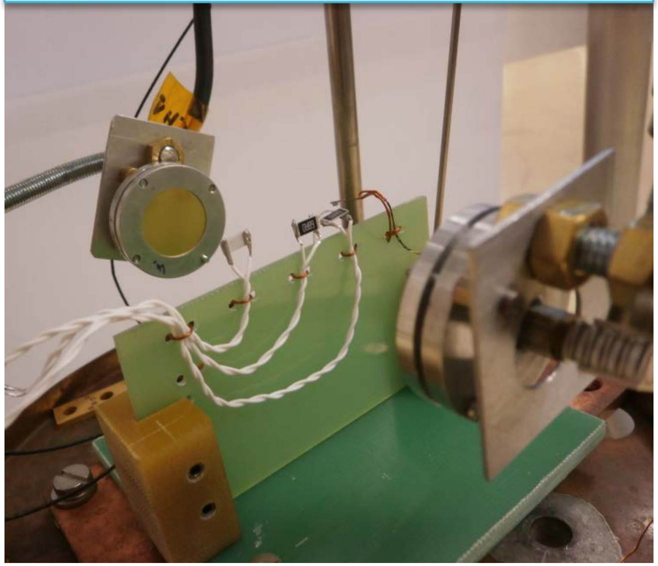
New Coating Technologies: HIPIMS on 1.3 GHz cavities

Collaboration with S. Calatroni and G. Terenziani

Fundamental SRF studies using the Quadrupole Resonator

PhD Thesis S. Aull (Univ. Siegen)
Supervisor: S. Doebert

Cavity Diagnostic Developments with OSTs



Master Thesis B. Peters (Univ. Karlsruhe)
Co-Supervisor T. Koettig

UPGRADE OF CERN FACILITIES / INFRASTRUCTURES

New Electron-Beam Welding Machine

O. Capatina

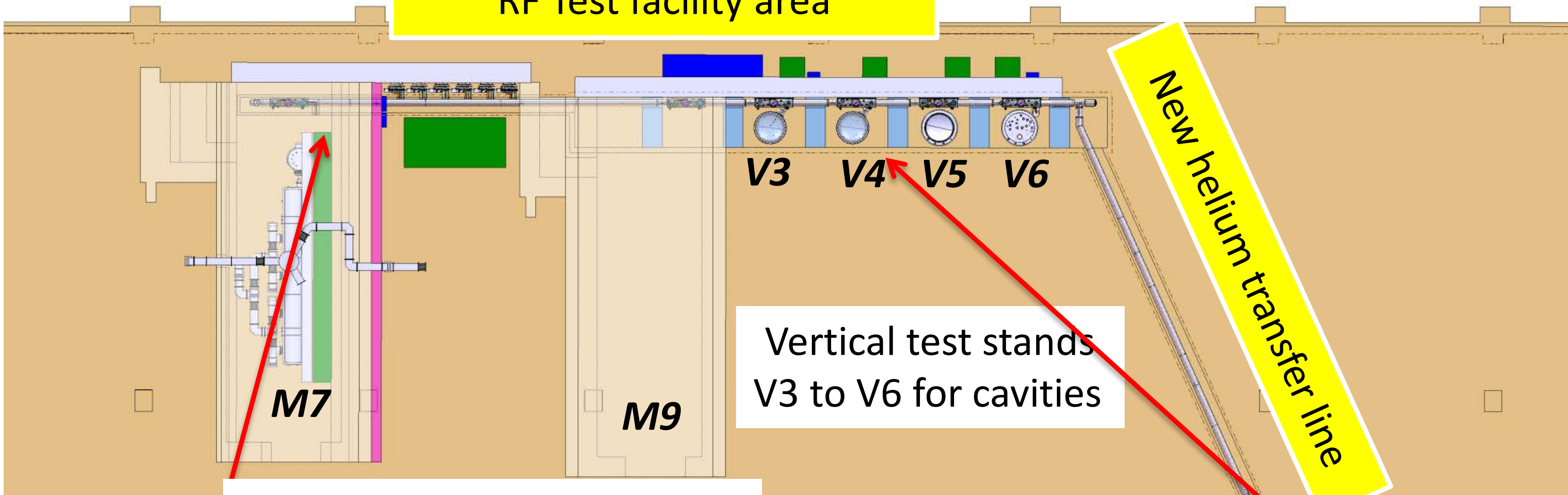
Electro-polishing

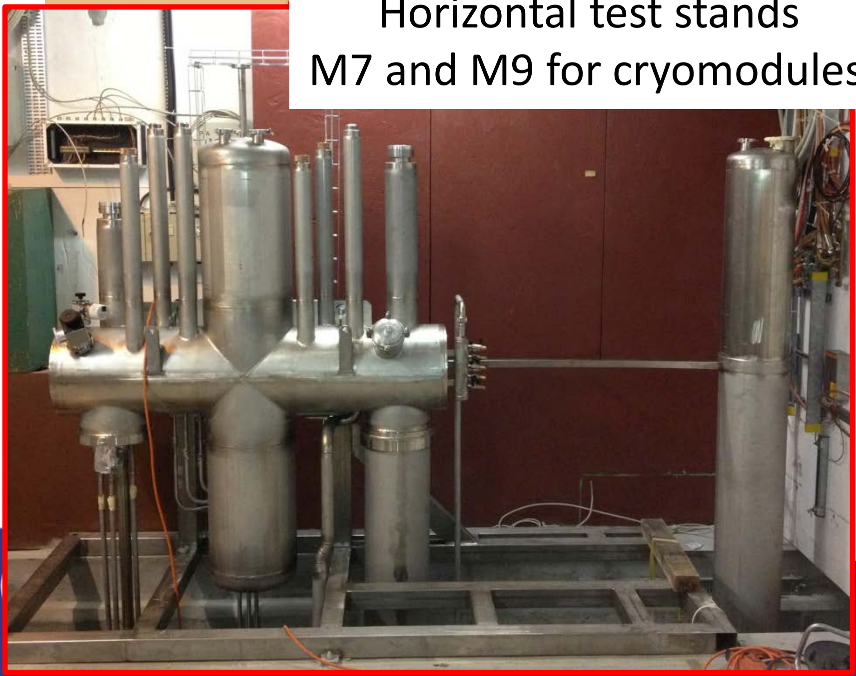
High pressure rinsing

O. Capatina, L. Marques, K. Schirm

2 K Cryo-upgrade in SM18

T. Koettig, O. Pirotte, K. Schirm





Cavity and module test area SM18

Service module in horizontal bunker

Helium tank

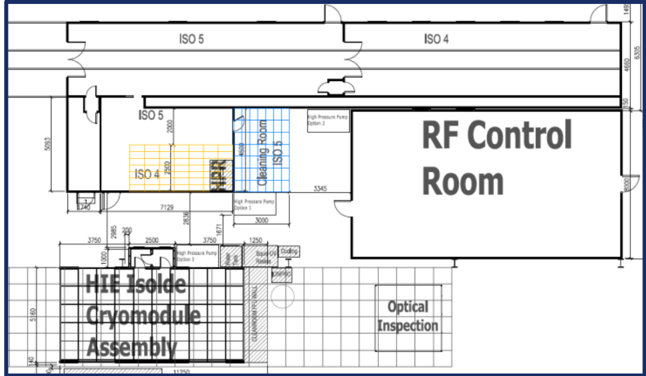
Cavity RF Test Area

CERN CRISP

SM18: Clean room & Preparation Zone Upgrade

Existing clean room upgrade and extension

New clean room facility – HIE-ISOLDE

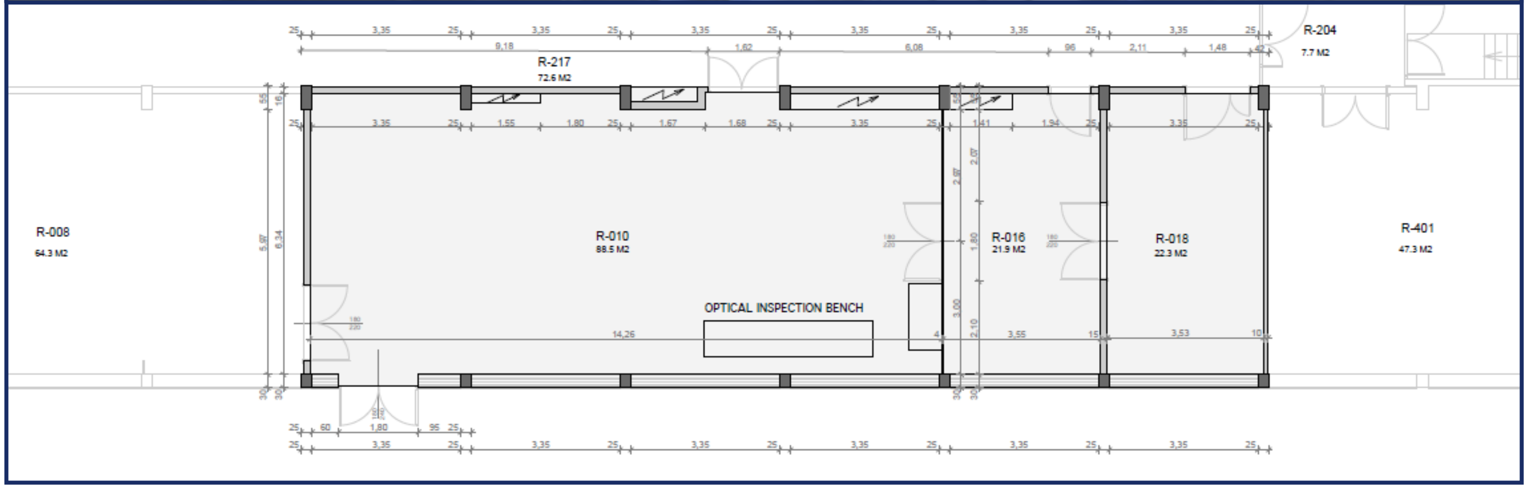


Clean room layout

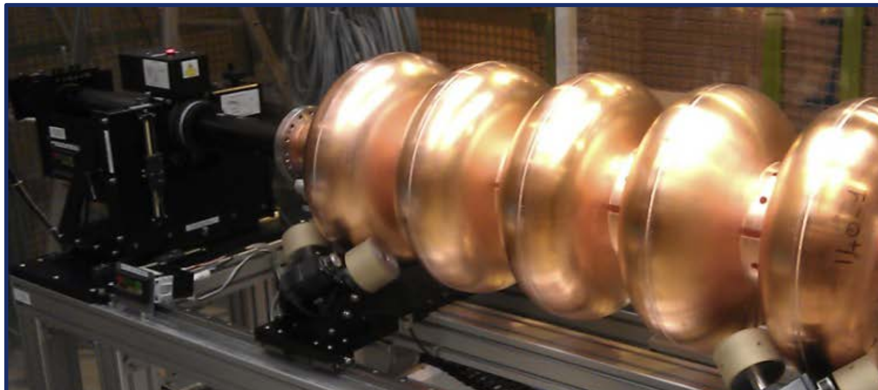
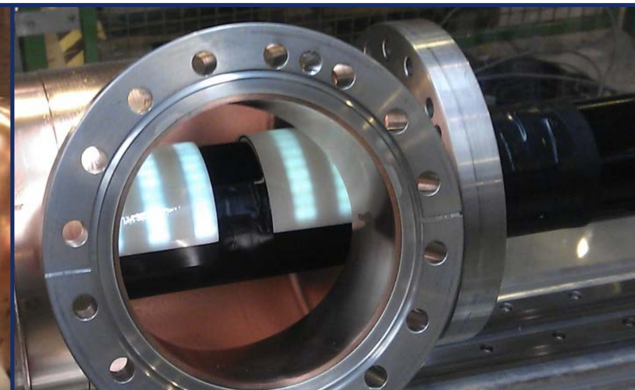
High-pressure rinsing

Ultra-pure water station

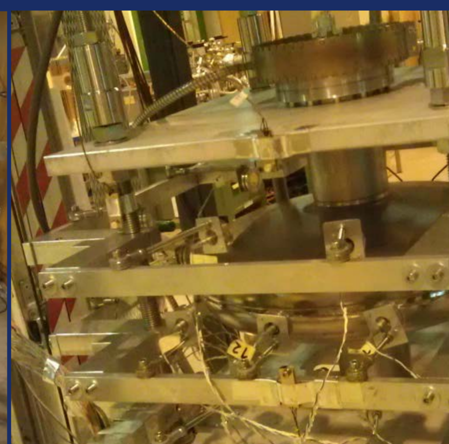
New cavity reception area



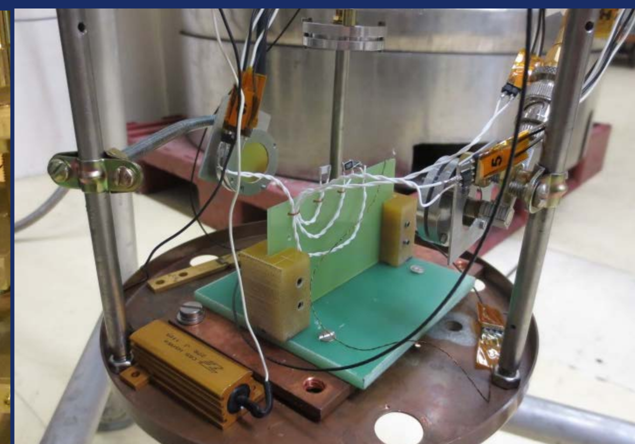
Cavity diagnostics

Optical Inspection Bench

Quench localization via second sound on SPL cavities

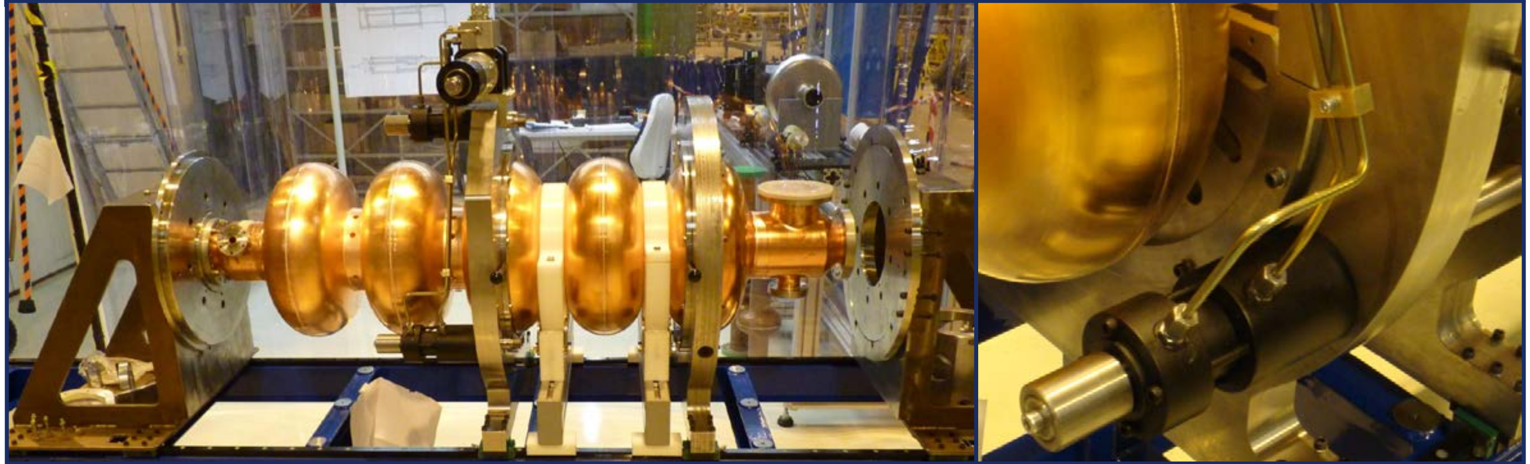


Fundamental research

J. Chambrillon, K. Liao, B. Peters, K. Schirm

Cavity ancillaries

Bead-pull measurement setup for field mapping



Cell-by-cell tuning system

F. Pillon, S. Mikulas, K. Schirm

Summary

- The concept of the ERL-TF is designed to allow for a staged construction with verifiable and useful stages for an ultimate beam energy in the order of 1 GeV.
- A key part of the design study is the development of superconducting RF cavities and CM's.
- This study has started in collaboration with JLAB and JG|U Mainz.
- There is strong synergy with the JG|U Mainz project "MESA" – the cavities/cryomodules would be identical.
- CERN is in the process of re-establishing know-how and upgrading its facilities for SRF R&D.
- Ongoing work in SRF at CERN also includes SPL, HIE-ISOLDE, crab cavities HL-LHC; planned future work will include the study of a large lepton collider (FCC-ee).

Thank you for your attention!

THANK YOU FOR YOUR ATTENTION

Many thanks to K. Aulenbacher, O. Brüning, O. Brunner, E. Ciapala, R. Calaga, S. Calatroni, A. Hutton, M. Klein, T. Junginger, K. Schirm, D. Schulte, E. Shaposhnikova, R. Torres-Sanchez, J. Tückmantel †, A. Valloni, W. Venturini, W. Weingarten and many more …

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