SRF Activities at CERN

Ed. Ciapala, Erk Jensen

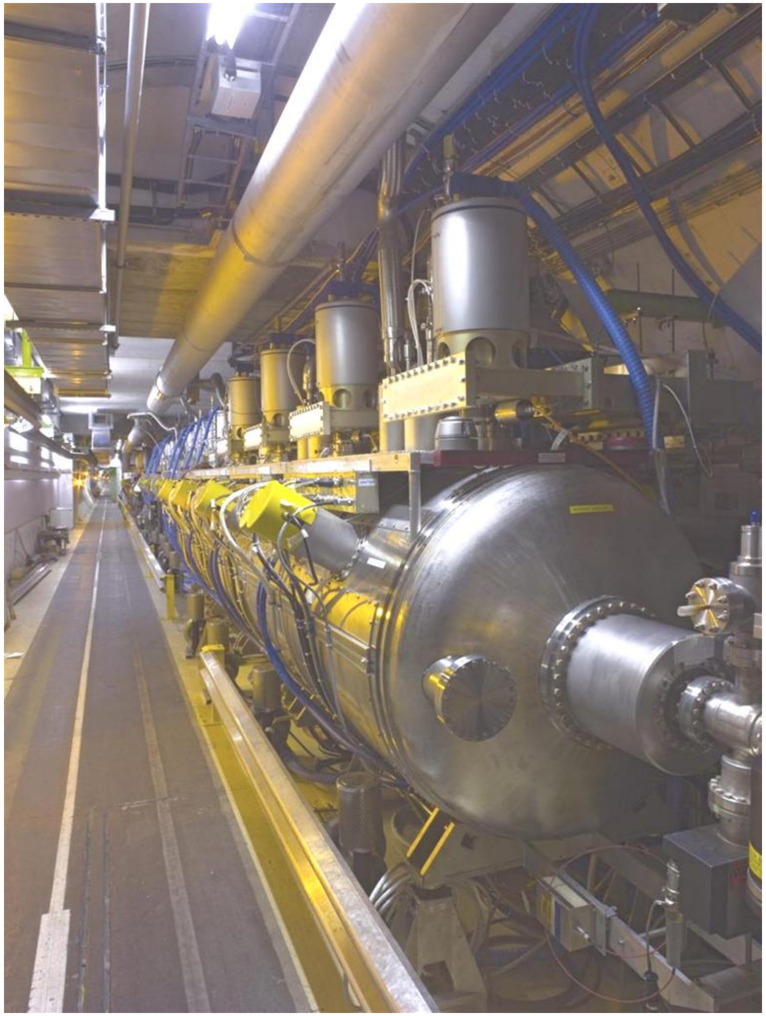
Jefferson Lab Seminar

August 2012

SRF Systems at CERN

- SRF systems at CERN
- Approved projects now under way at CERN
- SRF infrastructure and facilities upgrade
- SRF Diagnostics and R&D
- New SRF projects under study
- Summary / Conclusions

The LHC RF system at IP4



LHC Cryomodules in RUX45

Basic parameters:

- 8 SC single cell cavities per beam, total 16 cavities in 4 cryomodules at IR4
- Need to handle very high beam currents – LHC nominal beam is 0.56 A d.c.
  - LHC could go up to twice nominal..
- Low R/Q: 44 Ω (Low Z at high Q_{ext})
- **Technology: Nb sputtered on Copper – as LEP**
- 2 MV nominal per cavity, 5.5 MV/m nominal gradient
- Conditioned to 50 % higher prior to their installation in LHC – Could just reach max. 11 MV/m in test
- Variable power coupler, 11,000 < Q_{ext} < 200,000
  => High bandwidth at injection for damping of injection transients / higher voltage during physics
- High power handling of coupler (> 300kW)
- One klystron per cavity, rating 330 kW

Performance has been good, but currently one cavity runs at reduced gradient. Repair planned during LS1

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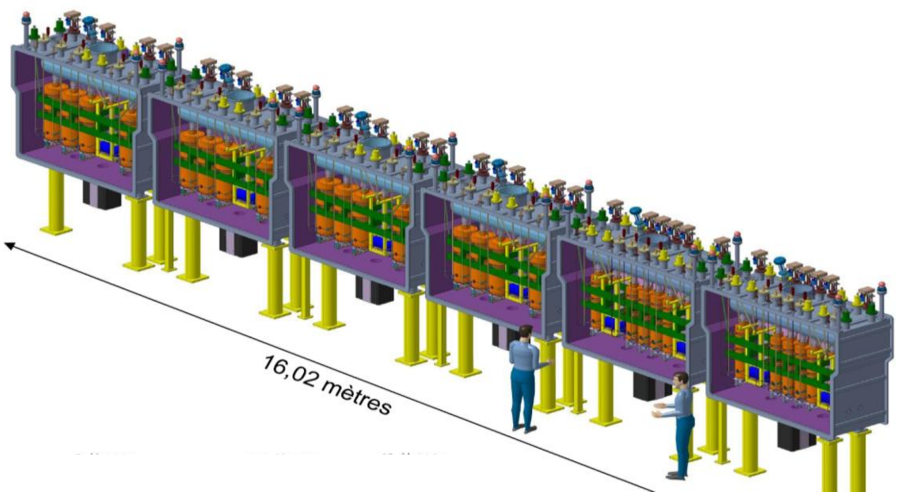
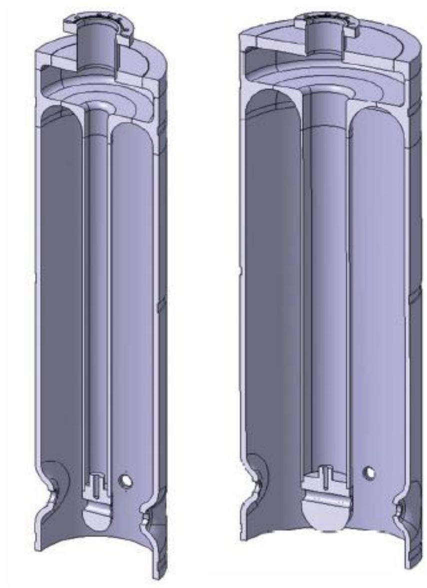
SC Post Acceleration Linac

- Variable energy between 1.2 and 10 MeV/u
- 32 SC QWR (20 @ β=10.3% and 12@ β=6.3%)



- A string of 6 cryo-modules:
  - 4 cryo-modules with 5 high-beta cavities + ancillaries *(first phase – Energy upgrade)*
  - 2 cryo-modules with 6 low-beta cavities + ancillaries *(second phase – Intensity upgrade)*

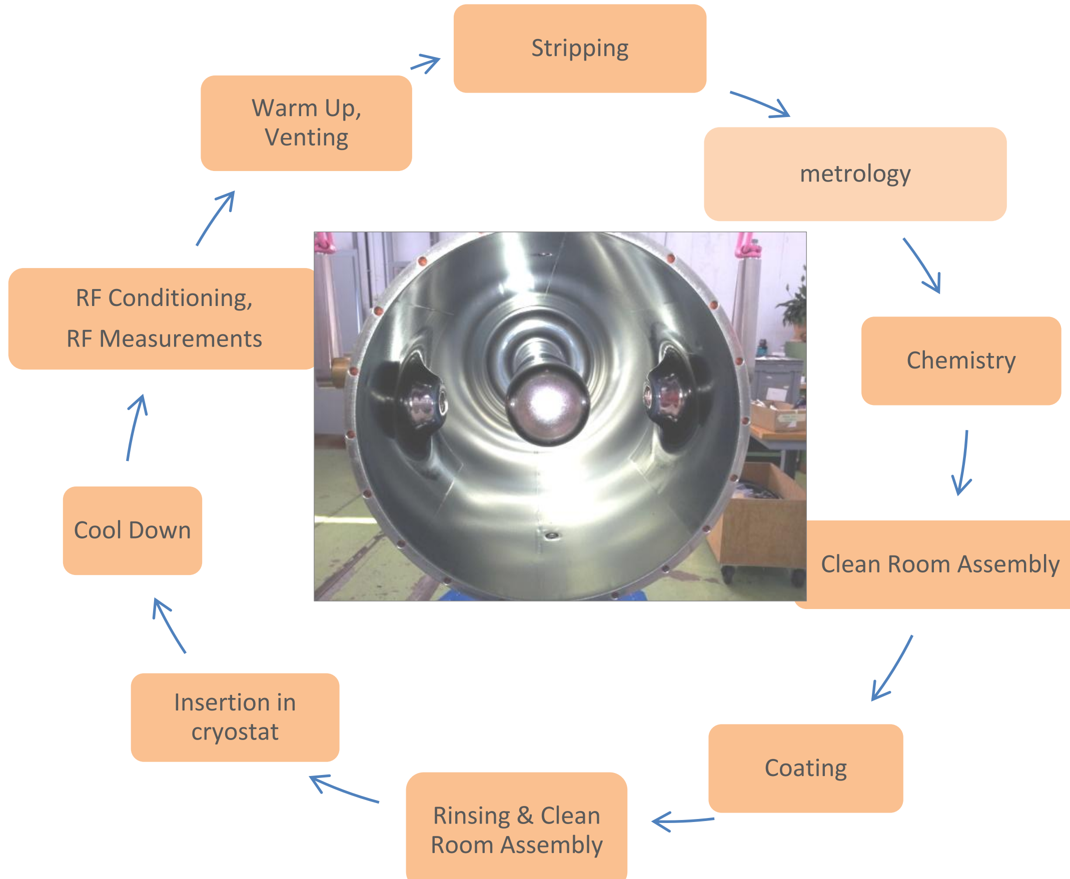


Low QWR (left) and high QWR (right).

- Technology is Nb sputtered on Cu
- First cavities being tested – learning process, collaboration with INFN Legnaro

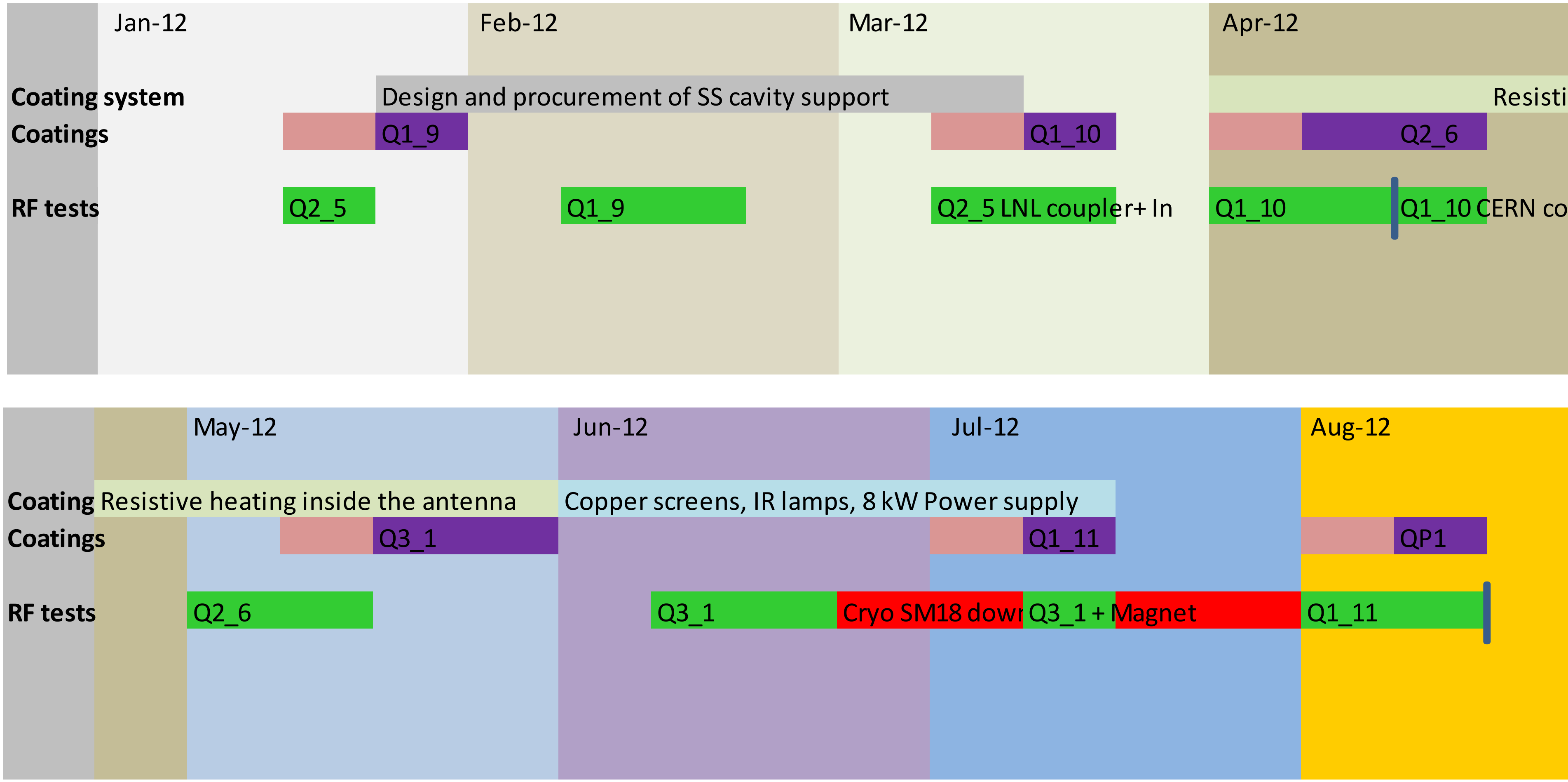
QWR workflow, tests in 2012

W. Venturini



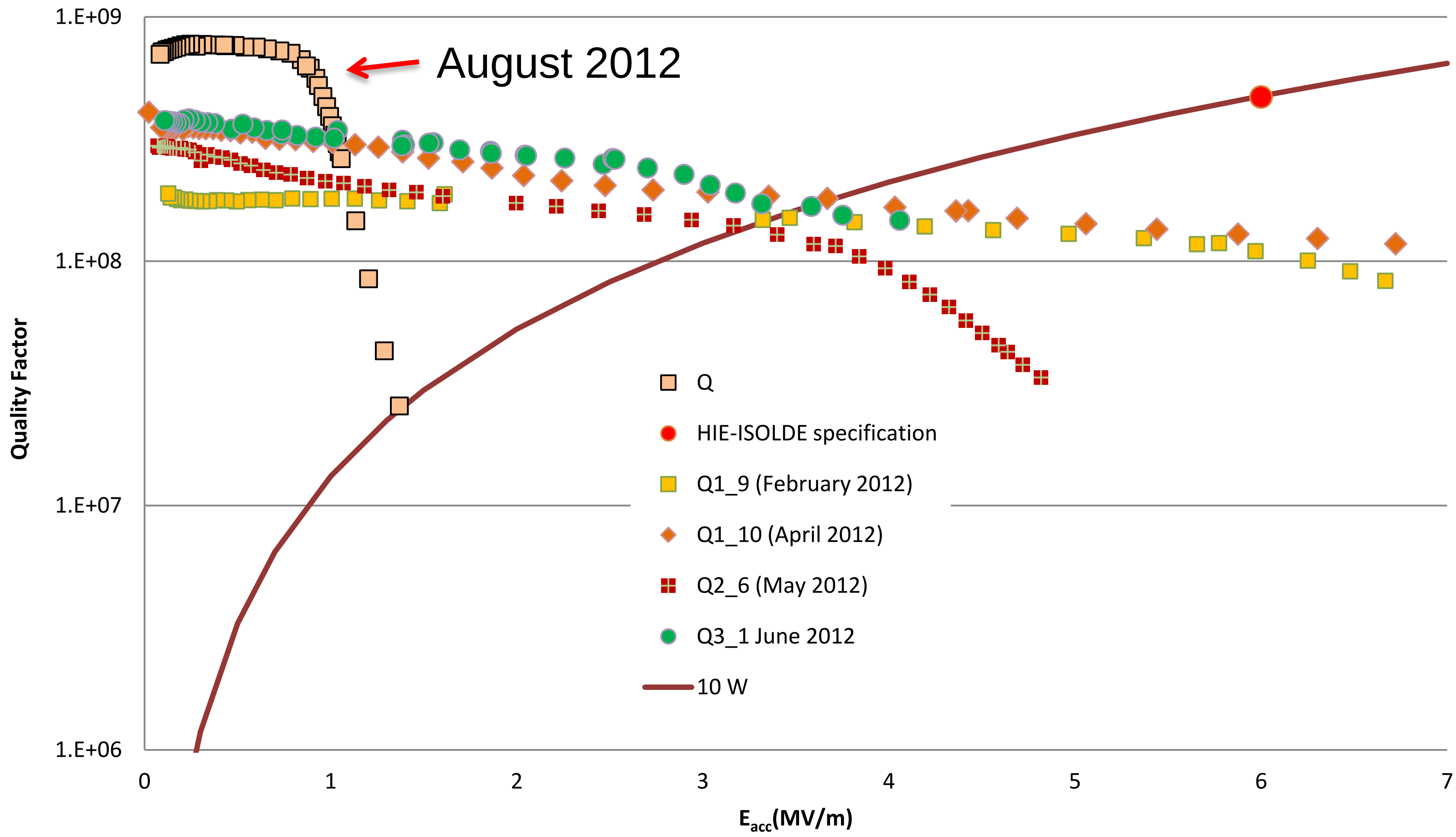
W. Venturini

Prototype cavities Jan-Jul 2012



W. Venturini

Cavity performance



W. Venturini

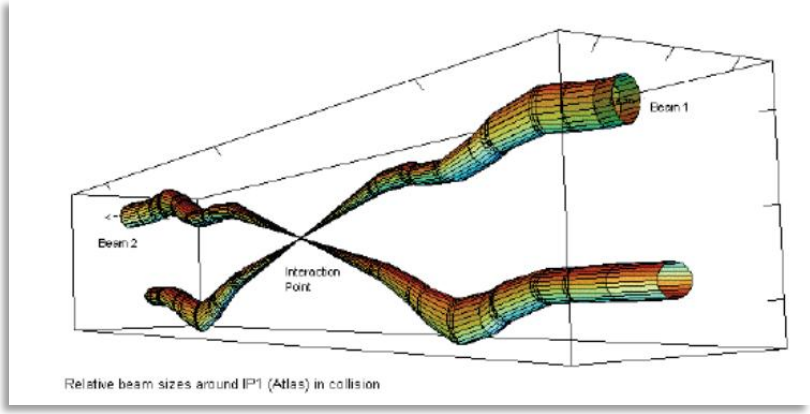
Planning for Cavity Production

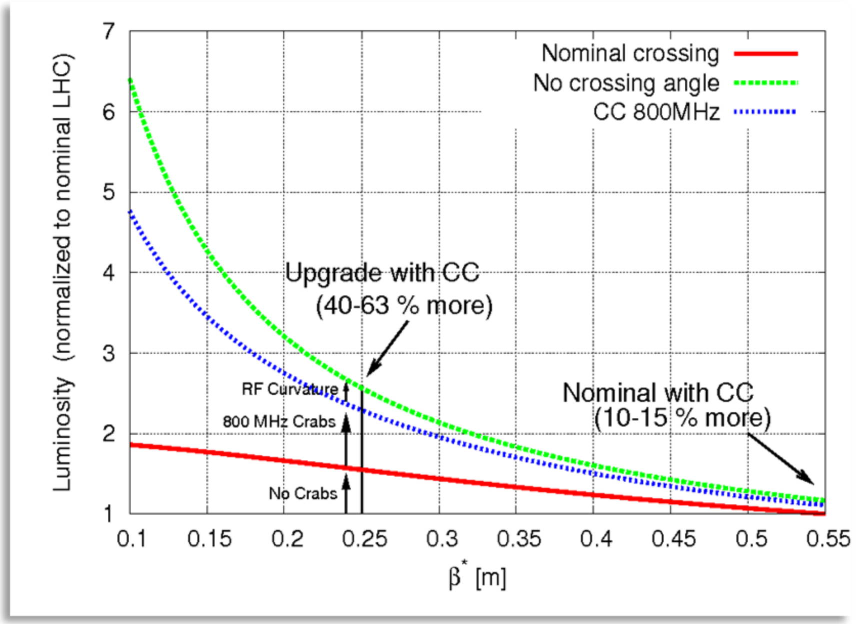
	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
Q1																	
Q2																	
Q3		*															
QP1	*	*	*	*													
tests in SM18	1	2	1	1					2	2	2	2	2	2	2	2	
tests in IPN						1	2	1									
Copper billets	2	2	4	2	IT		2	2	2	2	2						
CATE substrates				1	2 *	2											
Purchased substrates			IT			1	2	2	2	2	2	2	2				
Coating series						2	2	2	2	2	2	2	2	2	2		
RF tests series cavities							2	2	2	2	2	2	2	2	2	2	
CM										New CR	CM1 Test Ass.		CM1 A	CM1 A	CM1 A/RF	CM1 RF	CM1 RF

Production of 20 cavities in 2013

Deflecting (Crab) Cavities for the HL-LHC

- A beam of closely spaced bunches requires non-zero crossing angle at the IR to avoid parasitic collisions and to reduce beam-beam effects
- With non-zero crossing angle, luminosity gain by squeezing beams further is small (red curve below).

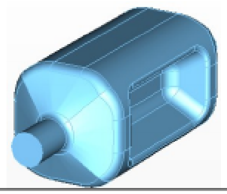
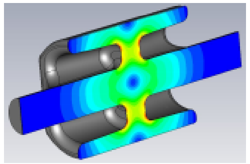
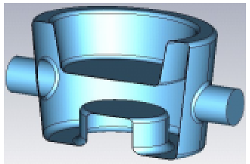




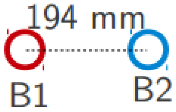
- Crab cavities can compensate for this geometric effect by tilting the bunch giving a luminosity increase of about 50 % at β* of 25 cm.
- In addition, crab cavities provide an ideal knob for **luminosity levelling**;
- This allows optimizing for **integrated** rather than peak **luminosity**!

400 MHz SC compact deflecting cavities

- Novel designs to fit tight space requirements in IR1 and IR5

		Double Ridge (ODU-SLAC)	4-Rod (UK)	¼ Wave (BNL)
Geometrical	Cavity Radius [mm]	**147.5**	**143/118**	**142.5/122**
	Cavity length [mm]	597	500	330-405
	Beam Pipe [mm]	84	84	84
RF	Peak E-Field [MV/m]	33	32	43
	Peak B-Field [mT]	56	60.5	61
	R_T/Q [Ω]	287	915	345
	Nearest Mode [MHz]	584	371-378	657



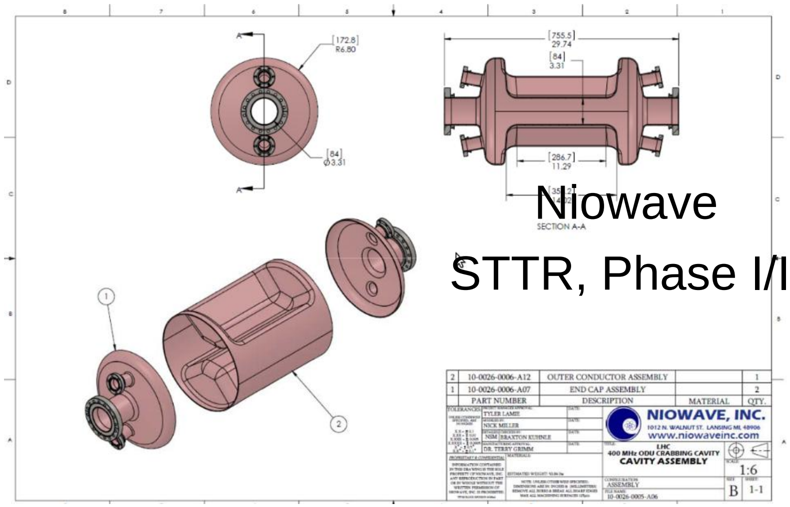
< 50 MV/m

< 80 mT

Prototypes of these cavities to be tested this year

ODU: Double Ridge CC

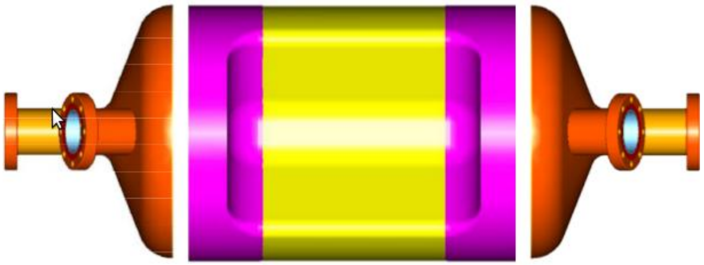
- Courtesy: J. Delayen (JLAB ODU), Niowave Inc.

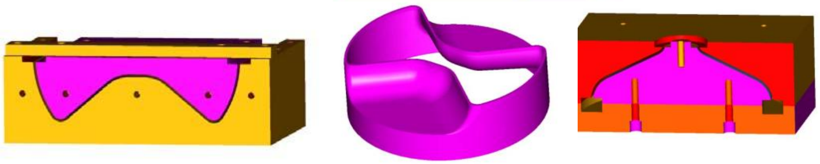


Niowave

STTR, Phase I/II

Jan 2012



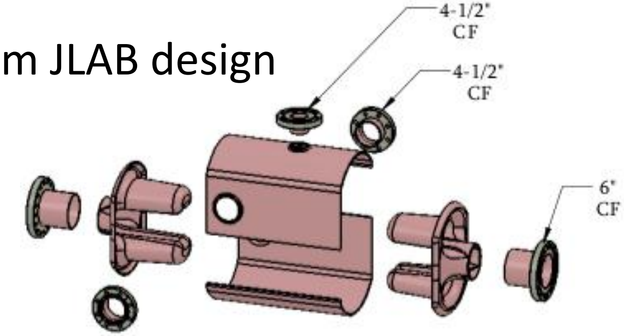


May 2012

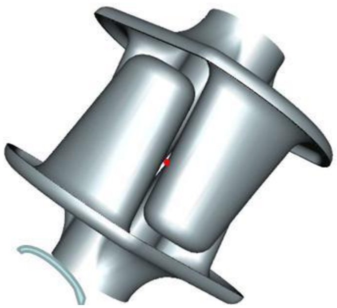
CC-UK 4Rod Prototype CC

- Courtesy G. Burt (Lancaster)

From JLAB design



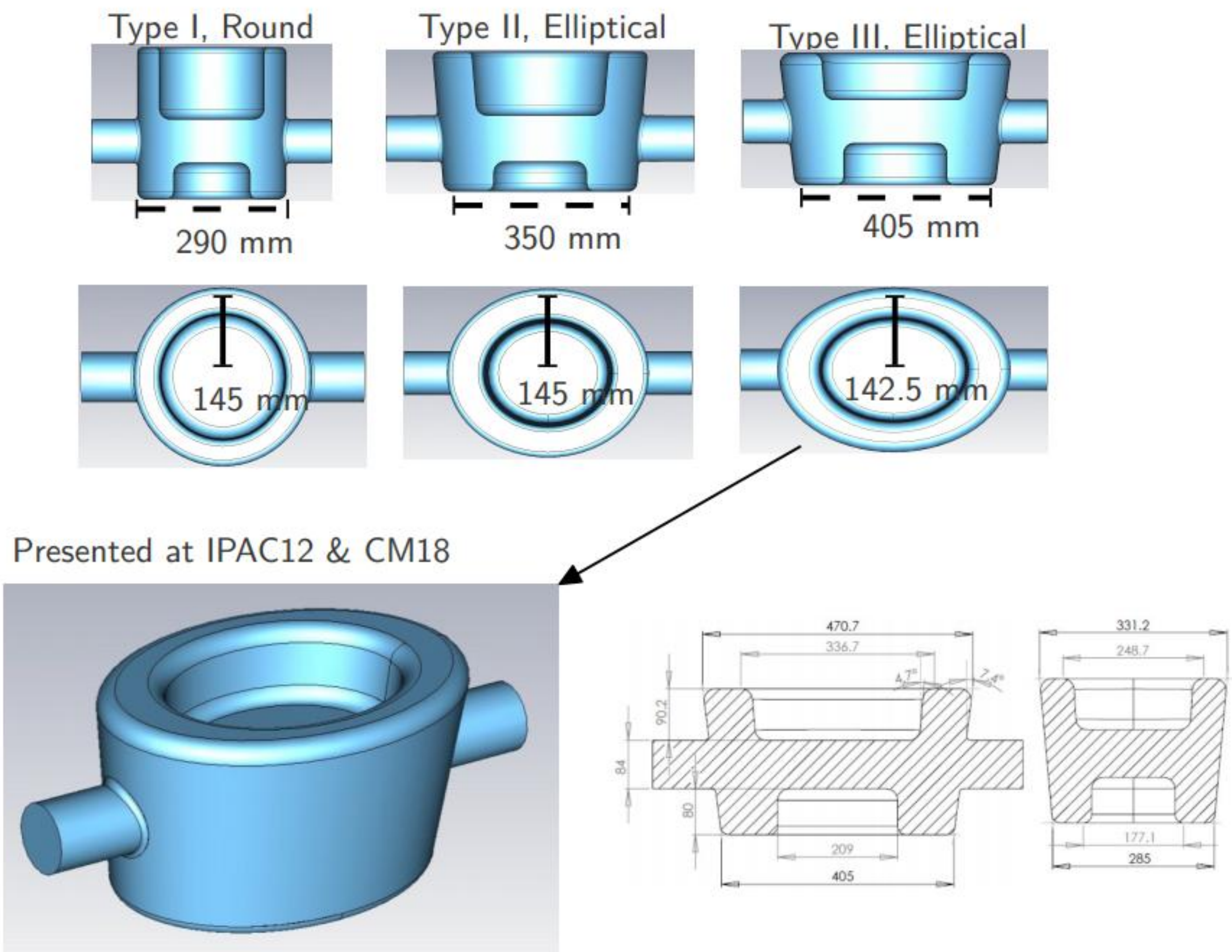
Nb rods from solid Ingot via EDM (significant material saving)



Finished cavity at Niowave

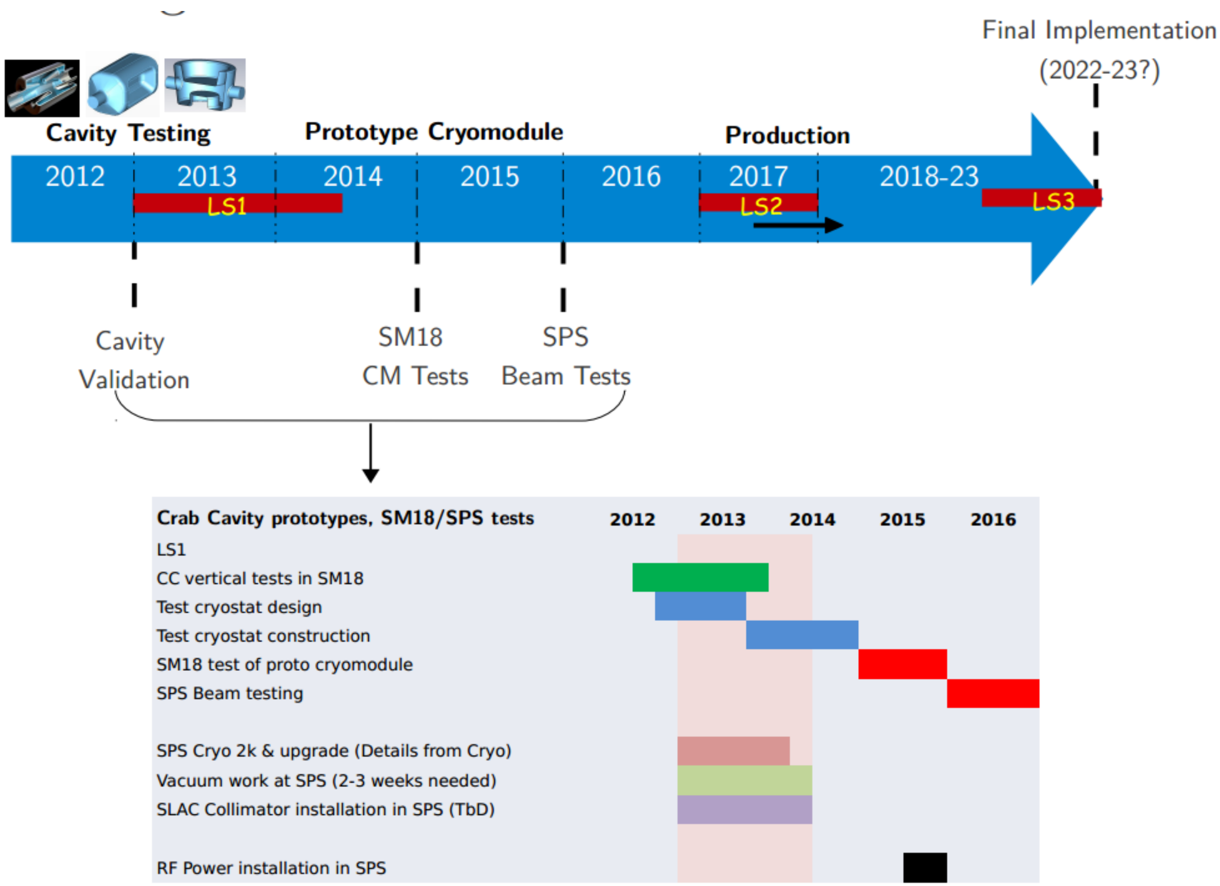
¼ Wave Topologies

- Courtesy I. Ben-Zvi et. al (BNL)



Testing of Compact Cavities and Cryostats

- Ultimately, installation of 8 crab cavity modules around IR1 & IR5 (2022-23?)
- Complete validation and test of compact CCs in a complete cryomodule with beam in SPS in 2016
- SPS working group was recently set up for a complete study (A. Macpherson)
- Test in LHC IR4 would follow in 2017… (just before Long Shutdown LS2)



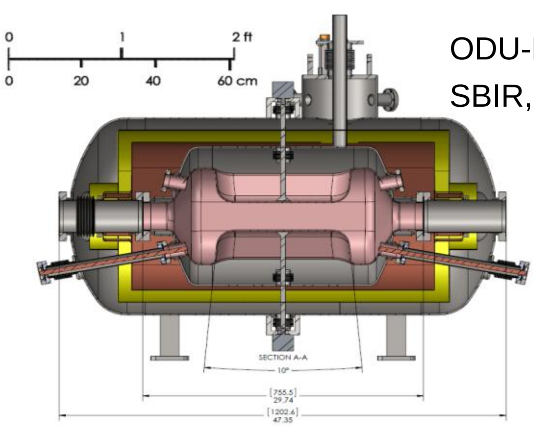
CC - Cryomodule Development

Seen as a high priority collaboration with US & European partners

- ODU-Niowave: Phase I SBIR for a test cryomodule approved
- LARP Collaboration:

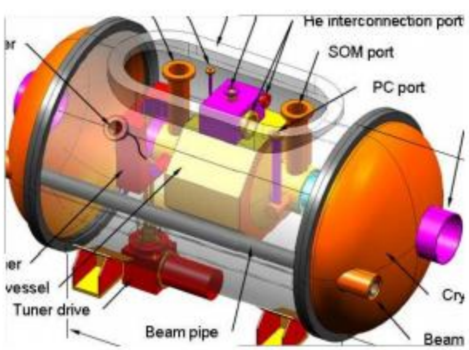
    FNAL has made a proposal on CM development to DOE, positive recommendation from the recent DoE LARP review:

    - “Develop a realistic plan tor testing crab cavities in the SPS”
    - “Start immediately on the specifications and design of a cryomodule”.
- Actions (R. Calaga’s presentation at the review)
    - Develop initial concepts in 6-8 months (FNAL, SBIR, Triumph, CEA-CNRS)
    - Immediate task is to identify specific SPS constraints (environmental & RF)
    - Crab Engineering Meeting will be held 13-14 Dec. 2012 at FNAL



ODU-Niowave
SBIR, Phase I

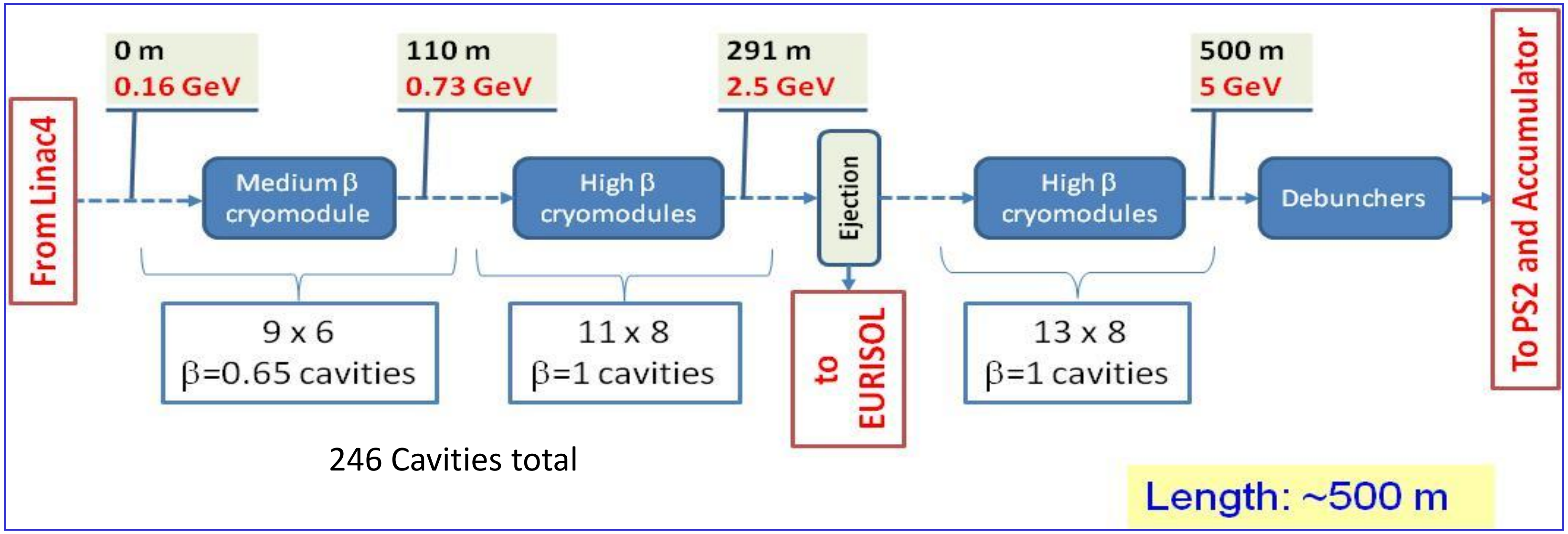
Initial work for elliptical
Cavities
(Y. Yakolev et al FNAL 2010)



Super Conducting Proton Linac (SPL)

- **LP-SPL:** SC-linac (160 MeV to 4 GeV) with ejection at intermediate energy
  - High gradient: 25 MV/m at 704 MHz in β = 1 section.
  - Part of the upgrade of the CERN injectors, with PS2

- **HP-SPL:** High Intensity Higher Energy SC-linac (160 MeV ® 5 GeV)
  - Longer duty cycle
  - New klystron modulators, upgraded infrastructure (cooling & electricity, etc.)
  - 5 additional β = 1 cryomodules to reach 5 GeV (π production for ν Factory)



SPL - Present Project Scope

In 2010, original upgrade plan for LHC injectors abandoned

However, program launched for **study of SC RF for high intensity proton driver** in the context of possible future neutrino facilities at CERN.

- Included in CERN MTP, with resources.
- Comprises:
  - Continuation of design work on HP-SPL, excluding integration & site specifics.
  - Includes prototyping of critical components: **high gradient cavities, RF ancillaries and the construction of a 4-cavity test cryomodule**
  - Upgrade of clean room and assembly facilities at CERN
  - Preparation of a power test stand
- Plan to power test the cryomodule in 2014 (CERN SM18)
- Updated CERN yellow report on SPL to be completed by mid 2012

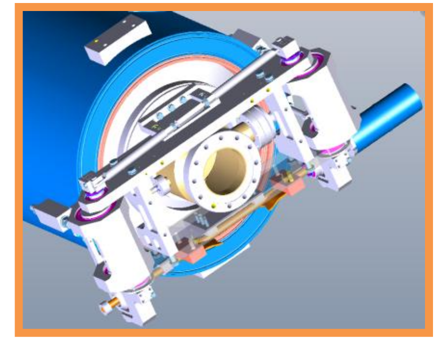
➢ SPL documentation in EDMS [https://edms.cern.ch/nav/SLHC-000008]

➢ SPL (SLHiPP) meetings in Indico [http://indico.cern.ch/categoryDisplay.py?categId=1893]

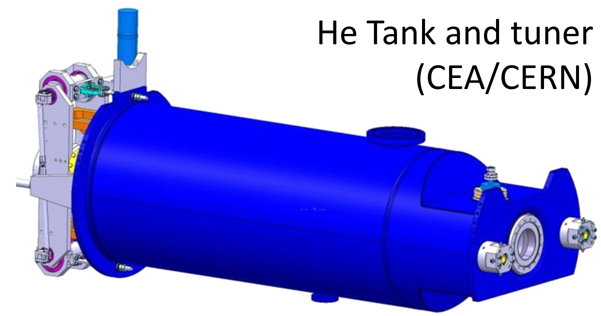
SPL 704 MHz Prototyping

- **Collaboration with CEA Saclay** - Cavity design by Saclay
- Low β protos built & tested at CEA
- Tuner design & construction by Saclay
- He tank & cryomodule designs ongoing (CEA/CERN)
- Four $\beta = 1$ 5-cell cavities being made in industry
- Cryomodule working group doing CM design
- 704 MHz klystron ordered, power systems being prepared for SM18 power testing

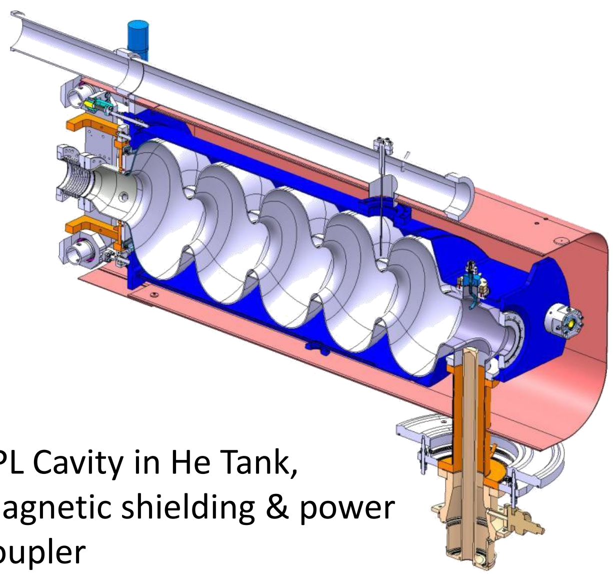
- **Close collaboration with European Spallation Source (ESS) in Lund**



CEA Tuner



He Tank and tuner (CEA/CERN)



SPL Cavity in He Tank, magnetic shielding & power coupler

BNL 704 MHz cavity (20 MV/m with high Qo demonstrated)

SPL Cavity Latest Status

- First industrially produced cavity just received from Research Instruments
- Will be treated, rinsed and tested at CERN
- First of 5 5-cell cavities expected end of 2012
- Bead pull, tuning system and diagnostics being prepared.
- Hopefully a test can be done before the SM18 Cryo system shut down at the end of the year…

- Comparison of results with other Labs for cavities in this frequency range is of interest

- Synergy with LheC and eRHIC….

SRF Systems at CERN

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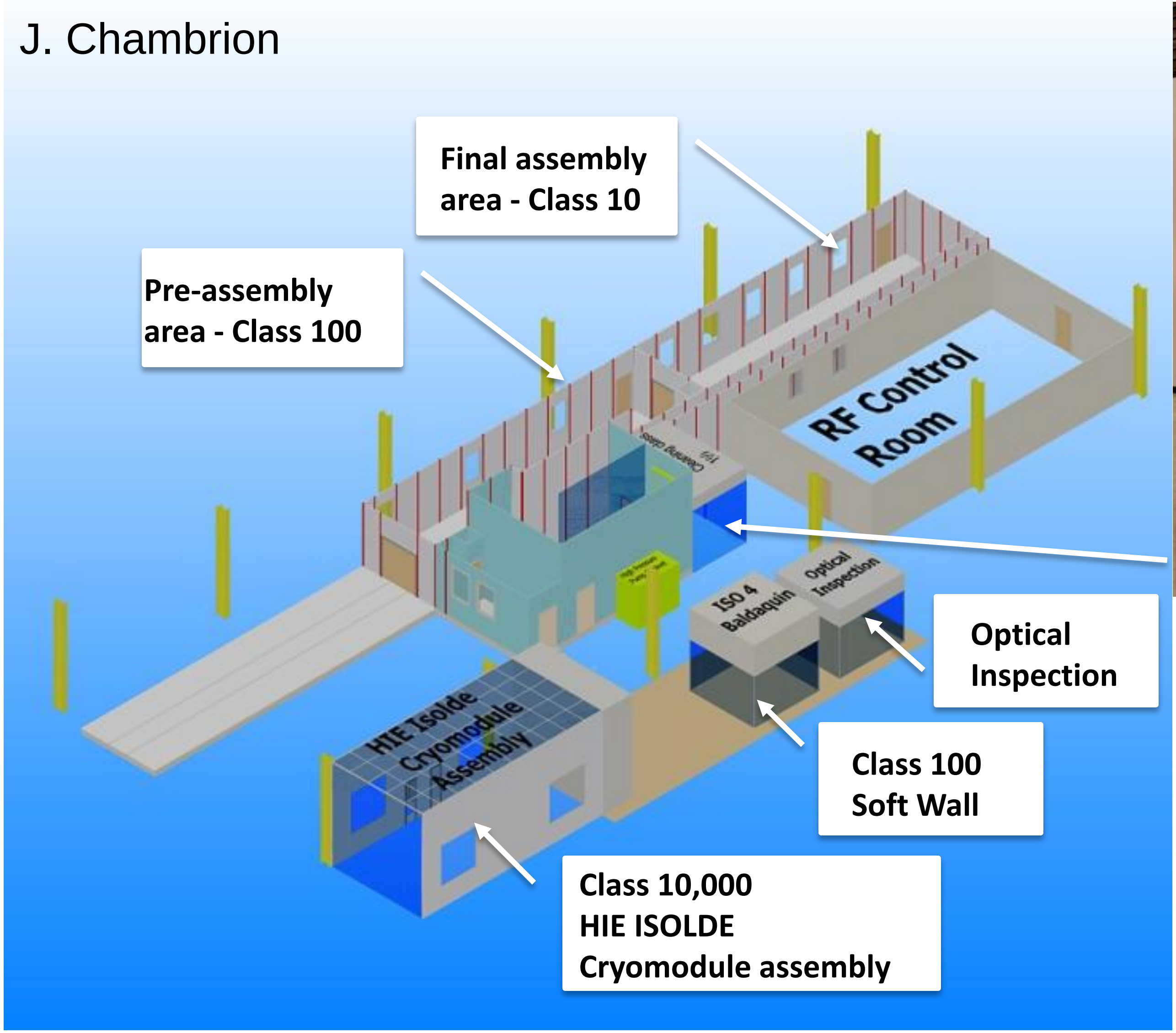
SC cavity assembly and testing at CERN

- CERN SCRF Installations in SM18 date from 1990s and LEP, with minor refurbishing for the LHC cavities

- For new projects, a major upgrade of facilities is in progress to handle modern <u>high gradient</u>, <u>high Q cavities</u>:
  - New HP rinsing equipment & UP water for preparation of cavities and components
  - New clean rooms
  - Improved cryo, upgrade of low efficiency line, and 2K operation
  - Modern diagnostics equipment
- Not intended for Large Scale production…
  - *Advice from other Labs, e.g. DESY, SACLAY, BNL, Fermilab & JLAB gratefully acknowledged*

SRF Clean Room Upgrade in SM18



Need to complete by early 2013…

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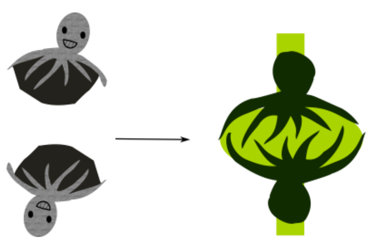
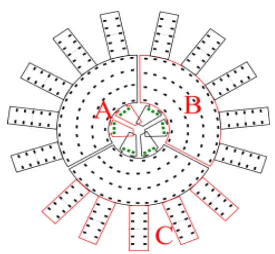
Diagnostics for SRF Cavities

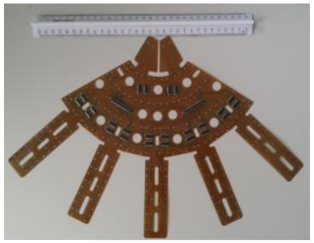
K. Liao

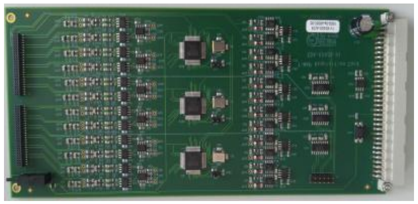
- Temperature Mapping
  - “Octopus” flexible kapton PCB fits around the cavity in 2 halves
  - Using Allen Bradley resistors with exact calibration in microprocessor system
  - 560 resistors on a single cell SPL cavity
  - 3000 on 5-cell cavities

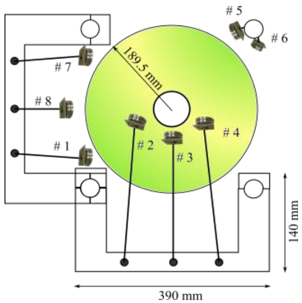
- Second Sound Diagnostics
  - Using OSTs (Oscillating Superleak Transducers)
  - Tests on sensor design in cryolab
  - Used in SPL single cavity tests – 28 OSTs
  - Trying to get results that are more precise & consistent
  - 64 OSTs on 5-cell cavity

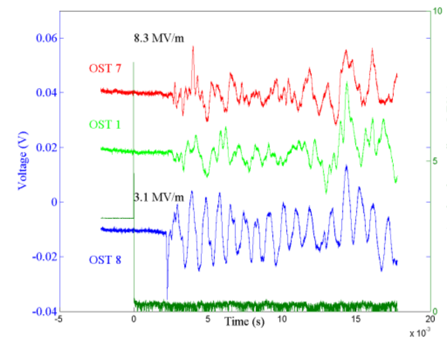












Studies on SRF materials and surfaces

(W. Weingarten) T. Junginger, S. Aull

MOTIVATION

- Power consumption in a superconducting cavity is proportional to its surface resistance R_S
- R_S shows a complex behavior on external parameters, such as temperature, frequency, magnetic and electric field

$$P_c \propto R_S(f, T, B, E)$$

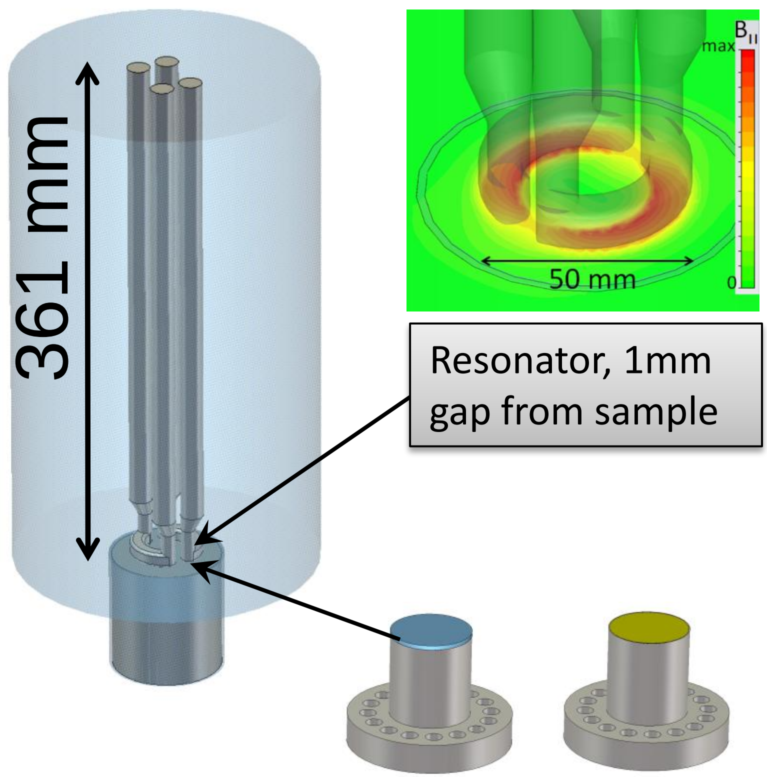
Some Open Questions:

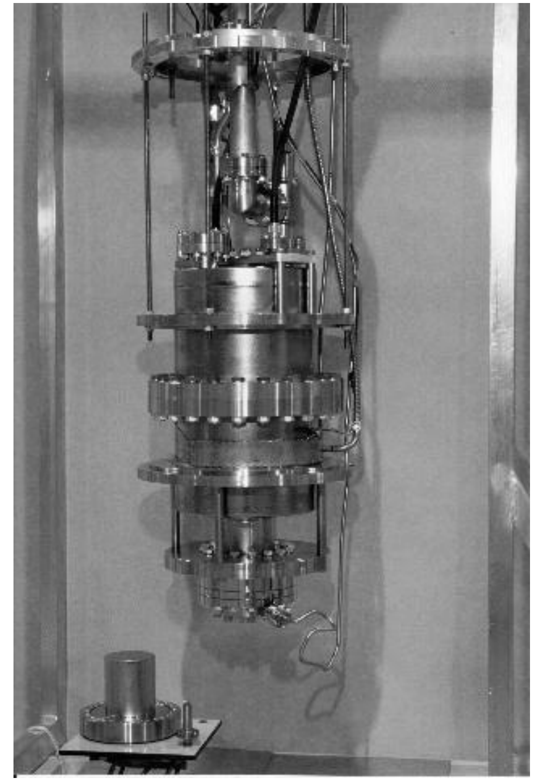
- Origin of the residual resistance
- Origin of the Q-Slope/Q-drop
- Stronger Q-Slope of niobium films compared to bulk niobium
- Influence of magnetic and electric field
- Influence of the surface properties

The Quadrupole Resonator

Enables RF characterization of small samples over a wide parameter range

- Resonant frequencies: 400MHz, 800MHz, 1.2 GHz
- Almost identical magnetic field configuration
- Ratio between peak magnetic and electric field proportional to frequency





- Sample diameter: 75mm
- The sample needs to be EB-welded to the sample cylinder
- Bulk niobium and copper samples are available

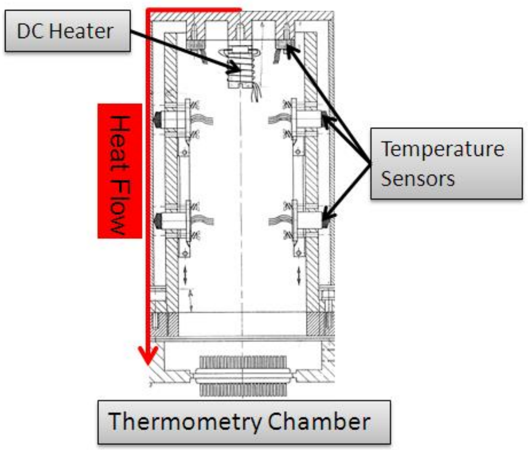
Quadrupole Resonator - results & outlook

Calorimetric and trapped field measurements

By mounting DC heaters and coils in the cylinder below the sample the QR has allowed measurements on various materials and with different qualities:

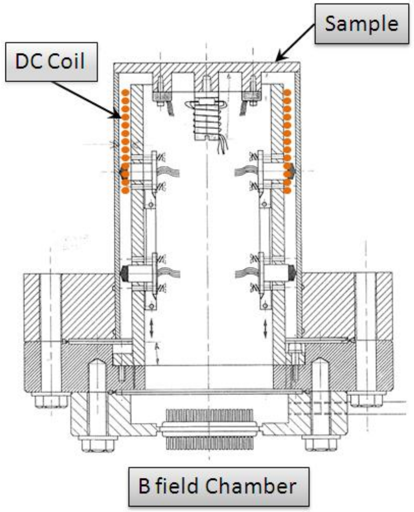
- Rs(B,T,f),
- penetration depth
- quench field (High T)
- thermal conductivity and RRR and studies on the influence of trapped magnetic flux

  (Sarah Aull, 2012 Thin Films Workshop – JLAB)



Future Work

- Production of HIPIMS Sample (CERN)
- Current bulk Nb sample: Diffusion of N to produce NbN (INFN)
- MgB_2 (AASC) – currently surface (CERN) and composition (HZB) measurements; DC critical field measurements (CERN) being planned



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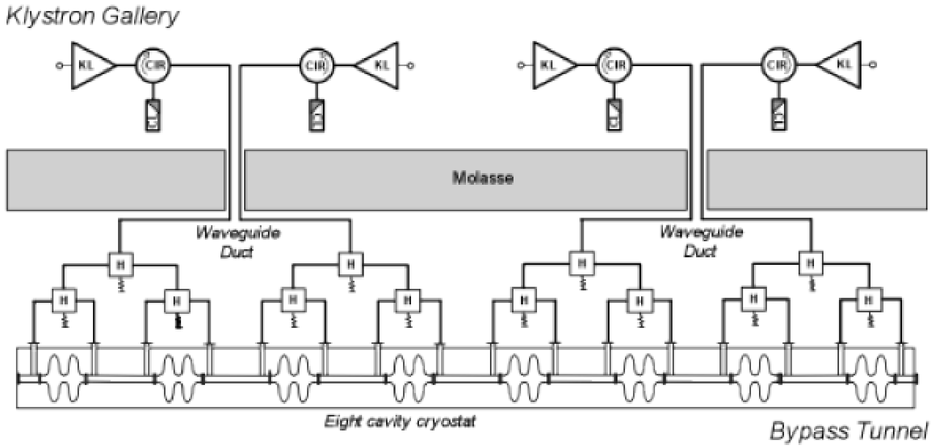
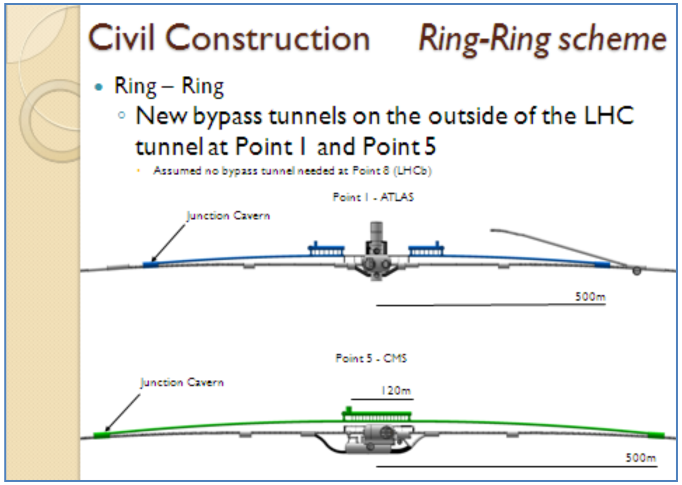
LHeC – RF for the Ring/Ring Option

60 GeV 100 mA electron ring in the LHC tunnel:

- 560 MV, 721.42 MHz cw RF
- 112 two cell cavities at 11.9 MV/min
- 14 cryomodules of ~ 10 m, 8 at CMS and 3+3 at ATLAS
- One 1 MW klystron feeding 2 cavities, 56 total
- One 6 MVA Power Converter per 4 klystrons on surface
- Total 49 MW klystron RF power, 79 MW grid power



RF distribution layout for an 8-cavity cryomodule



J. Osborne – 2012 LHeC Meeting Chavannes

Disadvantages:

- Need for By-Passes at ATLAS and CMS
- Many other integration difficulties
- Would stop LHC running during its installation

RF for LHeC – ERL/Ring Option

From LHeC design report: Linacs

- 60 GeV
- Two 10 GeV Linacs, 0.3 GeV injection and 6 linac passes
- 6.6 mA beams

RF System

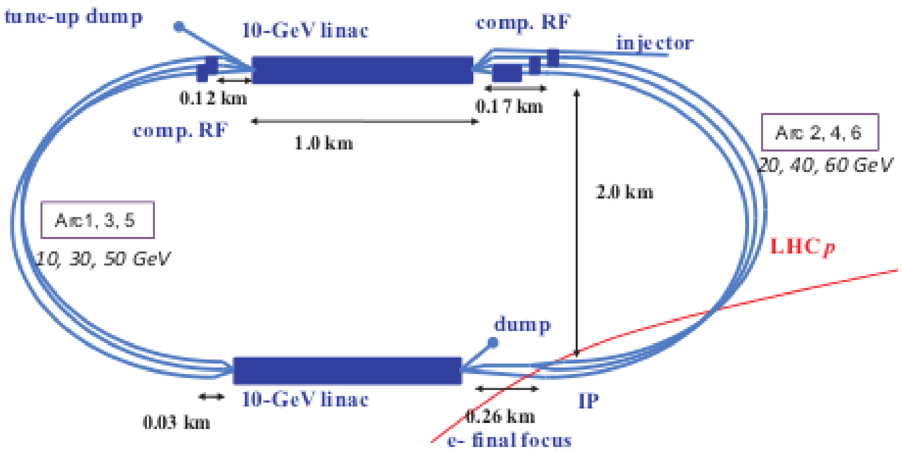
- 5-cell cavity at 20 MV/m (20.8 MV per cavity) 721.42 MHz
- Q_o = 2.5 E10
- 480 cavities per linac (960 in total)
- 60 cryomodules of ~ 15.5 m length per linac (990 m)
- One 21 kW rated (solid state) power source per ca
- RF and controls in separate tunnel
- 24 MW grid power for RF

Arc RF systems – if needed ..

- 1442/721 MHz - 58/38 cavities
- 10.5 MW RF, 23 MW Grid power

Strong synergy with SPL

- R&D directly applicable to LHeC ERL
- And with BNL work for eRHIC at 704 MHz



Demonstrator for the LHeC ERL

- Motivation
  - Study behaviour of a high energy multi-pass multiple cavity ERL for LHeC
  - Namely - Optics, RF power requirements, synchronization & delay issues …
  - HOMs & HOM couplers, Cryogenics, instrumentation, controls, LLRF …
  - Injector studies DC gun (JLAB) or SRF gun FZR Rossendorf, BNL
  - Reliability issues, operation issues
  - Could be foreseen as the injector to LHeC ERL ? (See E. Jensen's talk)
- Specs
  - High Energy ~0.5 GeV, and CW.
  - High beam current: 40 -100 mA ?
  - At least 2 passes (optics studies, synchronization & delay issues)
  - Multi cavity cryomodule
  - Two Linac layout as LHeC ERL
- Other Physics Motivation:
  - ERL demonstration, FEL, γ-ray source, eCooling ? (@PS/SPS energies),
  - Ultra short electron bunches
- Potentially one of first low-frequency SC-ERL test facilities
  - Synergy with SPL-ESS, JLAB & BNL activities.

R&D work for LHeC

- Optimum frequency
  - 721 MHz a good choice - gradients of ~20 MV/m can be achieved with good Qo

    Cryo power, HOMs, synergy with CERN R&D and other projects

- Highest Qo at medium gradients
  - BCP and/or electro-polishing - recipes
  - Surface inspection (optical microscopy or by other means)
  - Diagnostics

    All part of CERN SCRF activities and infrastructure upgrade
  - Encouraging news from JLAB – Heat treatment at 1400 degrees - Qo > 4E10 !! G. Ciovati et al.
  - Would reduce cryo consumption considerably compared to our estimated Qo of 2.5E10 in the DR !!
  - Further studies on this and other methods ..

- Studies of material other than bulk niobium e.g. Thin films ? Nb_3Sn ?
  - Sputtered coating would significantly reduce cost
  - Extensive studies at CERN (Quadrupole Resonator - T. Junginger et. al.)
  - HiPIMS CERN effort ongoing with Legnaro/Sheffield – First cavity tested at Legnaro recently !
  - Nb_3Sn could be studied at CERN (QR) in collaboration with other labs

Conclusions

- SCRF has played a major role in CERN's Flagship accelerators (LEP => LHC)
- But CERN has fallen behind in state-of-the art technology needed, and in research
- Several exciting & challenging new projects are now under way
- The SRF team at CERN is modest but the activities are growing steadily

- Collaboration to be strengthened with other Labs on SRF issues

=> cavity and component preparation, surface treatments, new materials, assembly procedures, tests and diagnostics, cryostat and cavity ancillary design.

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Thank you for your attention

Spare Slides

Demonstrator for the LHeC ERL

- Feasibility
  - SPL type CMs are being produced. Only minor frequency & coupler adjustment needed for LHeC
- Infrastructure
  - Need cryogenics, shielding, electricity, water, RF power, LLRF & Controls
- Location
  - SM18 or close to SM18 a first obvious suggestion, cryo availability, already has RF activity.
  - Cryo Capacity would be sufficient
  - Sharing of cryo ?
  - **All equipment could be eventually be reused, for example on the injector site**
- Timeline – determined by
  - Availability of cryomodules – in 2014 SPL cryomodule will be ready
  - Time to produce cryostat(s) and introduce 721 MHz cavities
  - 3 years a reasonable estimate ?
- Cost
  - TbD, but material for cryomodule construction ~ 2M CHF each (SPL F. Gerigk))