SPL R&D at CERN

Frank Gerigk for the SPL team

SLHIPP5, Lund, 18 March 2016

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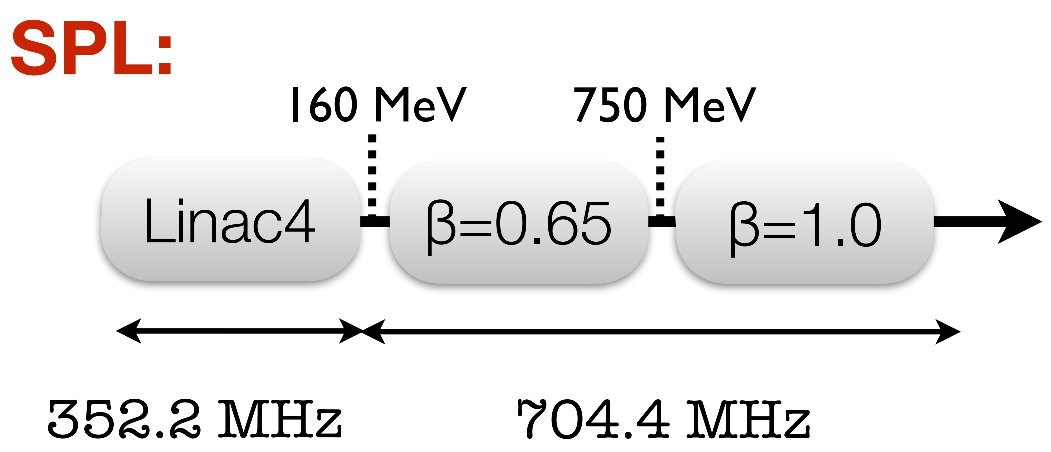
- SPL R&D (cavities, cryomodule, couplers, IOT test stand)
- SPL budget & status

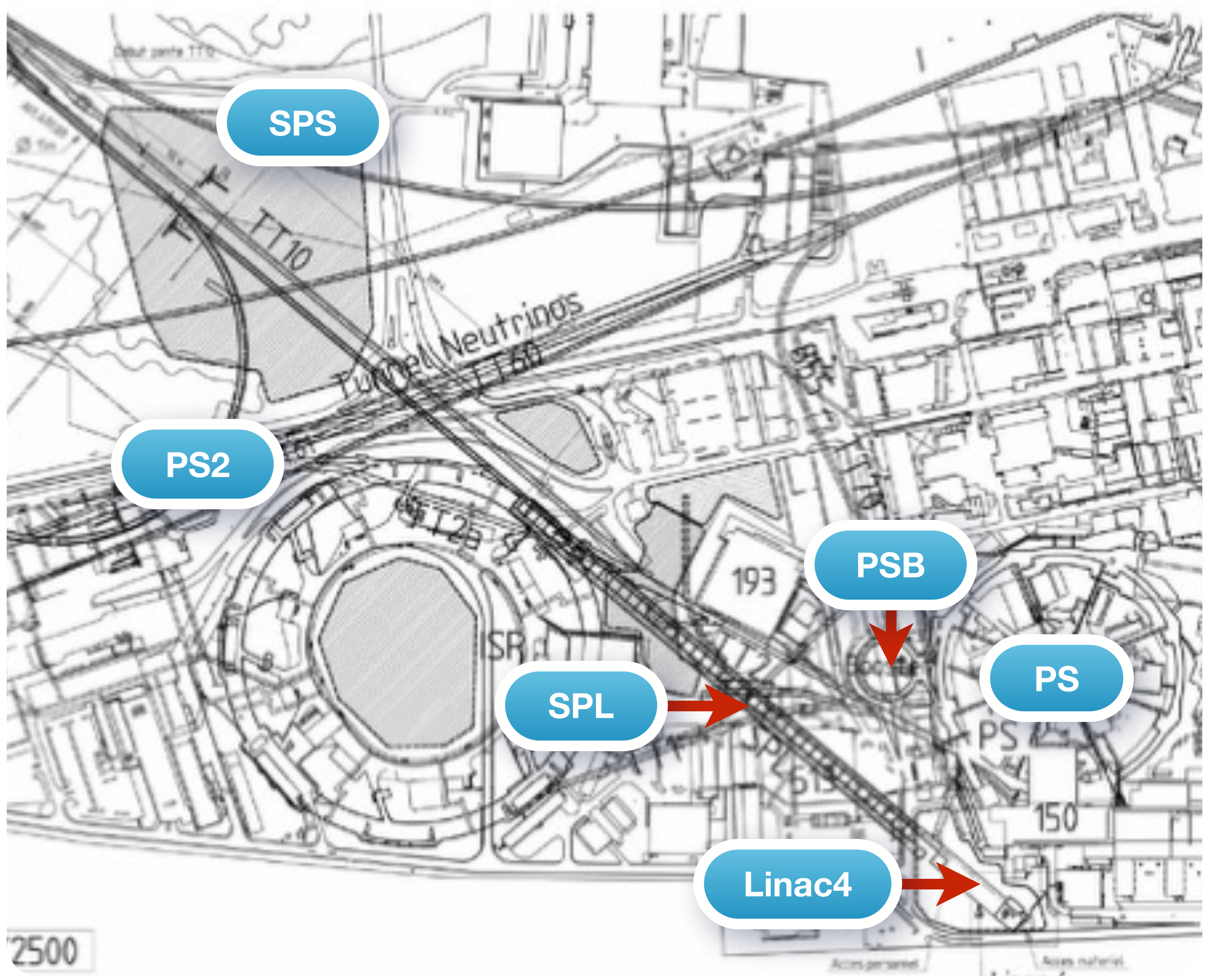
+ MOTIVATION



1. Develop CERN expertise on SC multi-cell cavities, including the necessary infrastructure.

2. Option for LHC (or FCC) injector upgrade.

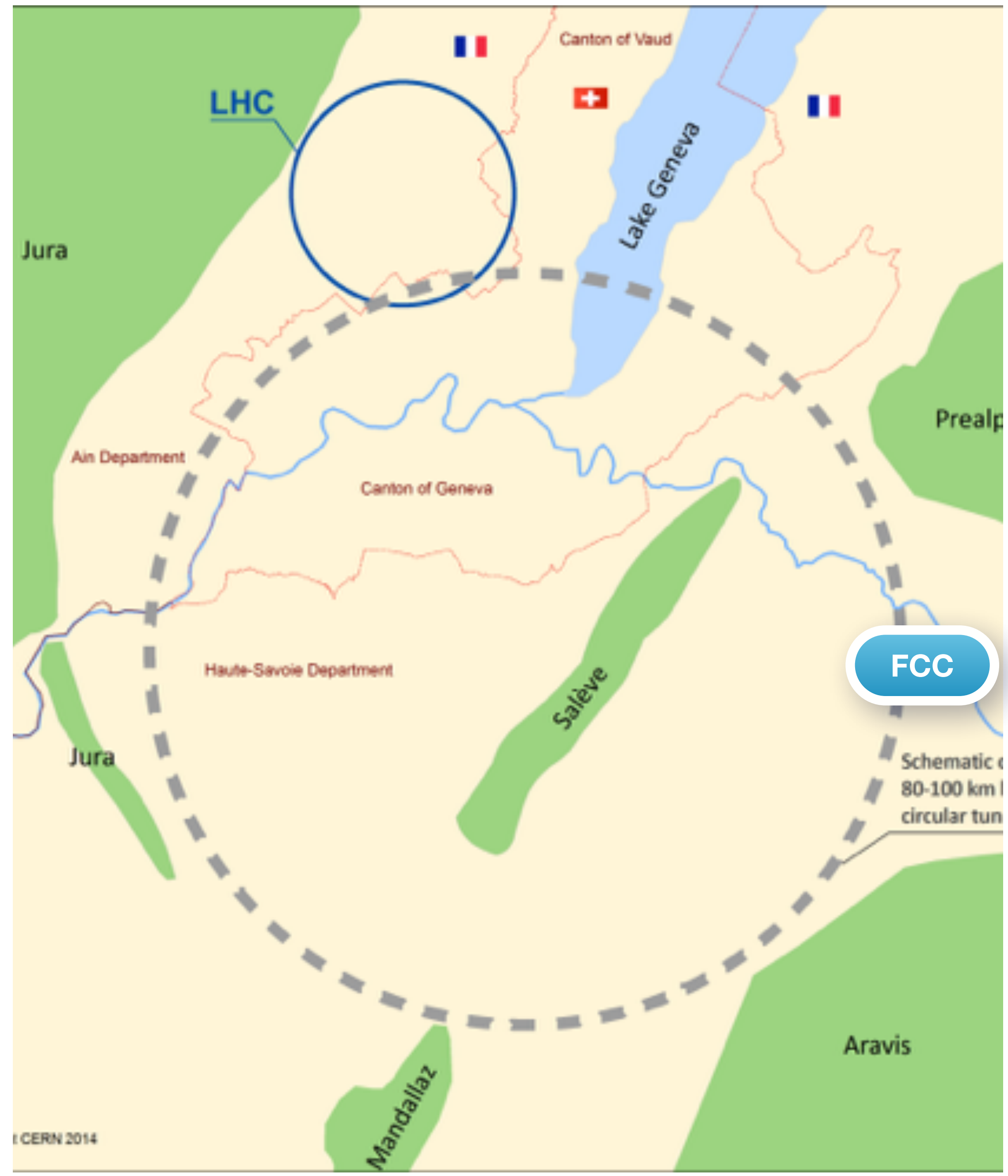
3. Driver for high-power proton physics (neutrino, RIB).



✚ Motivation (FCC + collaborations)

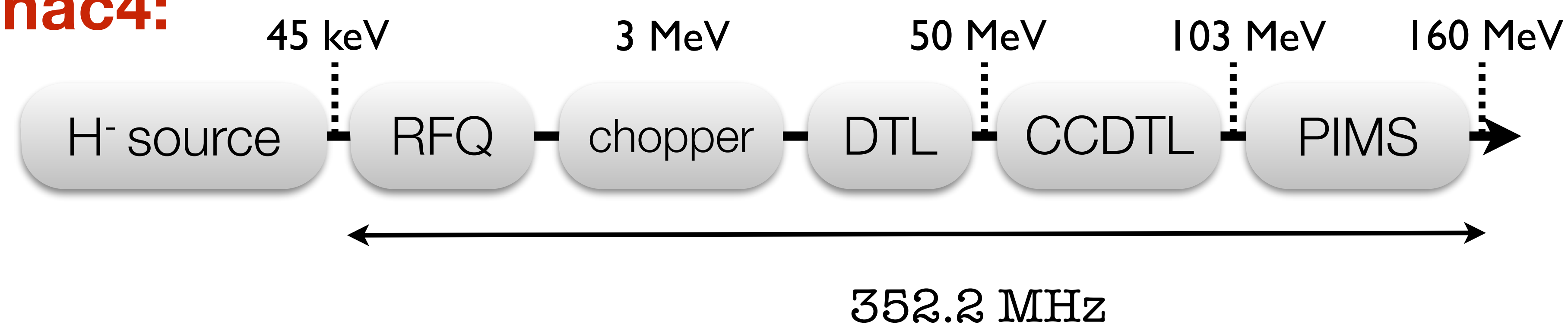
- The next planned circular collider will use multi-cell SC cavities at a frequency around 700 - 800 MHz. The e-e option will need up to 11 GeV acceleration/turn (~500 cavities)

- Synergies with other projects: e.g: ESS, FNAL, ADS (Myrrha), ..



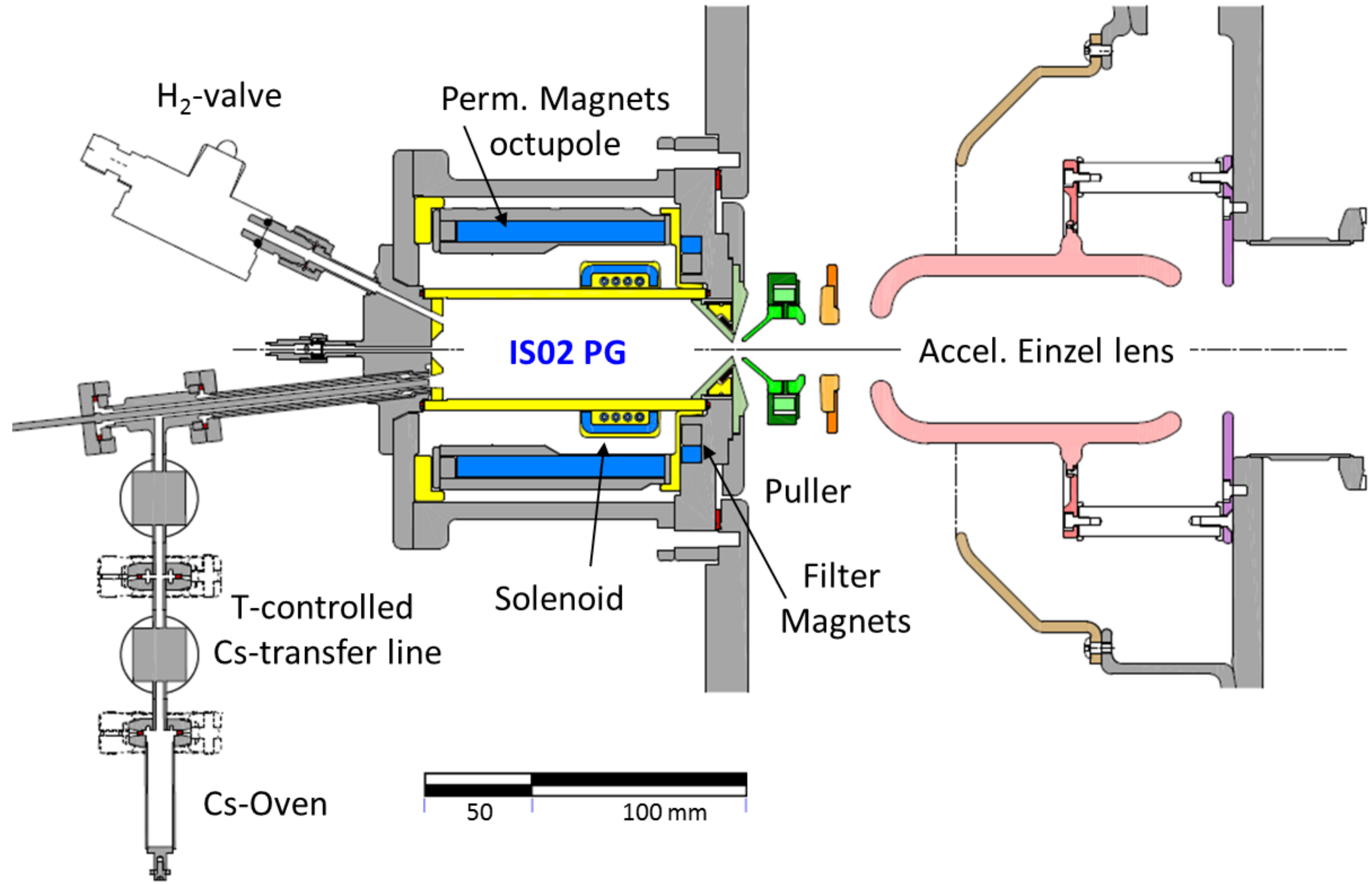
+ Status Linac4

Linac4:



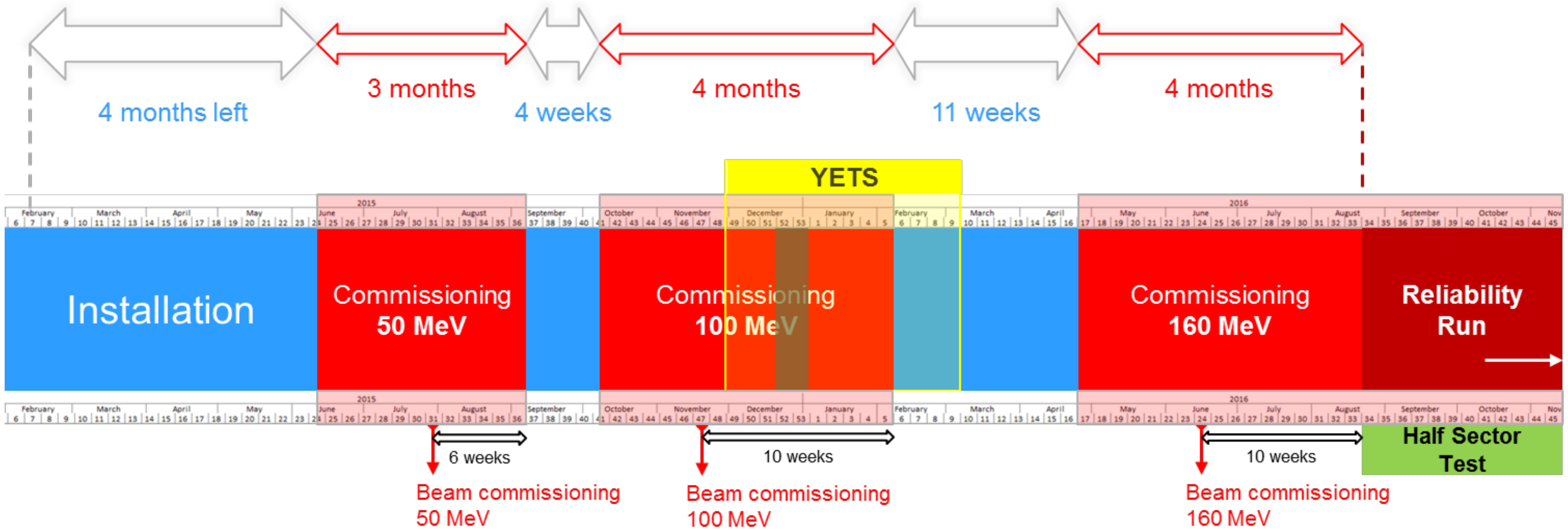
- Commissioned up to 10 MeV (LEBT, RFQ, chopper line, DTL1).
- Installation of DTL2 and 3 until June 2015.
- 50 MeV commissioning from end of July 2015.
- Installation of CCDTL 1,2,3, fine-tuning of CCDTL 2-7, conditioning of CCDTL 4,6,7 until October 2015
- 100 MeV commissioning starting in October 2015.

Linac4 ion source (J. Lettry)



- February 2012: 45 keV H- beam produced at the test stand.
- November 2013: 45 keV H- (18mA) beam produced in the Linac4 tunnel.
- October 2013: Successful test of CERN's Magnetron at BNL
- December 2013: 50 mA from a caesiated RF source in the test stand (large emittance).
- September 2014: >30 mA from a caesiated RF source in the test stand.
- February 2015: ~45 mA from caesiated RF source in test stand (90% in emittance of 0.3 π mm mrad).
- 33 publications between 2010 and 2014

✚ Linac4 RF structures

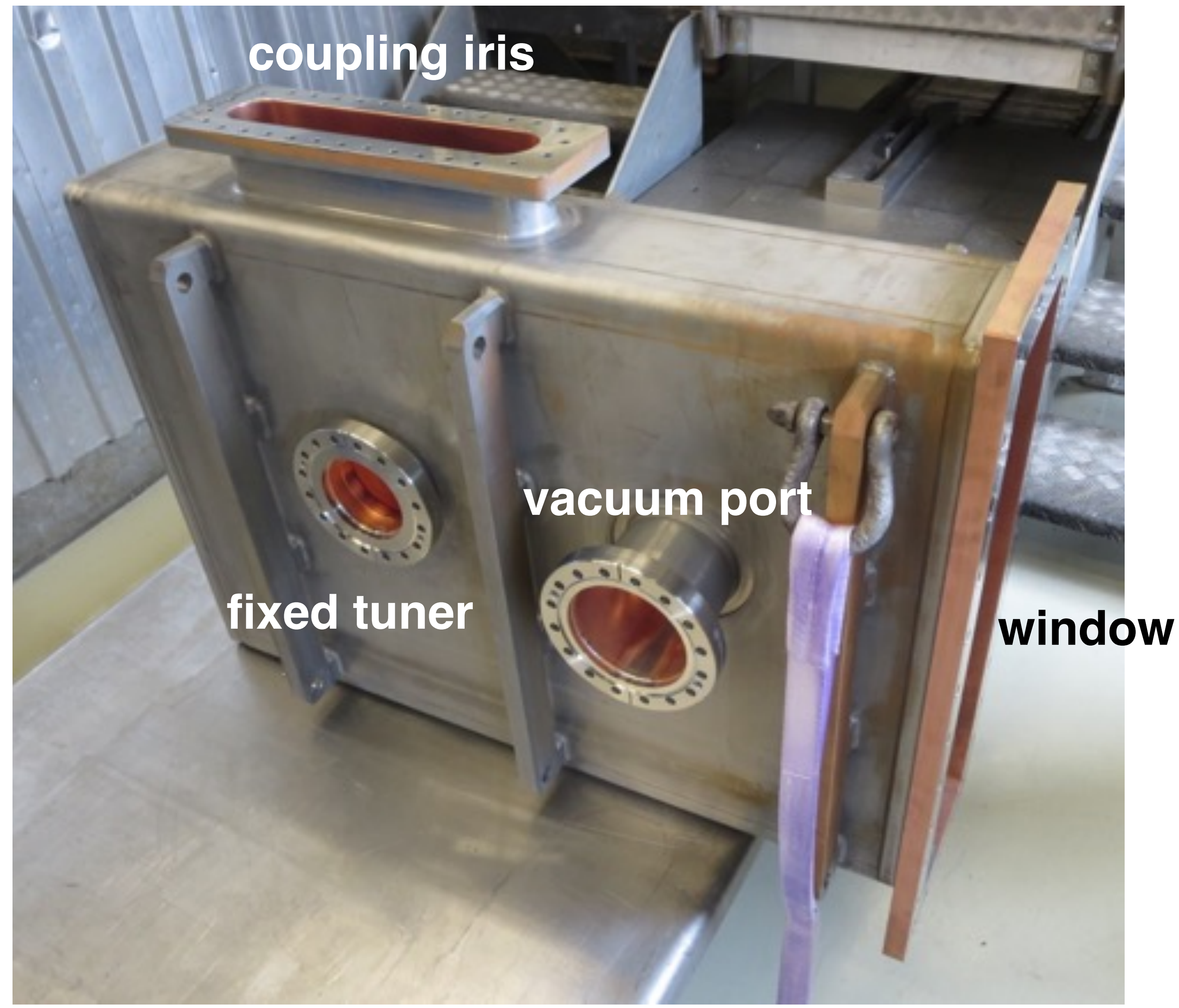


On the critical path are:

- **RF couplers:** qualification of welds was extremely time consuming. After qualification of Cu plating process we found that the plating company is under "liquidation" and that we are no longer allowed to do business with them.
- **Pi-Mode-Structure:** after a change in the brazing procedure for the piece with the coupler port, 2 of these elements became unusable. Re-machining, re-brazing, re-qualification (5 months delay, 3 months impact on Linac4 planning).

✚ Linac4 coupler

- waveguide - iris coupling with λ/4 short circuit plate,
- adjustable coupling factor,
- welded stainless steel with copper plating,
- 25 couplers needed for Linac4 with 3 different types (different iris height),
- seemingly simple design…



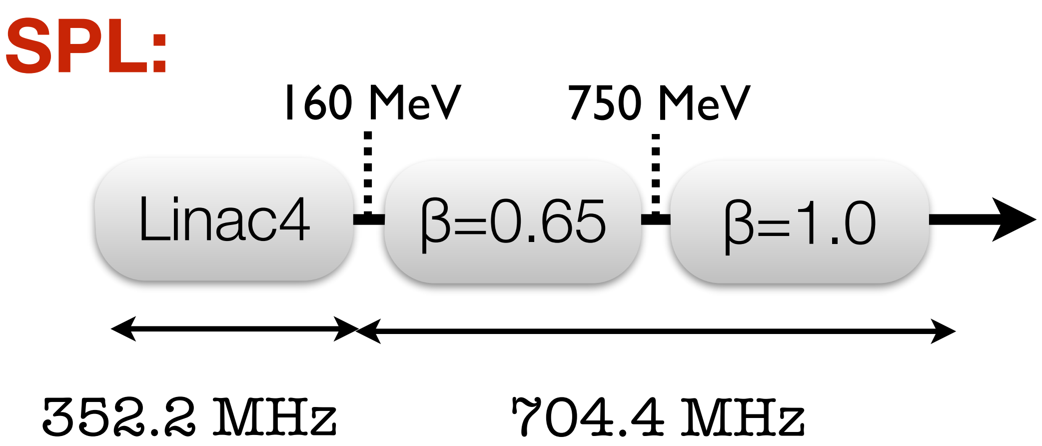
+ PIMS

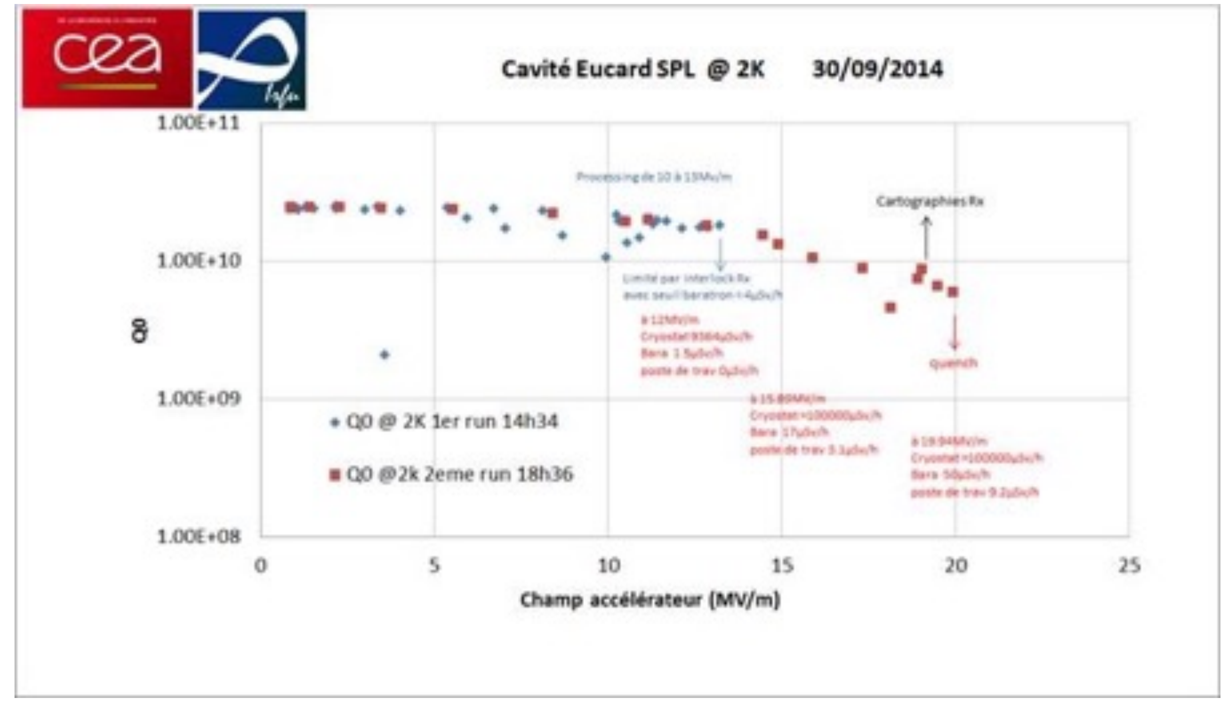
- 7-cell Pi-Mode structure.
- Each cavity scaled to its respective β value.
- CERN Prototype took around 1 year.
- Technology transfer and qualification at the company took almost 3 years.
- Extensive work at CERN: metrology checks, pre-assembly, tuning (via machining), pre-assembly, welding of rings and discs, fine-tuning…

✚ Linac4 status

In-house development of H- ion source	ongoing
In-house production of 4-vane RFQ incl. 0.1deg temperature regulation	commissioned
In-house development of beam chopper incl. amplifier (goal: rise time < 2 ns)	<4 ns achieved
DTL without alignment mechanism and with PMQ	tank1 commissioned, tank2,3 with beam in July
Design and construction (with BINP/VNIITF) of first ever CCDTL for an operational machine	4/7 conditioned, 4 in tunnel, fine tuning of 6 pending
Design and construction (with NCBJ/FZ Jülich) of first ever Pi-Mode structure for low-energy protons	3/13 completed
In-house design and production of waveguide windows	tested & in production
Tuner-adjustable coupler (TaCo): matching of lambda/4 coupler with a single fixed tuner	tested & in production
Operation of solid state amplifiers for buncher and debuncher cavities	tested & operational
Built to print klystron modulator (CERN design)	tested & operational

Status SPL cavities

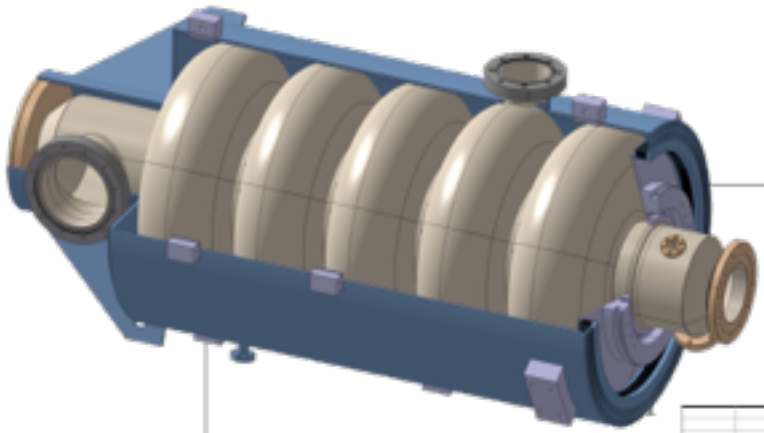




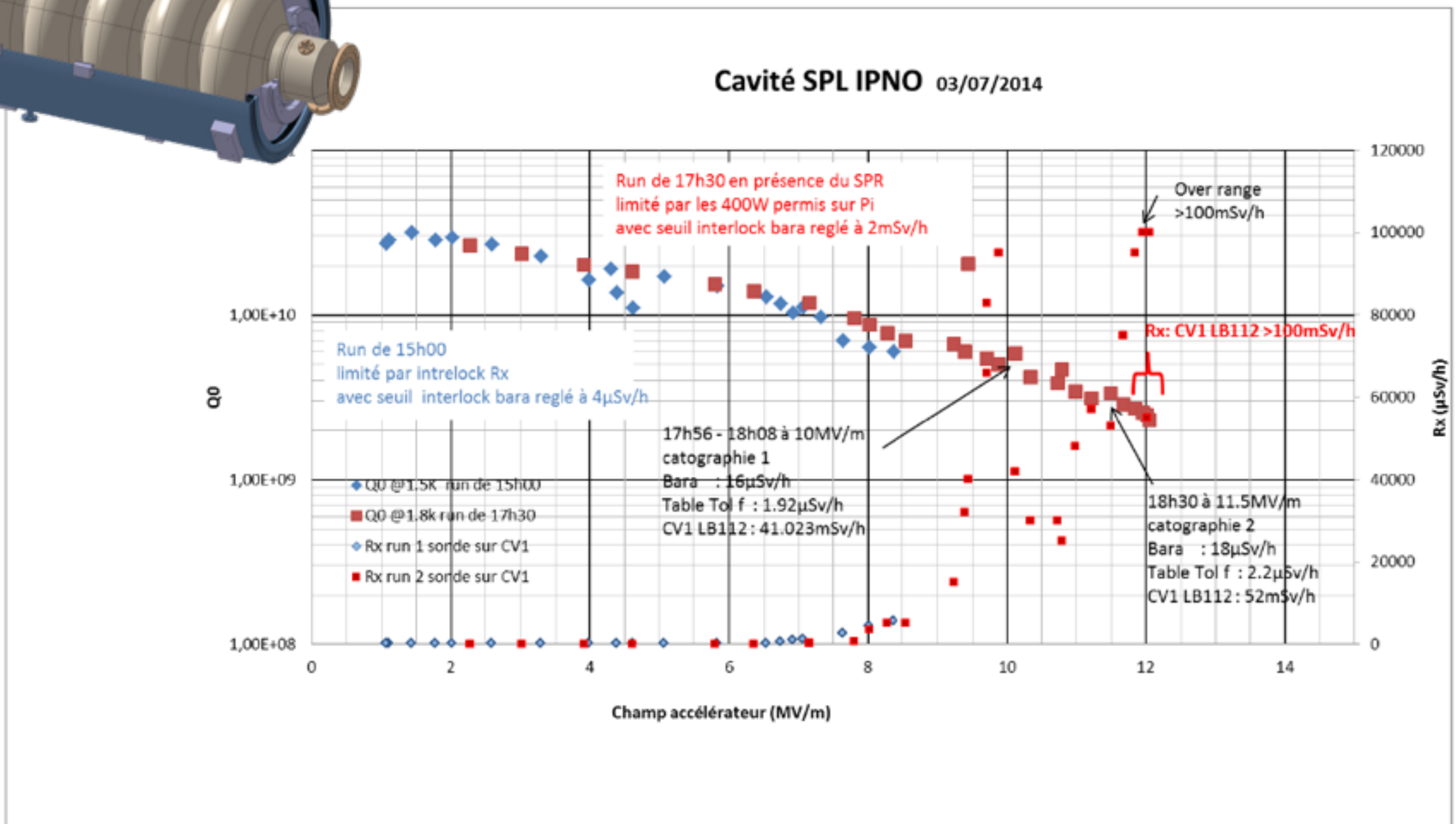
- β=0.65: IPNO, June 2014: 12 MV/m (quench) @ Q_0=2x10^9,
- β=1: 4x RI cavities, 1x CEA collaboration (Eucard), 1 under construction at CERN,
- August 2014: first cold test of SPL1 (5-cell), surface treated at CERN: a few MV/m.
- September 2014: Eucard cavity achieves 20 MV/m (quench) @ Q_0≈5x10^9
- December 2014: He tanks at CERN via CEA.
- December 2014: 2nd cold test (repaired compensation of magnetic field, He-processing,), Initial Q_0=1.2x10^{10}, field emission onset 5-6 MV/m, field probe connectors burnt at 9 MV/m, maximum field probably 15 MV/m, test stopped because of end-of-year shutdown and because of burnt connectors.
- Waiting for re-start of cryogenics in SM18 end of March 2015.

see: A. MacPherson, 14:10 today

EUCARD - SPL TYPE BETA = 0.65 CAVITY FROM IPN ORSAY, TESTED WITH HELIUM TANK

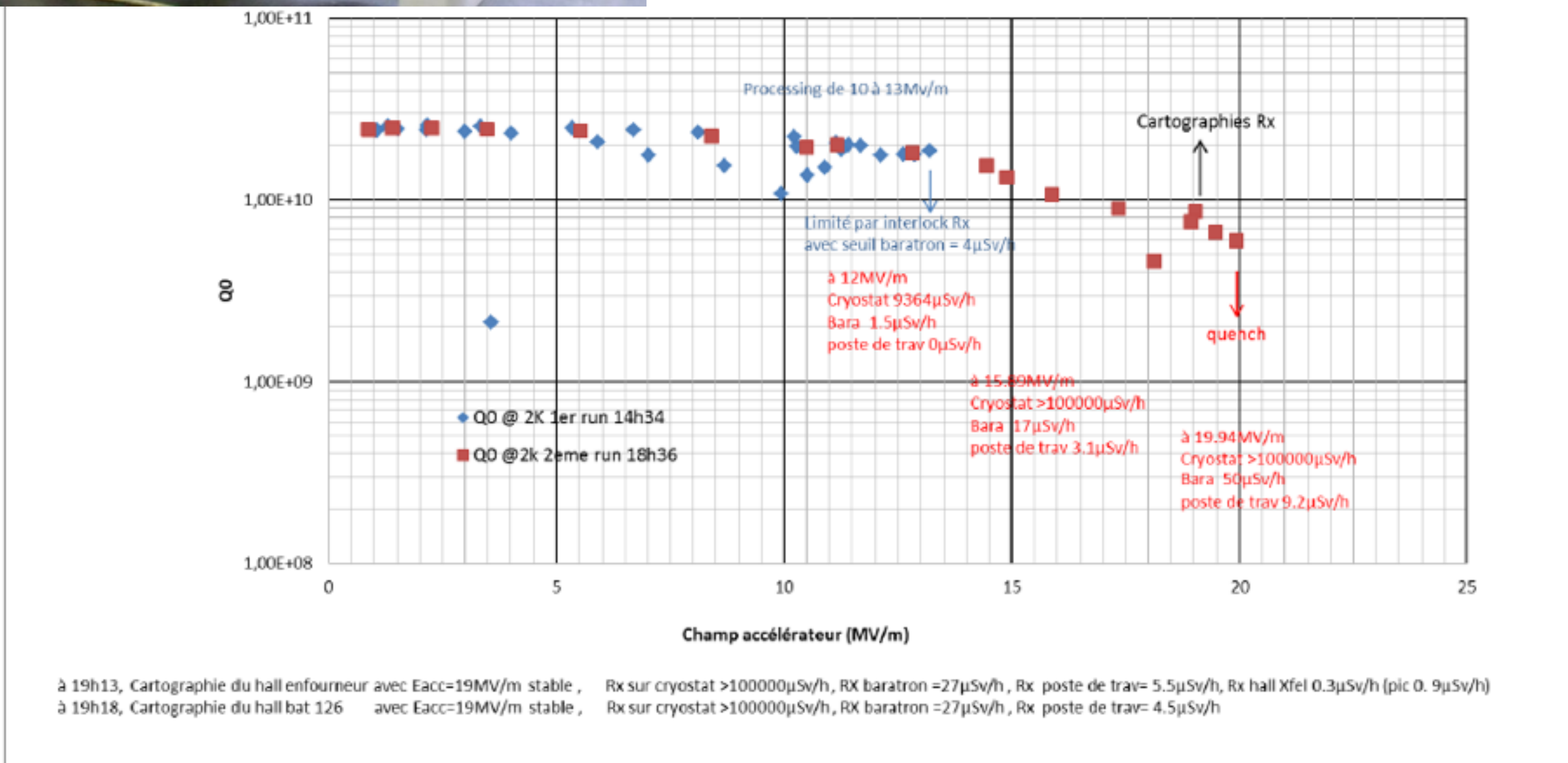


Franck Peauger, CEA



EUCARD – SPL TYPE BETA = 1 CAVITY AFTER VERTICAL ELECTROPOLISHING

Franck Peauger, CEA

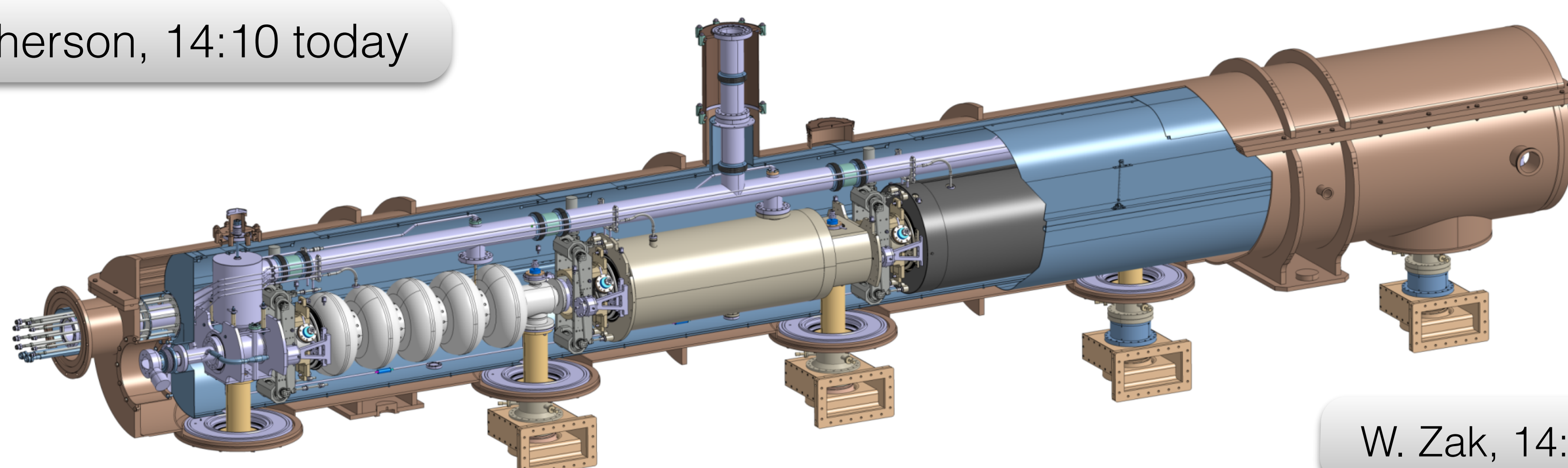


+ Status cavities and cryomodule

L. Ferreira, 14:20 today

- New EP electrode fabricated and first treatment of cavity 2 took place last week.
- Improvement of high-pressure rinsing procedure (plexiglas cavity will be constructed).
- Cryomodule vacuum vessel expected for end of May 2015.
- Manufacture of magnetic shielding is launched, delivery foreseen for Nov 2015.
- MLI is ordered.
- Remaining drawings, orders, and assembly of cryomodule will be completed by TE-MME + BE-RF with support by TE-MSC and the assembly tooling developed by CNRS-IPNO.
- **Construction of 5 more cavities has been launched (CERN/Bmax).**
- **2015 goal is to have 4 cavities at high gradient (25 MV/m).**

see: A. MacPherson, 14:10 today



W. Zak, 14:20 tomorrow

+ High velocity forming (electro-hydraulic-forming) of superconducting RF structures (S. Atieh)

- High-velocity forming is a potentially alternative process. It involves a high-strain rate deformation, through a process lasting a few milliseconds, that allows reaching higher formability (larger plastic deformation, smaller spring-back).

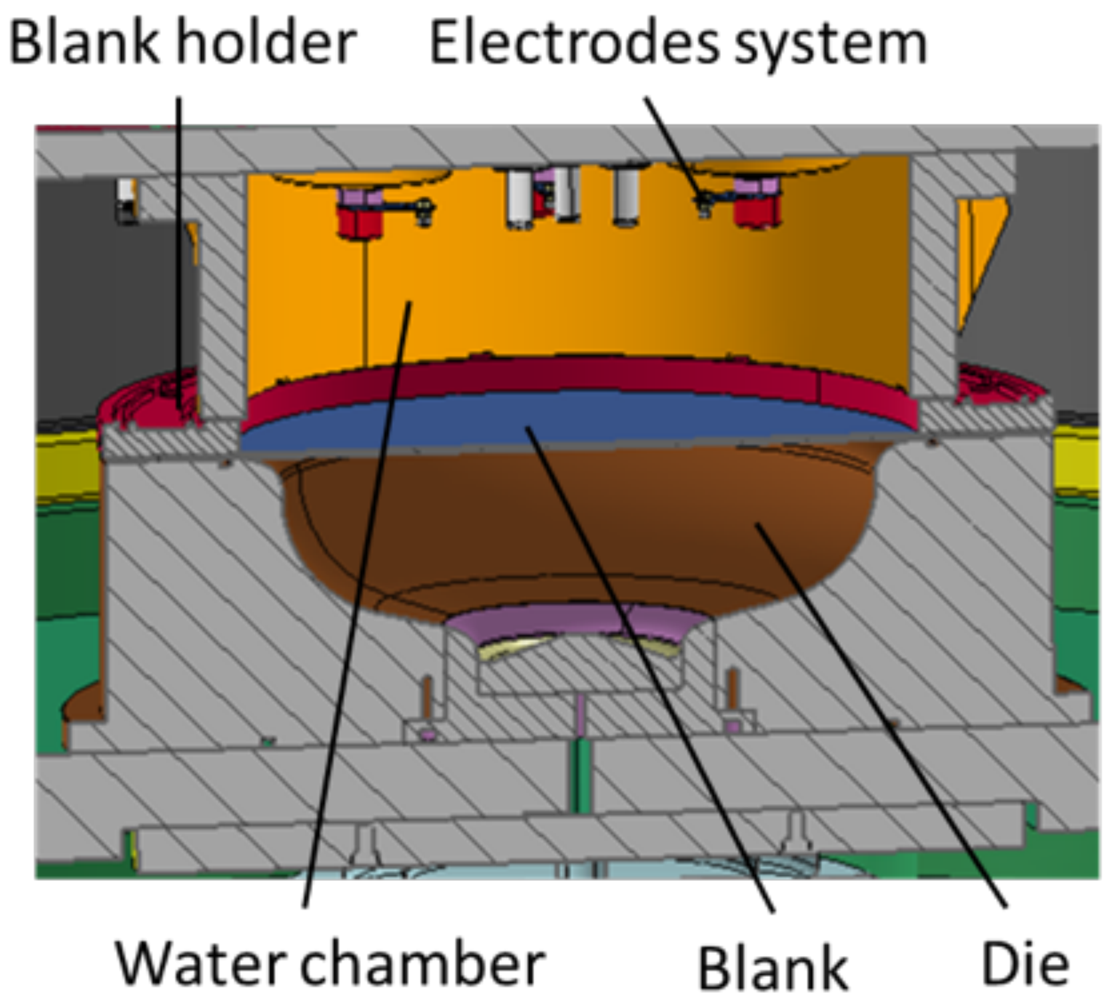
- Applications to copper and niobium have only recently been started using electro-hydraulic forming (EHF).
- CERN EN-MME / Bmax:
- COLLABORATIVE R&D ON MANUFACTURING AND QUALIFICATION OF NIOBIUM HALF-CELLS FOR SUPERCONDUCTING RF CAVITIES

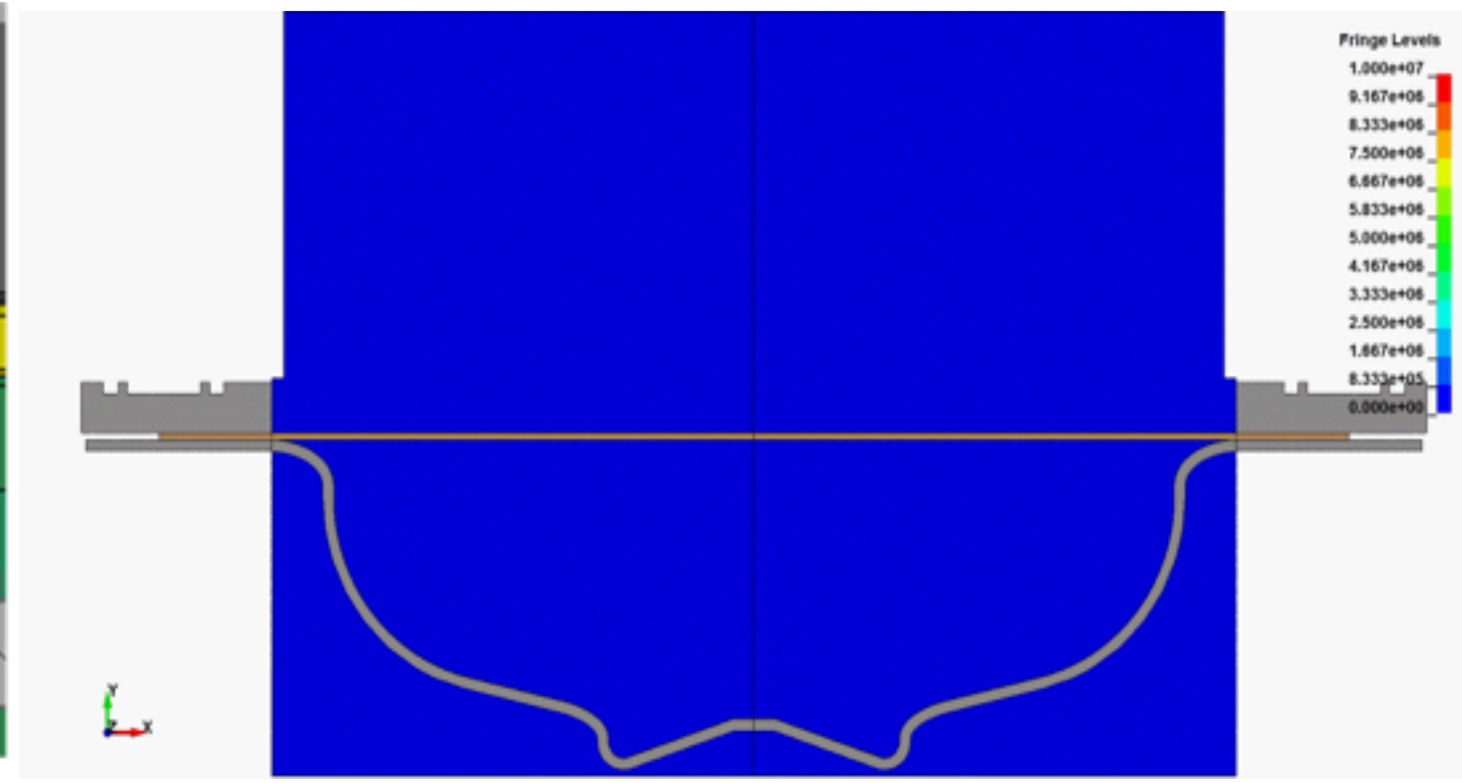
- Advantages are expected in metallurgy, geometrical precision, reproducibility, suitability for economic, large series production.

ENGINEERING DEPARTMENT

Bmax

+ Geometry and simulation of the EH Forming

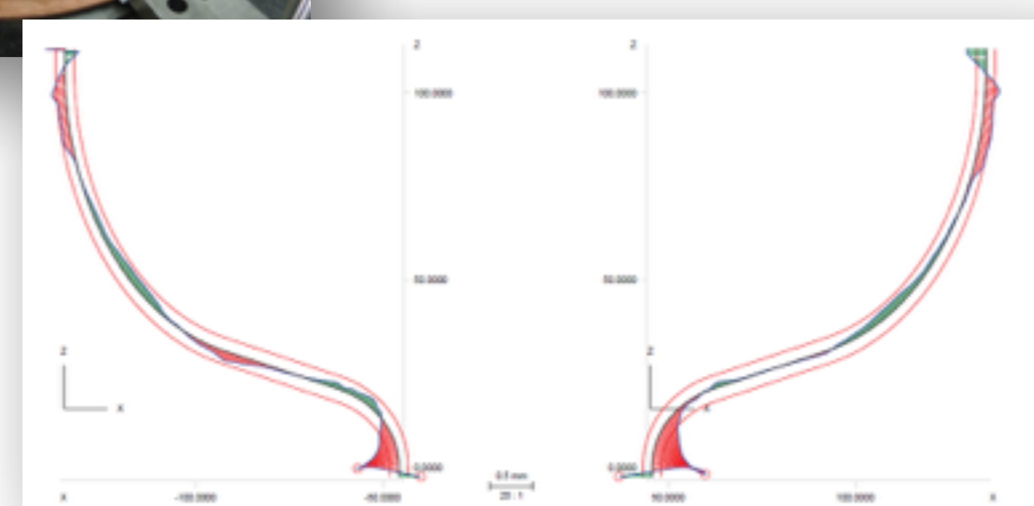




The video shows a simulation of the full forming sequence made of 4 successive discharges. Pressure is displayed.

Experimental results

- 3 OFE half-cells formed
- Good fit in between the experimental results and the simulation
- Achieved shape accuracy: ± 150 μm
- (instead of 600 - 800 μm for deep drawing or spinning)
- High reproducibility



Next:

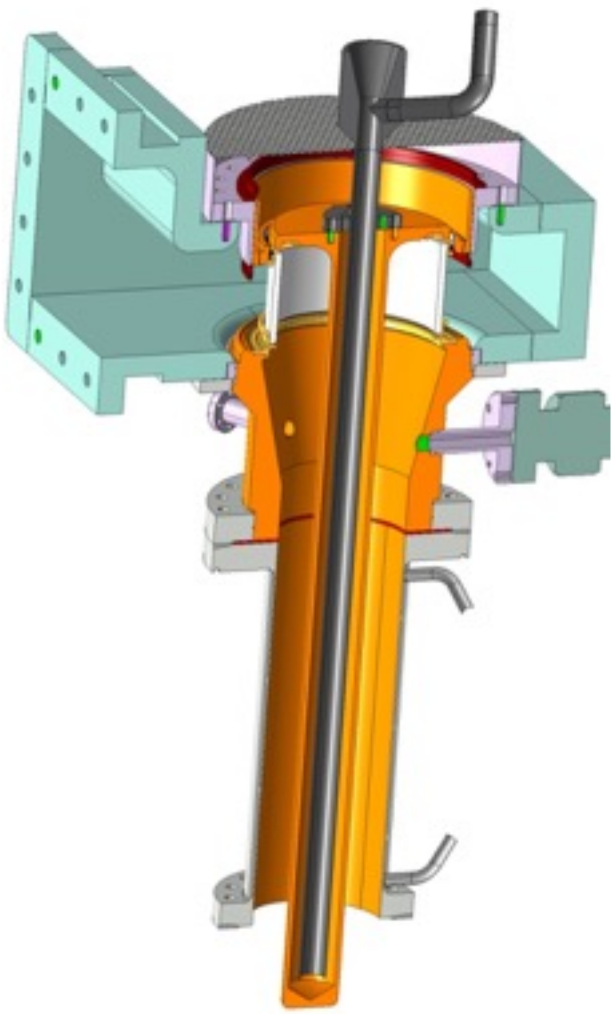
- Forming of 2 Nb half cells is ongoing, results expected for June 2015
- Parts Shaping for a full 5 cells SPL_Nb ($\beta = 1$) cavity in 2015

SPL Power Coupler (E. Montesinos)

RF characteristics	
f0	704.4 MHz
Power levels	1 MW pulsed 0.4 + 1.2 + 0.4=2 ms
Cavity design gradient	19 - 25 MV/m
Qext	1.2×10^6
Input line diameter	100/43.5 mm = 50Ω
Waveguides	WR 1150

Technical choices
Single window coupler
Fixed coupling
Double walled tube
Mounted in clean room
Vertically below cavity and used as support for cavities
HV DC biasing capacitor
Air cooled

Both designs have the same:

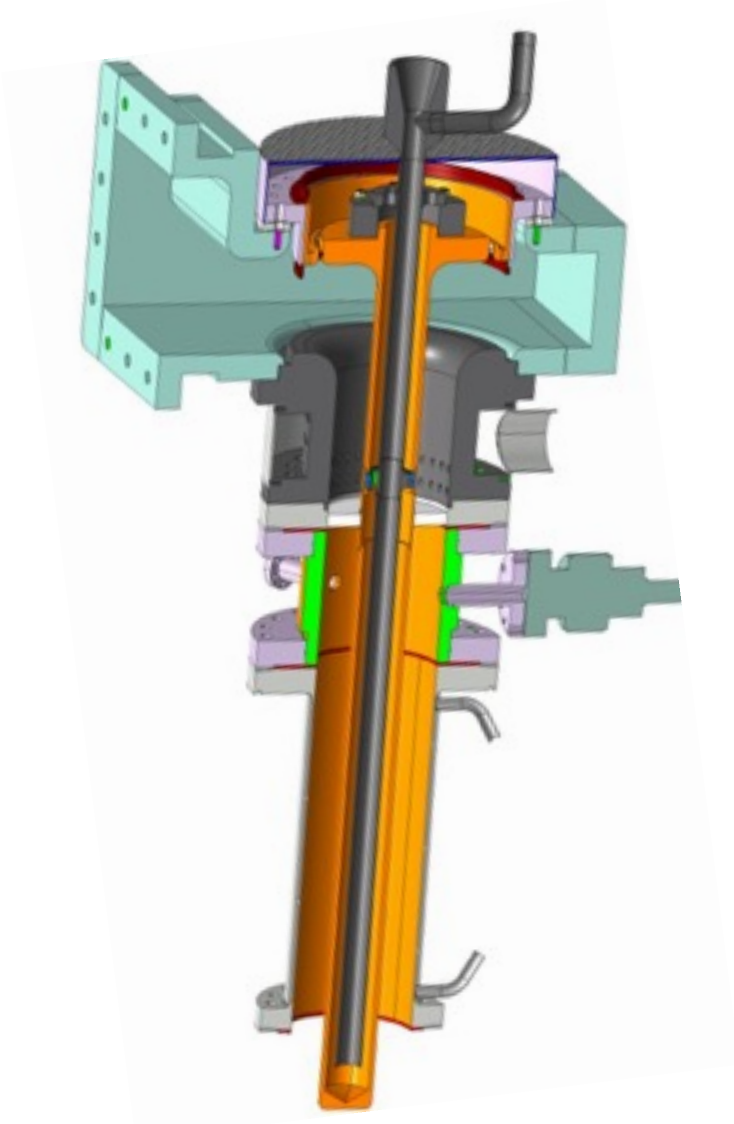


Double walled tube

Matching waveguide without doorknob

Contacts ring including DC capacitor

Interface to cryomodule flange & RF + vacuum gasket



Cylindrical window Coupler

Disk window Coupler

Tests results

Coaxial window couplers have passed all the (mitigation) test programme

Cylindrical window couplers have arced during full reflection test on some phases even at lower power

Coaxial windows couplers have been selected as SPL couplers

Test repetition rate 50 Hz	**Power level kW**	**Coaxial window coupler**	**Cylindrical windows coupler**
TWC	***1000***	√	√
SW 100 µs	1000	√	√
SW 200 µs	***500***	√	√
SW 500 µs	250	√	X
SW 1 ms	***250***	√	*X*
SW 2 ms	250	√	X

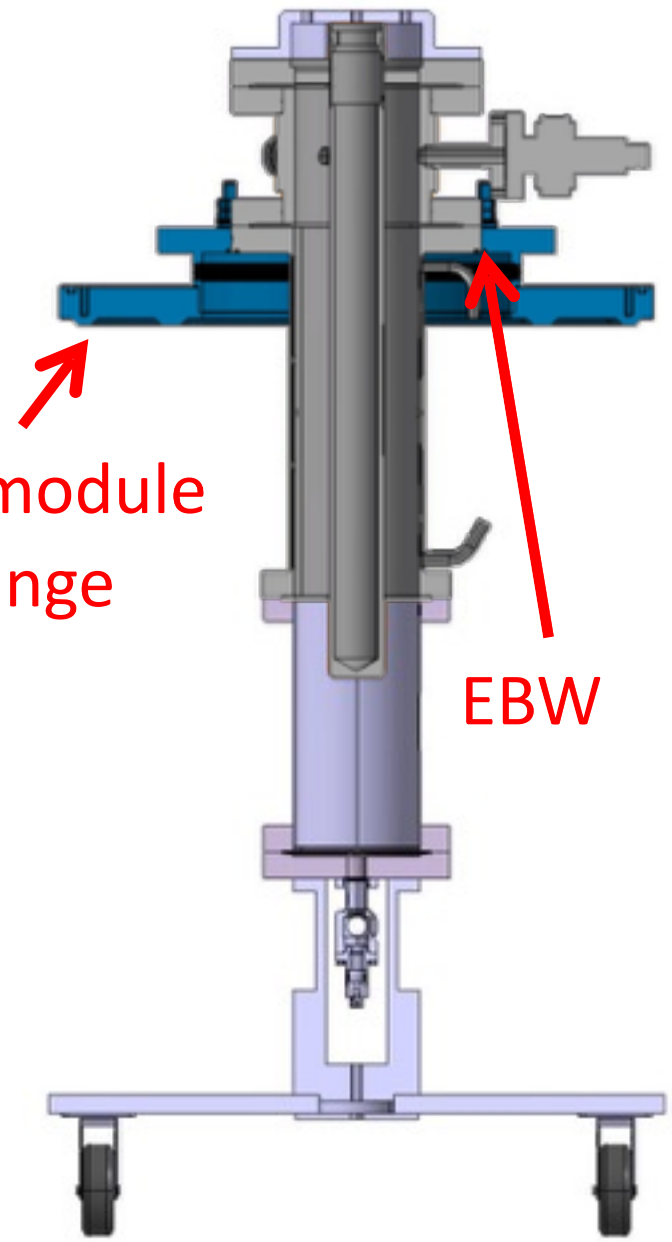
Next steps

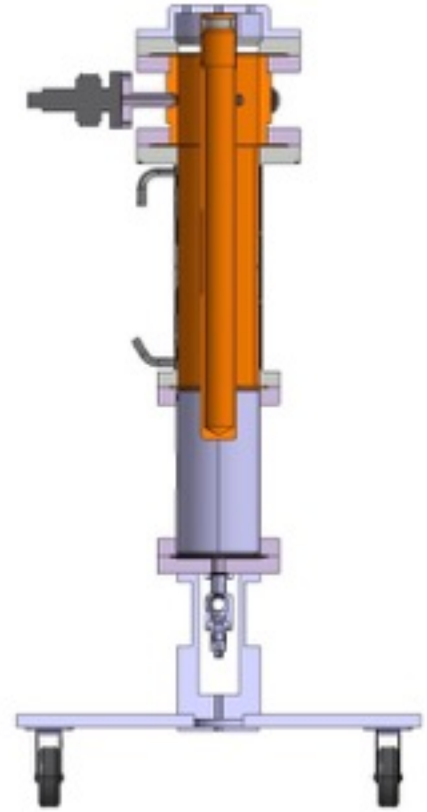
EBW of couplers to the cryomodule ‘flanging system’

Very delicate step as it can destroy 5 years of construction and tests

Flanges are being provided by cryo-module team

Final EBWs are expected to be done by September 2015

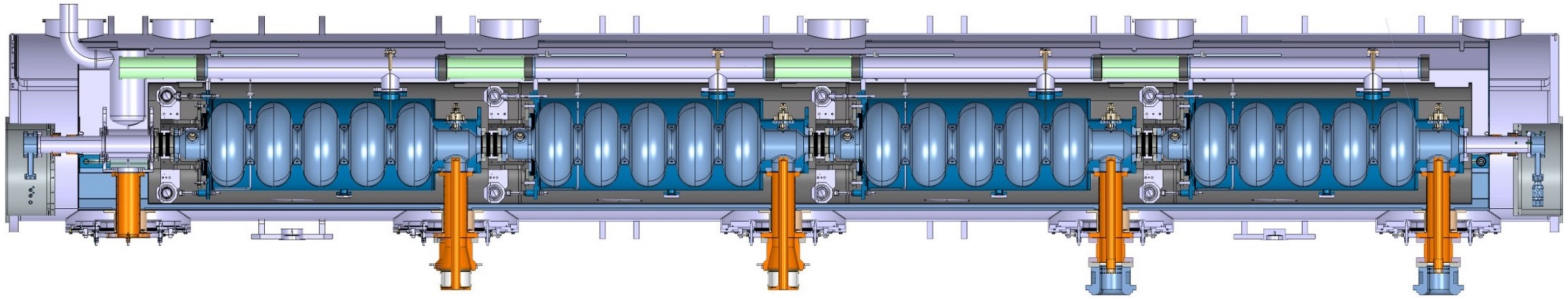




Couplers as they are today, already removed from test box, ready for EBW of cryomodule flange

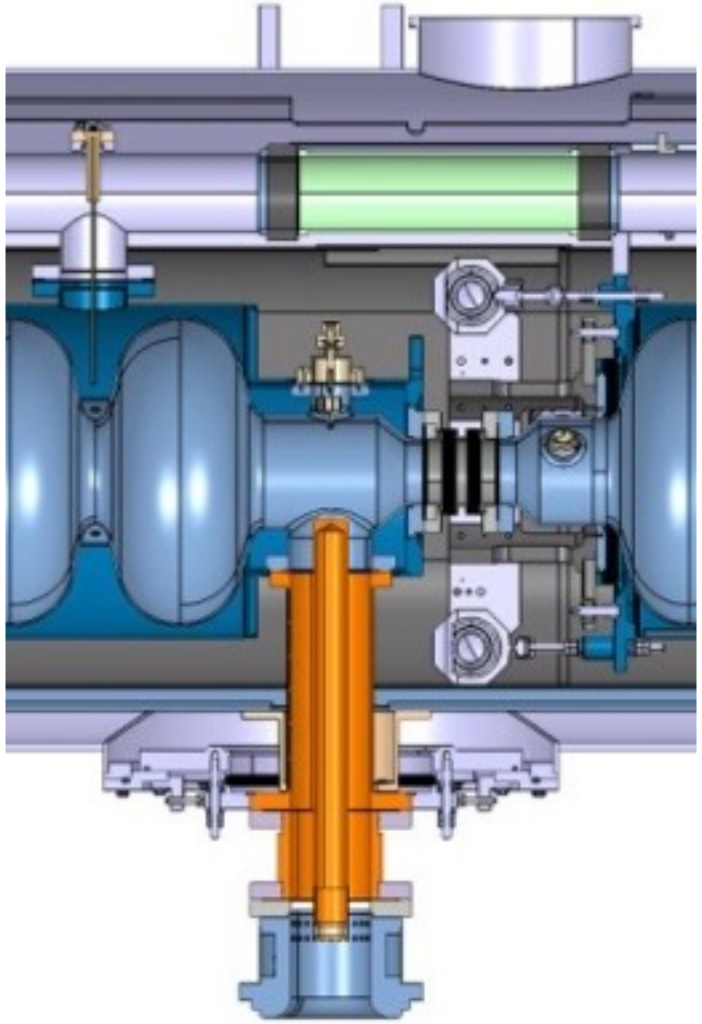
Last critical operation on couplers before assembly onto cryomodule

Next steps



Integration into cryomodule in SM18 clean room

FPC TD being the support for the cavities



Generation 3.0

FPC SPL 3.0
(compatible with ESS parameters)

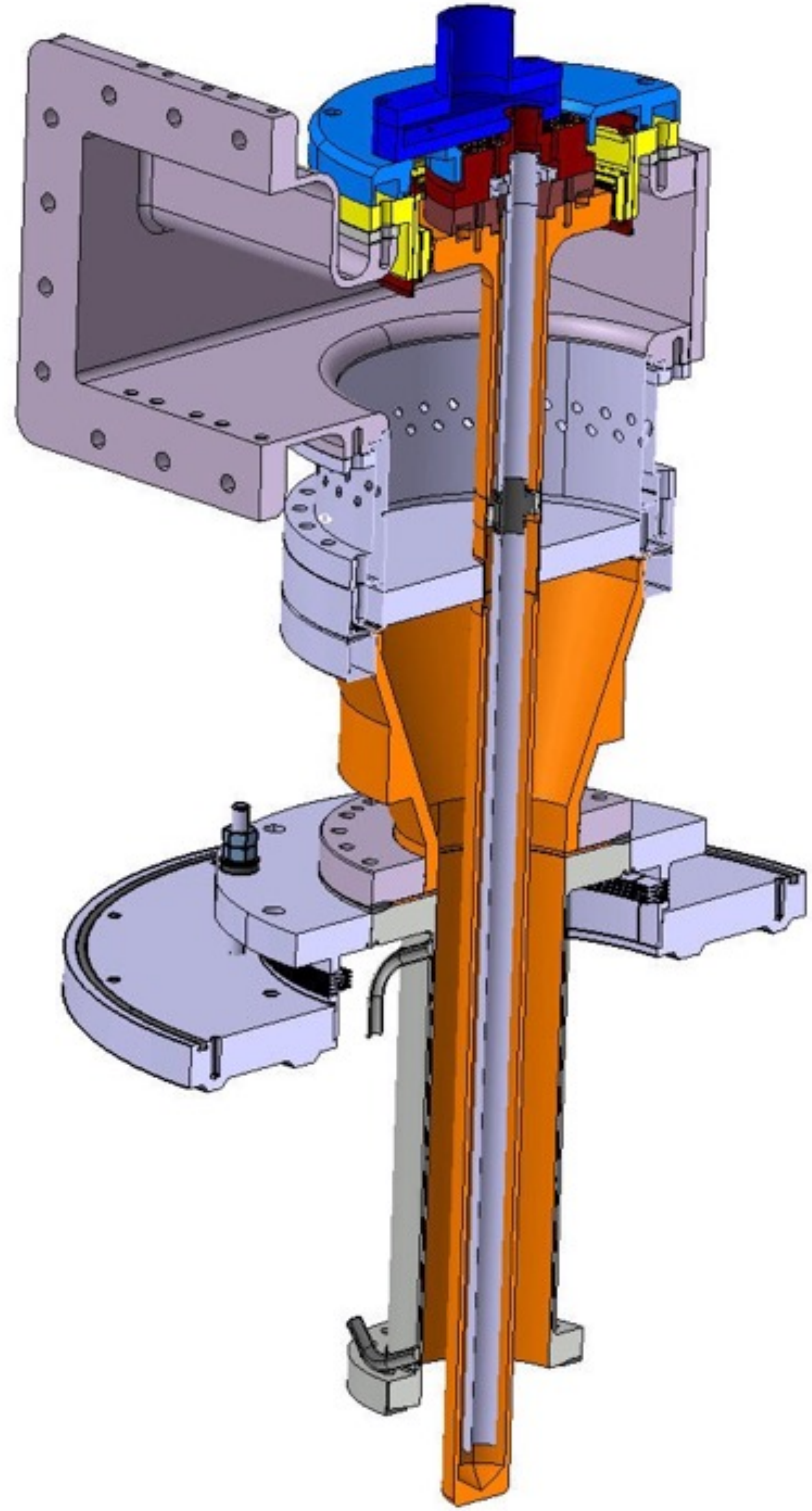
Increased diameter on vacuum side with pseudo-conical line and larger ceramic window: less sensitive to arcing on the air side

Goal: sustain 2 MW peak @ 704 MHz full reflection and 10 % duty cycle
(SPL 2 ms - 50 Hz and ESS 4 ms – 28 Hz)

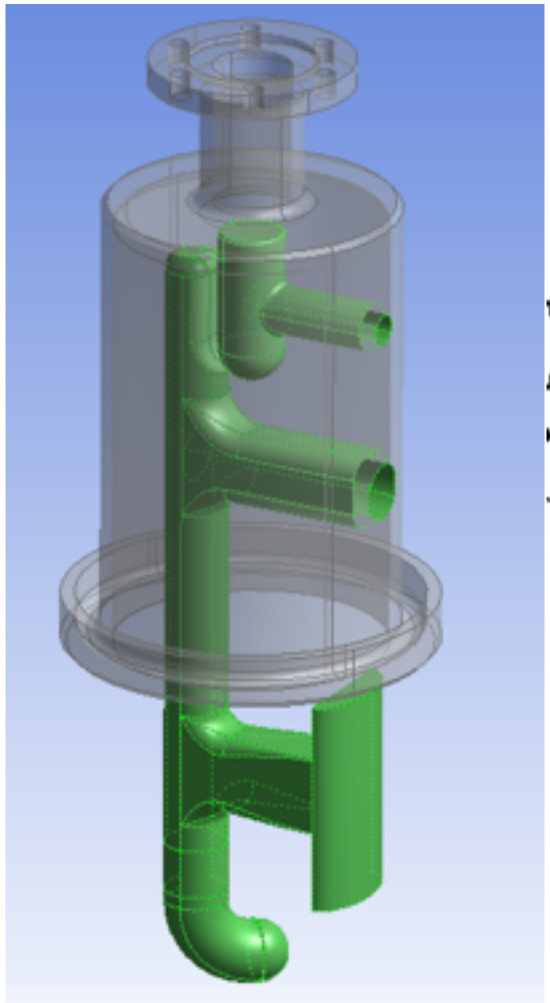
Design under completion

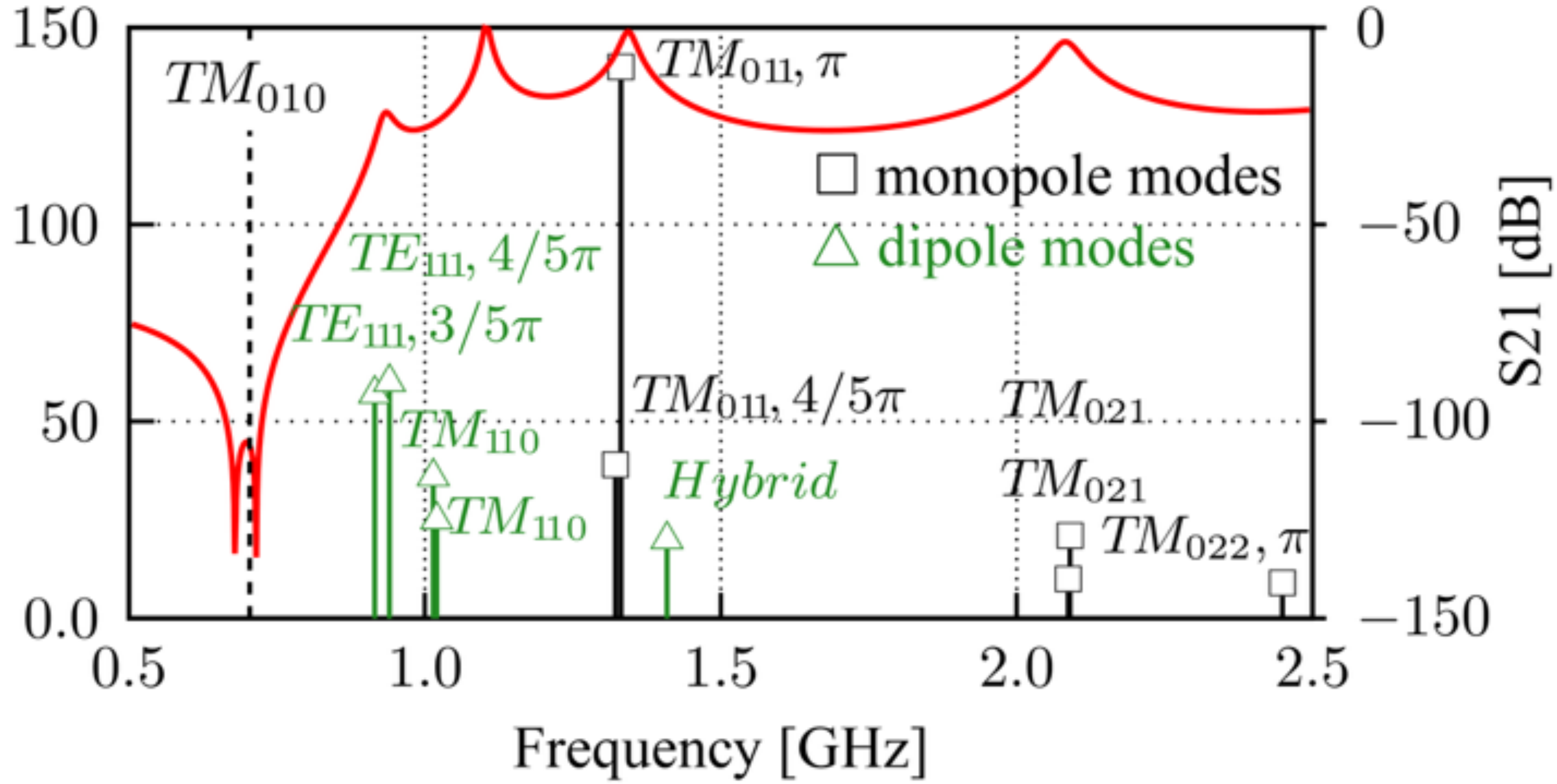
Fabrication and first tests of two couplers by the end of 2015 in SM18

Test box and DT already available



✚ HOM couplers





- Since CERN machines are always used with changing pulse patterns, we decided to keep the option of adding HOM couplers.
- First HOM coupler model has been 3D printed and Cu plated and was characterised successfully. Nb prototype under construction.

K. Papke, 16:00 today

+ IOT test stand

- Revised cost estimate for a single IOT test place: 300 kCHF
- Preparations for IOT test place are done in 2015.
  - modification of existing HVPS and preparation of test bench area
  - low voltage power supplies are provided by manufacturer
- A 2nd test place would cost another 400 kCHF + LVPS (200 kCHF)
- We consider it premature (and too expensive) at this point to invest in a technically identical 2nd test place without having had any test experience with the 1st IOT.

Applications of High Power Induction Output Tubes in High Intensity Superconducting Proton Linacs

M.R.F Jensen[1], R. Garoby[2], F. Gerick[2], M. Lindroos[1], D. McGinnis[1], E. Montesinos[2], A. Sunesson[1]
(1) European Spallation Source (ESS), Sweden
(2) CERN, 1211-Geneva, Switzerland

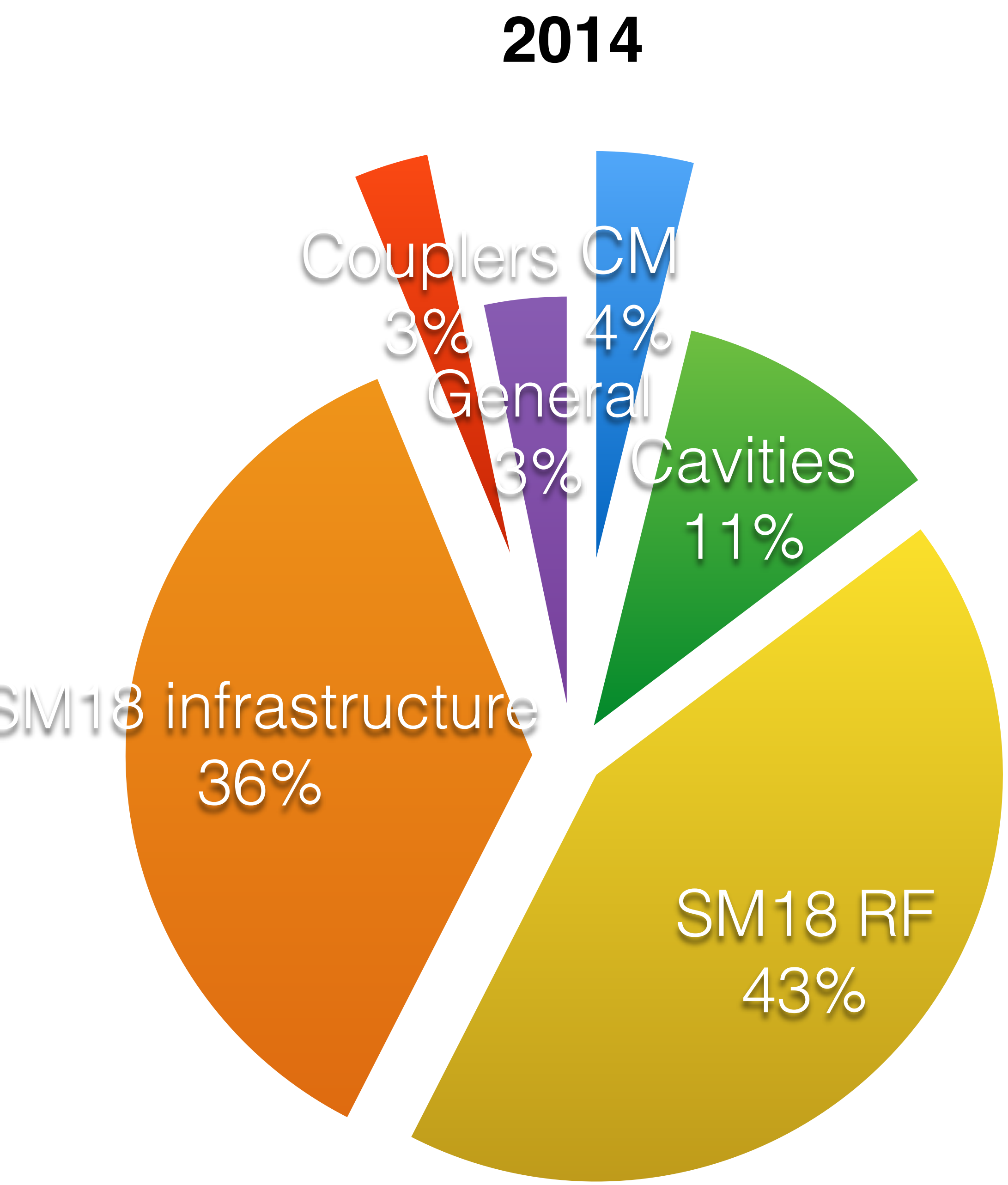
Abstract: *Very intense proton sources are being planned at many facilities worldwide. These facilities are based on superconducting radio frequency accelerating structures. The nature of these structures require many power sources with a peak power capability in the 1 MW range with a duty factor on the order of 10%. In the past, the conventional choice for RF power has been klystron based systems. The cost and efficiency of klystron systems has caused a number of accelerator laboratories to consider lower cost and more efficient technologies. This paper will explore the possible use of induction output tubes (IOTs) with a peak power level in the range of 1 MW as an alternative for powering high intensity superconducting proton linacs.*

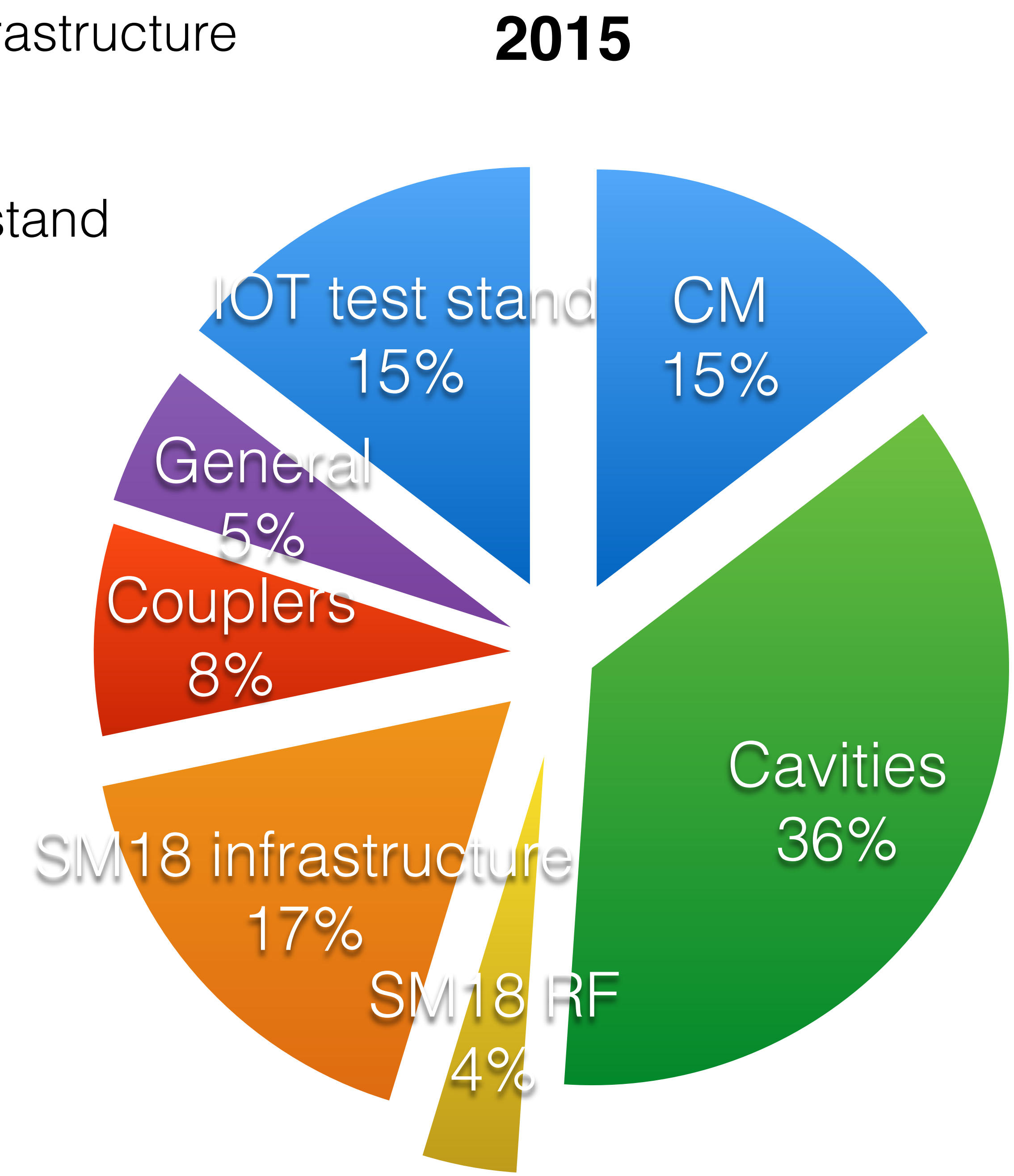
constructed from many shorter accelerating structures. Since the accelerating gradients are high but the RF losses low, the duty factor can be increased allowing the beam current to be reduced and still achieve the same power on the target. Current high power linac projects and studies include ESS in Lund (Sweden), SPL at CERN (Switzerland) and Project-X in Fermilab (USA).

The high number of cryomodules required for the medium and high β parts of the accelerator, results in a requirement for many pulsed RF sources in the power range from a few 100 kW to about 1.2 MW peak with pulses of a few ms. The RF sources required in the current design of the SC part of the ESS linac are given in Table 1 [1].

+ SPL spending

- CM
- Cavities
- SM18 RF
- SM18 infrastructure
- Couplers
- General
- IOT test stand





more funds available for "other" SC R&D

see: K. Schirm, 14:50 today

✚ SPL summary

Standard cavity production in industry & quality assurance		done
In-house production of cavities		ongoing
Electropolishing	L. Ferreira, 14:20 today	improved cathode t.b.c.
Electro-hydraulic-forming of cavities		ongoing
Field measurements & tuning	A. MacPherson, 14:10 today	understood
HOM coupler development		pre-prototype tested
High power couplers	K. Papke, 16:00 today	4 couplers ready, next generation in preparation
Surface treatment facilities	L. Ferreira, 14:20 today	operational
Clean rooms for assembly and HPR	P. Maesen, 14:40 tomorrow	tested & operational
Infrastructure for vertical cold testing	P. Maesen, 14:40 tomorrow	operational
Cavity preparation and vertical cold testing		ongoing
704 MHz test stand	D. Nisbet, 10:20 tomorrow	ESS modulator in place, klystron in preparation
Cryomodule vessel		May 2015
Dressing of cavities		2015/2016
Cryomodule assembly and testing	W. Zak, 14:20 tomorrow	2016/2017

Thank you