Planned RF Upgrades in IR4 for the 2014/15 Shutdown

E. Ciapala, on behalf of the BE-RF Group

Special Acknowledgements:

Eric Montesinos, Elena Shaposhnikova, Joachim Tuckmantel, Serge Claudet, Laurent Tavian.

Outline

- **Baseline Planned Upgrades**
  - ACN 200 MHz:
    - *Historical*
    - *Present hardware status*
    - *Layout in IR4*
    - *Installation planning estimate*
  - Transverse Damper Upgrades
  - Cryo Upgrade in IR4
- **Other upgrade needs – longer term**
  - Crab cavity installations in IR4
  - Higher harmonic cavities
- **Conclusions**

200 MHz RF in LHC – Background & History

- 200 MHz originally proposed as a longitudinal feedback system (ADL)
  - Four cavities per beam, 225 kV total
  - Ultimate beam intensity 250 kW – 60kW tetrode amplfier per cavity
  - Later considered unnecessary, natural fs spread found sufficient
  - Cost estimated 5.2 MCHF
- Before SPS upgrade (impedance reduction program) emittance of extracted bunch exceeded the 1 eVs nominal.
- Solutions envisaged:
  - Passive 400 MHz RF in SPS (tried)
  - LF capture system in LHC (ACN)

ACN 200 MHz RF in LHC

- Present ACN proposal (1998)
  - **Improve capture, minimize losses for large emittance beams from SPS with large injection errors**

    (Estimated as up to 1eVs and ± 50 MeV/± 15° respectively)
  - Comprises 4 cavities per beam, 3 MV total per beam, 240 kW per cavity, for ultimate intensity
  - More expensive than original ADL (13.9 MCHF cf 5.2 MCHF)
- 2001 budget crises => proposal to install only half of the ACS and half of the ACN, since OK to half nominal…
  - But SPS improvements (successful impedance reduction program) had resulted in nominal emittance being obtained up to nominal intensity, and even above…
- **Decision taken to install all ACS,**

  Postpone 200MHz ACN till later when needed..

Capture Simulations : J. Tuckmantel, Chamonix 1999

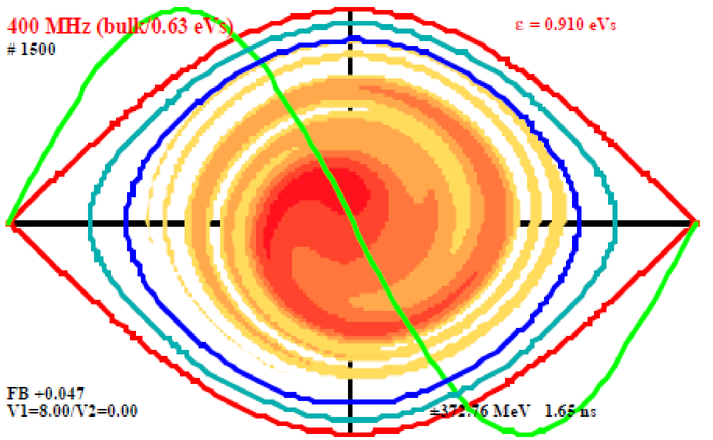


Fig. 5a: Bulk of bunches at 0.63 eVs injection with a simple 400 MHz system in LHC

- **0.63 eVs:** Beam can be captured directly in 400 MHz bucket

- **Up to 1.1 eVs:** 200 MHz capture then adiabatic transfer to 400 Mhz system avoids losses

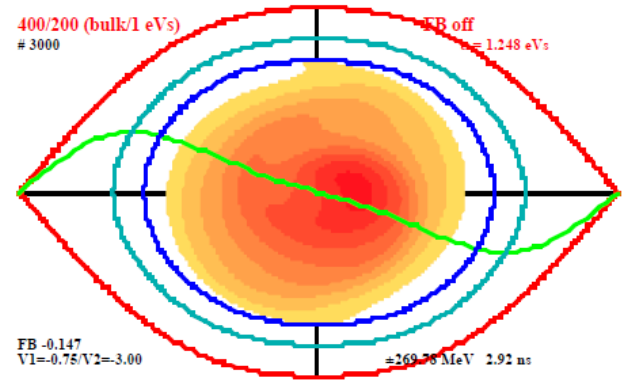


Fig 8a: 1.0 eVs bulk bunch captured by the 200 MHz system running at 3 MV with 0.75 MV 400 MHz as higher harmonic system. Displayed is the status after 3000 turns where the feedback (0.3 MV peak) is switched off

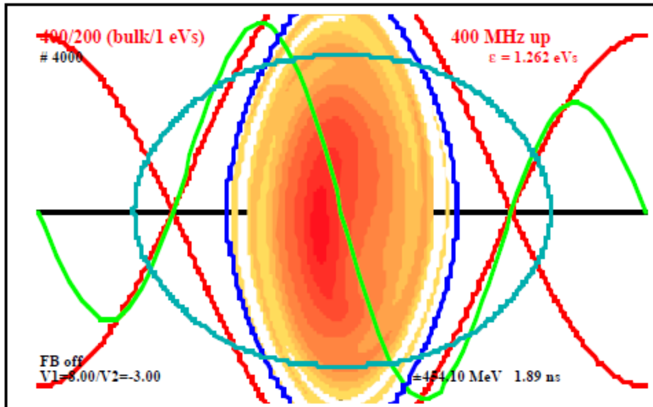
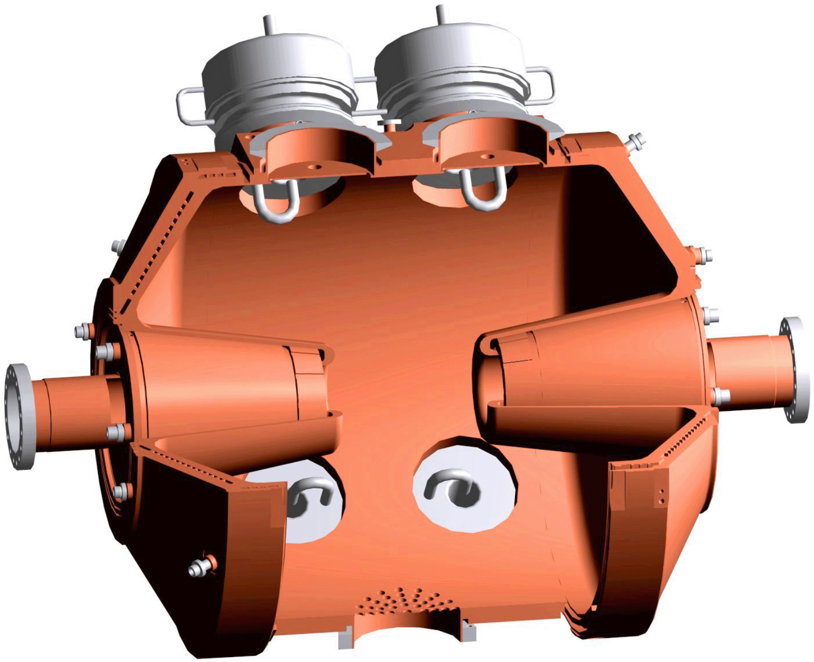


Fig 8b: As fig 8a but after 4000 turns: 400 MHz system ramped to 8 MV

ACN Cavities - Bare Cavity



- Design based on SPS 200 MHz standing wave cavities. (Leptons - 1980s)
- Nominal frequency is 200.210 MHz.
- Main design constraints:
  - Reduced diameter due to 420 mm beam separation.
  - Keeping HOM frequencies away from multiples of the 40 MHz bunch frequency
  - Slightly higher shunt impedance and lower Q than SPS SWC.
- With R/Q = 192 Ω and Q_o = 30,000 power dissipated in the cavity at nominal field of 0.75 MV is 49 kW : Special cooling channels to evacuate the high power.
- Optimum operation: Coupler Q_{ext} =5000, Z= 960 kΩ, V_b = 1 MV for nominal 0.58 mA beam current (Y=1.3) RF power needed 250 kW to handle injection transients (JT simulations)

- 4 HOM Couplers, with 1 kW loads
- Power coupler (high av. power)
- Piston tuner
- Two passive damper loops (brought in after capture or in coast)

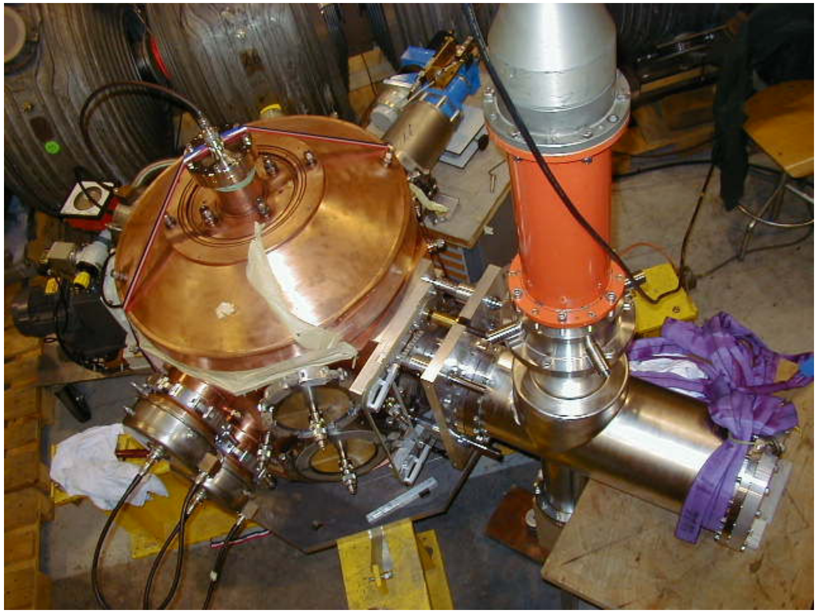
ACN Cavities

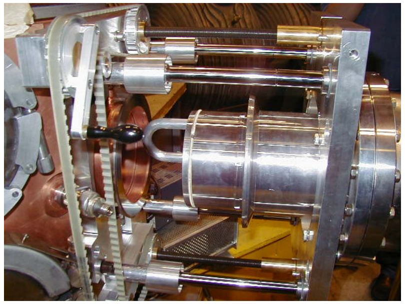
- Eight bare cavities have already been built by Ettore Zanon, Italy),
- All RF tested at low power and accepted (completed end 2003 by R. Losito)
- Stored in Prévessin B869 under dry nitrogen
- One has a small vacuum leak to be repaired
- **They have not yet seen any RF power!**

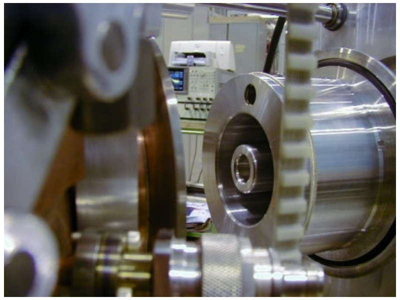
Power coupler – HOMs, Couplers, Tuners .....

- Higher Order Mode (HOM) couplers, tuner (200 kHz range), the two fundamental mode dampers recuperated from SWC cavities and refurbished.
- **The HOMs may need tuning**:

  for 50/75 ns bunch spacings
- **New power coupler**, based new SPS TWC one. Same ceramic. Low power version built to validate the geometry.
  - Special capacitive coupling loop without contact for higher power, separate water cooling of the body, inner coaxial line and the coupling loop
  - Low power tests have proven feasibility of design
  - Needs to be finalized and proto type tested
- **Need a 200 MHz 500 kW test stand** Planned in BB3 with the diacrode tests for SPS upgrade in BB3)

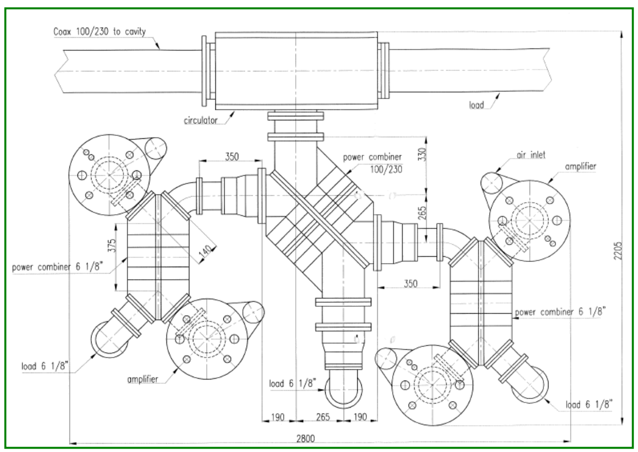




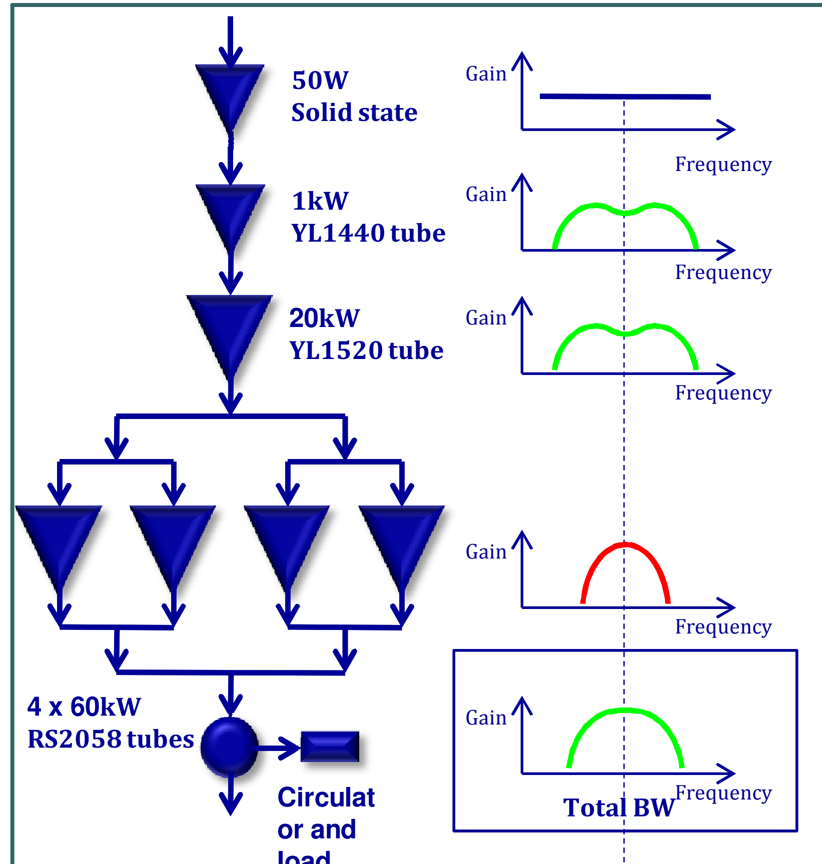


ACN Power Plant

- **RF drive chain -** as PS and SPS200, tetrodes
- **Re-use SPS SWC200 final amplifier design**, based on RS2058 tetrode. Have 25 amplifiers from SPS. Need 30 more (will take 2 years !)
- Final **amplifier combiner** arrangement as in the SPS200 power plant



- **Circulator** prevents reflected power going to the final stages (Prototype now delivered).
- **Power loads** same SPS200 ones (to be built)
- **New Power Converters needed**

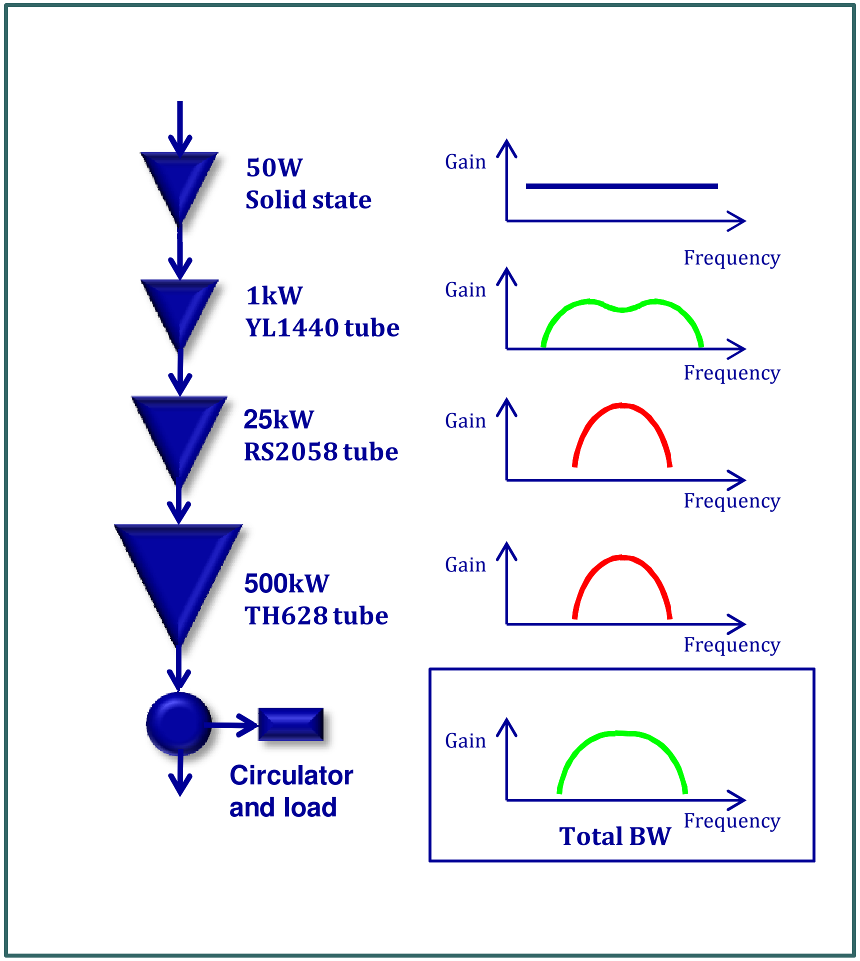


ACN RF Power Layout

ACN Power Plant : Diacrode power option

E. Montesinos.

- Option to use single diacrode as final stage instead of combined tetrodes
- Diacrode study will start in 2010 for SPS200 upgrade and TIARA collaboration (MICE)
- Eliminates the complex combiners system
- Higher power available (500 kW)
- Less tubes to operate, reduced maintenance
- Needs a completely new power converter (35 kV instead of 12 kV)
- Tube more expensive (because designed for higher power level)



Controls, LLRF

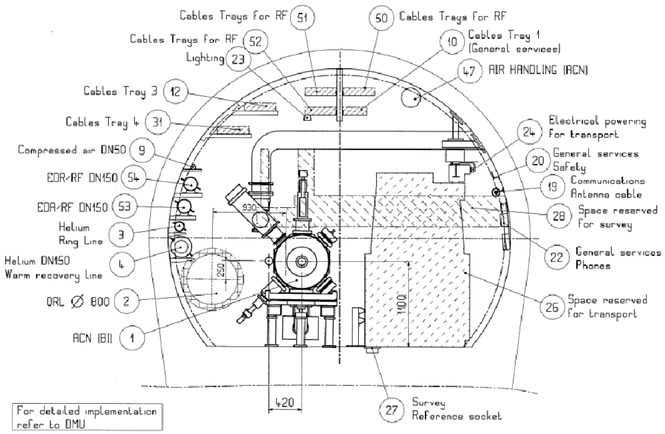
- Each cavity will need a cavity control system with almost the same complexity as the ACS SC cavities.
- Tuner control, No ‘Polar loops’ but RF feedbacks, Longitudinal damper, function generators etc.
- No major change to SR4 beam control system
- Will be installed close to the power system in UL44/46, in shielded units (No Faraday cage possible)

Total Budget - Rough Estimate

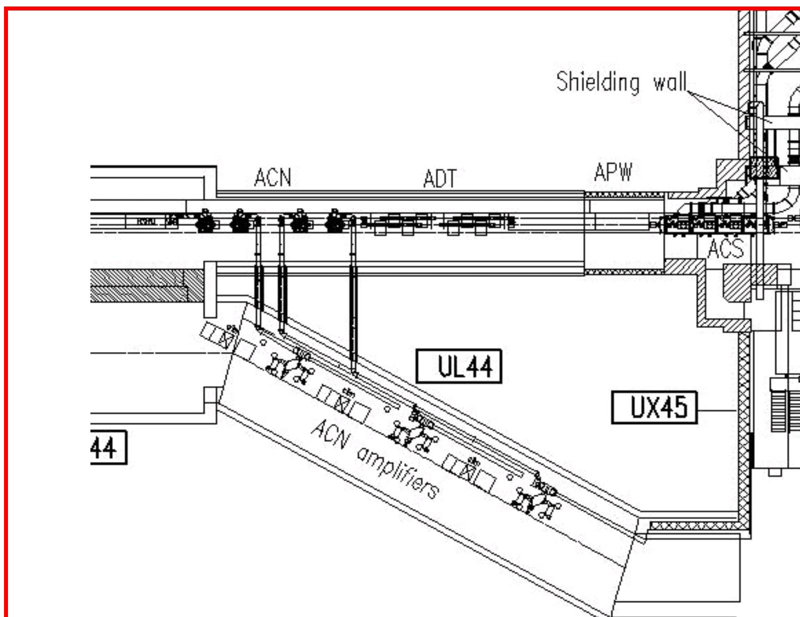
(bare cavities = 1’600’000 CHF already paid)

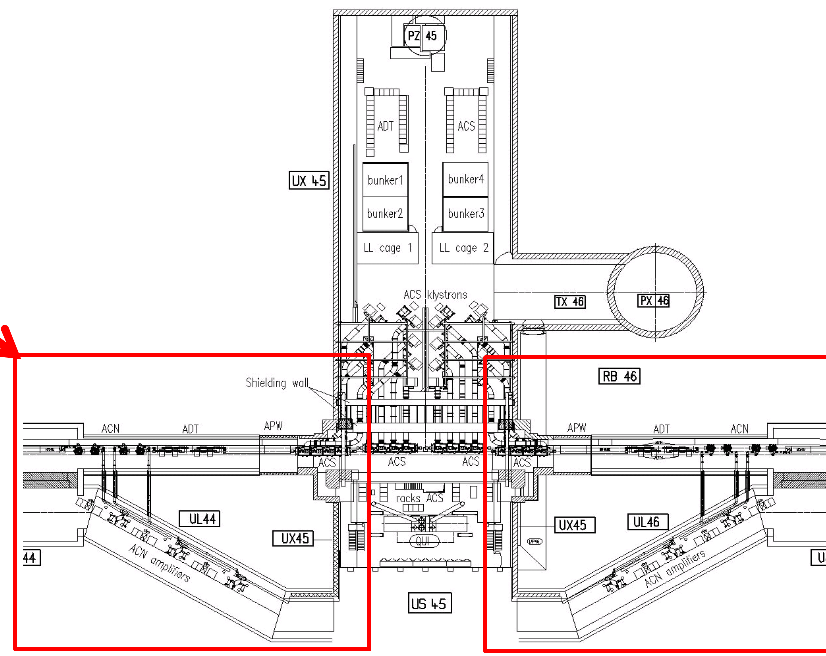
	Machine	Test	Spare	Have	Purchase	Unit Price [kCHF]	Total [kCHF]
Tetrode Amplifiers (add 750kCHF for Diacrode)							2’750
Power couplers	8	2	2	0	12	70	840
Conditioning test bench		1		0	1	250	250
Cavity auxiliaries (HOM, Tuner, Damping loop,..)	8	1	2	10	1	150	150
RF power distribution (including circulators + power loads + directional couplers)	8	1	1	0	10	285	2’850
Power supplies **(New)** (Ua + Ug2 + Ug1 + heaters)	8	1	1	0	10	350	3’500
Cabling	8	1	0	0	9	175	1’575
Cooling	8	1	1	0	10	35	350
Controls & LLRF	8	1	1	0	10	75	1’200
Total							**13’465**

ACN Integration



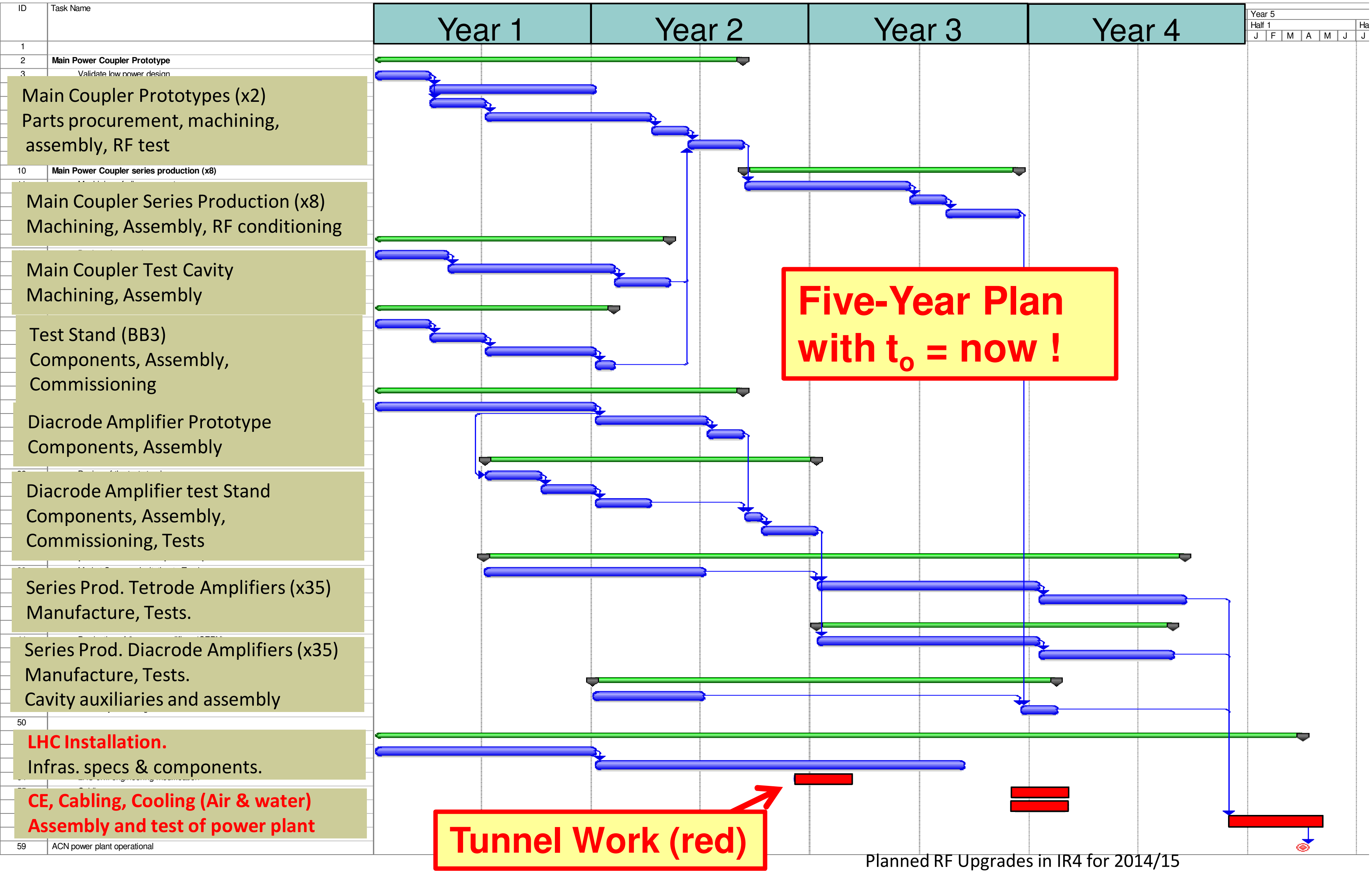
- Very tight space around the cavities to integrate auxiliaries and power coupler (also longitudinally)
- Holes in the RB walls have already been drilled
- Can make space in Controls Rack area for additional equipment





Planned RF Upgrades in IR4 for 2014/15

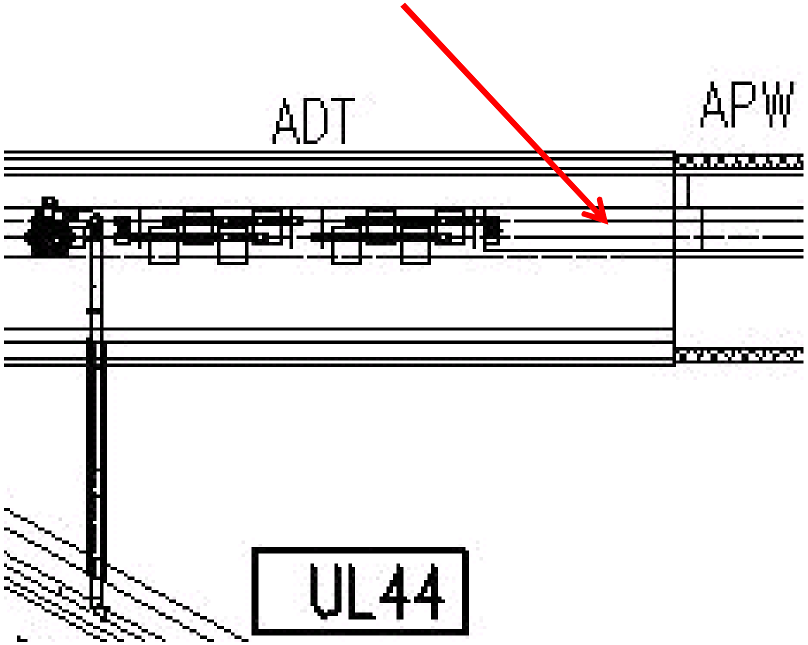
Draft planning for ACN construction and installation

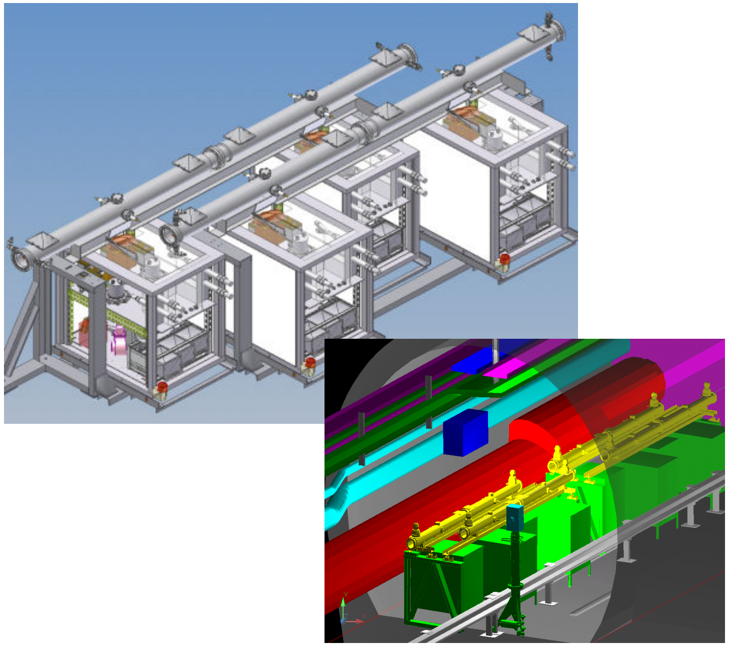


LHC ADT upgrade needs (1)

W. Hofle

- **In case of lack of kick strength** (due to large injection oscillations for example)
  - Push system to its limits +40% feasible (pulsed mode, reliability?)
  - Increase of beta functions at kickers (to be checked), scales with $\beta^{1/2}$
  - **Additional kickers in IR4** - space is reserved to increase present 2 kicker modules/plane per beam to 3 (4 MCHF for this 50% addition)





Planned RF Upgrades in IR4 for 2014/15

- **In case of large instability growth rates @ limit of bandwidth (20 MHz) (due to large impedance at higher frequency, for examples from collimators)**
  - **New power amplifiers** with increased bandwidth, possibly dedicated damping of modes which are unstable
  - **New kickers** (matched strip-line) and power amplifiers -> expensive; signal processing electronics can be re-used

- **If need for feedback at higher frequencies than 20 MHz** (to fight electron cloud induced single bunch instabilities and TMCI
  - **New dedicated high frequency feedback system** in reserve space

  Related to ongoing SPS studies on ecloud and feedback systems, new signal processing electronics, kickers and power amplifiers developments (long lead times !)

Cryogenics Upgrades in IR4

From L. Tavian / S. Claudet

- Definitely needed for Phase 2 10x Luminosity (Triplet at IR5)
- Not needed for IR upgrade Phase 1 (2x in Luminosity)
  - Unless larger dynamic losses than presently expected, e.g. electron cloud..
- Performance of cryo to be monitored during 2010 run,
  - Increasing beam intensity
  - nominal RF, + running with gradients approaching 8 MV/m, RF load 270W to 430 W/sector
  - less constant cooling requirements
- IR4 is critical !
- Layout of upgrade still need study (Integration in UX45)
- Would take 2 years to prepare, several months to install & commission
- Requires knowledge of e-cloud (extrapolation) by end of 2012 ..!

- Crab cavity requirements probably still inside the present capacity, simple extension proposed to QRL RF extension with modification of RF service modules. (B. Vullierme CC09)

- Independent cryo in IR4 would be a major operational advantage for RF !

Establishing Upgrade Needs - Baseline

ACN Review – 1

- We may be able to capture successfully directly in the ACS 400 MHz:
  - We can get nominal intensity from SPS in 0.7 eVs
  - Injection seems stable from 2010 experience, injection phase errors can be tracked and corrected pulse-to-pulse in LHC (planned for 2010). To see at higher intensity.
- The ACN system is technically feasible. We have bare cavities plus tuners and major components. BUT Still need do a lot of work, including HPRF testing.

  Costly to construct and maintain
- It would be two additional substantial new high power RF systems in LHC
  - Operational complexity, additional cavity feedback & control loops
  - Reduced reliability (needs to be on at injection, on or passively damped after)
  - Increase LHC impedance, lower fault tolerance, gets worse with high intensity

Establishing Upgrade Needs - Baseline

ACN Review – 2

- Beam still needs to be transferred to the 400 MHz RF system at end of filling, risk of dilution in 200 MHz then lossy transfer/ghost bunches during transfer into 400 MHz if we spend a long time at injection.
- Like ACS, it will not work effectively above ultimate… (Power limitation, Beam loading Y>>2, transient effects, tolerance to phasing and cavity tuning errors, RF hardware imperfections)
- Nevertheless, can't say now it is **not needed**, need therefore to continue with critical developments, study beam behaviour in 2010, to get to a final decision..

Establishing Upgrade Needs

Crab Cavity in IR4

- After Crab Cavity Workshop CC09, strongly renewed interest.
- CC09 agreed that compact SC crab cavity would be best option
- Global scheme in IR4
- Would not manage to install this for 2015….
- Use either ACN or ADT space in IR4
- Could prepare cryo upgrade during any shutdown

  Modification of RF service modules, extra He connections on RF Service Module

  – a few weeks estimated by B. Vullierme

See R. Calaga Session 9

Establishing Upgrade Needs

800 MHz in LHC

- Higher harmonic Landau cavities frequently installed in high energy proton machines, ISR, SPS, RHIC.. Bunch lengthening/shortening modes.
- HH cavity introduces spread in synchrotron frequency inside the bunch.

  Stability thresholds depend on both energy spread and synchrotron frequency spread; HH cavity an alternative to emittance blow up in presence of instabilities
- Possibility of bunch instabilities from impedances at frequencies outside range of cavity feedbacks, not easy to combat - May pose limitation as we go to higher intensities ?
- LHC Project Note 394 (2007 T. Linnecar, E. Shposhnikova), proposes a study on an 1.2 Ghz system with 3 SC cavities per beam providing ~3 MV

  Recent thinking leads to 800 MHz, with easier requirements on HOM coupler, power coupler designs.
- Would need studies & RD on cavities, couplers, HOMs
- Time scale would certainly be beyond 2014/15, but we should certainly invest time and effort in a preliminary study

Conclusions - 1

- Baseline planned upgrades in IR4 have been presented (ACN, ADT, Cryo)
- Crab cavity in depends on liberating spare ADT or ACN reservations.
- 200 MHz upgrade in SPS emerges as a significant potential benefit for LHC
- Several questions on the best upgrade strategy for RF with ultimate beam

  Q: If we see good results for capture of beams to nominal, and we decide to do SPS upgrade, could we take the risk to drop ACN
- Other options
  - 800 MHz in LHC
  - Cryo upgrade
- All need beam experience
- Will we have enough beam experience by end 2012 ?

Conclusions - 2

- To keep all options open, preparation work would need to go on for **planned** and **proposed** upgrades:
  - **ACN (hardware)**
  - **ADT hardware**
  - **Crab cavity design**
  - **LHC 800 MHz**
  - **Cryo upgrade in IR4**
  - **SPS 200 MHz upgrade**
- Resource & planning issues
- Agree on priorities of the activities and the time scales !

Planned RF Upgrades in IR4 for 2014/15

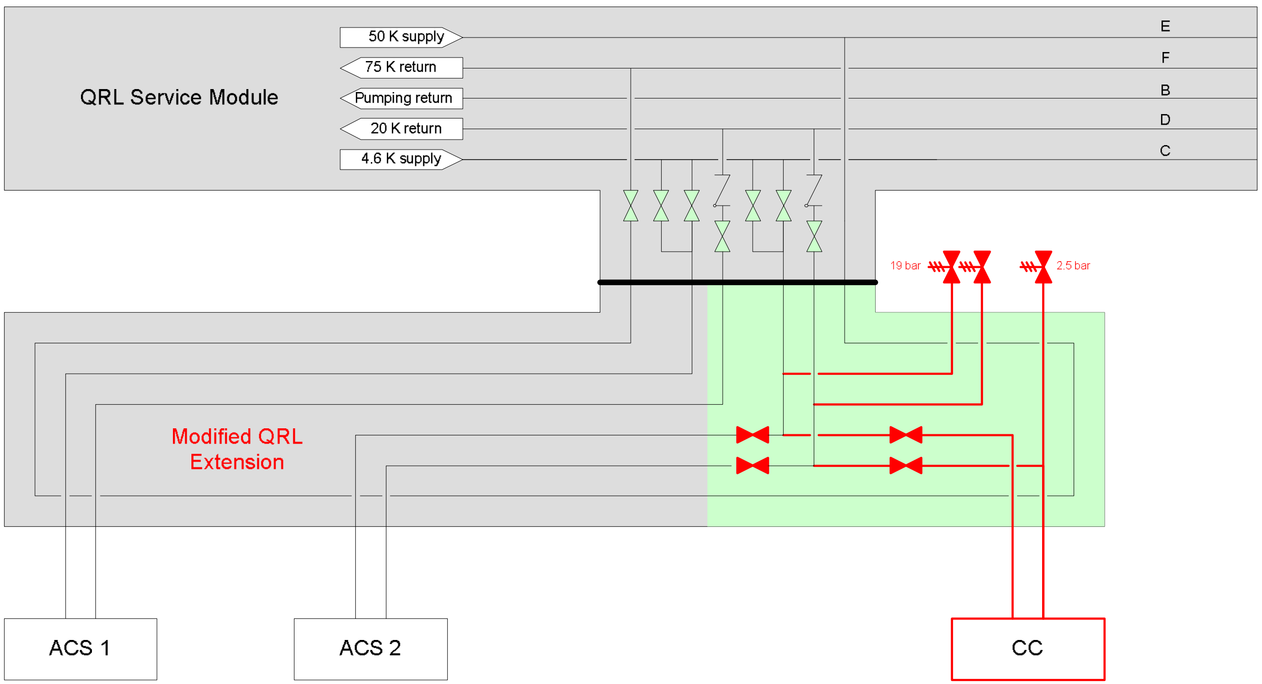
Thanks for your attention

Spare Slides

Cryogenics Installation - BV

- Option 2) 4.5 K simple option

The straightforward solution is to finally modify the supply and return lines of the *QRL extension* to one of the two ACS cryomodules, in order to connect the CC in parallel, via an additional set of valves.



Beam parameters and heat load data

Scenario		Nominal	Ultimate	Short-bunch	Long-bunch
energy, E	[TeV]	7	7	7	7
beam current, I	[A]	0.58	0.86	1.72	1
bunch number, nb	[-]	2808	2808	5616	936
bunch spacing, sb	[ns]	25	25	12.5	75
bunch current, Ib	[mA]	0.2	0.3	0.3	1.1
rms bunch length, s_z	[mm]	75.5	75.5	37.8	144
luminosity, L	[$cm^{-2}.s^{-1}$]	10^{34}	$2.3.10^{34}$	$9.2.10^{34}$	$8.9.10^{34}$
resistive heating	[W/m]	0.1	0.1	0.1	0.1
synchrotron radiation	[W/m]	0.34	0.50	1.0	0.58
image currents	[W/m]	0.30	0.66	3.7	1.9
beam gas scattering	[W/m]	0.076	0.11	0.23	0.13
average e-clouds	[W/m]	2.1	2.1	**27**	0.52
RF losses per half insertion	[W]	214	480	1000	2040
secondaries per half insertion	[W]	190	440	**1770**	**1710**

Required cryoplant capacity (Without contingency)

Scenario	Layout	Existing LHC Cryoplant margin			New Cryoplant capacity	
		1.8 K unit		4.5 K Cryoplant	RF Cryoplant	IT Cryoplant
		IT @ 1.8 K	IT @ 4.5 K			
		[kW @ 1.8 K]		[kW @ 4.5 K]	[kW@ 4.5 K]	[kW @ IT Temp.]
Nominal	**Layout 1**	**1.0**	**N/A**	**1.2**	**N/A**	**N/A**
Ultimate	Layout 1	0.6	1.1	**-1.2**	N/A	N/A
	Layout 2	**0.6**	**1.1**	**0.2**	**1.4**	N/A
	Layout 3	1.1	1.1	**-0.1**	N/A	0.9
	Layout 4	1.1	1.1	1.3	1.4	0.9
Short-bunch	Layout 1	**-1.8**	0.0	**-51**	N/A	N/A
	Layout 2	**-1.8**	0.0	**-48**	2.4	N/A
	Layout 3	0.0	0.0	**-47**	N/A	3.5
	Layout 4	0.0	0.0	**-44**	2.4	3.5
Long-bunch	Layout 1	**-0.7**	1.1	**-9.0**	N/A	N/A
	Layout 2	**-0.7**	1.1	**-3.1**	4.5	N/A
	Layout 3	1.1	1.1	**-4.5**	N/A	3.4
	Layout 4	**1.1**	**1.1**	**1.4**	**4.5**	**3.4**

Blue: Possible layout | **Blue Bold: Recommended layout**