Choice of single or double RF windows

Eric Montesinos (cern)

with data from many worldwide colleagues:

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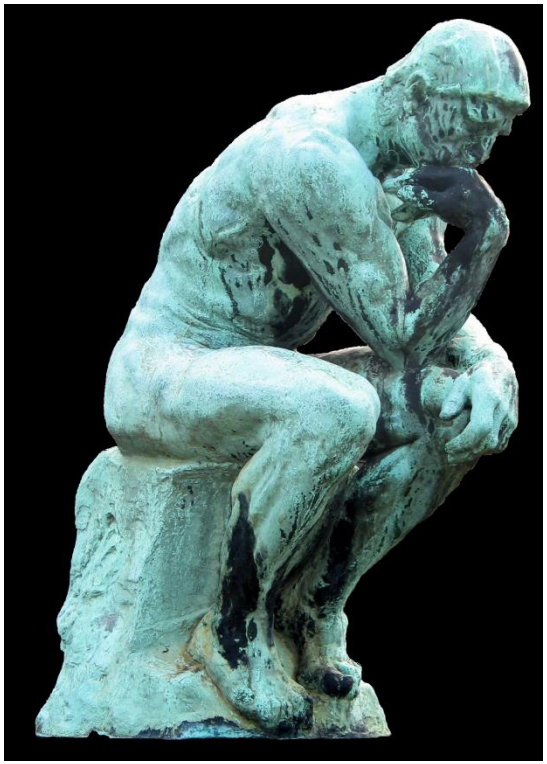
The Eternal question



The thinker, Auguste Rodin

How many windows a coupler has to have: one or two?

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One or Two windows

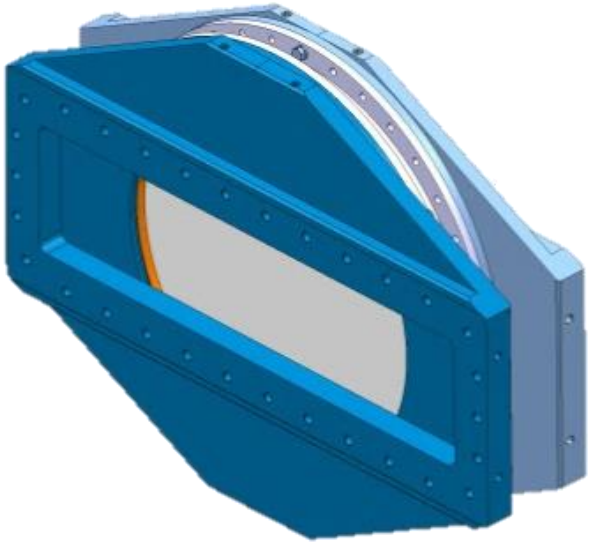
One window couplers

Lab	Coupler	Technology	Frequency [MHz]	Average [kW]	Peak [kW]	Quantity	Years of operation
KEK	KEK-B	Cylindrical	508	800	800	10	5
KEK	cERL	Disk	1300	50	180	6	0.5
J-park	ADS	Disk	972	165	2200	4	0
Oak Ridge	SNS	Disk	805	45	2000	81	9
Argonne	APS	Cylindrical	352	80	100	20	18
DESY	HERA	Cylindrical	500	80	80	16	17
ESRF	BR+SR	Cylindrical	352	100	100	16	19
Cern	SPS	WG	801	225	225	8	25
Cern	SPS	Cylindrical	200	375	500	16	20
Cern	SPS II	Disk	200	550	800	16	12
Cern	LEP II	Cylindrical	352	100	160	288	7
Cern	LHC	Cylindrical	400	350	600	16	6

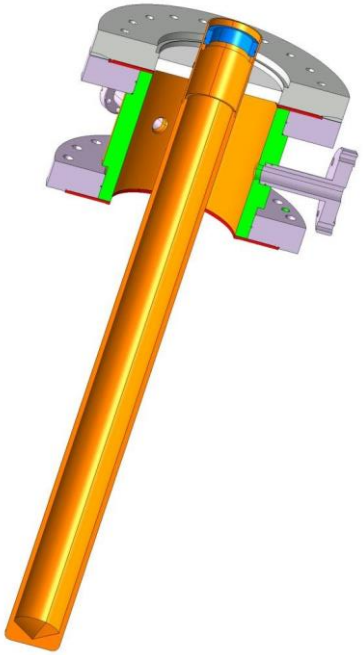
Two windows couplers

Lab	Coupler	Technology	Frequency [MHz]	Average Power [kW]	Peak power [kW]	Quantity	Years of operation
KEK	STF1	Disk + Disk	1300	7.5	1500	4	1
KEK	STF2	Disk + Disk	1300	7.5	1500	2+16	1+0
Cornell	ERL	Cyl + Cyl	1300	65	85	1	1
FNAL		Conical + WG	1300	2.6	1000	13	20
DESY	TTF I	WG + Cyl	1300	2.6	1000	8	2
DESY	TTF II	WG + Cyl	1300	4.5	1100	16	17
DESY	TTF III	Cyl + Cyl	1300	4.5	1100	32	15
BESSY	TTF III	Cyl + Cyl	1300	10	10	1	0
LAL	TTF V	Cyl + Cyl	1300	4.0	2000	2	0

One window couplers



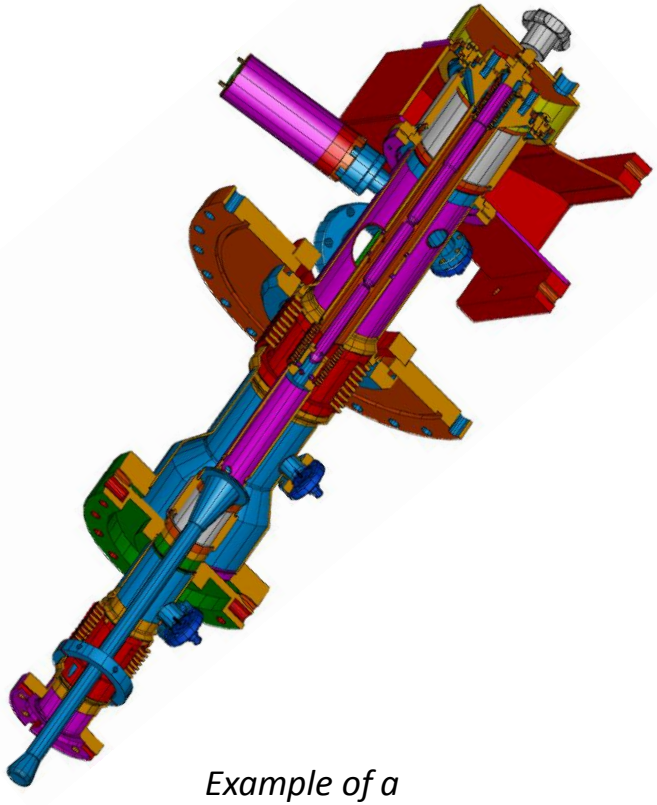
Example of a
Wave guide window
Cern-Linac4
1 MW – 2 ms – 50 Hz SW



Example of a
Coaxial Disk window
Cern-SPL
1 MW – 2 ms – 50 Hz TW

Example of a
Coaxial Cylindrical window
Cern-SPL
1 MW – 2 ms – 50 Hz TW

Two windows couplers



Example of a
Two Cylindrical windows
TTF III
1.2 MW – 400 µs – 10 Hz TW

Example of a
Two Disk windows
STF2
1.2 MW – 400 µs – 10 Hz TW

Experience with one window coupler

CERN - SPS

- 16 couplers in operation
- Few prototypes broken during 70's
- From 1975 to 2000, two couplers broken in 1998
- Since 2000, new coupler design without a single trouble

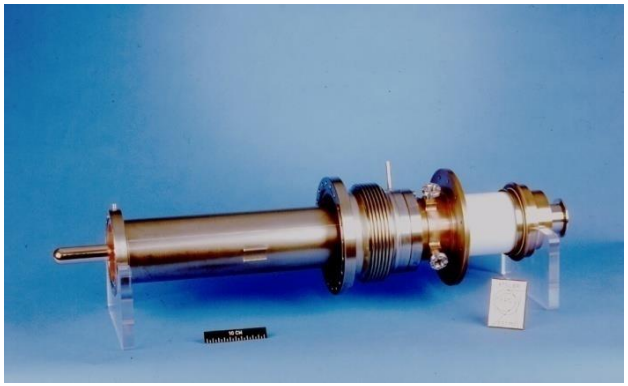
SPS cylindrical window 1975-2000

SPS disk window 2000-…

Experience with one window coupler

CERN - LEP

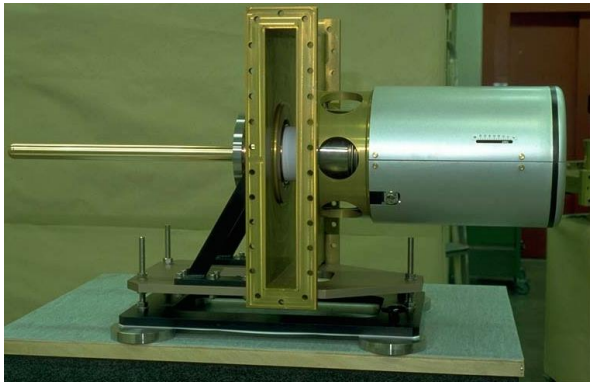
- 288 couplers in operation from 1994 to 2000
- Not a single coupler broken during operation
- After dismantling in 2001, few couplers were found strongly metalized



LEP II cylindrical window 1994-2000

CERN - LHC

- 16 couplers in operation since 2006
- Not a problem right now



LHC cylindrical window 2006-…

Experience with one window coupler

ESRF

- 16 cylindrical window couplers (LEP I type) in operation since 1992
- 2 broken ceramics in 1994 after opening the cavity to change the coupling
  - Strongly metalized
  - Too slow vacuum interlock ~ 100 ms and at too high pressure 1 x 10-6 mbar (now ~5 ms and 1 x 10-7 mbar)
  - Probably a too fast conditioning process as well
  - Few couplers exchanged as overheating or leaky
- One cavity with 6 coupler exchanges between January and August 2008
  - Very small leaks
  - Always onto the same cavity even with spare couplers
- New spare couplers (LEP I)
  - A first 'dirty' series shows glow discharge and overheating, couplers removed from operation
  - A second 'clean room' series shows not a trouble
- Since 2008
  - Few 'pinhole' leaks, ok for operation
  - varnished method is ok, but couplers have to be replaced during the next long stop

Experience with one window coupler

APS

- 20 cylindrical window couplers (LEP I type like) in operation since 1995
- 6 failures were caused by arcing on the vacuum-side of the coupler which resulted in overheating ceramics due to Cu plating
  - There was typically no warning
  - Just one huge vacuum pressure spike which tripped off the rf system and caused a beam loss
- 2 failures were due to pinhole vacuum leaks in the ceramics
  - Developed suddenly with no warning or other symptom
  - First detected by noticing slowly rising vacuum pressure
- In all cases of coupler failure, there was no damage done to the cavities themselves
- The booster coupler that developed a leak resulted in approximately 3 days of downtime, mostly spent conditioning the new coupler up to power

Experience with one window coupler

DESY - HERA

- 16 couplers (LEP I type) with 17 years of operation
- Two couplers had to be exchanged, small leak in the ceramic
- No degradation of the cavity Qo
- No degradation of gradient, but the gradient was very low: 4 MV/m

Experience with two windows coupler

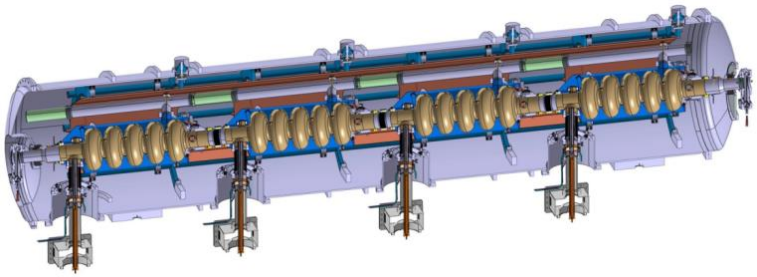
DESY - FLASH

- Three different versions to date
  - 8 couplers with warm wave guide window, cold conical window Fermilab version
  - 16 couplers with warm wave guide window, cold cylindrical window TTF2
  - 32 couplers with two cylindrical windows TTF3
- Not a single ceramic failure impacting the machine over the years
- Some problems with wave guide boxes at the doorknobs of TTF3, easy to exchange
- Absolutely no degradations in Q or E due to couplers was observed over 20 years of operation

Future projects

ESS

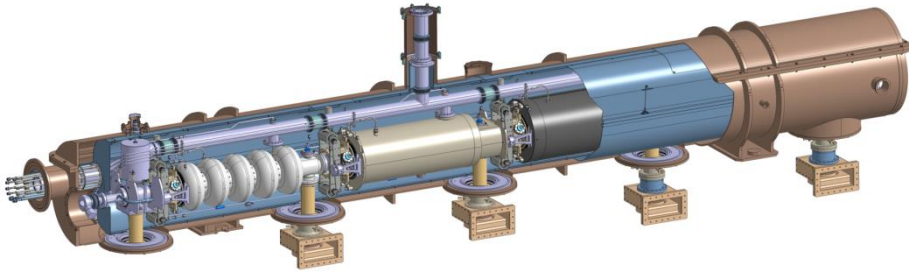
ESS cryomodule



- 120 cavities @ 704 MHz
- 1.1 MW - 3.5 ms - 14 Hz
- Average power = 54 kW
- CEA (Toshiba) one window couplers

CERN-SPL

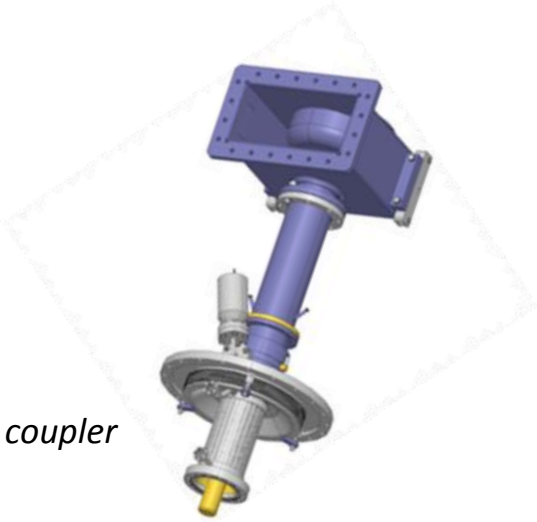
CERN-SPL cryomodule



- 246 cavities @ 704 MHz
- 1.1 MW - 2 ms - 50 Hz
- Average power = 110 kW
- CERN one disk or one cylindrical window couplers

Future projects

ESS



ESS-CEA coupler

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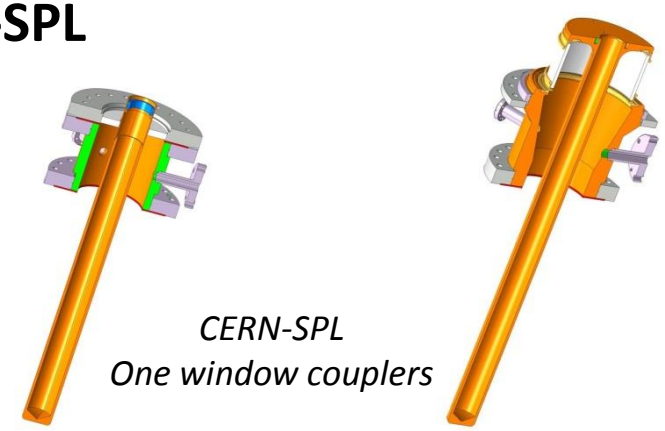
CERN-SPL



CERN-SPL
One window couplers

- 246 cavities @ 704 MHz
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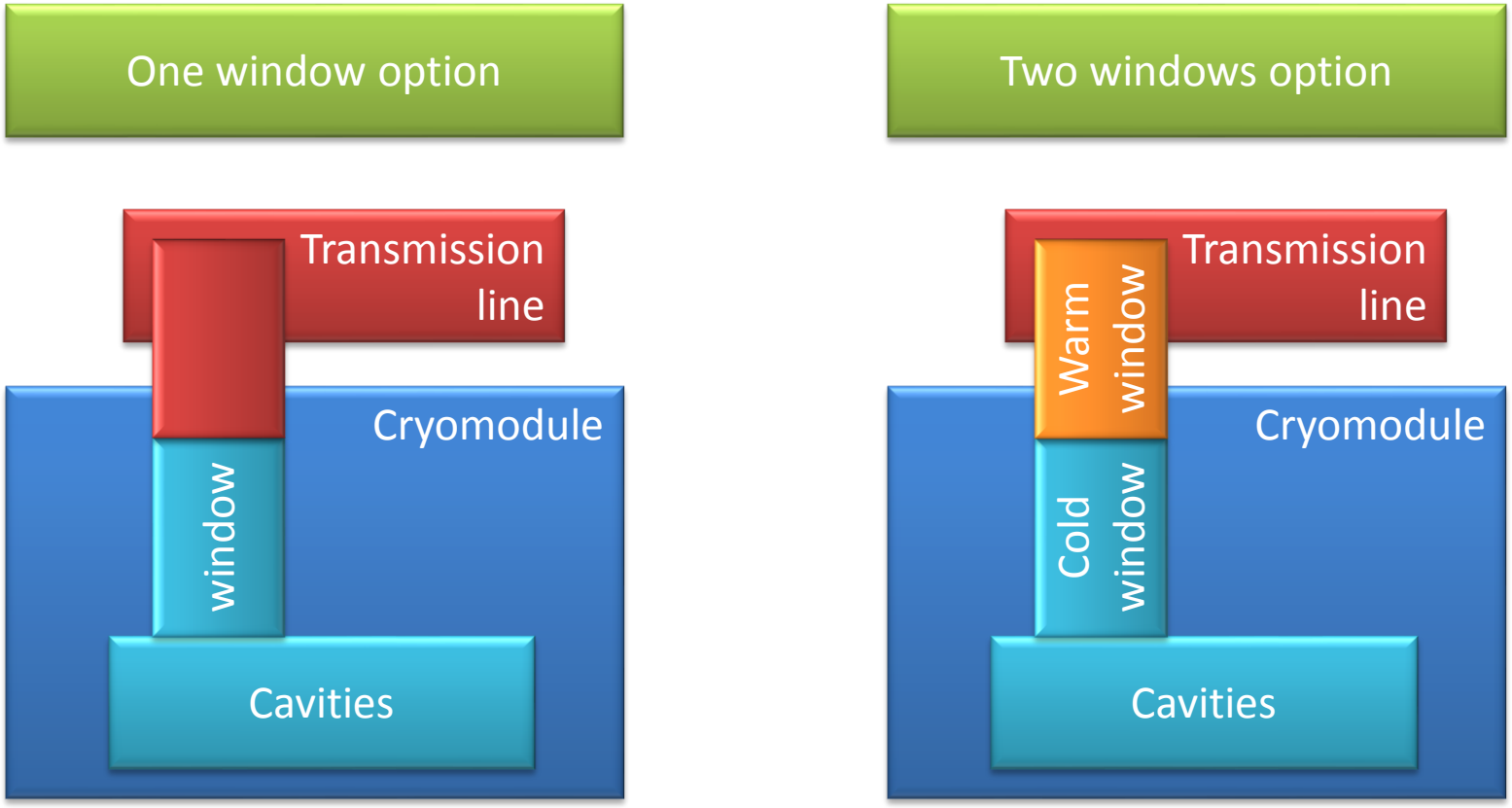
- Average power = 110 kW
- CERN one disk or one cylindrical window couplers

Is tube experience relevant regarding couplers ?

- Many tubes have been stored for years and years, some for more than a decade
- Suppliers and users do not remember a leak that developed during storage
- The main reason for a broken window ceramic is inhomogeneous heating
- Surface heating by multipactor
  - In this respect tube windows have a clear advantage over coupler windows, since in klystrons the anti-multipactor coating (usually TiN) is never again exposed to air after bake-out and RF conditioning, opposite to the coating on a coupler window
- Surface heating by RF arcs and/or metal coating of the ceramic
  - This is an accidental cause for damage, usually unrelated to the design of the window, because the arc is normally created somewhere else in the structure and only ends up at the window while moving towards the RF source, the coupler is seen, rarely the source

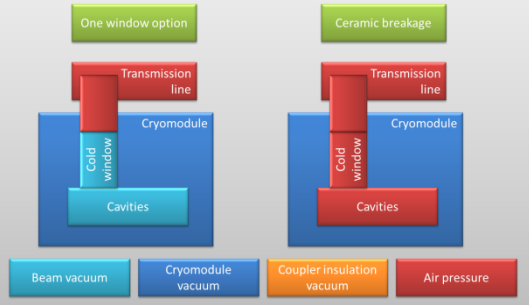
Basic concept of an ILC coupler with one or two windows



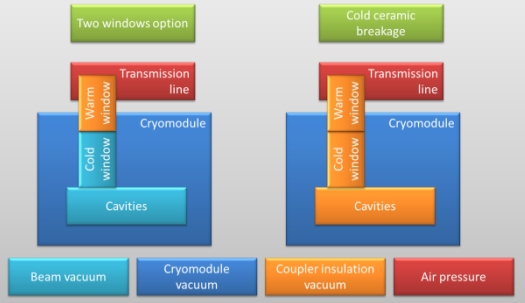
Beam vacuum | Cryomodule vacuum | Coupler insulation vacuum | Air pressure

Consequences of a ceramic failure

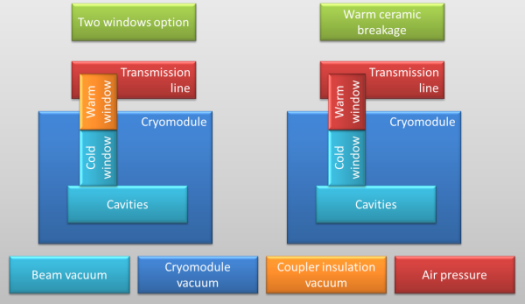
One window coupler
- Air will be in direct access to the beam vacuum
- Cavities will be polluted
- No in-situ repair as high gradient
- Regarding sectorisation scheme, several cavities will be affected



Two windows coupler, cold window failure
- Coupler insulation vacuum will be in direct to beam vacuum
- Even difficult to detect
- Probably cavities reduced performances

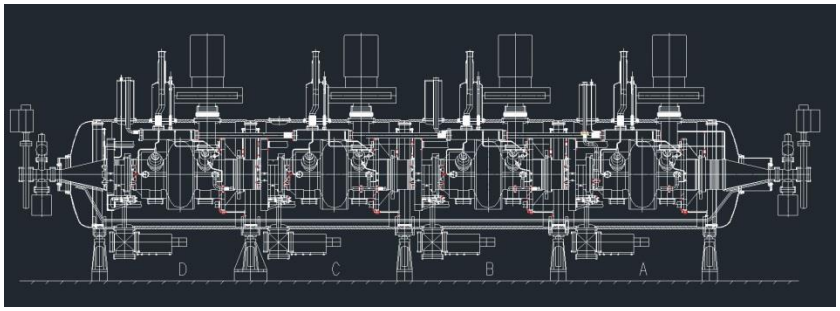


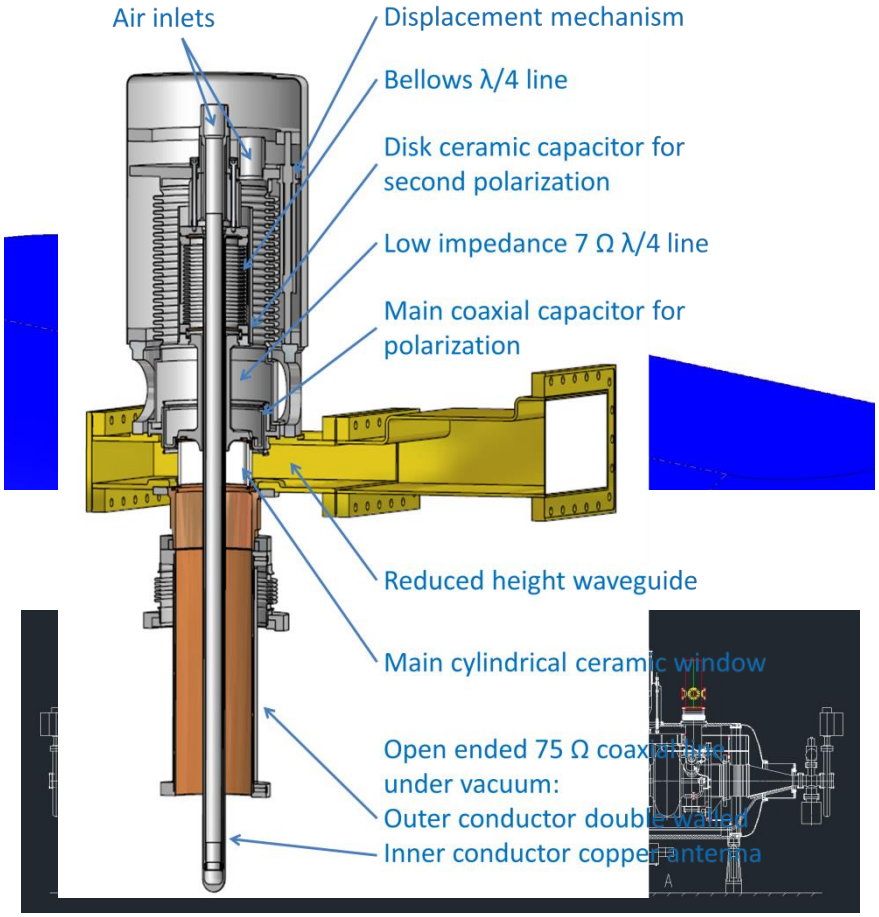
Two windows coupler, warm window failure
- Beam vacuum is preserved
- Warm window will be at atmospheric pressure
- Probably even possible to exchange the warm window



LHC single window strategy in case of breakage

- Based on past experiences with single window coupler, we believe a single ceramic coupler is now reliable enough for ~ 15 years of operation
- Couplers have an individual vacuum gauge
- If a leak is detected, beam is dumped
- Transmission line and mechanism are removed
- A vacuum cover is covering the window
- A coupler vacuum is insulating the ceramic
- The cavity is out of order, but should have preserved the other cavities thanks to the cryopumping of the cavity itself
- 8 MV/m cavities
- We wait for a long stop to exchange the module (1 month work)
- Our way to mitigate time/cost to repair/replace a coupler

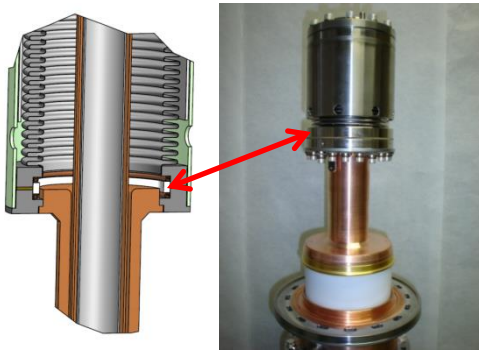




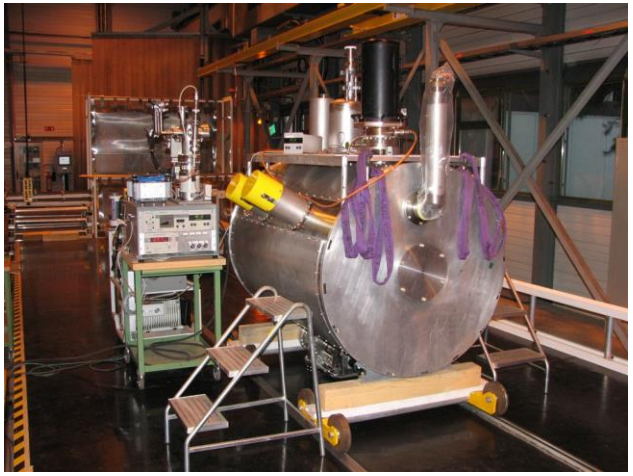
LHC failure in situ (no) repair

- In situ repair will NOT be an option
  - The LHC test cavity presented a very small leak (2 x 10^{-9} mbar l/s) at a coupler second ceramic
  - We tried a vacuum liquid sealant repair (as often successfully done with SPS warm cavities)
  - The leak was repaired
  - It was absolutely catastrophic
    - We could not reach more than 2 MV/m
    - We had to completely dismantle everything
    - All the components were polluted
    - It took a year to repair it
  - We (re-)learnt in-situ repair with SRF cavities is forbidden
- Must have spare modules for exchange

Vacuum sealant



Leaky polarisation ceramic



LHC test cavity 21

Sectorisation

- In case of breakage of a one window coupler, we must keep in mind that
  - NO in-situ repair is possible
  - We must be ready to exchange a whole sector
  - This is a huge job
  - This has to be taken into account for sectorisation issues
- We have to weight the time/cost to repair/replacement of a coupler especially if you have to warm up an entire section of the machine (in a hurry?)
- We have to take care of the huge helium gas volume to be stored

Conclusion : reasons for a failure

- Surface heating by multipactor

  the ceramic has to be RF re-conditioned after any warm-up or air pressure exposure

- Surface heating by RF arcs and metal coating of the ceramic

  The arc is normally coming from somewhere else in the structure and only ends up at the window while moving towards the RF source

  This generates metal coating (copper) of the ceramic, additional losses and mechanical stress to the ceramic, and finally this induces a crack

- Pinhole leaks

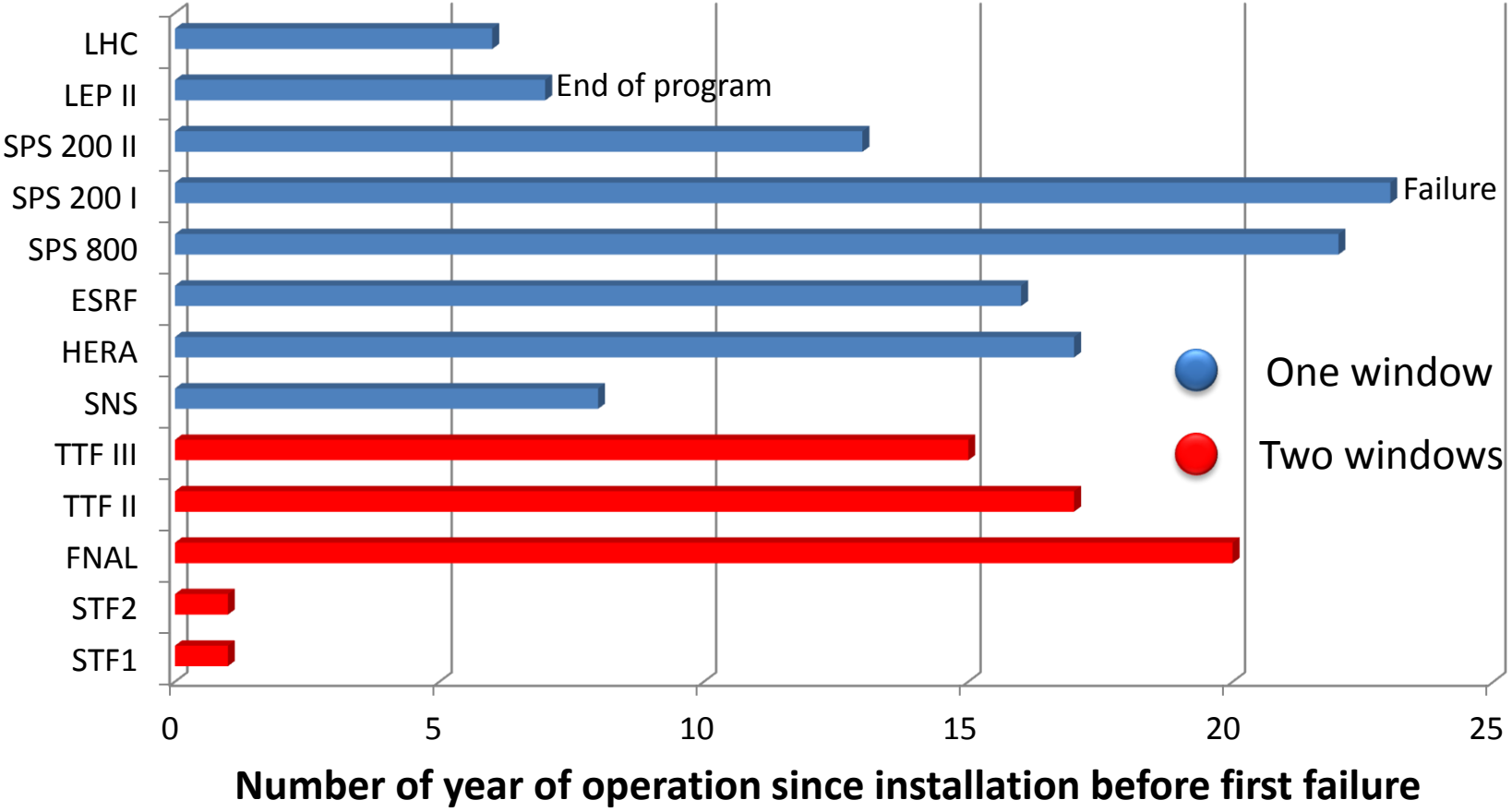
  Develops in time, linked with the structure of the ceramic itself, very difficult to predict

- Brazing leaks

  Develops in time, very difficult to predict

Conclusion : First Failure in Operation

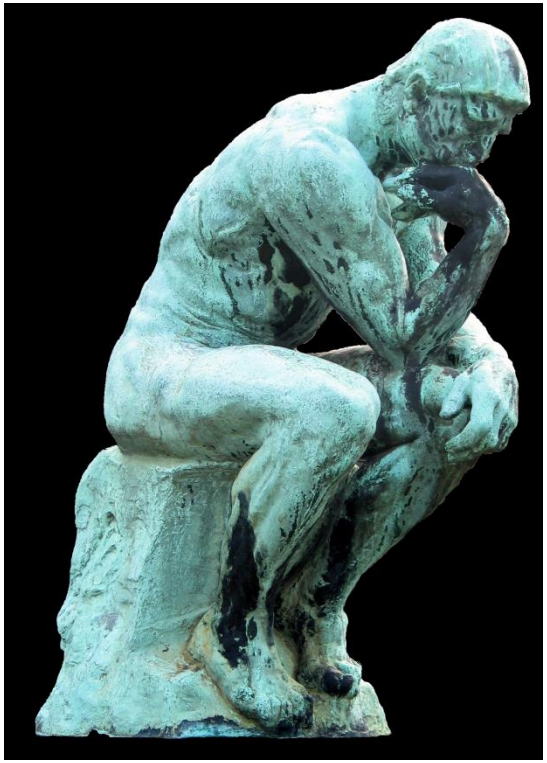
Maximum lifetime before first failure : 15-20 years ?



Conclusion : One window coupler Prototype

- It would be very interesting to setup a collaboration with industrials, asking for a one window coupler
- It will be an ILC warm window based on TTF III or STF2 cold window as close as possible to the cavity for integration issues reasons
- The goal is to make it much less expensive
- We could ask some prototypes to be extensively tested in order to compare them with the two windows option

The Eternal question : conclusion



The thinker, Auguste Rodin

- How many windows a coupler has to have: one or two?
- Entities must not be multiplied beyond necessity
- Sectorisation of the machine is a key parameter to answer such a question
- Prototyping should give us the final answer