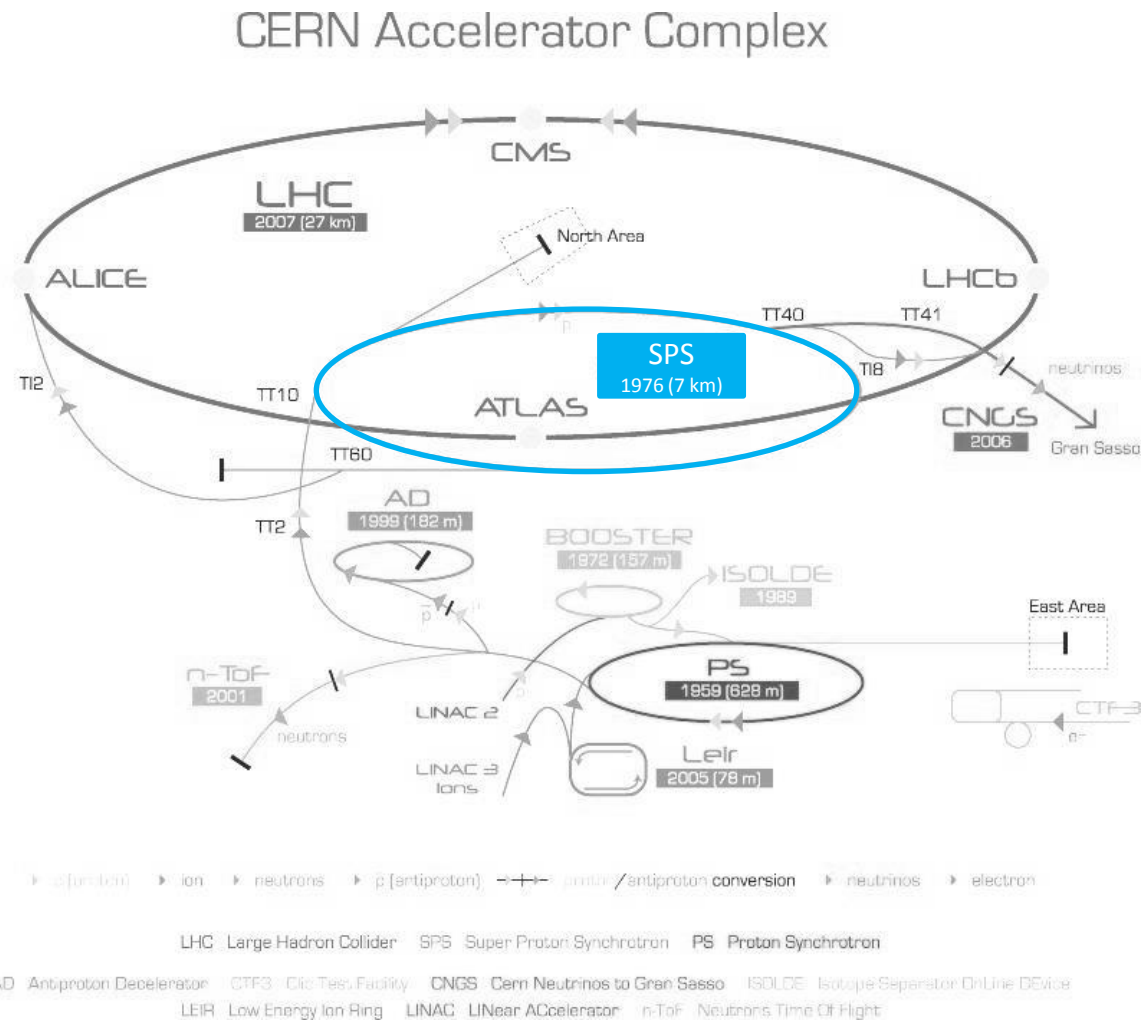
Almost 40 years of operation with tetrodes in the CERN-SPS

CWRF workshop 2014, Trieste

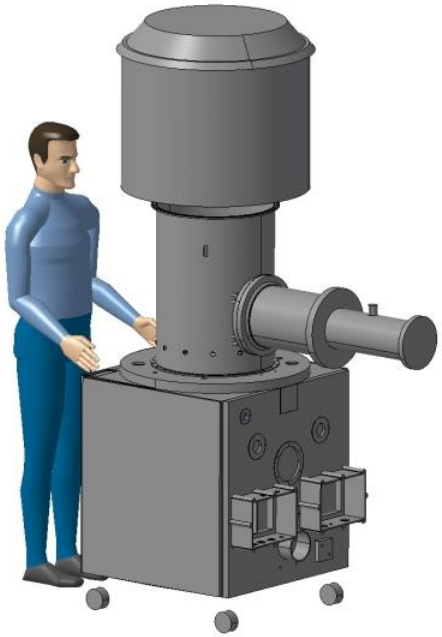
Eric Montesinos, CERN-RF, on behalf of RF-SPS team

What is the CERN-SPS ?

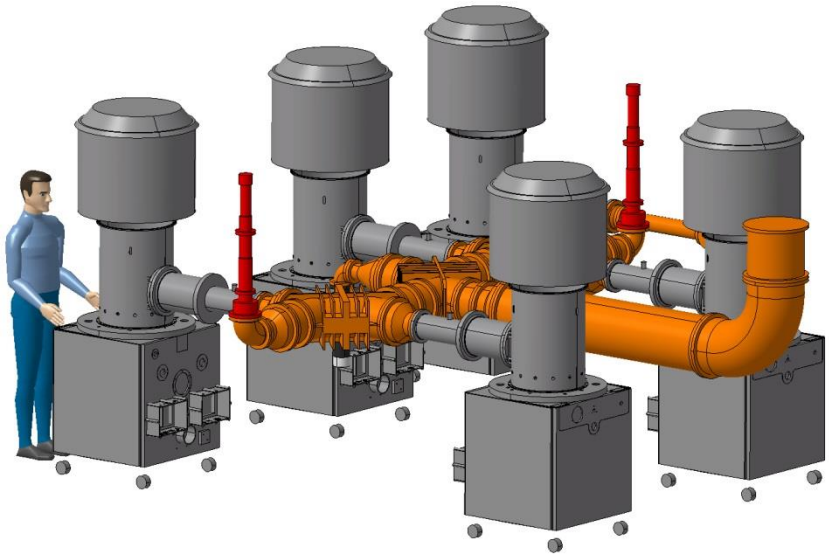


RF in the SPS

1972
prototype Siemens Amplifier
RS2004 tetrode
137.5 kW CW @ 200.2 MHz

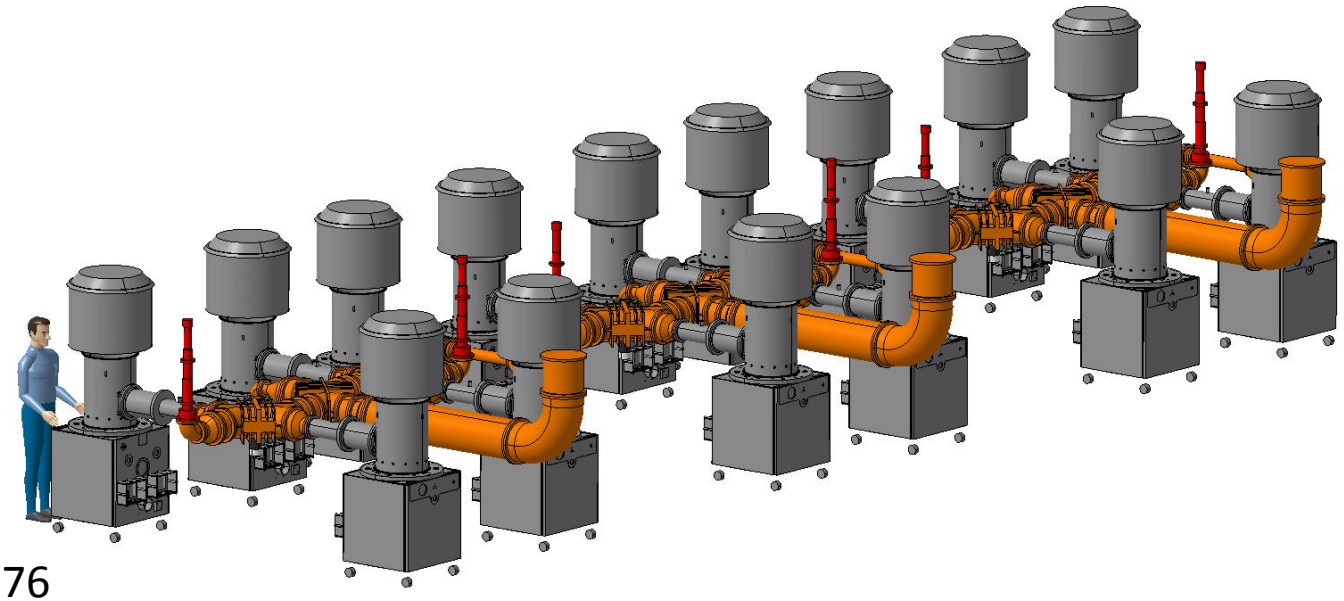


RF in the SPS



1974
First Siemens Transmitter
1 x RS2004 Driver
4 x RS2004 Finals
Total output power = 515 kW CW

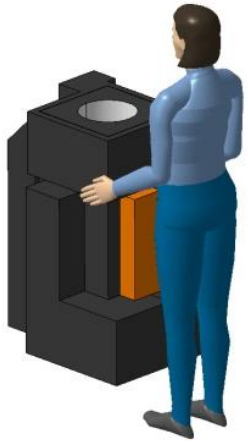
RF in the SPS



1976
Three Siemens Transmitters
3 x 515 kW CW

RF in the SPS

1978
prototype Philips Amplifier
YL1530 tetrode
35 kW CW @ 200.2 MHz



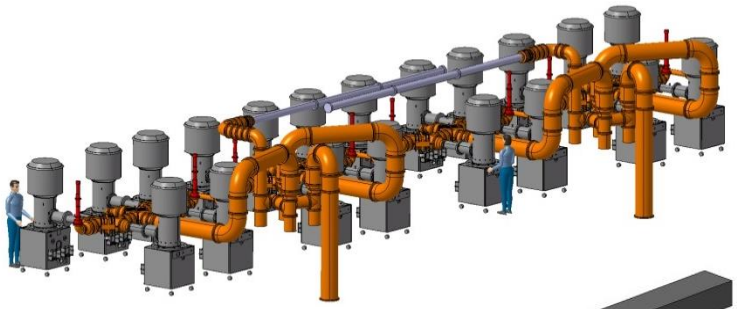
RF in the SPS

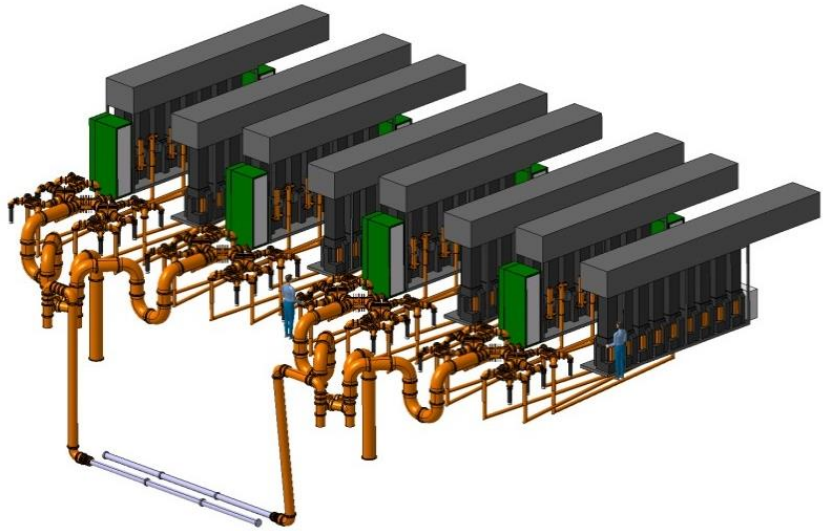
1970 1980 1990 2000 2010 2020

1980

2 Siemens Lines
20 x RS2004
2 x 1 MW CW

2 Philips Lines
72 x YL1530
2 x 1 MW CW





RF in the SPS

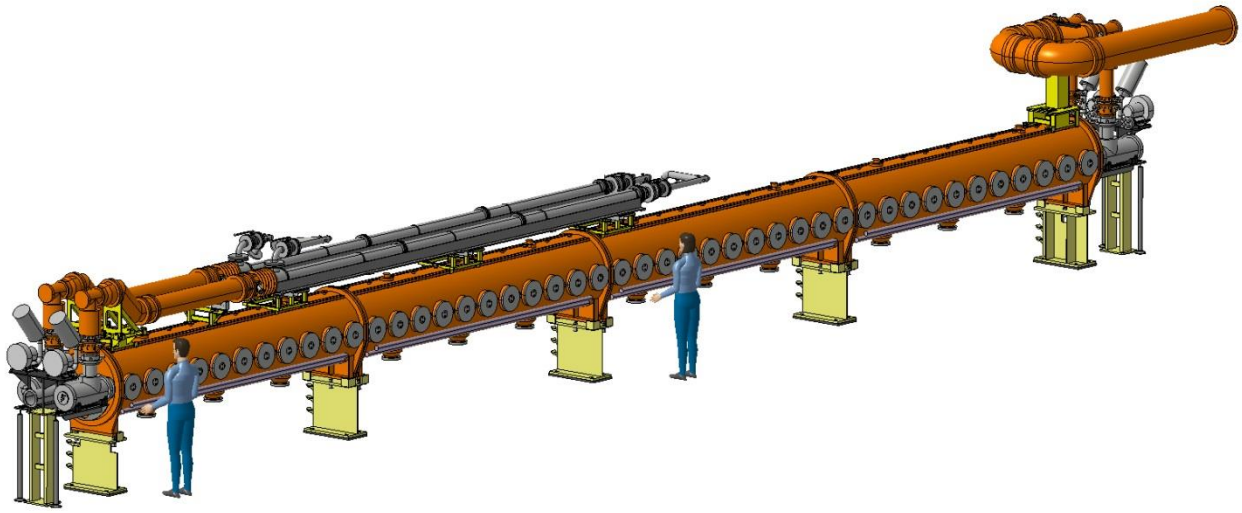
1970 1980 1990 2000 2010 2020

2 x 4 sections
2 x 5 sections
Travelling Wave
Cavities

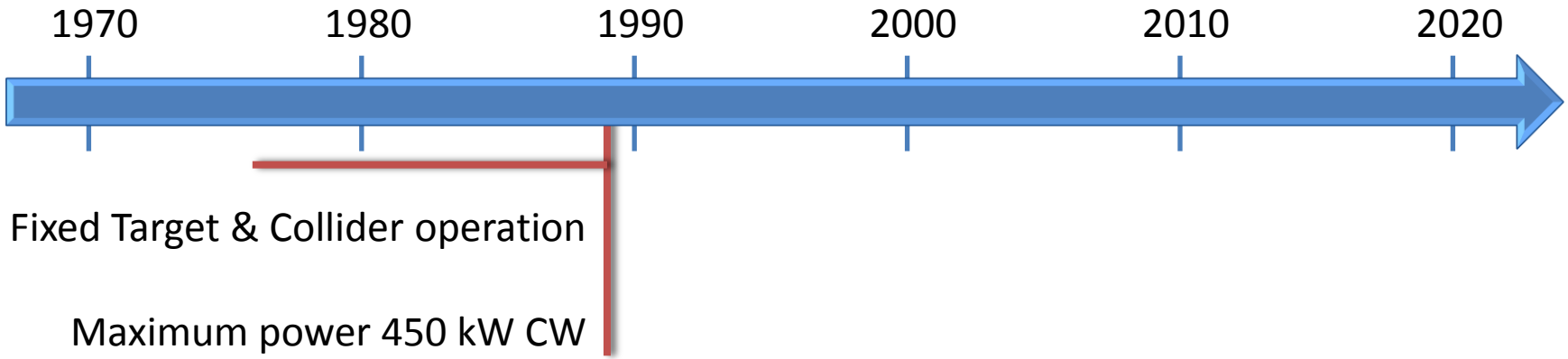
Per TWC:

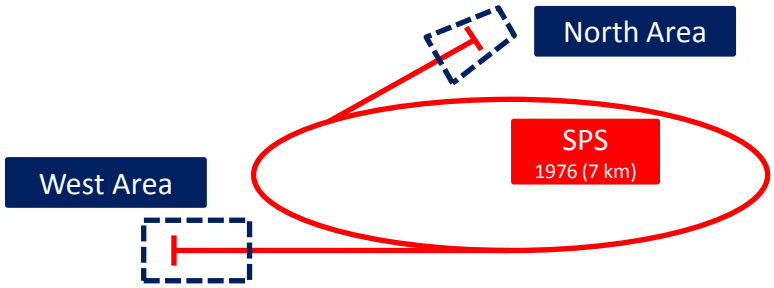
2 x 2 x 375 kW
Fundamental
Power Couplers

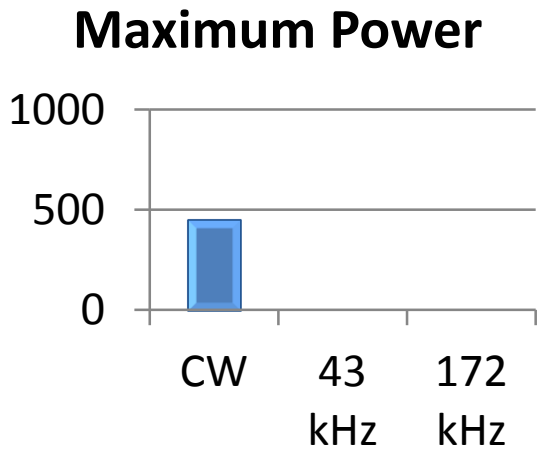
2 x 500 kW
Power Loads



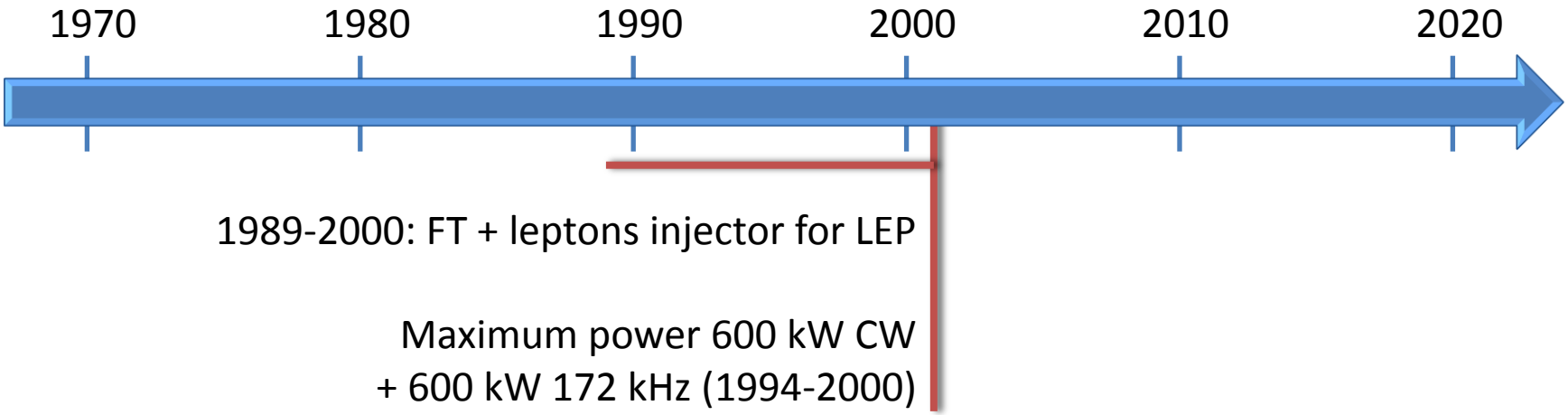
First period 1976-1988





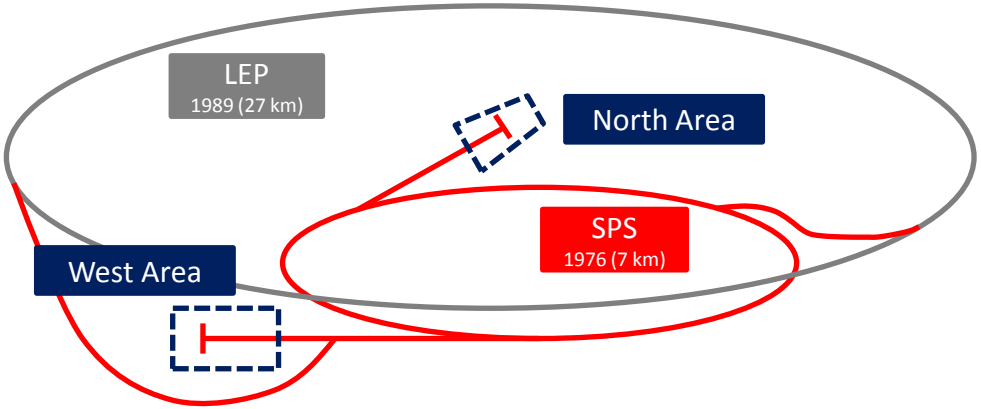


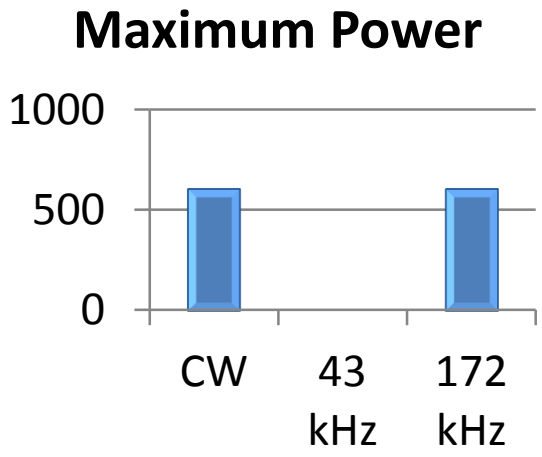
Second period 1989-2000



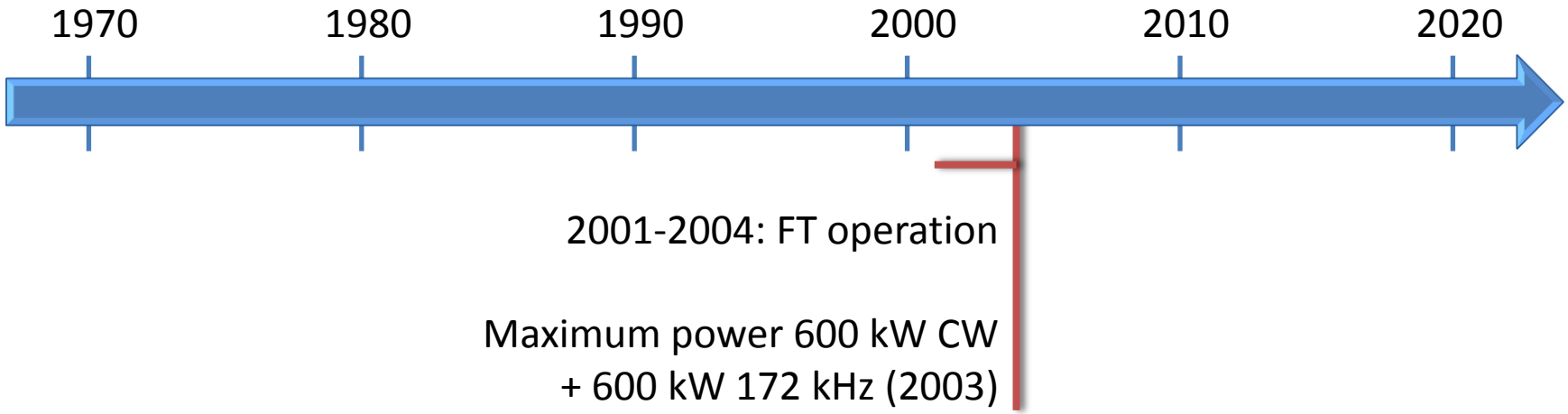
1989-2000: FT + leptons injector for LEP

Maximum power 600 kW CW
+ 600 kW 172 kHz (1994-2000)



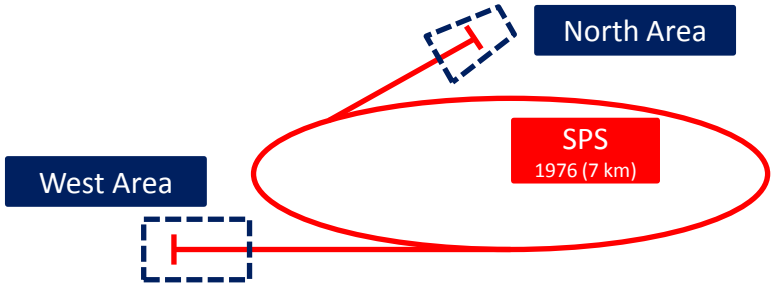


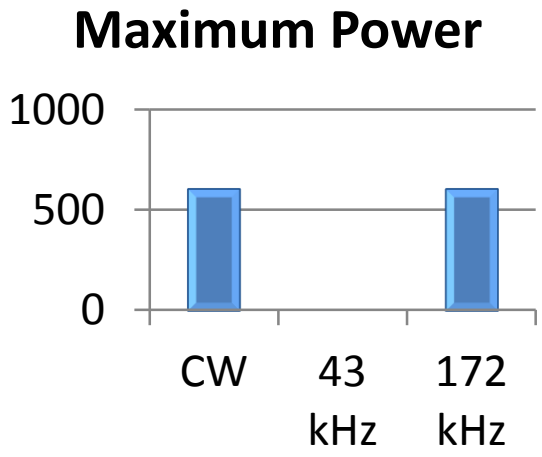
Third period 2001-2005



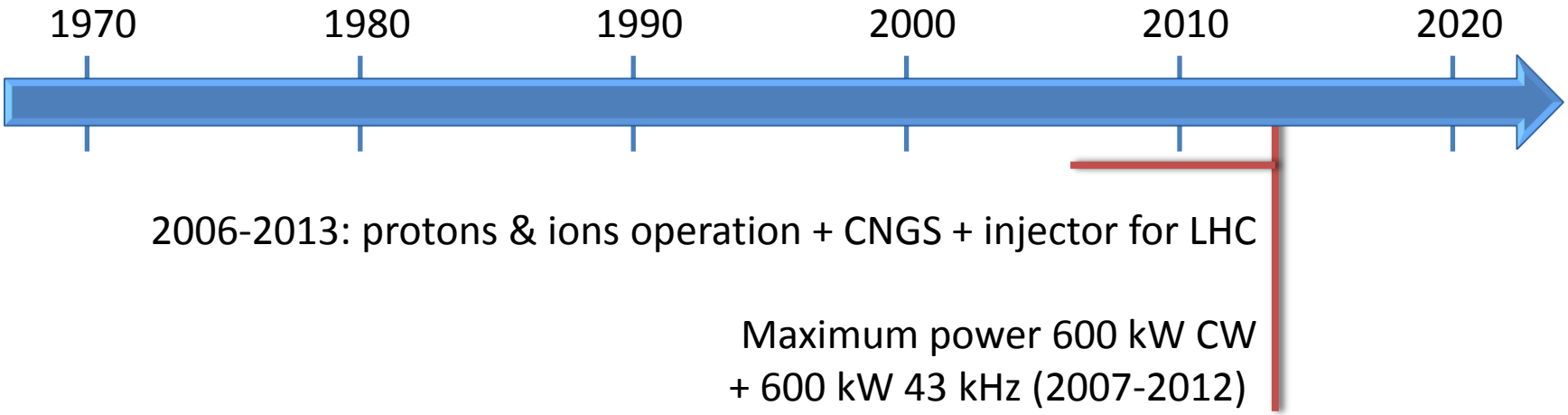
2001-2004: FT operation

Maximum power 600 kW CW
+ 600 kW 172 kHz (2003)



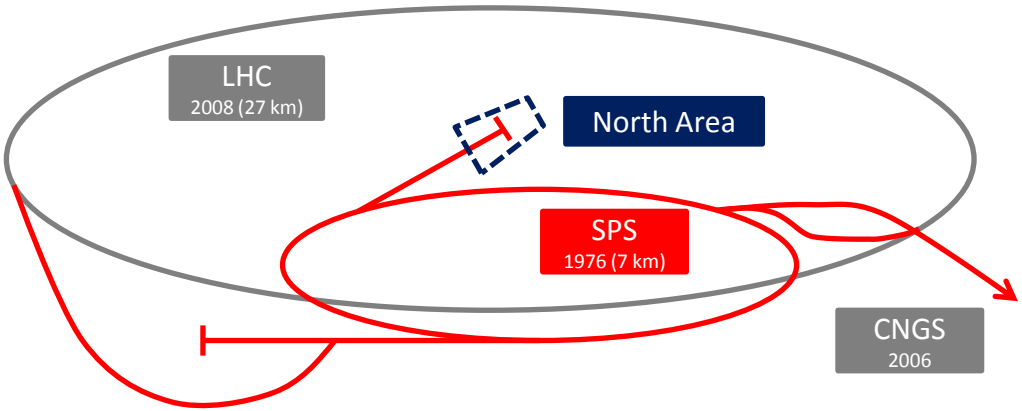


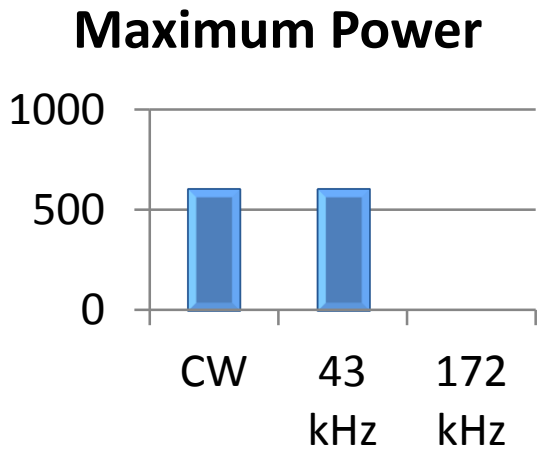
Fourth period 2006-2013



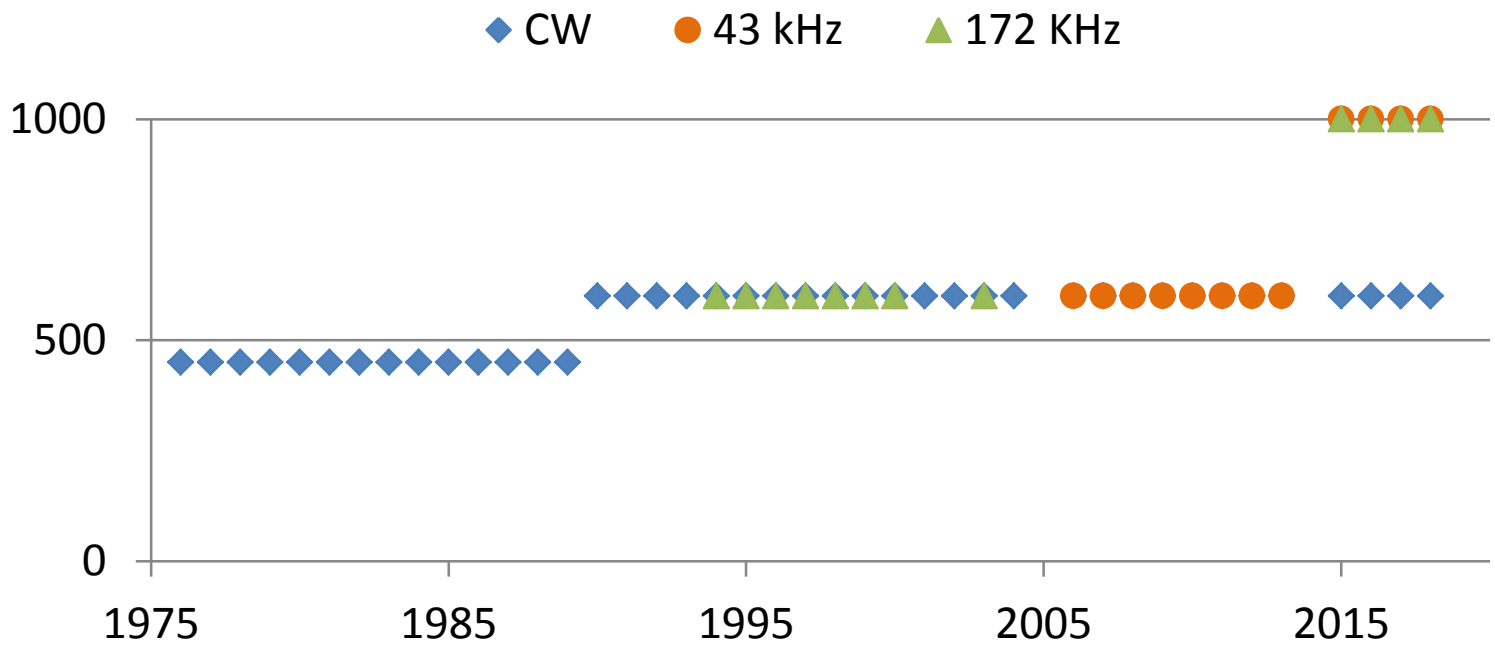
2006-2013: protons & ions operation + CNGS + injector for LHC

Maximum power 600 kW CW
+ 600 kW 43 kHz (2007-2012)

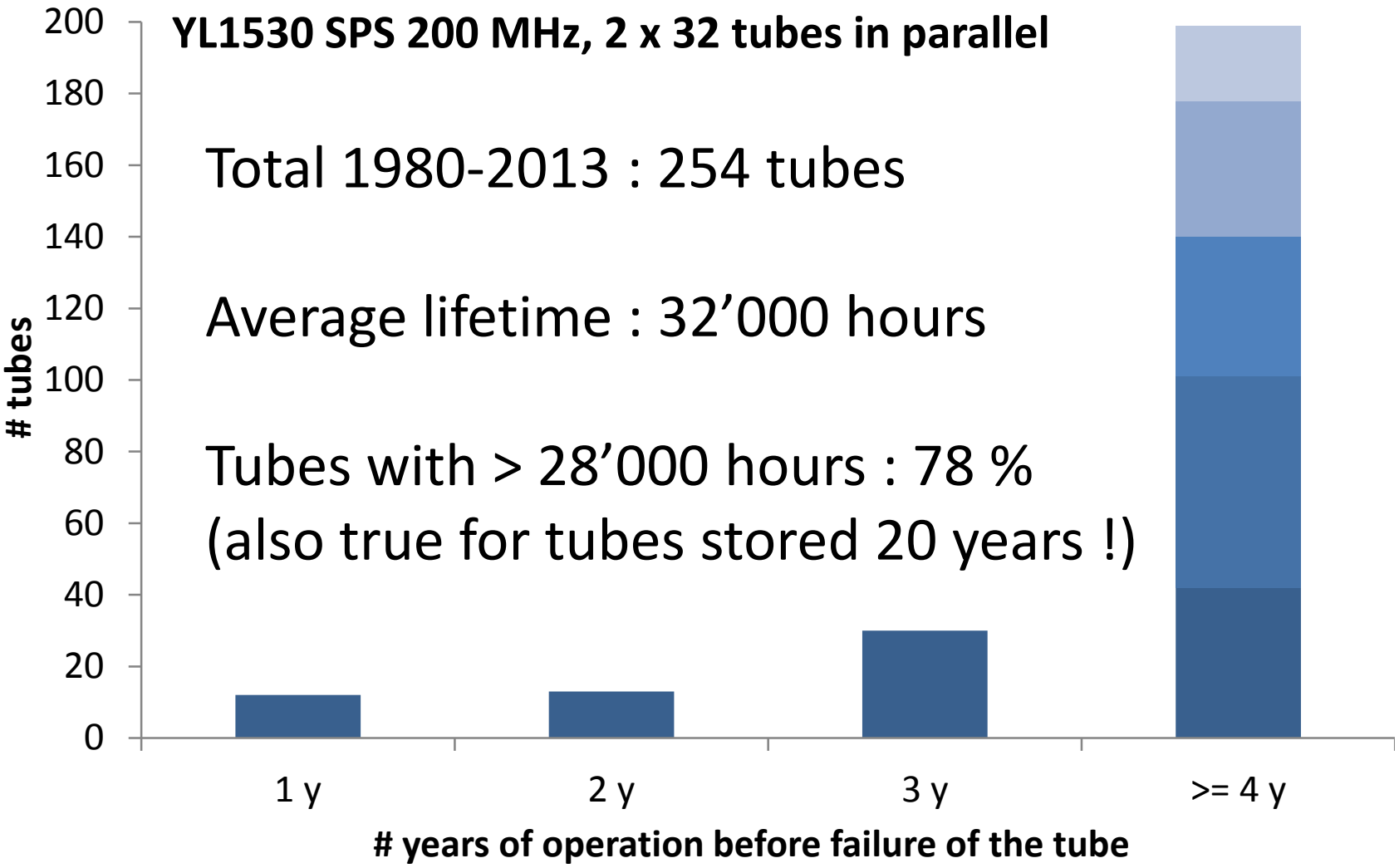




Power request 1976-2018

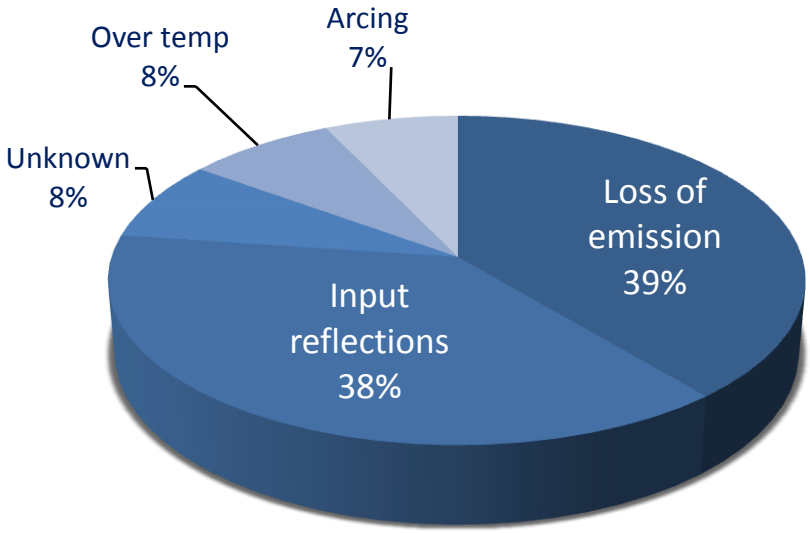


Tubes statistics



Amplifiers statistics

YL1530 SPS 200 MHz, 2 x 32 tubes in parallel



Reason of fault	# of faults	% of faults
Loss of emission	99	39
Input reflections	97	38
Unknown	20	8
Over Temp	20	8
Arcing	18	7

Unpredictable : 23 %

Graceful degradation : 77 % (possible to monitor and predict)

Graceful operation : 99.5 % (2012)

Operating with 'OFF Line' Tubes

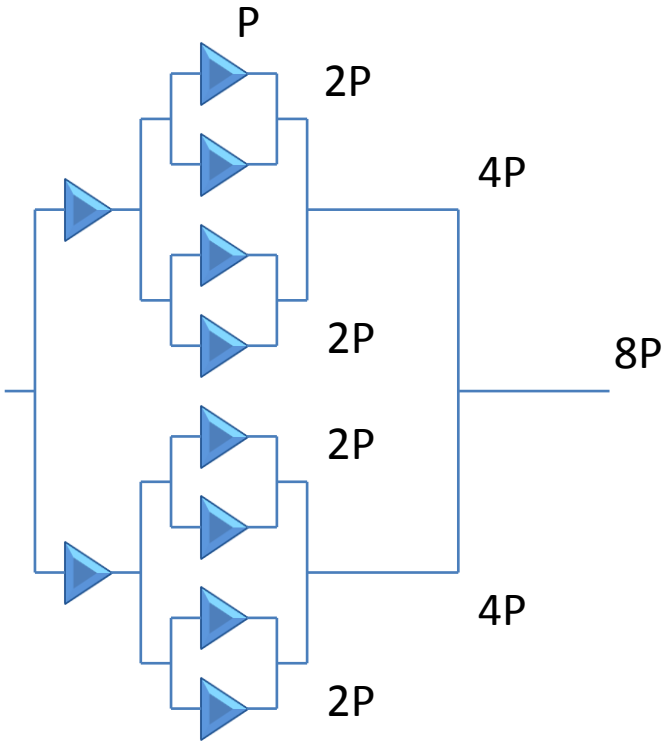
In normal operation, one tube delivers 600 kW / 8 = 75 kW

Systems have been designed (1976) to deliver full voltage into the cavity even with 3/4 + 3/4 tubes

In case of two tubes 'OFF Line', remaining tubes shall deliver 75 kW x (8/6)^2 = 133 kW

RS2004 tubes are rated 137.5 kW, just ok

Pout $_{3dBCombiner}$ = (A+B)/2 + SQRT(A.B)



Operating with 'OFF Line' Tubes

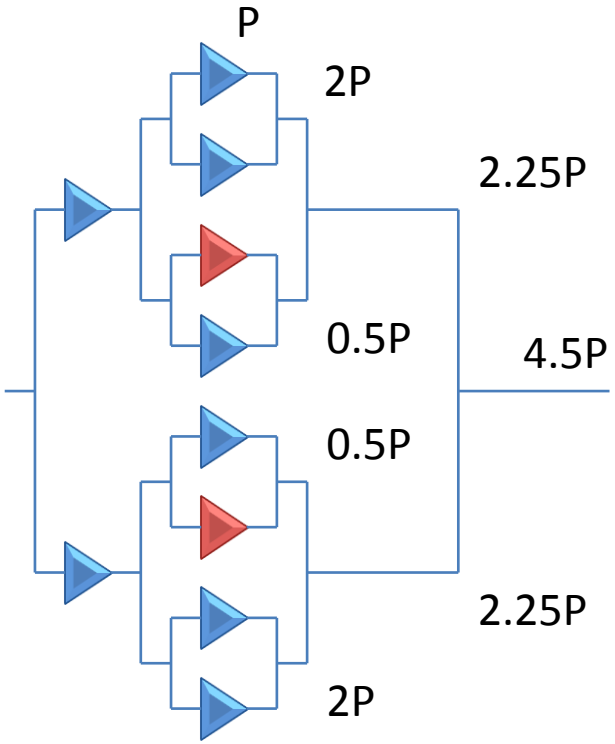
In normal operation, one tube delivers 600 kW / 8 = 75 kW

Systems have been designed (1976) to deliver full voltage into the cavity even with 3/4 + 3/4 tubes

In case of two tubes 'OFF Line', remaining tubes shall deliver 75 kW x (8/6)^2 = 133 kW

RS2004 tubes are rated 137.5 kW, just ok

Pout $_{3dBCombiner}$ = (A+B)/2 + SQRT(A.B)

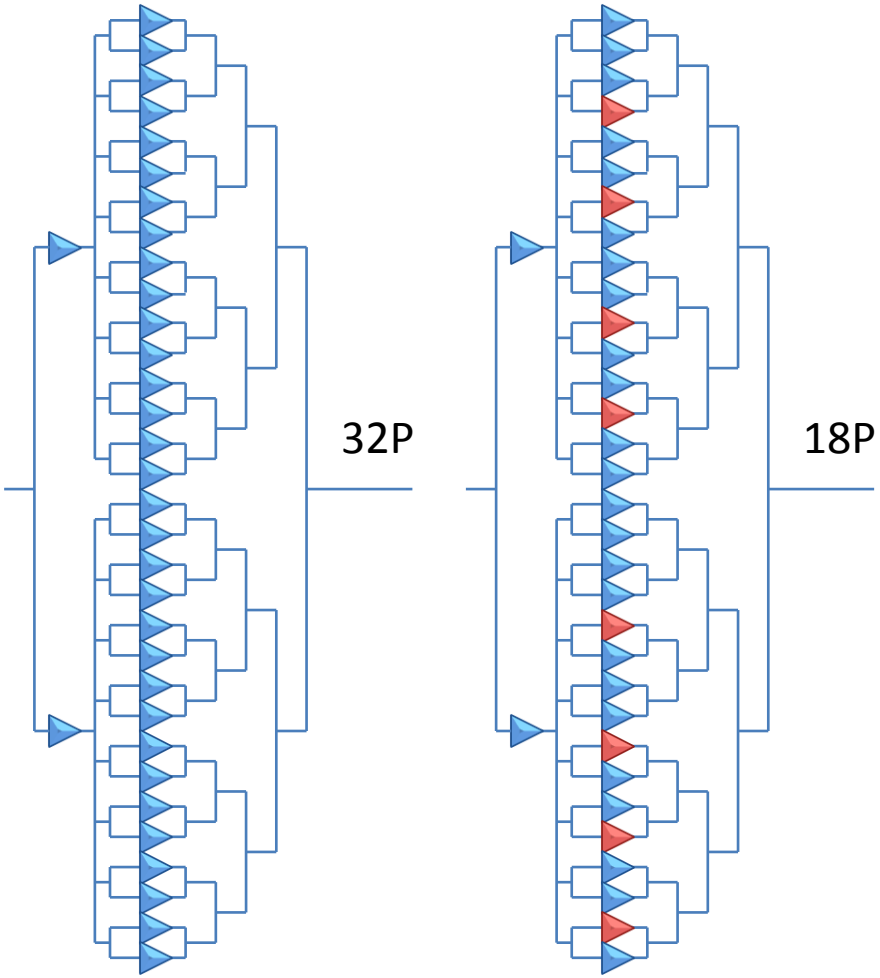


Operating with ‘OFF Line’ Tubes

The same philosophy applies to Philips amplifiers, in normal operation, one tube delivers 600 kW / 32 (+ 3 dB combiner losses) = 20 kW

In case of 2 x 4 tubes ‘OFF Line’, remaining tubes shall deliver
20 kW x (32/24)^2 = 36 kW

YL1530 tubes are rated 37 kW



Operating with 'OFF Line' Tubes

Along the year we loose
- 6 Siemens tubes
- 16 Philips tubes

Thanks to the graceful degradation and the OFF line possibility we change these tubes during the 'one day technical stop' every 8 weeks

We sometimes operate Philips plant with one 'OFF line tube'

We rarely need to use it with the Siemens plant, but from time to time it helps us to remain available

Even if we operate with faulty tubes, we still have some margin in power

So, we apply the rule

$-5\% \; U_{filament} \rightarrow +25\%$ lifetime

I cannot say if the rule is true, I can simply say that our tubes have a very long lifetime

Please keep it in mind looking at our tubes statistics

Major events 1970-2010

1970-1980
- Development phase + first operation, no major troubles

1980-1990
- No major troubles

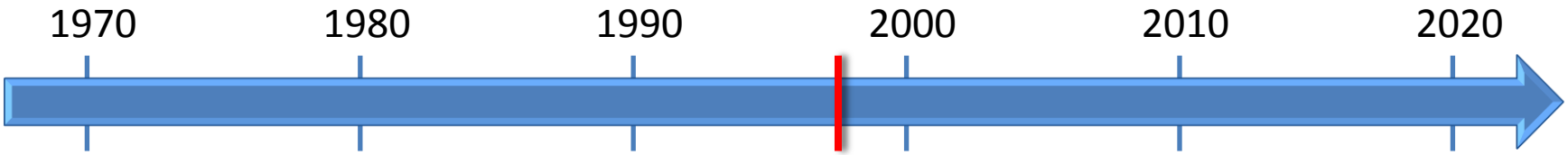
1990-2000
- HVPS 18 KVAC capacitor explosion
- Fundamental Power Coupler failures
- Power Load failures

2000-2010
- Near miss Tunnel ceiling water infiltration
- Crowbar/water pipe failure
- HVPS Transformer failure

Local / Remote Control

Miscellaneous

HVPS 18 KV-AC capacitor explosion

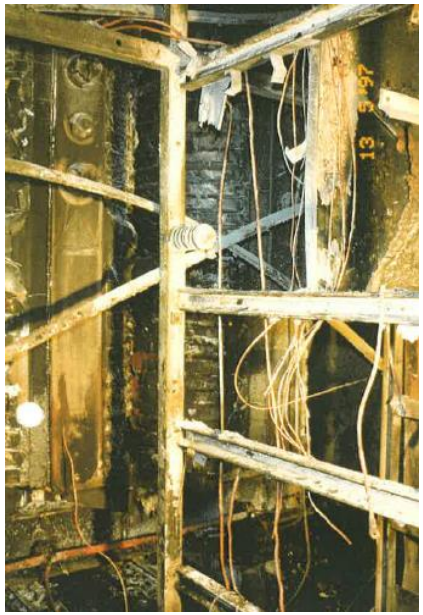


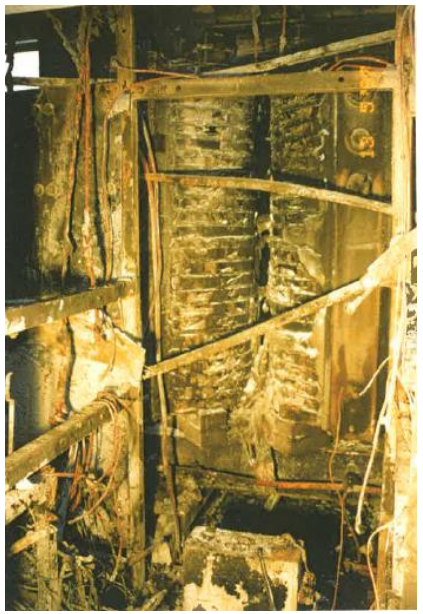
Spring 1997, after few weeks of operation, explosion of a HVPS (18 kV-AC capacitor)

Fire in the cubicle

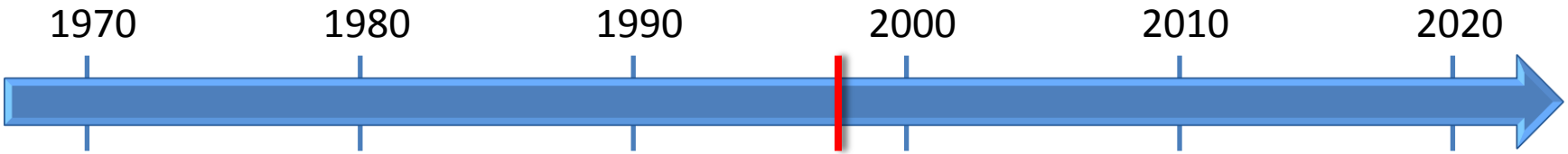
Mercury crowbar system vaporised

SPS stopped for 3 months





HVPS 18 KVAC capacitor explosion



Spring 1997, after few weeks of operation, explosion of a HVPS (18 kV-AC capacitor)

Fire in the cubicle

Mercury crowbar system vaporised

SPS stopped for 3 months

Fundamental Power Couplers

Ceramic failures with the Fundamental Power Couplers

- 1994
- 1998
- 1999

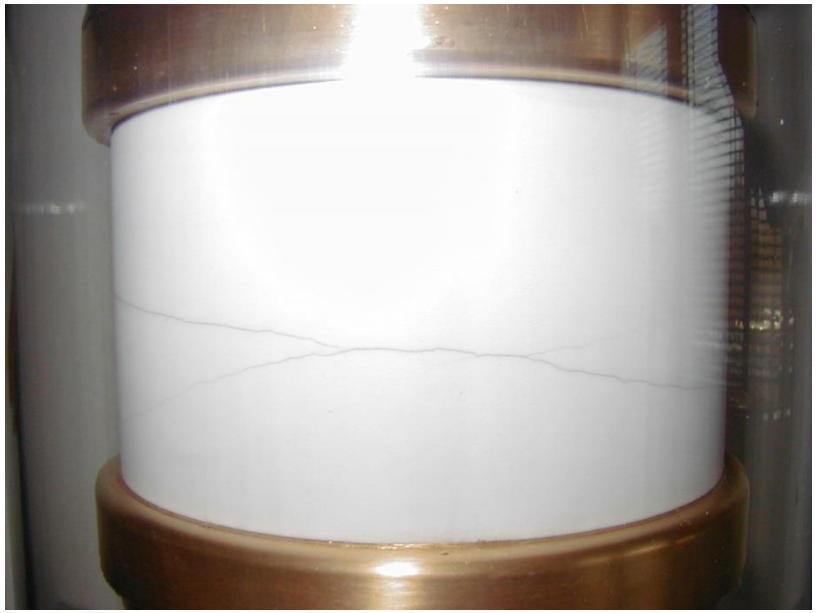
We made a new design, more powerful, based on a Thales klystron disk window, still in operation

Fundamental Power Couplers

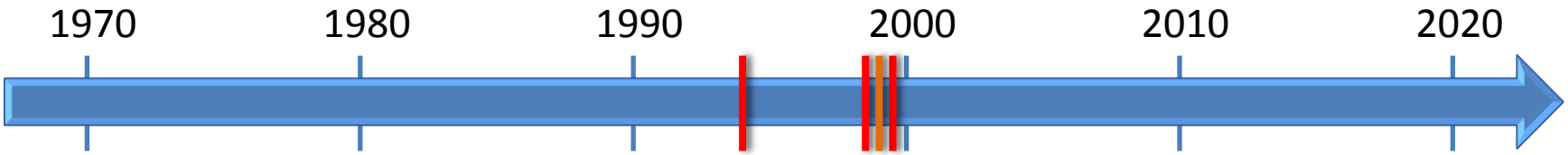
Ceramic failures with the Fundamental Power Couplers

- 1994
- 1998
- 1999

We made a new design, more powerful, based on a Thales klystron disk window, still in operation



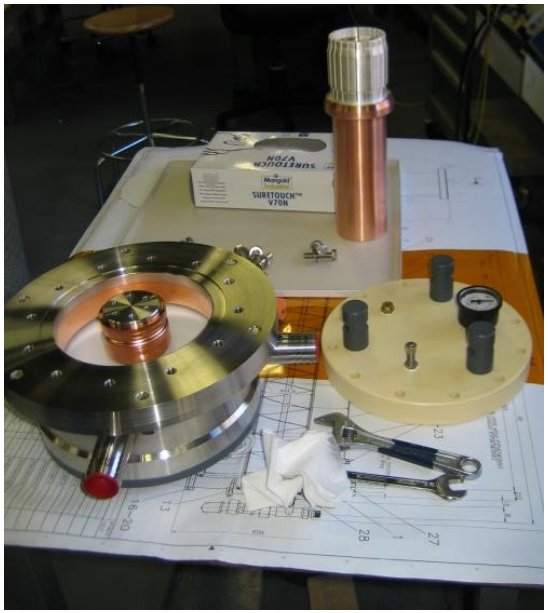
Fundamental Power Couplers



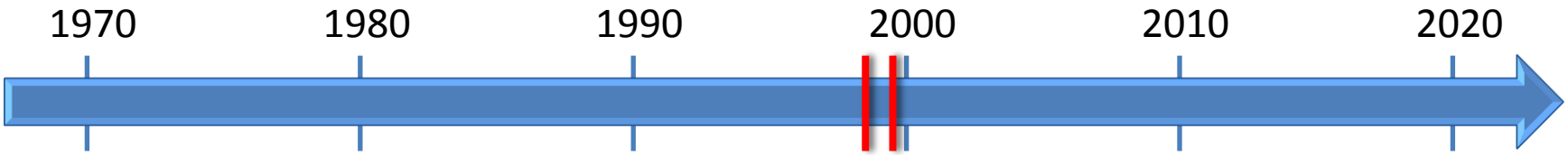
Ceramic failures with the Fundamental Power Couplers

- 1994
- 1998
- 1999

We made a new design, more powerful, based on a Thales klystron disk window, still in operation



Power load window failure

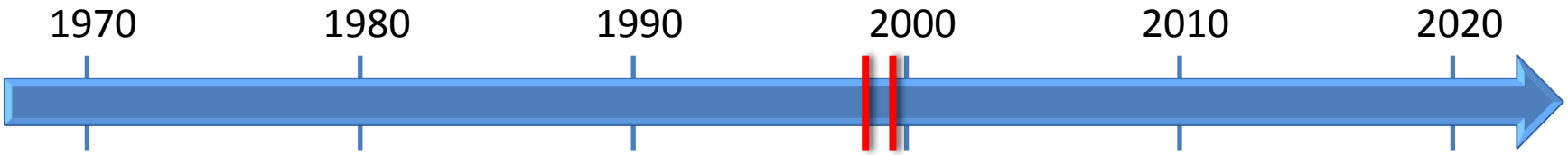


After 20 years of operation, we had three failures with the window of our power loads

- First one on the Siemens amplifier (1998)
- Two on the cavities (1999)

We made a new design, without a molybdenum junction, thanks to new brazing possibilities

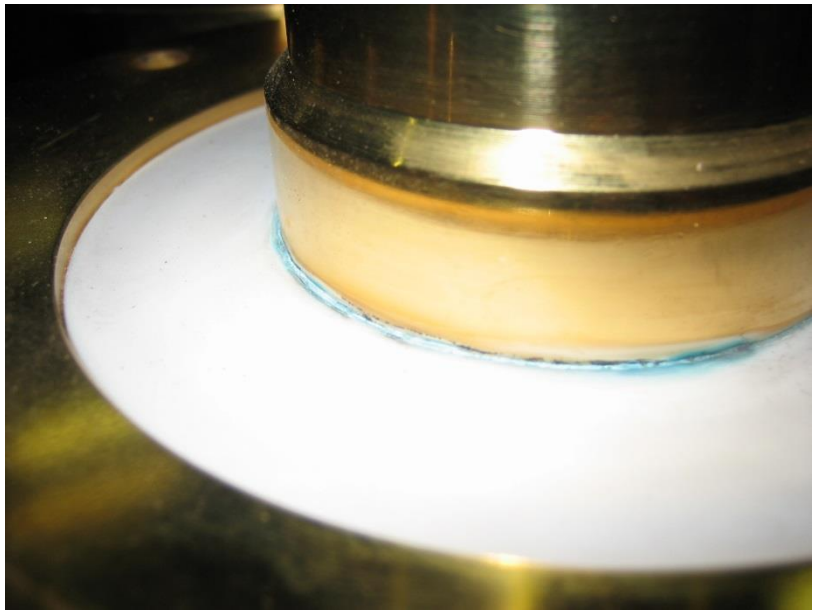
Power load window failure



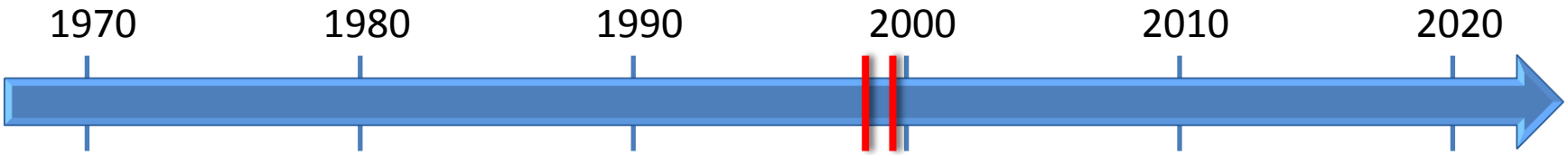
After 20 years of operation, we had three failures with the window of our power loads

- First one on the Siemens amplifier (1998)
- Two on the cavities (1999)

We made a new design, without a molybdenum junction, thanks to new brazing possibilities



Power load window failure



After 20 years of operation, we had three failures with the window of our power loads

- First one on the Siemens amplifier (1998)
- Two on the cavities (1999)

We made a new design, without a molybdenum junction, thanks to new brazing possibilities

Near miss coaxial lines

During the 2005 one year shutdown, we had to repair the vault above the cavity#2 (water infiltration)

Some of the vacuum seals on the cavity were damaged

The coaxial lines were about to be perforated

Near miss coaxial lines

During the 2005 one year shutdown, we had to repair the vault above the cavity#2 (water infiltration)

Some of the vacuum seals on the cavity were damaged

The coaxial lines were about to be perforated

Near miss coaxial lines

During the 2005 one year shutdown, we had to repair the vault above the cavity#2 (water infiltration)

Some of the vacuum seals on the cavity were damaged

The coaxial lines were about to be perforated

Near miss coaxial lines

During the 2005 one year shutdown, we had to repair the vault above the cavity#2 (water infiltration)

Some of the vacuum seals on the cavity were damaged

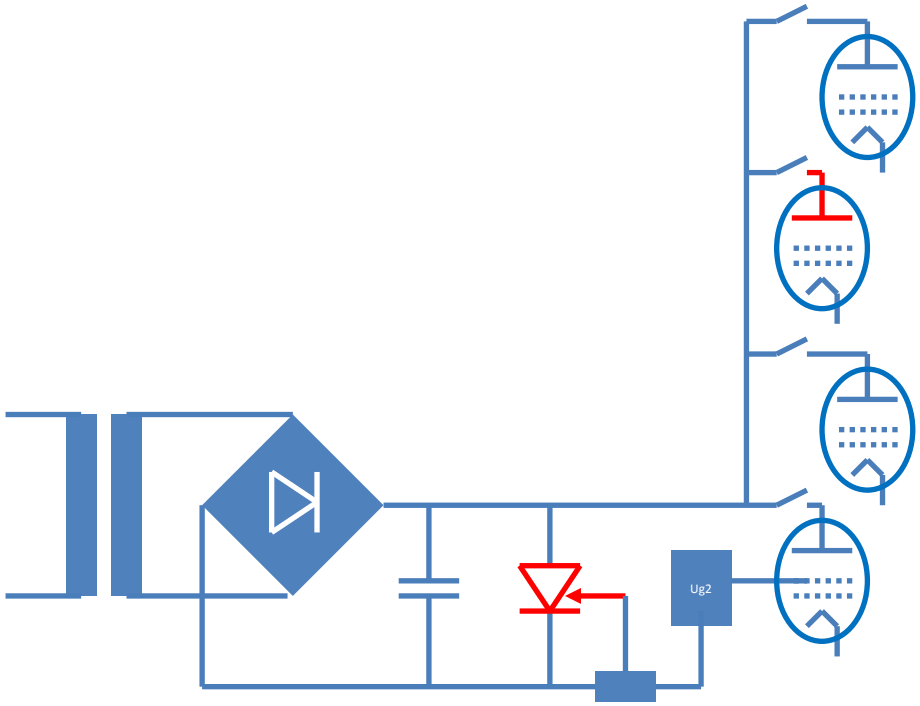
The coaxial lines were about to be perforated

Crowbar/water pipe

Two faults with the same symptoms

- New GTO crowbar system unstable (10 kV)
- A water pipe intermittently arcing between HVDC and GND triggering the crowbar

It took us a long time to fix these, explanation for bad statistics during 2008 to 2010

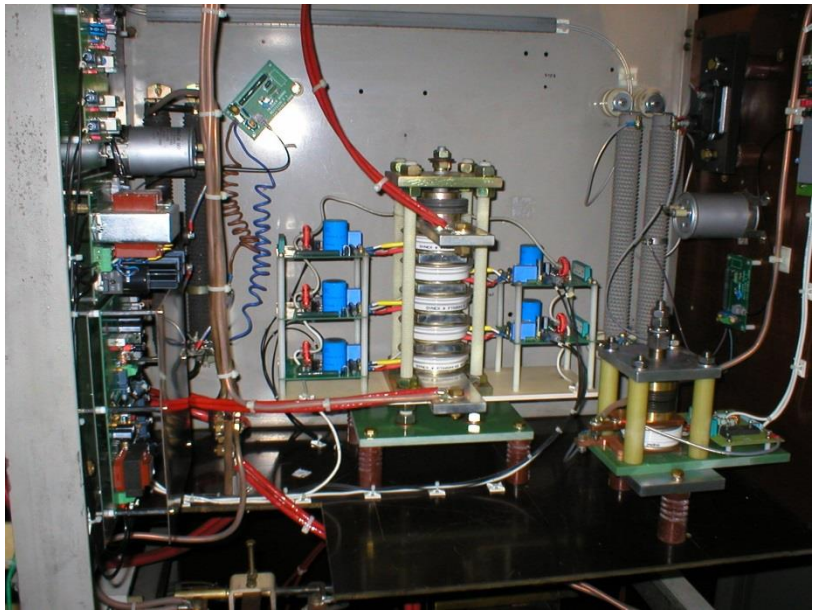


Crowbar/water pipe

Two faults with the same symptoms

- New GTO crowbar system unstable (10 kV)
- A water pipe intermittently arcing between HVDC and GND triggering the crowbar

It took us a long time to fix these, explanation for bad statistics during 2008 to 2010



Crowbar/water pipe

Two faults with the same symptoms

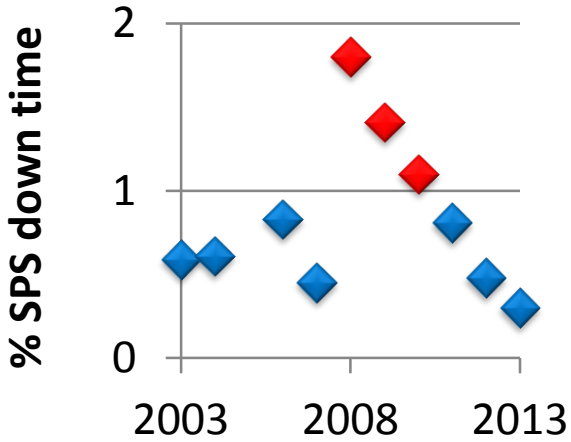
- New GTO crowbar system unstable (10 kV)
- A water pipe intermittently arcing between HVDC and GND triggering the crowbar

It took us a long time to fix these, explanation for bad statistics during 2008 to 2010

Crowbar/water pipe

Two faults with the same symptoms

- New GTO crowbar system unstable (10 kV)
- A water pipe intermittently arcing between HVDC and GND triggering the crowbar



It took us a long time to fix these, explanation for bad statistics during 2008 to 2010

HVPS Transformer failure

We had two majors faults with the HV transformers

2012 near miss

- one connection of the coil started to burn
- We exchange the transformer before any accident
- Transformers have a lifetime and replacement must be correctly scheduled on old machines

2013

- Measuring cable connection broke and 18 kVAC accidentally touched GND

HVPS Transformer failure

We had two majors faults with the HV transformers

2012 near miss

- one connection of the coil started to burn
- We exchange the transformer before any accident
- Transformers have a lifetime and replacement must be correctly scheduled on old machines

2013

- Measuring cable connection broke and 18 kVAC accidentally touched GND

HVPS Transformer failure

We had two majors faults with the HV transformers

2012 near miss

- one connection of the coil started to burn
- We exchange the transformer before any accident
- Transformers have a lifetime and replacement must be correctly scheduled on old machines

2013

- Measuring cable connection broke and 18 kVAC accidentally touched GND

HVPS Transformer failure

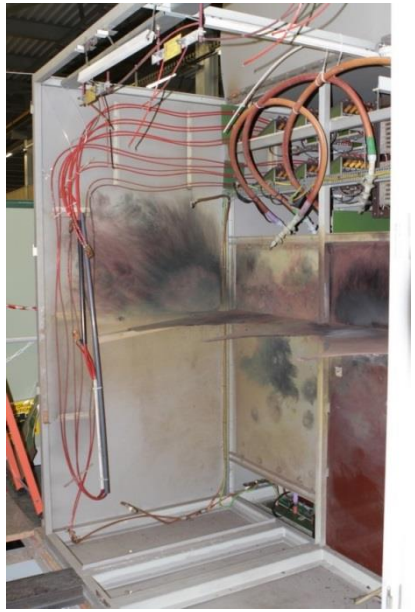
We had two majors faults with the HV transformers

2012 near miss

- one connection of the coil started to burn
- We exchange the transformer before any accident
- Transformers have a lifetime and replacement must be correctly scheduled on old machines

2013

- Measuring cable connection broke and 18 kVAC accidentally touched GND



Local/Remote control

Local electronics are still the same since the beginning, faults are very rare (electricians of the team are able to repair it)

Remote systems had to be upgraded as not robust enough (specialists needed)

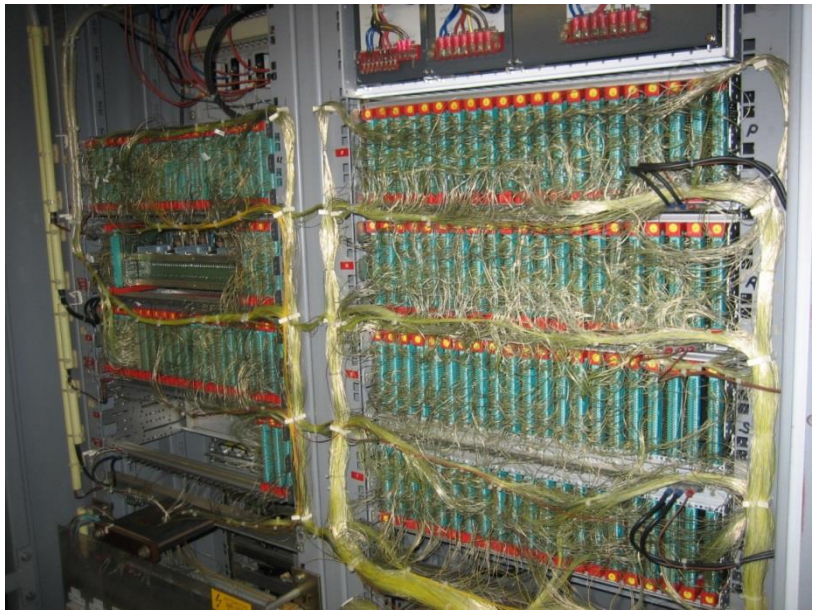
1970-1991	Nodal
1991-2013	Siemens S5
2014-…	Beckoff

Local/Remote control

Local electronics are still the same since the beginning, faults are very rare (electricians of the team are able to repair it)

Remote systems had to be upgraded as not robust enough (specialists needed)

1970-1991	Nodal
1991-2013	Siemens S5
2014-…	Beckoff



Local/Remote control

Local electronics are still the same since the beginning, faults are very rare (electricians of the team are able to repair it)

Remote systems had to be upgraded as not robust enough (specialists needed)

1970-1991	Nodal
1991-2013	Siemens S5
2014-…	Beckoff

Local/Remote control

Local electronics are still the same since the beginning, faults are very rare (electricians of the team are able to repair it)

Remote systems had to be upgraded as not robust enough (specialists needed)

1970-1991	Nodal
1991-2013	Siemens S5
2014-…	Beckoff

Local/Remote control

Local electronics are still the same since the beginning, faults are very rare (electricians of the team are able to repair it)

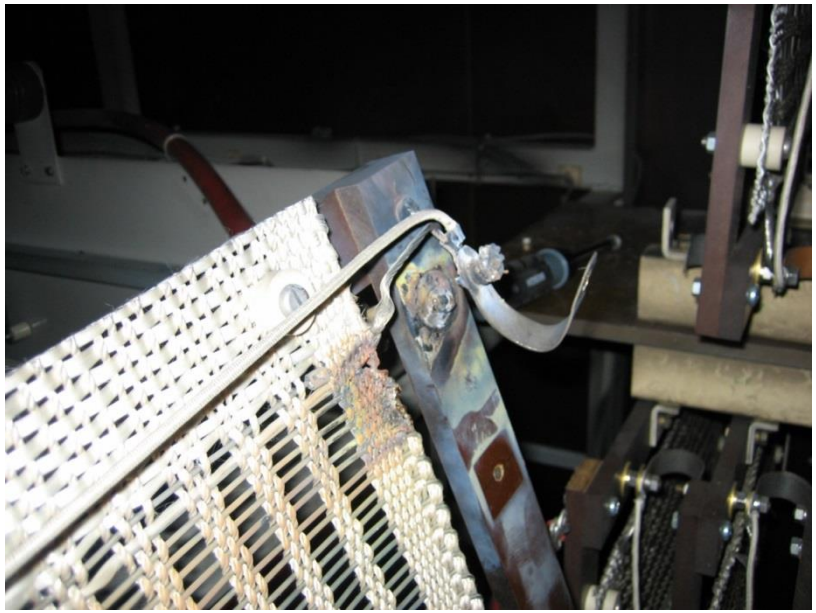
Remote systems had to be upgraded as not robust enough (specialists needed)

1970-1991	Nodal
1991-2013	Siemens S5
2014-…	Beckoff

Miscellaneous

We had several troubles with usual suspects

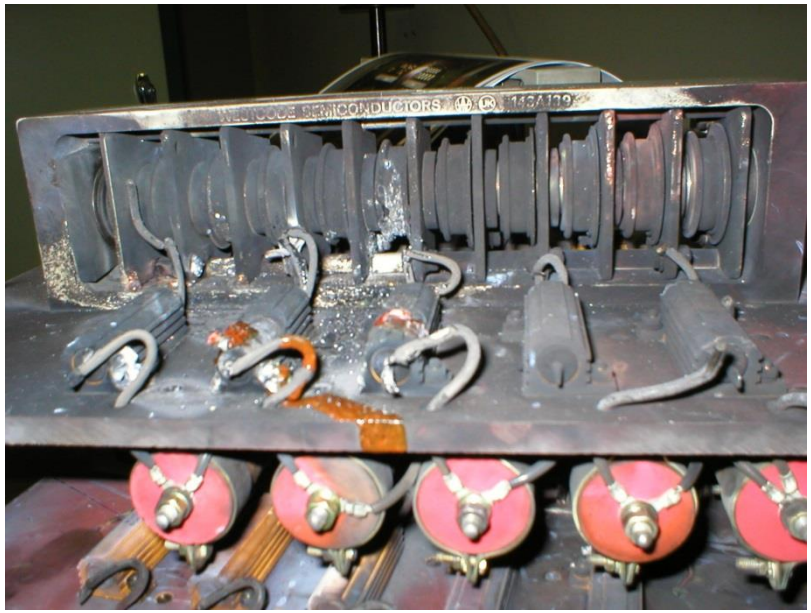
- HV wiring
- High Power transmission line connections



Miscellaneous

We had several troubles with usual suspects

- HV wiring
- High Power transmission line connections



Miscellaneous

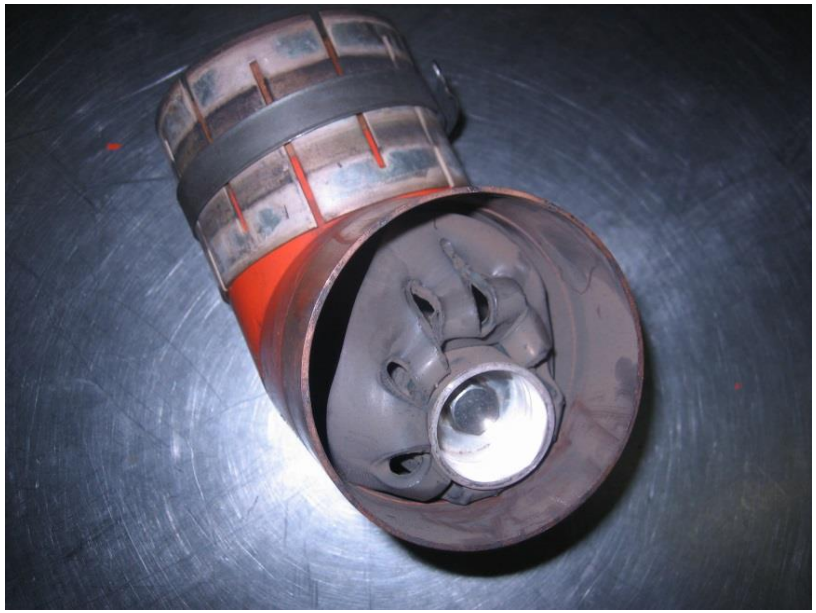
We had several troubles with usual suspects

- HV wiring
- High Power transmission line connections

Miscellaneous

We had several troubles with usual suspects

- HV wiring
- High Power transmission line connections

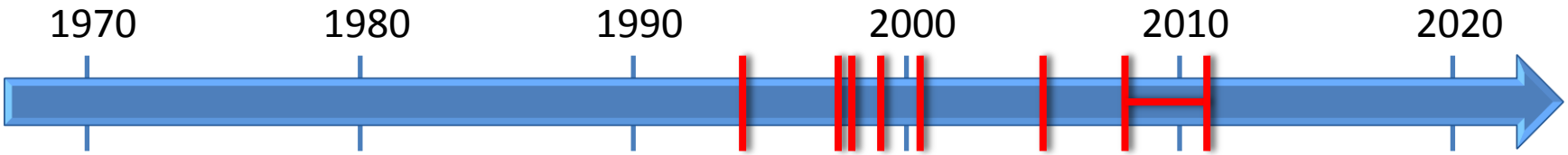


Miscellaneous

We had several troubles with usual suspects

- HV wiring
- High Power transmission line connections

Improvements



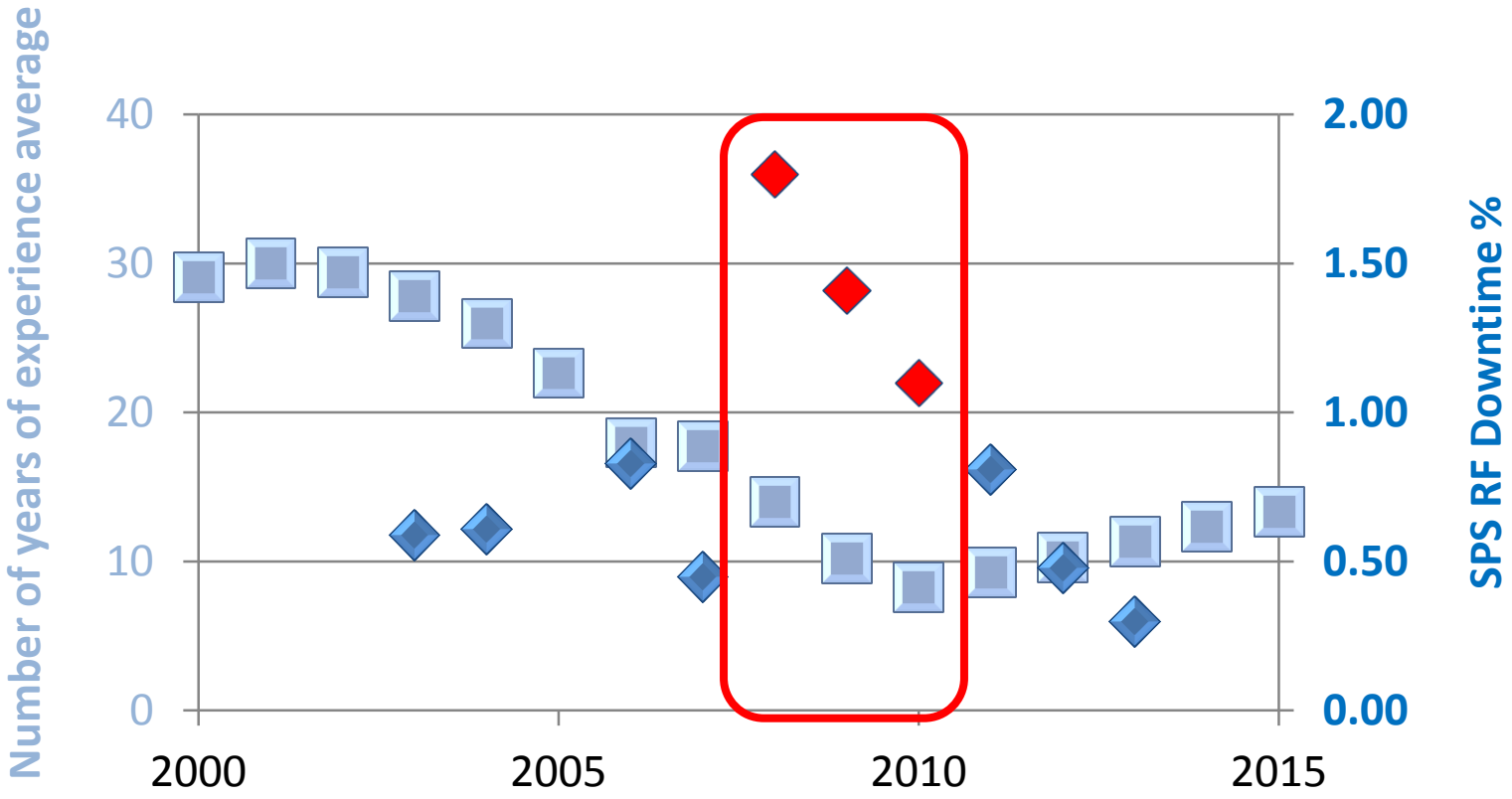
All these troubles have been improved case by case and not occurred again

We simply need an experienced team

Manpower strategy

Good Machine = (when my boss does not hear about it) =

(a*efficiency)*(b*reliability)*(c*AVAILABILITY)*(d*Experienced team)*k



Manpower strategy

Availability of an Injector is the key parameter

CERN's total annual electricity consumption is 1 TWh, for an operation of almost 7000 hours per year, 130 MW average

When SPS is down, electrical bill costs 5 000 CHF / hour

SPS RF is down ~ 1 % of the SPS operating time, 70 hours lost per year

1 % of the SPS operating time costs
~ 350,000 CHF per year (electrical bill only)
Please do hire young persons early enough
to ensure a correct overlap and experience sharing !

When SPS is down, almost 40 % of the electrical bill is for nothing (lost money)

- 20 % for LHC cryogenics + cooling and ventilation
- 10 % for LHC experiments
- 7 % for the North Area experiments

(http://cds.cern.ch/record/1324541?ln=en)

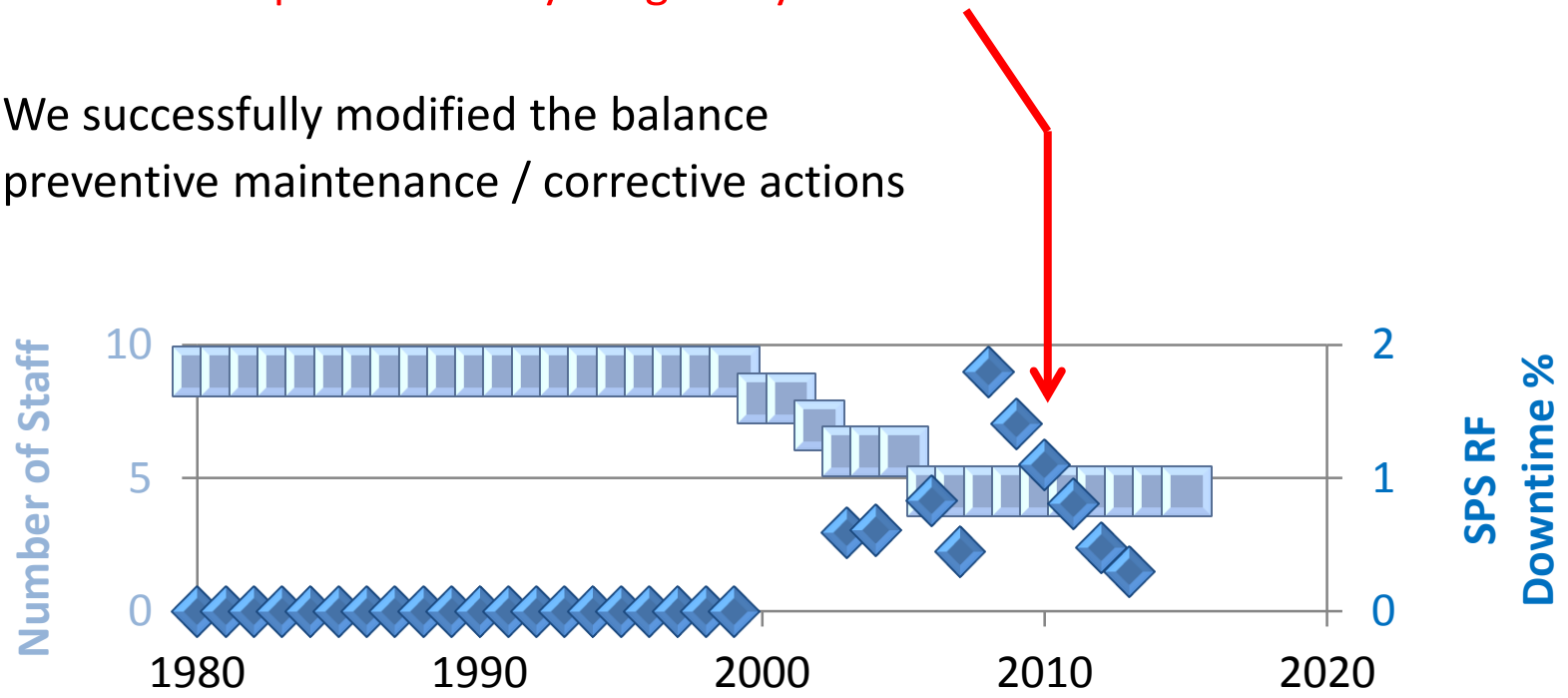
Hiring a new colleague with three years overlap before retirement of an experienced colleague would save 1% additional along three years,
210 hours x 5000 CHF/hour = 1 MCHF !

Maintenance strategy

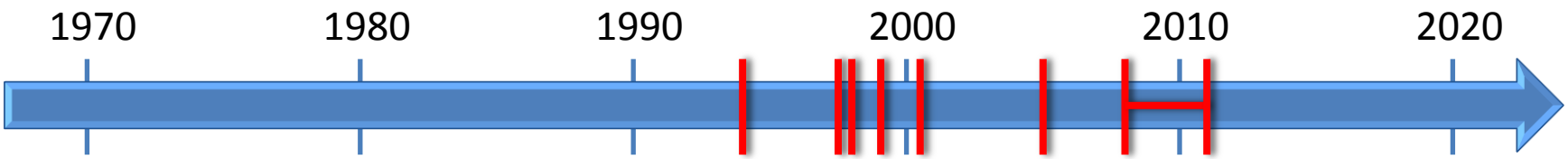
From 1970 to 2009, preventive maintenance was systematically done on the whole series of items, regardless the quantity in operation

Nowadays, we are not preparing large series of spares anymore, except few specific items such as trolleys or RF loads, we are 'only' having:
'Two tested spares of everything everywhere'

We successfully modified the balance
preventive maintenance / corrective actions



Conclusion



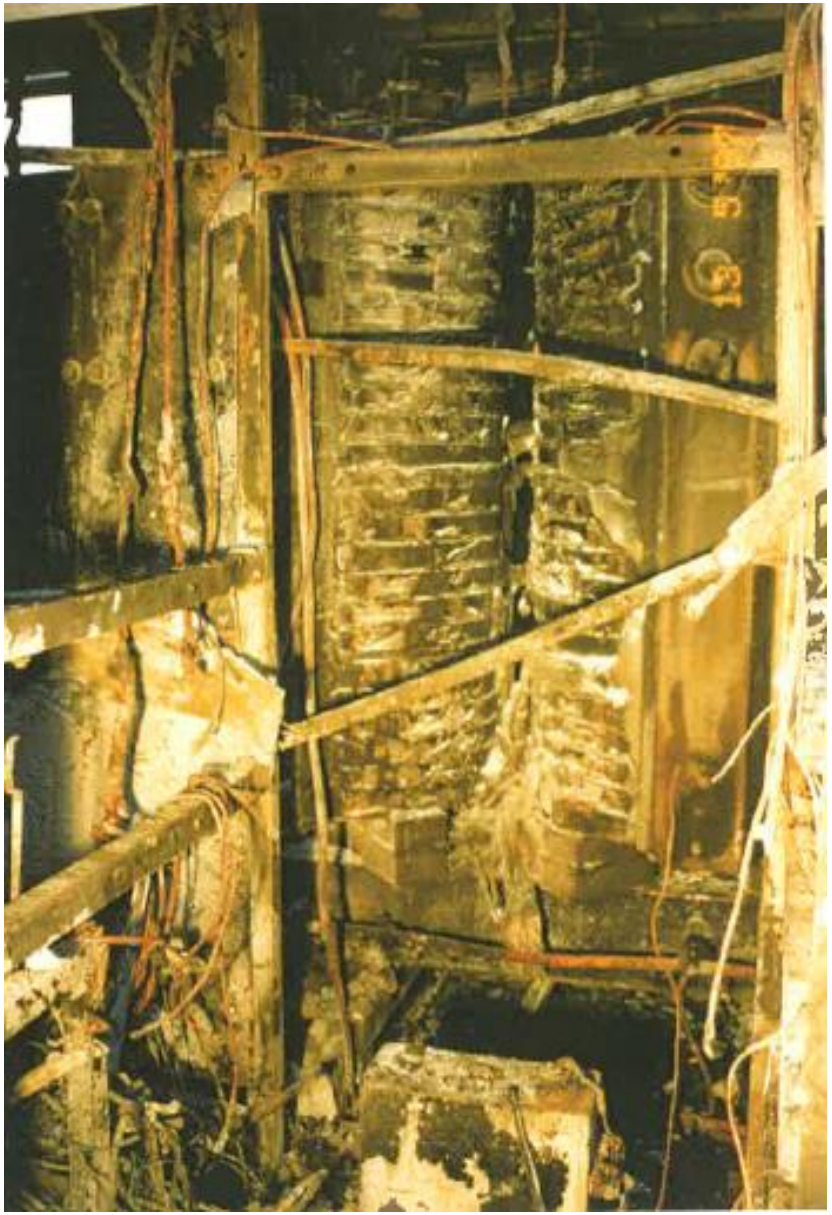
We had several major failures along this long period of time, mostly ageing of components

- 15-20 years for FPC
- 20 years HVPS main items
- 15 years controls
- 30 years infrastructure
- Not any major RF amplifier trouble, tubes are very nice devices

A good balance of preventive maintenance / corrective actions allows good results, if and only if

- Systems have correctly been overdesigned (redundancy)
- Systems are as simple as possible (minimum number of items, of connections, of interlocks, …)
- Team has enough experienced staff

Thank you very much for your attention



I wish you all to never experience that !