Status of the ESRF Radio Frequency System

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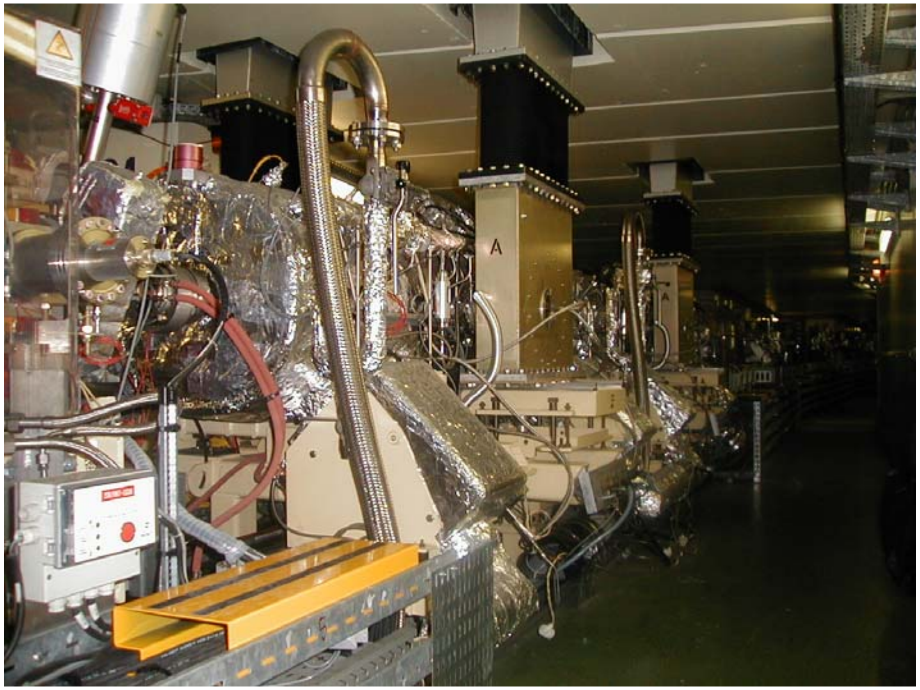
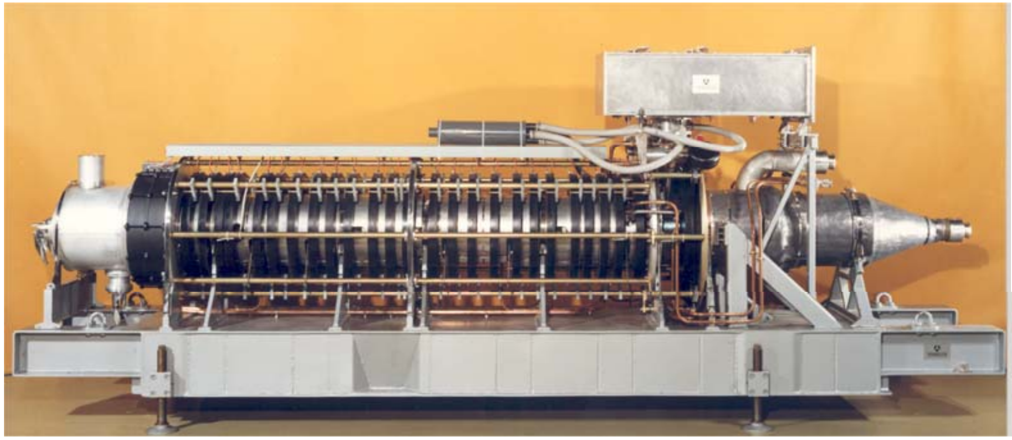


1. ESRF 352 MHz RF system
2. RF operation statistics
3. Experience with 1.3 MW klystrons
4. Waveguide switches
5. Arc detectors
6. New HV deck
7. Cavities



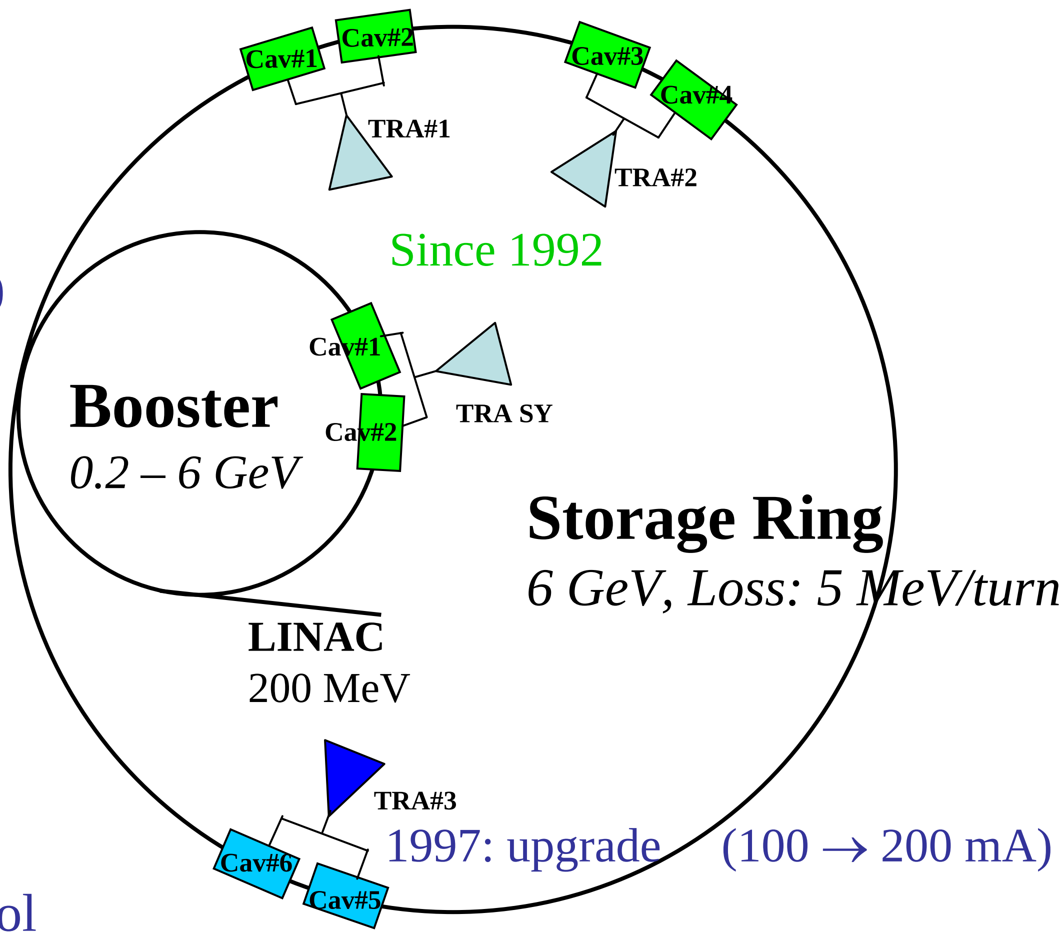
1. RF system based on 352.2 MHz CERN-LEP design

CAVITIES:

- 5 cell LEP type copper cavities
- 2 couplers / cavity => beam loading
- Max Window power: 170 kW
- Booster: max 4 MV/cavity in 10 Hz pulsed mode
- SR: max 2.5 MV/cavity in CW

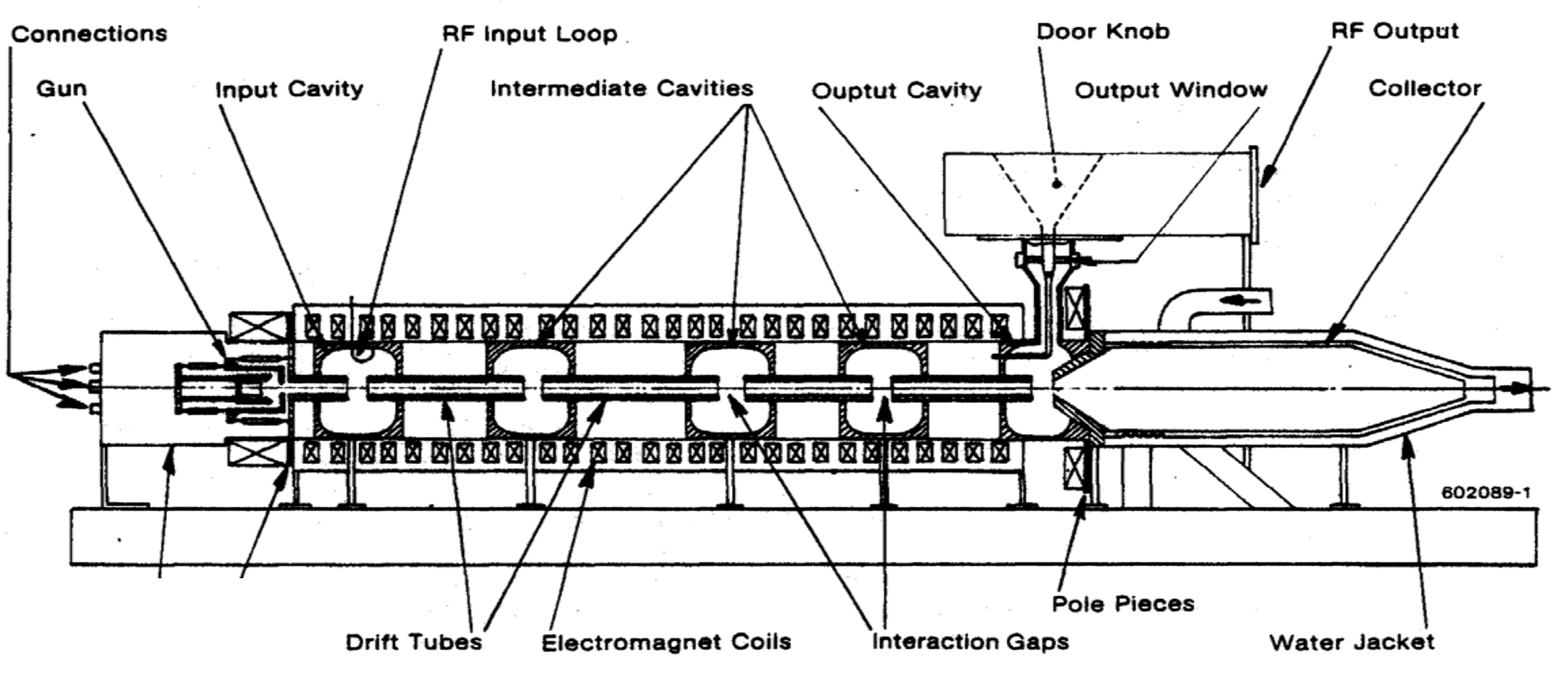
TRANSMITTERS:

- 1.3 MW klystrons
- feeding 2 or 4 cavities
- HVPS: 100 kV DC, 20 A
- Anode Modulator => gain control



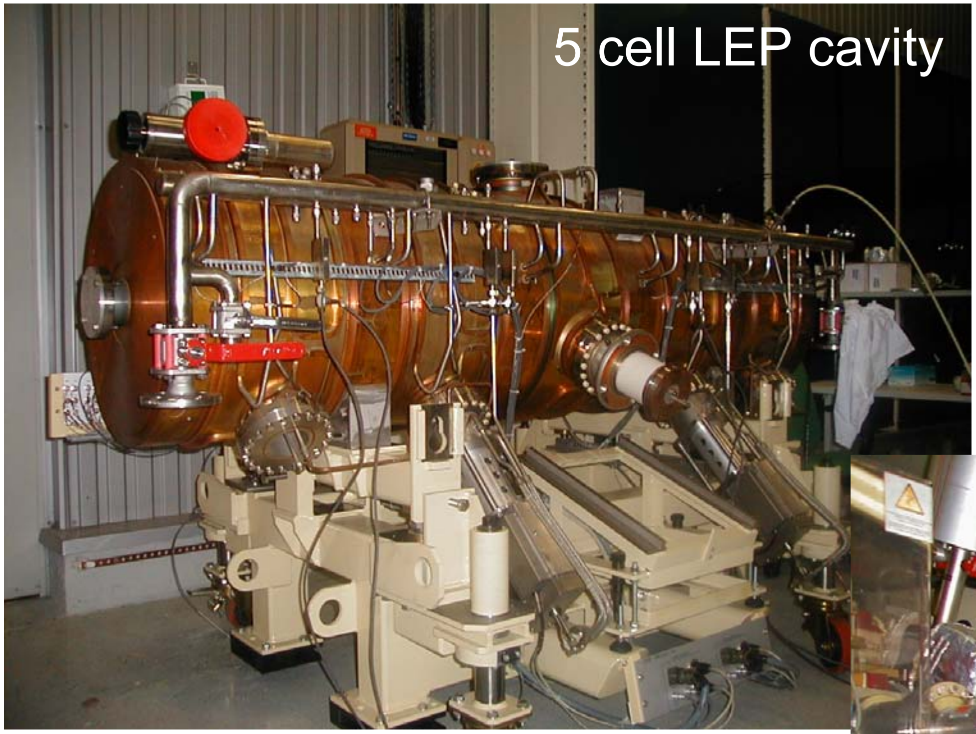
1.1 Klystrons

1.1 & 1.3 MW – 352.2 MHz – CW Klystrons from THALES, PHILIPS, EEV



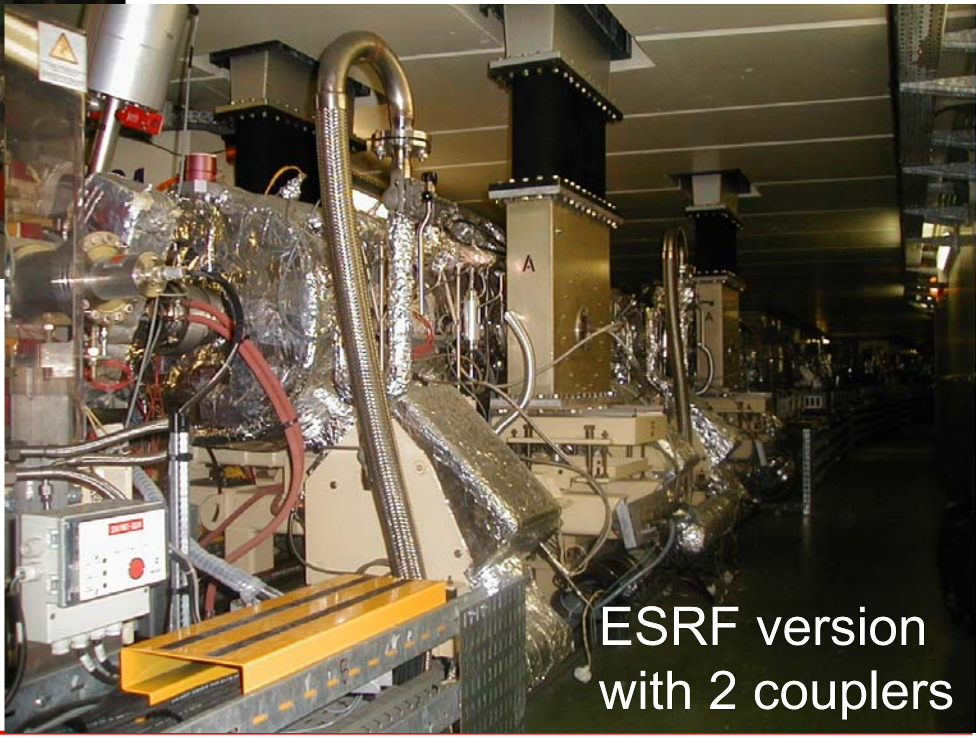
Example: THALES klystron

1.2 Cavities



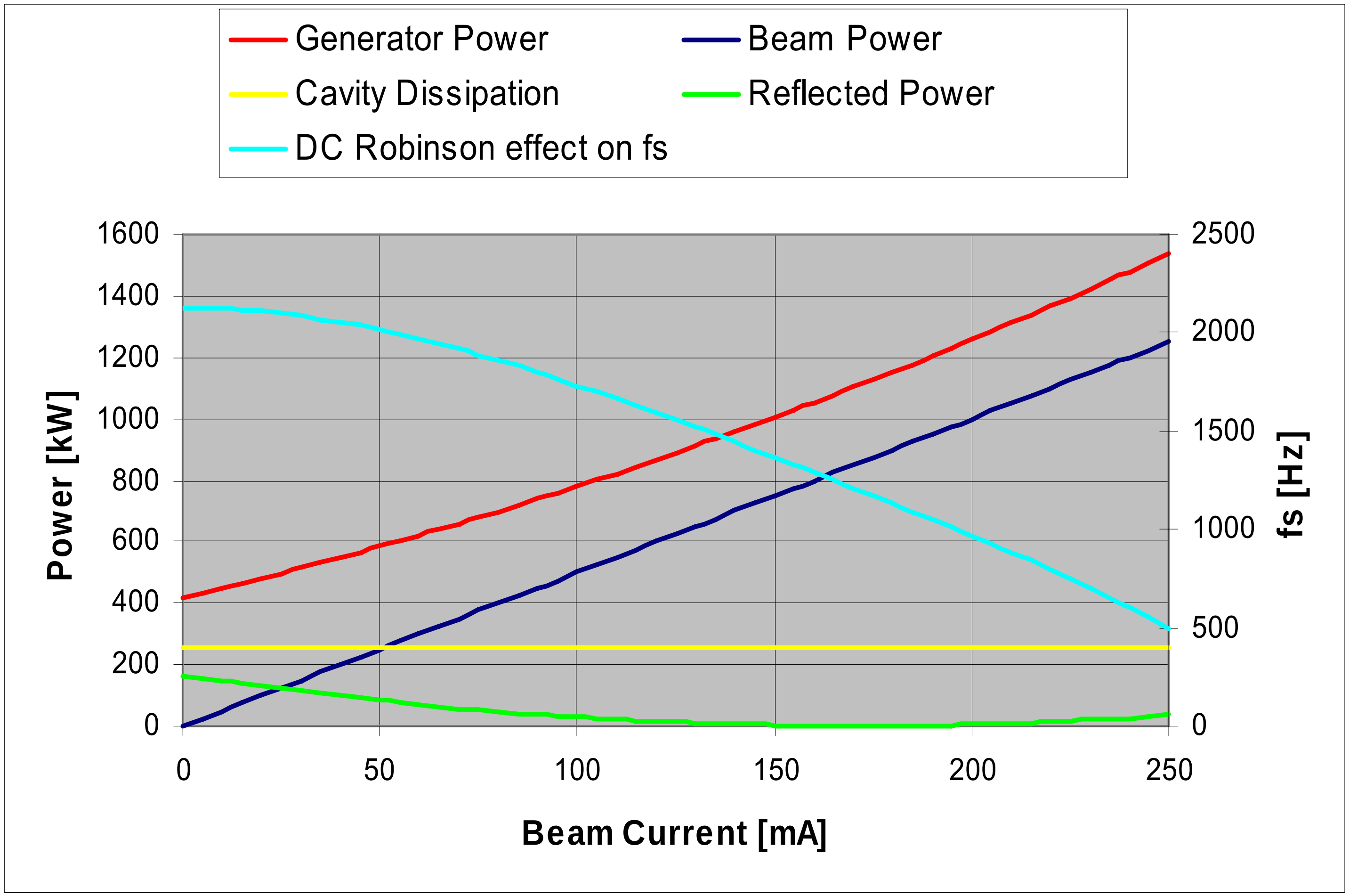
← 2 LEP cavities (1 coupler) configured to replace ESRF cavities in the booster (goal: more spares for SR)

← 1st LEP cavity already reached required 4 MV in pulsed mode on the RF power teststand

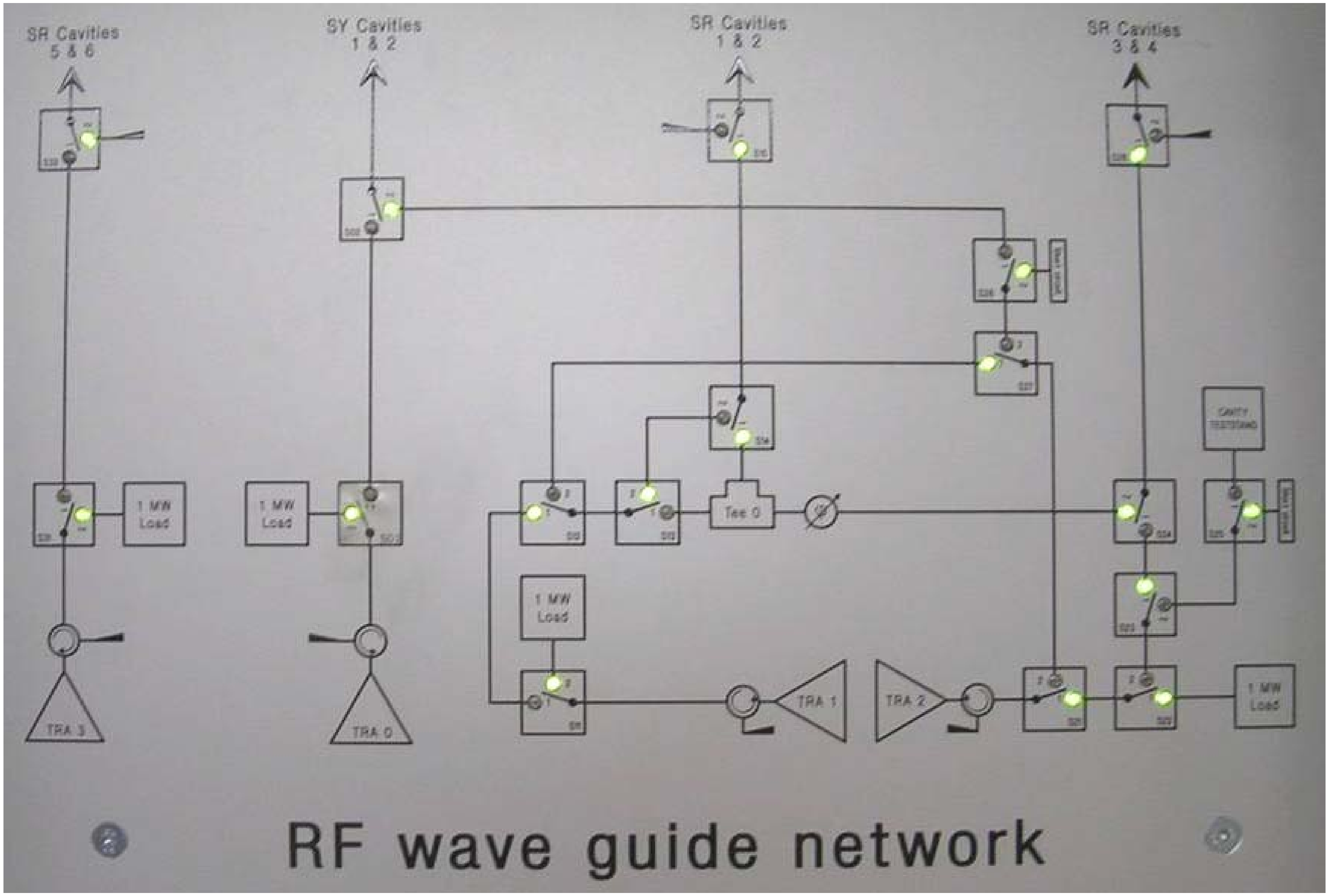


1.3 RF working point

Typical SR working point in multibunch operation with 6 cavities providing $V_{acc} = 9\ MV$



1.4 Redundancy of RF system: flexible configuration



1.5 RF configurations

Nominal 200 mA multibunch operation with

- *SRRF1 transmitter at 900 kW on Cavities 1, 2, 3 & 4*
- *SRRF3 transmitter at 450 kW on Cavities 5 & 6*
- *SYRF transmitter at 600 kW on Booster Cavities 1 & 2*

SRRF2 operational for

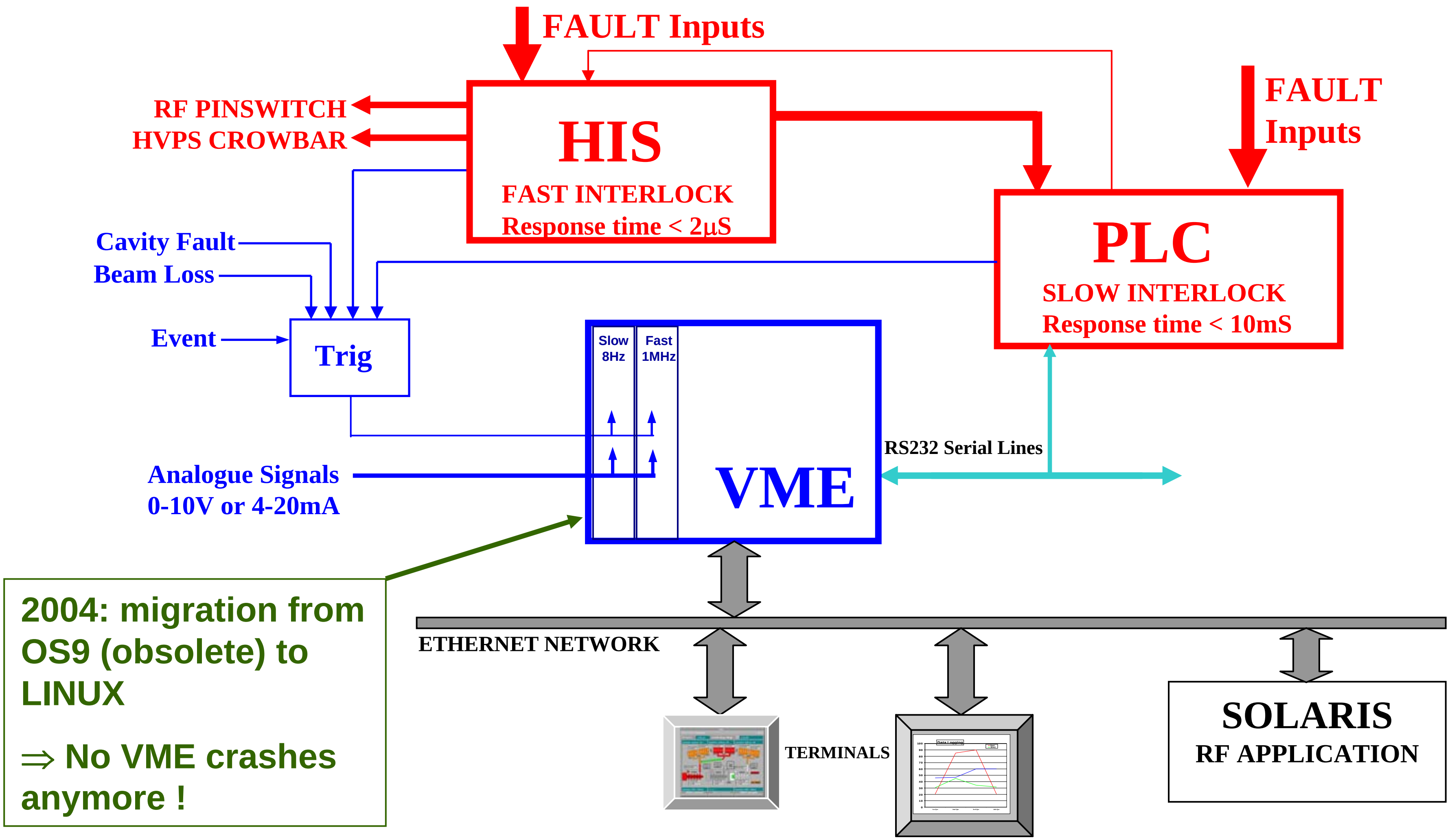
- *Back up of SYRF*
- *Back up of SRRF1*
- *Fall back with SRRF1&2 on 4 cavities without SRRF3*
- *Klystron tests on 1.3 MW dummy load*
- *High power cavity teststand*

NB: Single bunch (10 mA) 4 bunch (40 mA) and 16 bunch (90 mA) operation:
8 MV with SRRF1 on Cavities 1, 2, 3 & 4, Cavities 5 & 6 not powered

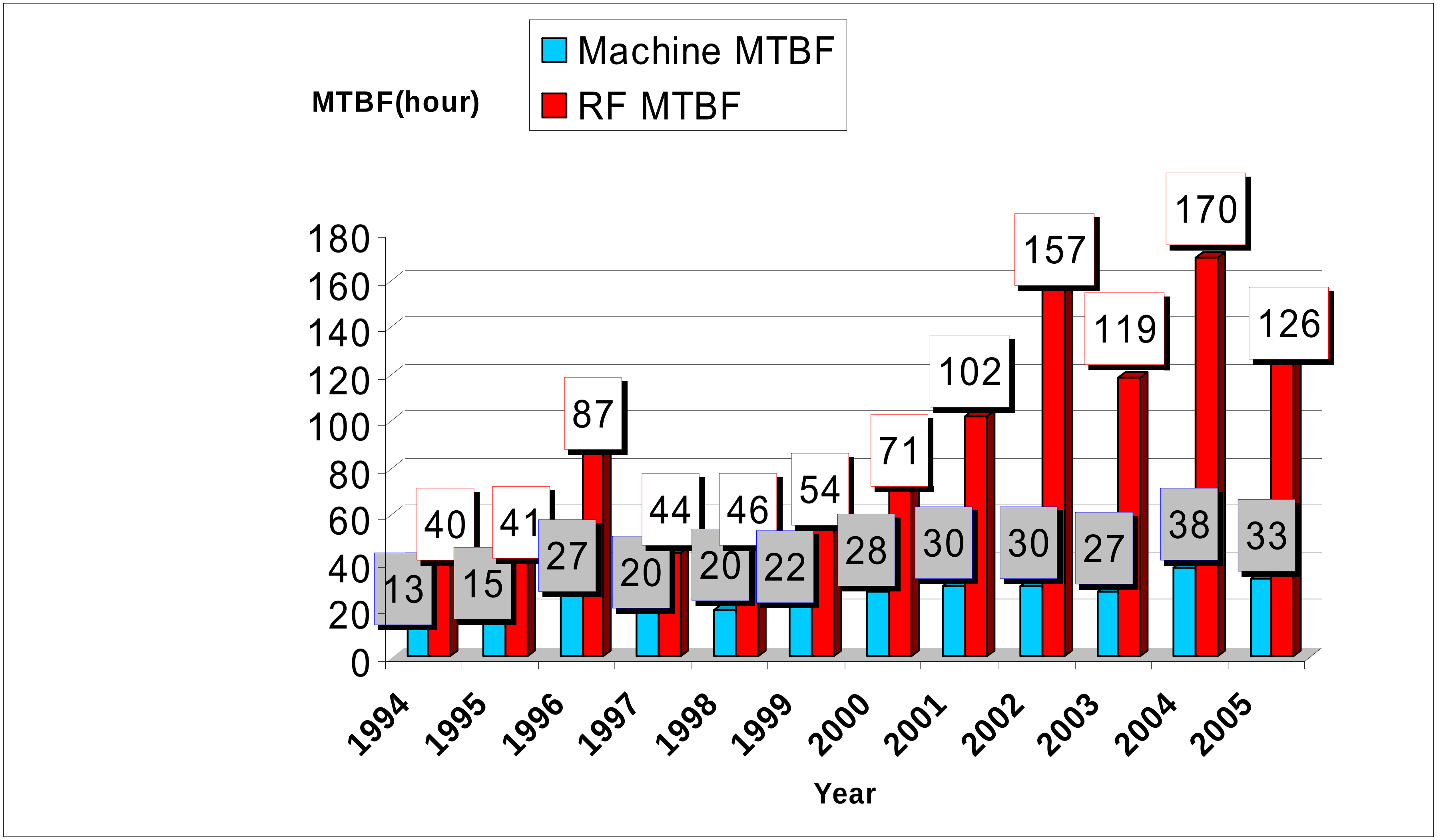
1.6 RF loops

- *TIMING system with master source in control room: distributes the RF to all transmitters. Frequency controlled by software orbit control to compensate DC orbit drifts.*
- *Fast Hardware AC Phase loop on klystron drive chain → to suppress phase noise induced by HV ripples*
- *Slow software loops to control:*
  - → *Cavity tuning angle (Voltage / Incident wave phase), acts on cavity tuners (plungers), compensates thermal drifts and detuning from reactive beam power*
  - → *DC phase control of each transmitter in order to keep all cavity voltages in phase*
  - → *SR: Cavity Voltage control via the klystron anode modulator (gain control, with constant input drive power)*
- *SY: fast DSP amplitude control of the drive power for 10 Hz booster pulse (at constant klystron current = constant gain)*

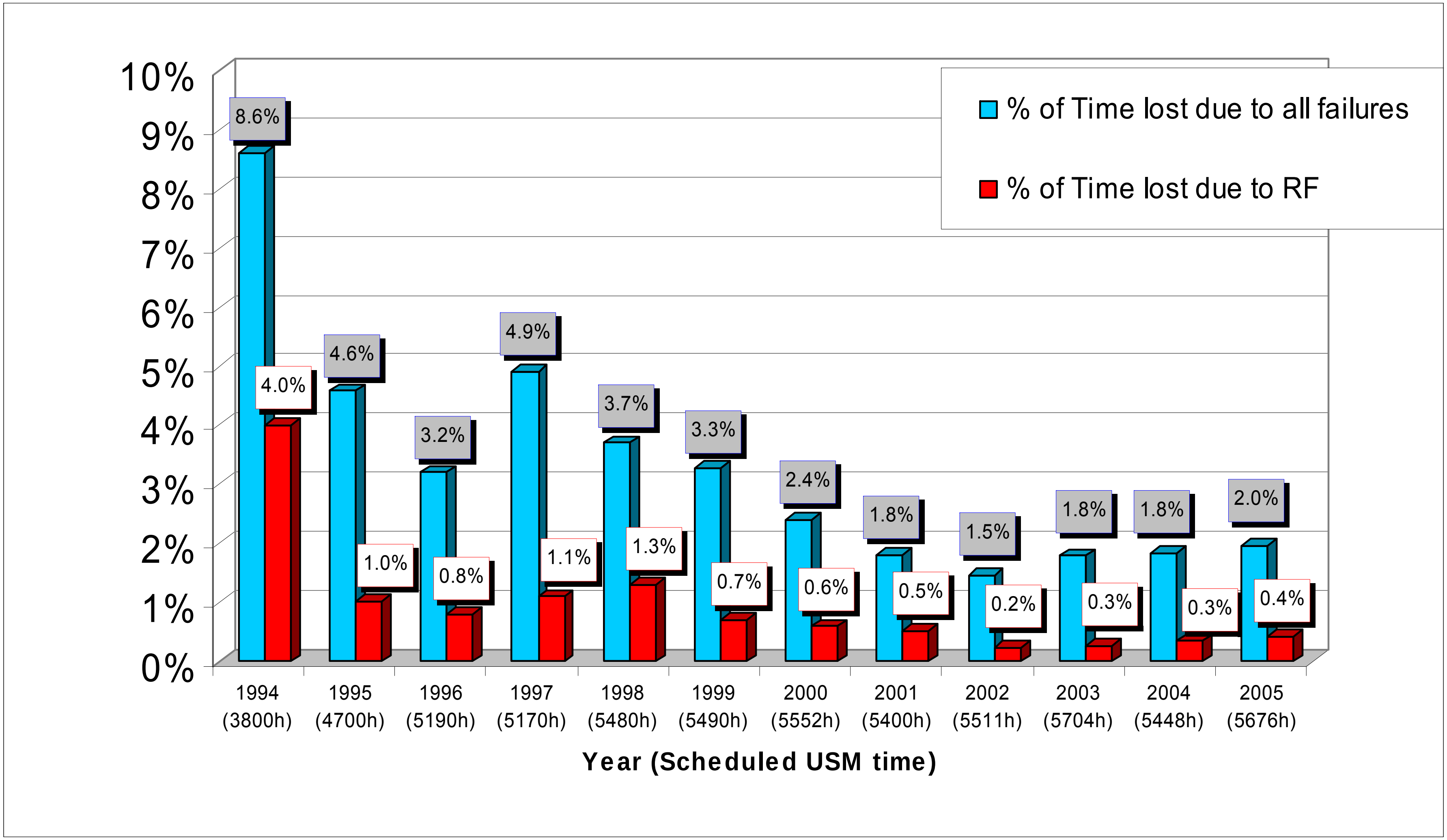
1.7 RF control system and Data logging



2. RF operation statistics (engineering figures)



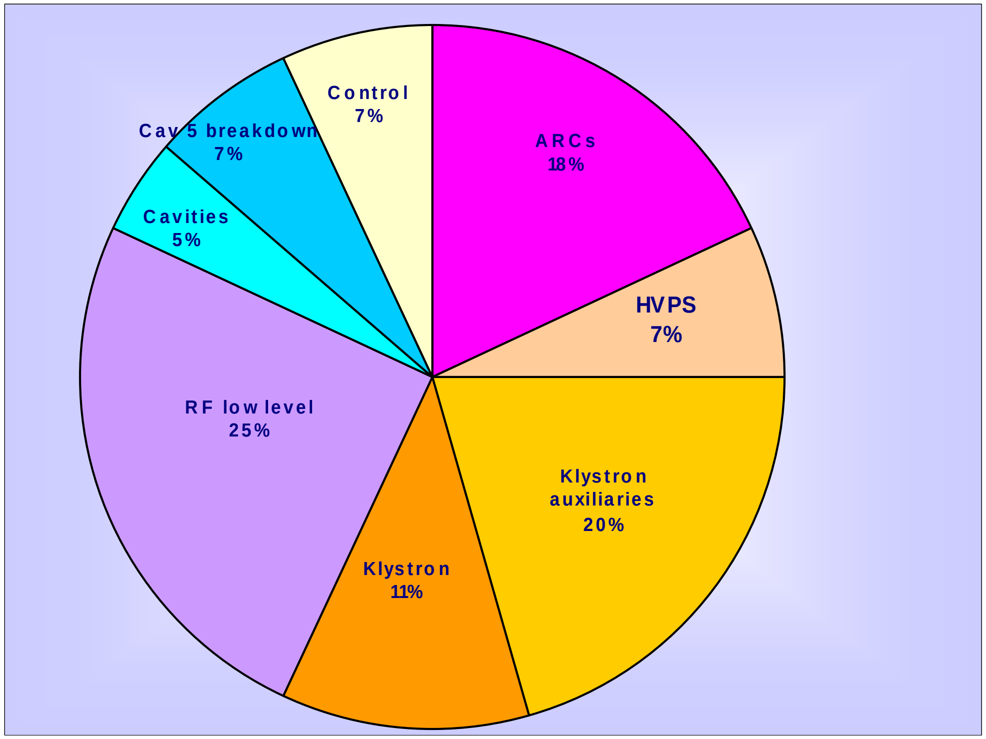
Availability



Example 2005

44 RF trips in 2005 (32 in 2004)

- **RF low level: 11 trips**
  - 9 trips due one bad cable connector
- **Klystron auxiliaries: 9 trips**
  - 3 trips: mod. anode PS
  - 2 trips: Ion pump PS (replaced by new type)
  - 4 trips: Focusing PS (replaced Interlockelectronics)
- **Arcs: 8 trips**
  - 5 real arcs on Tee0 ⇒ then replaced
  - 3 on circulators (no damage)
- Klystrons: 5 trips
  - 2 gun break downs (SRRF1)
  - 1 Outgassing (SRRF1)
  - 1 Sideband (SRRF2)
  - 1 Overdrive (SYRF)
- Cavity 5: 3 trips
  - 3 breakdowns
  - RF reconditioned, stop Ti-Sublimation: no conclusion on impact yet
- 8 other trips:
  - Essentially understood and corrective actions taken



3. Experience with 1.1 / 1.3 MW klystrons

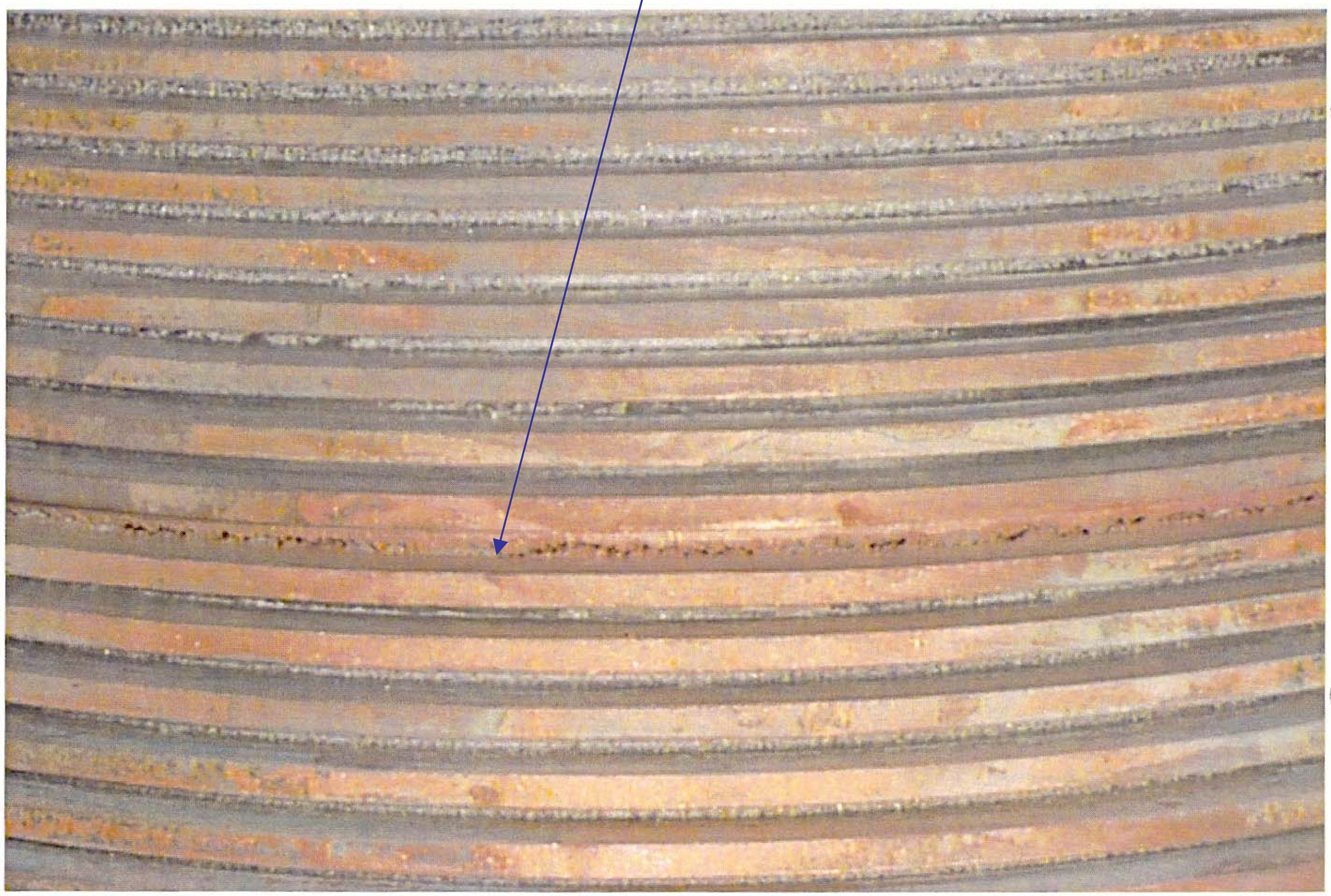
- Only small contribution to RF trips:
  - HVPS + Klystrons = 18 %
- No Klystron damage for more than 7 years:
  - last failure: December 1998 !

Klystron failures / early faults at ESRF

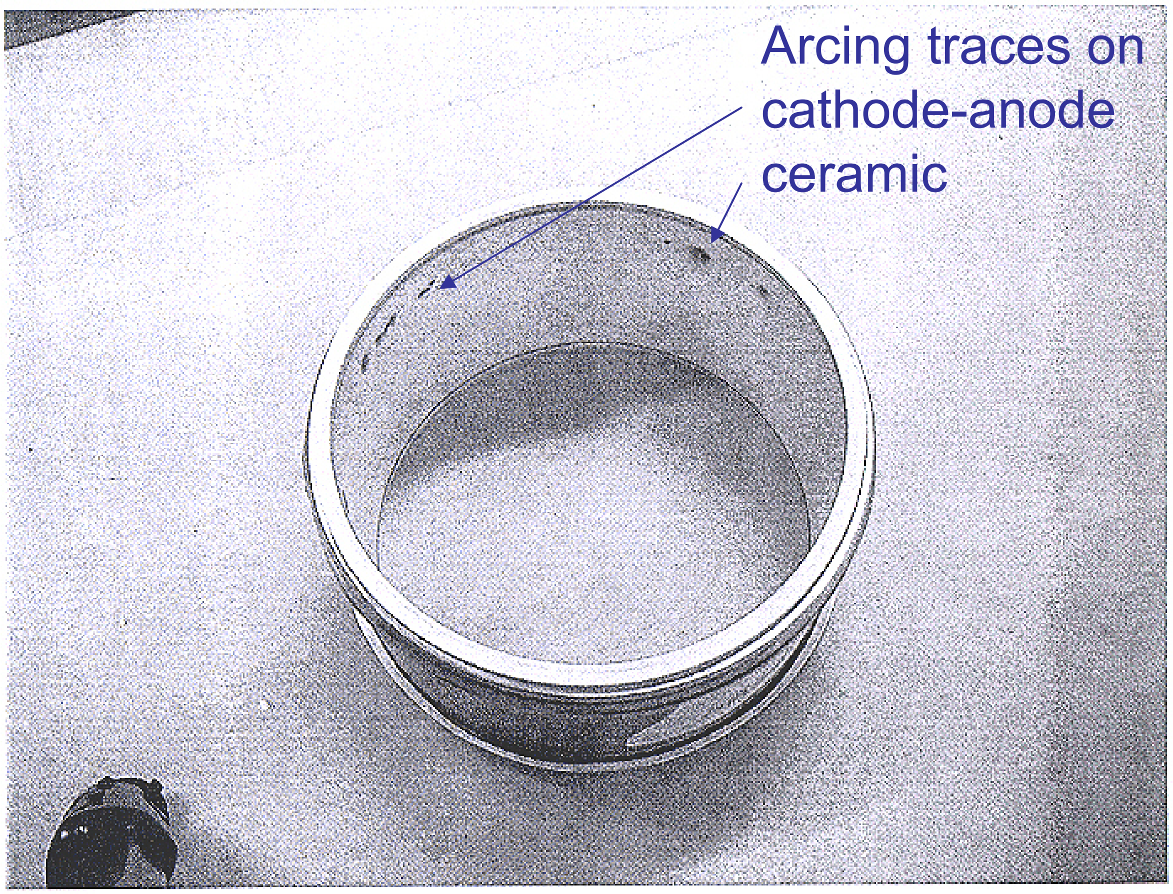
Date	*Klystron*	*HV time [h]*	*place*	*Fab / Op*	*Failure description*
Sep 92	TH89016-1	1216	SYRF	Fab	Filament contact broken: shipment?
Feb 95	EEV1	0	SAT	Fab	Anode/body discharge, youth pb → solved
Mar 96	TH89022-1	8200	SYRF	Fab	Vacuum leak / Cavity 1 brazing → repaired
Apr 97	EEV2	0	ship	Fab	Vacuum leak / brazing on coaxial output → repaired
Apr 97	TH89016-2	7000	SRRF3	Op	Barium evap → I_{anode} → spotknocking → window break
Jan 98	TH89012-1	8395	SYRF	?	Collector partly molten (Ca deposit → ?) → no repair
Jul 98	TH89016-3	0	FAT	Fab	Collector failure → no further repair
Nov 98	EEV2-1	1898	SRRF1	Fab	Cavity 2 feedthrough burnt (loose connect) → repaired
	TH89018-1	2668	SRRF1	Op	Ba evap → I_{anode} → spotknocking & window sand blast
Dec 98	TH89018-1	11306	SYRF	Fab	Collector microleak (although clean) → major repair
Nov 99	EEV5	0	FAT	Fab	Anode/body discharge → repaired
CERN	TH89015-1	8800	LEP?	Op?	Gun breakdown → repaired, then loan to ESRF
CERN	EEV-1	2800	LEP?	Op?	Gun Breakdown → repaired, then loan to ESRF
CERN	Philips-1	9020	LEP?	Op?	Gun Breakdown → repaired, then loan to ESRF

Example: unrepairable collector damage

TH 89012 collector opening risk



Effect of Baryum evaporation and subsequent arcing



ESRF Klystron status / April 2006

11 operational Klystrons in house for 4 sockets

	HV time [h]	Today's allocation
EEV Emily 2 (CERN)	16626	SRRF1: 6500 h/year
TH89015-2 Pauline (CERN)	1228	SRRF2: 100 – 800 h/year
Philips Marika 2 (CERN)	10796	SRRF3: 5000 h/year
TH89022-2	17521	SYRF (booster): 1800 h/year
TH89018-2	12203	stored
EEV1	23727	stored
EEV2-2	8429	stored
EEV3	8374	stored
EEV4	9218	stored
EEV5	10631	stored
Philips	6146	stored

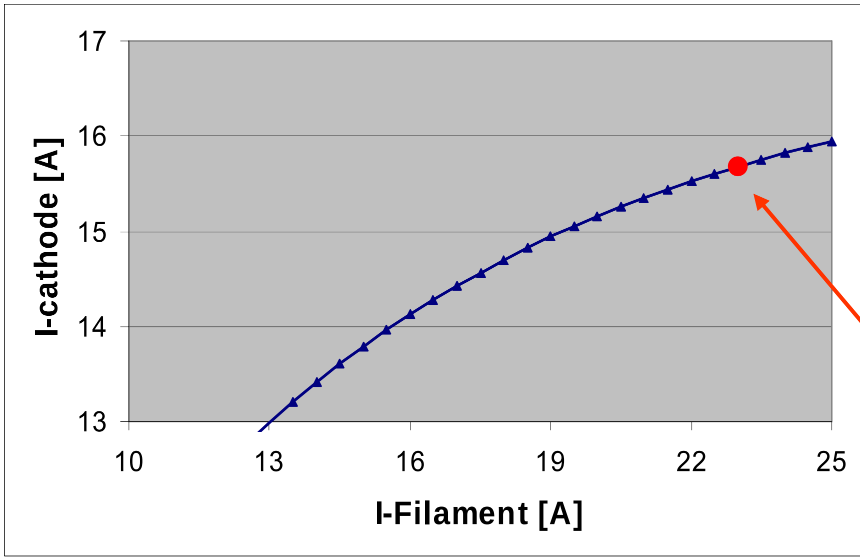
Secrets for long klystron lifetime?

Out of 14 listed failures:

- 9 failures = material or fabrication problems:
  - Likely to appear early
  - Youth problems: now better understood by manufacturers ?
  - Manufacturing errors: improved quality management ?
  - 2 collector problems on booster: enhanced by
    - high collector power?
    - bad cooling in one case?
- 0 failure linked to high CW RF power level
  - No difference: SRRF1 / 900 kW ↔ SRRF3 / 450 kW
- 5 failures = Gun problems
  - To a certain extend: due to operation conditions.i.e. filament heating
  - 3 gun breakdowns experienced at CERN: conditions ?
  - 2 cases of barium evaporation experienced at ESRF → **definitely linked with filament heating**

ESRF secrets for long lifetime

1. Carefull adjustment and regular check of filament working point:



Heating curves:

- Every 6000 h or once/year
- Working point optimized for nominal $(V_{cathode}, I_{cathode})$ settings

$$\text{Criterion}: \frac{I_{cathode}}{I_{filament}} \approx 0.15$$

- $I_{filament}$ too low ⇒ field emission ⇒ bad for cathode lifetime
- $I_{filament}$ too high ⇒ Barium evaporation ⇒ I_{anode}, Breakdowns

2. Low heating: $I_{filament}$ reduced by 30 % ☞ systematically for HV OFF
3. Monitor Anode current (< 1 to1.5 mA)

Booster operation

1. Problems of pulsed booster operation
   - CW HV power: 1100 kW
   - 10 Hz pulsed RF power: typ 450 kW peak / 25 % duty cycle

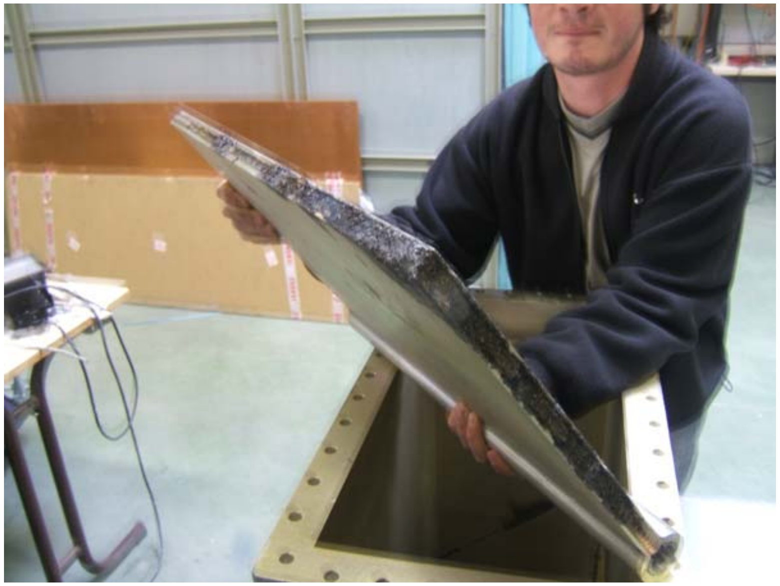
     ⇒ High collector power: ≈ 1000 kW fluctuating at 10 Hz
   - Drive modulation ⇒ multipactor regions difficult to avoid

     ⇒ sometimes klystron instabilities: not dramatic for normal booster operation

2. ESRF plans frequent topping up operation (1 injection every 5 min)
   - RF ON for 30 s every 5 min
   - Planned RF LOW & HV LOW in-between
   - No experience so far ⇒ questions:
     - ◊ How to avoid Cathode overheating?

       → reduce filament current?
     - ◊ Many cycles: fatigue?
   - Klystron instabilities not tolerated for topping up

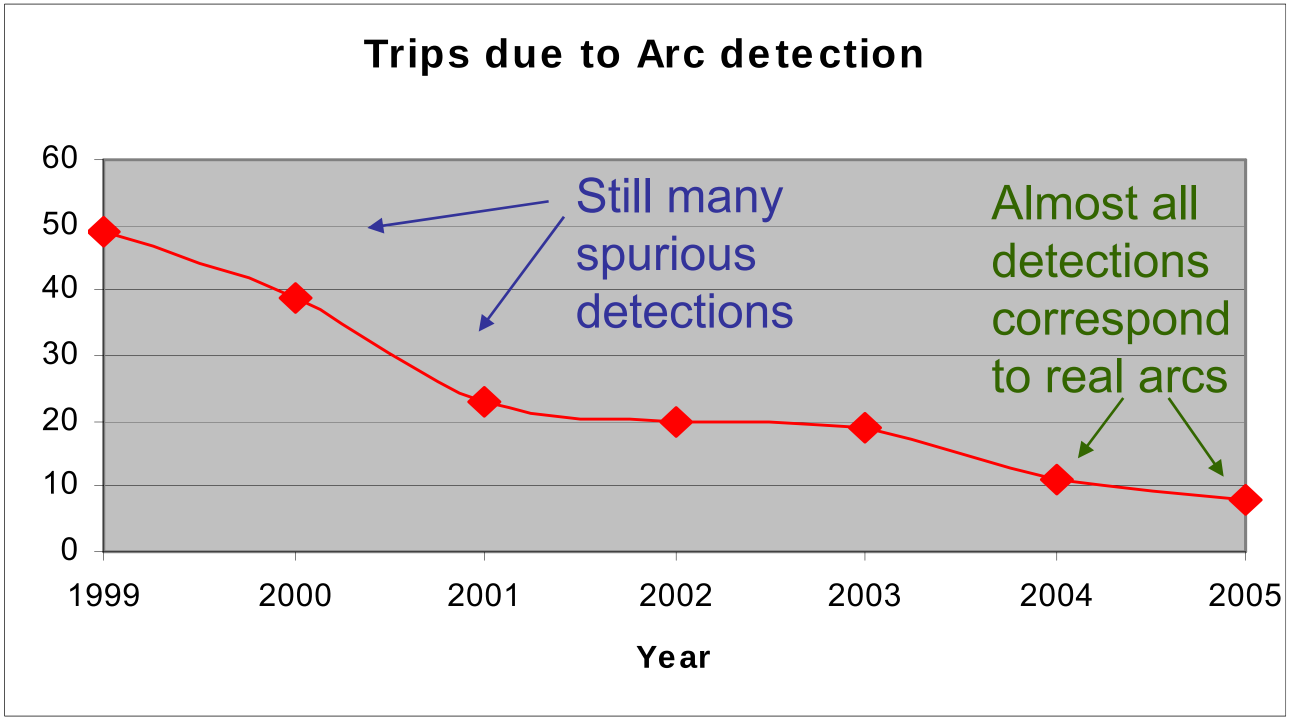
4. Waveguide switches



- Already
  - 3 waveguide switches destroyed
  - 15 installed / 2 good spares left
- Mechanical problems:
  - RF fingers
  - Flap position
  - Limit switch adjustment
- Experience ⇒
  - Arc detectors not too far (maximum at 1 bend, 2 to 3 m distance)
  - Several arcs ⇒ immediate verification and maybe exchange
  - Regular check
    - 1st Mechanical ajdustment, incl. axis excentricity
    - 2nd Check RF isolation ≥ 80 dB

5. Arc detectors

Result from systematic improvement of arc detectors
[J.-M. Mercier, 3rd CW & High Power RF, SLS, 2004]



Places where arcs typically occur, and where fast detection is important:

- Magic Tee splitters (matching post)
- Phase shifters (RF fingers)
- Waveguide switches (RF fingers)

6. New HV deck

- Includes
  - Anode modulator
  - Filament PS
  - Control rack: optical fibre communication, interlocking and status control
- Refurbishment after 15 years and several faults indicating aging
- New HV deck prototype ready for tests:
  - June 2006: on SRRF2 in teststand operation
  - Autumn 2006: on SRRF1 in normal operation on SR

	Old HV deck	**New HV deck**
Mod anode PS	Resonant Inverter + Crockcroft (20 kHz): 120 kV - 10 mA	Resonant inverter + step up transf (100 kHz): 70 kV – 8.6 mA
	Weight ≈ 80 kg ⇒ difficult to replace	Weight ≤ 10 kg ⇒ easy and fast exchange
	Price: 41000 € in 1995	Price: 5600 € in 2004
Filament PS	Linear: 30 V - 28 A	Switched: 40 V - 30 A
	Weight ≈ 20 kg	Weight ≈ 2 kg
	Price: 5000 € in 1995	Price: 2400 € in 2002

7. Cavities

- Not many trips (3 break downs in 2005)
- Fast vacuum interlock protects windows against glow discharges with Cu sputtering
- Not a single glow discharge in 2005: also no event detected with new optical detection using CCD [J.-M. Mercier, 3rd CW & High Power RF, SLS, 2004]

☺ Several days operation at 200 mA without window air cooling on one cavity (by mistake): heating but no damage !

Main conclusions

- RF reliability comparable to other machine equipment → ca. 20-25 % of machine trips and down time
- Continuous effort for doing better AND refurbishment of auxiliary equipment:
  - ⇒ Hope to further increase the reliability
- If carefully tuned and followed up, 1.3 MW klystrons turn out to be very reliable:
  - ➢ Klystrons & HVPS together responsible for less than 20% of RF down time
  - ➢ No klystron failure since December 98
- Greatest problem of klystrons is pulsed operation for the booster rather than high CW power for SR