What can be learned from HERA Experience for ILC Availability

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F. Willeke, DESY

- HERA Performance
- Critical Design Decisions
- What could be avoided if HERA would have to be built again?
- HERA Failure Analysis
- Positive Experience

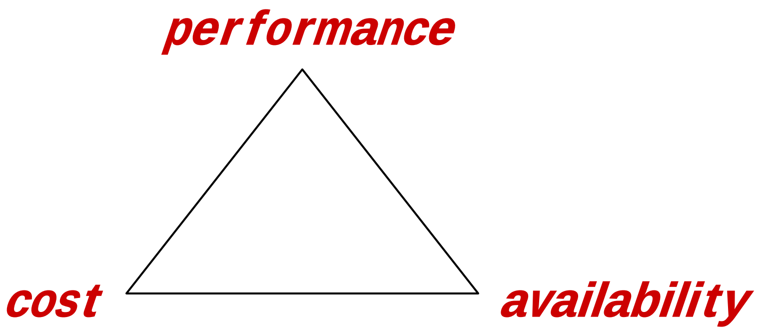
Context

The original idea for this talk was to give it in the context of availability analysis for at least several other large accelerator facilities (TEVATRON, SLC, LEP, SPS....) as an attempt to extract generic information which could be fed in the global design considerations of the ILC.

By looking only at one specific facility, it will be much more difficult to extract ILC relevant information

Introduction

- Optimizing the triangle



is the major challenge of large accelerator projects (this is common place)

- Experience from one accelerator usually cannot be carried over to another one
- Specific HERA experience more relevant for LHC rather than for ILC based on a s.c. LINAC
- Less specific conclusions are dangerously close to banalities and conventional wisdom
- System designers and representatives have a different view than system users ➔ information (hopefully) complementary (and not contradictory)
- Hard to decide what of HERA experience relevant for ILC
  ➔ depends on technical details

Accelerator System Overview

2 rings: p-Ring, e-Ring; 6km circ., 20m deep tunnel
600sc. Magnets, peak field 5T,
1200 water cooled magnets, 1000 corrector magnets
1300 magnet ps, controllers,
84 r.t. 500MHz RF cavities, 16
16 x 500MHz klystrons 12MW output power
6 proton RF systems
800 BPM, 400BLM, 50 movable collimators necessary for operation
On-line magnetic measurements and feedback necessary for operating
3D Dampers systems leptons necessary for operating
Machine protection system, beam dumps,
High spin polarization
4-5 stages of pre-acceleration

Large system with ~10^6 active components (~25% of ILC?)

Critical Design Decisions

- Low energy injection of protons
- Use of existing facilities as injectors
- Avoiding transition crossing
- Design beam lines with cost as the highest priority design criterion
- Beam line instrumentation poor
- Use controls soft- and hardware of the previous accelerator generation
- Re-usage of the RF cavities designed for large gradient but low current
- Operate with SC cavities which suffer from hydrogen sickness
- ...

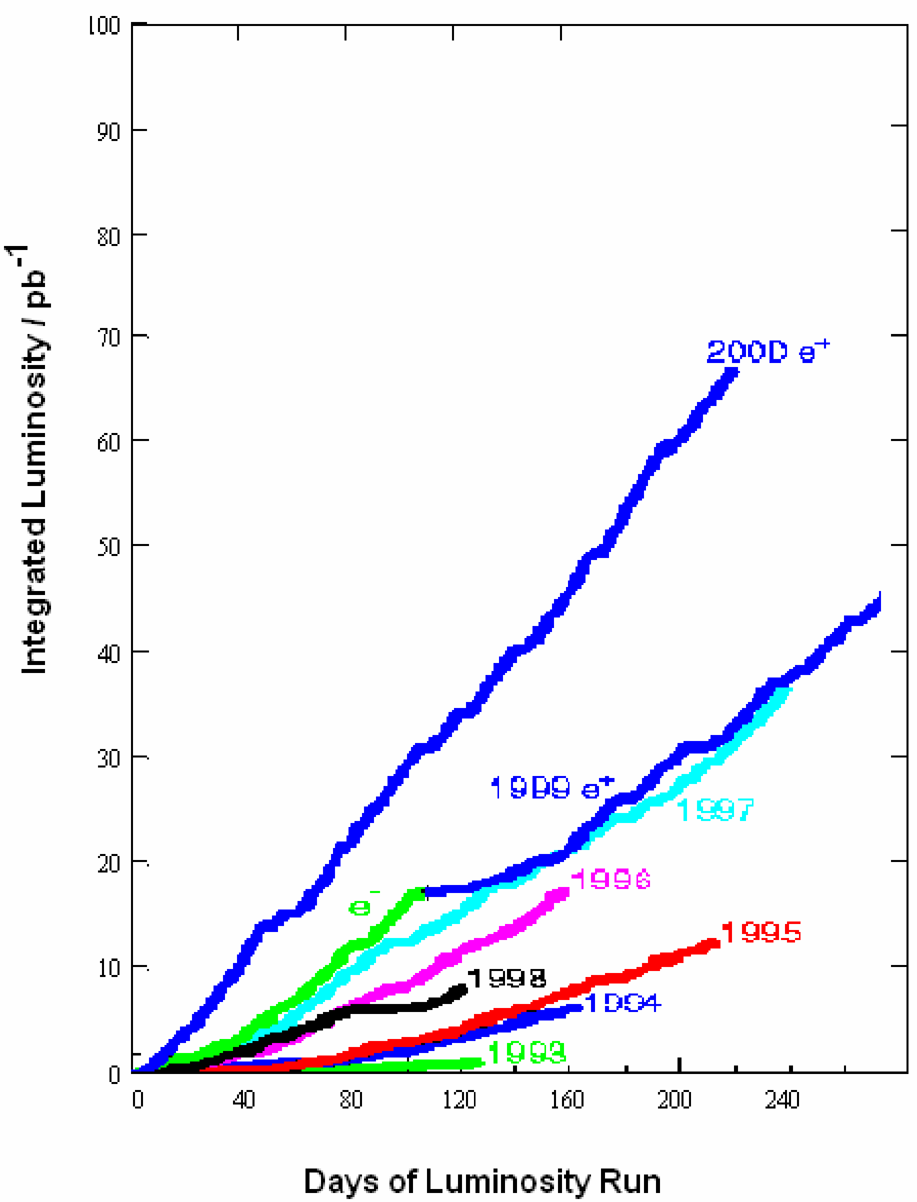
Lessons learned form HERA critical decisions:

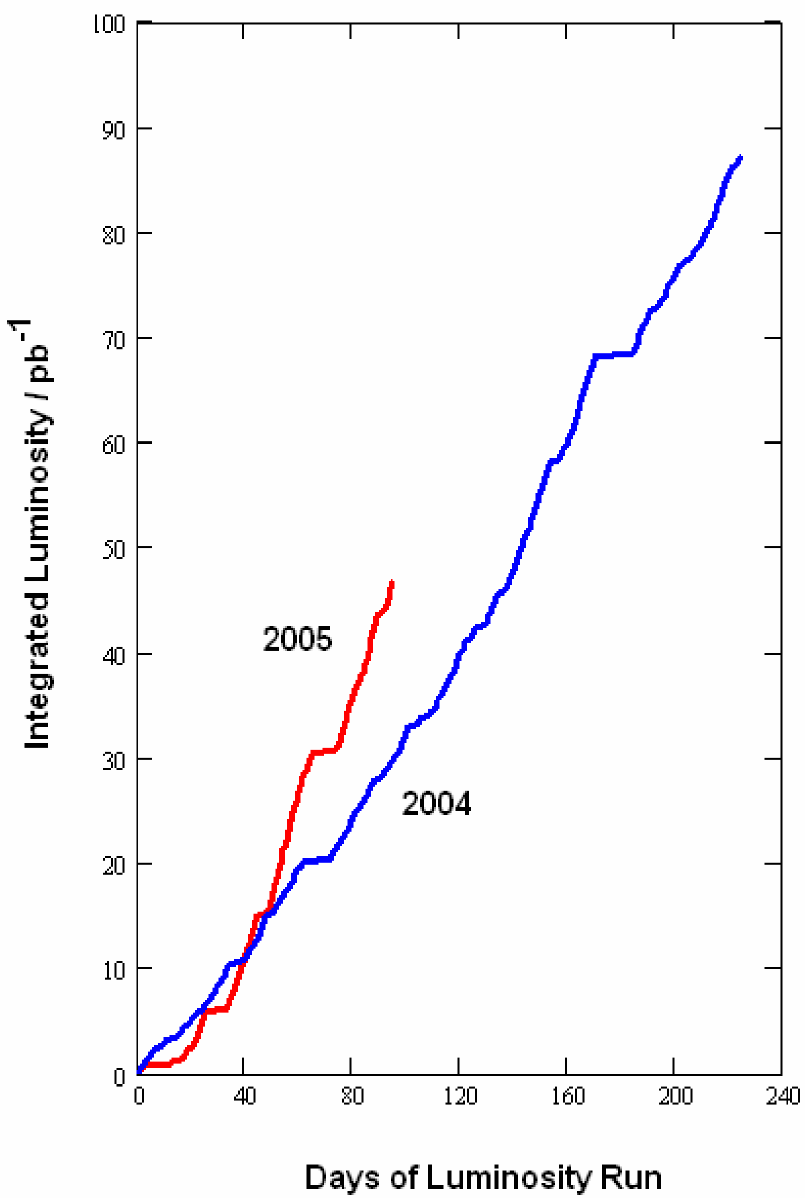
Dependency and conspiracy of bad effects should be considered (this is common place as well)

HERA Examples:

- Tight e-Beam lines & slow injectors & insufficient beam line instrumentation & missing controls
- Tight p-beam lines & slow and low energy injectors & limited dynamical injection stability & missing controls
- Non Optimum RF design & missing power redundancy & insufficient and inflexible interlock systems & missing control
- Active equipment in the tunnel & slow injection and acceleration procedures

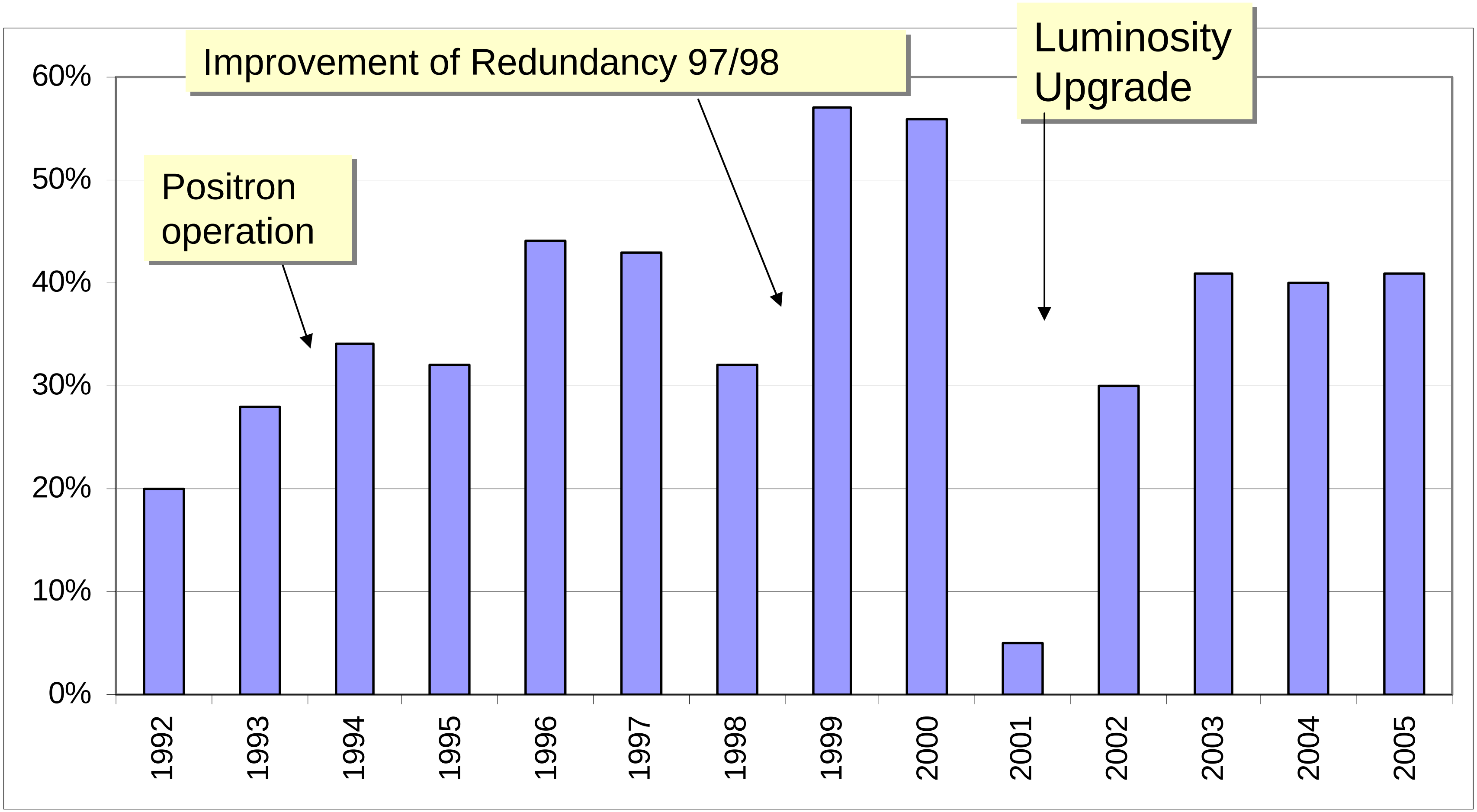
HERA Performance



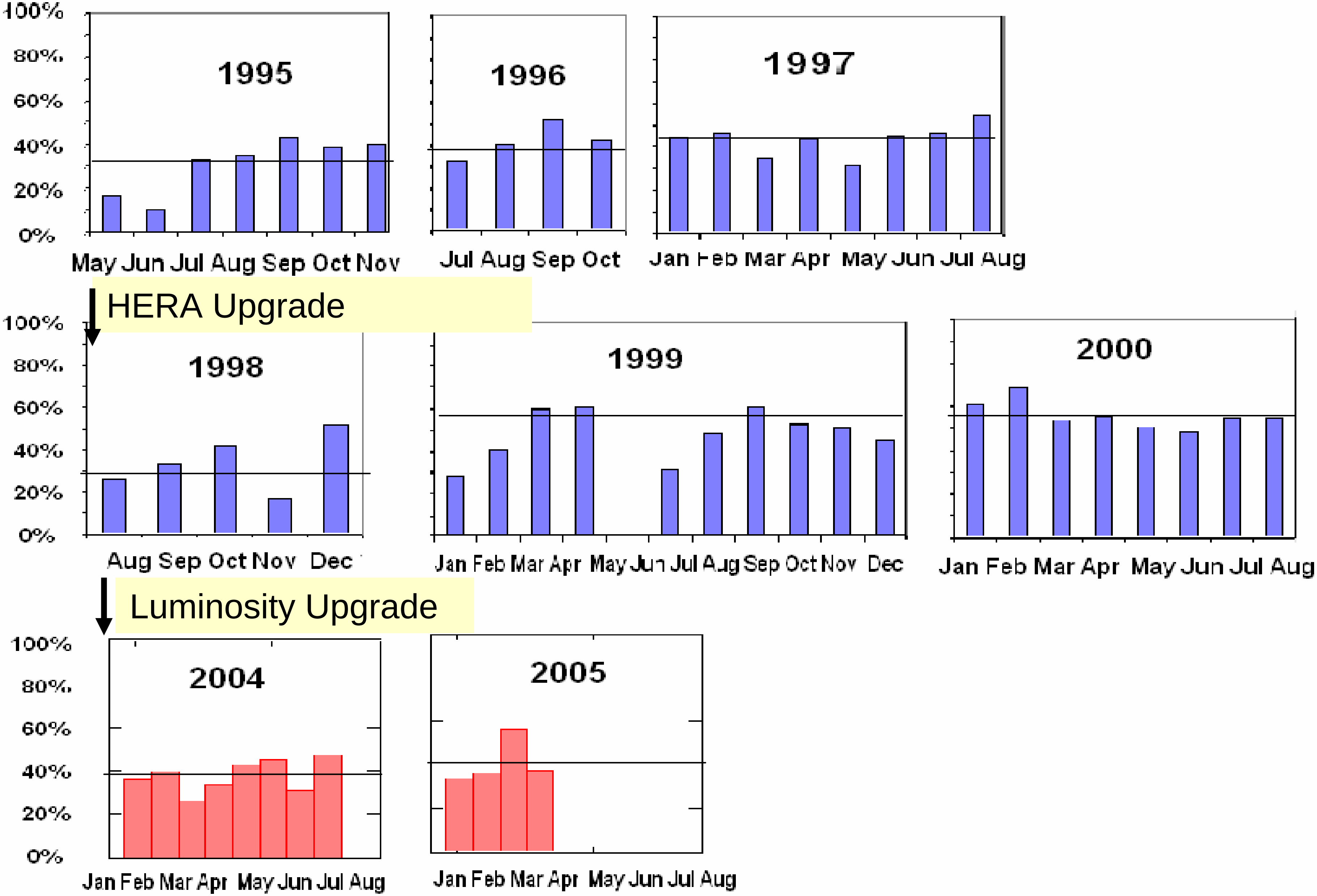


HERA Efficiencies

DEFINITION: Time spent with collision divided by scheduled time



HERA Efficiencies 1995-2005



Remarks on Overall Availability

- HERA Average Luminosity Efficiency is **~40%**
- The HERA average availability (1992-2005) is **53%** (based on the assumption of 75% possible efficiency)

→ This is a factor of almost 2 reduction in performance this is significant

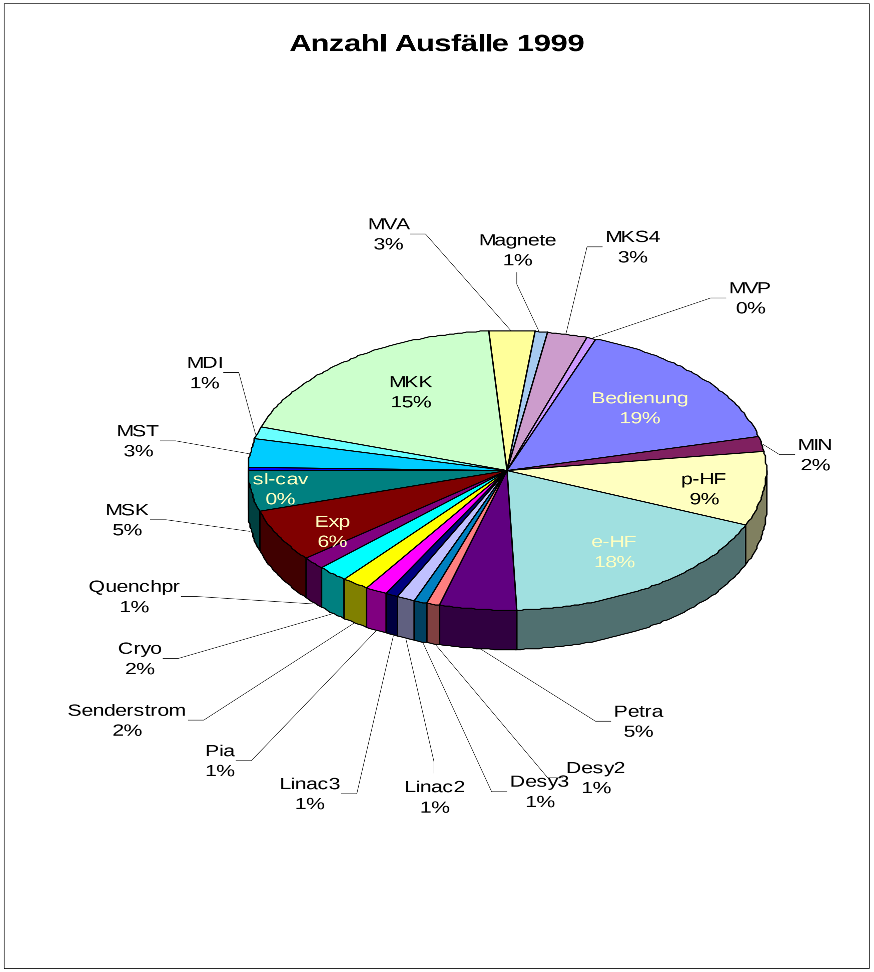
(**It however is comparable with LEP or TEVATRON)**

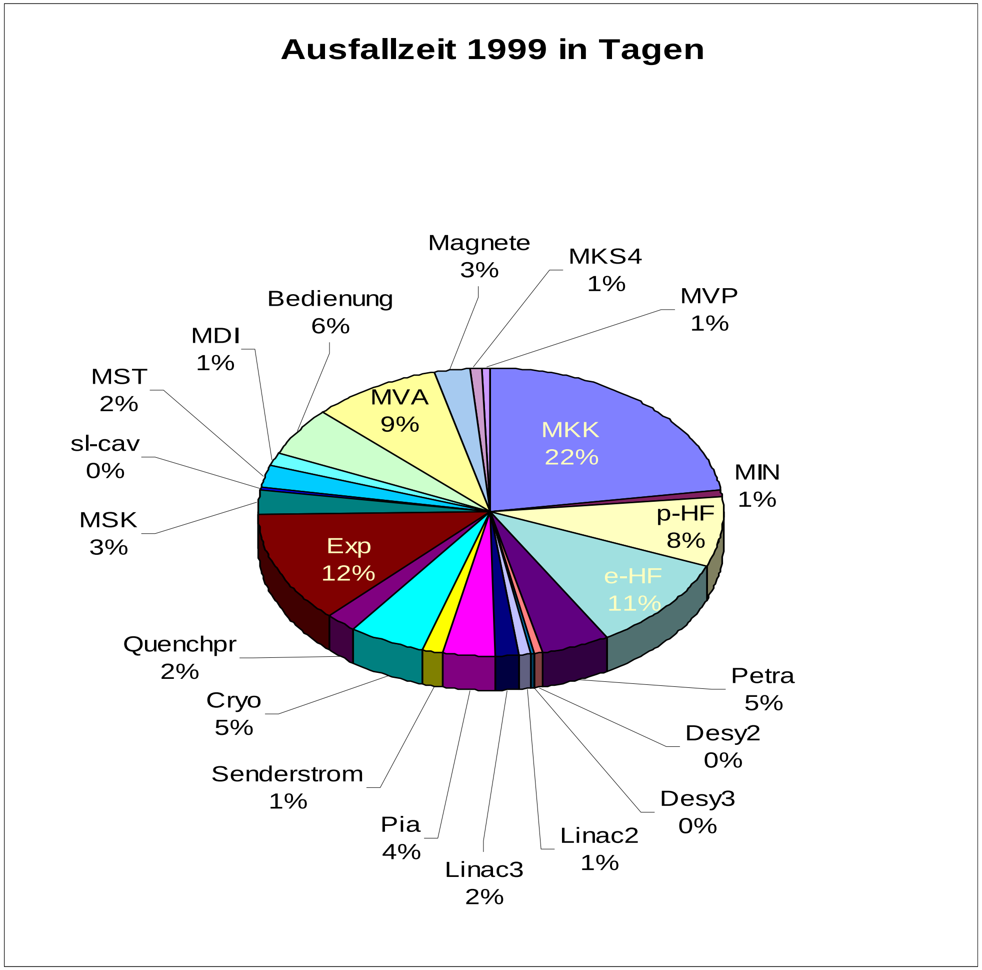
Remarks on Availability

- HERA availability, after initial improvements in '94 did not make fast progress
- Reliability Upgrade in 1997 enhancing redundancy of RF, improving critical systems (p-Main P.S., S.C. Cavities, control systems) made a considerable step forward

  (correcting a few less fortunate design decisions)
- Recently there are indication that global aging is becoming a problem

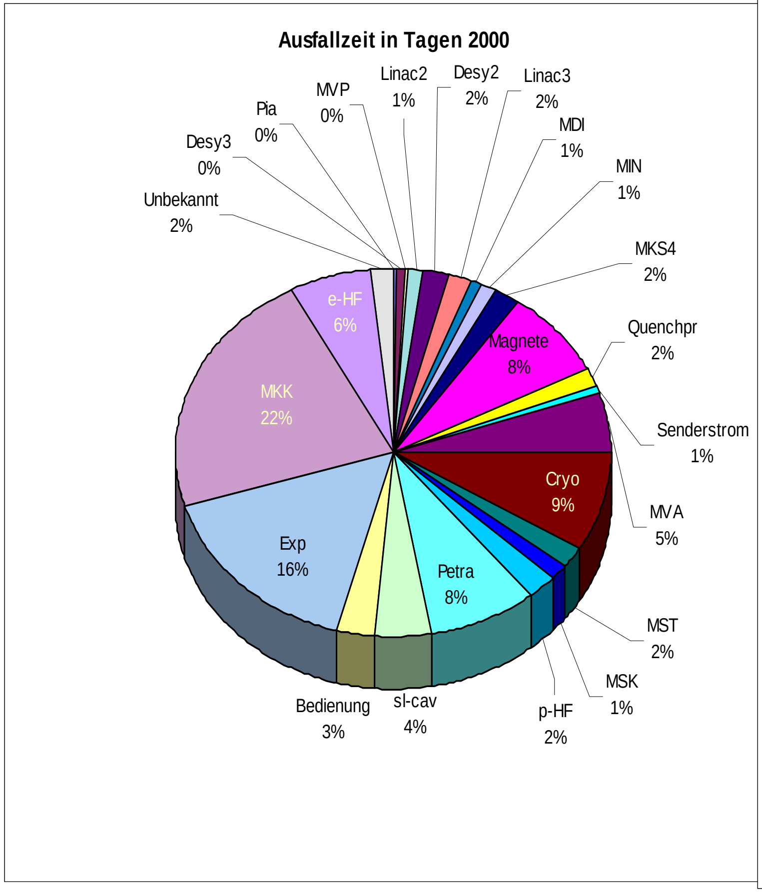
1999 Failure Statistics



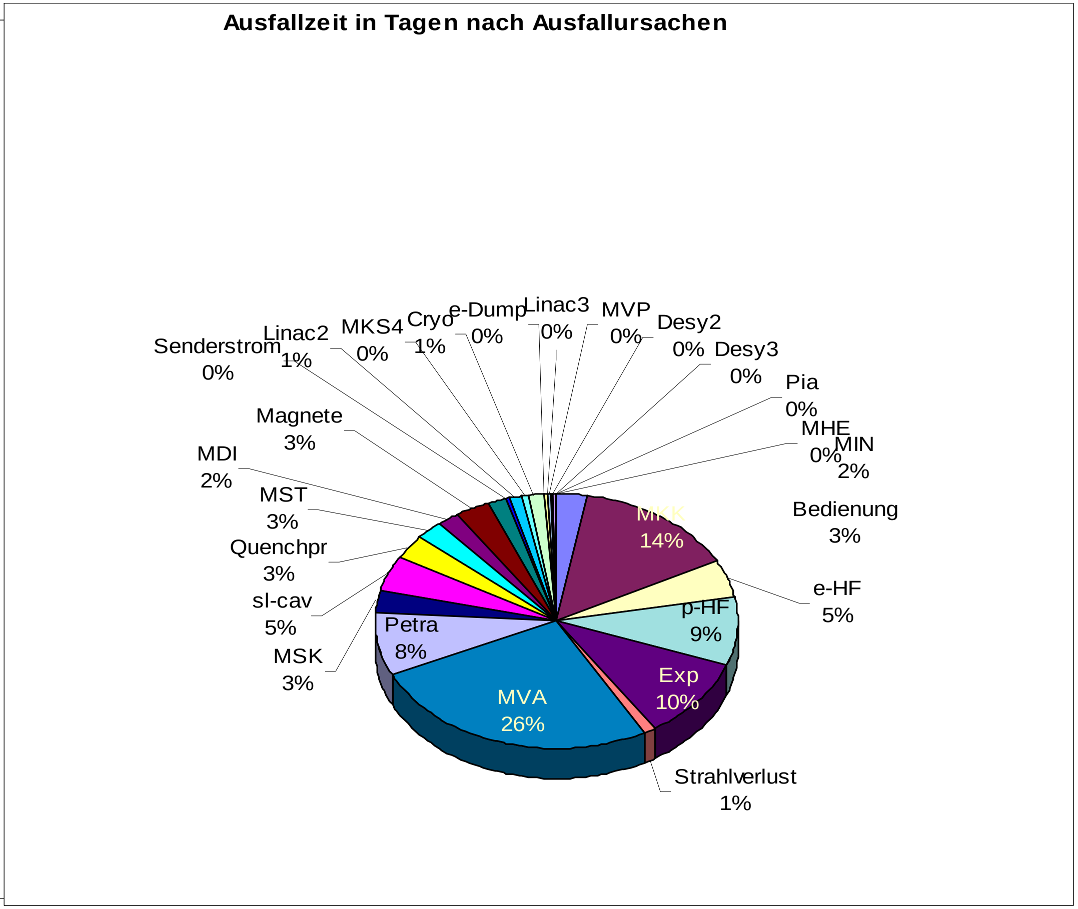


Failure Statistics

Y 2000



Y 2004



Remarks on Failure Statistics

Failure statistics is remarkably stable over the years: Suspicion that the failure rate is built into the system in a global way

There are examples of improvements: **Power systems and e-RF**

this is (hopefully) due to the large effort in error tracking, preventive maintenance, post mortem analysis

There is also some (unconfirmed) suspicion of global aging. Aging of particular components like magnet coils, proton BPMs etc, is established

Remarks on HERA Failure Statistics

HERA failures were a problem mainly for the conventional systems:

n.c. Magnets, power supplies, e-RF systems, water cooling, power distribution, cabling!,

Relatively little problems with new technologies:
s.c. magnets, quench protection

exception: Alarm loop, inadequate cabling

exception: s.c. cavities, insufficient support

➔ **Beware of underestimating "Trivial Systems"**

Remarks on Failure statistics

Compromise must be made between protection of components and availability

➔ **~ 50% of all trips are due to failing interlocks**

HERA counter measures:

- RF systems are not turned off but reduced in voltage
- Delayed response to magnet failures
- Delayed and selective response to cryogenic failures

General Conclusions:

HERA technical interlocks are often not flexible enough to provide both efficient protection and at the same time good performance

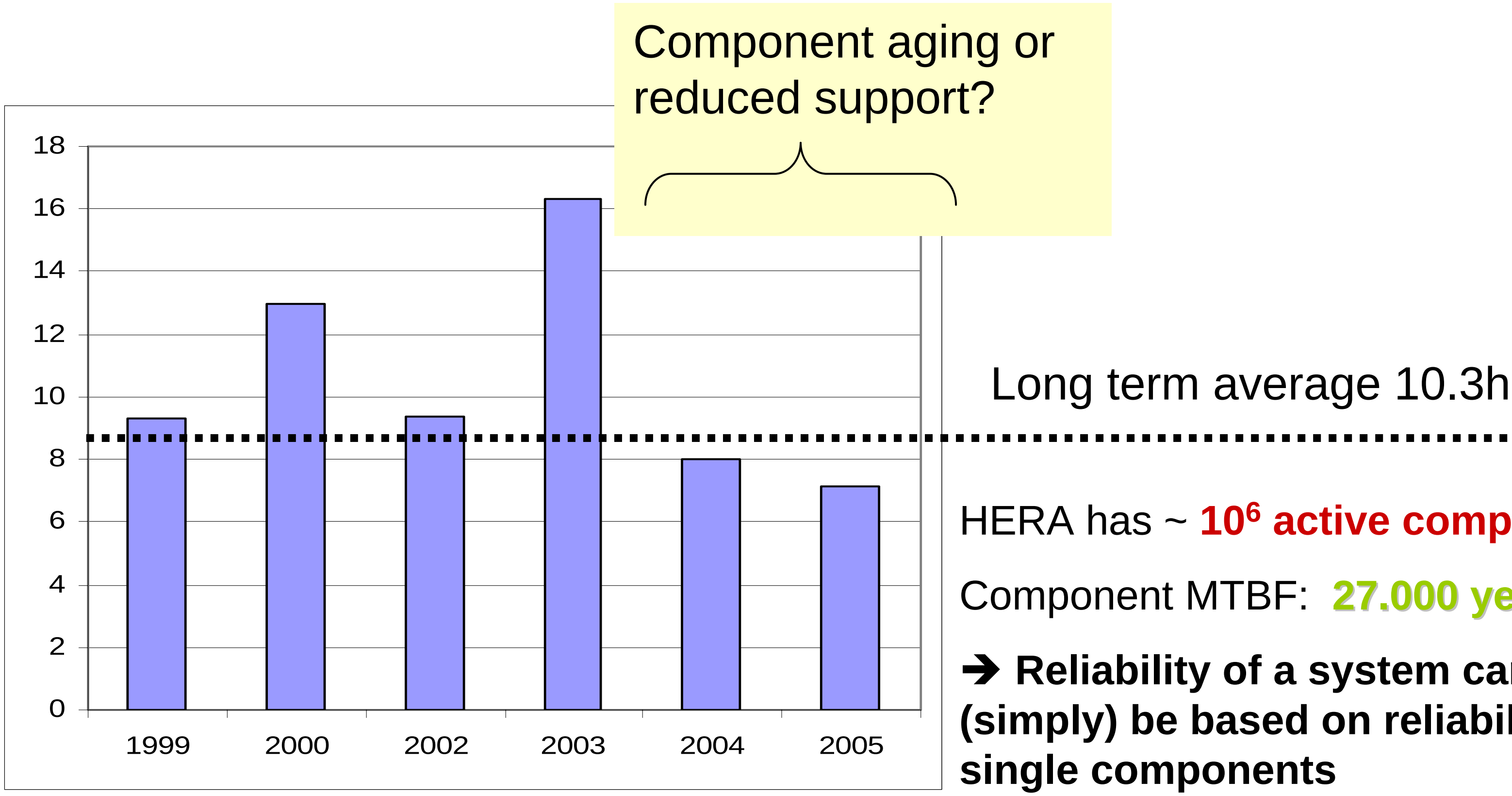
Some of the flexibility has been added later to the benefit of operations

These are often critical compromises

More flexibility is needed in future designs

The possibility to optimize between the contradictory requirements should be designed into the components!

HERA Mean Time between Failure



HERA has ~ **10^6 active components**

Component MTBF: **27.000 years**

➔ **Reliability of a system cannot (simply) be based on reliability of single components**

➔ systematical assessment based on basic modules very problematic

➔ Analysis must be based on larger subsystems “lumped system”

➔ Since this depends very much on the nature of the system, a TTF analysis probably more suitable for X-FEL than HERA

Component Reliability

Example HERA Magnet Power Supply System

1200 supplies, >200 active components/ supply, >20 000 relays …

A trip in any supply ➔ beam loss, ~20% of the supplies are always needed

Time lost due to power supply trips

Year	Time Lost	Operating Hours	
1999	163	3288	5.0%
2000	175	4999	3.5%
2003	114	2167	5.3%
2004	169	5280	3.2%
2005	56	1920	2.9%

Diode Supplies:	27
Thyristor:	45
Chopper:	570
Correctors:	550
Sum:	~1200

1200 power supplies Trips in 2004 ≈ 90 in 227 days ➔ MTBF = 71150

640 large supplies+choppers Trips in 2004 ≈ 49 in 227 days ➔ MTBF = 38737

HERA P.S. system: no aging due to continuous maintenance effort

Error logging and tracking crucial

➔ **Payoff of considerable MKK effort to keep the system up and working**

Despite this effort ...

5% loss in operation time for a single system failure is not desirable

Not obvious that optimum Number of independent supplies has been chosen as trade off

between system flexibility and potential performance increase

and

availability and operational efficiency

(note: the 550 3A correctors of e-Ring are only of minor importance in this context)

Remarks on Redundancy

Partitioning of systems to be taken into account availability considerations

➔ Large monolithic systems create single point failures
➔ Large number of system creates a large number of potential failures

HERA Examples:

- Double Klystrons instead of single klystrons,
- Shared HV supplies for RF systems
- Unequal splitting of RF voltage between S.C and n.c. system
- Chopper concept: Feeding supply trip causes up to 50 chopper trips

versus

Large number of power supplies ➔ many power supply trips

Remark on Equipment in the Tunnel

HERA experience with equipment in the tunnel is not good:

A component which could be fixed within 20min may cause downtime of several hours because of the slow injectors and long injection, optimization and ramping procedures

(frequent case : SEDAC power supplies in electronic racks under the concrete)

➔ Minimizing active and complex components in the accelerator tunnel is advisable

Remark on HERA Controls

- HERA control system was developed from a very successful, adequate and state of the art control system (PETRA, 1978)

- HERA controls (1992) were completely inadequate and obsolete and efficient operating was not possible

- Emphasis in the early control system was remote control of hardware components

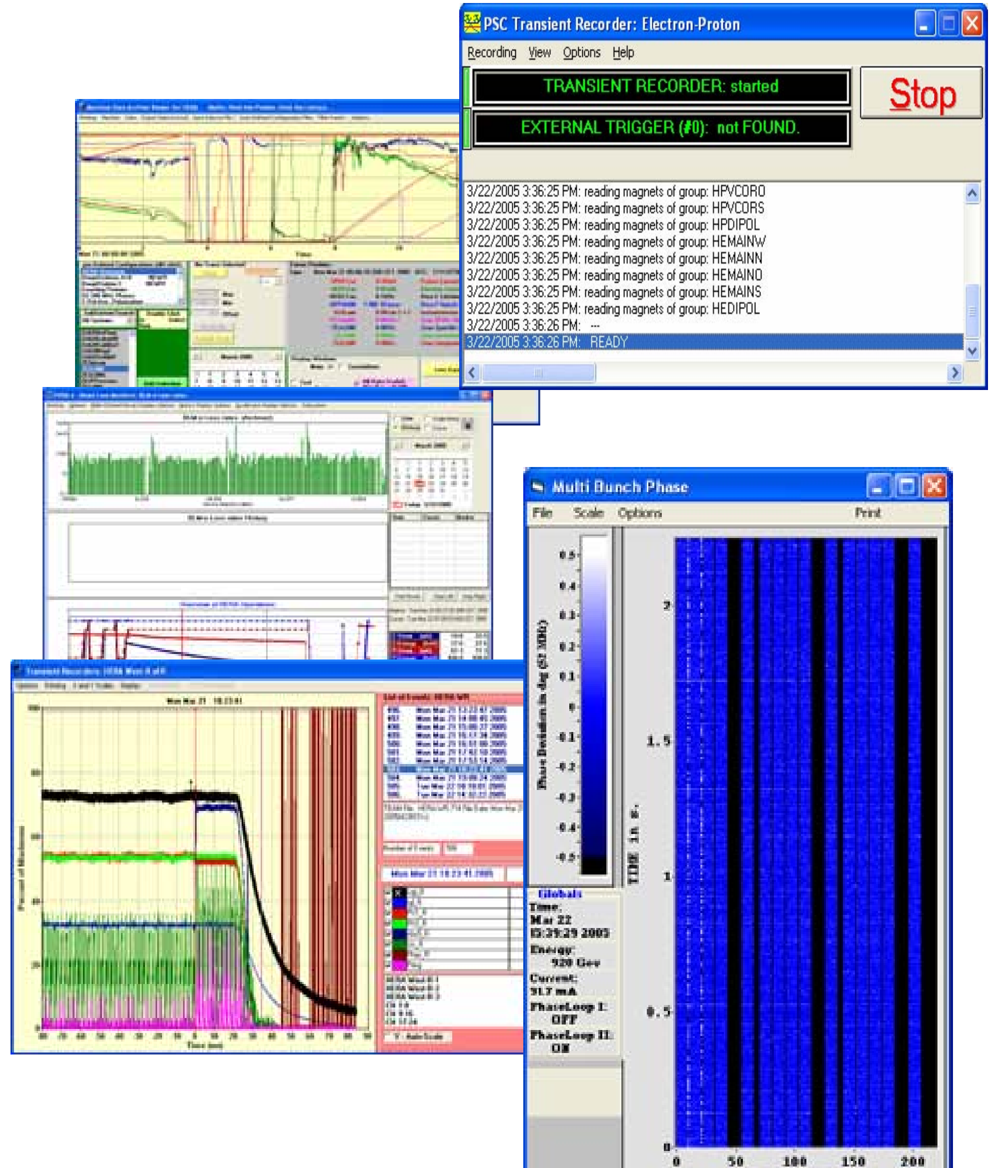
- Missing was integrating application software, automation of complex operation

➔ A new control system was developed on the fly which was only available in 1998

Process Data Acquisition and Visualization

- Good progress could be made by a comprehensive data logging and archiving
- Viewing and analyzing software are important for large amounts of data, HERA initial control were suffering from the lack of both
- A comprehensive system of transient recorders was mandatory for HERA, before such systems were made available, it was very hard to trace down trivial errors in the

- HERA systems have been developed while operating the accelerator
- Systems came several years too late
- No systematic design of data acquisition system and specification of analyzing software



Conclusions

Systematic assessment of HERA (and all the other large accelerators) operational statistics might be helpful in the design decisions for future accelerators

Data on operational statistics is available for the whole operation time (probably true for most facilities)

There is a detailed error logging since 1999

There are many archived data available for analysis

It would be a pity to repeat some of the less fortunate HERA (and other accelerator) design choices

A considerable amount of detailed technical information of the HERA system is available in the technical support groups