Lessons learned from 16 Years of HERA Operations

M. Bieler (DESY), F. Willeke (BNL)

- HERA Overview
- Critical Design Decisions
- HERA availability
- Lessons learned
- Conclusion

HERA System Overview

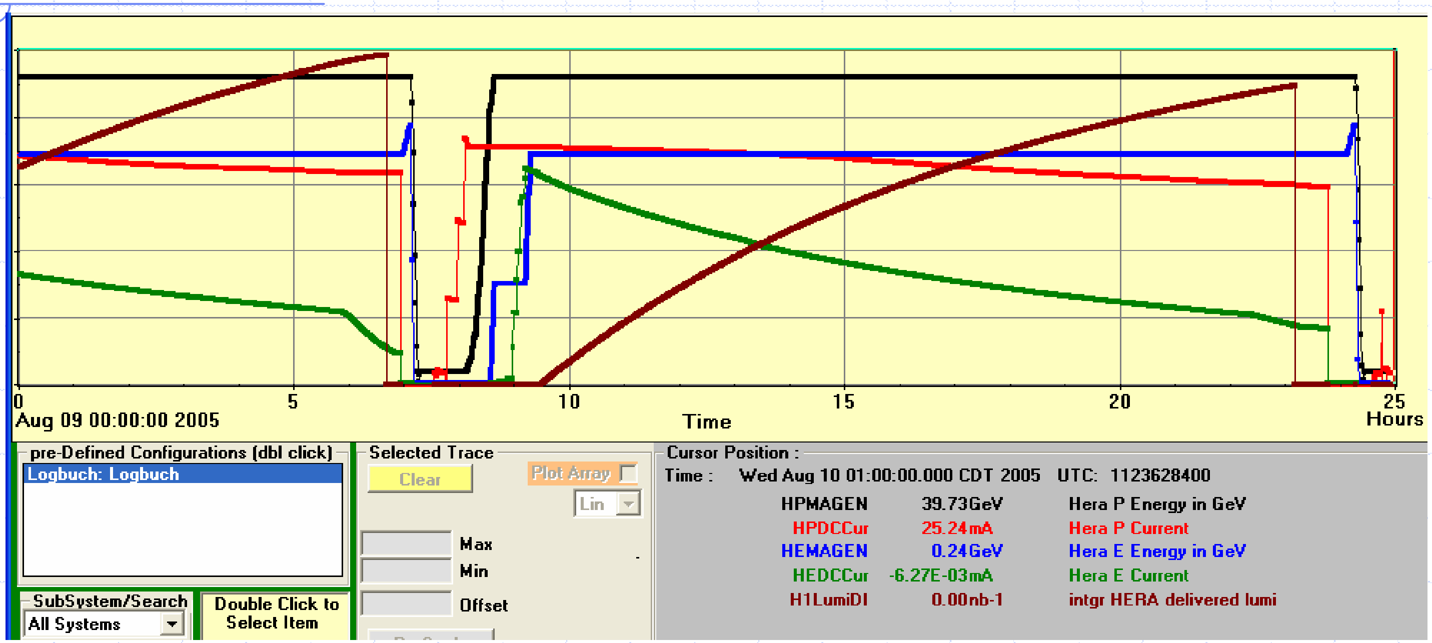
2 rings: p-ring (920 GeV), e-ring (27.5 GeV)
Tunnel: 6 km circ., 20m below the ground
600 s.c. magnets, peak field 5 T
1200 water cooled magnets
1000 corrector magnets
1300 magnet power supplies and controllers
84 n.c. 500MHz RF cavities
16 s.c. 500MHz RF cavities
16 klystrons (500 MHz), 12 MW total output power
6 proton RF systems

HERA System Overview

- 800 BPM, 400 BLM, 50 movable collimators necessary for operation
- On-line magnetic measurements and feedback necessary for operation
- 3D damper systems for leptons necessary for operation
- Machine protection system
- 2 beam dumps
- 4-5 stages of pre-acceleration

Large system with ~10^6 active components

The HERA Operation Cycle



2.5 hours (minimum) from beam dump to luminosity.

14 hours luminosity run.

(Average in 2006: 3.2 h fill time, 8 h lumi run)

Critical Design Decisions

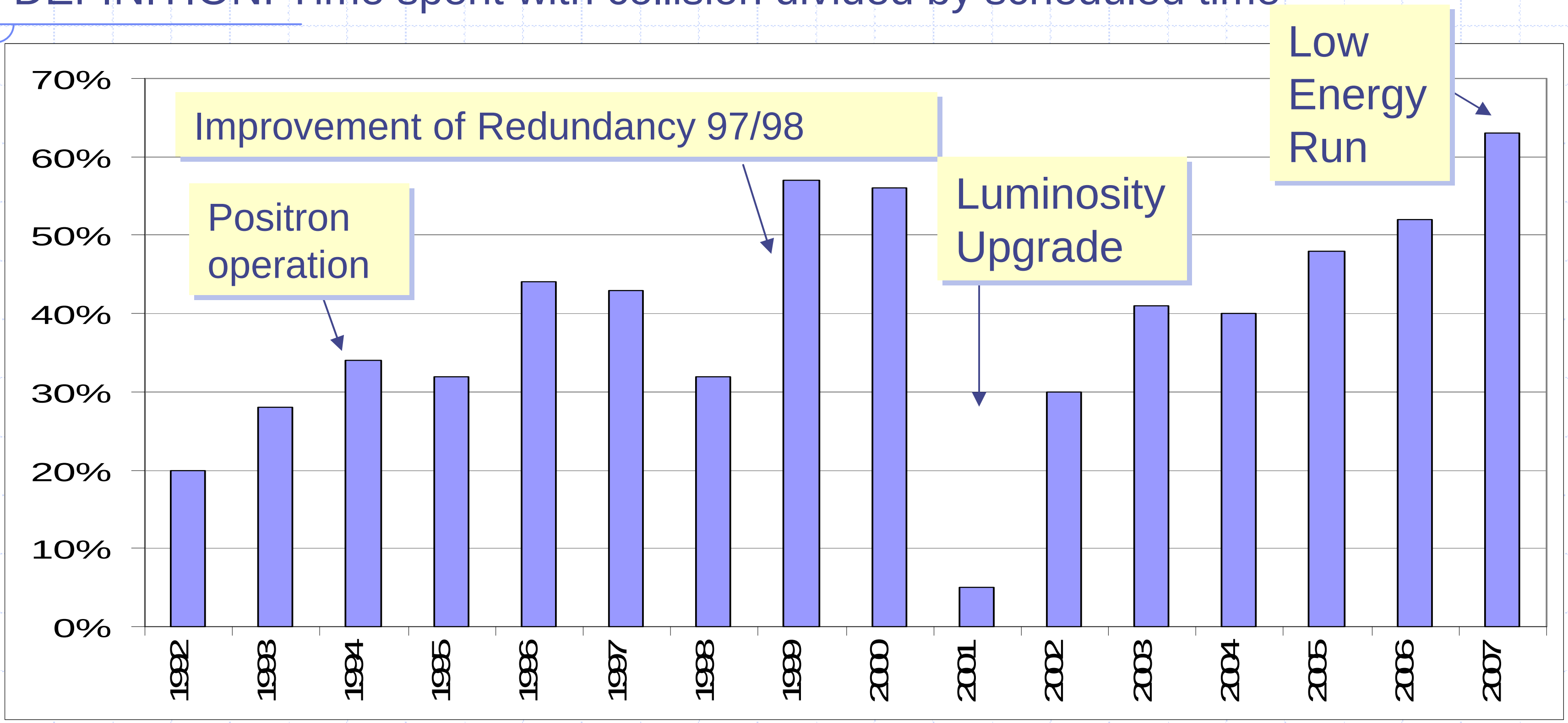
- Use of existing facilities as injectors (DESY, PETRA)
- Low energy injection of protons (40 GeV, 920/40=23)
- Design beam lines with cost as the highest priority design criterion
- Beam line instrumentation poor
- Use controls soft- and hardware of the previous accelerator generation
- Re-usage of the RF cavities designed for large gradient but low current
- Operate with s.c. cavities which suffer from hydrogen sickness

Lessons learned form HERA critical decisions:

- Tight e-beam lines + slow injectors + insufficient beam line instrumentation + missing controls = slow e-injection with low efficiency
- Tight p-beam lines + slow and low energy injectors + limited dynamical injection stability + missing controls = slow p-injection with low efficiency
- Non optimum RF design + missing power redundancy + insufficient and inflexible interlock systems + missing controls = frequent RF trips
- Active equipment in the tunnel + slow injection and acceleration procedures = long down times due to trivial faults

HERA Efficiencies

DEFINITION: Time spent with collision divided by scheduled time



Reliability Upgrade in 1997: Enhancing redundancy of RF, improving critical systems (p-dipole P.S., S.C. cavities, control systems).

Efficiency made a considerable step forward.

Remarks on Overall Availability

Assumption: Best luminosity efficiency achievable is **75%**
(due to long fill times)

1992 - 2007: HERA average luminosity efficiency is **40%**

The HERA average *availability* is **53%**

This is a factor of almost 2 reduction in performance.
This is significant.

(It however is comparable with LEP or TEVATRON)

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:
<u>Power systems and e-RF.</u>
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 Redundancy

Partitioning of systems to be taken into account for availability considerations

➔ Large monolithic systems create single points of failure
➔ Large number of components creates a large number of potential failures

HERA Examples:

Monolithic systems:

- Shared HV supplies for RF systems:
  One trip switches several transmitters off.
- Unequal splitting of RF voltage between s.c and n.c. systems:
  One trip of the s.c. system kills the beam.
- Chopper concept (One DC power supply feeds several chopper supplies):
  One chopper trip causes a feeding supply trip, causes up to 50 chopper trips

versus

Large number of power supplies ➔ many power supply trips

Lessons learned from HERA Operation

The following slides give some conclusions drawn after 16 years of operating one of the most complicated machines in the world.

These conclusions do not necessarily fit to any new project, but could at least give some hints.

No 'Amateur' Designs!

A good physicist can do everything, but
If you do not have the real experts in house,
get the component from somewhere else,
or you will have trouble afterwards.

Example:
Nearly all normal conducting proton magnets in HERA
sooner or later needed new coils due to water leaks.

Do not go to the Limit!

Do not use high power equipment
(RF stations, n.c. magnets, power supplies,...)
at 100% of the specified power.

You loose availability due to frequent trips and component failures.

You loose flexibility for future upgrades or necessary changes of machine parameters.

Example:
The trip rate of the RF stations in HERA increases dramatically if they are operated near their specified limits.

Provide Service for all Components!

Build up a service team for each component during the design phase of the component.

This is especially important for those components
-designed by that one ingenious specialist
-given as a donation from overseas

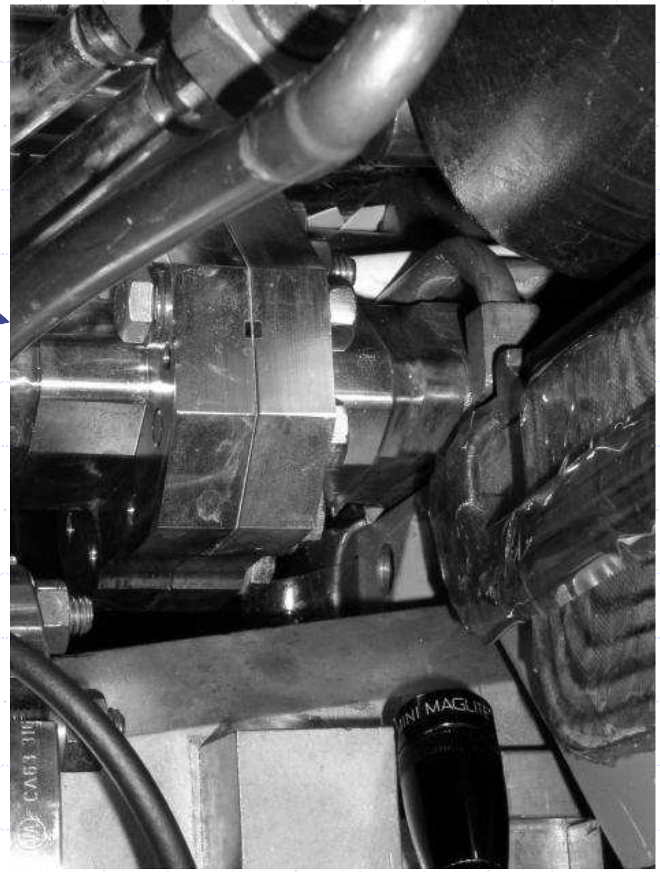
Examples:

Parts of the HERA machine protection system can only be serviced by one (very much over-committed) specialist.

PETRA proton RF (a donation from …) had to be partly rebuild.

Design for Service!

Include the possibility of system failure and repair into the design.
-How can we take this apart in case of…



Do not put NEG pumps and cryogenic systems into the same vacuum section.

In case of a leak:
-Warm up the system
-Vent the system
-Fix the leak
-Pump down
-Cool down
-Wait for two days
-Warm up
-Activate NEGs
-Cool down

} ~ one week

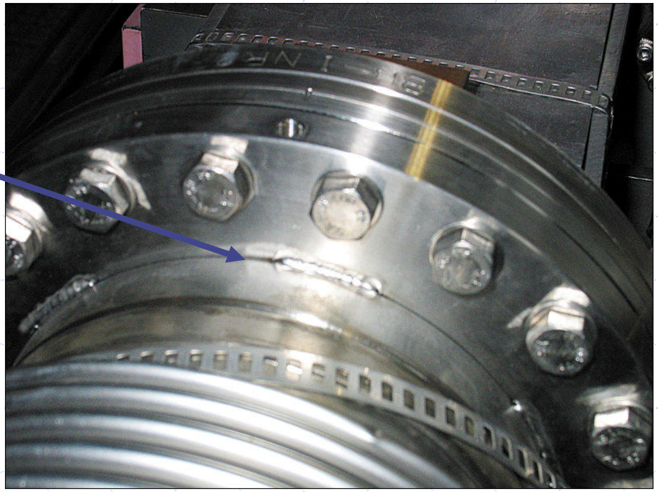
Quality Control!

Implement quality control during design and installation of components.

The best quality controller is the beam, but then it is too late.

Example:
Missing support welds on vacuum components.

The system worked well
until the vacuum weld
broke under thermal stress.



Good Controls from Day 1 on!

On day 1 of operation the control system must not be just a remote control of all components.

The operator needs
- automation of complex operations
- feedback loops
- sequencers for lengthy procedures
- permit systems to prevent operational mistakes

Example:
Orbit stabilization in machines with high synchrotron radiation loads.

Involve the Operators from Day 1 on!

A brand new machine is a beautiful toy for the physicists
(and they believe to be the only ones who really understand what is going on).

Involve the operators in this early stage!
Let them share your enthusiasm and your knowledge!

Example:
HERA was operated by physicists only for the first years and needed one physicists on every shift until the last day.

Operability!

Ergonomics:
- all controls on one control system
- all controls with the same 'look and feel'
- automation of complicated procedures

Operator training
(not only on the job, but also additional classes)

Example:
HERA fault statistics 2005: 19% of all faults were (partly) caused by the operators.

Components in the Tunnel?

For a slow cycling machine minimize the number of vulnerable components in the tunnel.
If you need temporary access to the tunnel to repair a broken fuse, a repair of 10 minutes will cost hours because of the lengthy access procedures and the lengthy procedure of filling and ramping the beam.

Example:
Trips of SEDAC (DESY's field bus) power supplies in electronic racks under the concrete in the tunnel.

Flexible Interlocks!

Most components are overprotected by their designers.

➡ ~ 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.

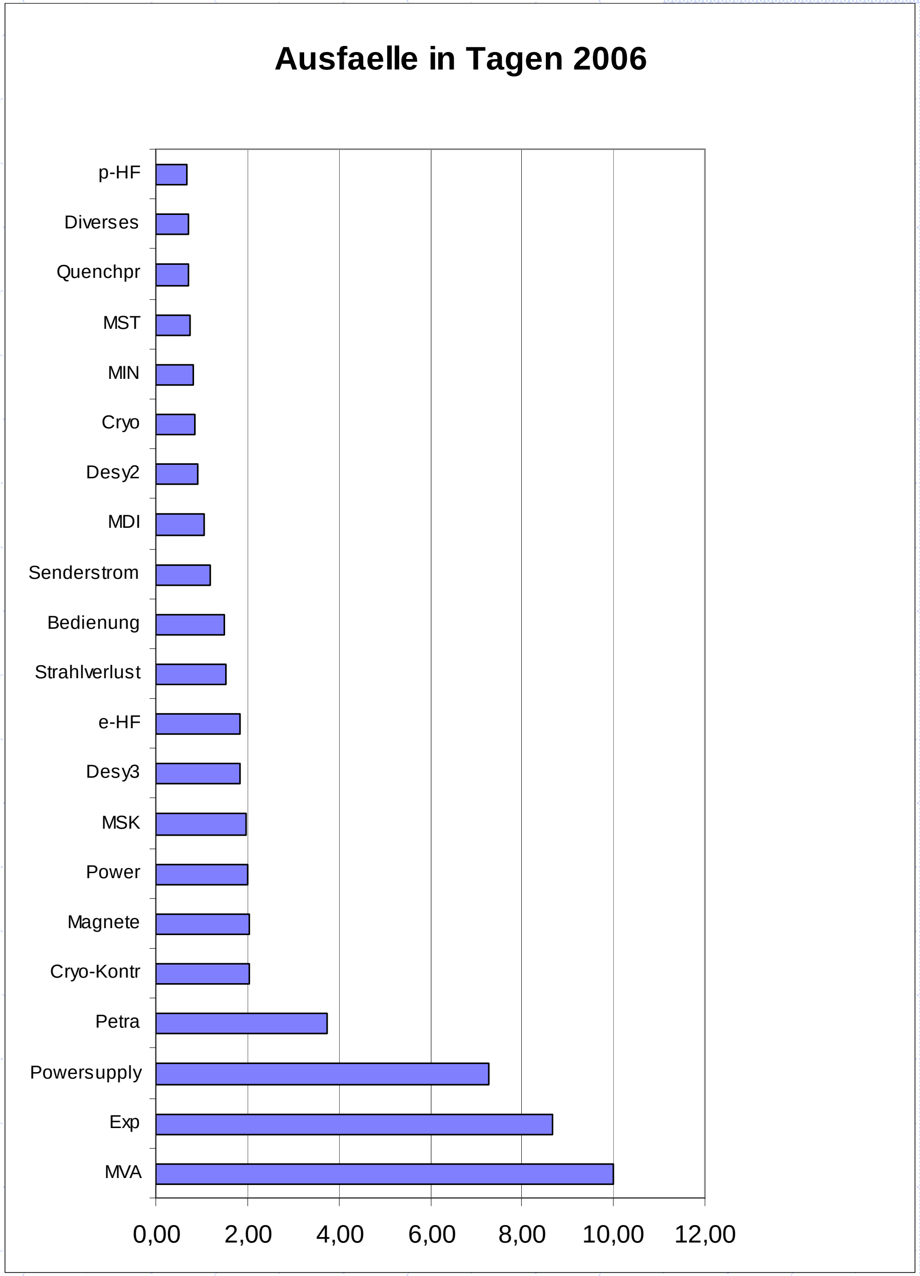
More flexibility is needed in future designs.

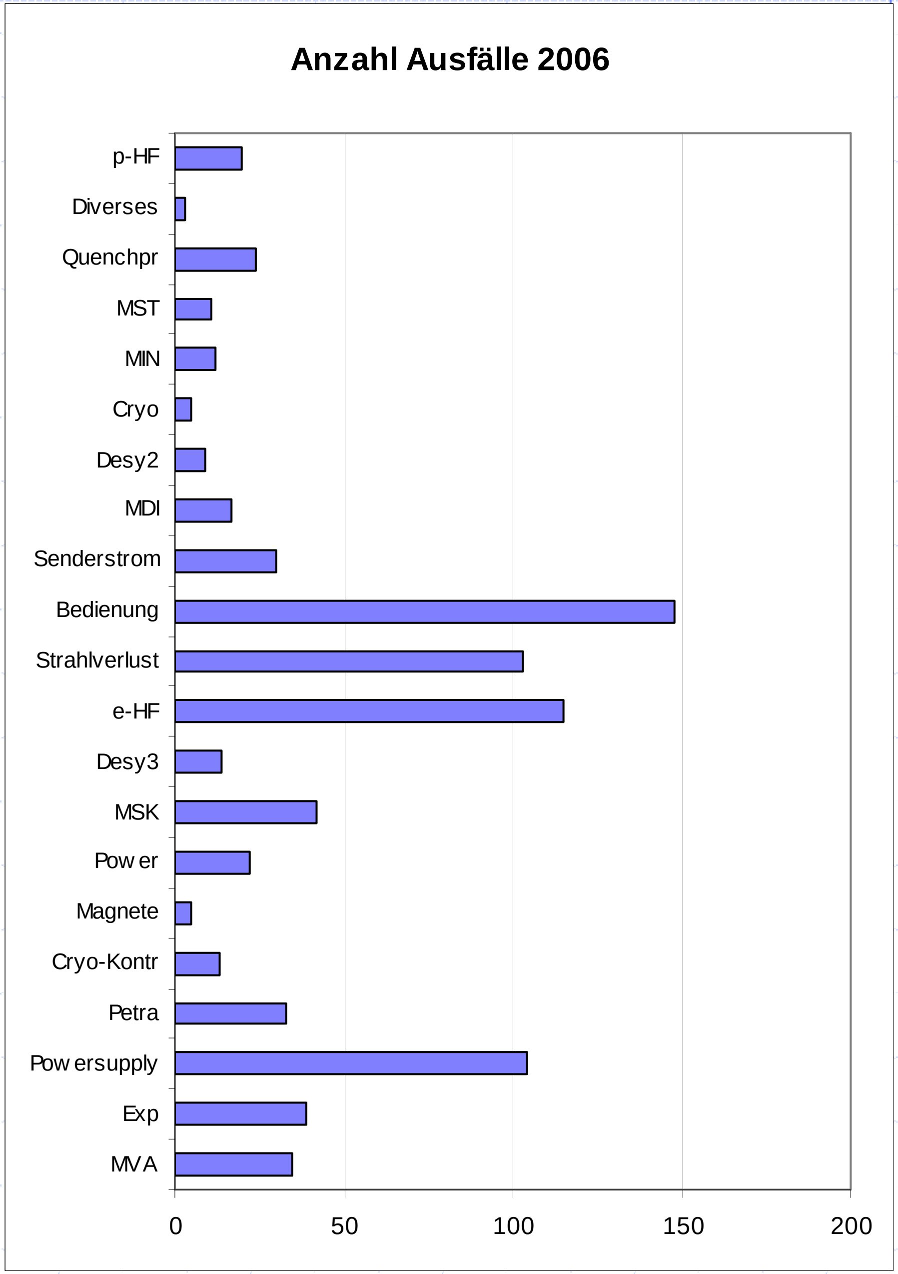
The possibility to optimize between the contradictory requirements should be designed into the components!

Conclusions (mostly trivial)

- Do not recycle old components (and pre-accelerators) just because you have them.
- Do not save money at any cost.
- Build in redundancy.
- Avoid large numbers of components.
- Avoid single points of failure.
- Do not use components at 100% power (or above…).
- Plan for maintenance.
- Provide good, ergonomic software from day 1 on.
- Avoid installing vulnerable components in the tunnel.
- Make technical interlocks flexible.
- ……

End of slide show, click to exit.


Ausfaelle in Tagen 2006
p-HF
Diverses
Quenchpr
MST
MIN
Cryo
Desy2
MDI
Senderstrom
Bedienung
Strahlverlust
e-HF
Desy3
MSK
Power
Magnete
Cryo-Kontr
Petra
Powersupply
Exp
MVA
0,00
2,00
4,00
6,00
8,00
10,00
12,00


Anzahl Ausfälle 2006
p-HF
Diverses
Quenchpr
MST
MIN
Cryo
Desy2
MDI
Senderstrom
Bedienung
Strahlverlust
e-HF
Desy3
MSK
Pow er
Magnete
Cryo-Kontr
Petra
Pow ersupply
Exp
MVA
0
50
100
150
200