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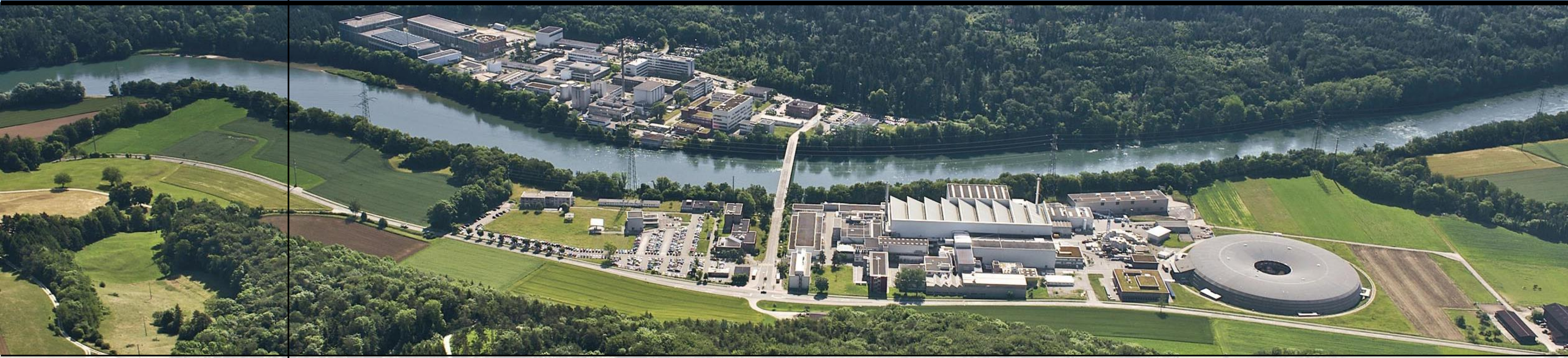


Wir schaffen Wissen – heute für morgen

Paul Scherrer Institute

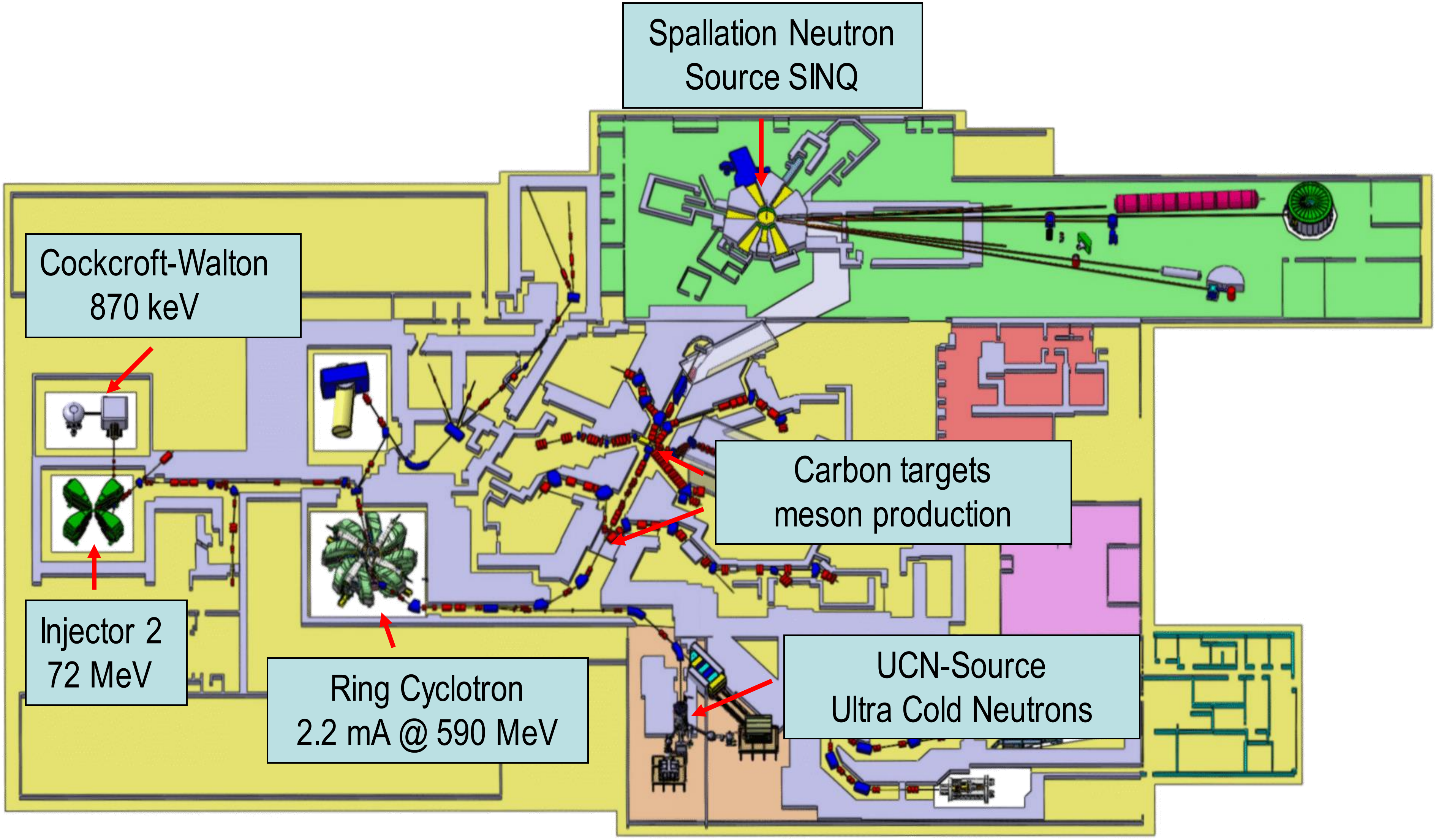
Joachim Grillenberger

Beam Availability at PSI

Outline

- Overview of the facility
- Definition of the beam availability at PSI
- Challenges of a High Power Beam
- Outage Characteristics
- Problems with RF
- Steps towards a higher availability
- Summary and outlook

Layout of the 590 MeV Proton Facility



PAUL SCHERRER INSTITUT PSI

Beam Availability at PSI

2015	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Shifts	M L N	M L N	M L N	M L N	M L N	M L N	M L N
29 - 4. Jan							
5 - 11. Jan							
12 - 18. Jan							
19 - 25. Jan							
26 - 1. Feb		Shutdown					
2 - 8. Feb							
9 - 15. Feb							
16 - 22. Feb							
23 - 1. Mrz							
2 - 8. Mrz							
9 - 15. Mrz	Cleaning, start-up cooling, vacuum						
16 - 22. Mrz	Cleaning, start-up cooling, vacuum						
23 - 29. Mrz	RF-Tests		Security system tests				
30 - 5. Apr	RF-Tests		Electrostatic elements				
6 - 12. Apr		RF-Tests					
13 - 19. Apr	Interlock system test		Rag test				
20 - 26. Apr	Beam development						
27 - 3. Mai	SINQ tests			SINQ interlock tests			
4 - 10. Mai	Setup		Start HE-operation				
11 - 17. Mai	BD BD A	S S A	S S A				
18 - 24. Mai							
25 - 31. Mai							
1 - 7. Jun							
8 - 14. Jun	BD BD A	S S A	S S A	BD BD			
15 - 21. Jun							
22 - 28. Jun				BD BD			
29 - 5. Jul							
6 - 12. Jul	BD BD A	S S A	S S A	BD BD			
13 - 19. Jul							
20 - 26. Jul							
27 - 2. Aug							
3 - 9. Aug	BD BD A	S S A	S S A	BD BD			
10 - 16. Aug							
17 - 23. Aug				BD BD			
24 - 30. Aug							
31 - 6. Sep	BD BD A	S S A	S S A	BD BD			
7 - 13. Sep							
14 - 20. Sep							
21 - 27. Sep							
28 - 4. Okt	BD BD A	S S A	S S A	BD BD			
5 - 11. Okt							
12 - 18. Okt				BD BD			TdoT
19 - 25. Okt							
26 - 1. Nov	BD BD A	S S A	S S A	BD BD			
2 - 8. Nov							
9 - 15. Nov							
16 - 22. Nov							
23 - 29. Nov	BD BD A	S S A	S S A	BD BD			
30 - 6. Dez							
7 - 13. Dez							
14 - 20. Dez	BD BD A	S S A	S S A				
21 - 27. Dez	Beam until Dec 23rd 6h						

Shutdown from Dec. 24^{th} to the 5^{th} of May (128 days)

198 days of user operation → 54%

$$\textbf{Availability} = \frac{\text{Beam on target*}}{\text{Scheduled user operation}}$$

Beam current > 1 mA

*On meson production targets without spallation source

PAUL SCHERRER INSTITUT PSI

Beam Availability at PSI

2015	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Shifts	M L N	M L N	M L N	M L N	M L N	M L N	M L N
29 - 4. Jan							
5 - 11. Jan							
12 - 18. Jan							
19 - 25. Jan							
26 - 1. Feb							
2 - 8. Feb			Shutdown				
9 - 15. Feb							
16 - 22. Feb							
23 - 1. Mrz							
2 - 8. Mrz							
9 - 15. Mrz	Cleaning, start-up cooling, vacuum						
16 - 22. Mrz	Cleaning, start-up cooling, vacuum						
23 - 29. Mrz	RF-Tests		Security system tests				
30 - 5. Apr	RF-Tests		Electrostatic elements				
6 - 12. Apr		RF-Tests					
13 - 19. Apr	Interlock system test		Rag test				
20 - 26. Apr	Beam development						
27 - 3. Mai	SINQ tests			SINQ interlock tests			
4 - 10. Mai	Setup		Start HE-operation				
11 - 17. Mai	BD BD A	S S A	S S A				
18 - 24. Mai							
25 - 31. Mai							
1 - 7. Jun							
8 - 14. Jun	BD BD A	S S A	S S A	BD BD			
15 - 21. Jun							
22 - 28. Jun				BD BD			
29 - 5. Jul							
6 - 12. Jul	BD BD A	S S A	S S A	BD BD			
13 - 19. Jul							
20 - 26. Jul							
27 - 2. Aug							
3 - 9. Aug	BD BD A	S S A	S S A	BD BD			
10 - 16. Aug							
17 - 23. Aug				BD BD			
24 - 30. Aug							
31 - 6. Sep	BD BD A	S S A	S S A	BD BD			
7 - 13. Sep							
14 - 20. Sep							
21 - 27. Sep							
28 - 4. Okt	BD BD A	S S A	S S A	BD BD			
5 - 11. Okt							
12 - 18. Okt				BD BD			TdoT
19 - 25. Okt							
26 - 1. Nov	BD BD A	S S A	S S A	BD BD			
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23 - 29. Nov	BD BD A	S S A	S S A	BD BD			
30 - 6. Dez							
7 - 13. Dez							
14 - 20. Dez	BD BD A	S S A	S S A				
21 - 27. Dez	Beam until Dec 23rd 6h						

Shutdown from Dec. 24th to the 5th of May (128 days)

198 days of user operation → 54%

← Service and beam development shifts (27 days)

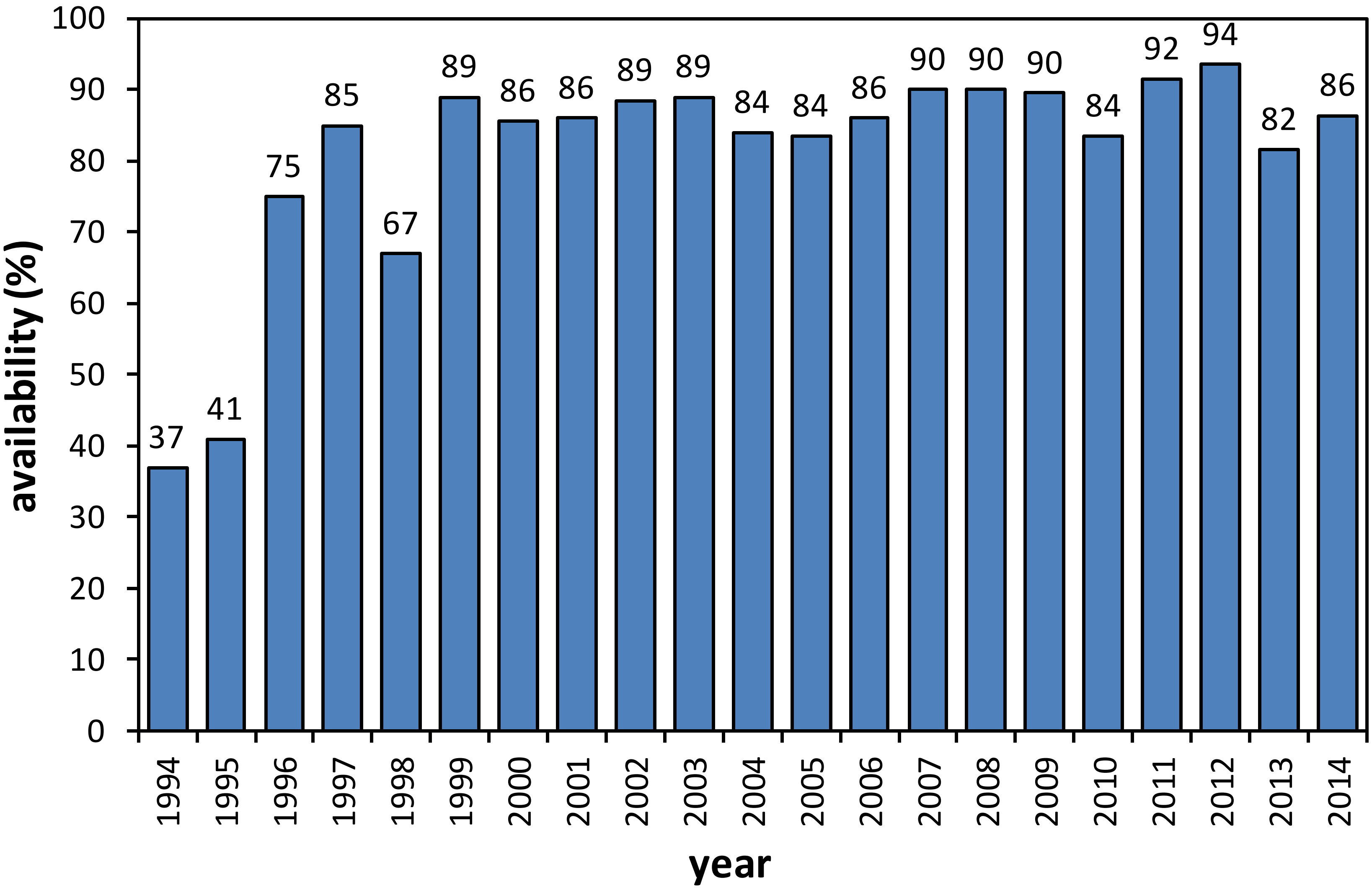
← Two shifts of beam development (7 days)

← PSI open day

← Begin of shutdown 2016 (5 days)

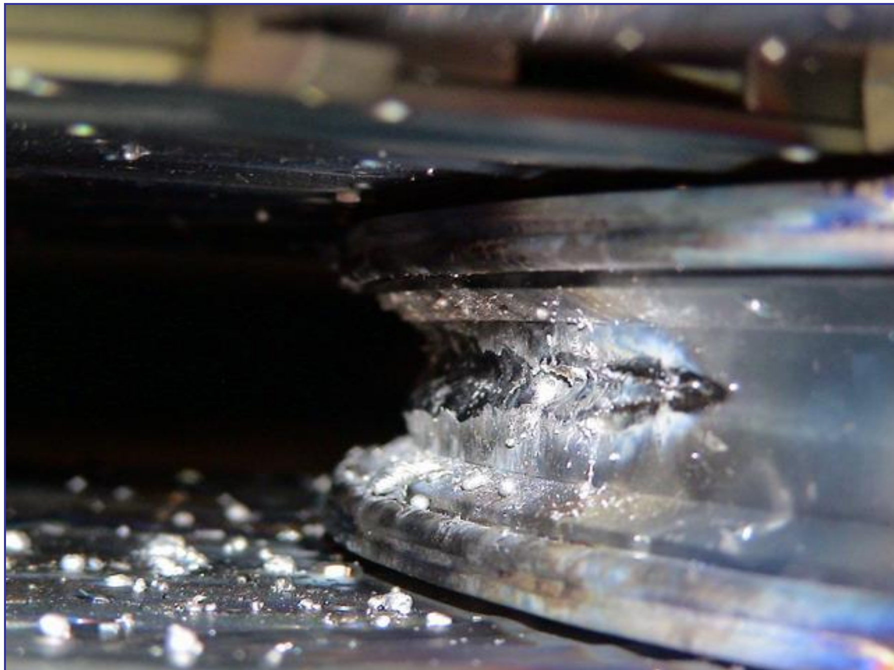
Availability of the PSI proton accelerator

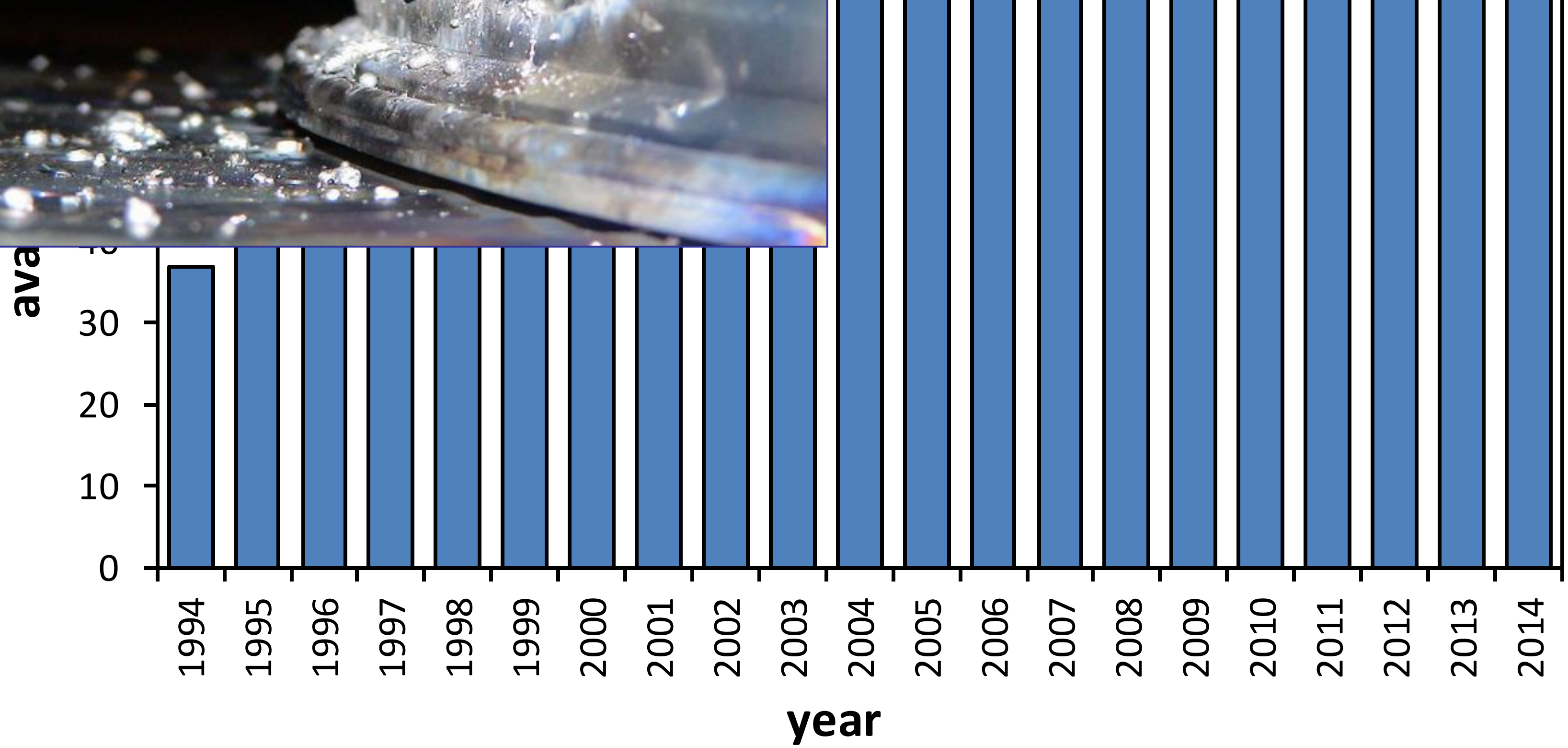
Average: 81% (1994-2014)
87% (2004-2014)



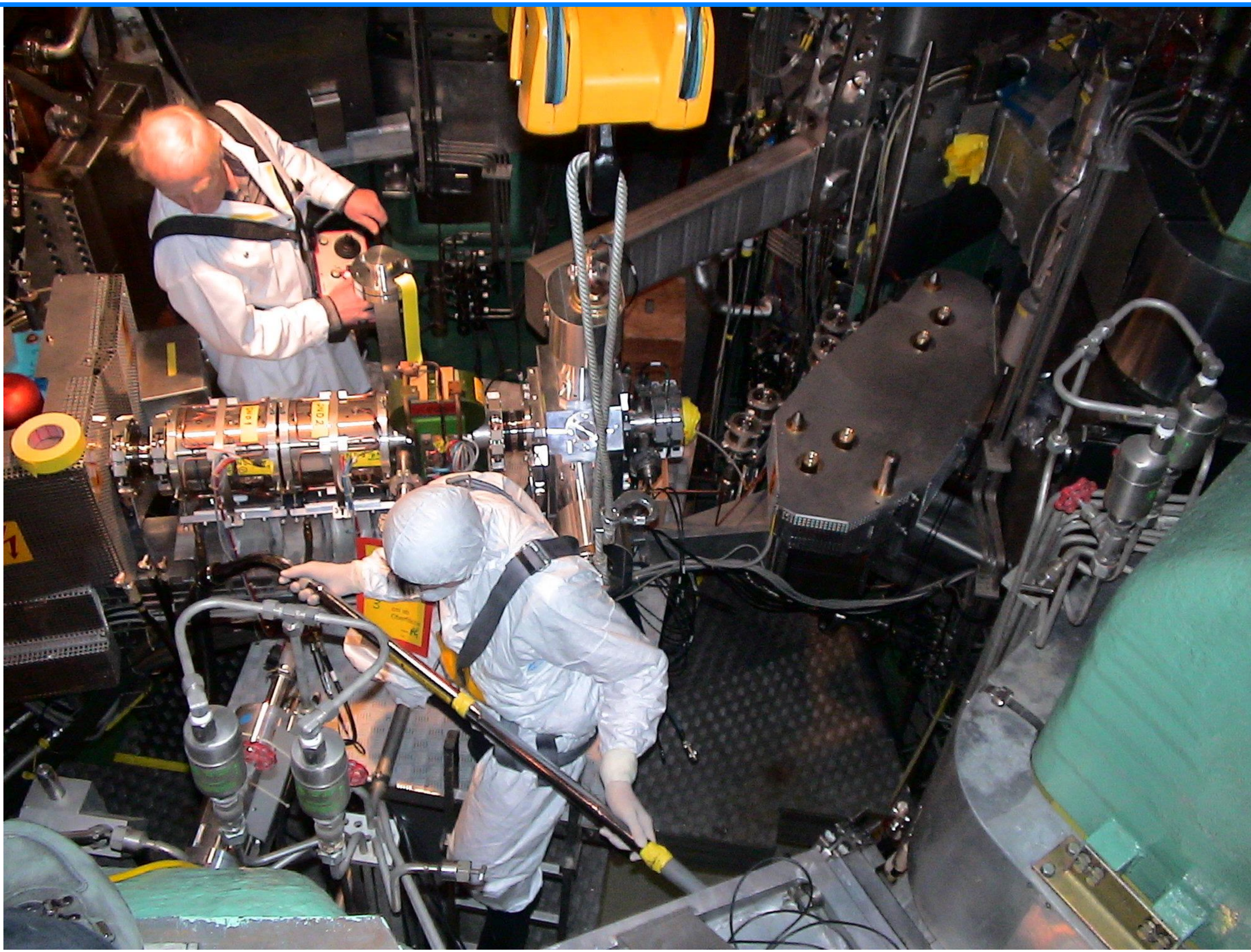
Availability of the PSI proton accelerator

Damage at ring injection caused by the beam





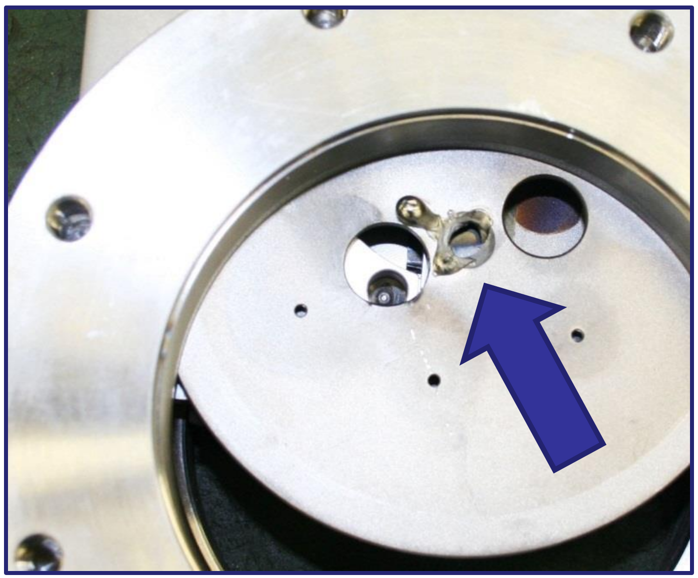
Interlock Failure 2004



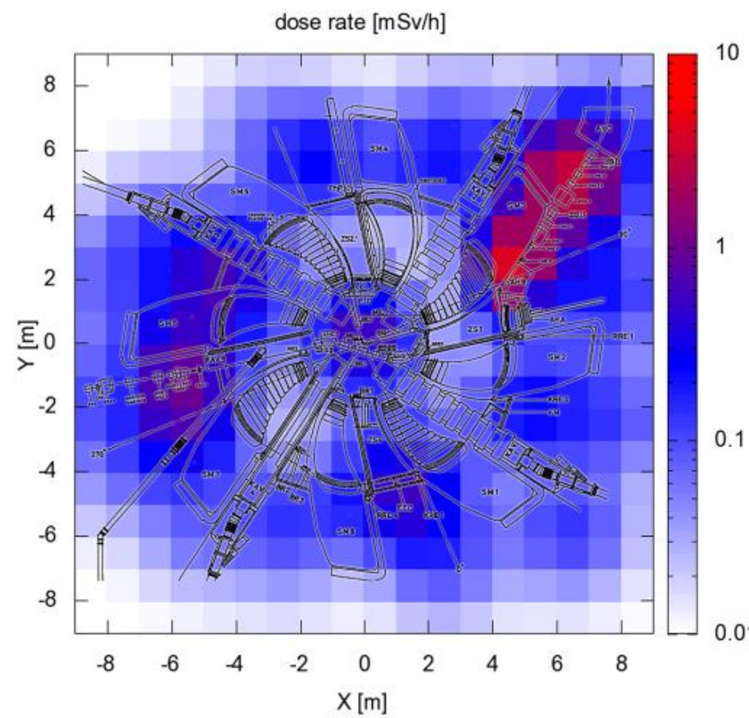
The Challenge of a High Power Beam

incomprehensive list:

- a Megawatt beam can be dangerous, it melts steel in 10 ms → interlocks!
- losses must be low (≈200 W ≅ $2\cdot10^{-4}$) to avoid excessive activation
- ....

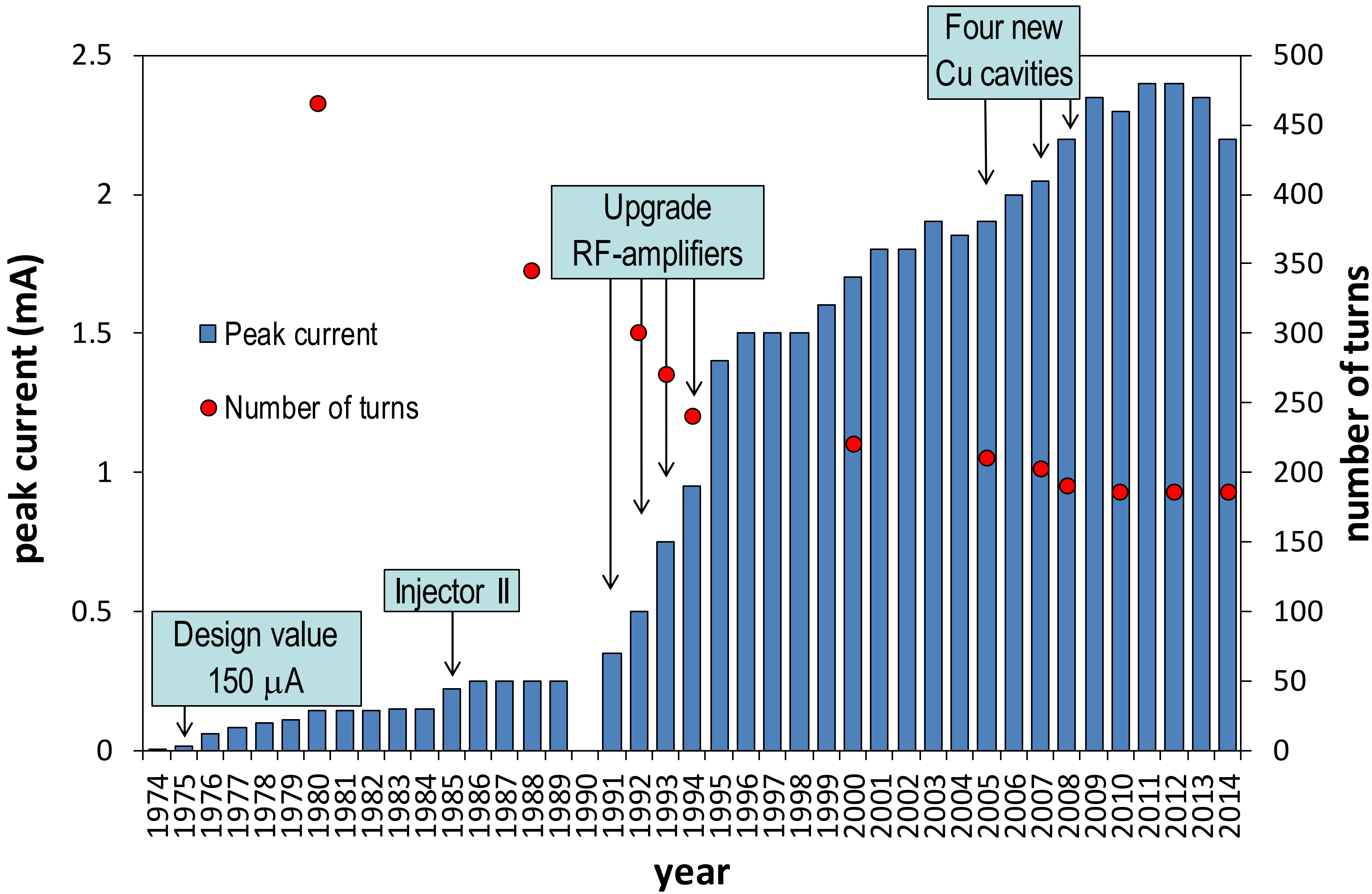


just 10 kW @870keV



main activation at extraction

History of the maximum current at PSI



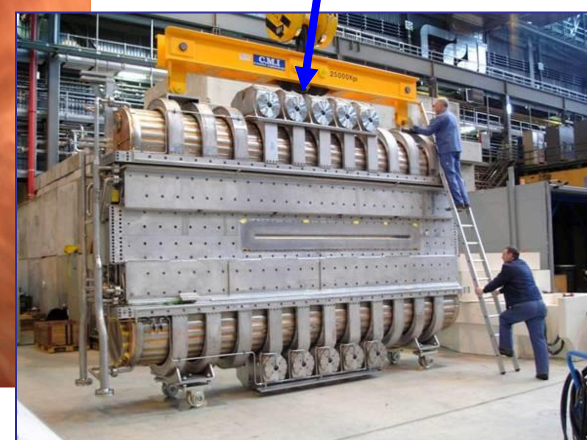
High Power Resonators

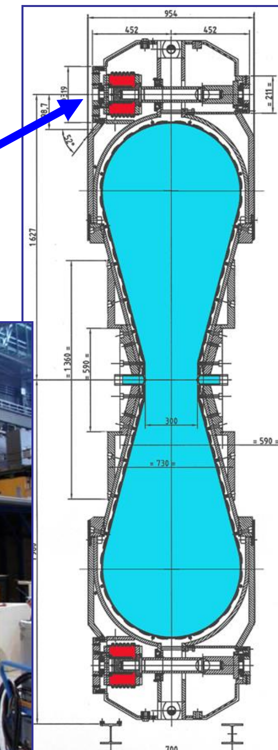
f = 50.63 MHz
U_{max} = 1.2 MV (presently 0.85 MV→186 turns in cyclotron, goal for 3 mA: 165 turns)

400 kW power transfer to the beam per cavity

resonator inside

hydraulic tuning devices (5x)

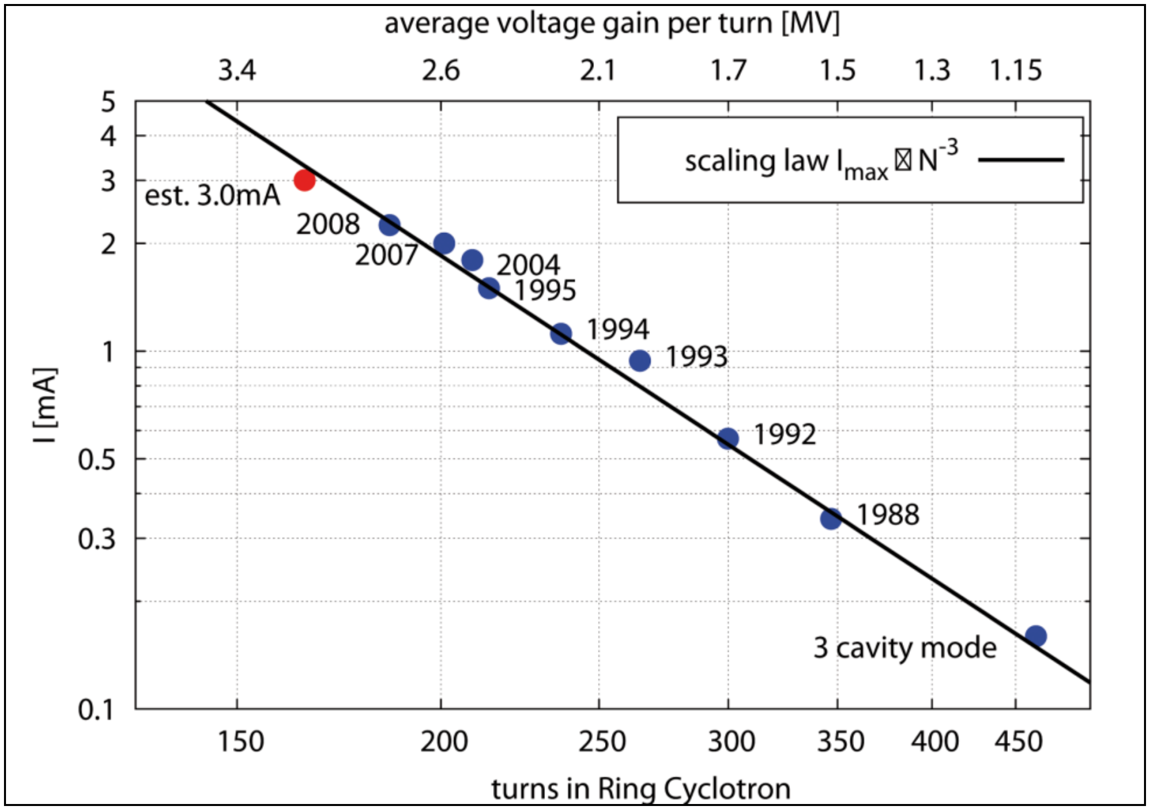




Historical development of the beam current at PSI

The maximum attainable current at PSI scales with the third power of the number of turns

Maximum energy gain per turn is of utmost importance in this type of high intensity cyclotron



W. Joho

→ with constant losses at the extraction electrode the maximum attainable current indeed scales as:

$$I_{max} \propto n_t^{-3}$$

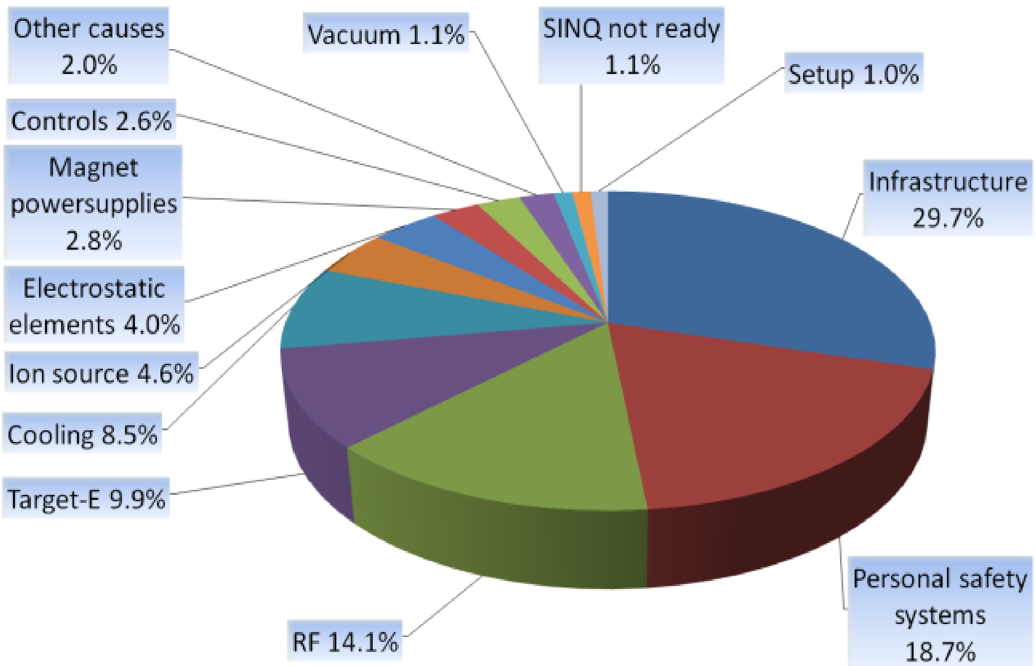
Losses scale with (the number of turns)^3

- Higher gap voltage, less turns
  → larger turn separation at extraction
  → lower charge density
  → less time in cyclotron

→ higher current at same loss rate

Outage Characteristics (2014)

Overall availability: 86%



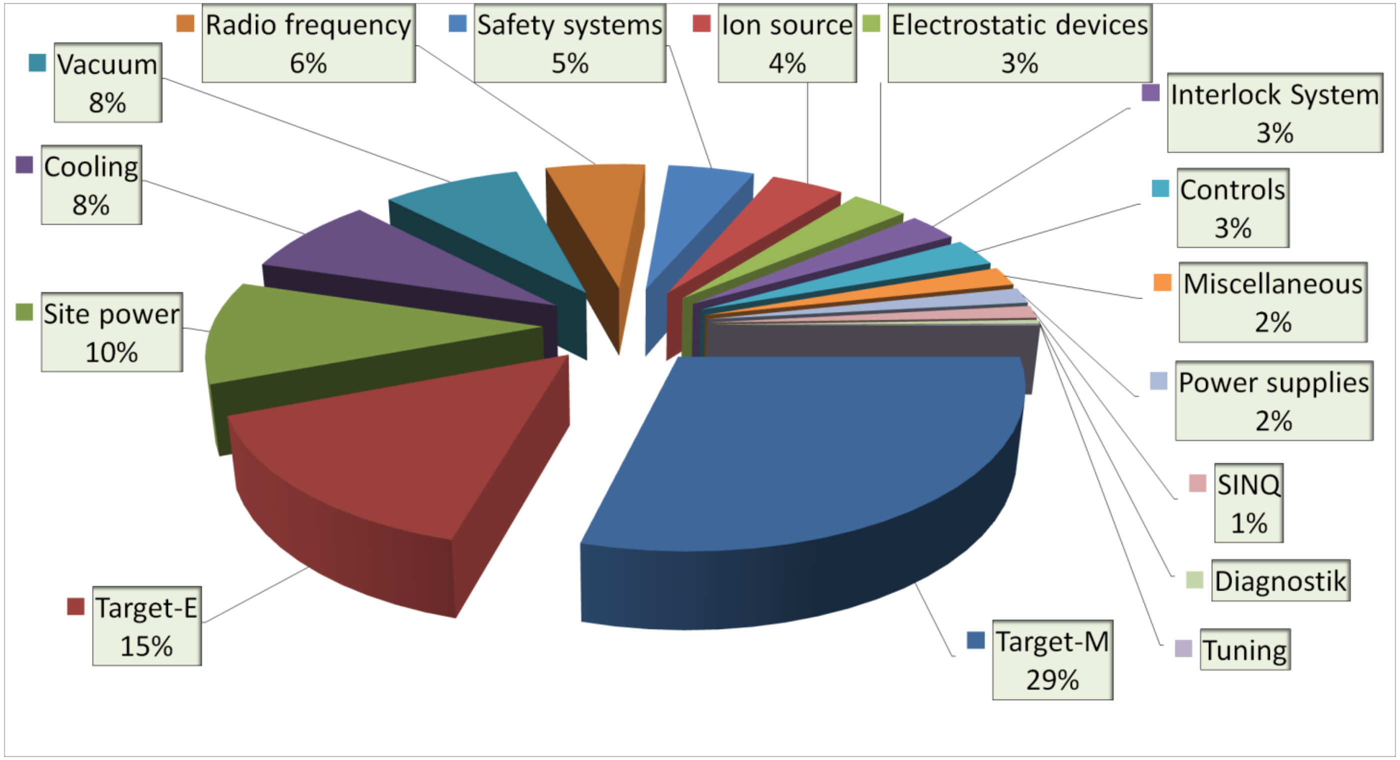
Beam-time statistics for HIPA	2014
Total scheduled user beam time	4608 h
Compensated outage time	+84 h
Beam current integral	
To meson production targets	9.1 Ah
To SINQ	6.0 Ah
To UCN	0.02 Ah
To isotope production targets	0.08 Ah
Outages	
Total outages (current < 1 mA, time > 5s) minutes)	520 h
Availability (with compensated outage time)	86.4%

Not representative:

- Infrastructure (crane repair)
- Personal safety system
- problem with flattop cavity

Outage distribution (2012)

Overall availability: 94%



In most cases failure of the ball bearings

Harsh environment:

- High radiation level
- Vacuum → no grease applicable

The Challenge of a High Power Beam

incomprehensive list:

- a Megawatt beam can be dangerous
  it melts steel in 10 ms → interlocks!
- losses must be low ($\approx$200 W $\cong 2\cdot10^{-4}$)
  to avoid excessive activation
- **Complex and expensive infrastructure for repairs and exchange of elements for**
  - **Radiation protection**
  - **Fast exchange**
  - **Storage of activated components**

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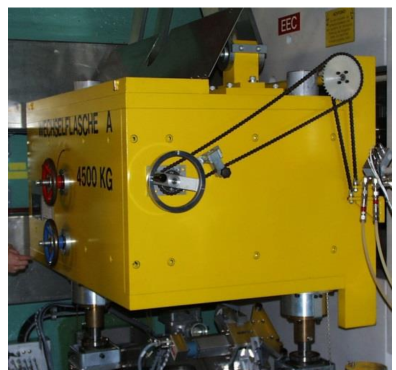
Infrastructure – Exchange flasks

mobile and specifically adapted shielding devices for
- targets
- electrostatic elements
- collimators
- septum magnets

exchange flasks are complicated and expensive devices (heavy, motors, instrumentation, SPS controls)

Exchange flask for meson production Target E (4 cm graphite wheel)



Electrostatic Extraction Element

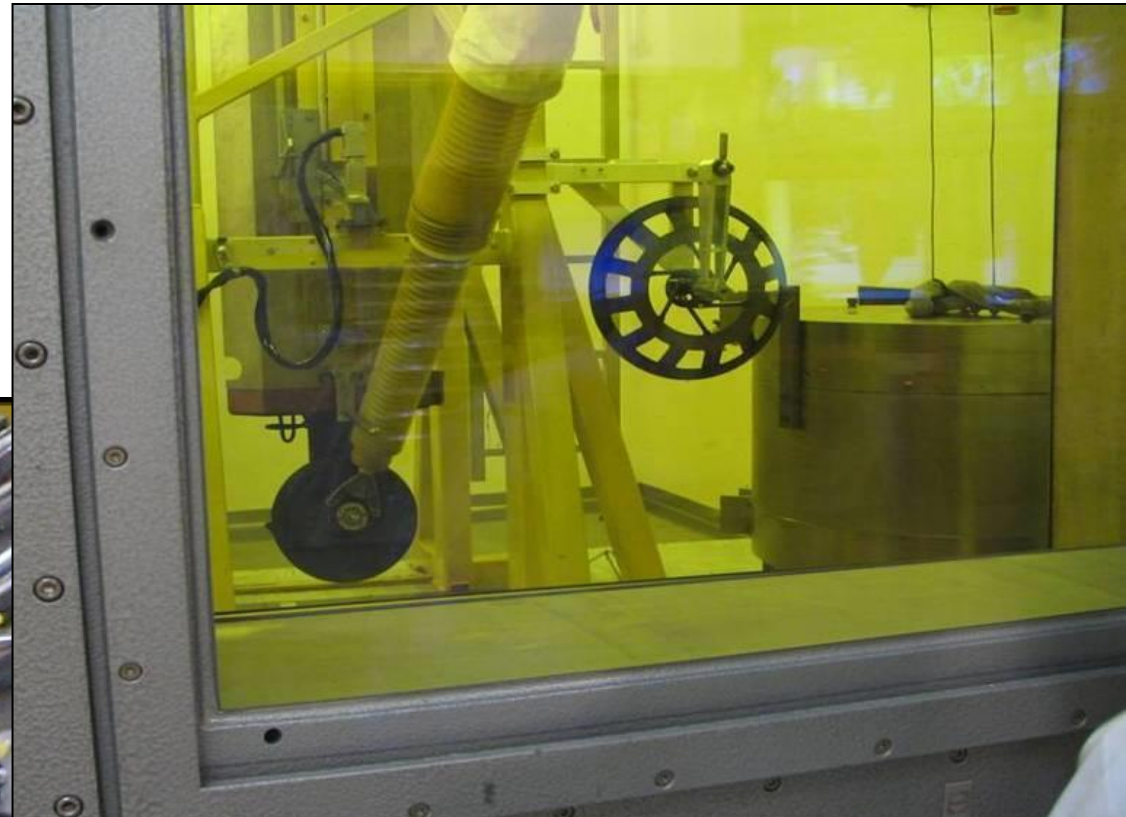
Beam Collimators

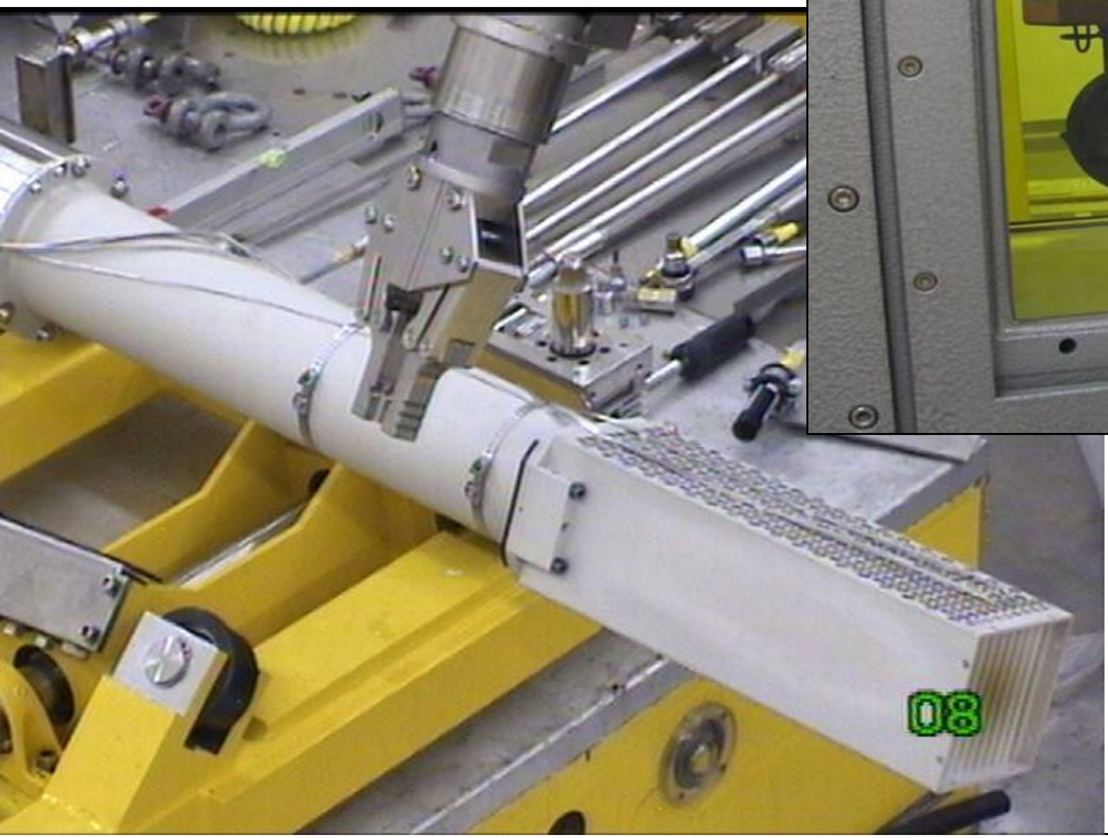
Beam Splitter

Infrastructure – Hot Cell

view through lead-glass window:

Meson production target wheel

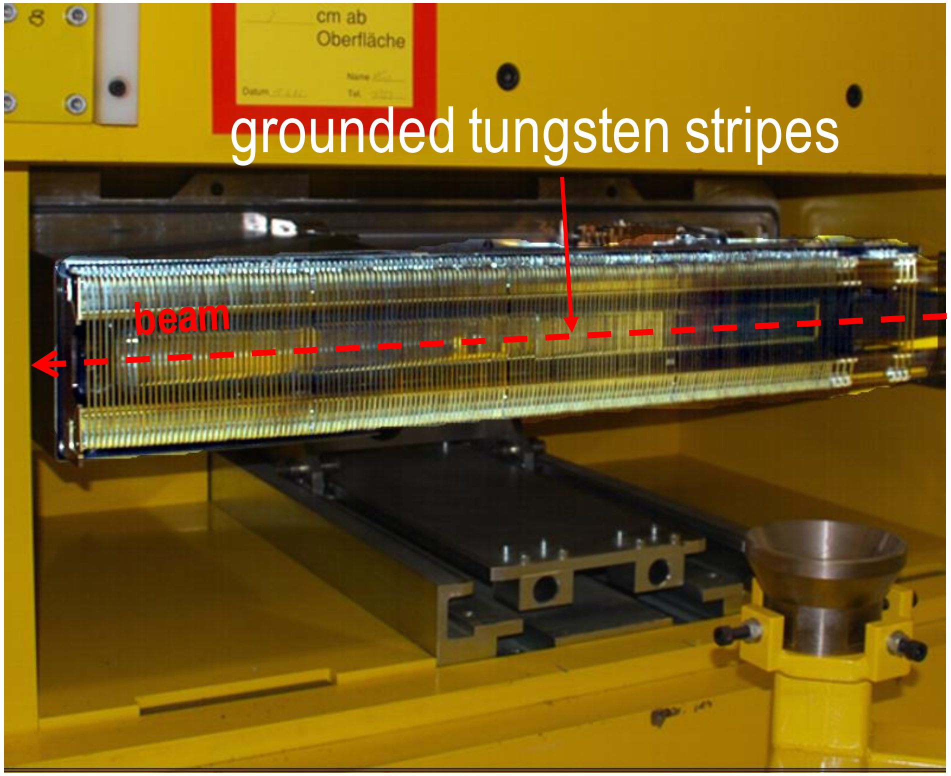


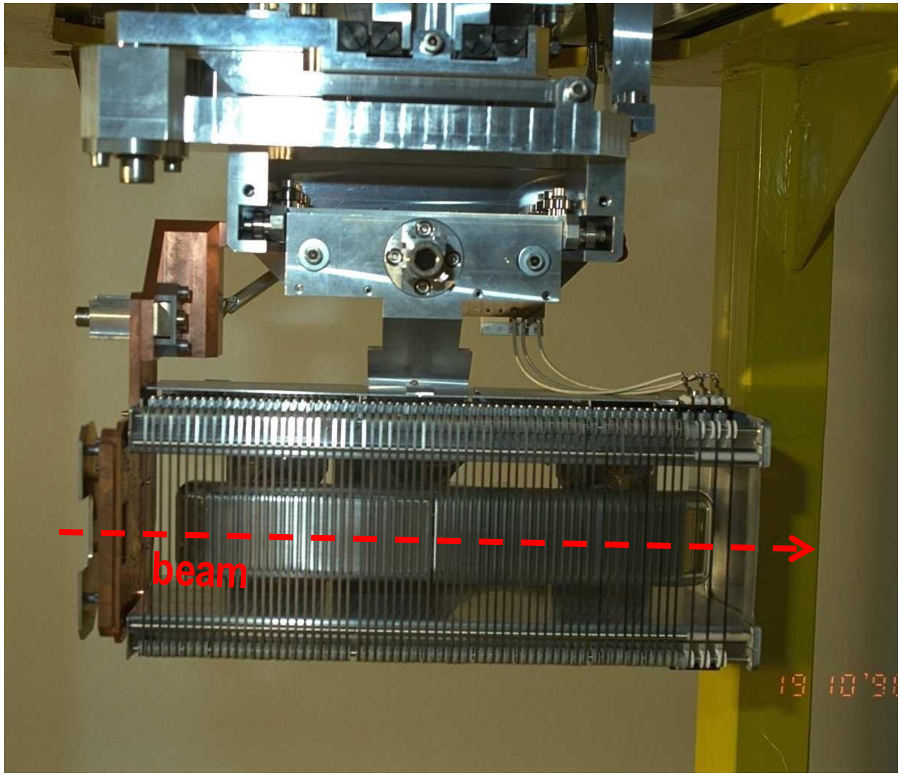


irradiated SINQ spallation target, taken out of the cover

Electrostatic Elements

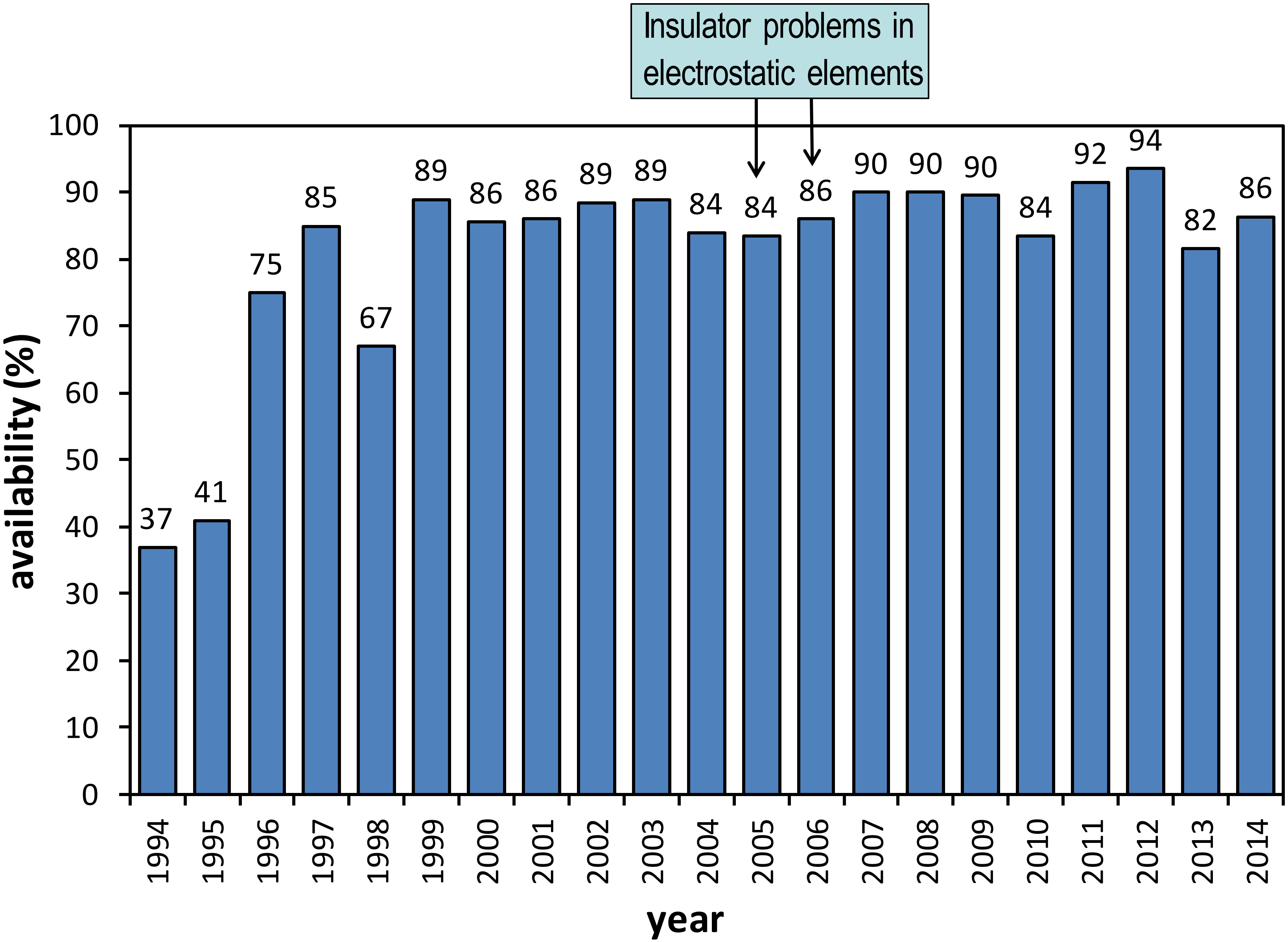
Extraction Channel EEC 145 kV	Injection Channel EIC 130 kV



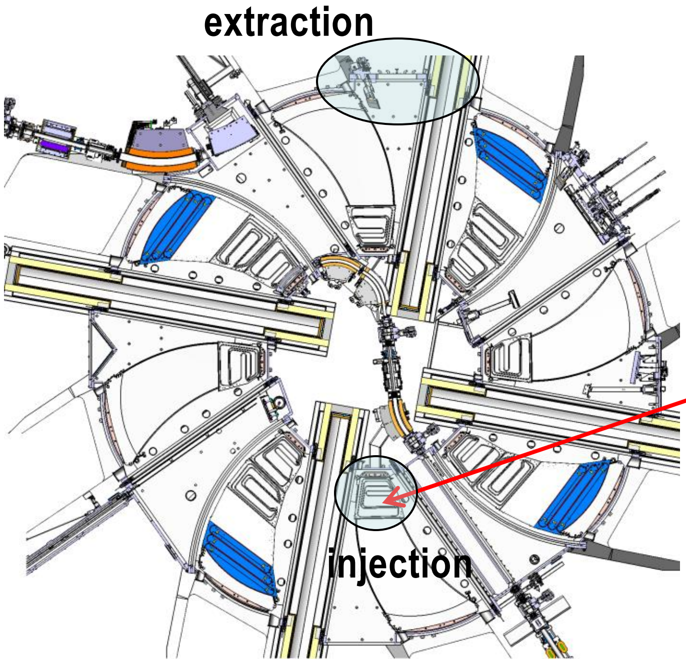


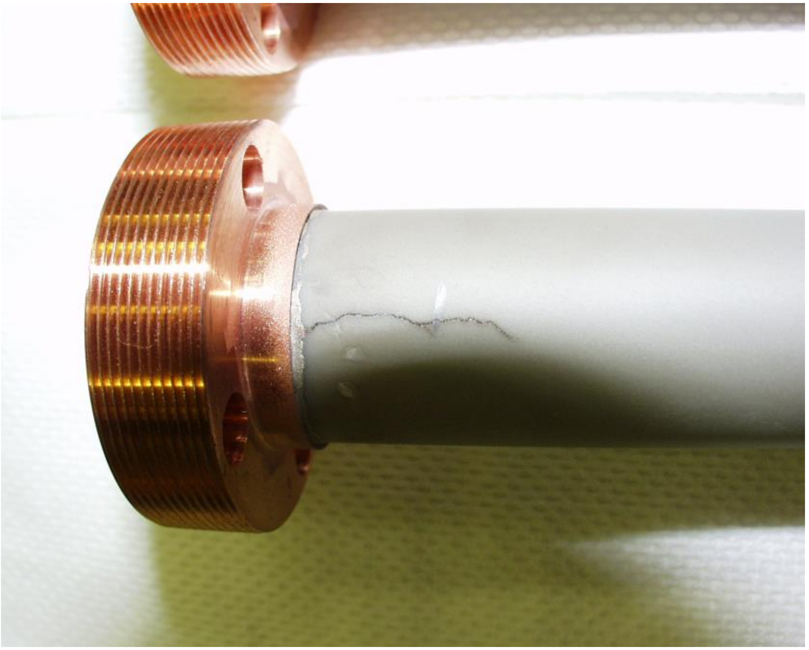
Most beam trips originate from discharges in these elements (2% of total availability)

Availability of the PSI proton accelerator



Problems with Electrostatic Deflectors 2005/06

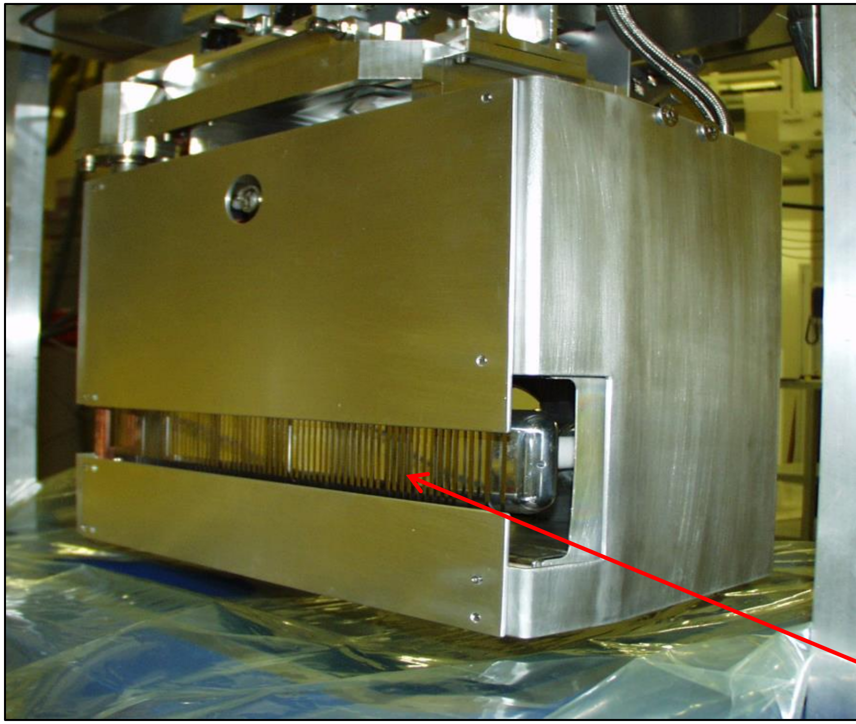


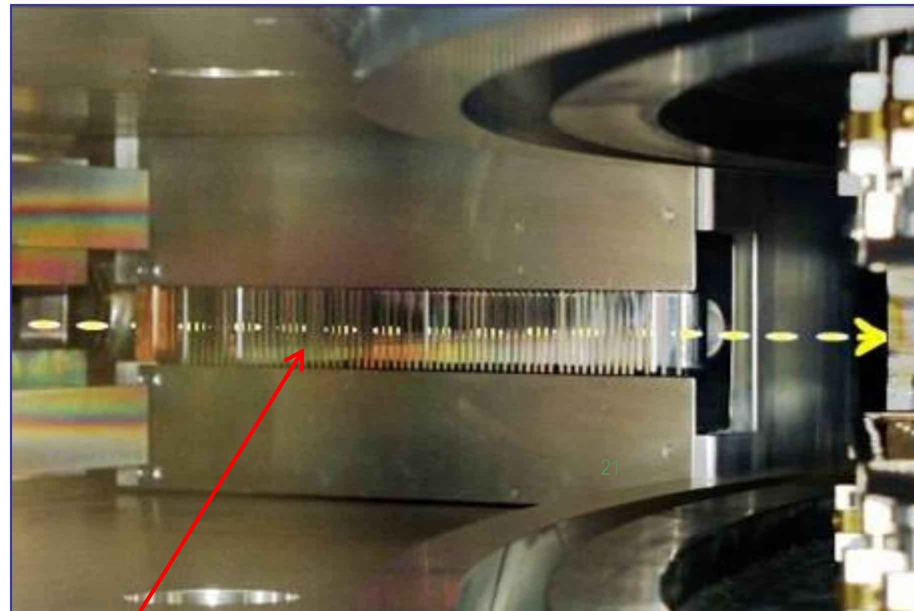


- high dark currents at electrostatic deflector
- exchange required due to damaged insulators
- insulator coated with thin metallic layer
- discharges only with RF switched on
- RF ignites plasma in the vicinity of the elements

Protective Shielding of the Electrostatic Elements

Electrostatic Inflection Channel





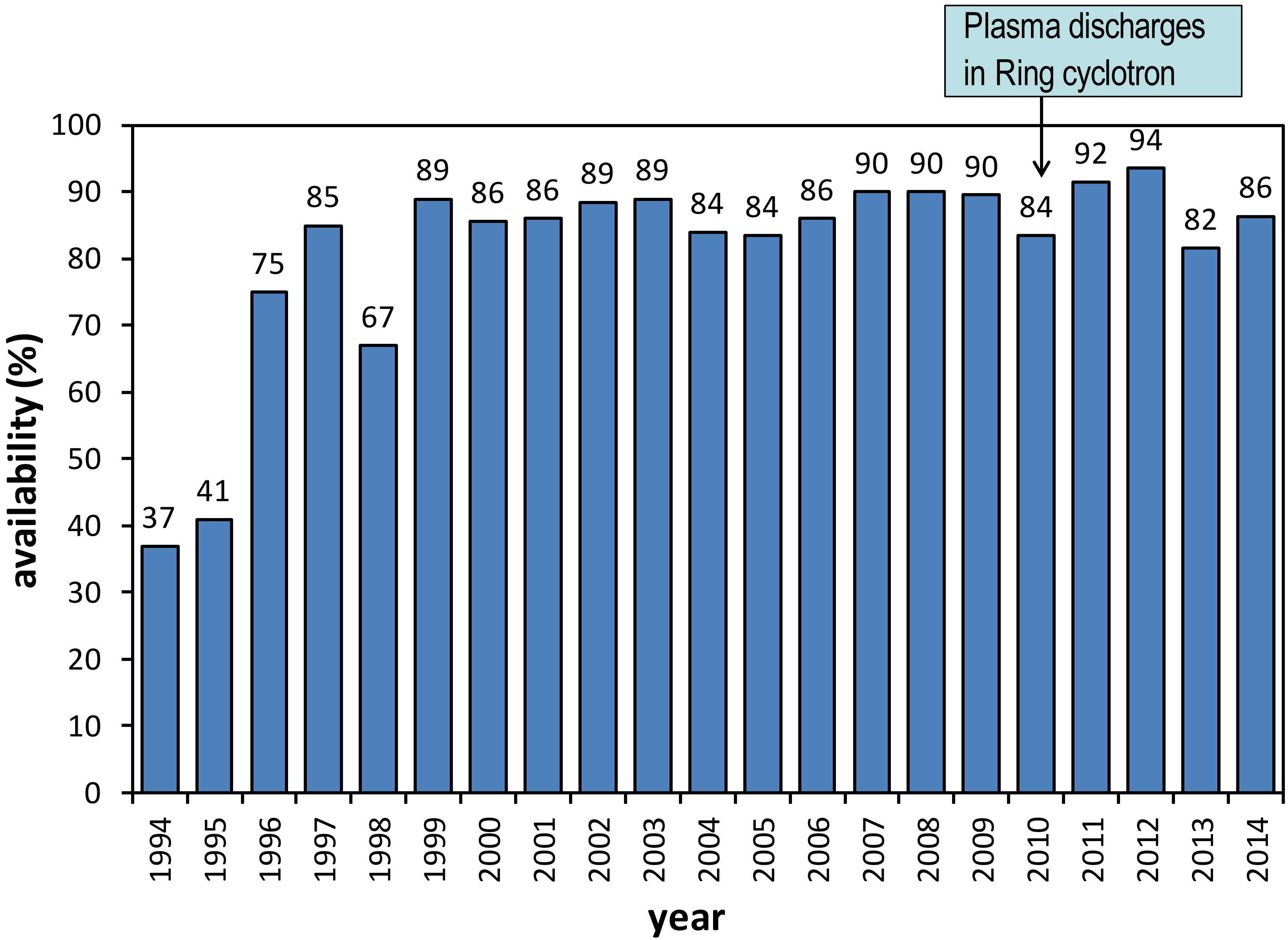
Tungsten stripes

The Challenge of a High Power Beam

incomprehensive list:

- a Megawatt beam is a dangerous beast, melts steel in 10 ms, interlocks!
- losses must be low ($\approx$200 W $\cong 2 \cdot 10^{-4}$) to avoid excessive activation
- Expensive infrastructure for repairs and exchange of elements
- **high power RF has side effects: discharges caused by decoupled RF, plasma generation, multipactoring, heating …**

Availability of the PSI proton accelerator



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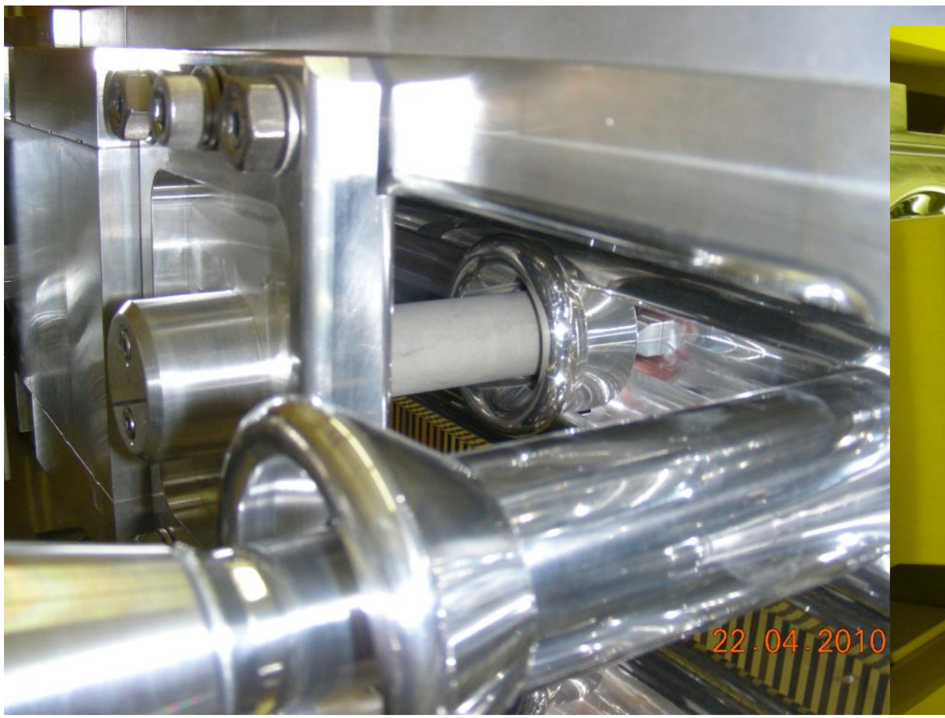
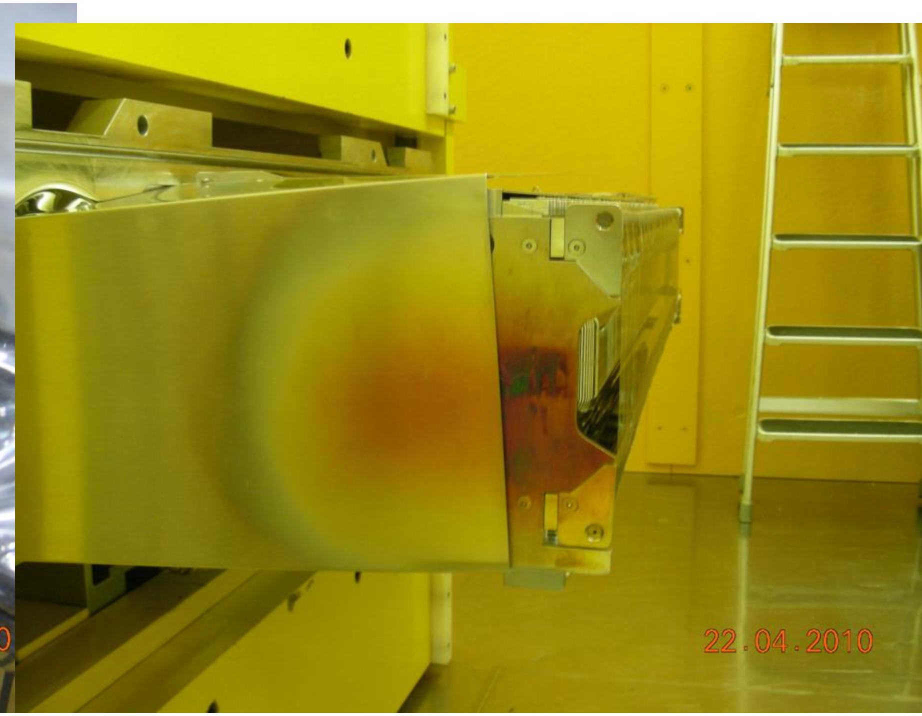
Damaged Electrostatic Deflector (2010)

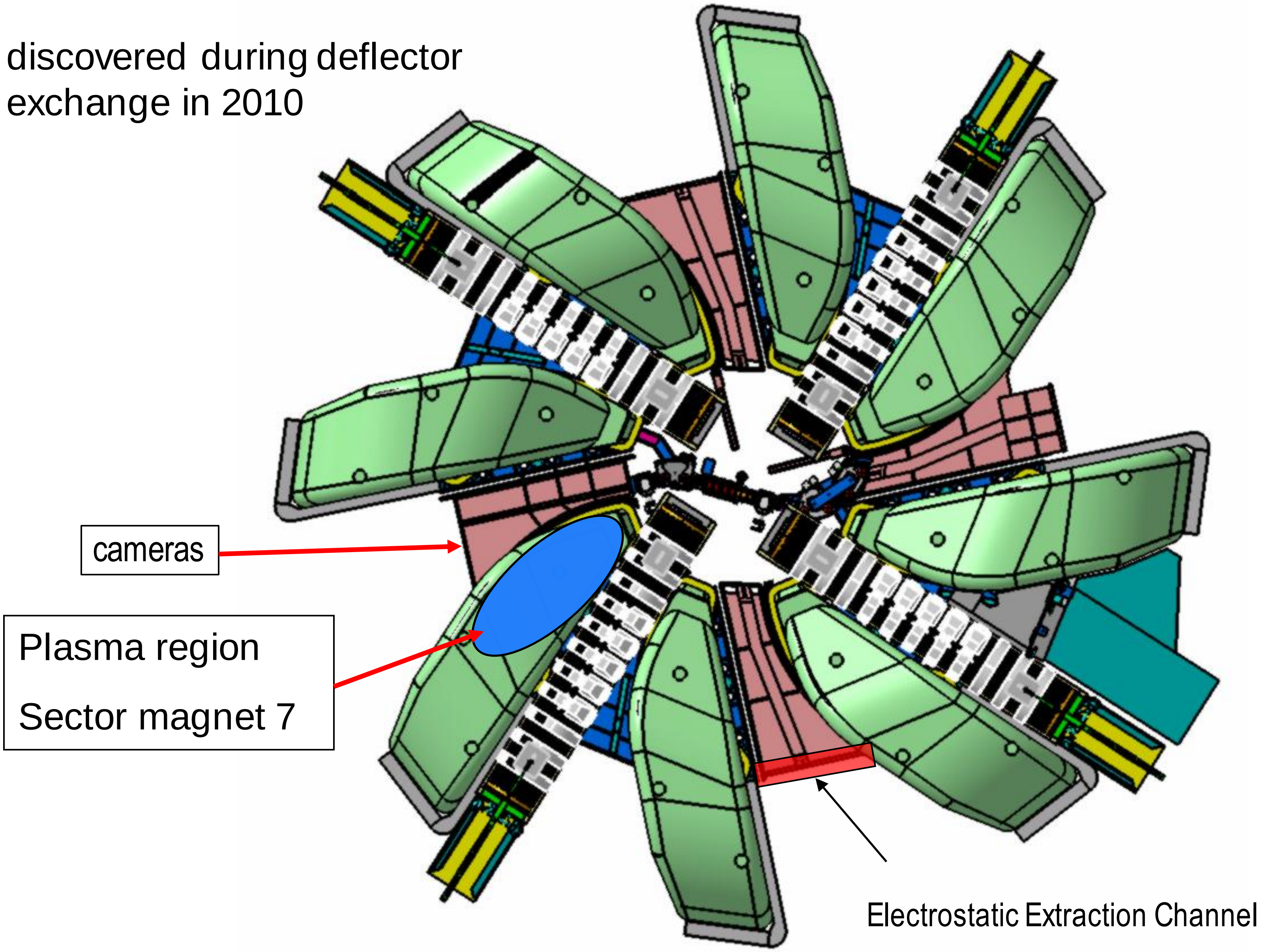
- high dark currents at electrostatic extractor
- Exchange required due to damaged insulators
- RF-shielding coated with thin metallic layer
- Reason: „Plasma“ in sector magnet vis-à-vis



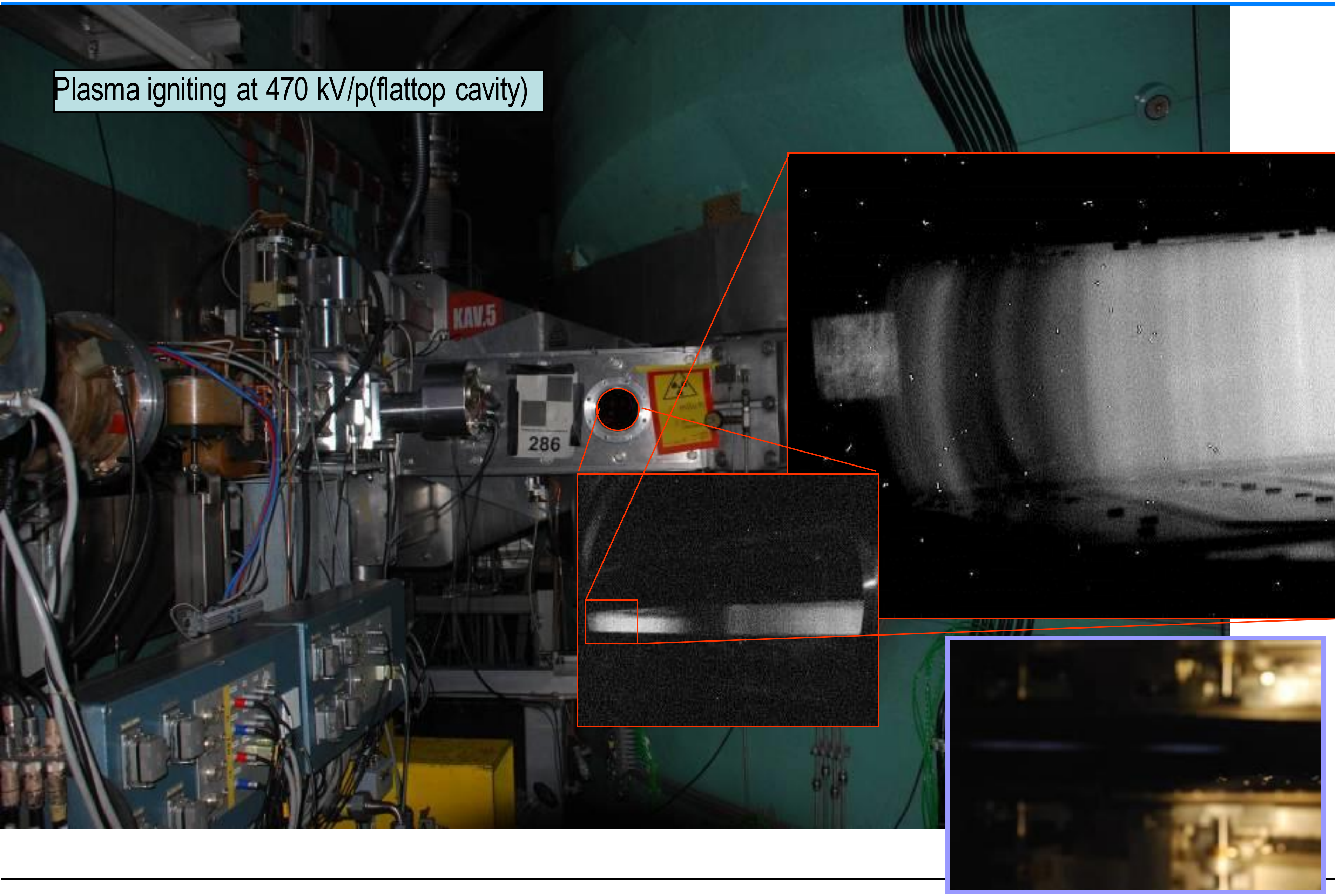


Plasma in ring cyclotron

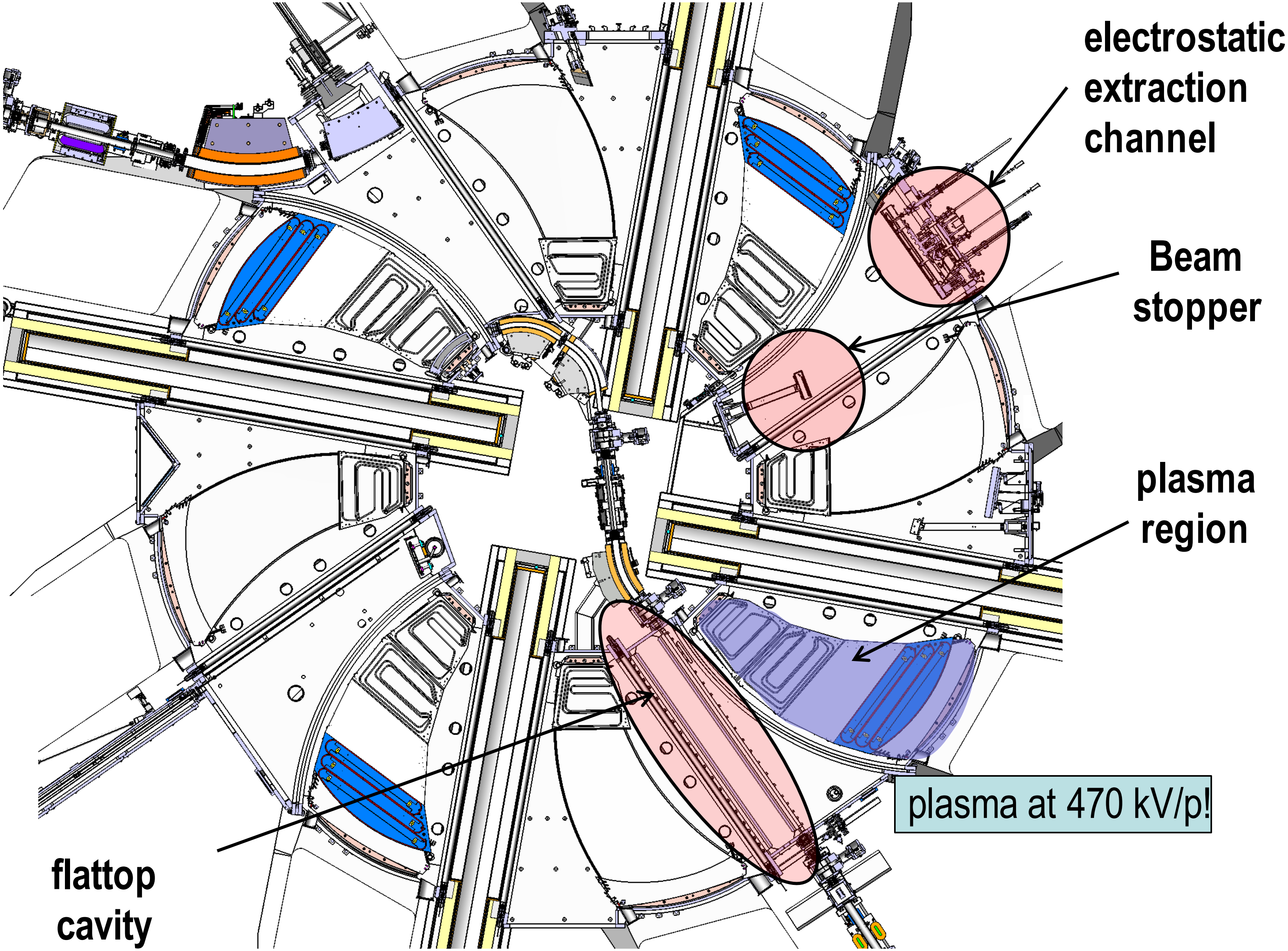
discovered during deflector exchange in 2010



Plasma in Ring Cyclotron

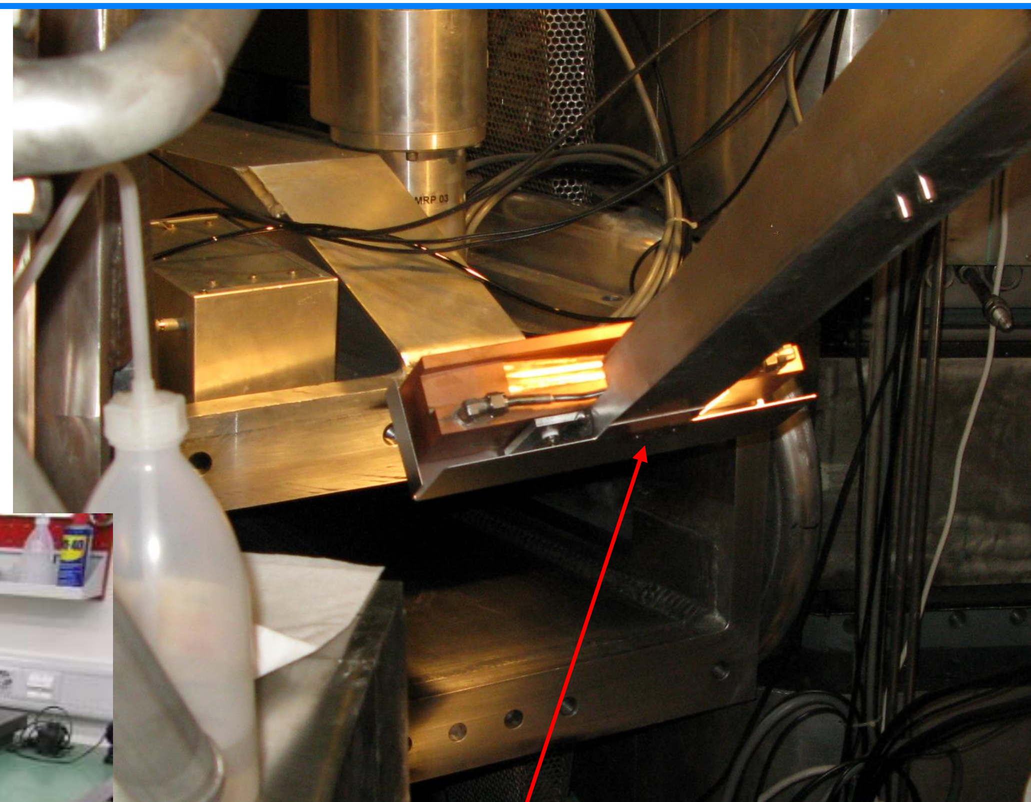


Plasma in ring cyclotron



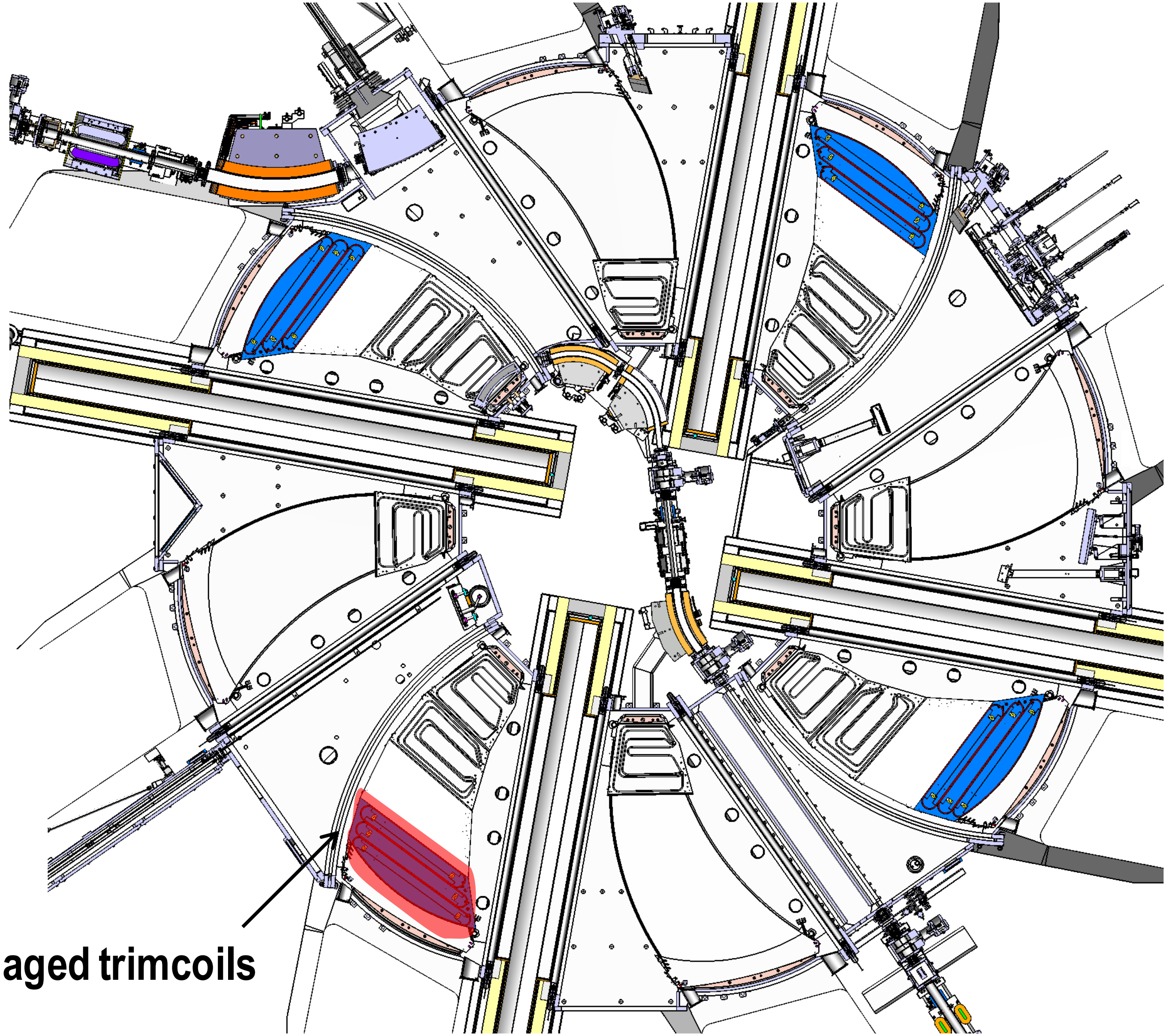
Beamstopper (123 MeV)

Poorly grounded beamstopper in the cyclotron center acts as an RF-antenna



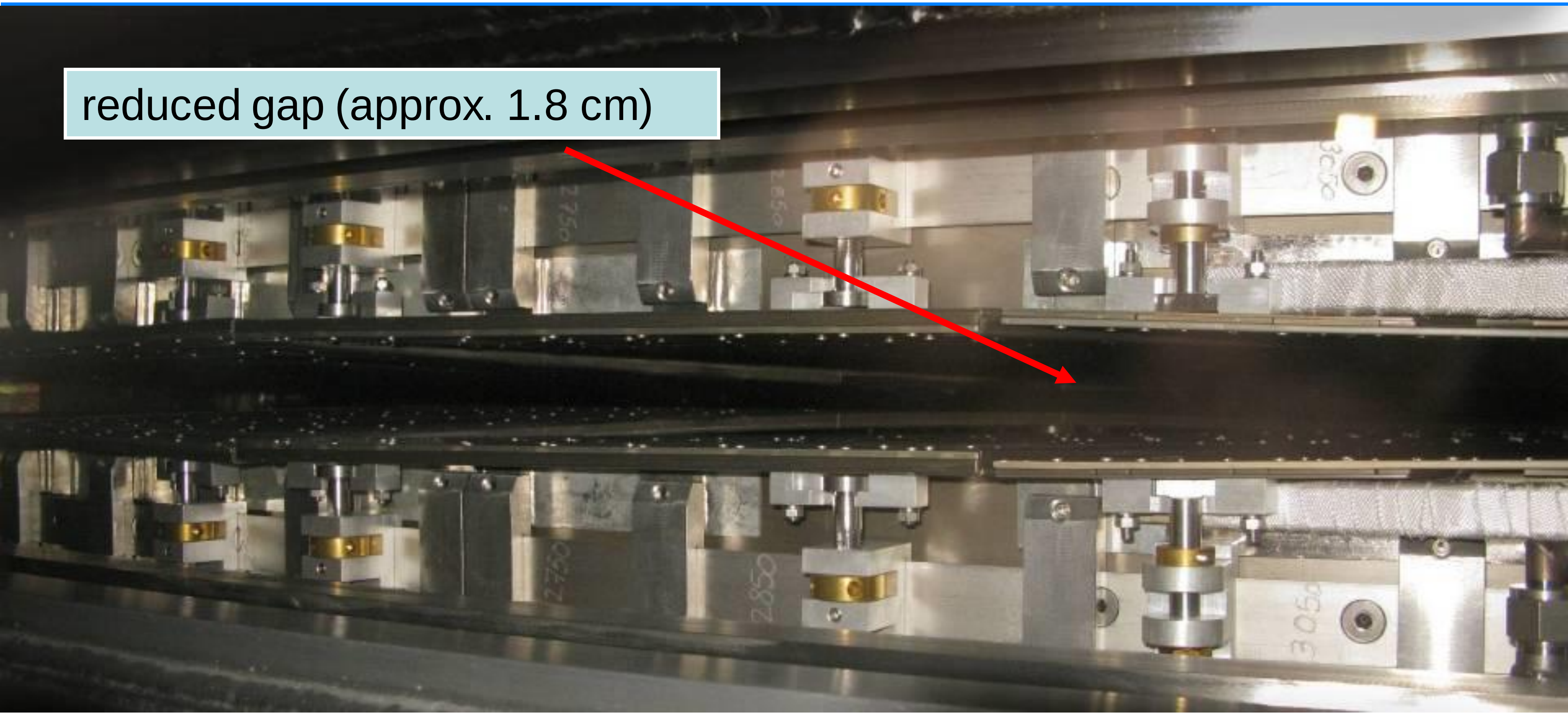
Plastic instead of metal

Plasma in ring cyclotron



Damaged trimcoils

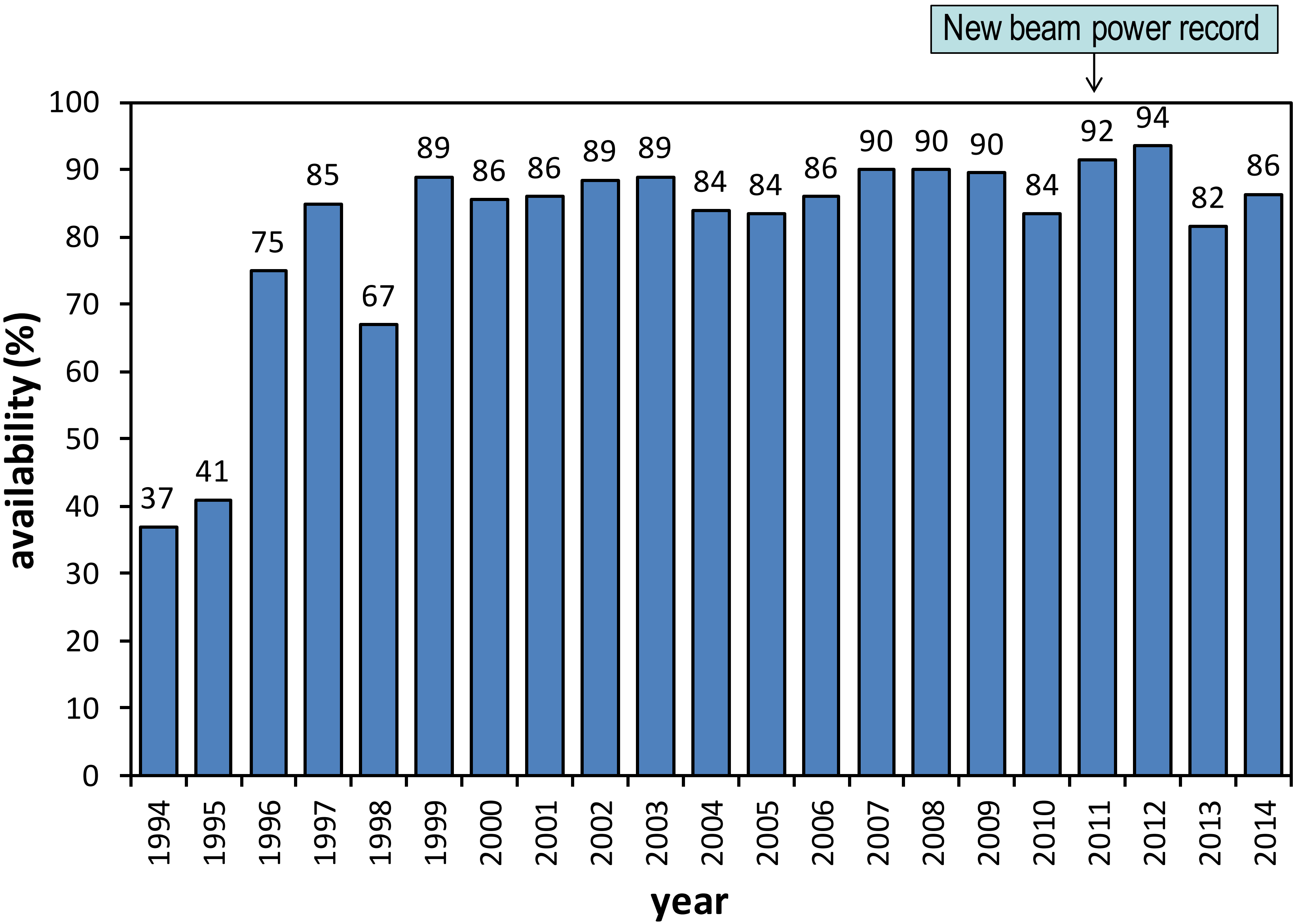
Deformed trim coils in sector magnet (2010)



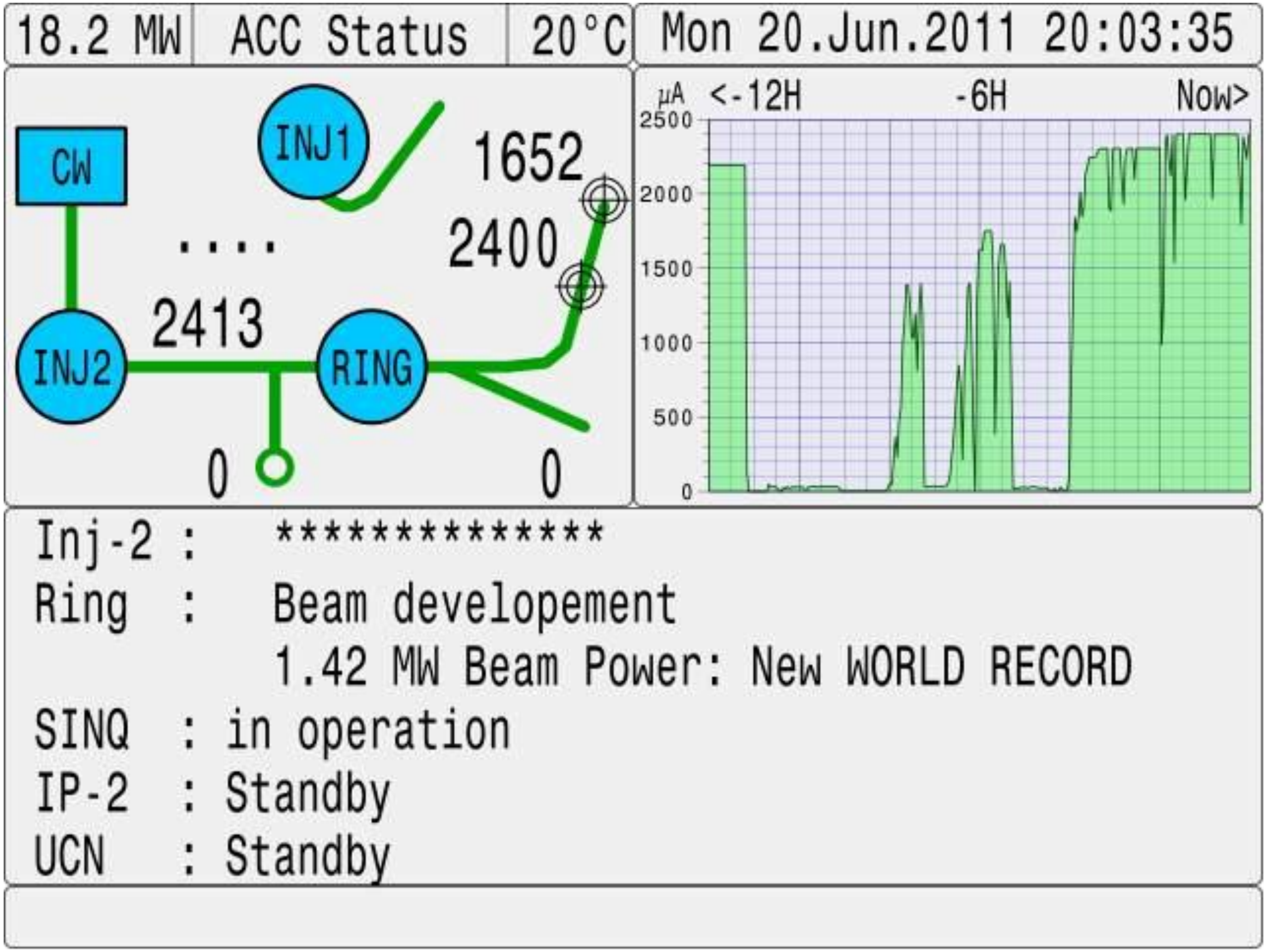
Cooling circuit failure
No interlock on RF-system

Several weeks for repair
→ continue operation **(with up to 2.2 mA!)**

Availability of the PSI proton accelerator

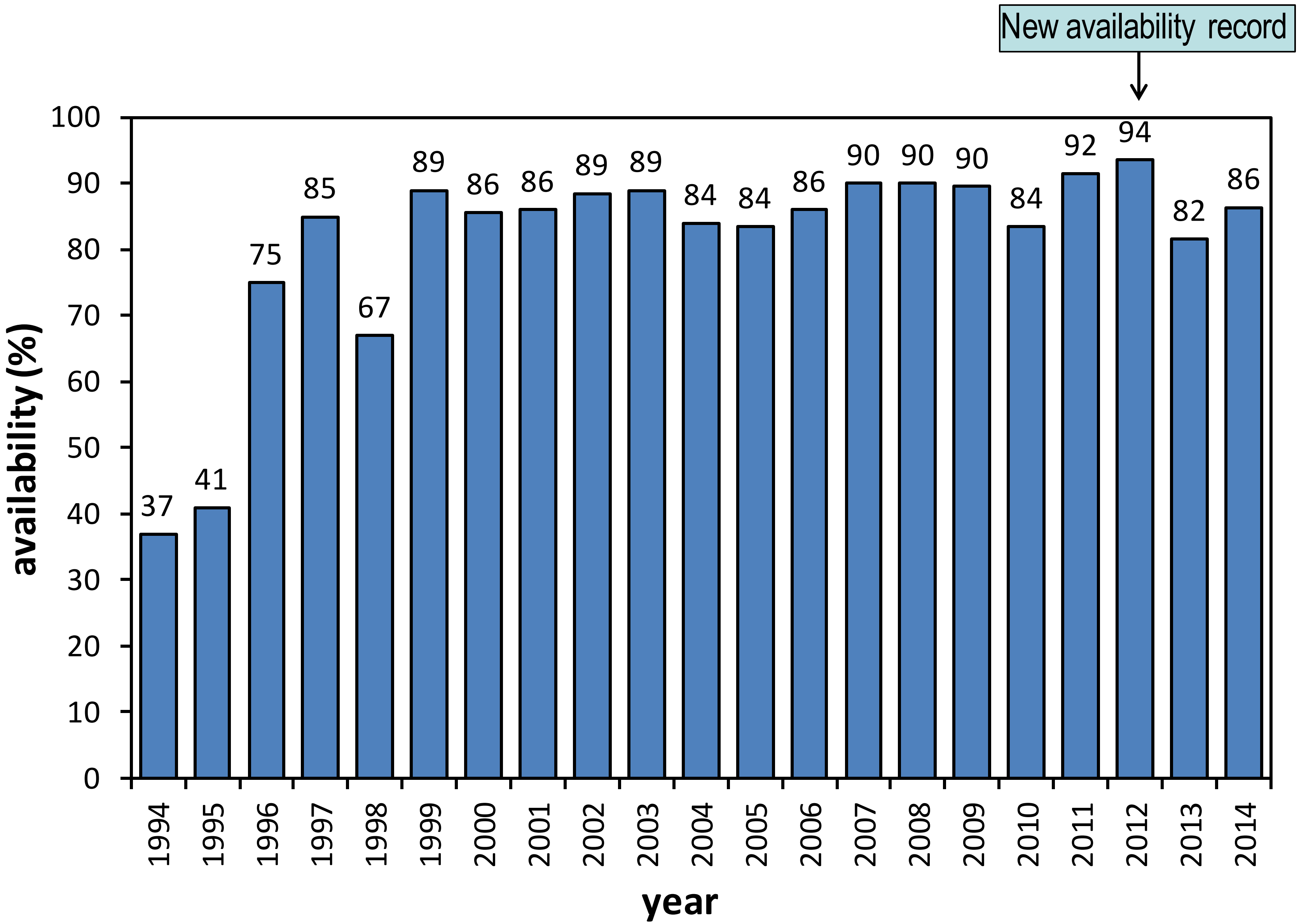


New beam intensity record 2011



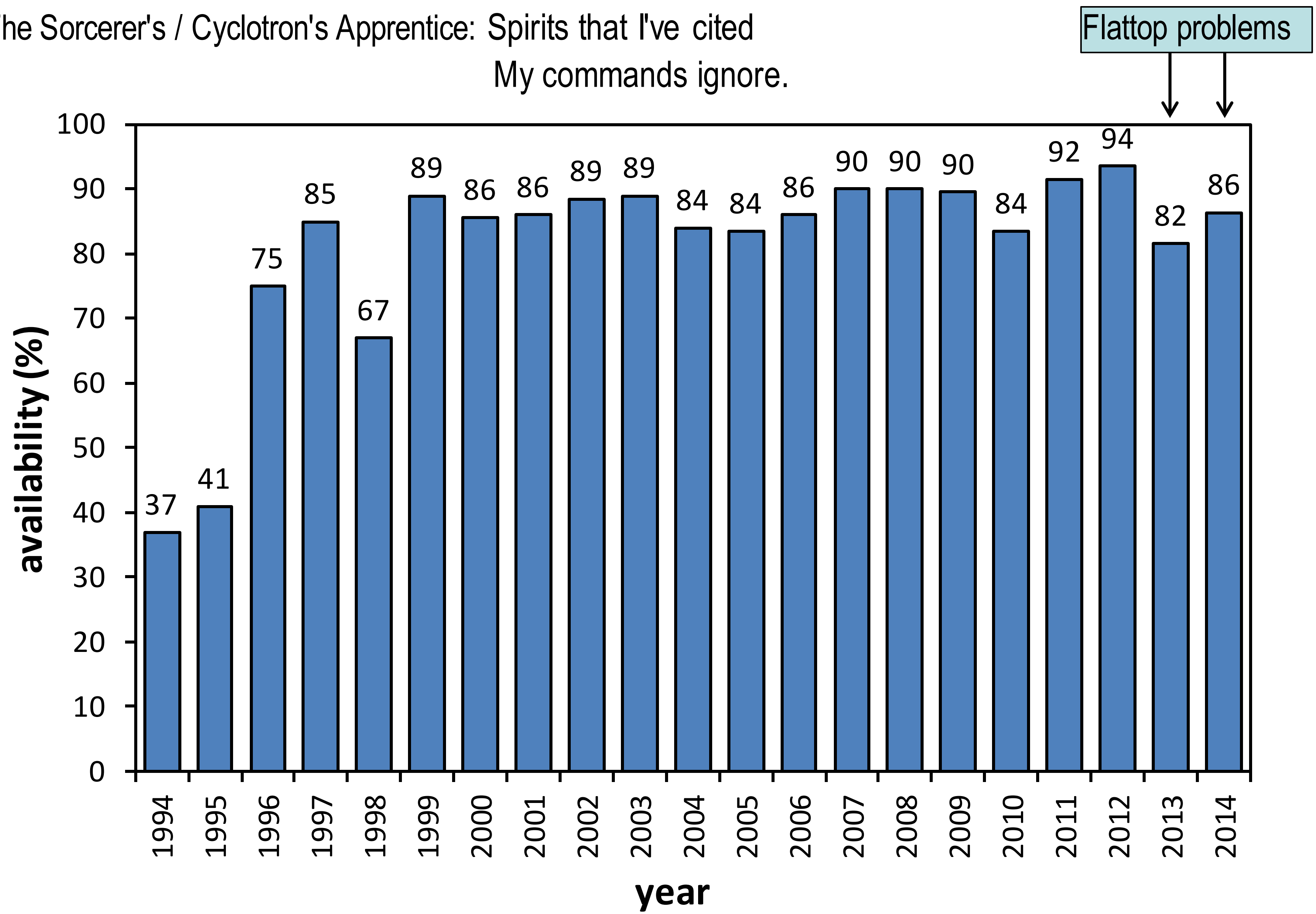
Limited by law and beam losses

Availability of the PSI proton accelerator

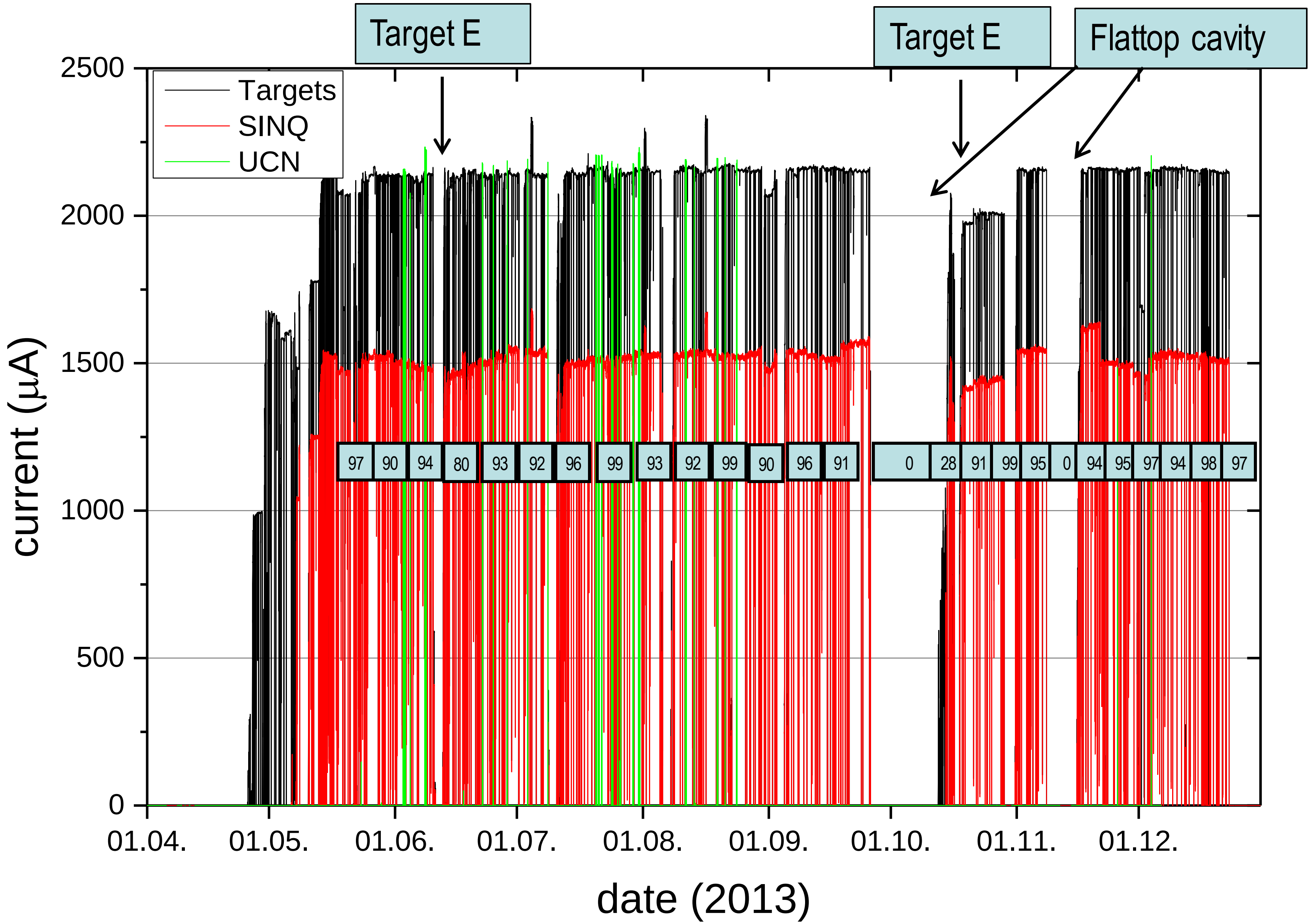


Don't halloo till you're out of the wood

The Sorcerer's / Cyclotron's Apprentice: Spirits that I've cited
My commands ignore.

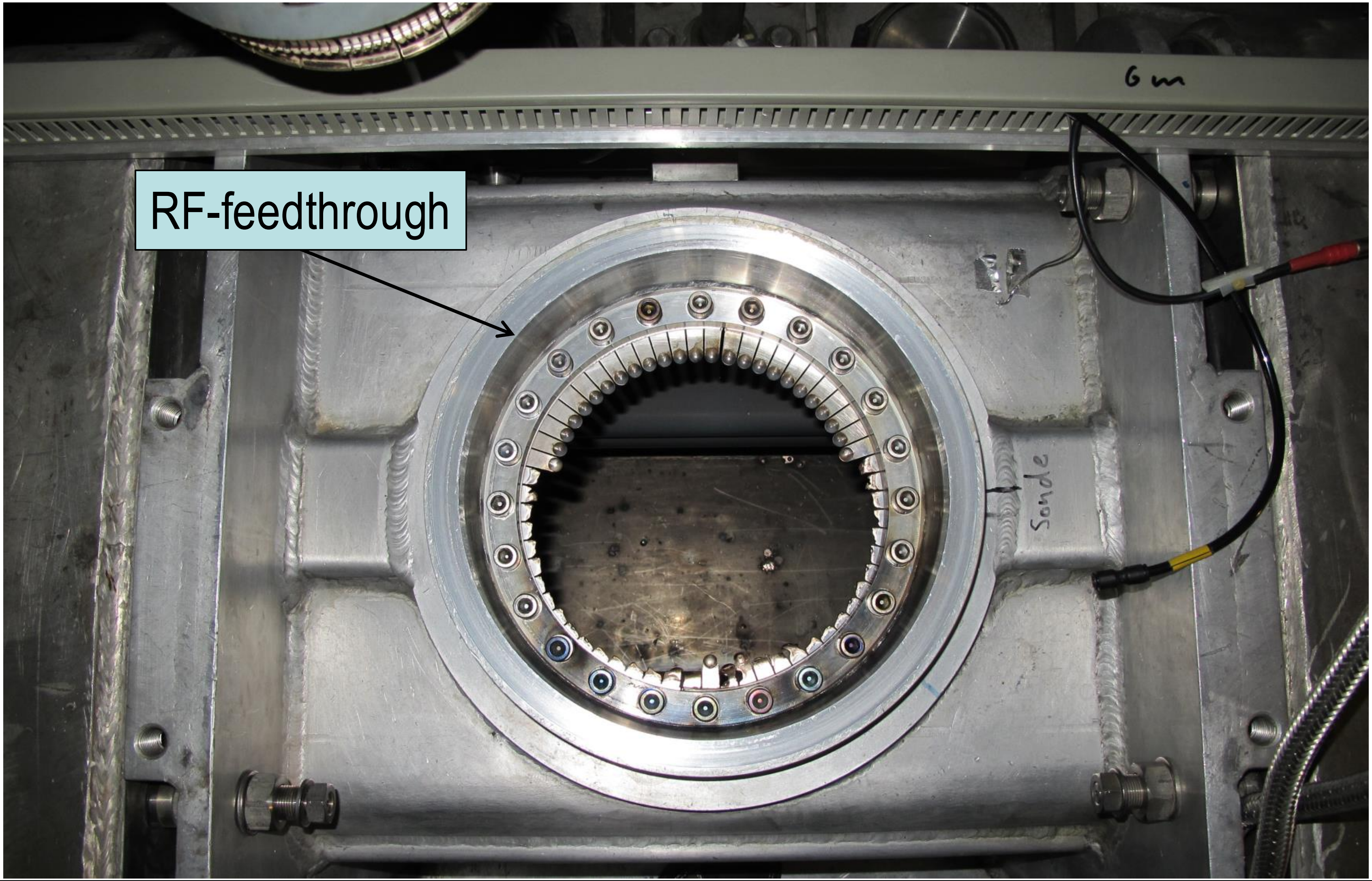


Operation 2013

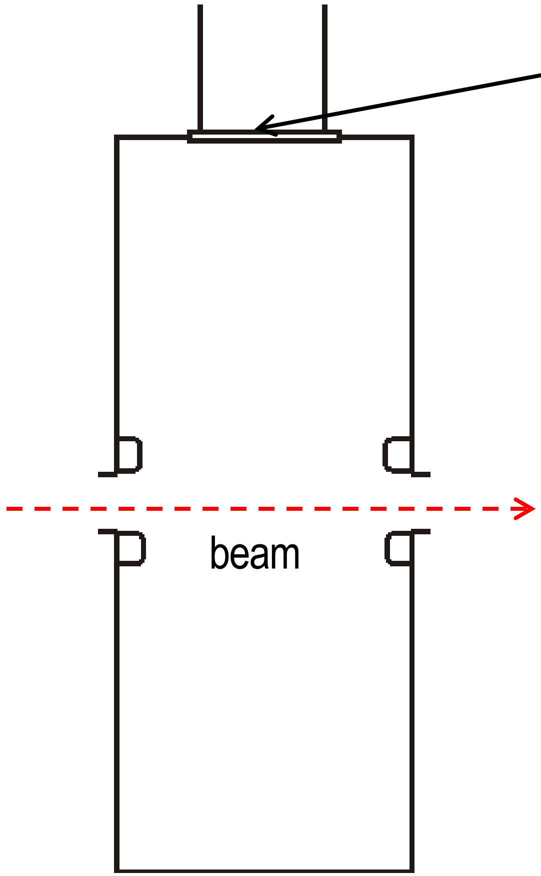


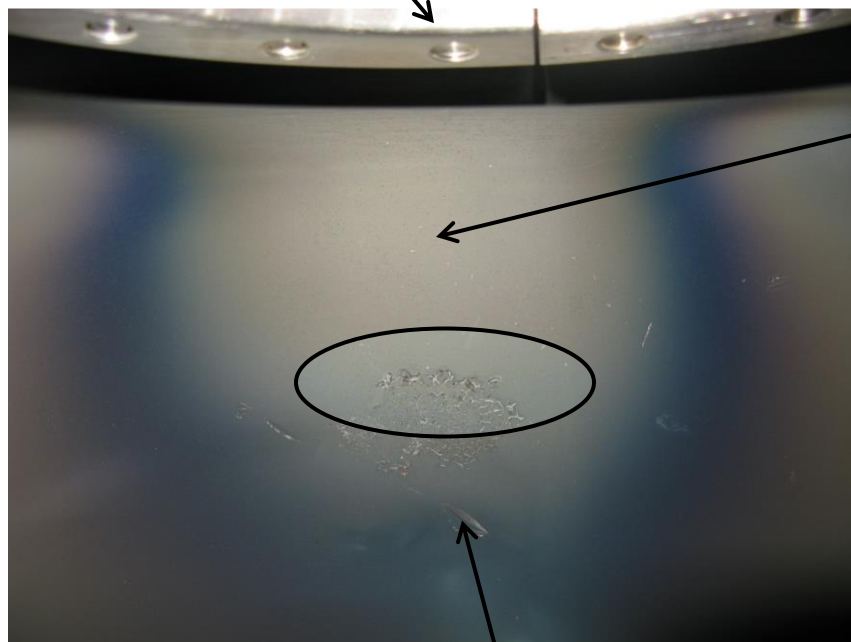
Problems with flattop cavity (2013)

Molten contact springs (3 times!)



Multipactoring inside Cavity



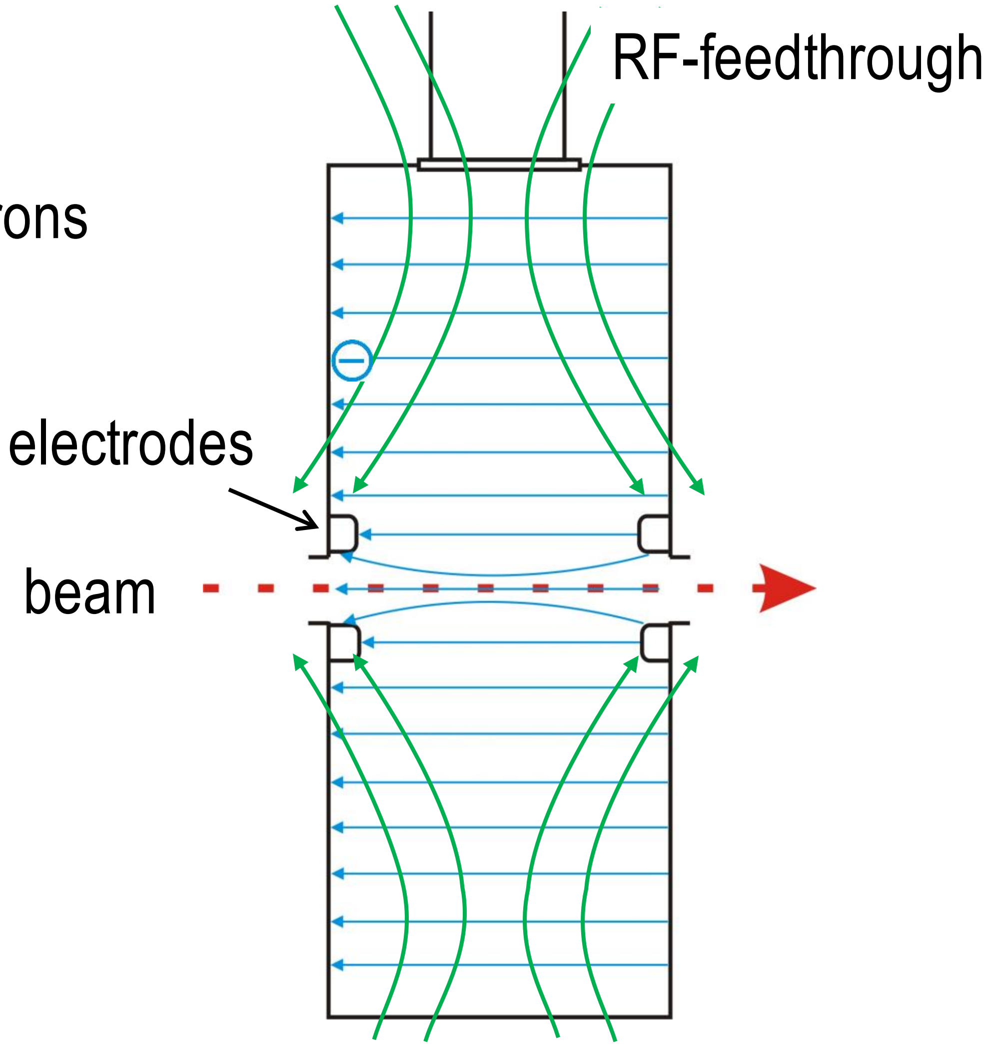


Multipactoring

Emission of secondary electrons in resonance with RF

- High electric fields
- Small work funktion for elektrons
- Fringe field

Work functions:
Al: 4.0 eV
Cu: 4.3 eV
C: 4.8 eV

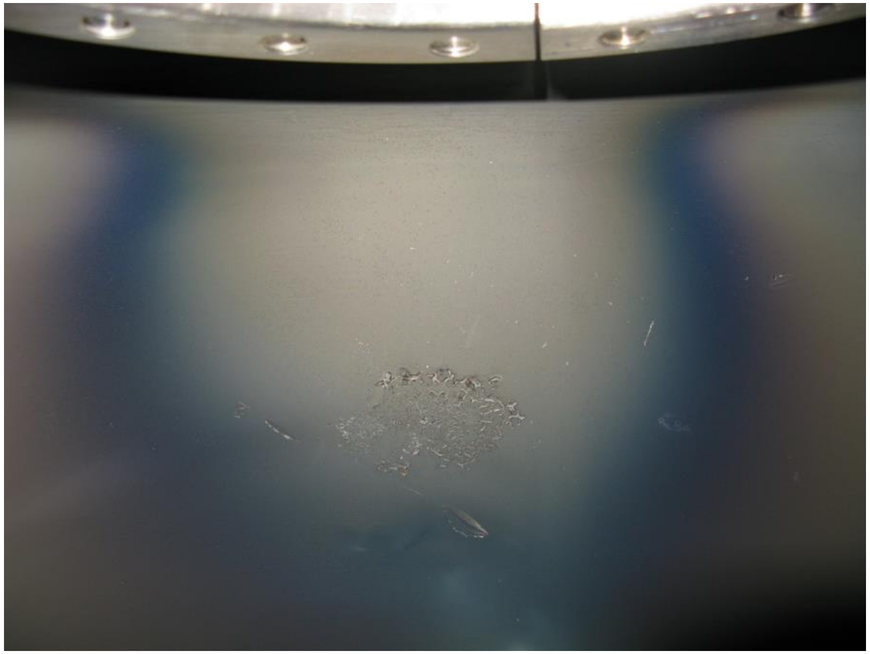


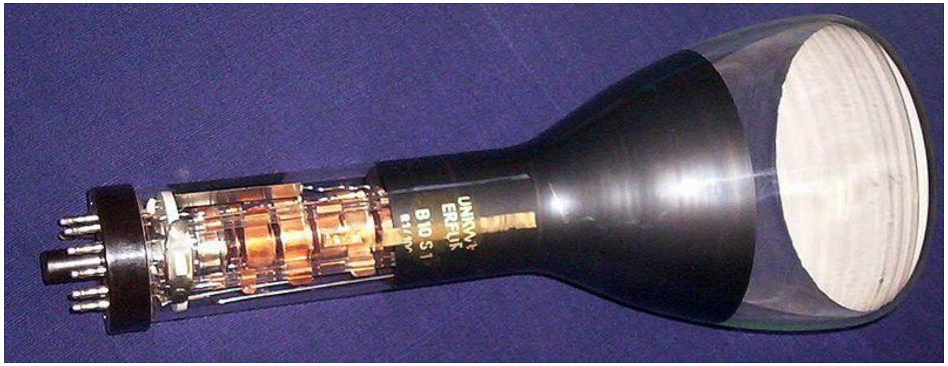
"Solution" against Multipactoring

Paint surface with **Aquadag**

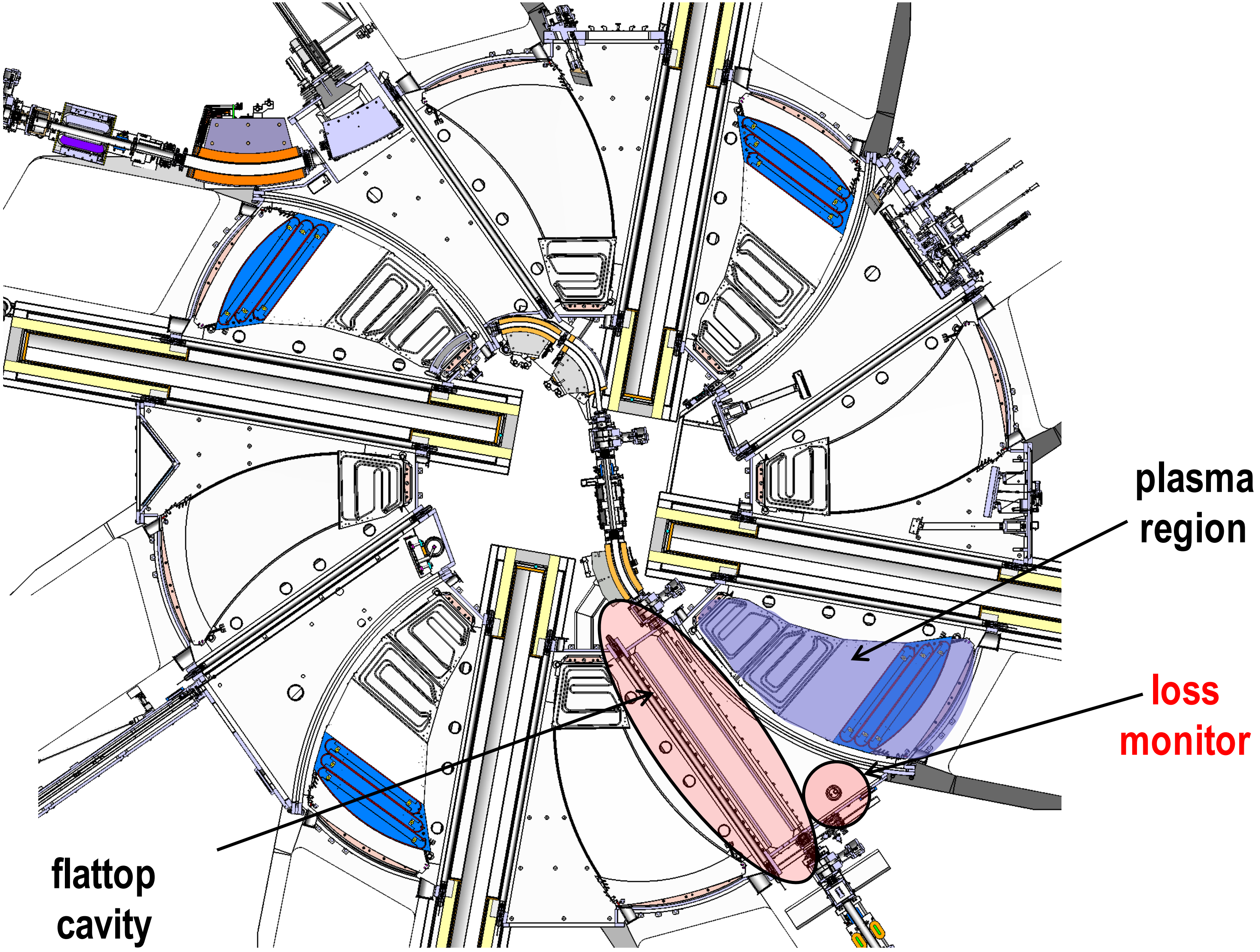
(***Aqua D***eflocculated ***A***cheson ***G***raphite

Agar, water, graphite, ammonia)



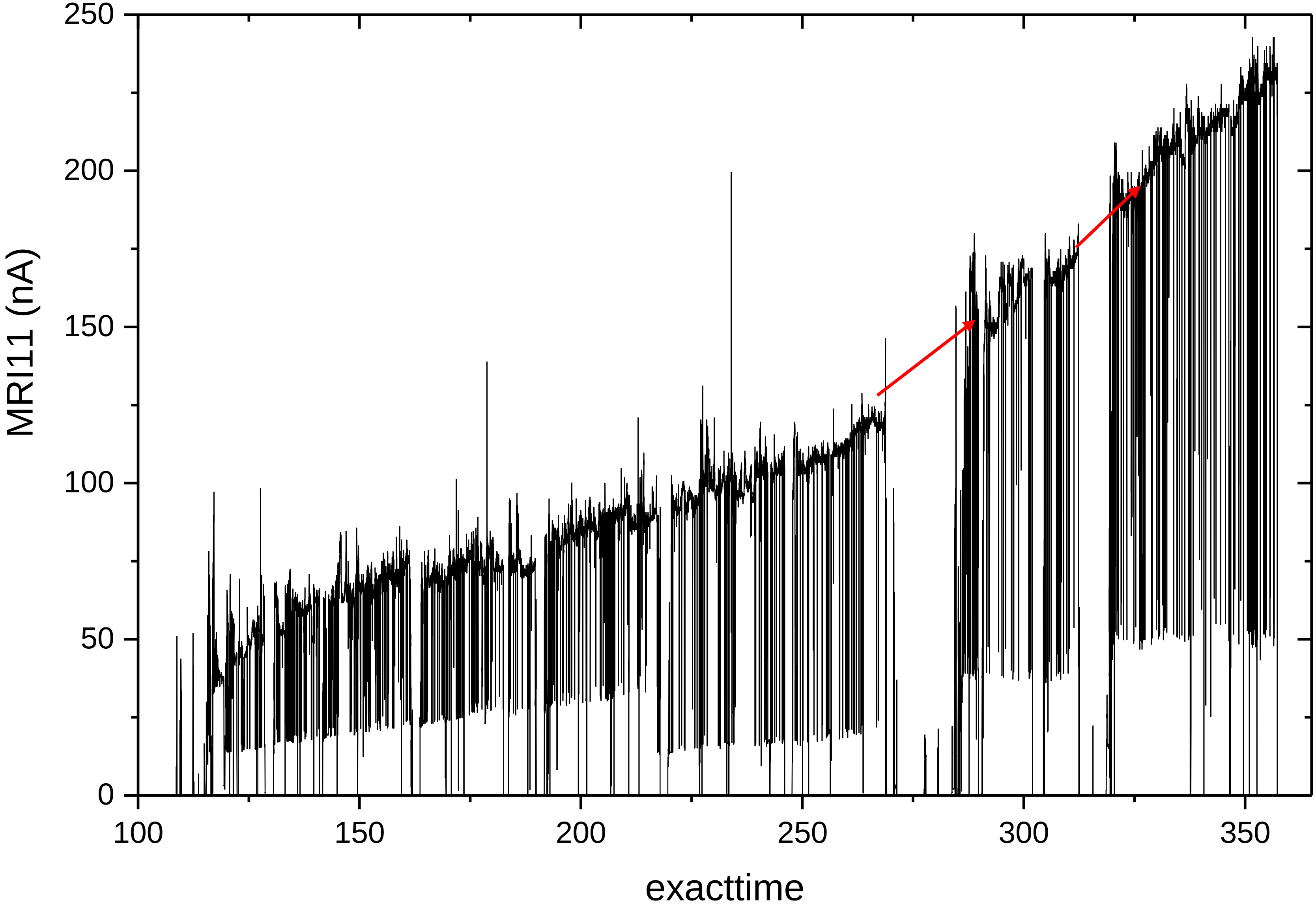


Plasma in ring cyclotron



Röntgen emission from flattop cavity

γ-spectroscopy: not losses but X-rays with up to 550 keV

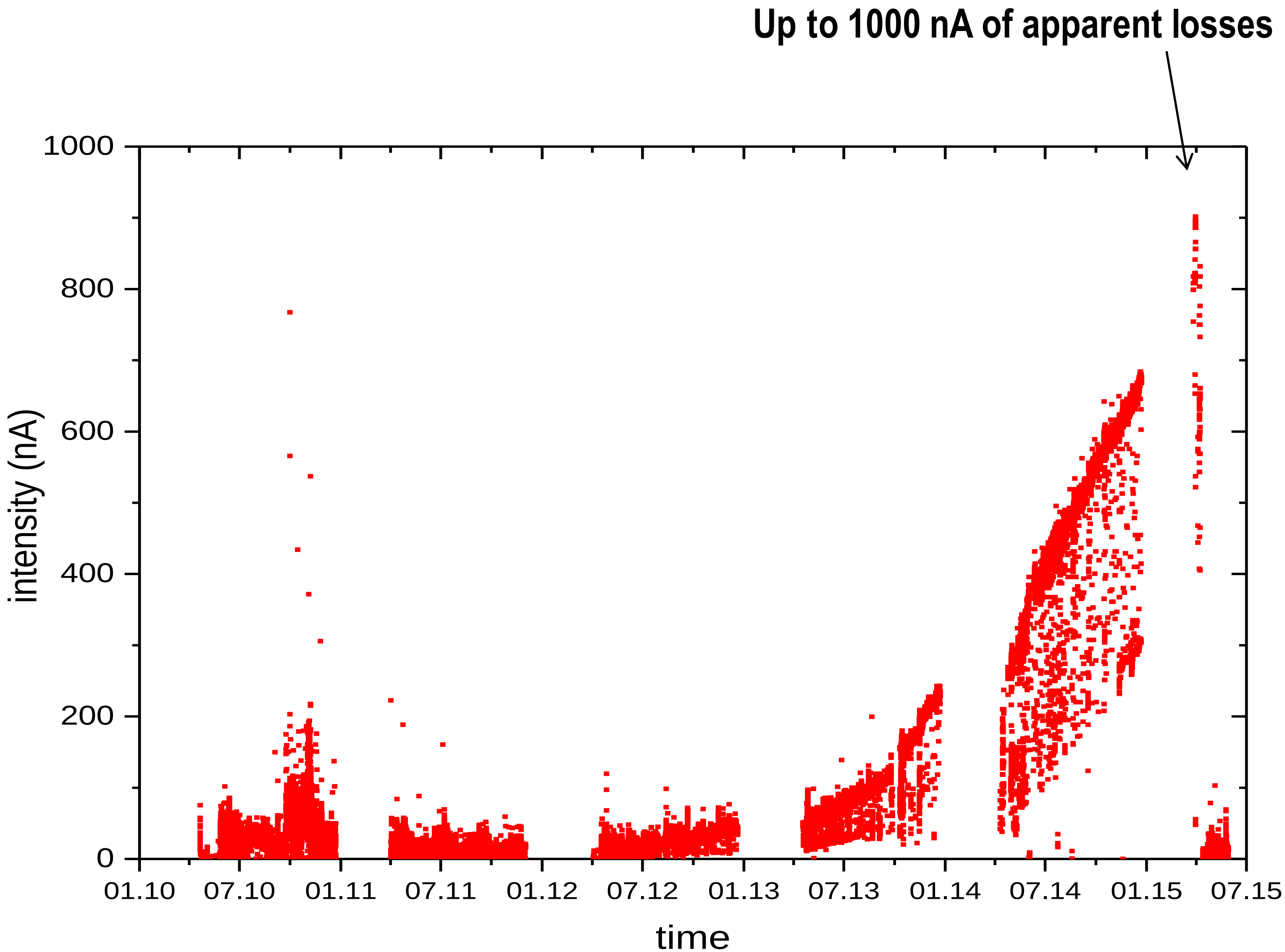


Problems with flattop cavity

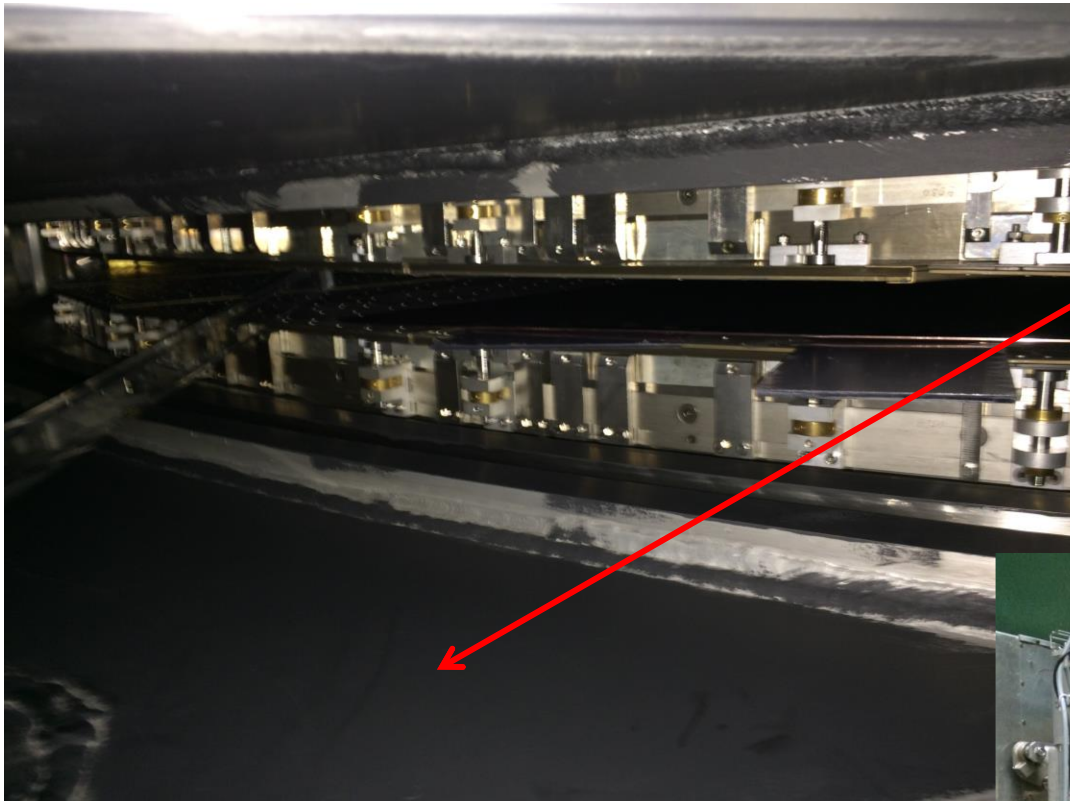
Shutdown 2015

- remove cavity
- refurbish hydraulic tuning system
- Improve vacuum (new square sealings)
- tighten screws for electrodes

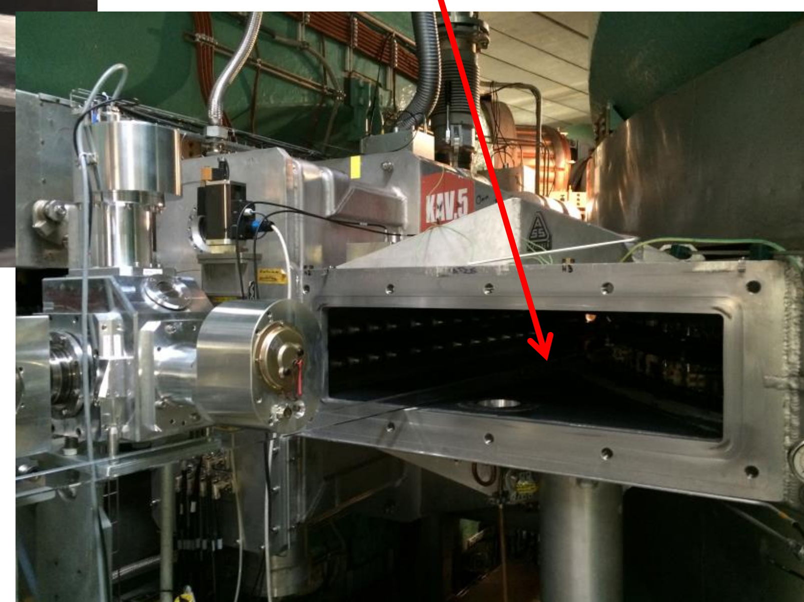
Röntgen emission from flattop cavity



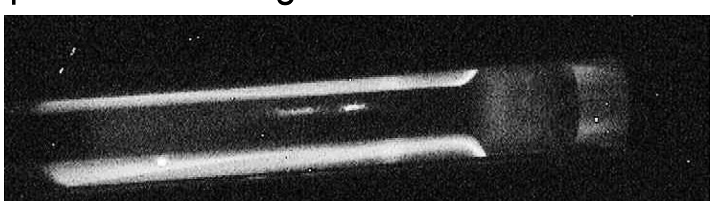
Measures to avoid multipactoring



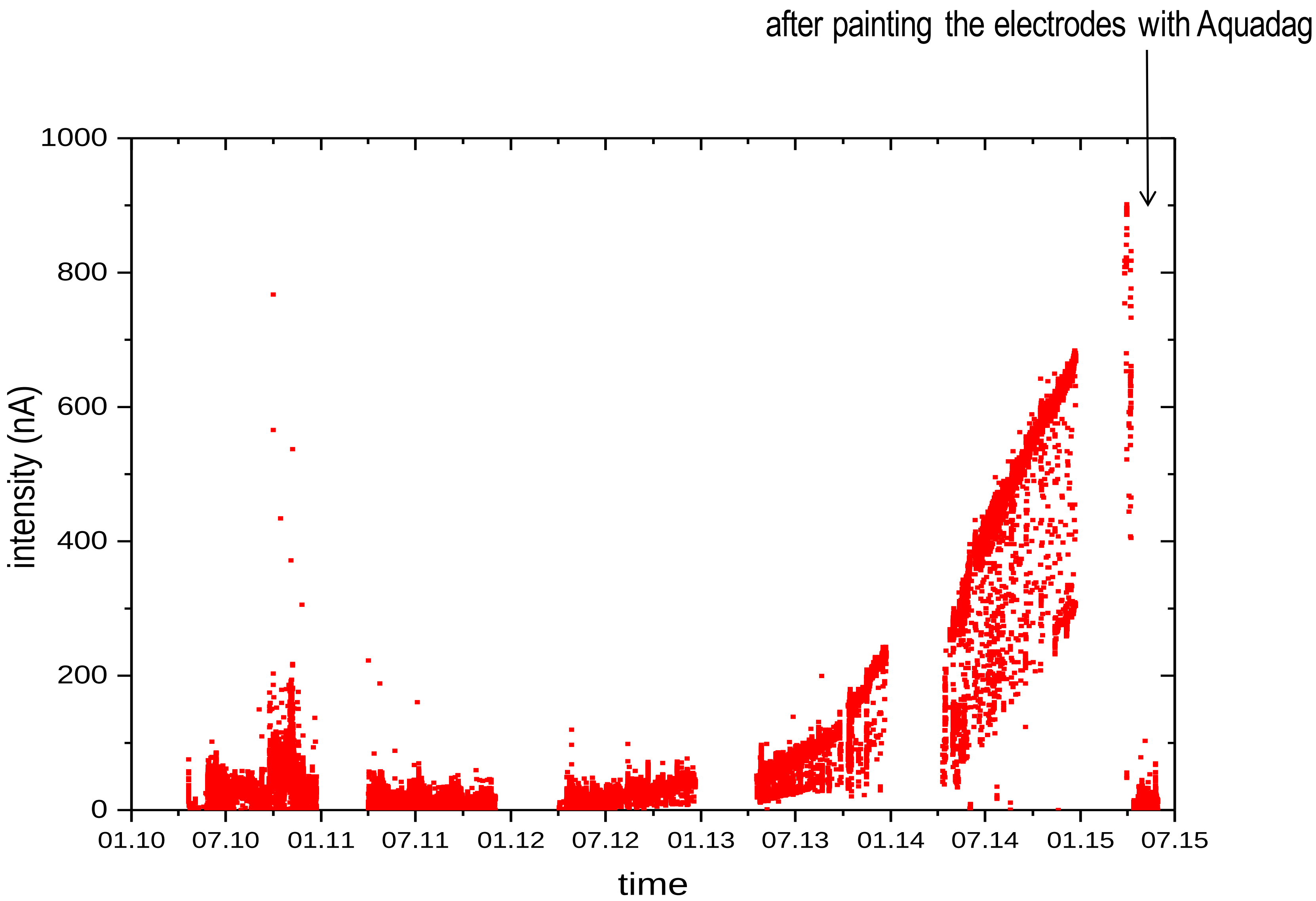
Paint surfaces and electrodes with Aquadag



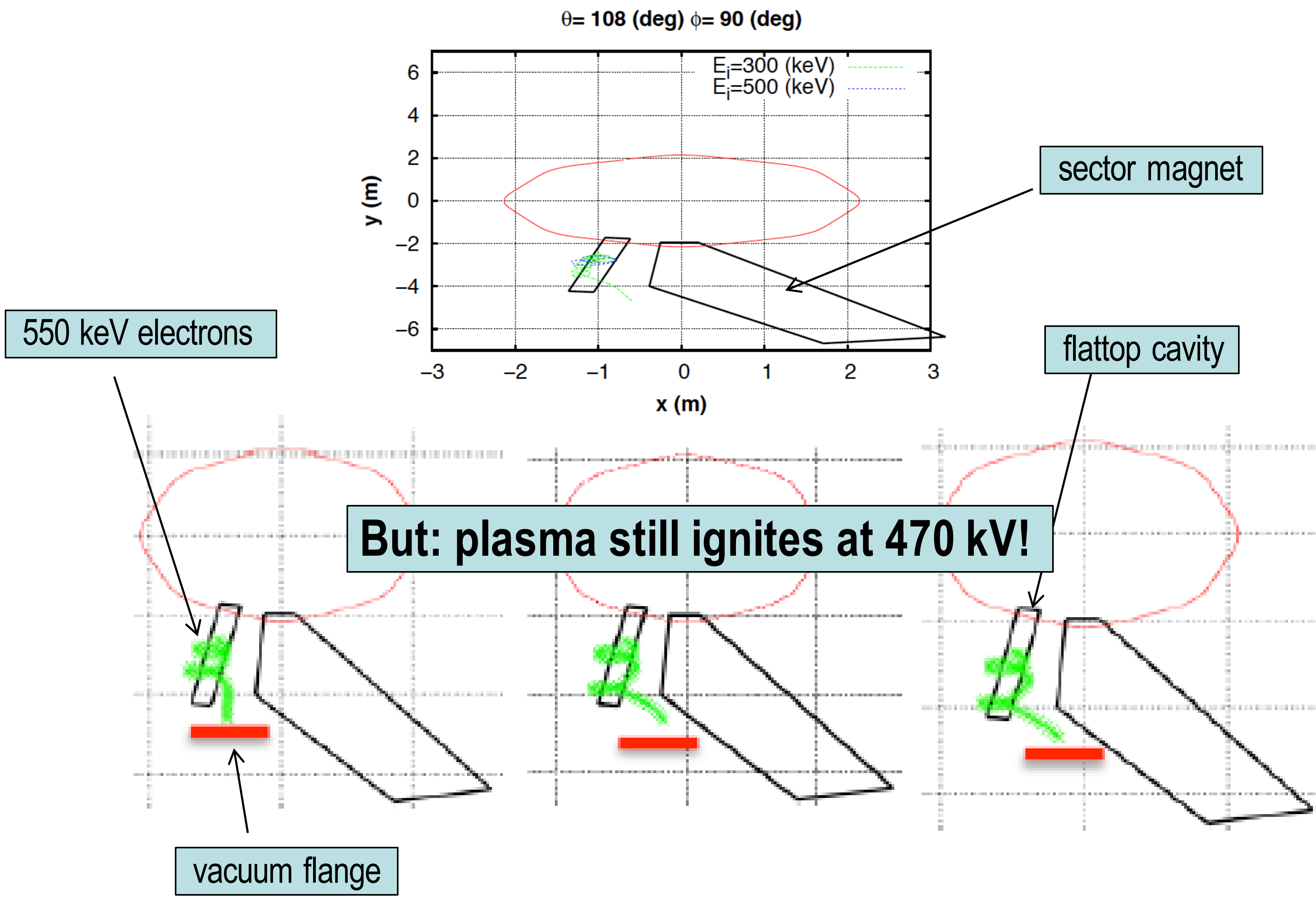
plasma discharges around electrodes



Röntgen emission from flattop cavity



Simulated Electron Orbits

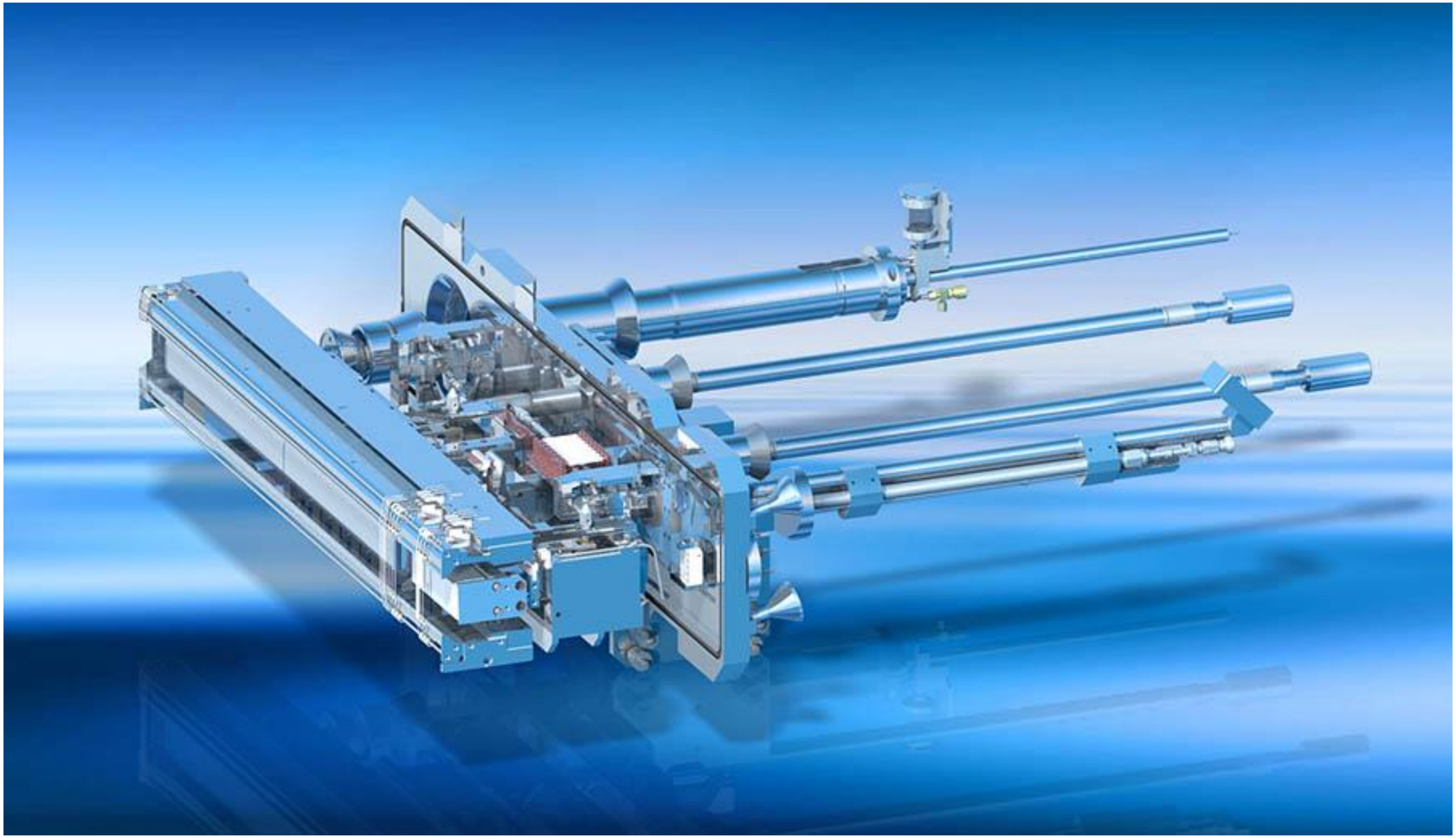


But: plasma still ignites at 470 kV!

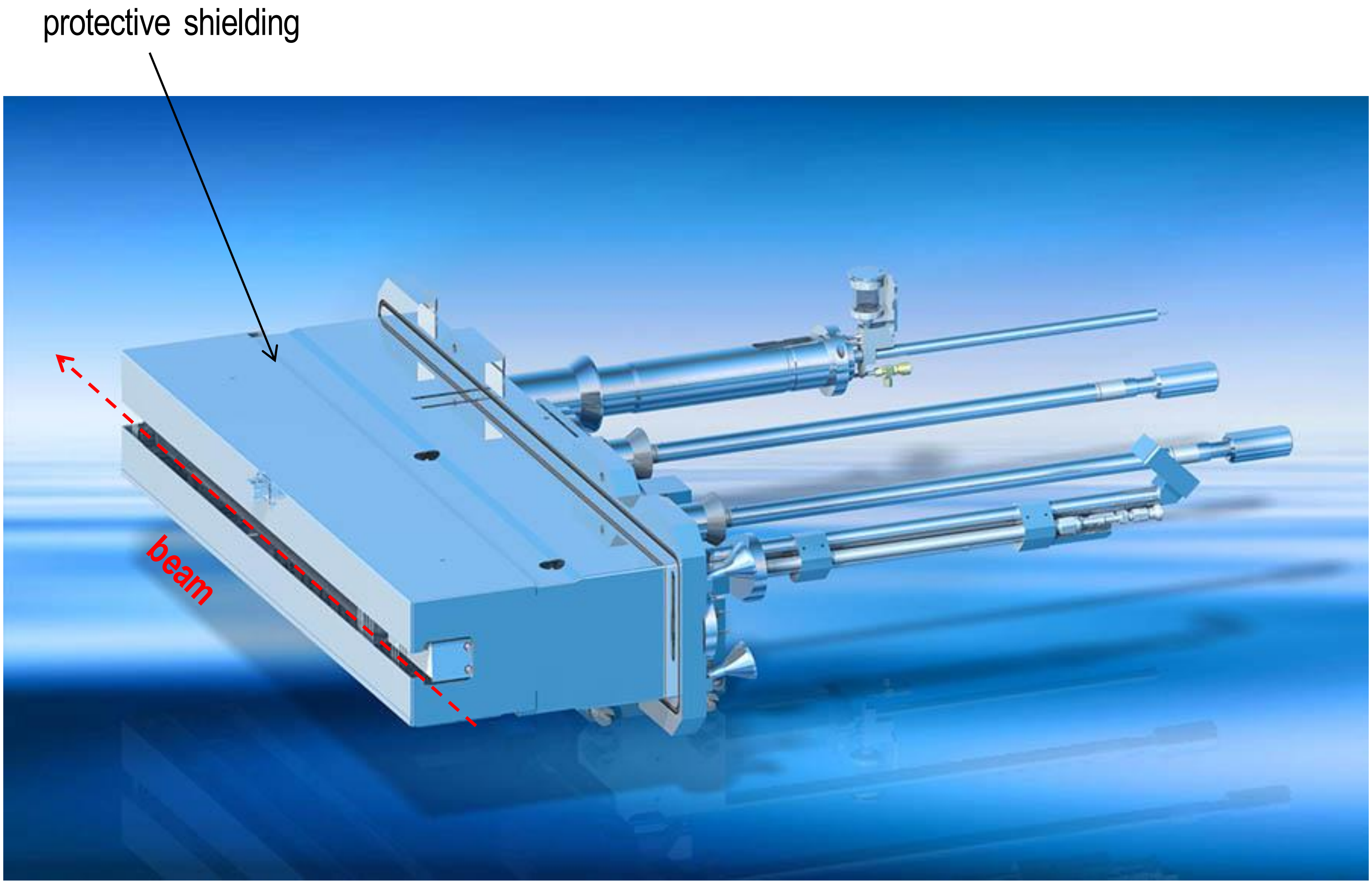
Courtesy A. Adelmann, PSI

Electrostatic Extraction Channel

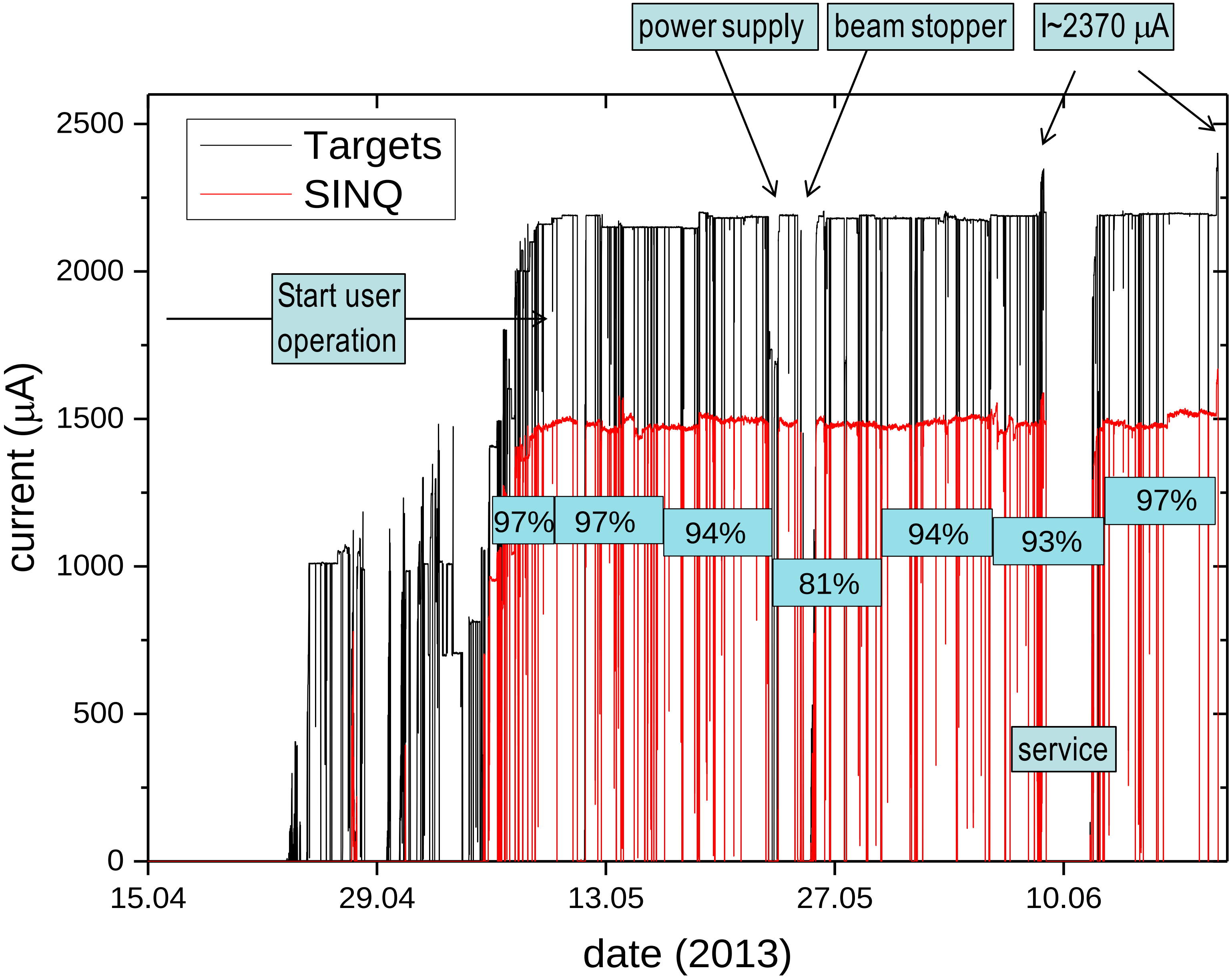
still plasma between trimm coils in sector magnet
→ discharges in electrostatic extraction channel



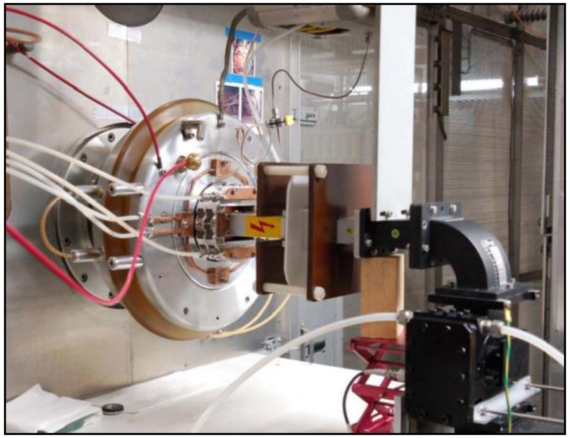
Electrostatic Extraction Channel



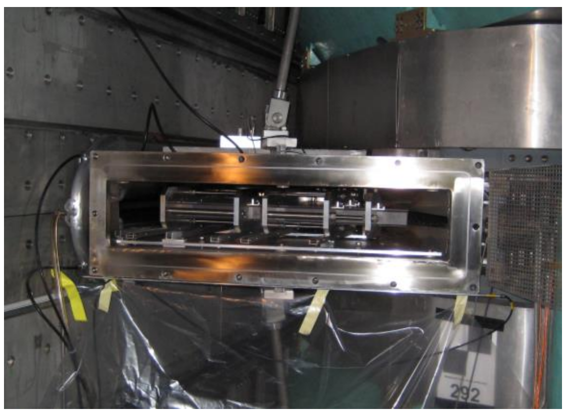
Beam Availability 2015



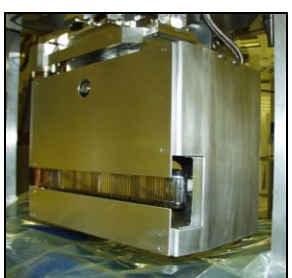
Steps towards a higher Availability

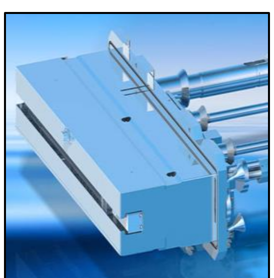


New ECR ion source
- Longer service intervals (> 8 weeks)
- Less unscheduled interruptions
- Higher proton fraction (80% instead of 33%)
- Smaller emittance
- Better beam stability
- 2.7 mA from Injector 2



Removal of aperture limitations and redundant elements
- Less interlocks caused by loss monitors
- Less discharges





Protective shielding for electrostatic elements
- against RF
- straying ions

Steps towards a higher Availability

- Remove the electrostatic elements (ESE) at the beginning of the shutdown
- Store ESE in a vacuum chamber with HV switched on
- Keep machine evacuated as often and long as possible (use N_2 to flood)
- Careful conditioning of the RF-system (heat up the system)
- Install ESE **after** RF-conditioning and ramp them up slowly
- Take time to setup the machine (at least a week)
- Longer running periods (4 weeks instead of 1)
- Beam development and well-trained operators are extremely important!

- Increase gap-voltage (1.2 MV/p are possible → less turns, less losses)
  New flattop required (limited to 550 kV/p)
- Re-bunch the beam within the injection line between Injector 2 and Ring cyclotron
- Upgrade Injector II with two new resonators → better beam quality for Ring cyclotron
- Improve vacuum (now $P > 10^{-6}$ mbar)
- Replace trim coils (avoid secondary electron emission, plasma)
- New ball bearings for targets
- Improve ESE

Steps towards a higher Availability

Short interruptions have a considerable impact on the availability

Ramping up the beam takes approx. 60 s.

With 50 short interruptions per day this corresponds **to 2% of lost availability!**

- Beam trips caused by microsparcs in cavities can be neglected (<500 μs)
- Discharges in the electrostatic elements switch the beam off
  - rapid re-charging
  - RF-resonator for injection and extraction

Summary

- the PSI accelerator delivers 1.3 MW beam power in CW mode
- the average availability is 87%
- significant reduction of beam trips (eg.: best week: 58 trips = 8.3 trips per day most caused by ESE)

- major performance step achieved by raising the gap voltage using the new cavities in the Ring
- results in reduction of losses by factor 2 at same current; new beam record current is 2.4 mA

- **modular design** allows for fast and save repair (usually < 2 d)
- **Infrastructure**

radiation safety, shielding, waste disposal, hot-cell and radio-analytic laboratories
also includes licensing and the ability to perform required studies and other formal aspects connected to safety and radiation issues which are challenging and often underestimated!

- **documentation for careful planning of repair and service work**
- Stock keeping of critical elements extremely important
- Continuous replacement of old or "outdated" components (especially the flattop!)
- remove redundant components from the machines

For a desirable spin-off: demonstrate applicability of cyclotron concept for ADS projects using our facility!

The PSI Ring cyclotron in 1974

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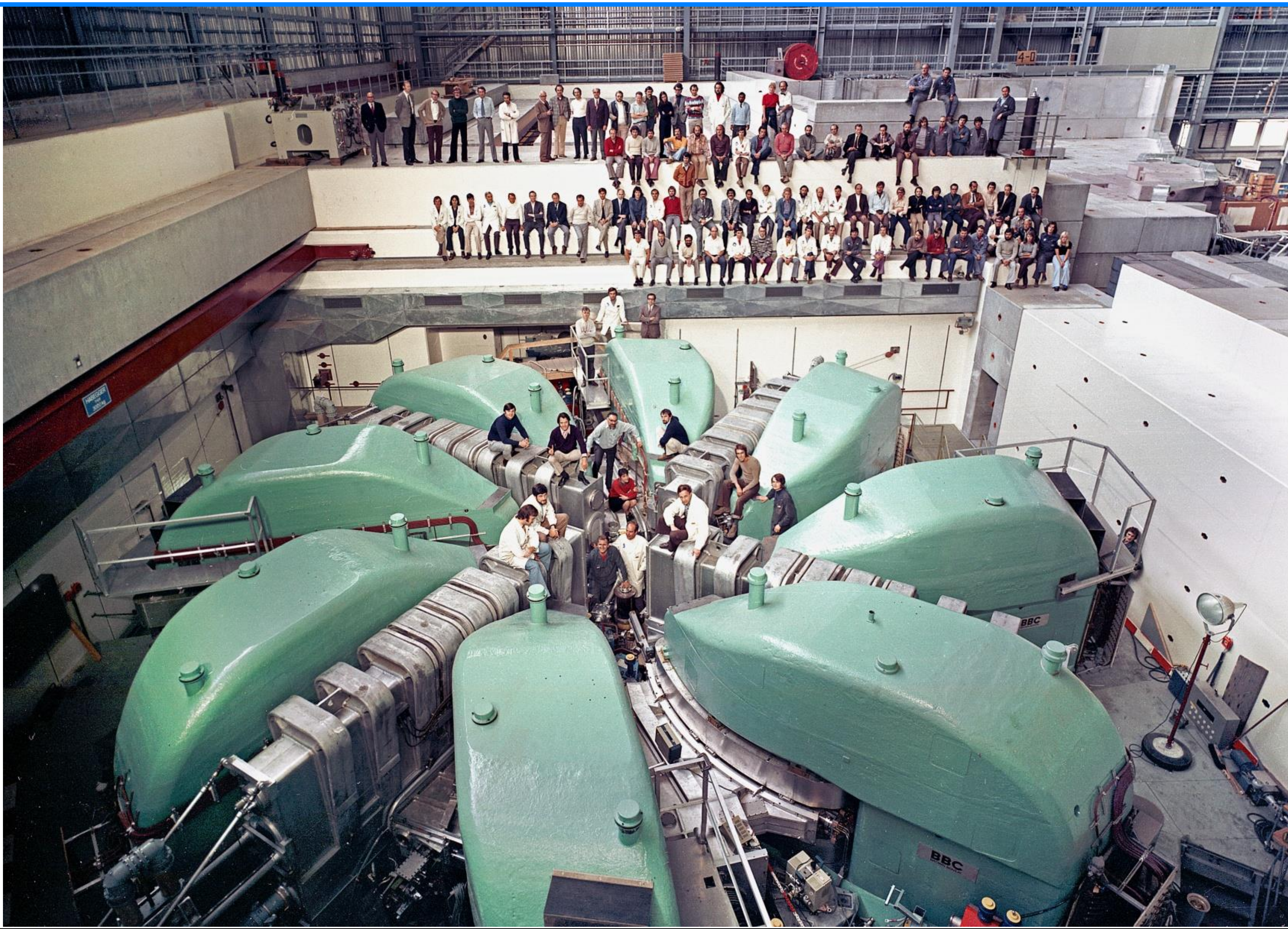
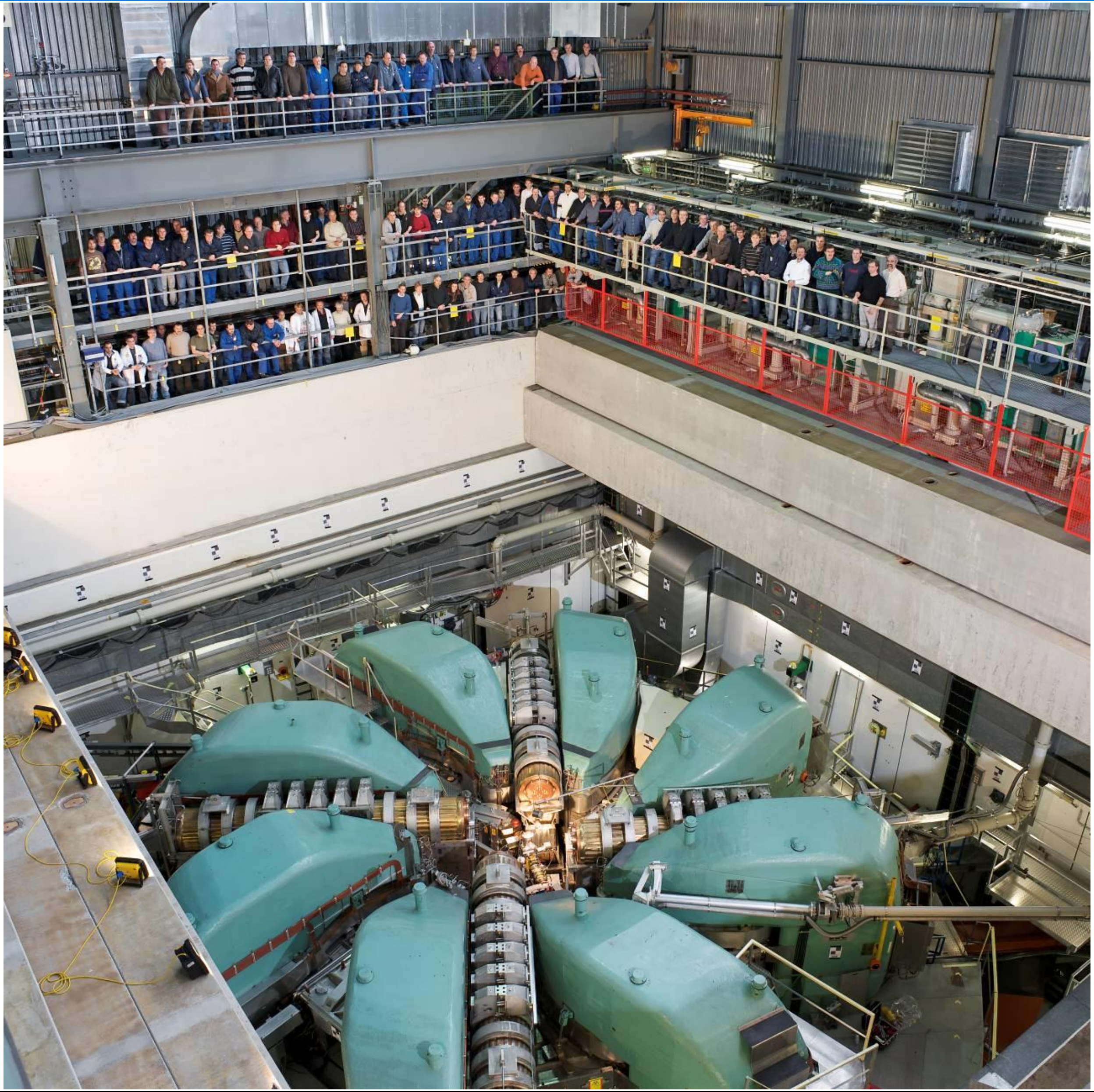
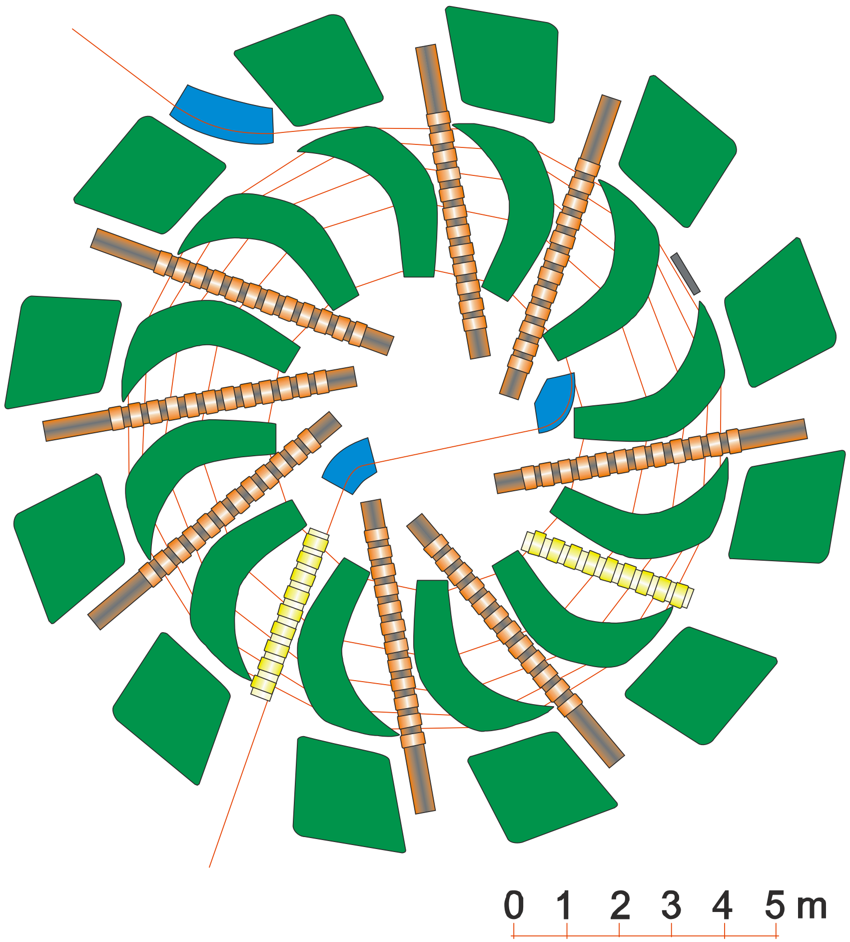


The PSI Ring cyclotron in 2010



Thank you for your attention

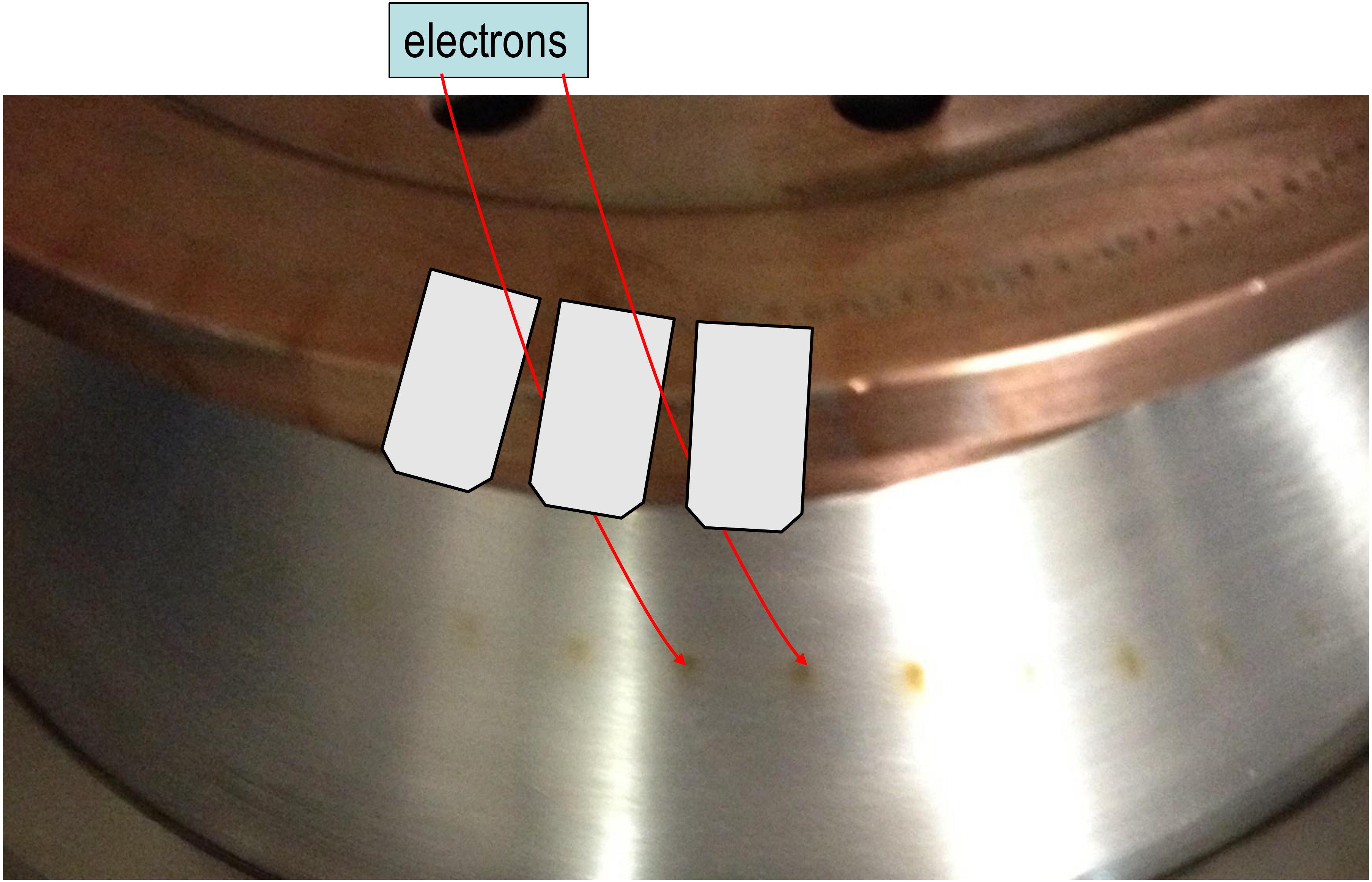
Proposal for a 10 MW driver



Parameter	1 GeV Ring	PSI Ring
Energy	1000 MeV	590 MeV
Current	10 mA	2.2 mA (3.0 @ 4 MV/turn)
Magnets	12 (B_{max} = 2.1 T)	8 (B_{max} = 1.1 T)
Cavities	8 (1000 kV)	4 (800 kV)
Frequency	44.2 MHz	50.63 MHz
Flat tops	2 (650 kV)	1 (460 kV)
Injection energy	120 MeV	72 MeV
Injection radius	2.8 m	2.1 m
Extraction radius	5700 mm	4462 mm
Number of turns N	140	186
Energy gain at extraction	6.3 MeV	2.4 MeV
$\Delta R/\Delta N$	11 mm	5.7 mm
Turn separation	7 σ	7 σ
Beam power	10 MW	**1.3 MW (2.4 MW)**

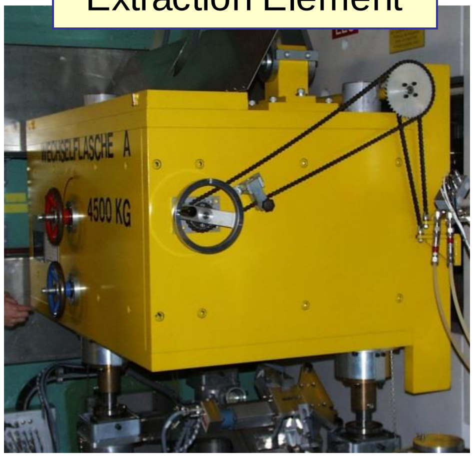
T. Stammbach et al.

RF-feedthrough



Infrastructure – Exchange flasks

Electrostatic Extraction Element



Collimators

Meson production target (4 cm)

beam splitter

Target E flask

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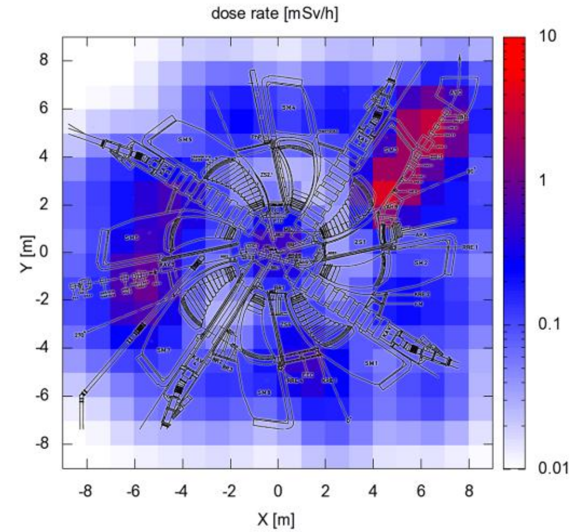
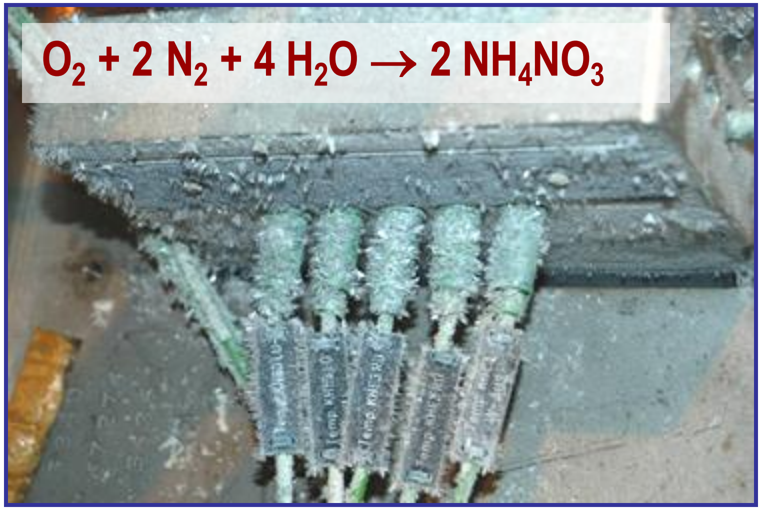
The Challenge of a High Power Beam

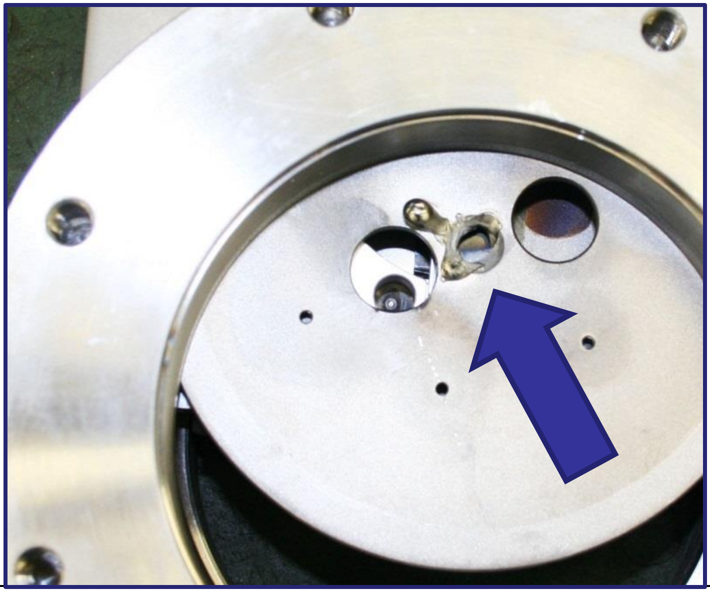
incomprehensive list:

- a Megawatt beam is a dangerous beast, melts steel in 10 ms, interlocks!
- losses must be low (≈200 W ≅ $2 \cdot 10^{-4}$) to avoid excessive activation
- **Expensive infrastructure for repairs and exchange of elements**
- high power RF has side effects: Plasma discharges, multipactoring, heating …
- Ammonium Nitride and much more …



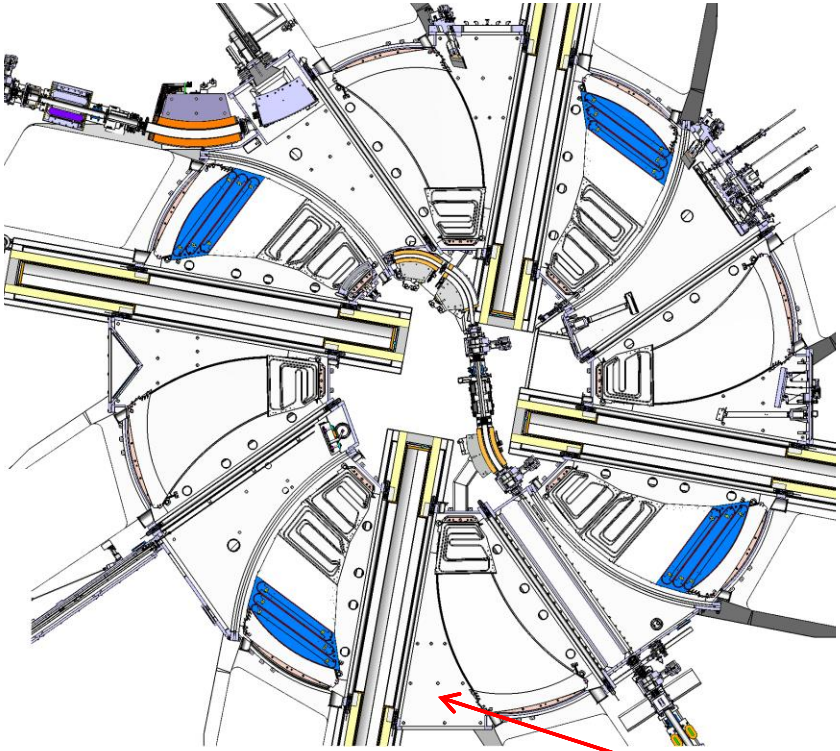
main activation at extraction

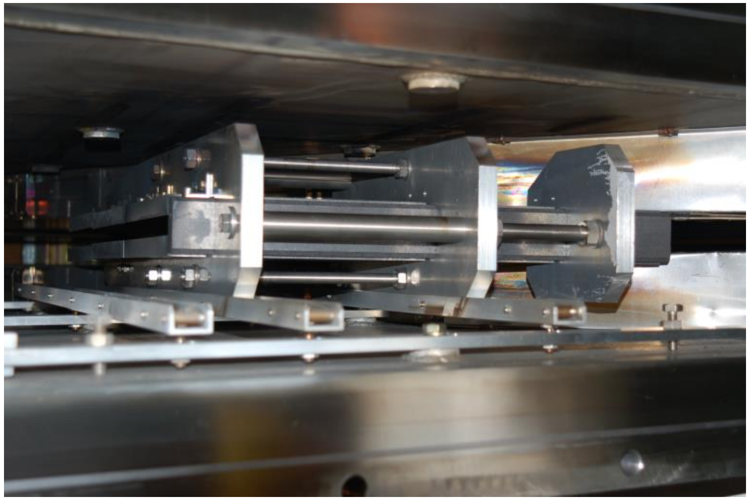


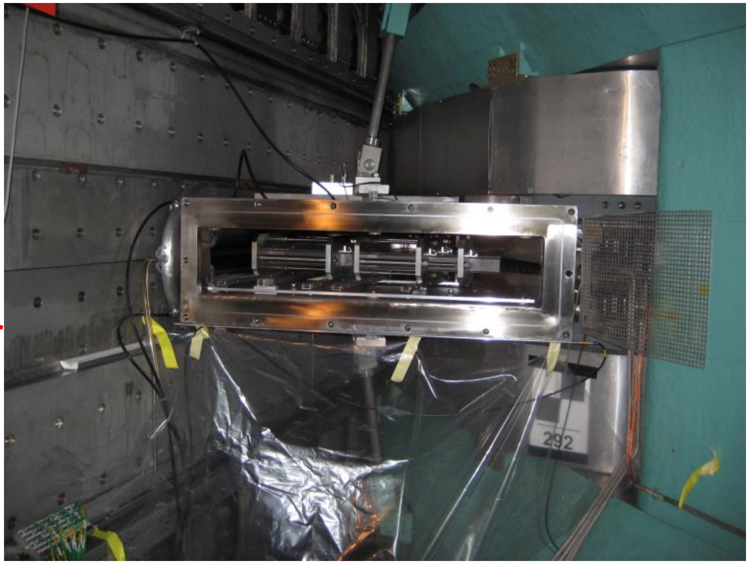


just 10kW @870keV

Removal of carbon collimator

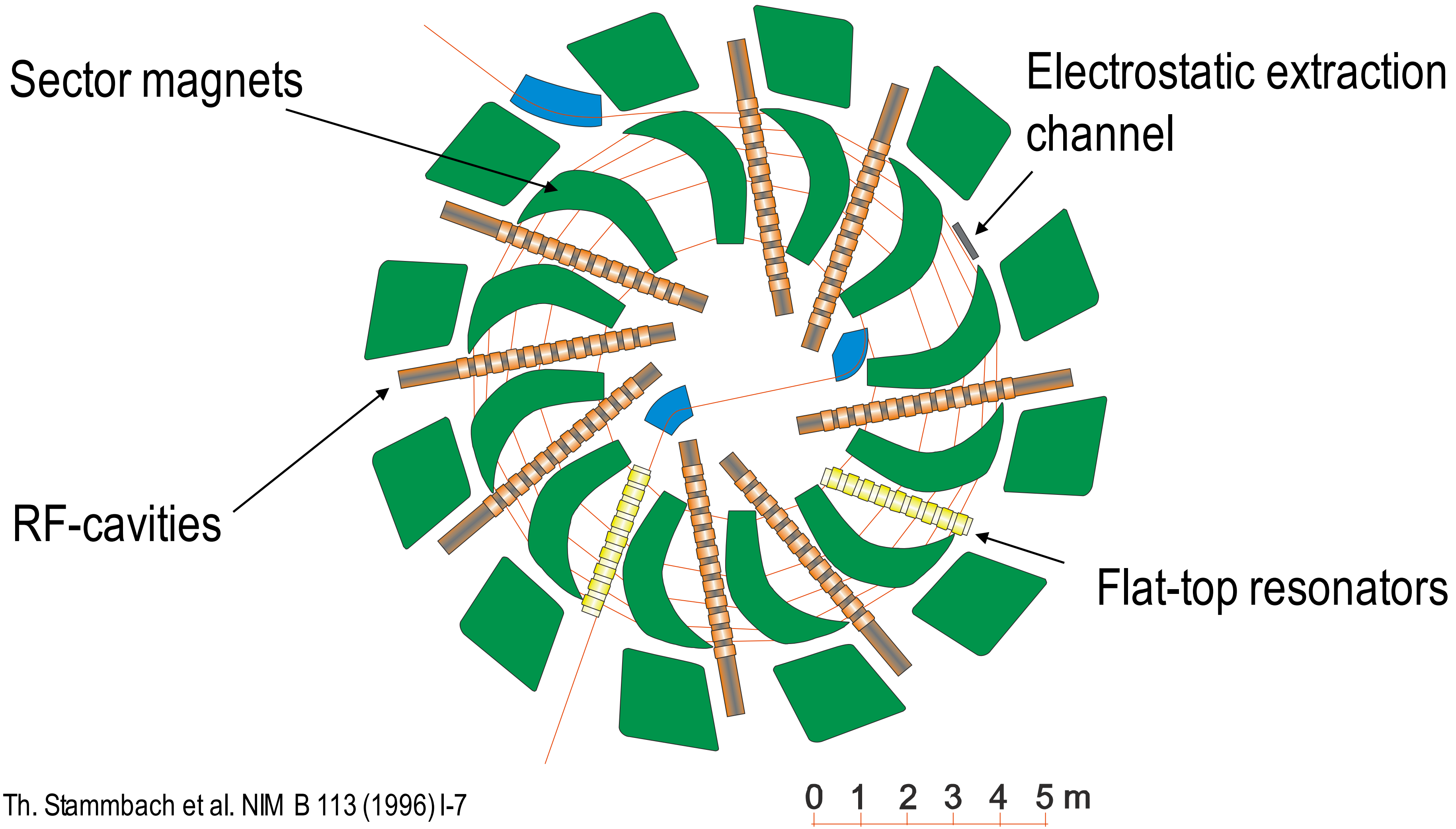






→up to a factor of 2 less losses in this region

Outlook: Proposal for a 10 MW driver



Th. Stammbach et al. NIM B 113 (1996) I-7

Conclusion

Cyclotron allows for

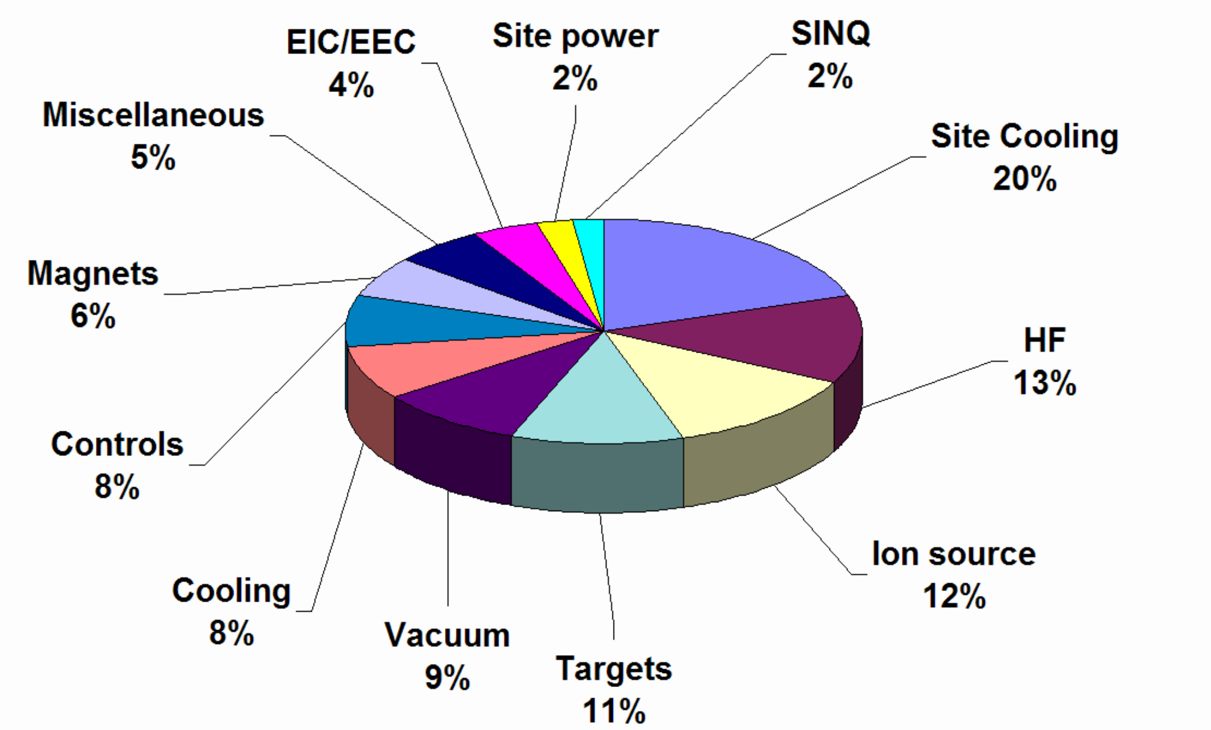
- sufficient beam-current and energy
- CW-operation
- low losses (sectors, cavities, bunchers)
- cost effective
- reasonable size
- modular design
- easy maintenance (individual dose)
- sound theoretical background

Important issues

- extraction losses
- decrease number of trips (el. stat. elements)
- intercept component failure (redundancy)
- RF-design with reserve
- reliable ion source (solved: ECR)
- machine protection (diagnostics, targets)
- space charge limits (flat-tops or bunchers?)

Statistics on technical failures

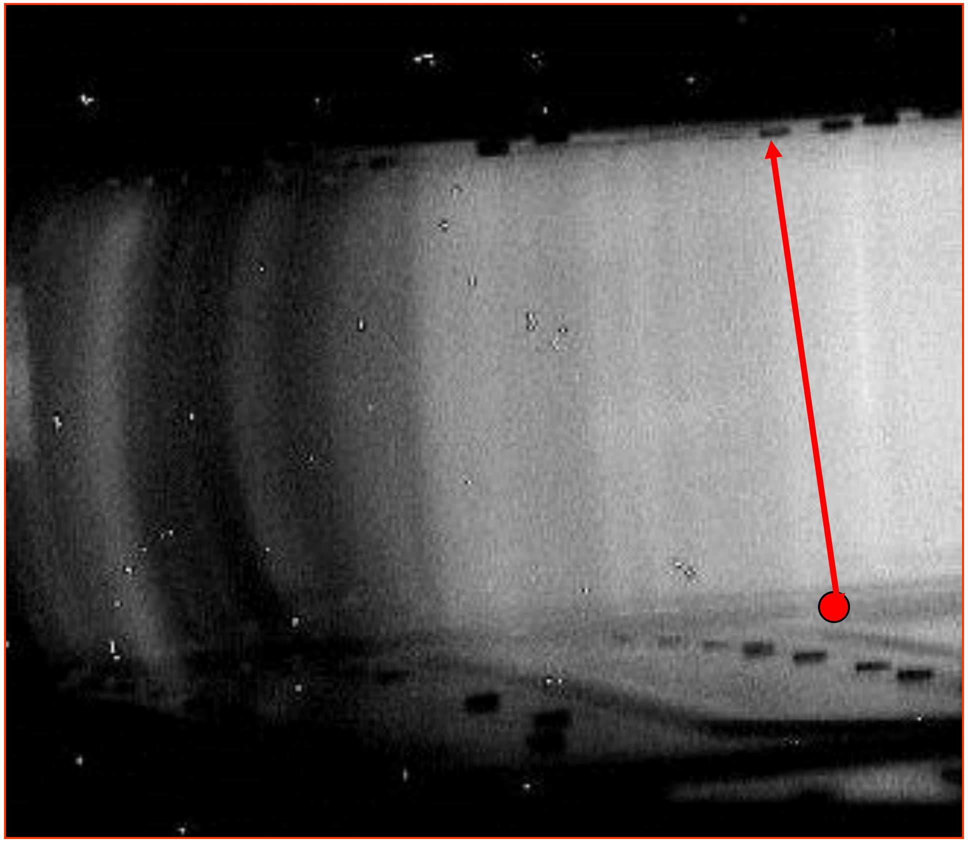
- **overall availability of the proton facility is now 95%**
- operation is typically distorted by short (30 s) interruptions
- significant improvement with reduced number of turns
- number of short interruptions reduced from **61/day** (2007) to **28/day** (2008)
- 0.5 failures per day that take longer than 10 min for recovery
- rate of longer interruptions (i.e. component failures) is not improved



Gas ionization by cyclotron resonnance

Assymetries in cavities lead to decoupled RF-power

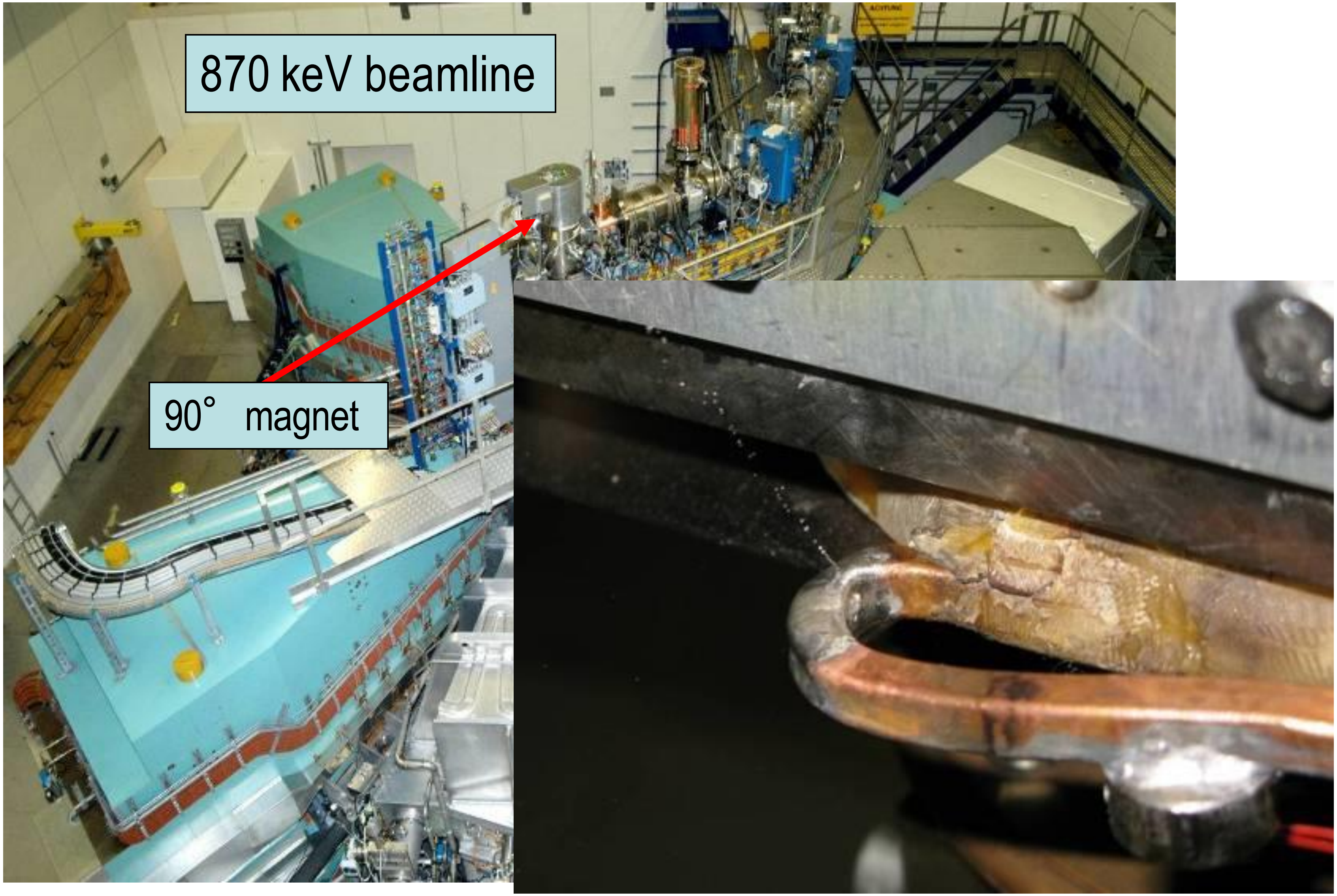
- multipactoring
- electrons are excited resonnantly
- rest gas is ionized
- ions sputter isolators with thin layers
- heat deposition on trim coils



$$f = \frac{q \cdot B}{2\pi \cdot m}$$

$$f = 150 MHz \Rightarrow B = 50 G$$

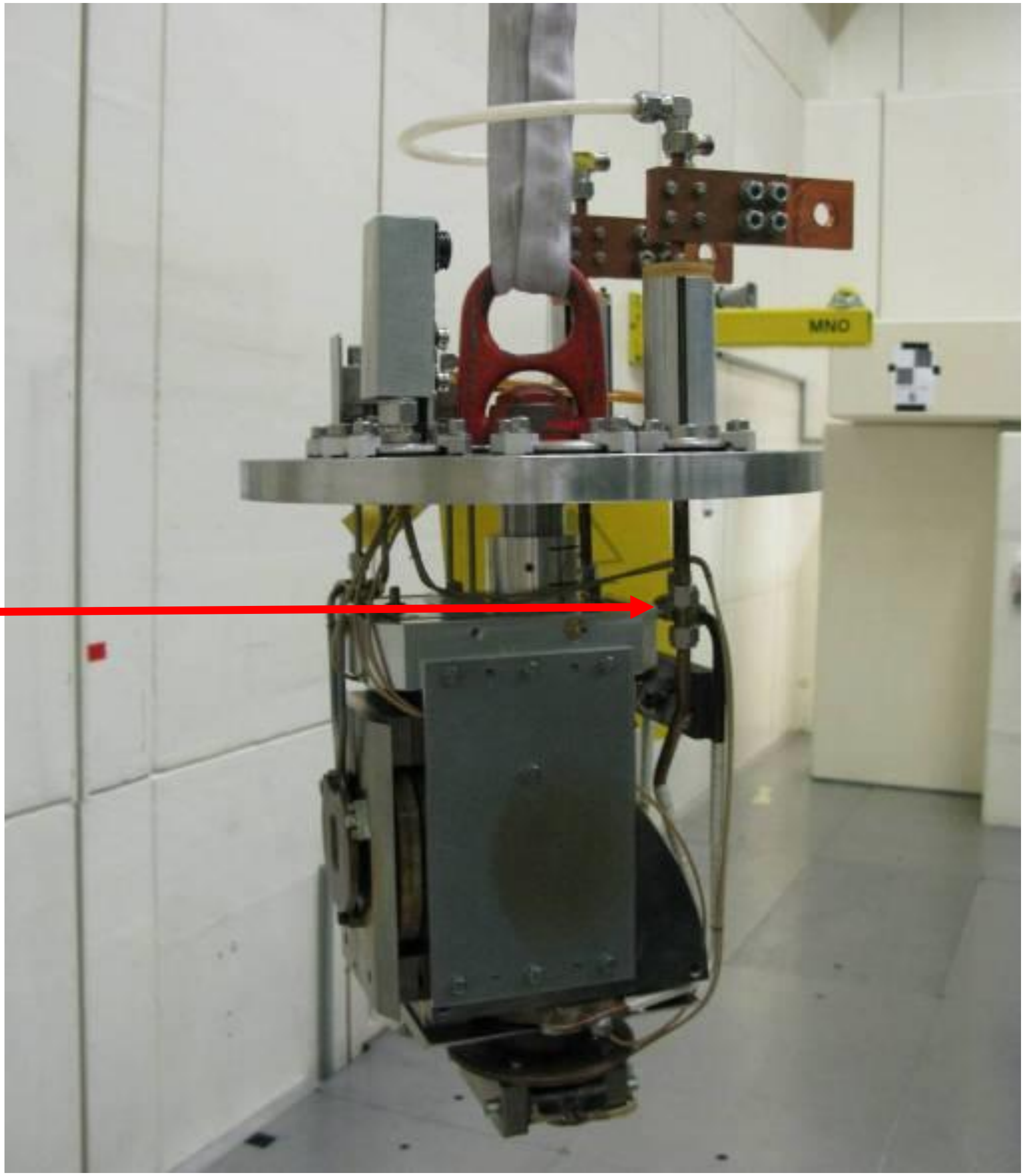
Waterleak in bending magnet (2013)

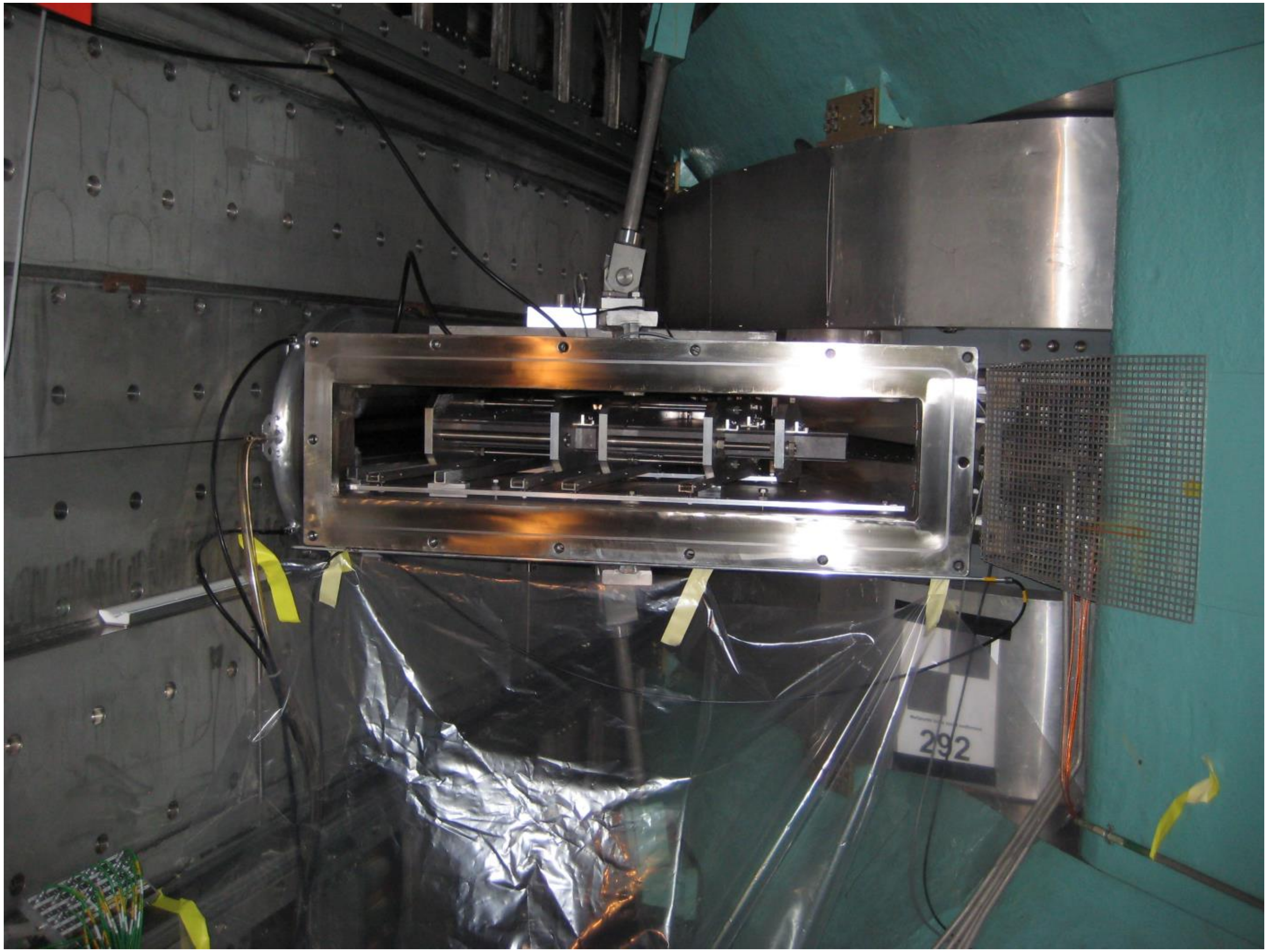


10 days of beam interruption (2010)

- repair impossible
- no spare magnet
- coils available
  need to be modified
- damaged Girolocks
- re-installation
- secondary damages

(motors, potentiometers)

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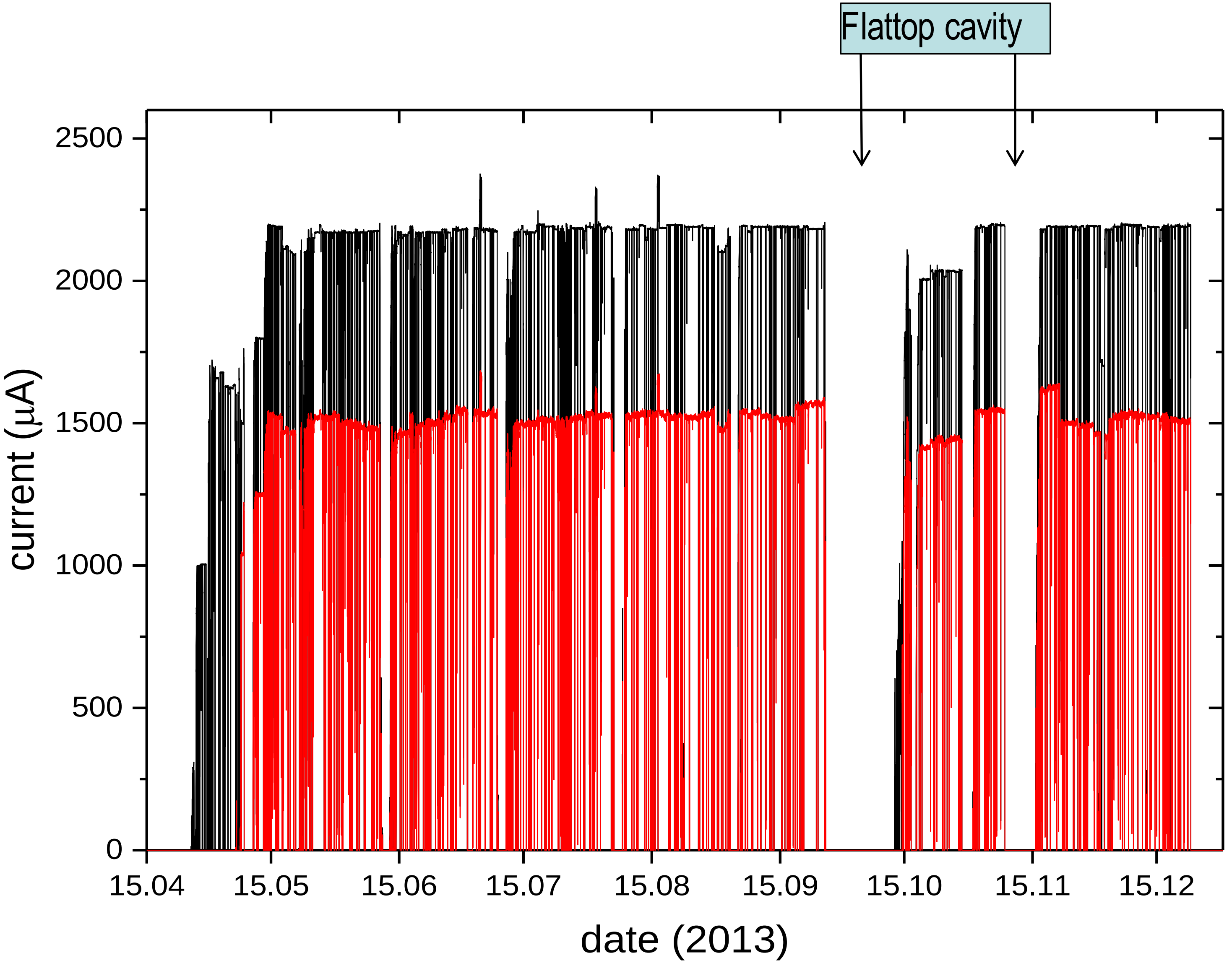
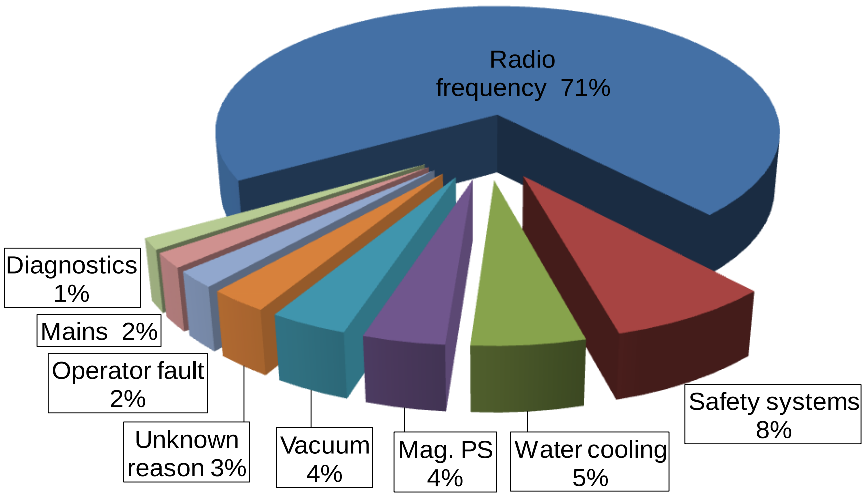
Beam availability 2013



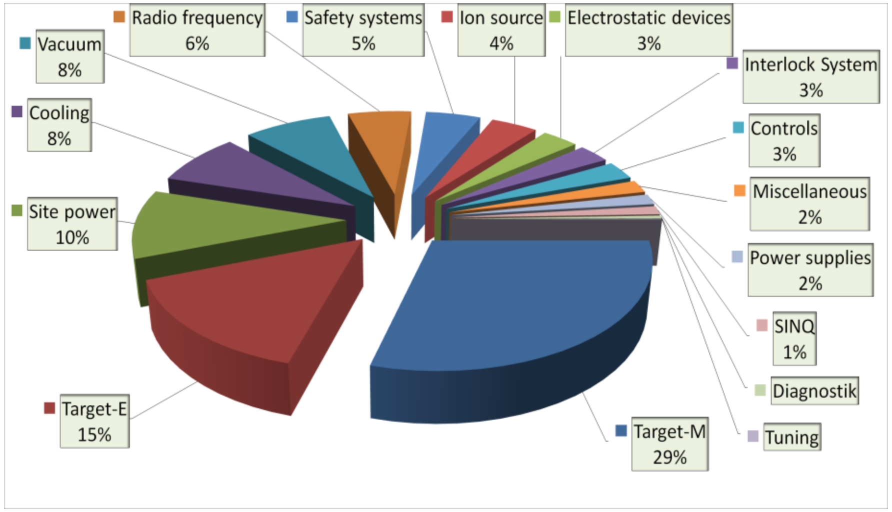
The schedule has strong impact on the overall availability

Outage distribution

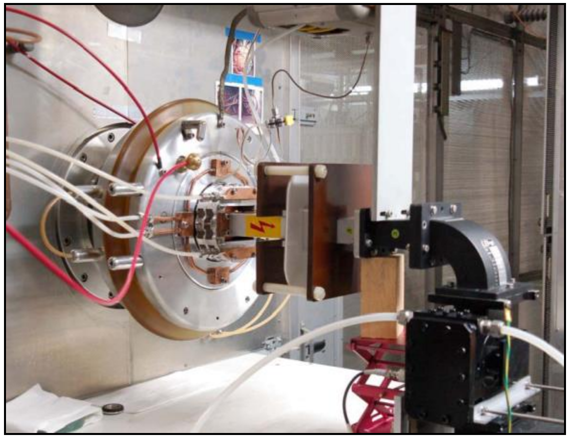
2013

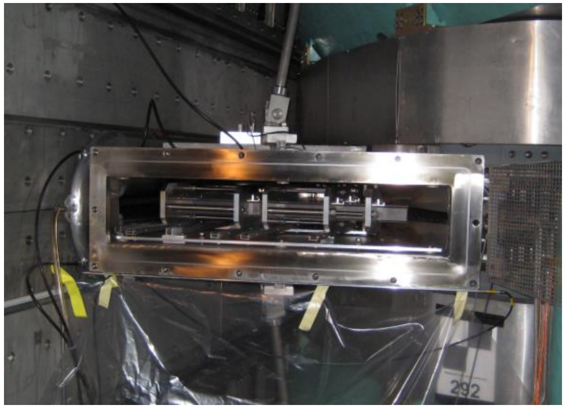


2012



Steps towards a higher Availability





New ECR ion source

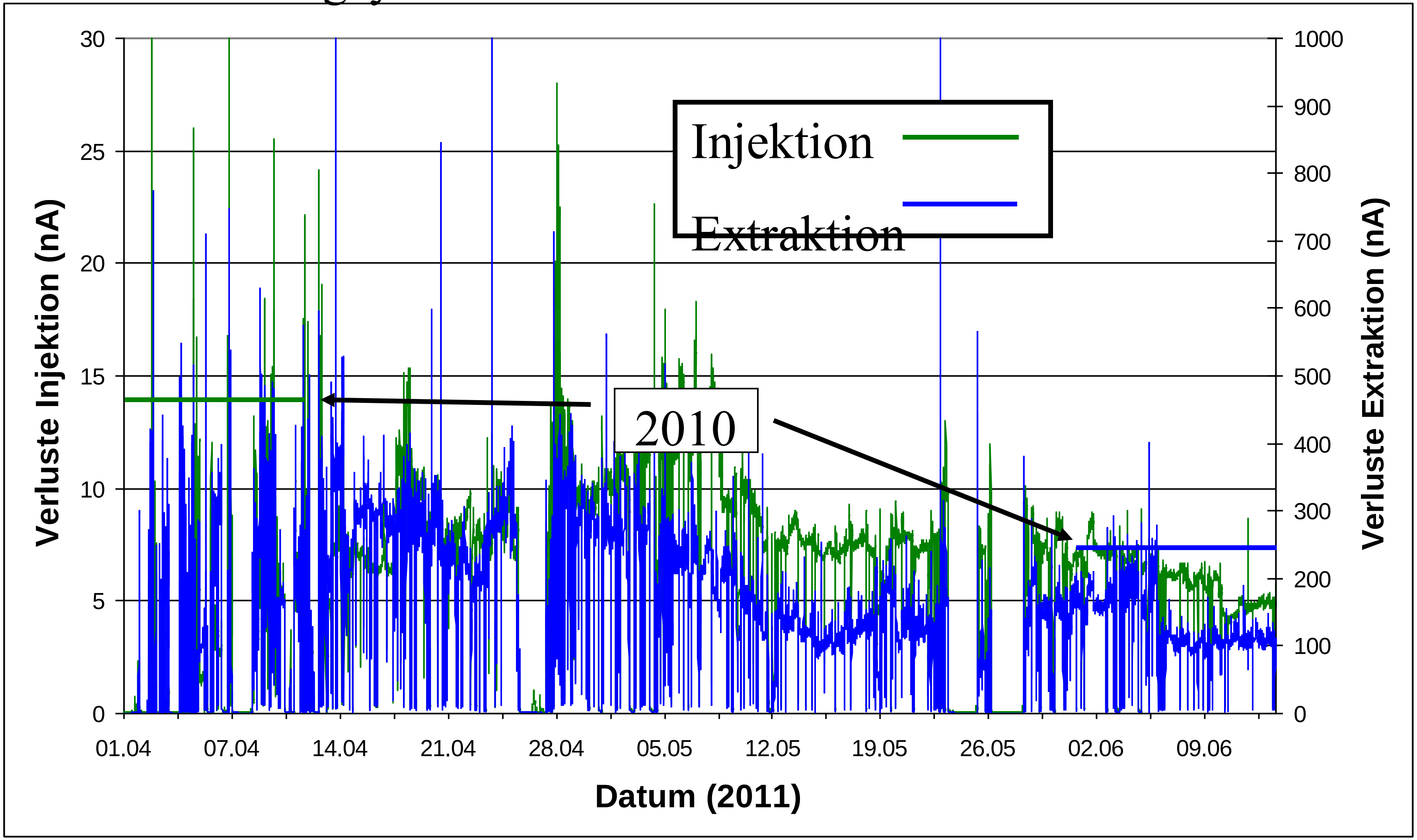
- Longer service intervals (> 8 weeks)
- Less unscheduled interruptions
- Higher proton fraction (80% instead of 33%)
- Smaller emittance
- Better beam stability
- 2.7 mA from Injector 2

Removal of aperture limitations

- Less interlocks caused by loss monitors

Betrieb 2011

Verluste Ringzyklotron



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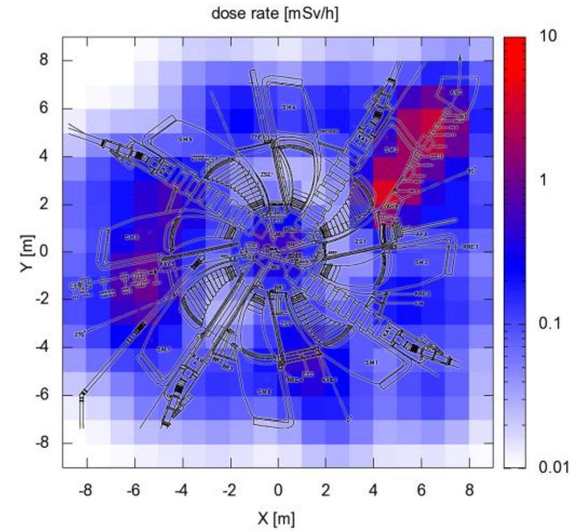
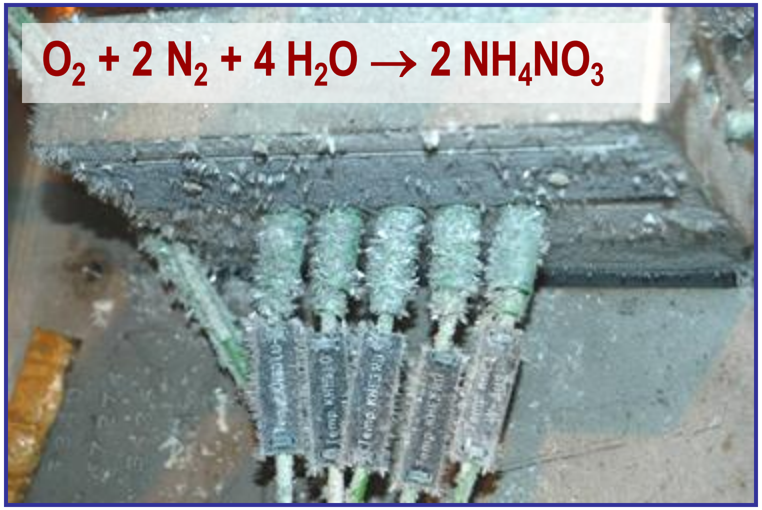
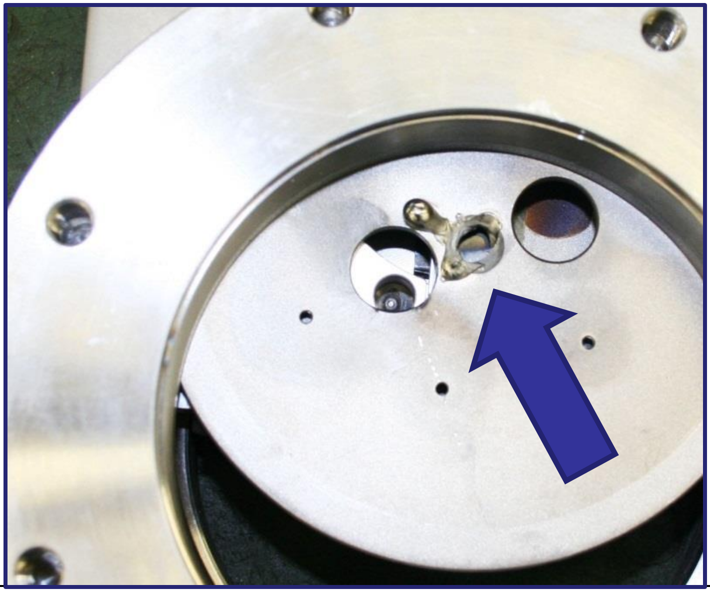


main activation at extraction





just 10kW @870keV

Documentation

3D of almost 70% of the facility (accelerator part)

Detailed dose rate mapping

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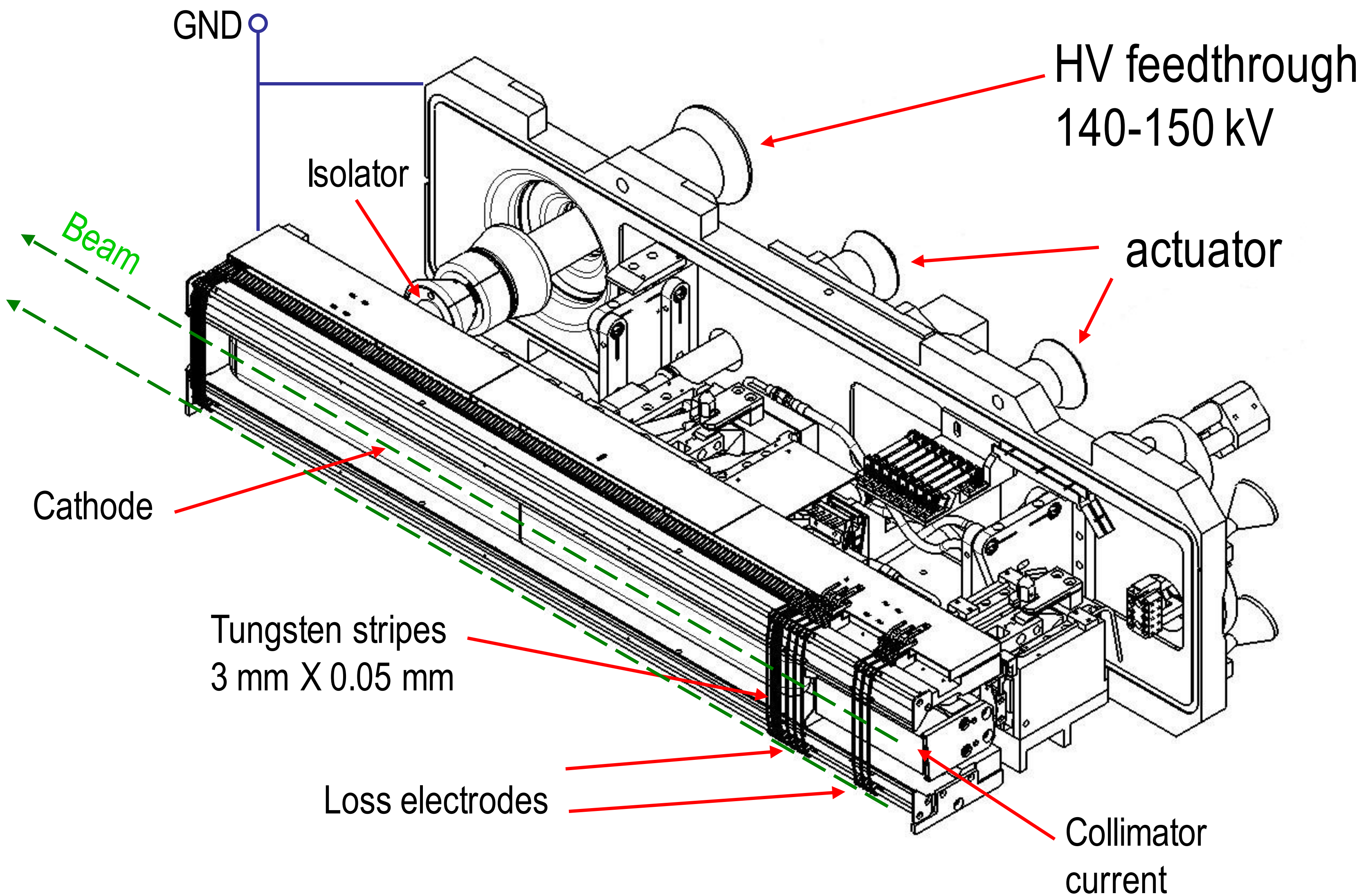
Technical Improvements

New ECR proton source

Shielding of the electrostatic elements

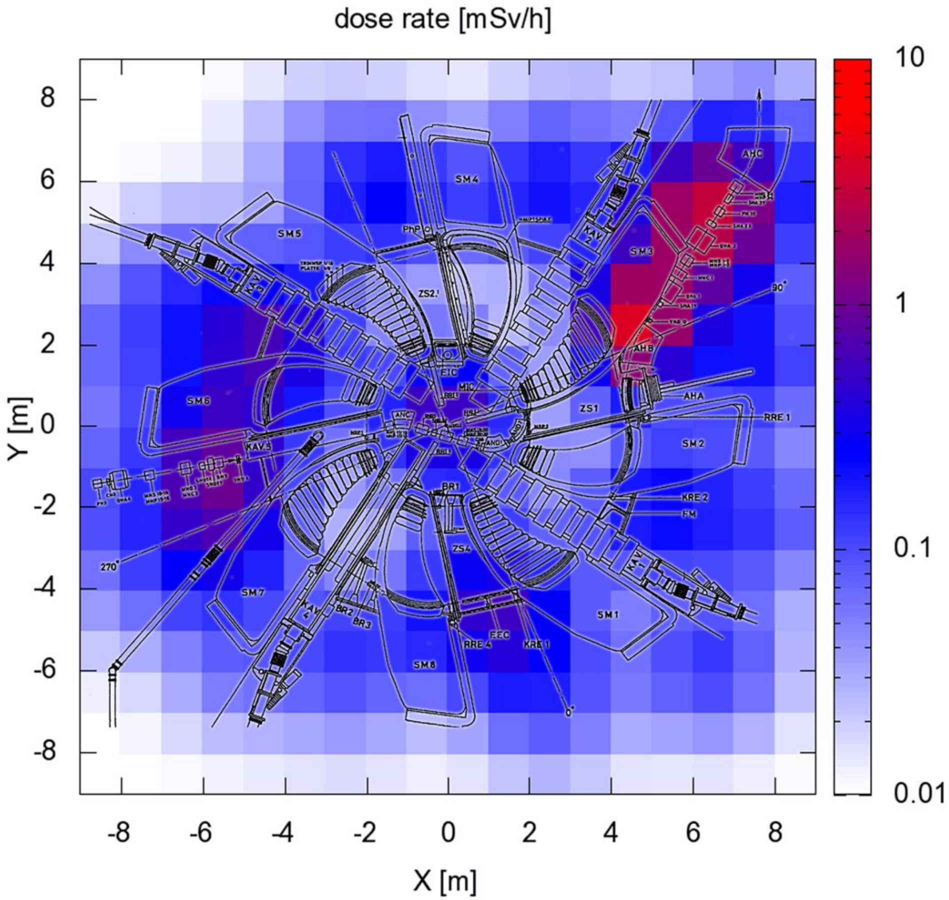
Injection / Extraction with electrostatic elements



Component Activation of Ring Cyclotron

Activation level allows for necessary service / repair work

- personnel dose for typical repair mission 50-300 μSv
- optimization by adapted local shielding measures
- shielded service boxes for exchange of activated components
- detailed planning of shutdown work



Activation map of Ring Cyclotron

(EEC = electrostatic ejection channel)

personal dose for 3 month shutdown (2008):

57 mSv / 188 persons
maximum dose: 2.6 mSv

cool down times for service:

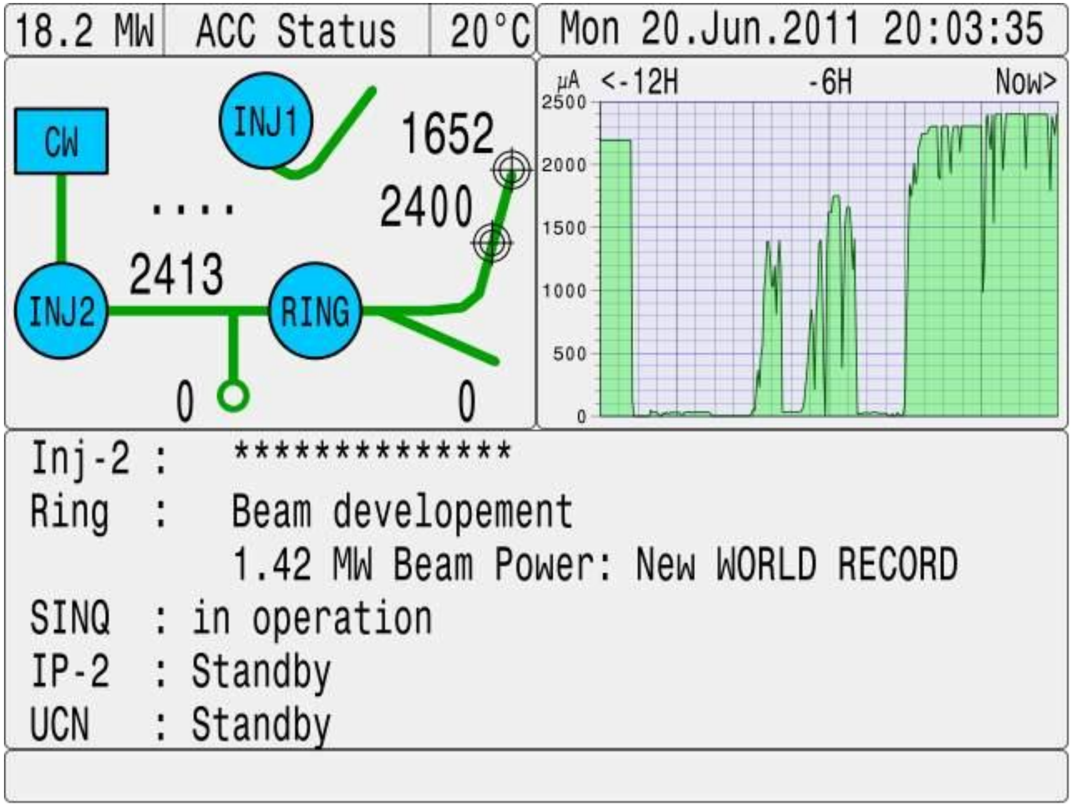
2000 → 1700 μA for 2h

0 μA for 2h

new beam intensity record at PSI-HIPA

- **low beam losses are key issue**
- **recent improvements**:
  - new ECR source (emittance)
  - reduced 50Hz residual beam jitter
  - aperture restrictions in Ring removed

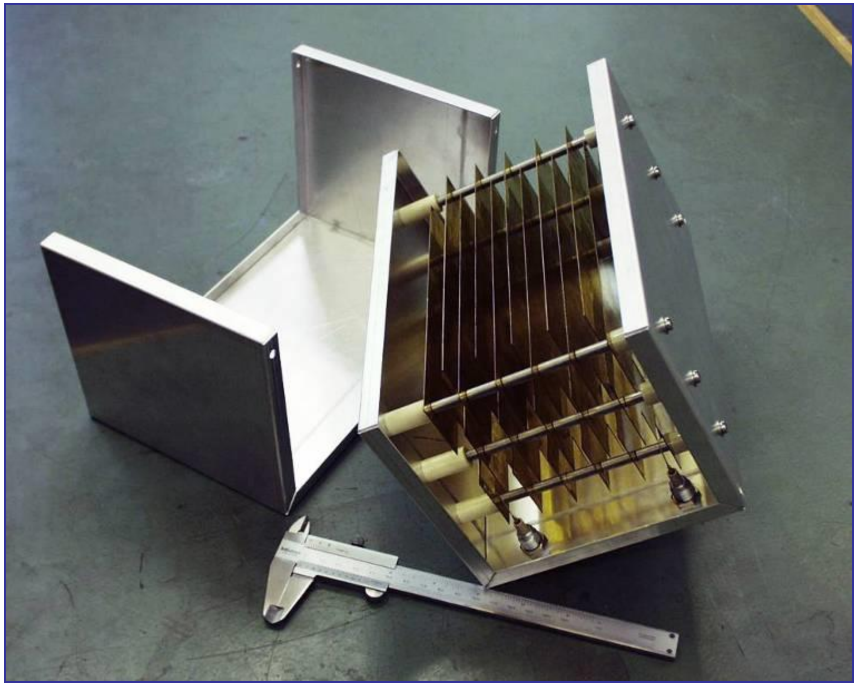
→ higher current at same loss rate possible

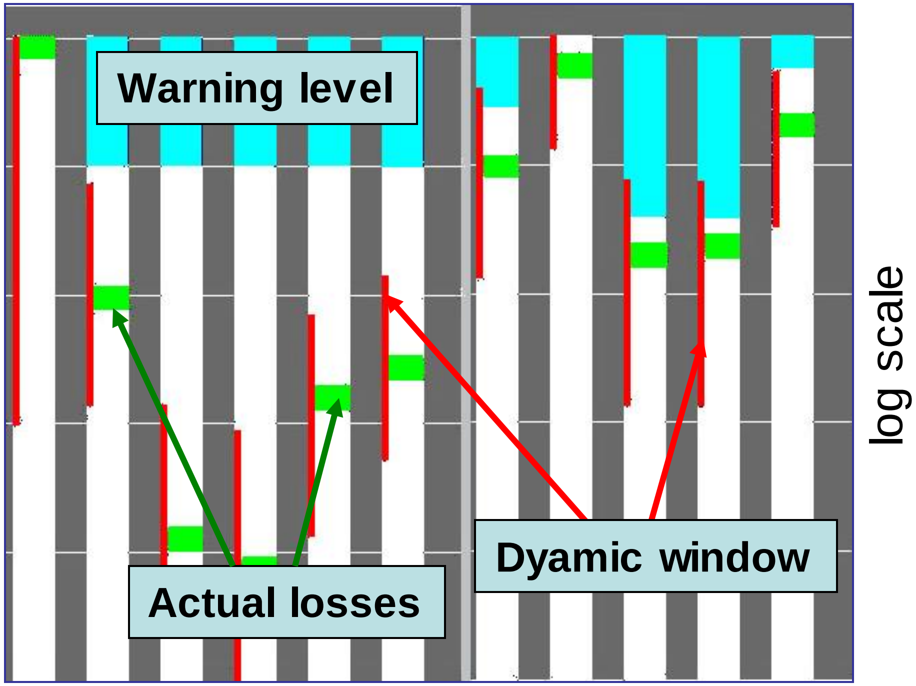


Diagnostics for Machine Protection

System based on ca. 150 interconnected very fast (**<100ms**) hardware **CAMAC** and **VME modules** treating about 1500 signals provided by the equipment:

1. **Ionisation chambers** as beam loss monitors





Simple and reliable device

Losses outside margins are interlocked (including low values)

- permanent display of losses
- fixed warning and interlock limits
- limits as a function of the beam current

High-Power Beams - Technical safety

beam hits material (e.g. steel vacuum chamber):

$$\frac{\Delta T}{\Delta t} \approx \frac{P_0}{2\pi \sigma_x \sigma_y \lambda_I [\mathrm{g/cm}^2]\, c_p} = 250.000\,\mathrm{K/sec}$$

beam power

beam size

material specific interaction length

heat capacity

melts after 8 ms !

→ fast and reliable interlock systems are necessary to avoid damage !

[even more so in pulsed machines with higher P_0]

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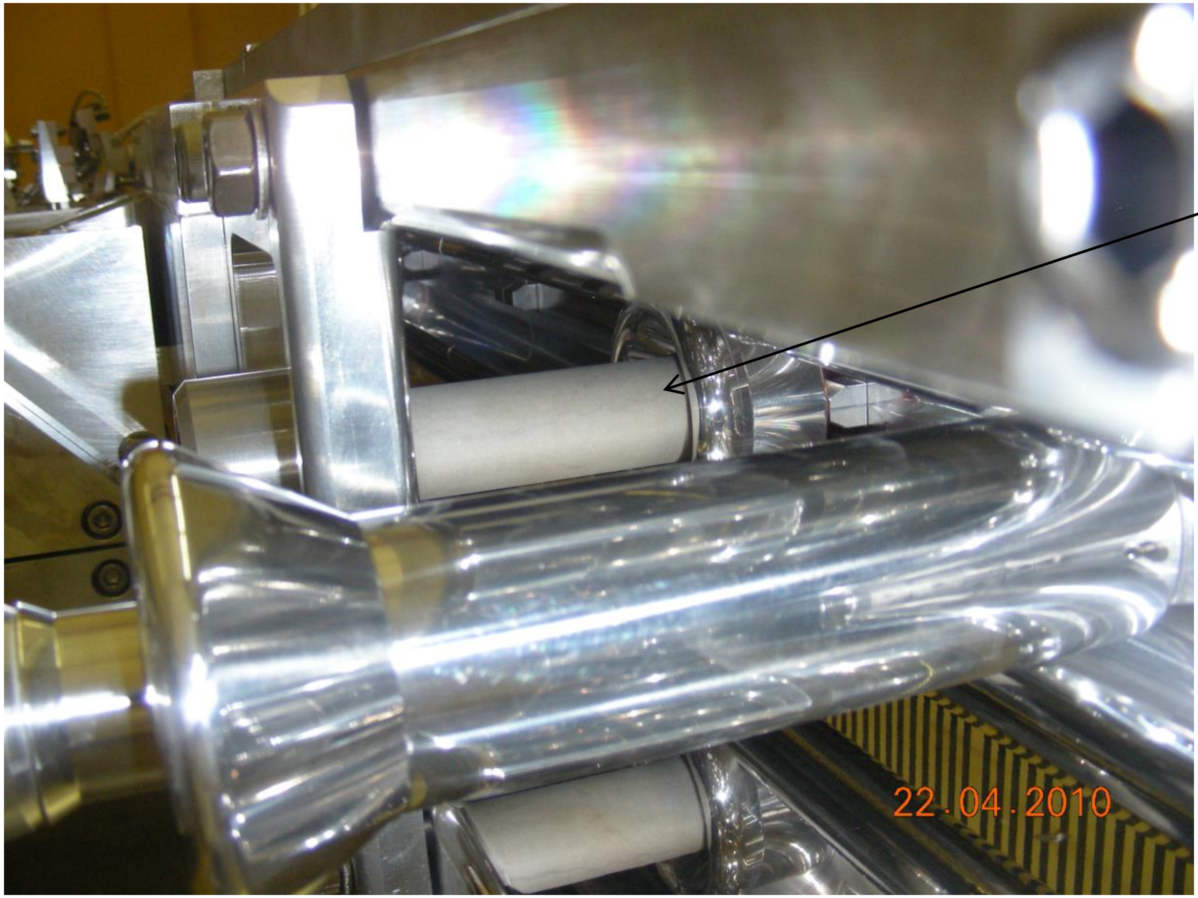
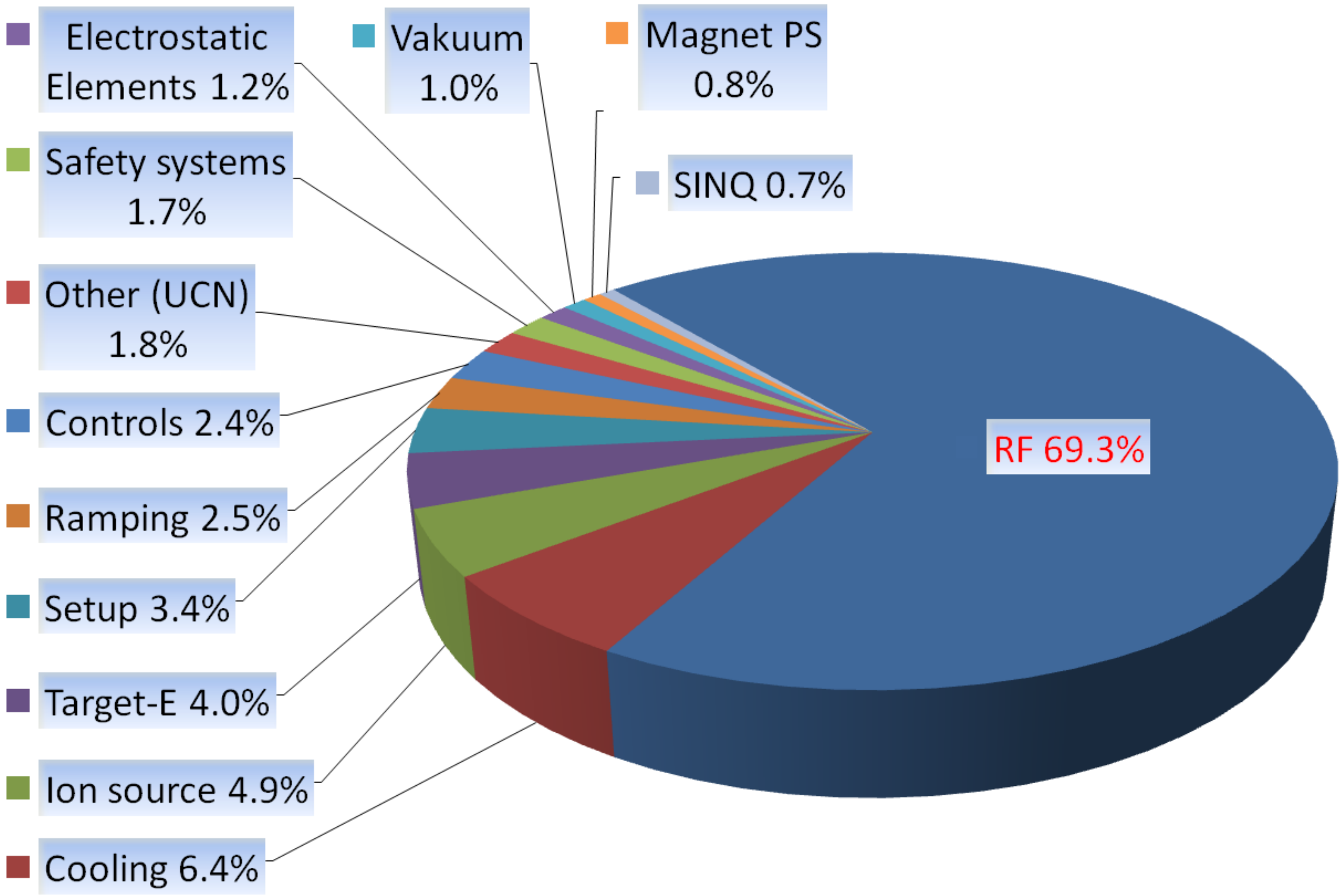
Discharges caused by Plasma

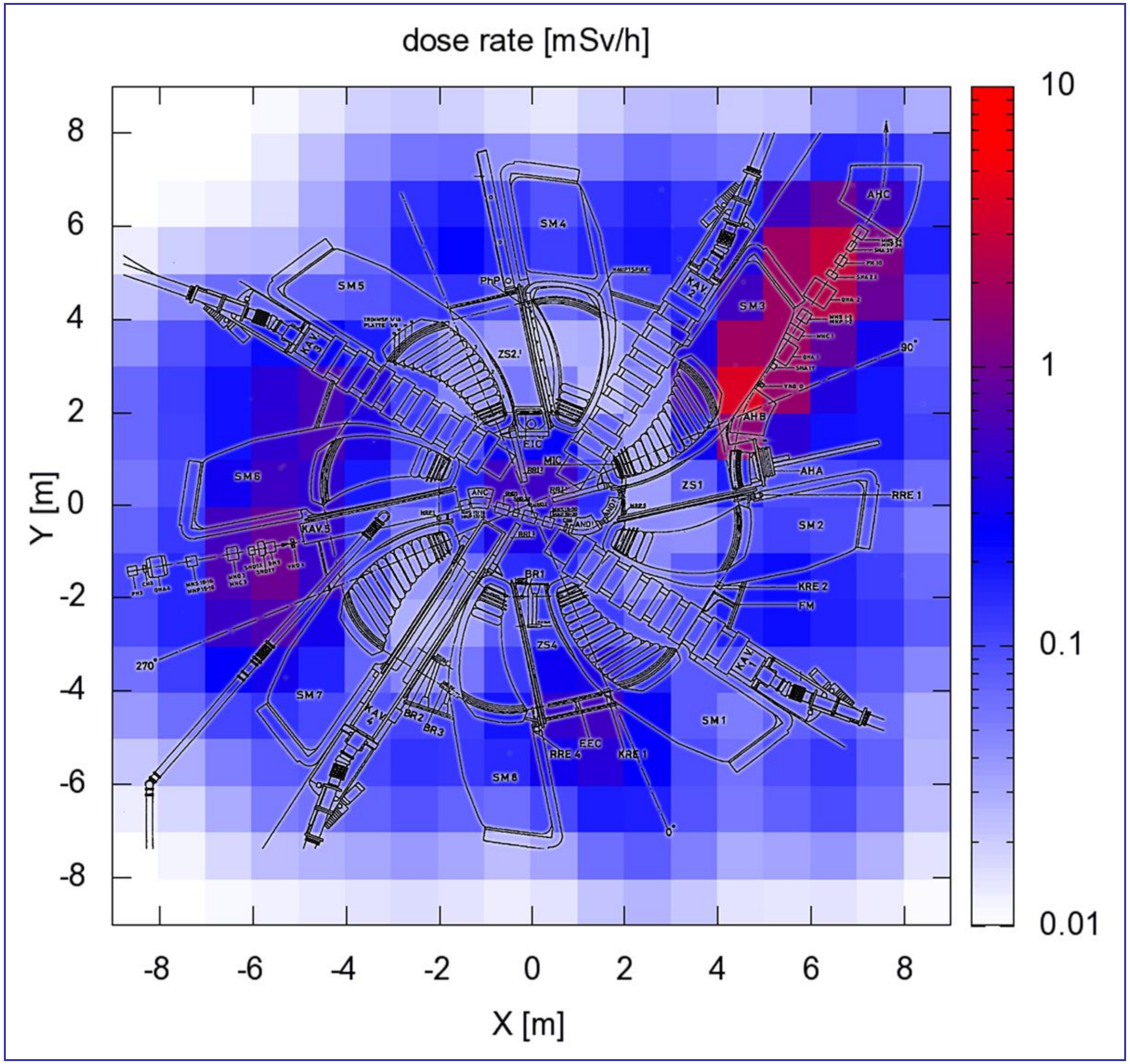


Deposition of material

Outages 2013



Ring activation



Operational data 2009

Performance 2009

Charge delivered: **9.7Ah**

Reliability: **89.5%**

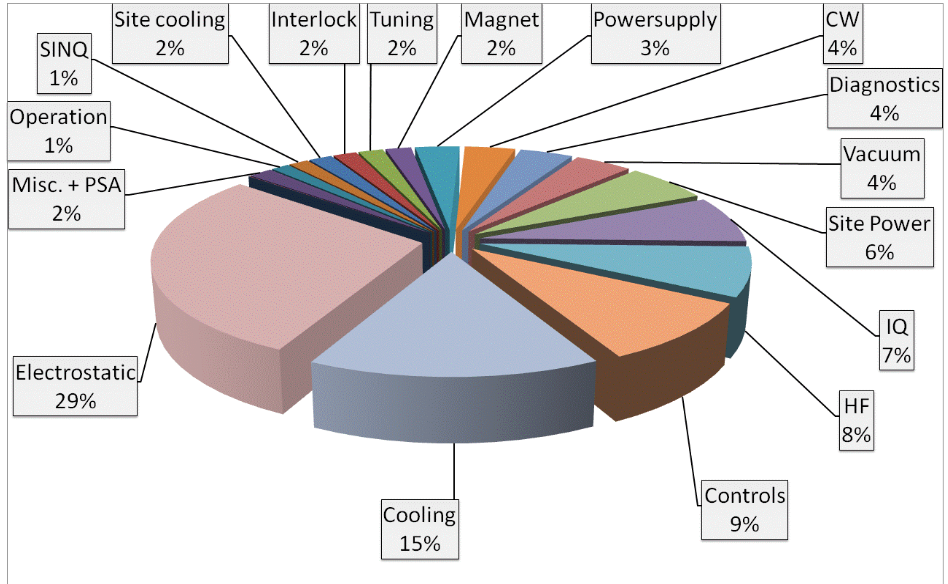
Beam trips: **25..50 d^{-1}**

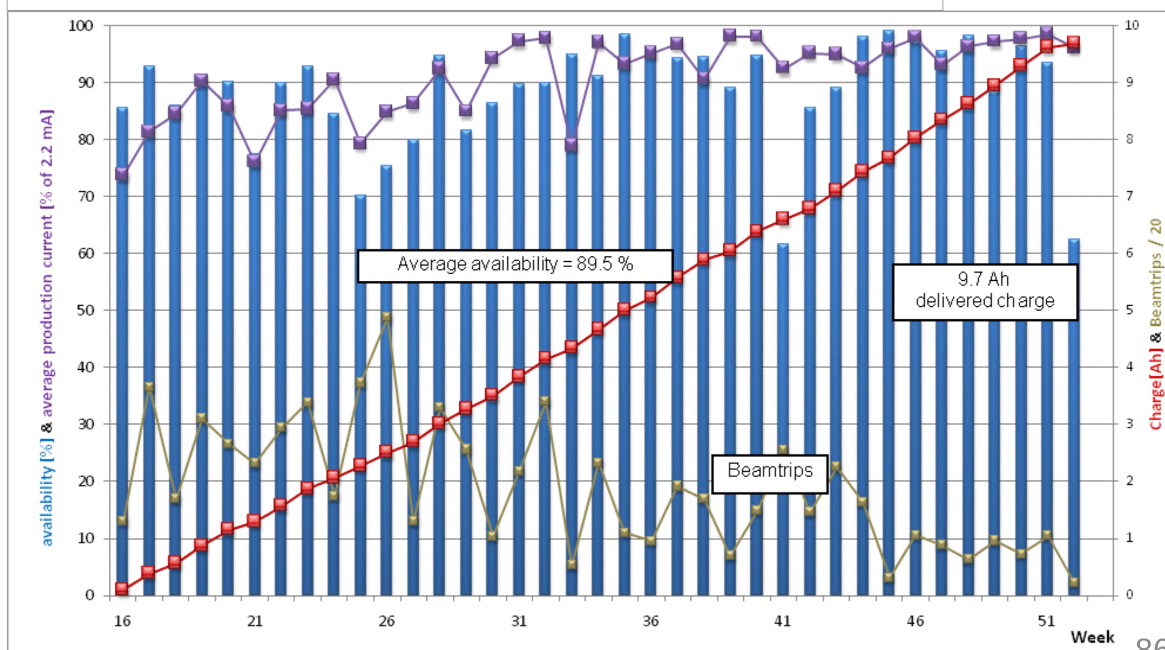
Downtime reasons

- electrostatic elements
- cooling/site power
- controls problems
- RF not prominent!

Reliability History:

2010:	**84%**
2009:	89%
2008:	90%
2007:	90%
2006:	86%
2005:	84%





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Mit Synchrotronlicht können wir am PSI in magnetische Materialien hineingucken und so …

…verstehen wir Details der Nanowelt, um Technologie zu optimieren.

…erforschen wir das Zusammenspiel von neuen Materialien.

…entdecken wir vielleicht neue Nanomagnete.

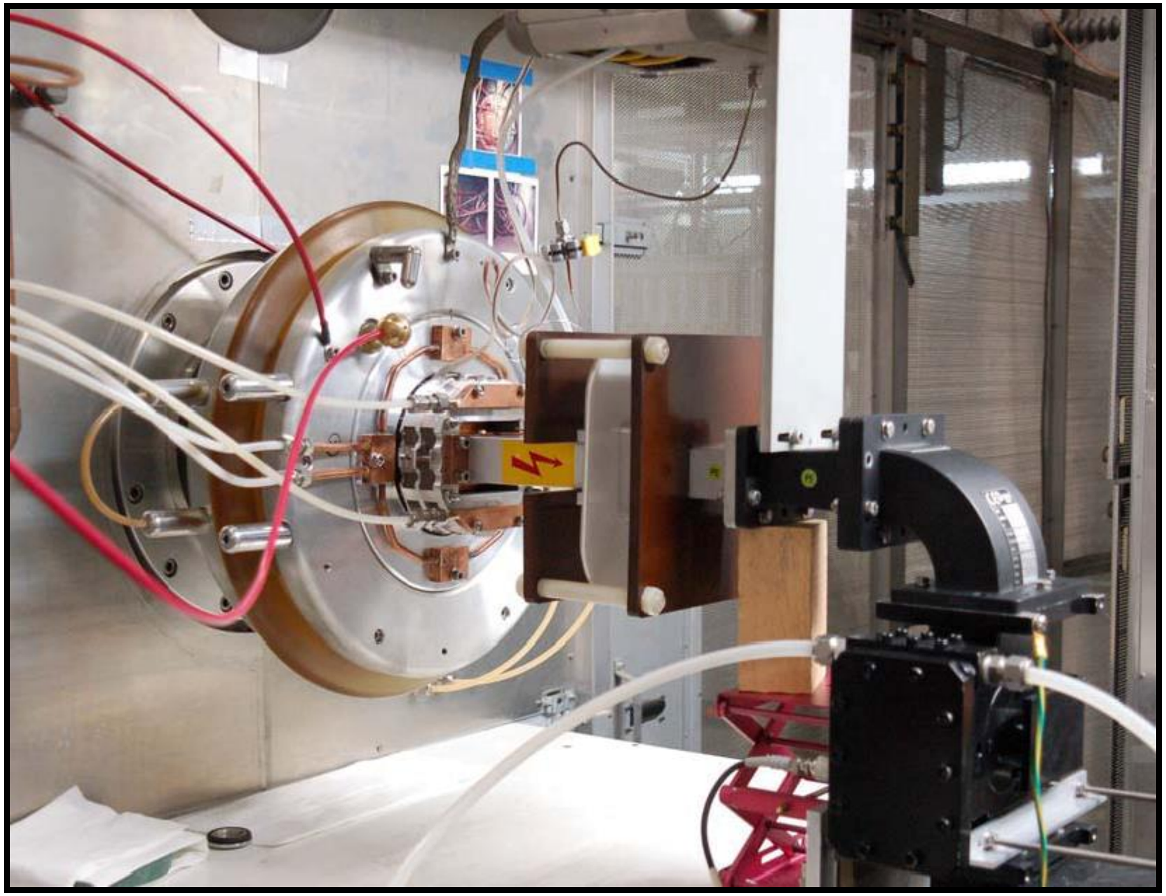
…schaffen wir Wissen für Morgen.

Mein Dank geht an

Hfkashfjkdashm, lksadjflkadsjf, fklasdjflasdjfkl, flakdjflkadsjf, kjdsfljsakdfjads, dfkjasdlfjaölsd, fasdfjlaksdjfklas, alsdfjladsjflökasd, lasdjflöasdjflkadsj, fklasdjfladsjf

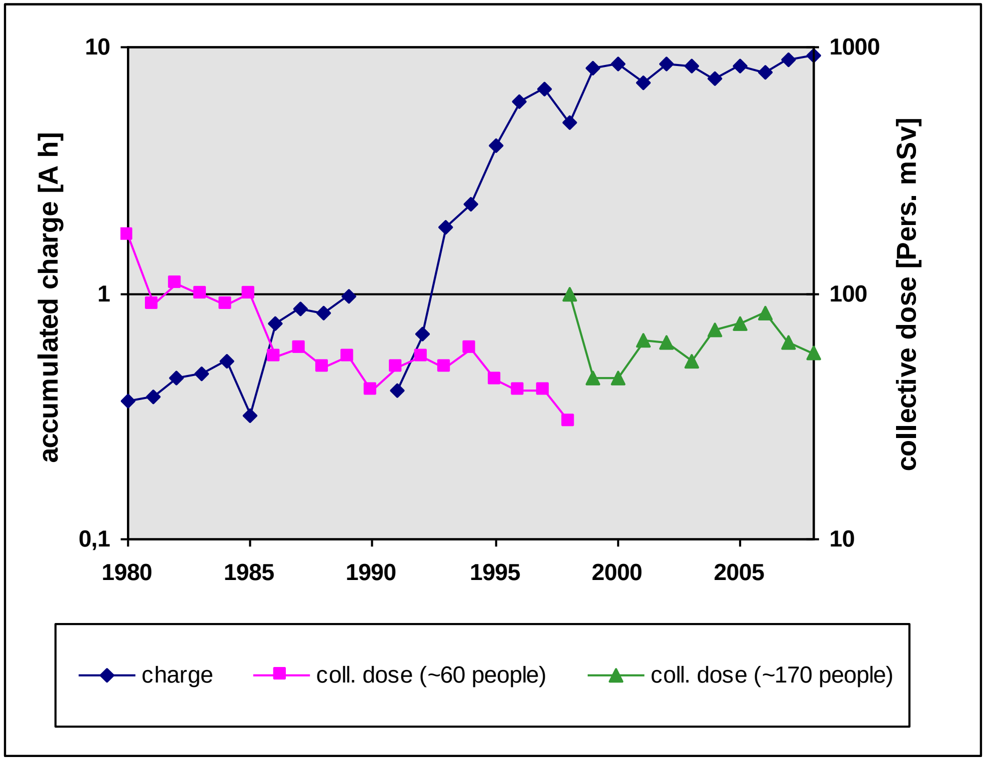
New ECR-Ion-Source

- Longer service intervals (> 8 weeks)
- Less unsceduled interruptions (2 instead of 5)
- Higher proton fraction (80% instead of 33%)
- Smaller exittance
- Better beam stability
- 2.5 mA from Injector 2



Radiation Safety

- considerable effort to monitor ~1300 employees
- ~170-190 employees really involved with accelerator critical maintenance or work on active components
- group of 10 colleagues responsible for radiation safety of the accelerator facility
- monitoring of radiation in accelerator facilities by TLD/CR39 dosimeters (~100) + grid of remotely readable dosimeters (12+4); some (~5) dosimeters outside PSI area
- 10 hand and foot monitors at exits of experimental hall
- access to hot-cell and specific radioanalytics



history of accumulated charge and collective dose

[note: step in number of considered persons]

Diagnostics for Machine Protection

3. Beam current transmission monitors compare the beam current at different spots for detecting loss of beam

normally 100% of transmission except at the targets and when beams are splitted.

100 % transmission in main cyclotron

100 % transmission in beam lines, (except for split beams)

97 % transmission of thin target M

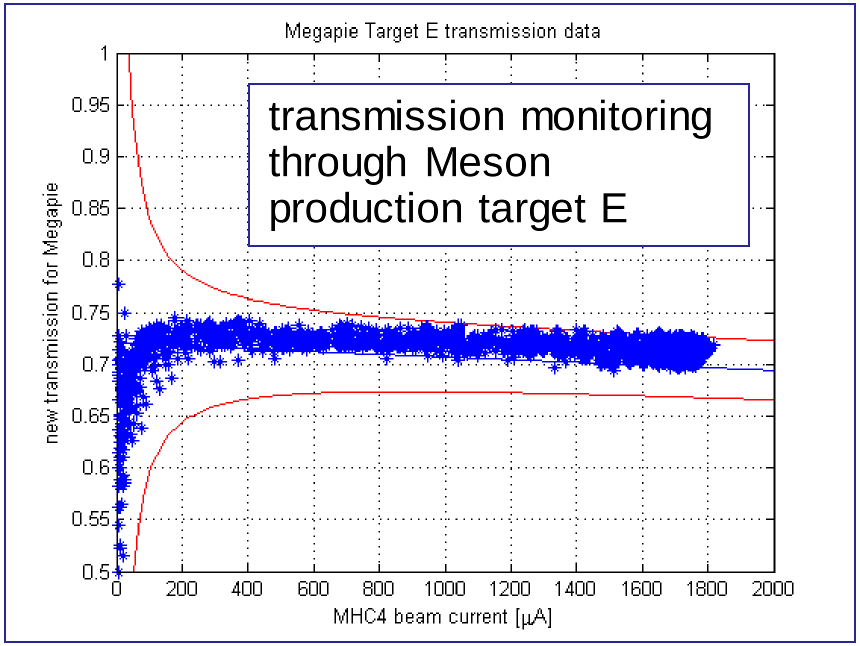
70 % transmission of thick target E

Integration time:

110 ms at 0 μA down to 10 ms above 1.5 mA

Window:

± 5 μA at 0 μA and ± 90 μA at 2 mA



4. Many other signals: validity window on magnet settings, cavity voltages, …

High Power Resonators

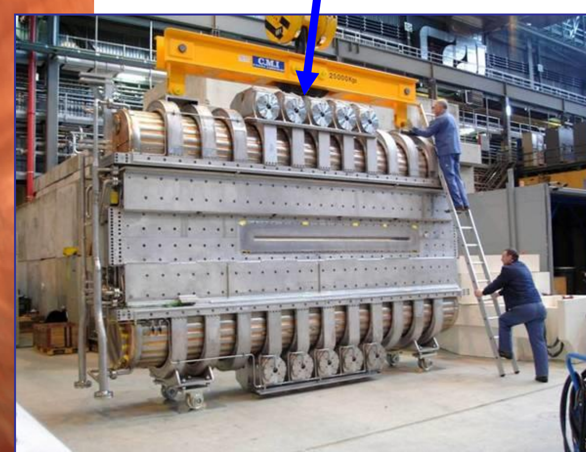
f = 50.63 MHz
U_{max} = 1.2 MV (presently 0.85 MV→186 turns in cyclotron, goal for 3 mA: 165 turns)
400 kW power transfer to the beam per cavity

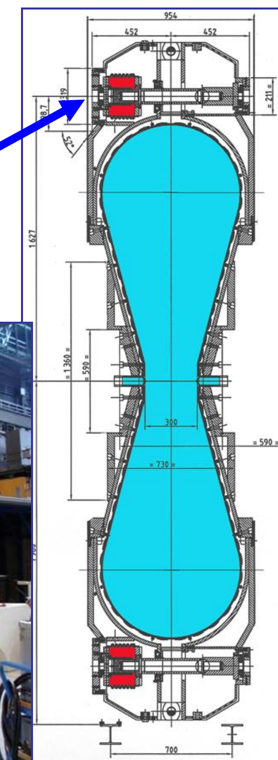
- less wall losses
- higher gap voltage
- better cooling distribution

deformation from air pressure ~20 mm
hydraulic tuning devices in feedback loop → regulation precision ~10 µm

resonator inside

hydraulic tuning devices (5x)

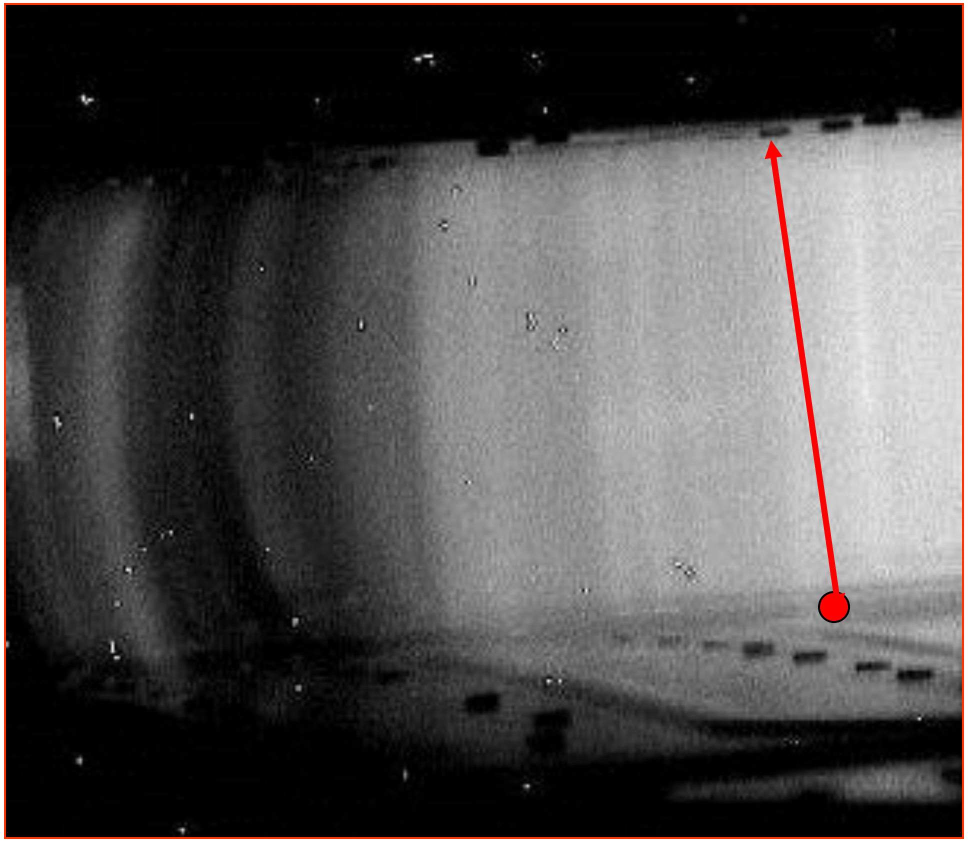




Gas ionization by cyclotron resonnance

Assymetries in cavities lead to decoupled RF-power

- multipacting
- electrons are excited resonnantly
- rest gas is ionized
- ions sputter isolators with thin layers
- heat deposition on trim coils

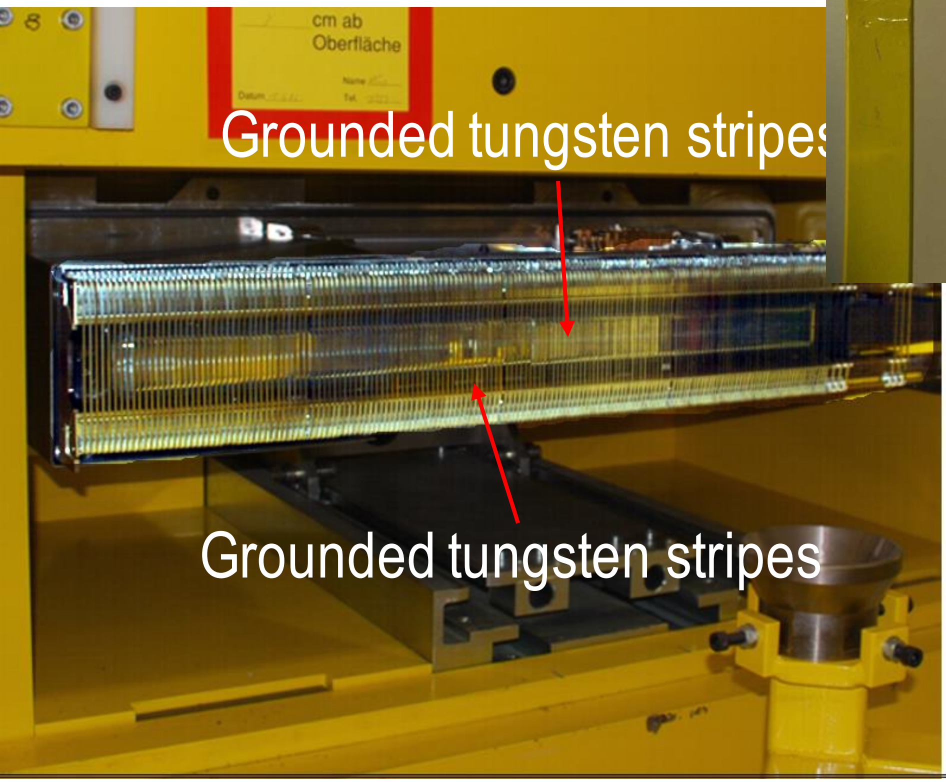


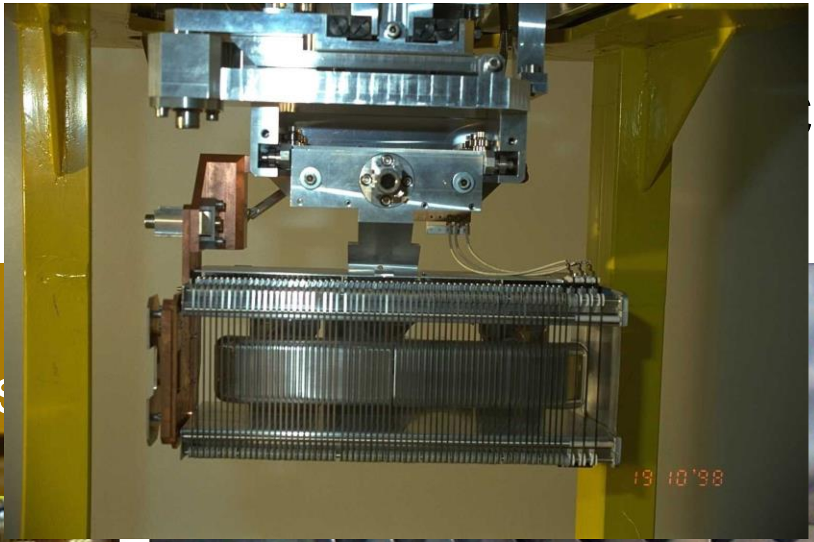
$$f = \frac{q \cdot B}{2\pi \cdot m}$$

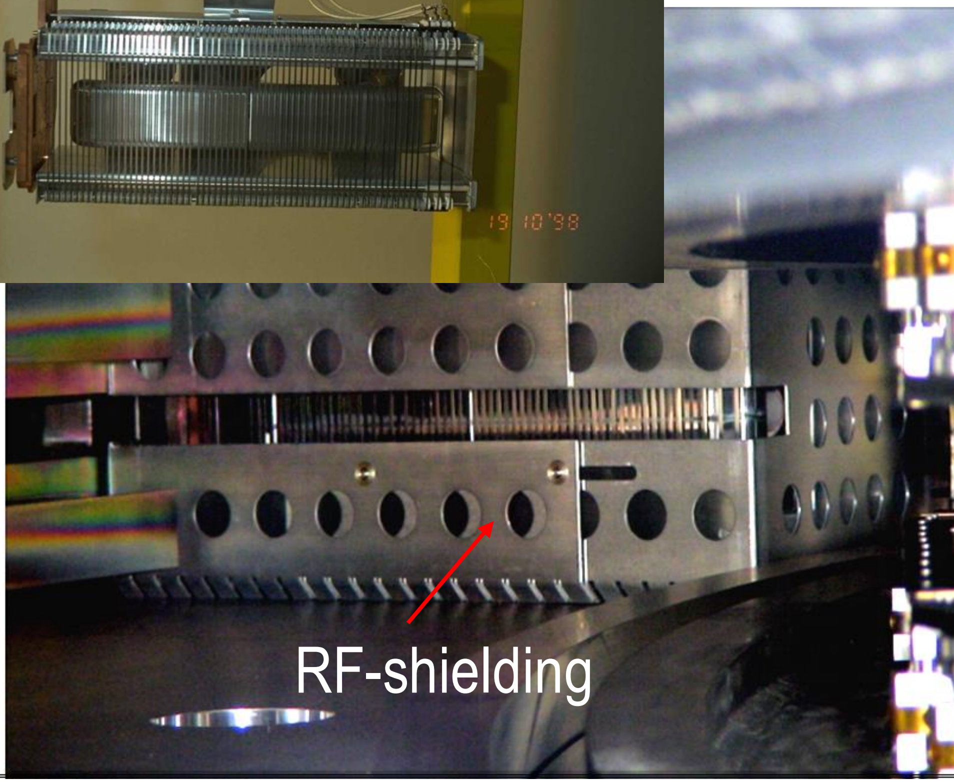
$$f = 150MHz \Rightarrow B = 50G$$

Electrostatic Elements

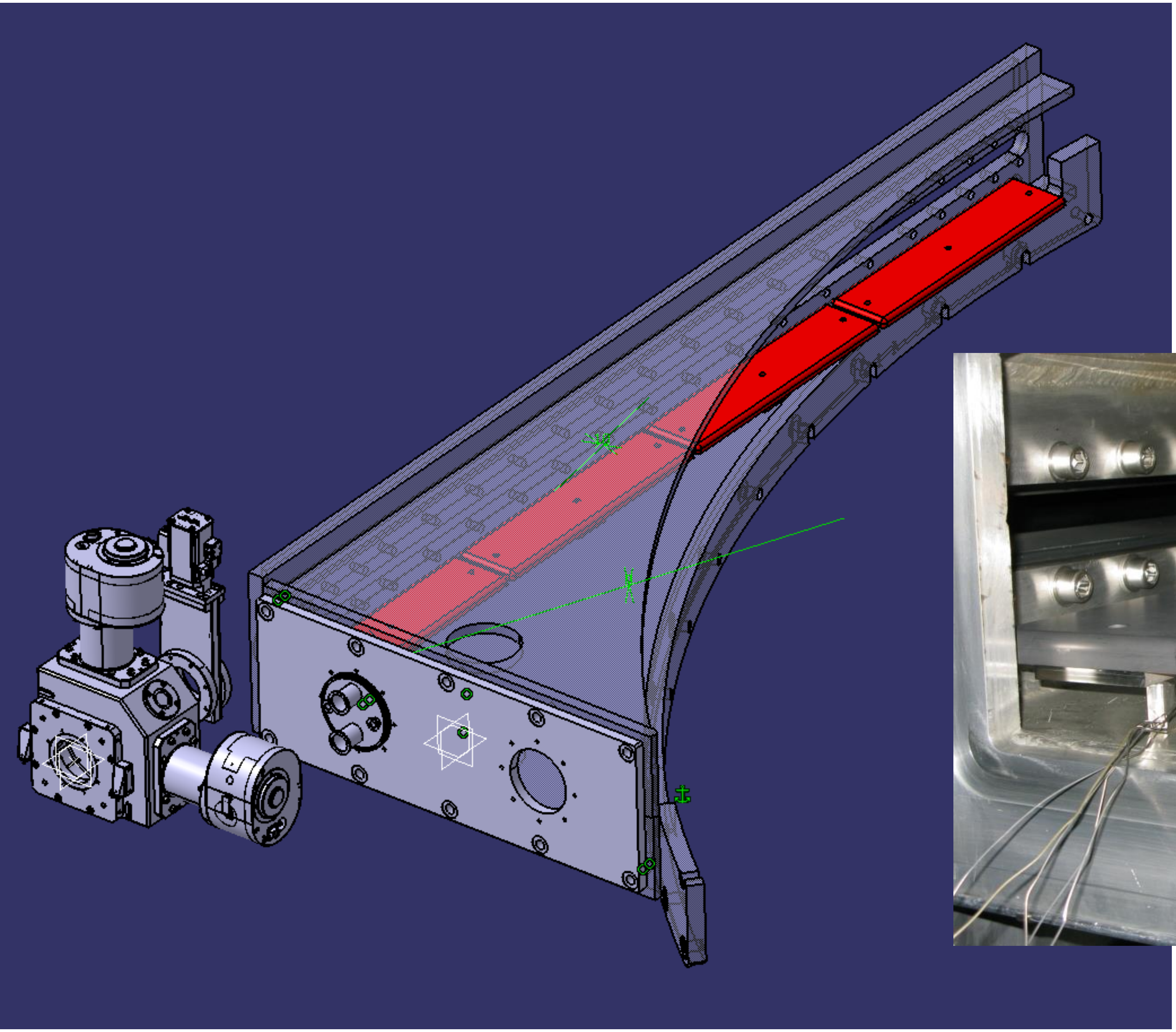
Extraction Channel EEC
145 kV

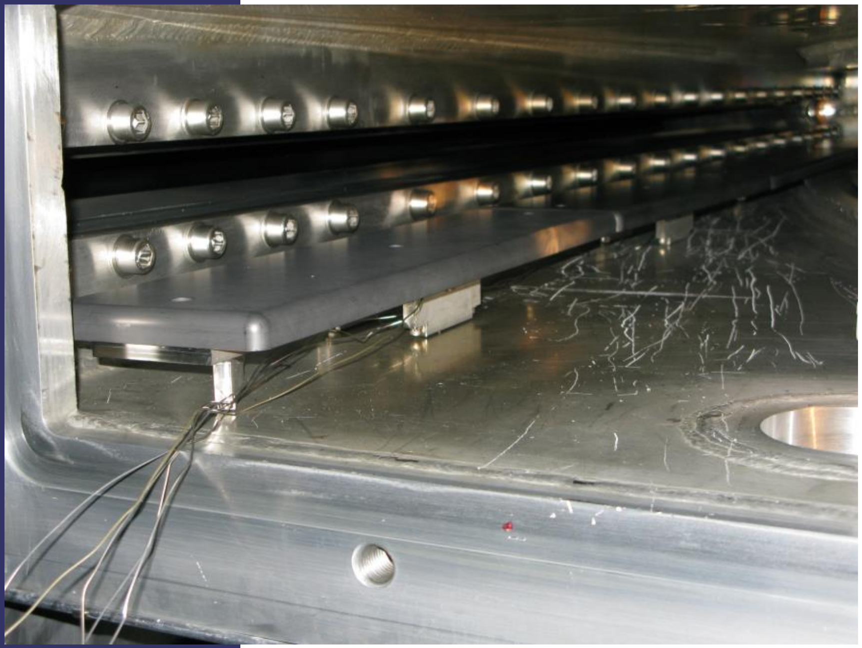






Graphit RF-Absorber (maybe show or not?)





PAUL SCHERRER INSTITUT

User threshold = 1 mA = available

Beam trips cause 5%