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Angelina Parfenova :: Large Research Facilities :: Paul Scherrer Institut

Analysis of High-Intensity Proton Accelerator Availability over the Last 15 Years of Operation @ PSI

ARW 2017 Versailles 20.10.2017

ARW 2017 Accelerator Reliability Workshop

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Paul Scherrer Institute - PSI

Layout of the high intensity proton facility at PSI

PSI Control room

How do we produce a 590 MeV CW beam of more than 1 Megawatt

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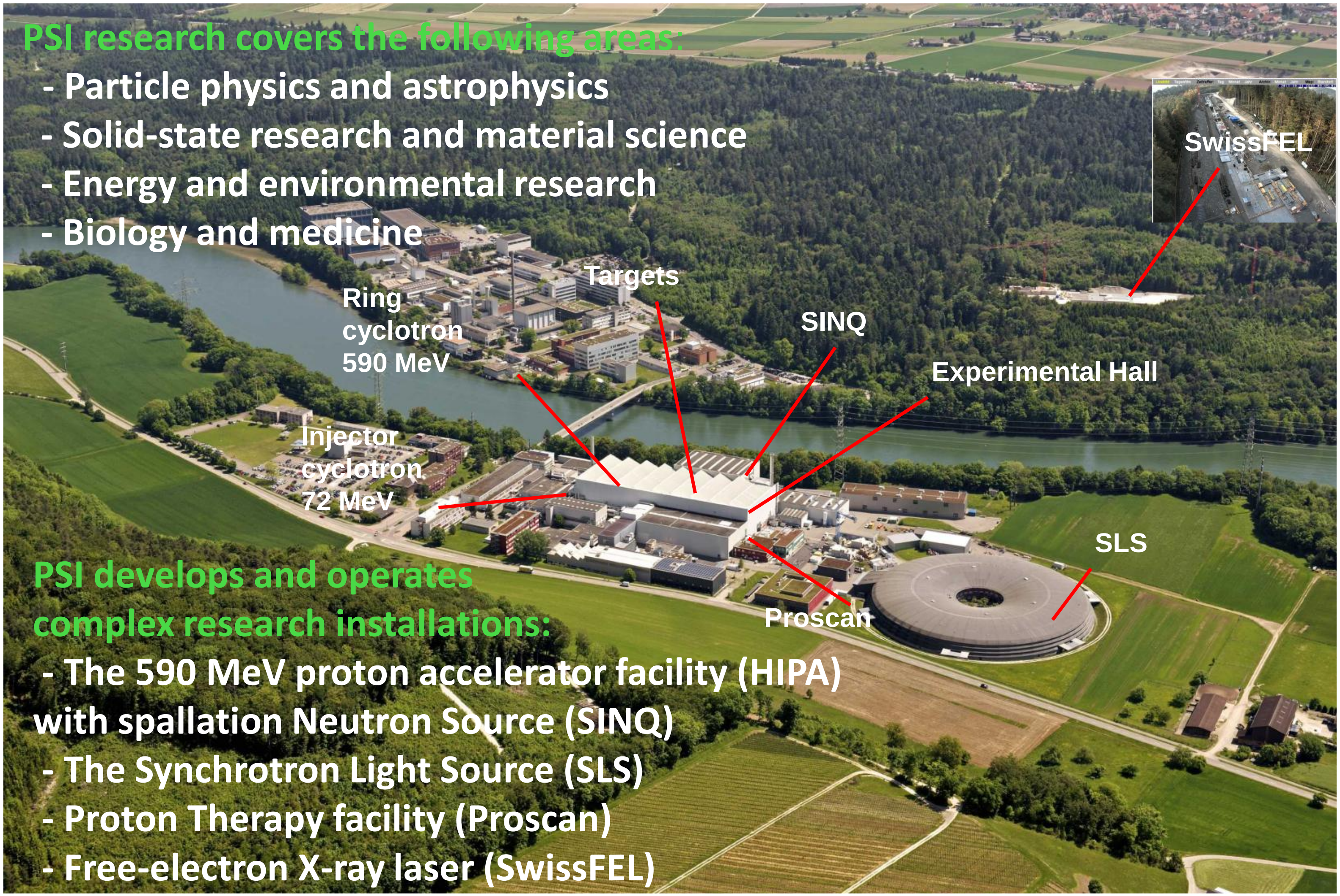
PSI aerial view



PSI research covers the following areas:

- Particle physics and astrophysics
- Solid-state research and material science
- Energy and environmental research
- Biology and medicine

PSI develops and operates complex research installations:

- The 590 MeV proton accelerator facility (HIPA) with spallation Neutron Source (SINQ)
- The Synchrotron Light Source (SLS)
- Proton Therapy facility (Proscan)
- Free-electron X-ray laser (SwissFEL)

Control room at PSI

SLS = Swiss light source

Infrastructure & personal safety

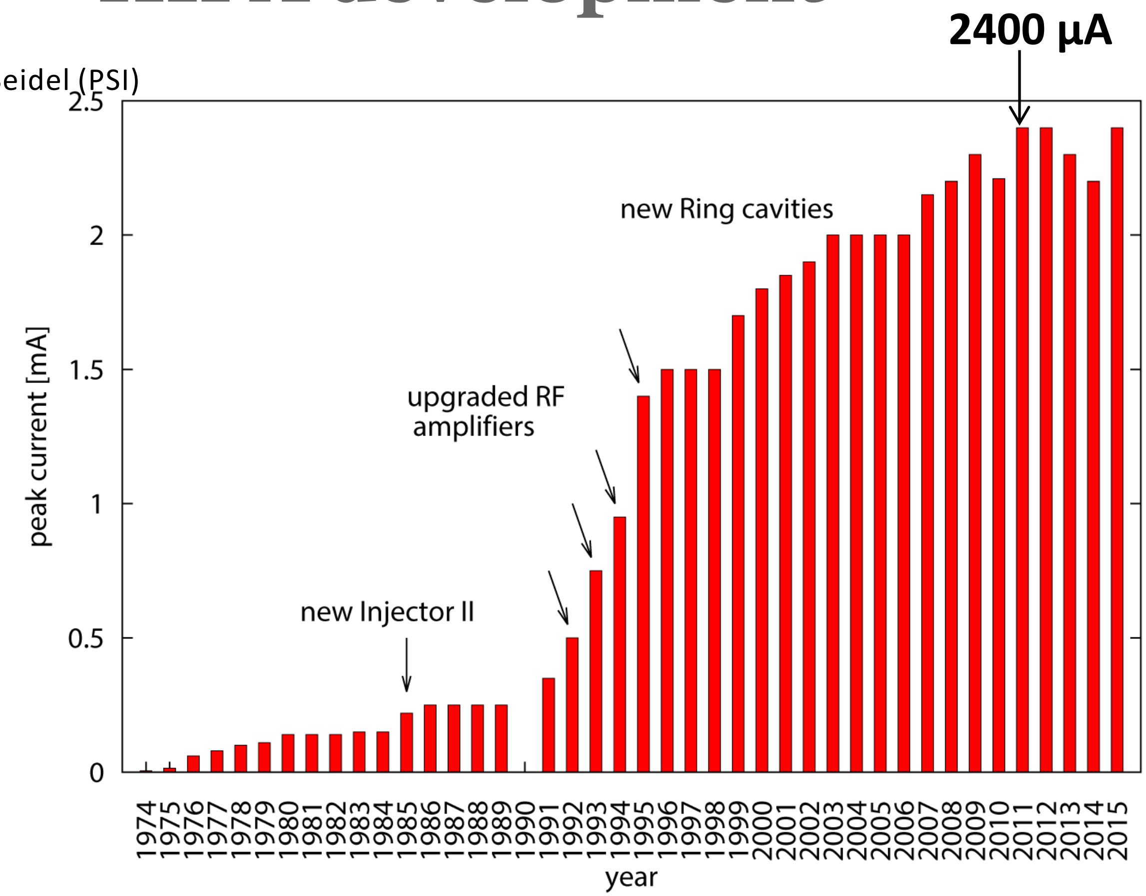
HIPA = high intensity proton accelerator

Proscan = 250 MeV proton accelerator for biomedical applications (cancer treatment)

SWISSFEL Project

HIPA development

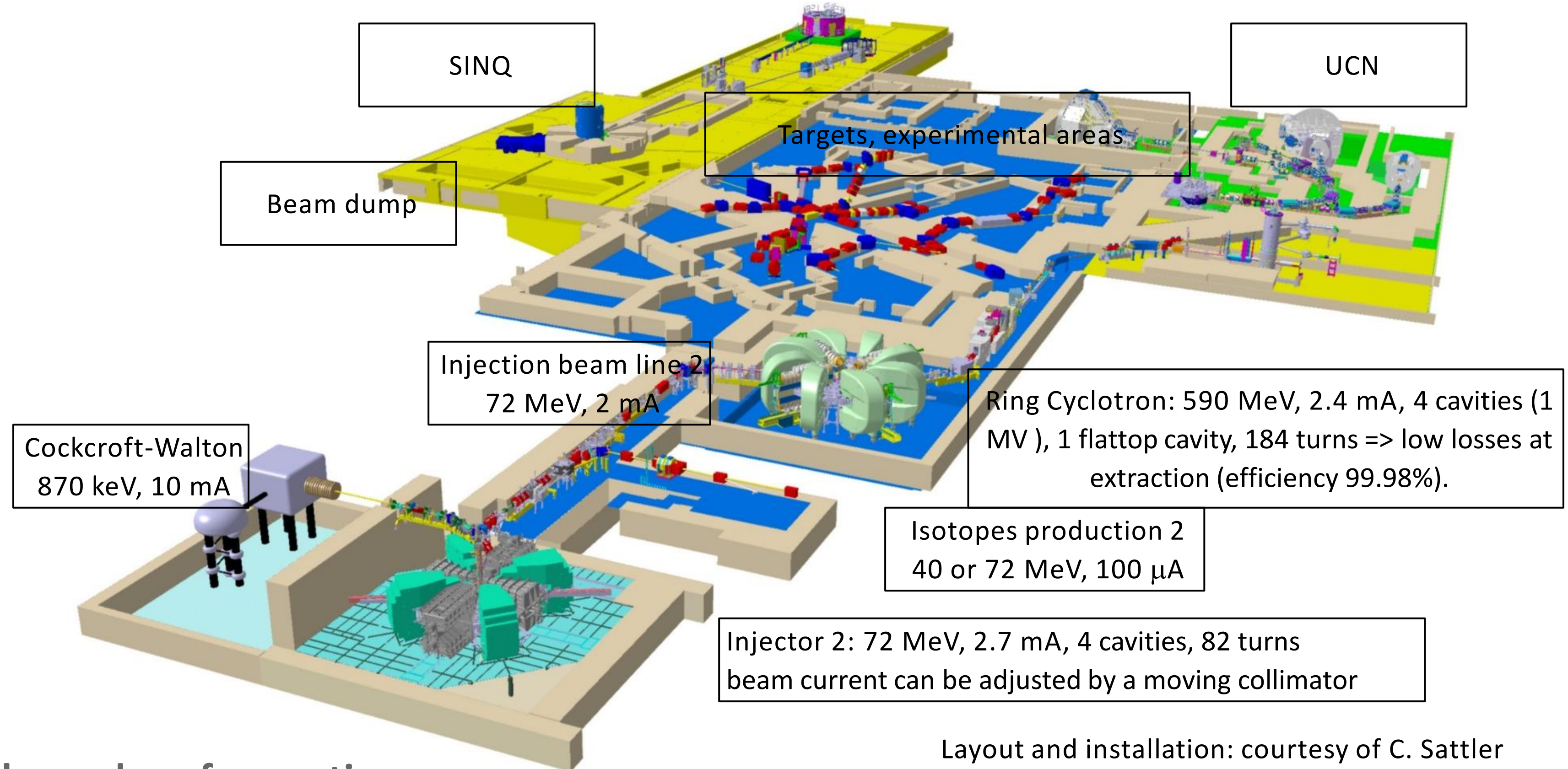
Figure: courtesy of M. Seidel (PSI)



- Beam current increased from 100 µA (1974) to 2400 µA @ 590 MeV (stable test operations 2015)

- In 2015 the average beam current to meson production targets was about 2100 µA with the beam loss under 400 nA

High Intensity Proton Accelerator

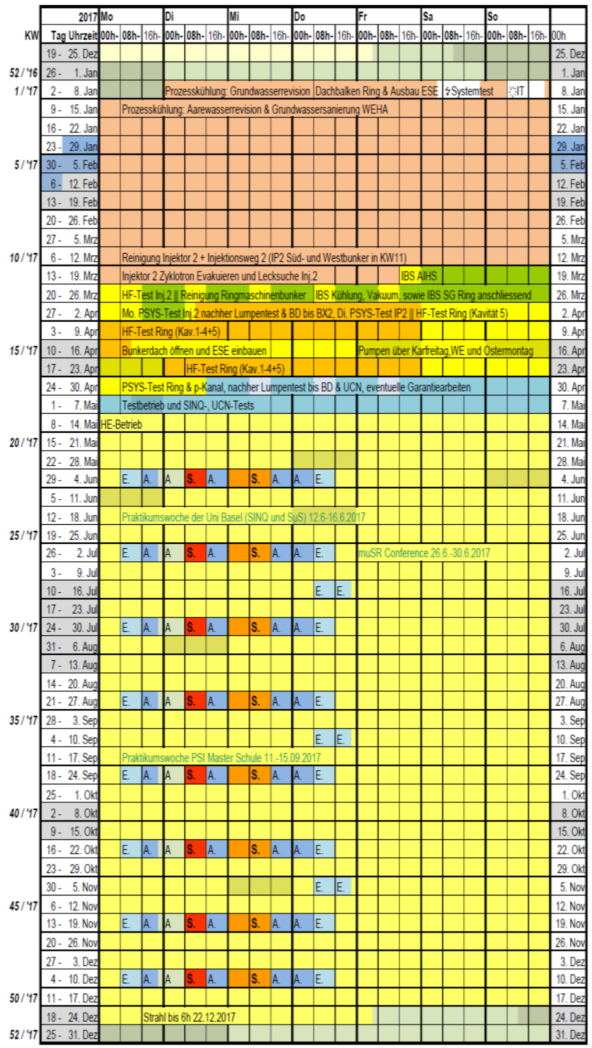


Layout and installation: courtesy of C. Sattler

Multiple modes of operation:

- **Mesons** (possible with beam on SINQ or beam dump <1.7mA)
- **Neutrons**
  - SINQ with 60% or 70% of the main beam depending on the mesons target (4 or 6 cm)
  - UCN full beam on UCN target is kicked (typically 8s every 5 min.)
- **Isotopes production IP2** (splitted or direct 72 MeV-beam under 100 mA): 40 MeV (Degrader), 72 MeV

HIPA user annual operations schedule



Shutdown from 24. December till 8. May (128 days)

200 days of user-operation

Service and machine development shifts

Run weekly operational status meetings

Begin of the next shutdown

Metrics, Availability and Analysis

Which metrics do we use to analyze operational data

Availability over the last decades

What do we see from our analysis

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Operational metrics

We measure operational efficiency by monitoring the following Key Performance Indicators:

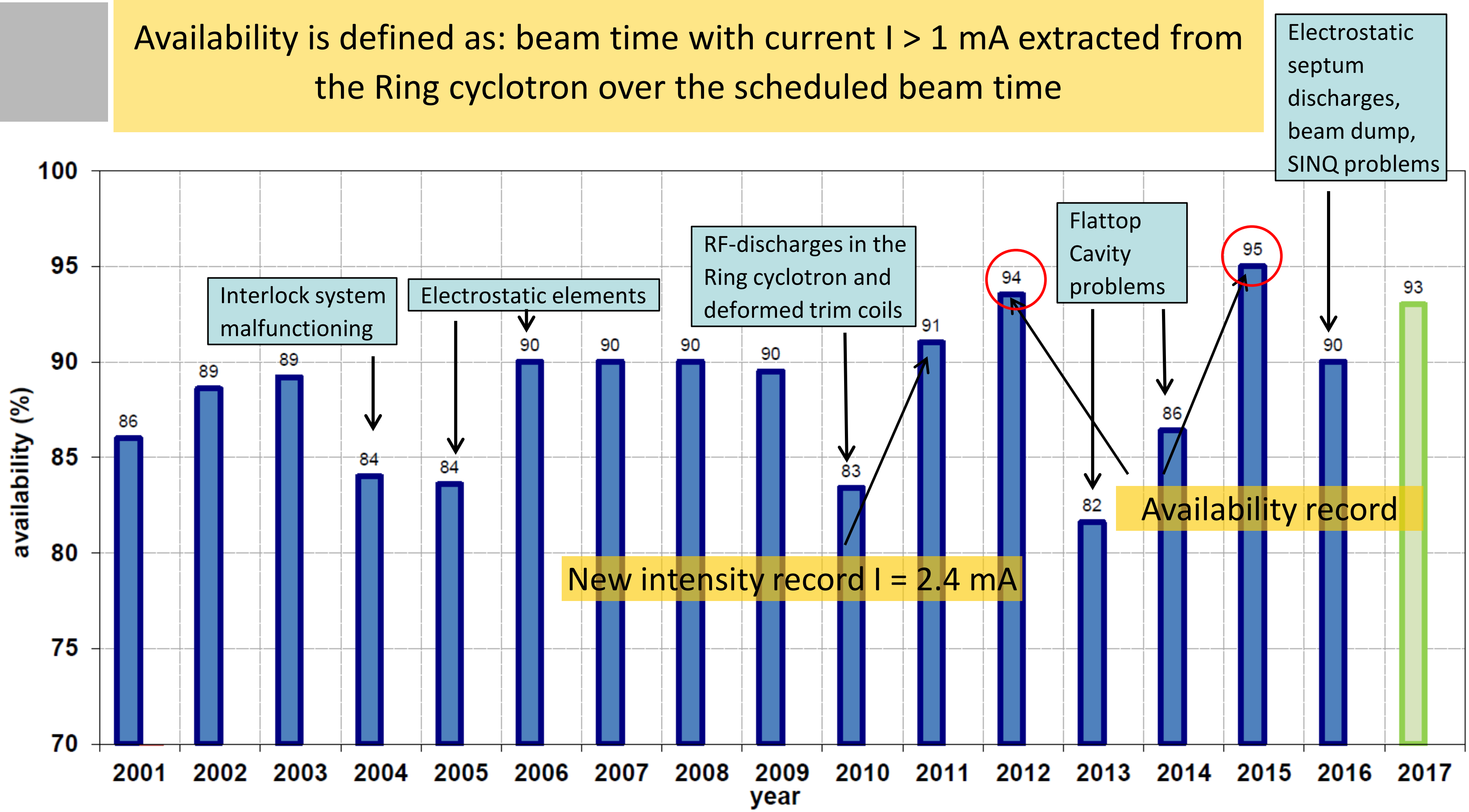
- Beam availability
- Current integrals at meson targets, SINQ, UCN, IP2
- Trip rate (number of trips)

Find “Happy-User-Index”!

A. Lüdeke (PSI)

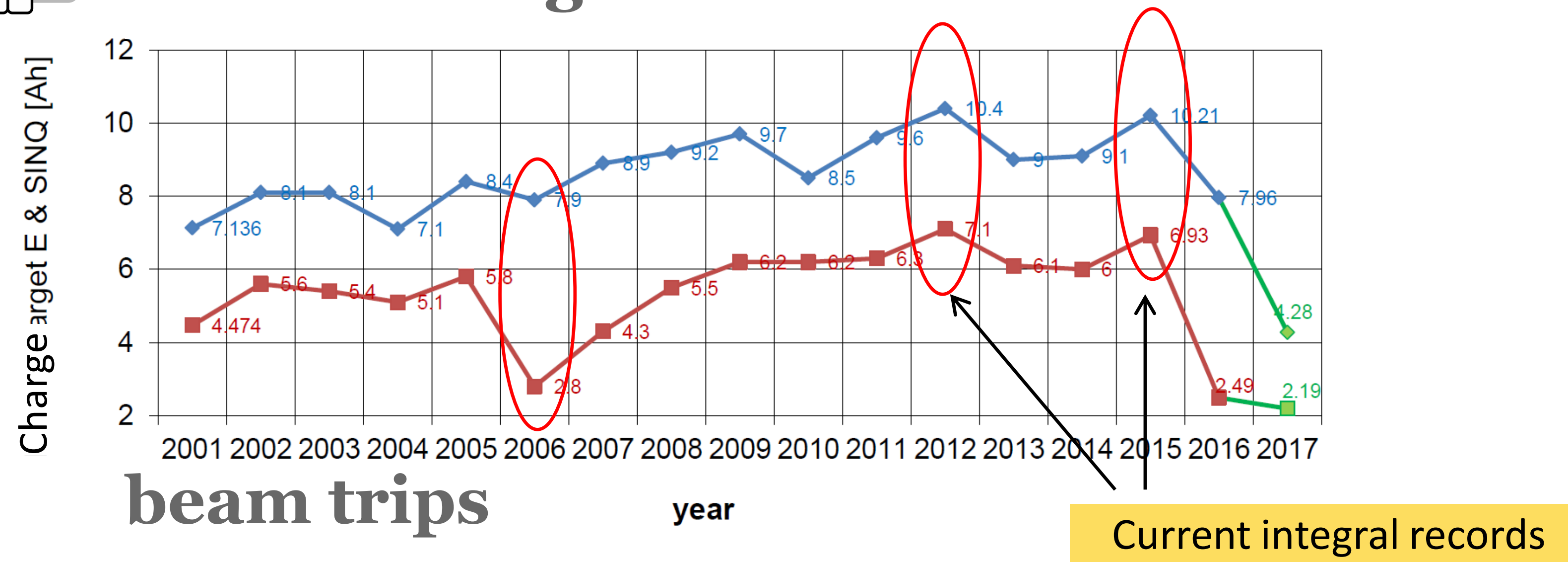
Availability 2001 – 2017 (I> 1 mA)

Availability is defined as: beam time with current I > 1 mA extracted from the Ring cyclotron over the scheduled beam time

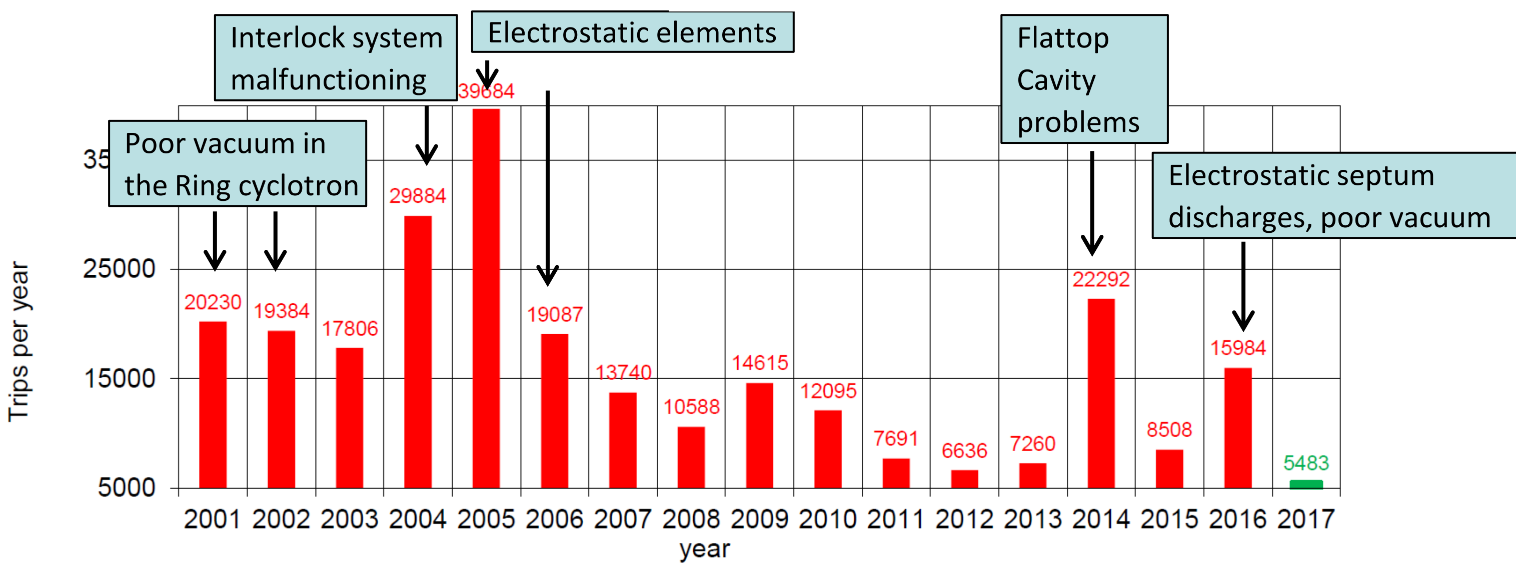


Availability averaged 89%

Current integrals



beam trips



Trips due to discharges at the septum's reach from 300 trips/week to 2000 trips/week (after) breaking the vacuum, or while damaged by the beam). Beam trips have an impact on the availability. To power up the machine again takes about 60s. Only 50 beam trips per day means **2% lost availability**!

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Operational events in detail, that have impacted availability over the last decade

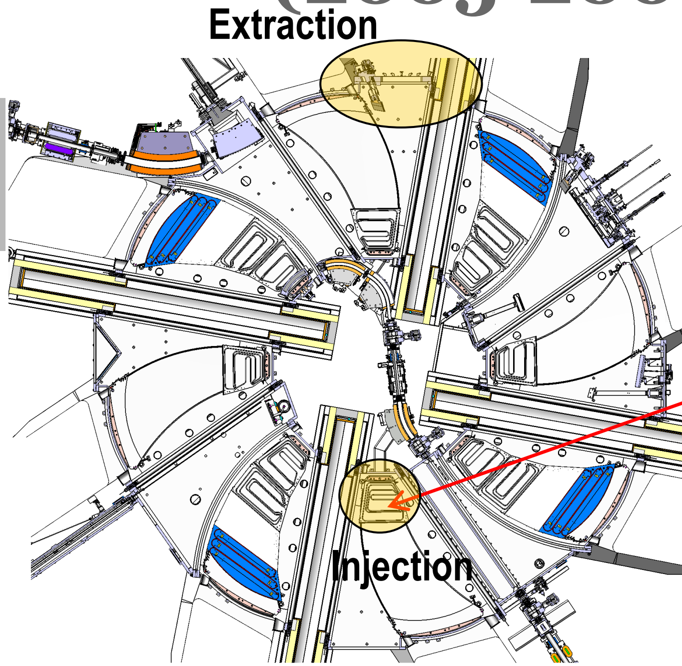
1 MW facility, what challenges do we have

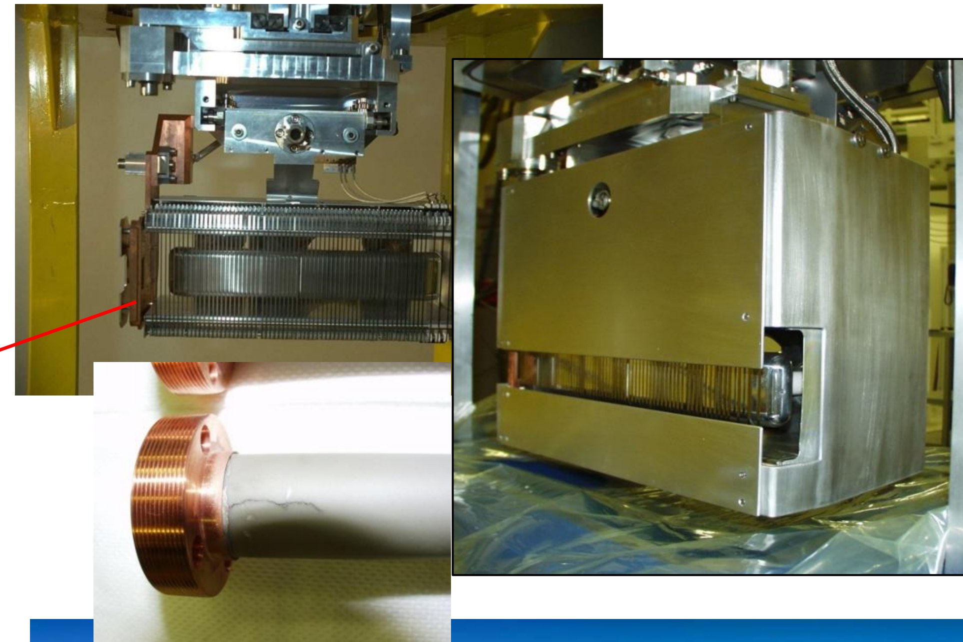
What problems did and do we have

2016 operations

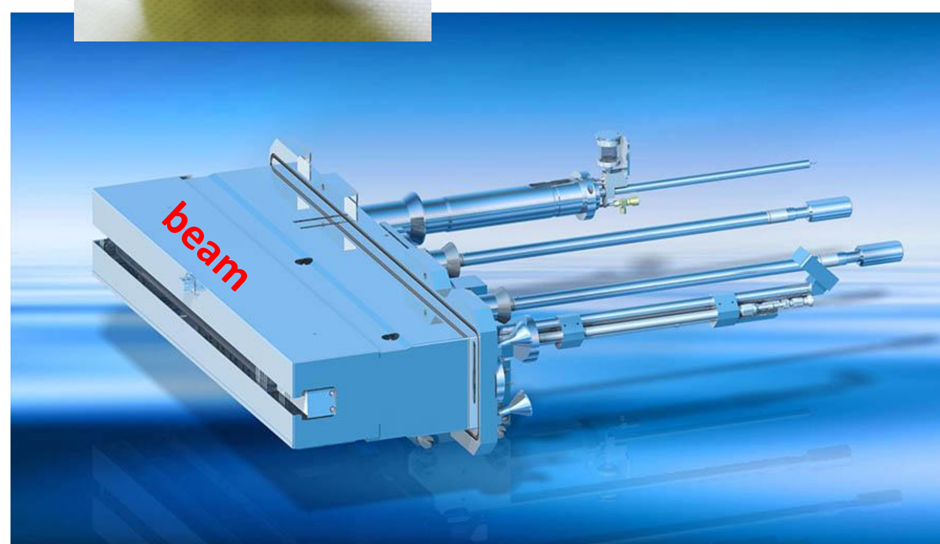
What do we do to successfully operate HIPA facility

Problems with electrostatic elements (2005-2006)





- Discharges with switched on RF
- Ionized gas in the surrounding of the electrostatic elements
- Defects on insulators

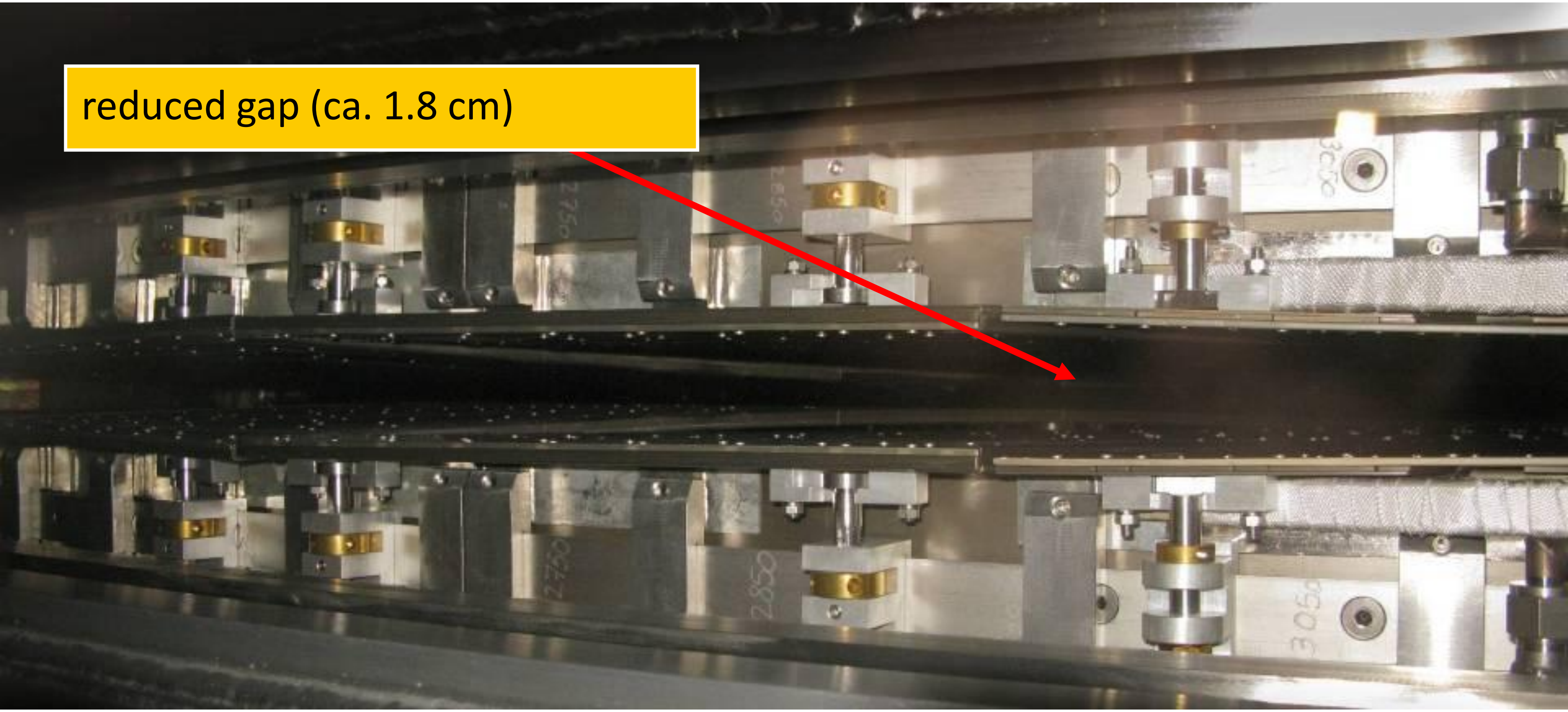


<u>Shielding of the electrostatic elements against</u>:

- Decoupled RF-Power
- Ionized gas (plasma)

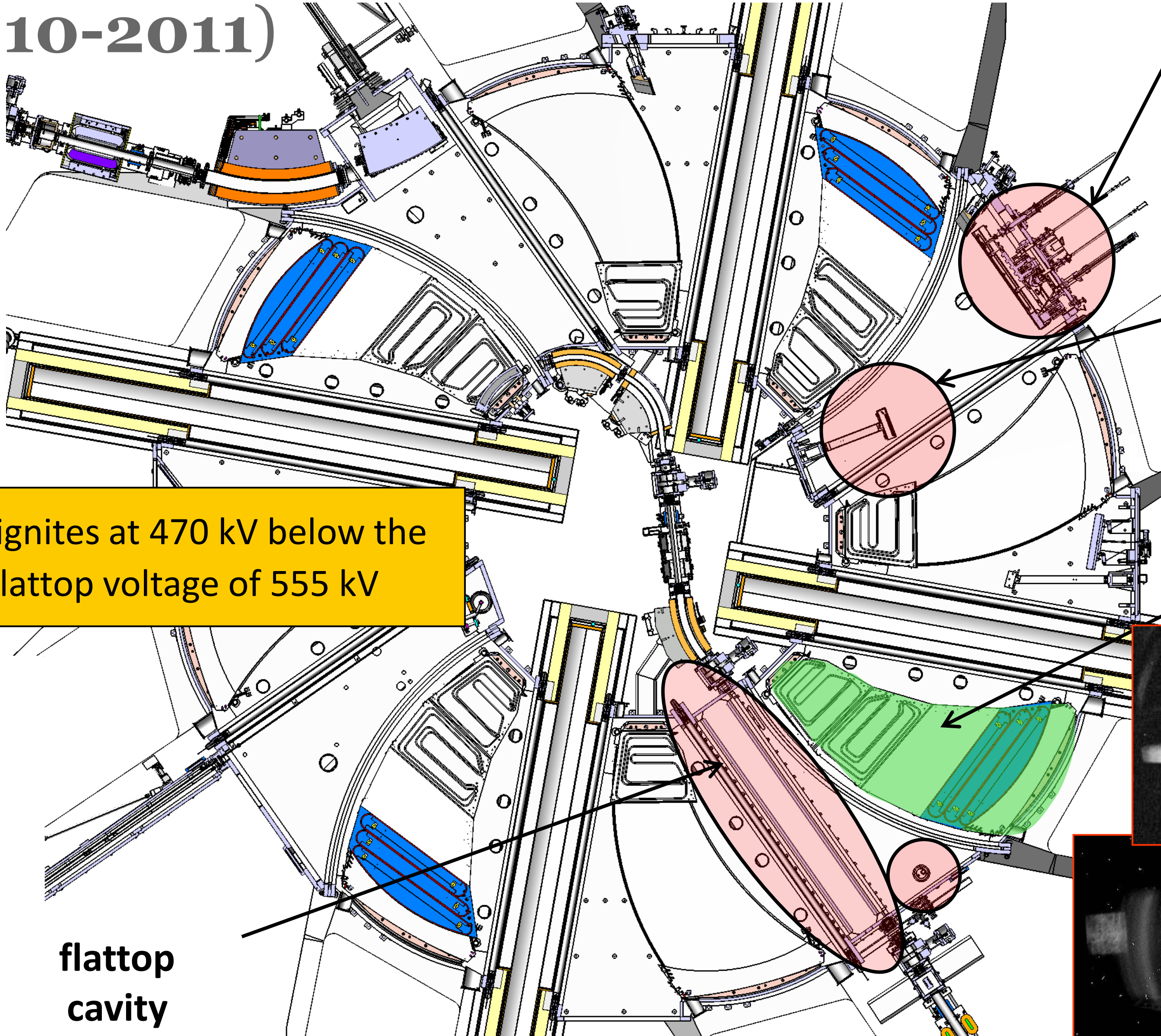
Photos: R. Kan, D. Götz (PSI)

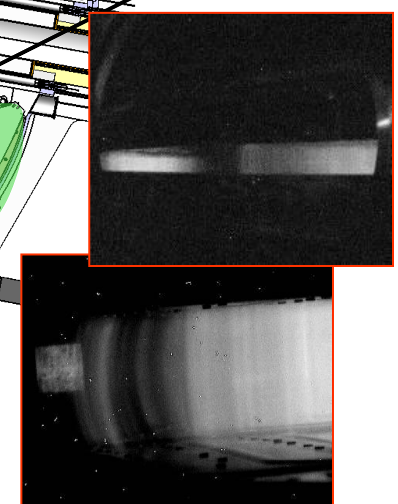
Deformed trim coils of sector magnets (2010)



- Deformation because of a failure of the cooling circuit
- Repair would take up to several week, continued operation **(under 2.2 mA!)**

RF-discharges in the Ring cyclotron (2010-2011)





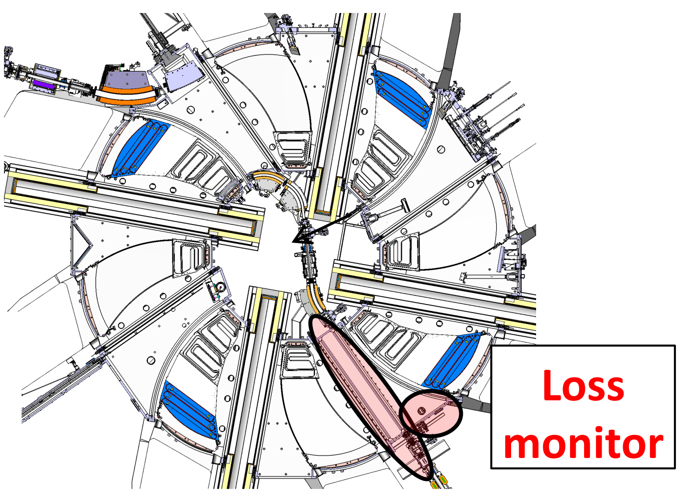
RF discharge ignites at 470 kV below the operational flattop voltage of 555 kV

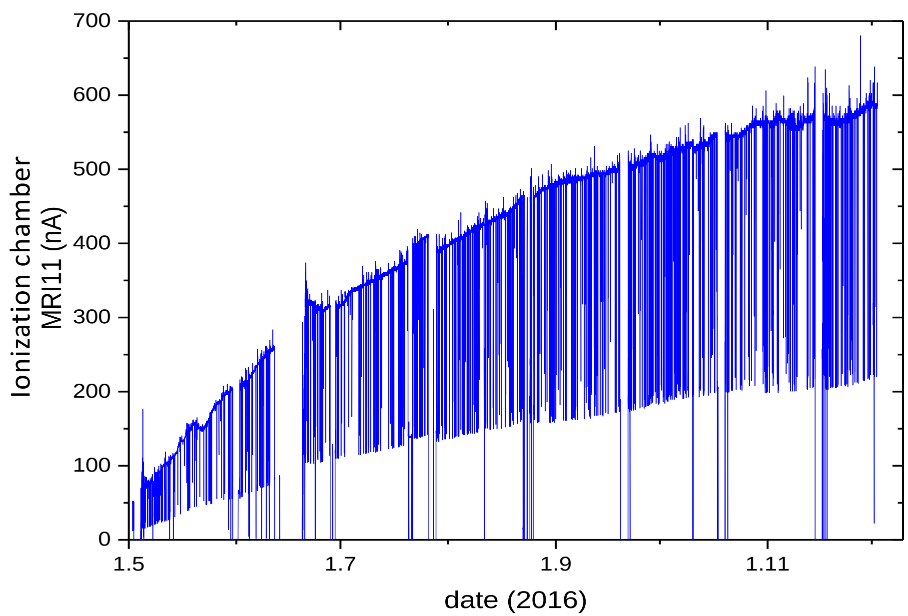
Photos. R. Kan (PSI)

X-rays emission at the flattop cavity (2014-2016)

Painting with AQUADAG (yearly)

- Suppression of multipactoring
- Reduction of X-rays emission
- Reduction of discharges at the electrostatic elements
- Less decoupled HR power





Problems with the flattop cavity (2013-2014)

- Shutdown 2015
- Dismount of the flattop cavity
- Service at the tuning-system (hydraulics)
- Vacuum (new seals)
- Tightening up of the electrodes

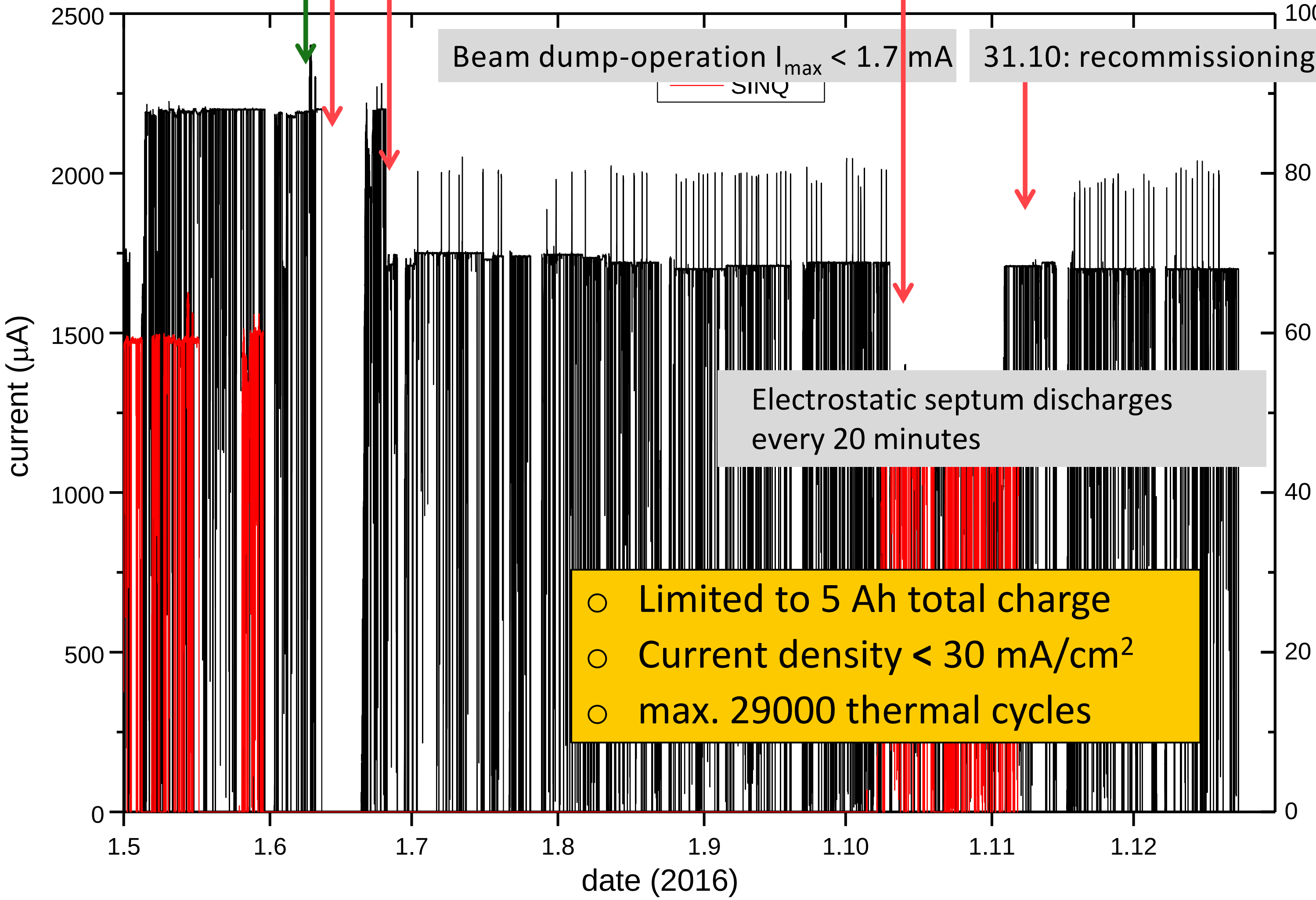
Operations 2016

12. - 20.6.: AHA and Target E exchange

25. 6.: SINQ-shutdown

9.10.: vacuum pressure increase in the area of the beam dump

09.06.2016: 2.4 mA with BAG-License



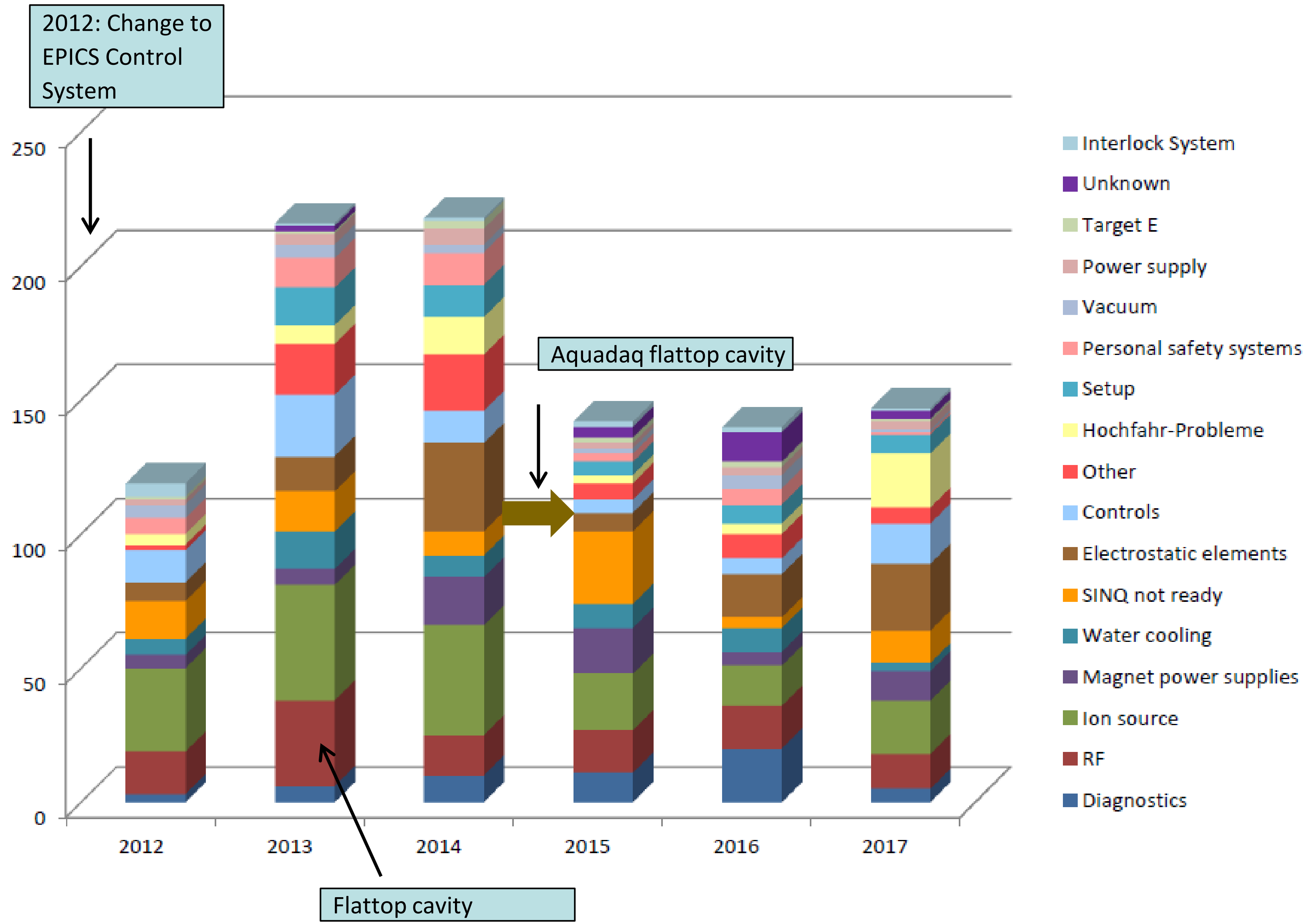
Beam dump-operation I_{max} < 1.7 mA

31.10: recommissioning SINQ

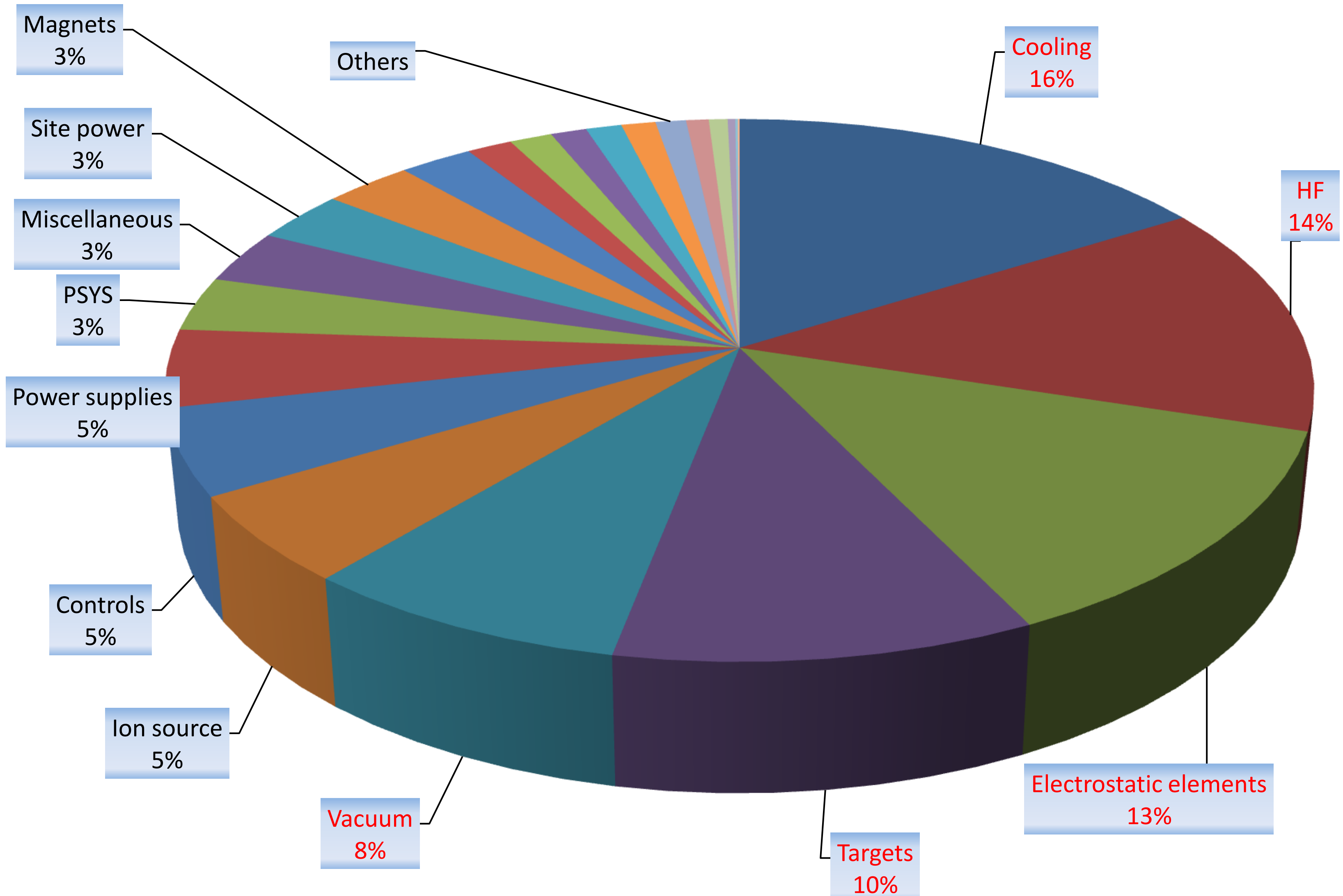
Electrostatic septum discharges every 20 minutes

- Limited to 5 Ah total charge
- Current density < 30 mA/cm^2
- max. 29000 thermal cycles

Number of outages 2012 – 2017

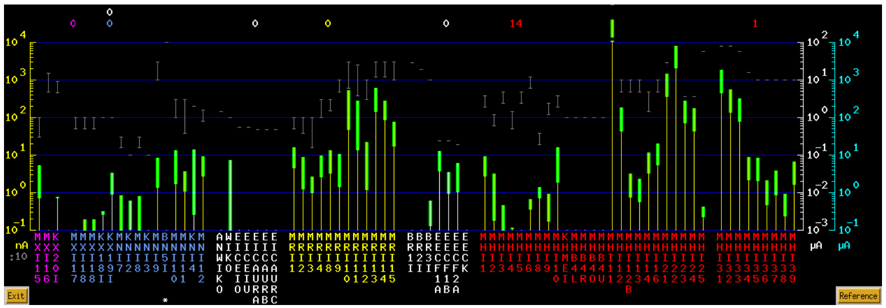


Integral outage representation averaged over 2004 – 2016

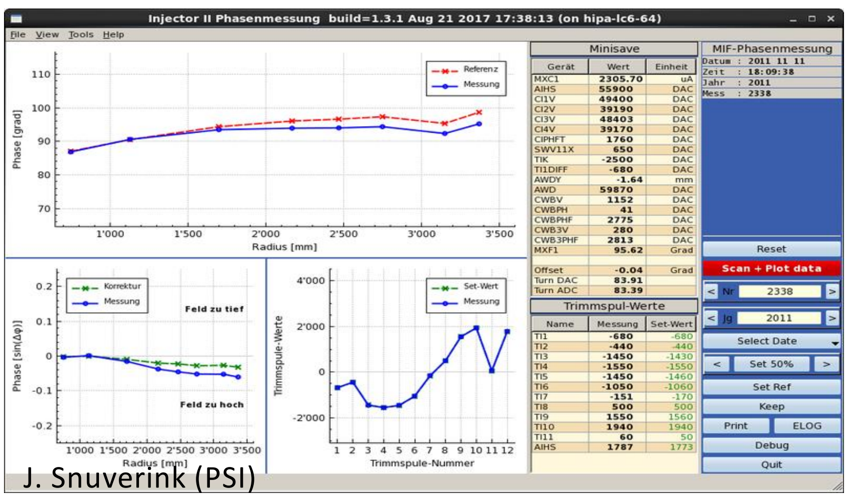


Operational tools

- Beam loss monitors ➔ important to protect against misbehavior of the beam and also gives appropriate feedback to the operator for minimizing the losses

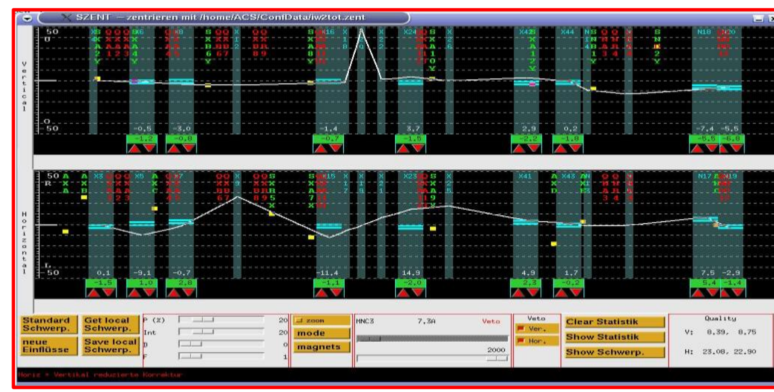


- Phase measurement devices ➔ beam dynamic and tuning tools



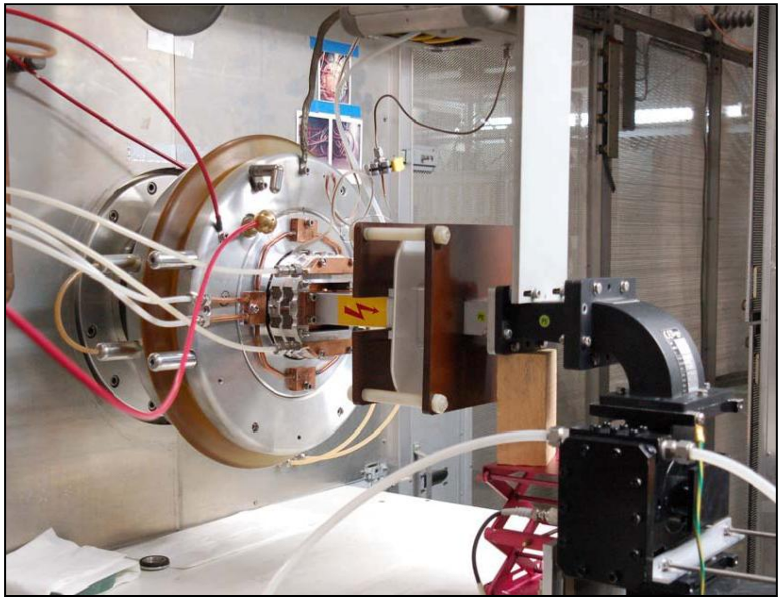
J. Snuverink (PSI)

Ref. A. Parfenova, C. Baumgarten, M. Humbel, A. Mezger, A. Petrenko, "Measurements of the Beam Phase Response to correcting Magnetic Fields in PSI Cyclotrons", TUPMR019, IPAC 2016.



- Beam position monitors ➔ automated beam steering using bpm's, steering and bending magnets
- Feedback tools for stabilizing phases, ion-source, …
- Beam dynamics tools

New ECR-ion source since 2009



- Longer intervals between services (> 8 weeks)
- Higher beam stability
- More proton efficiency (80% instead of 33%)
- Better beam quality (smaller emittance)
- Up to 2.7 mA from Injector 2

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Improvements and Operations

Steps to achieve higher availability and currents

Safe operations and operational risks

Conclusion

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Steps to achieve higher availability

- Enough time for the setup after the shutdown (at least 1 week)
- Longer beam time periods (4 weeks between maintenances)
- Lessons learned: Dismount of the electrostatic elements at the beginning of the shutdown. Storage of the electrostatic elements in a vacuum and under the high voltage. After RF-conditioning switching on the electrostatic elements and then slowly ramp up
- Injector2 upgrade with new resonators (spare parts are not provided anymore, better beam quality)
- Continuous updating and modernizing the operational tools (GUI, panels, programs)

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Steps to achieve higher currents

- Operation 2030 +
- Higher acceleration voltages (1.2 MV possible → less turns, less beam loss)
- For this a new flattop-system will be needed (limited now by U_{max} = 550 kV)
- New trim coils (secondary electron emission, ionized gas)
- Target, collimators upgrades, SINQ-Target (I_{max} > 2.4 mA), beam dump
- Injector 2 resonator exchange → better quality beam injected into the Ring cyclotron
- Machine developments (simulations, diagnostics, mutual work beam dynamics and operation)
- Energy efficiency of the proton facility

Today:
2.4 mA, U_{Kav}= 850 kV, 186 turns
η_{acc} ≈ 0.18

High current -Upgrade:
3.0 mA, U_{Kav}= 1 MV, 160 turns
η_{acc} ≈ 0.2

$$I_{\max} \approx U_{kav}^3$$

$$\eta_{acc} = \frac{P_{beam}}{P_{grid}} = \frac{I \cdot E_{kin} / q}{c \cdot I^{\frac{2}{3}} + I \cdot E_{kin} / q + P_0}$$

Ref. A. Kovach, J. Grillenberger, A. Parfenova, and M. Seidel, “Energy Efficiency and Saving Potential Analysis of the High Intensity Proton Accelerator HIPA at PSI”, TUPVA129, IPAC 2017.

Overview of HIPA Operations

PRESENT STATUS:

- HIPA delivers up to 1.4 MW beam power
- Average availability is 89% (maximum availability reached: 95% in 2015)
- Maximum power increase was reached through the increase of cavity voltages
- Maximum beam current is presently 2.4 mA (licensed for routine operation)
- Modular design allows fast repairs in case of failures
- Good infrastructure (radiation protection, shielding, disposal)

Risk = Number of components × Probability × Operational consistency

OPERATIONAL RISKS:

- Careful planning of maintenances (time for repair, availability and personal doses)
- Spare parts problems, because the facility is aged (magnets, flattop cavity, power supplies, cooling)
- Man power and retirements (loss of Know-How)

Thank you for your attention

My thanks go to

- All my colleagues that contributed to this presentation
- PSI Operations team

In particular to:

- Andreas Lüdeke
- Joachim Grillenberger
- Richard Kan
- Anton Mezger
- Mike Seidel
- Andras Kovach