Ultimate Capabilities of High Power Proton Cyclotrons: Challenges

Future Directions for Accelerator R&D at Fermilab Workshop

May 11-13, 2009 - Lake Geneva, Wisconsin

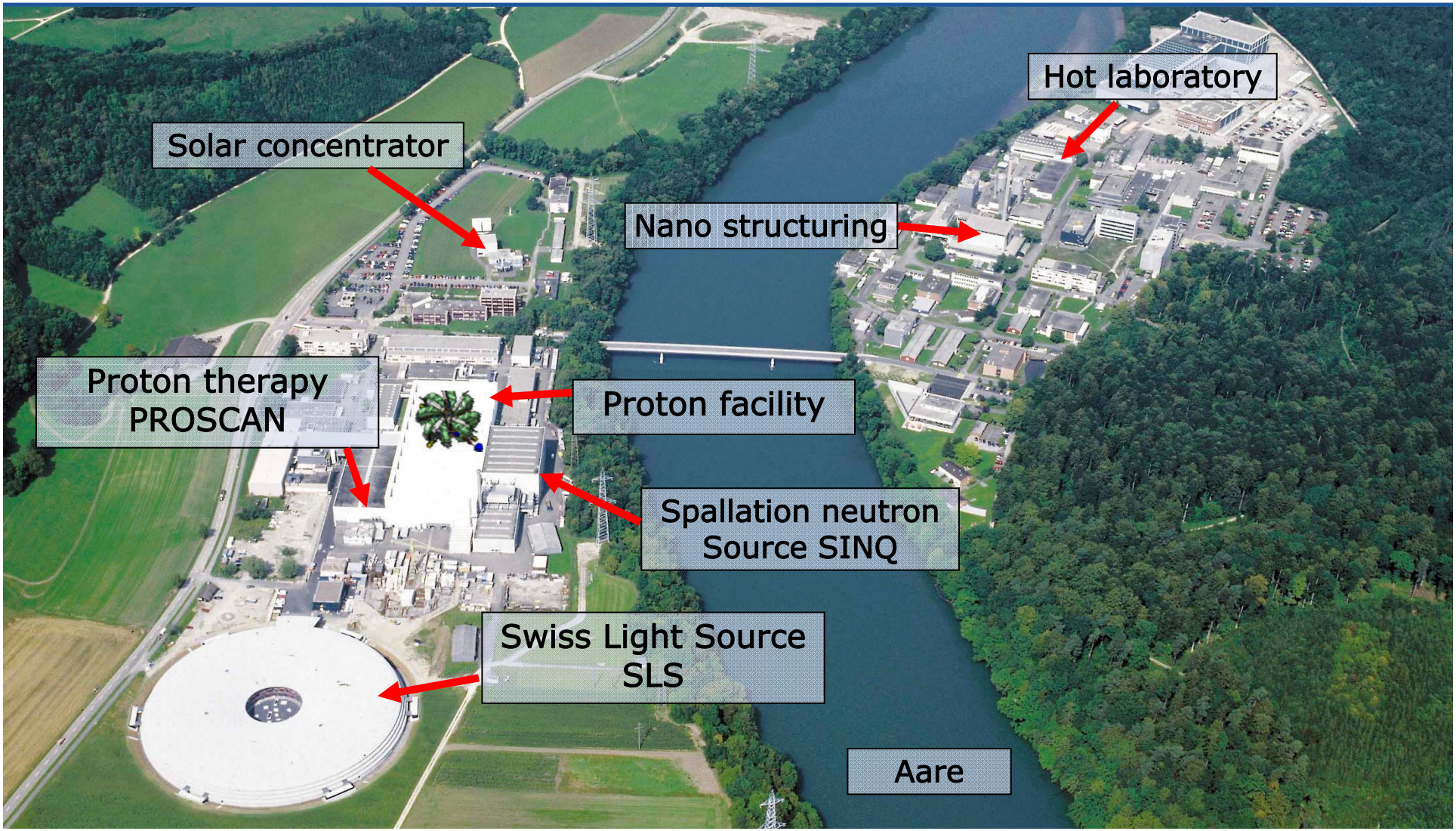
Joachim Grillenberger

Paul-Scherrer-Institut, CH-Villigen

PAUL SCHERRER INSTITUT

PSI

Paul-Scherrer-Institute, Villigen Switzerland



Outline

- Operational experience with the 590 MeV Ring-Cyclotron

  [upgrades, goals, performance statistics]

- Proposal for a 10 MW Driver

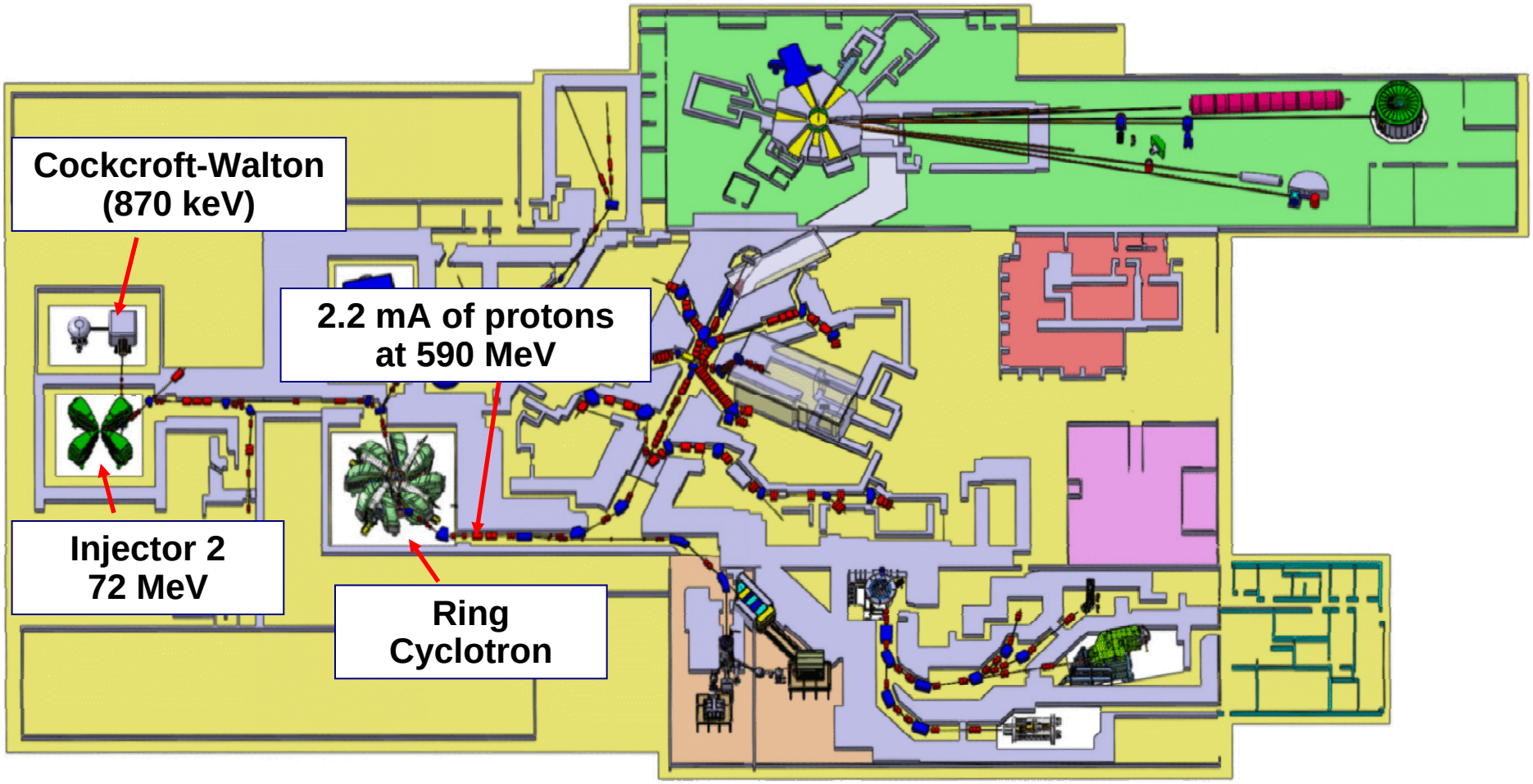
  [scheme, data, options]

- Challenges

  [cavities, electrostatic elements]

- Conclusion

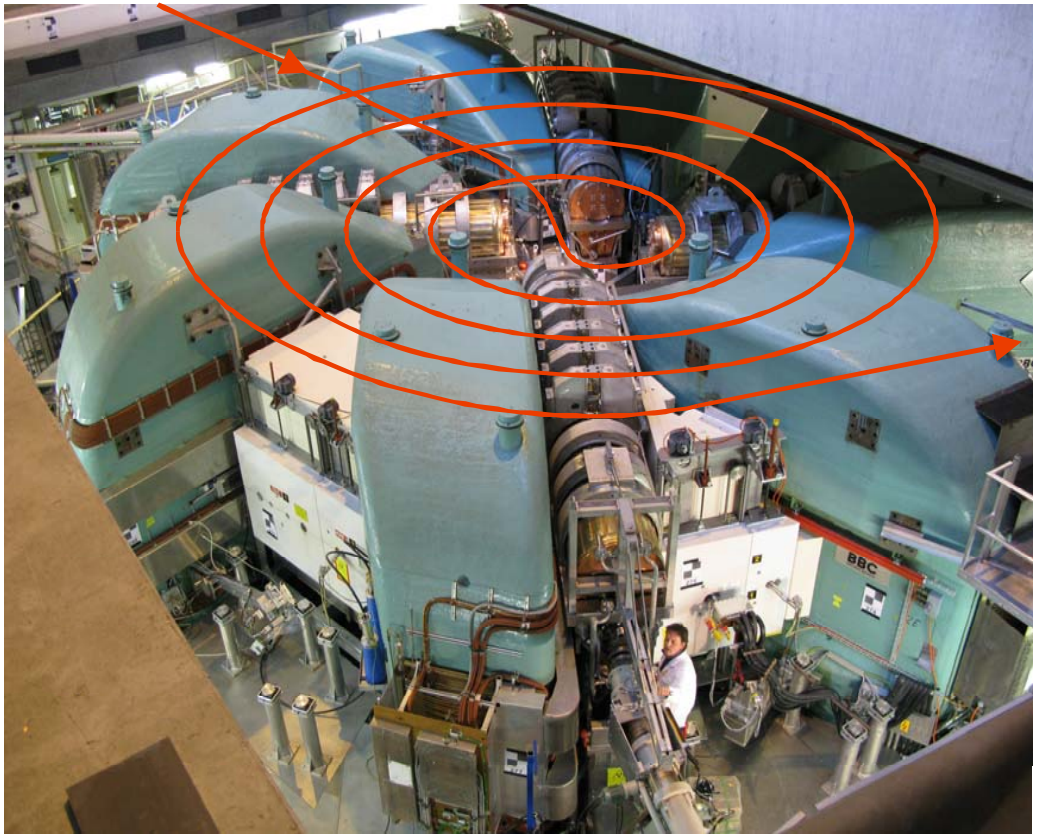
Layout of the PSI proton facility



PAUL SCHERRER INSTITUT

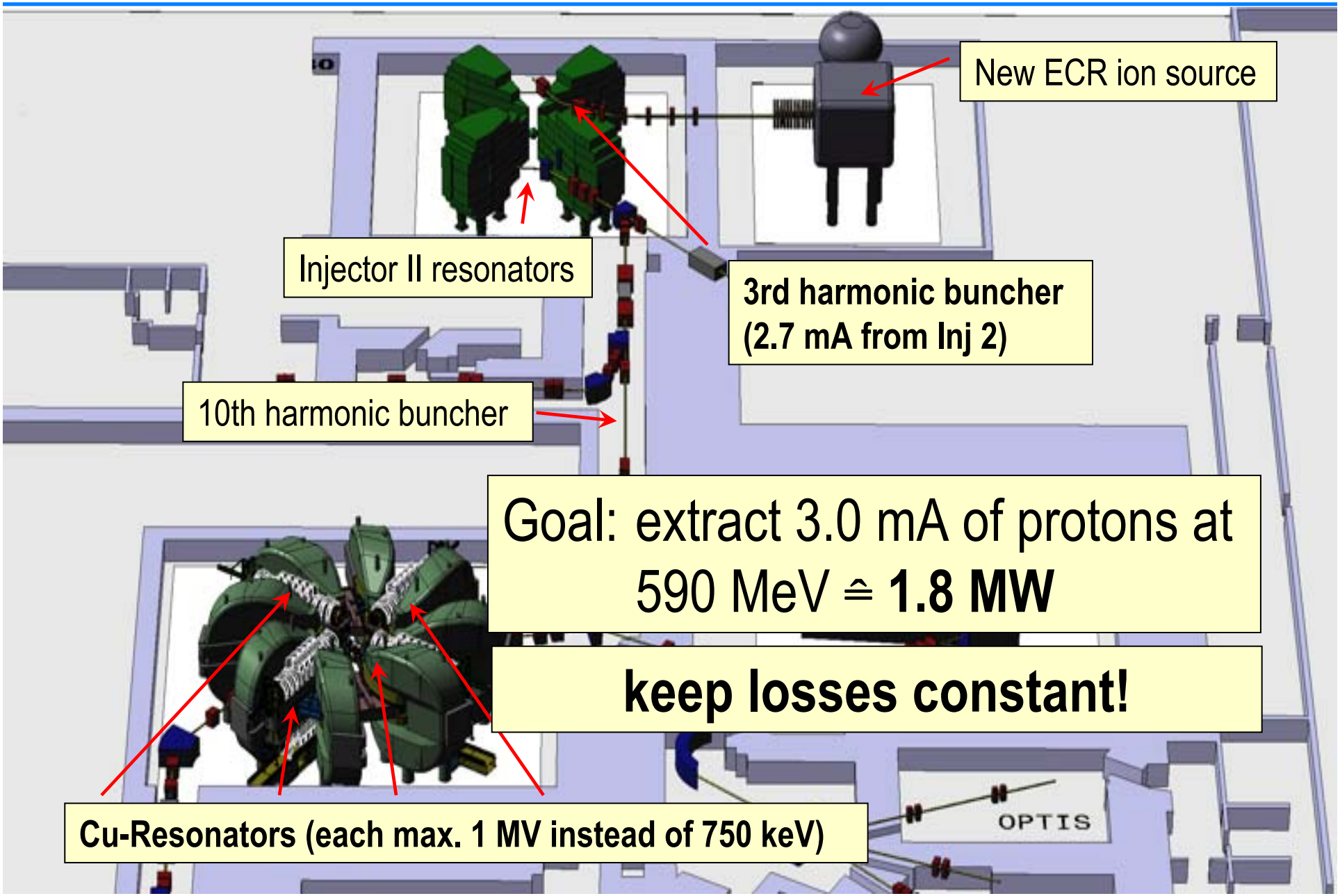
PSI

590 MeV Ring Cyclotron in April 2008



- 8 sector Magnets: 0.6 – 0.9 T
- weight per magnet: 250 tons
- 4 cavities 50.63 MHz: 850 kV
- 1 flat-top resonator: 150 MHz
- harmonic number: 6
- beam energy: 590 MeV
- beam current (now): 2.2 mA
- injection radius: 2.1
- extraction radius: 4.5 m
- relative losses: ~$2 \cdot 10^{-4}$

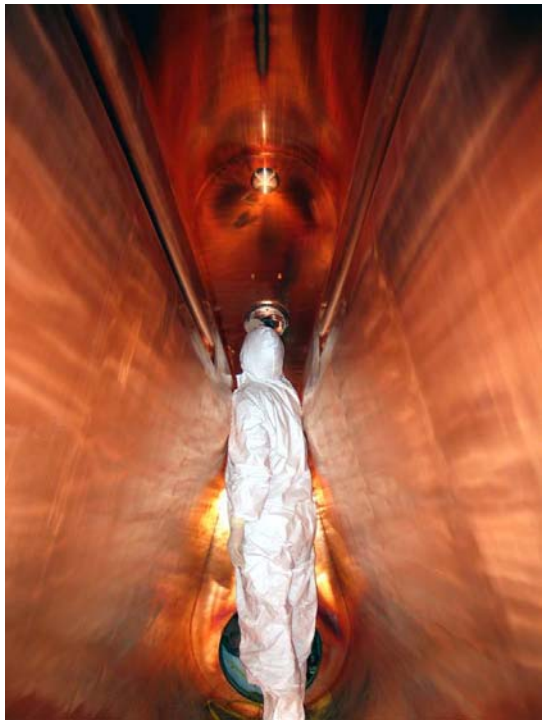
Upgrades and Goals

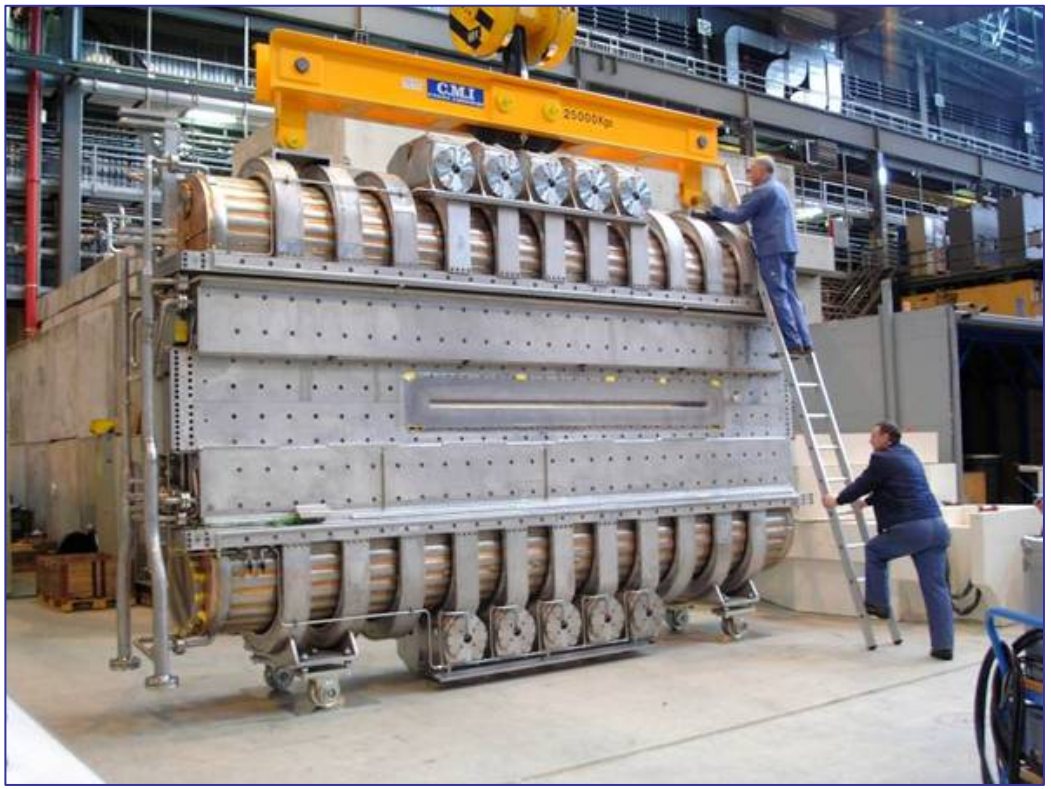


High power resonators

Cu Resonators f = 50.63 MHz

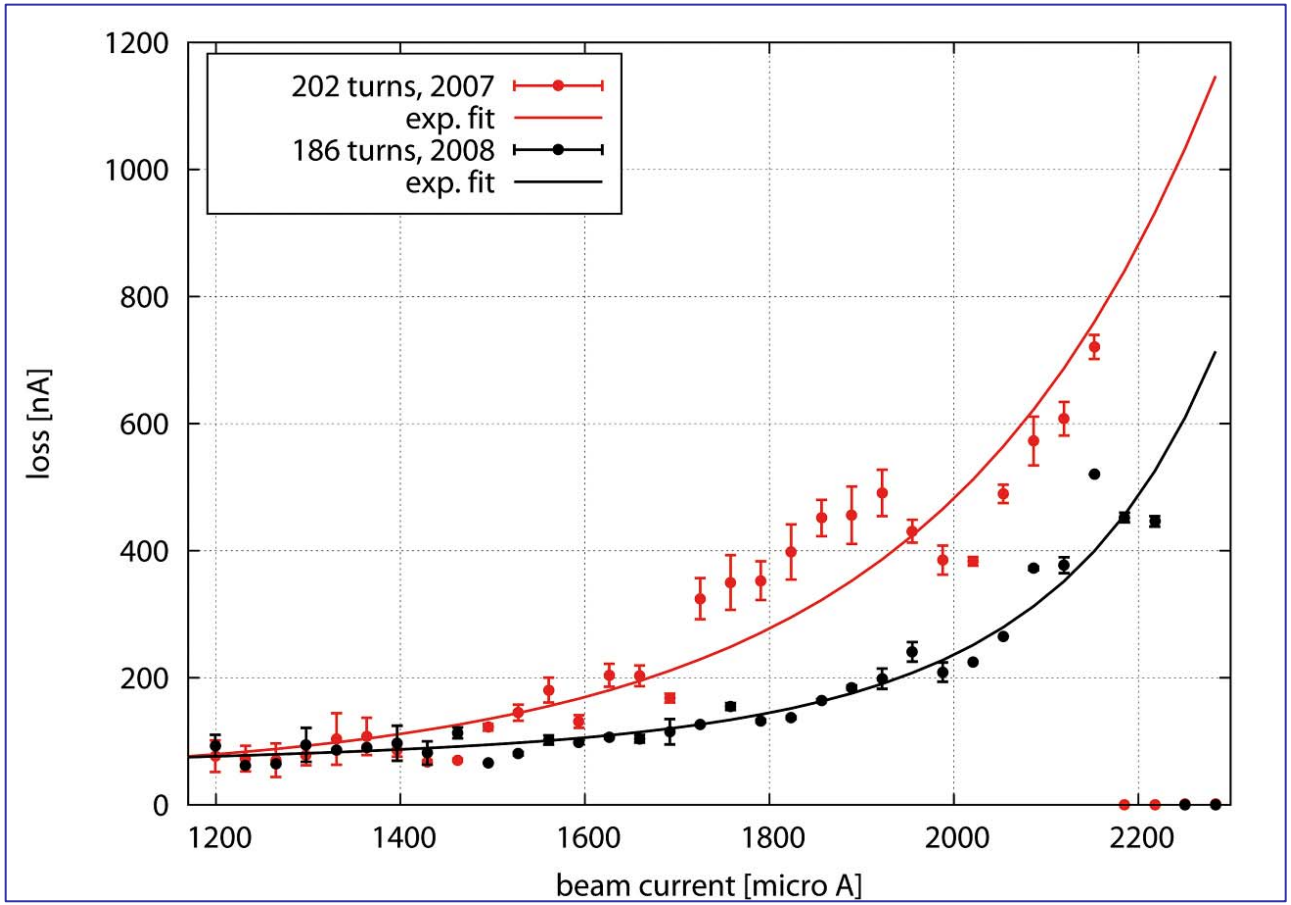
- less wall losses
- better breakdown characteristics
- higher gap voltage possible (1 MV)
- better cooling distribution
- regulation precision ~10μm





transfer of **500 kW power to the beam** per cavity

Losses in Ring cyclotron as a function of current



Achieved 2008:

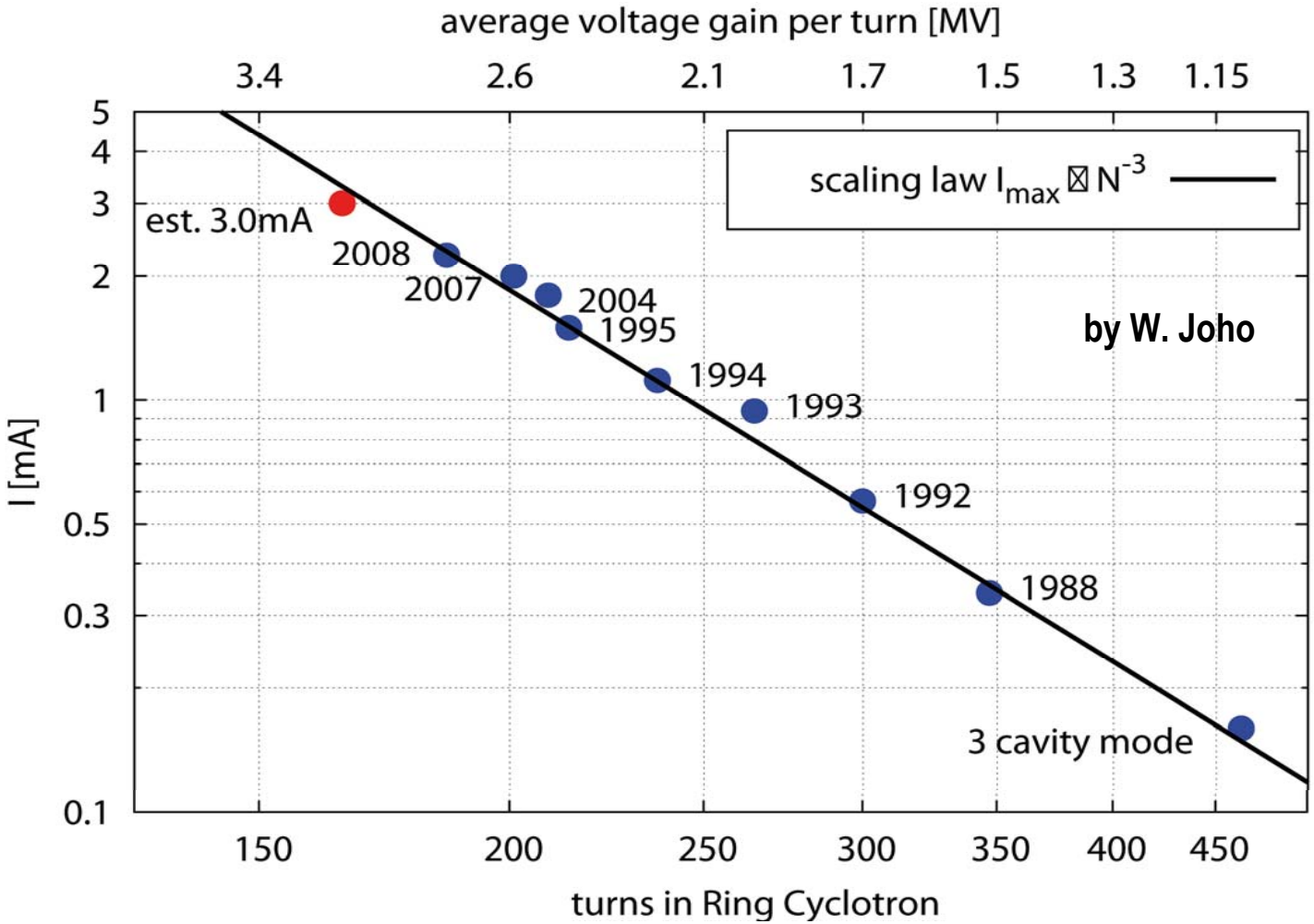
gap voltage increase:
780kV → 850kV

turn number reduction:
202 → 186

losses reduced by turn number reduction

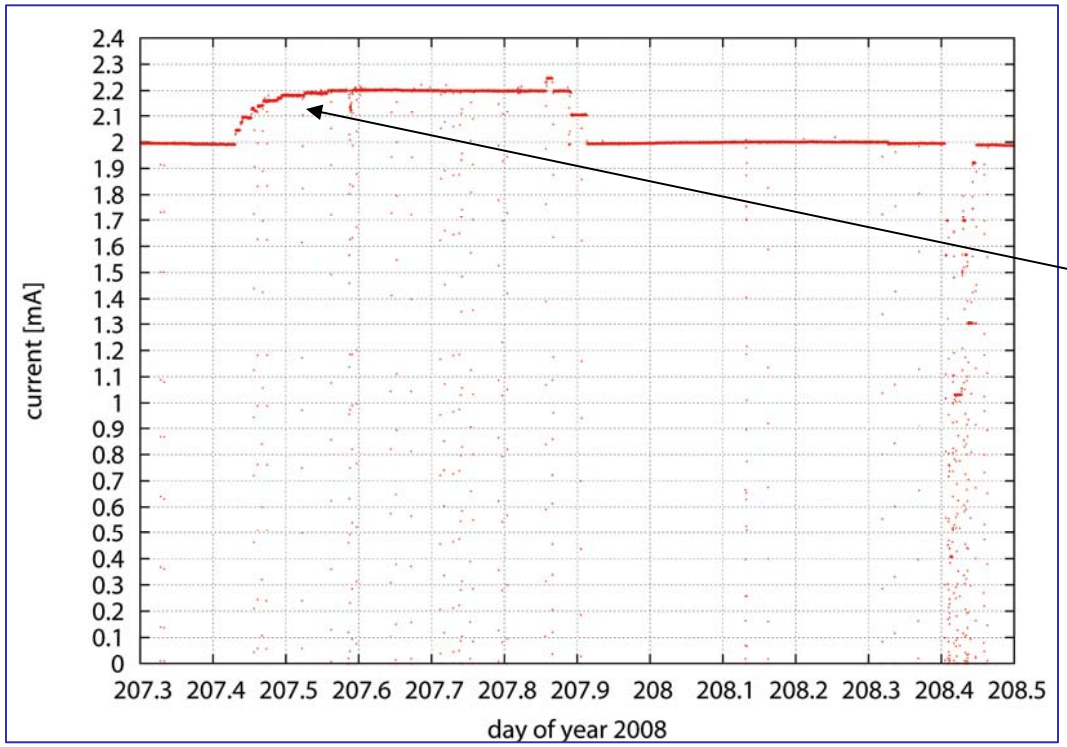
Goal: 150 turns

History of the beam-current and turn numbers in the PSI Ring Cyclotron



→ **fast acceleration and short bunches**

New record current: 2.2 mA @ 590 MeV ≙ 1.3 MW



First attempt to reach 2.2 mA.

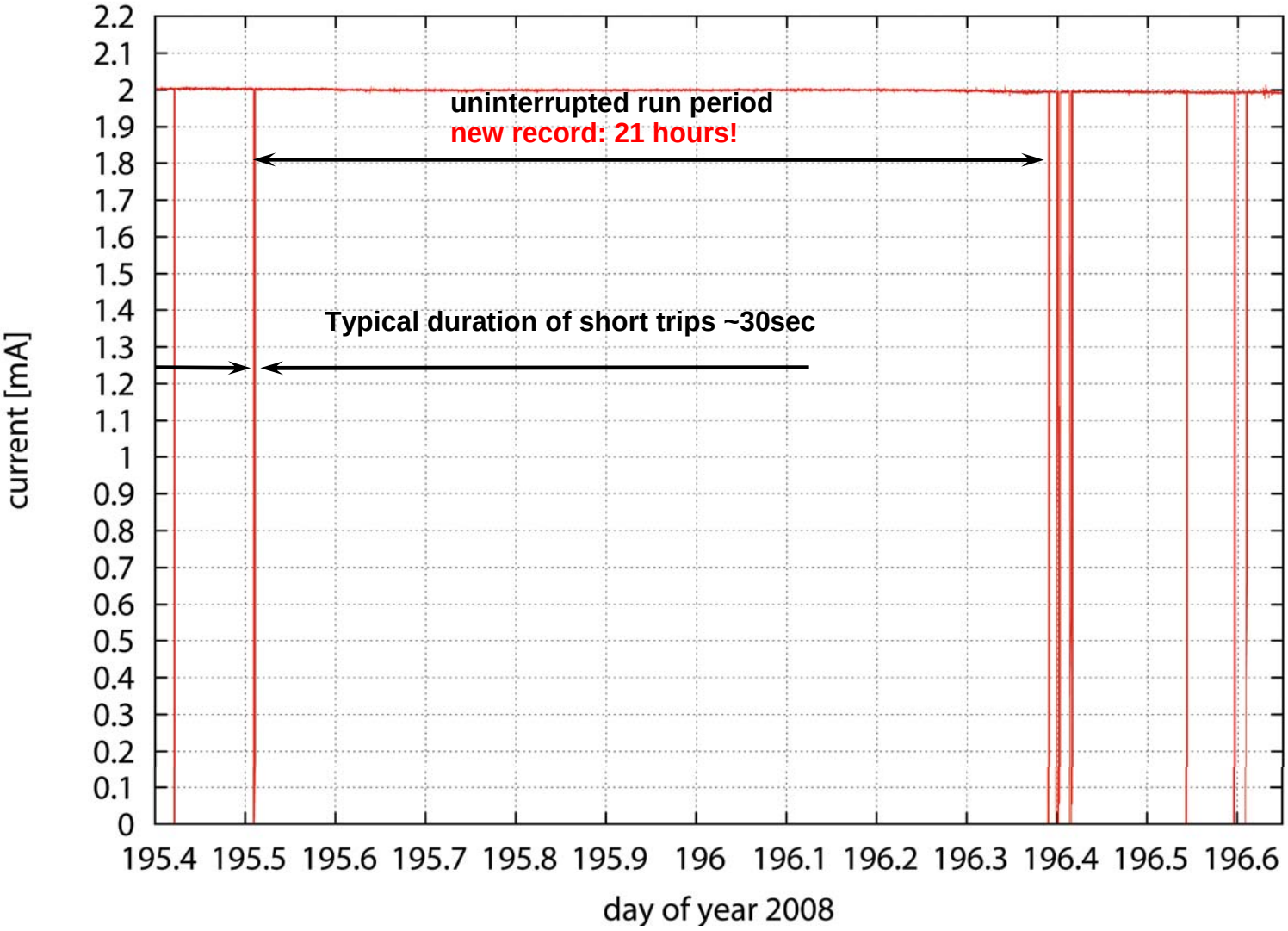
Was achieved within 5 h!

- legal authorization for continuous currents up to 2.2 mA was given by Swiss authorities
- authorization for up to **2.4 mA ≙ 1.4 MW** for **testing purposes**

  every other week for two shifts (16 hours) ⟶ en route

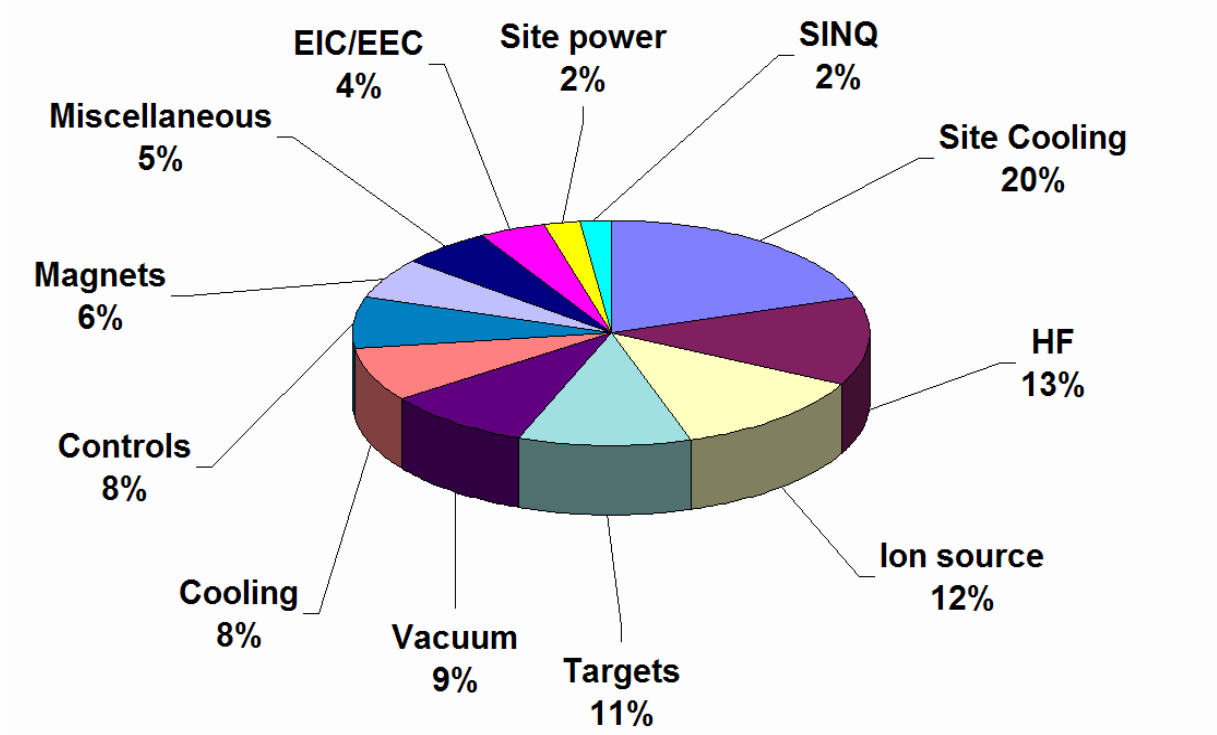
Performance statistics

For the application of cyclotrons in ADS systems the frequency of trips is of major interest

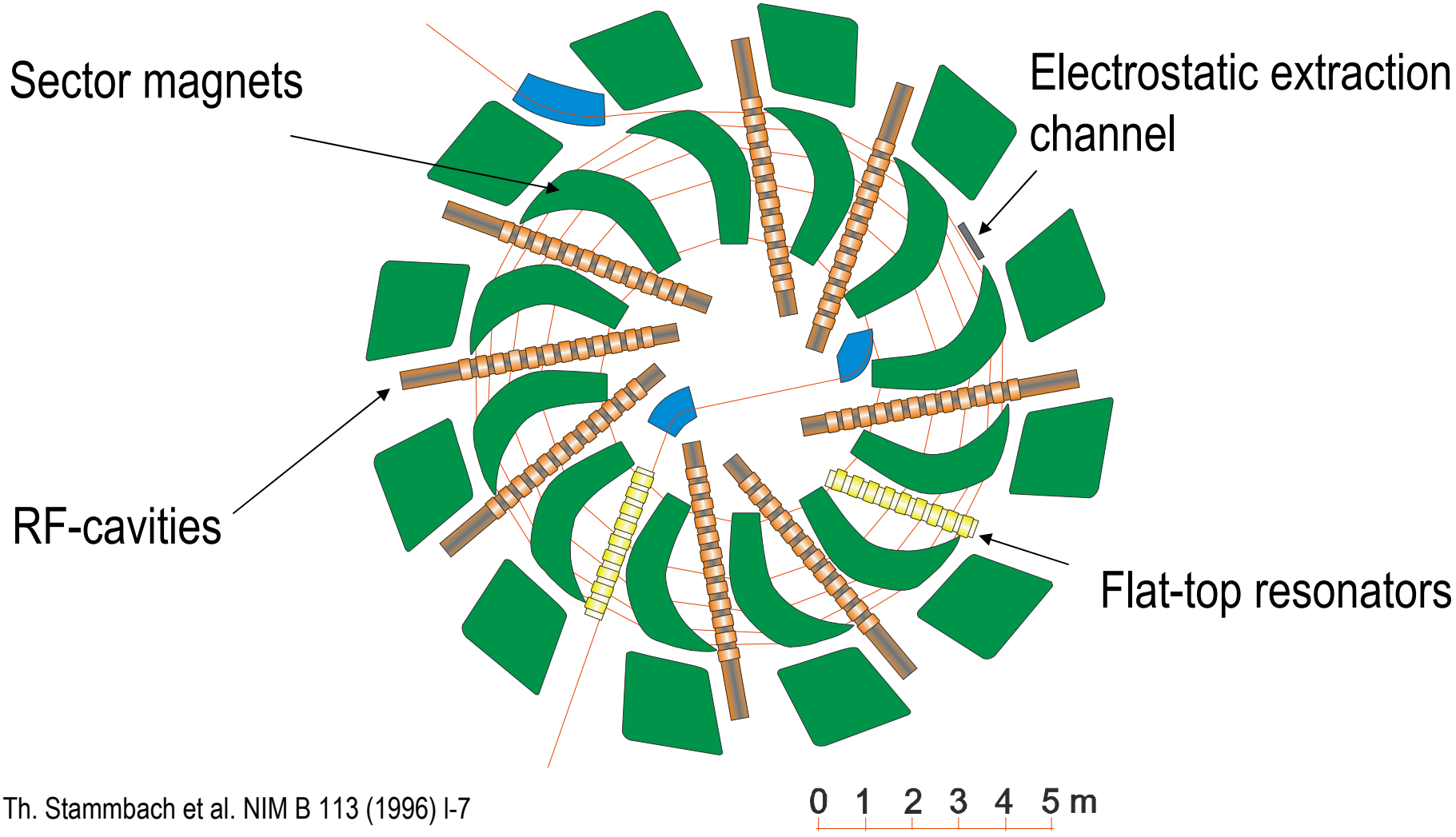


Statistics on technical failures

- 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
- **overall availability of the proton facility is now 95%**

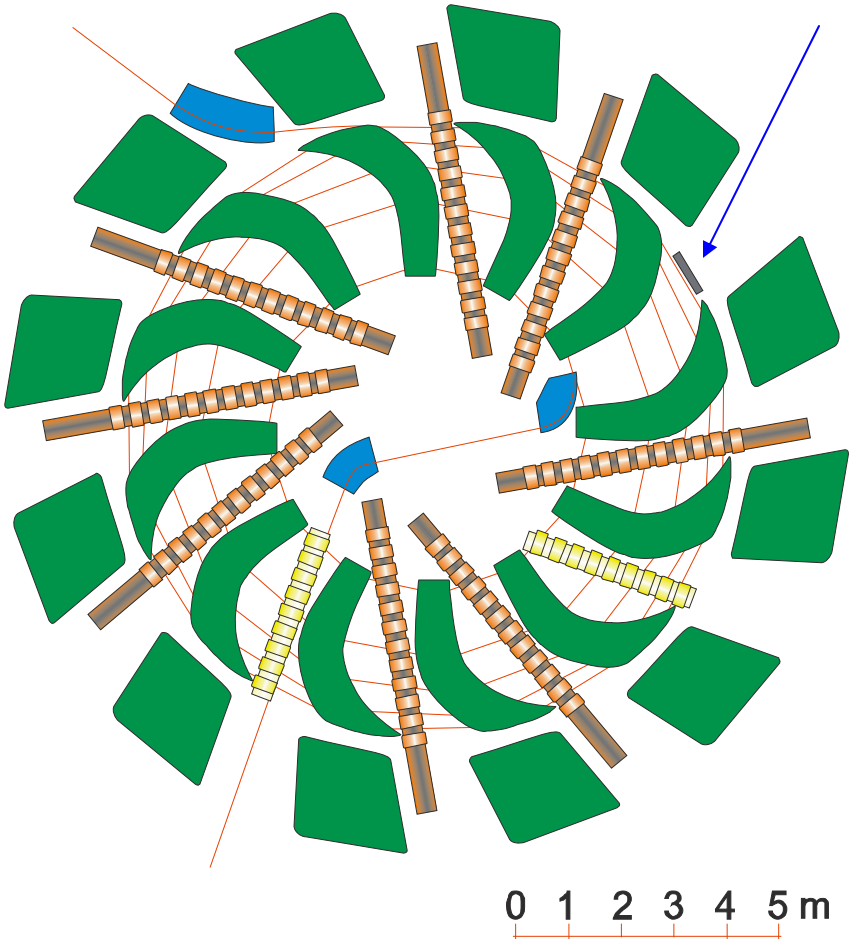


Proposal for a 10 MW driver



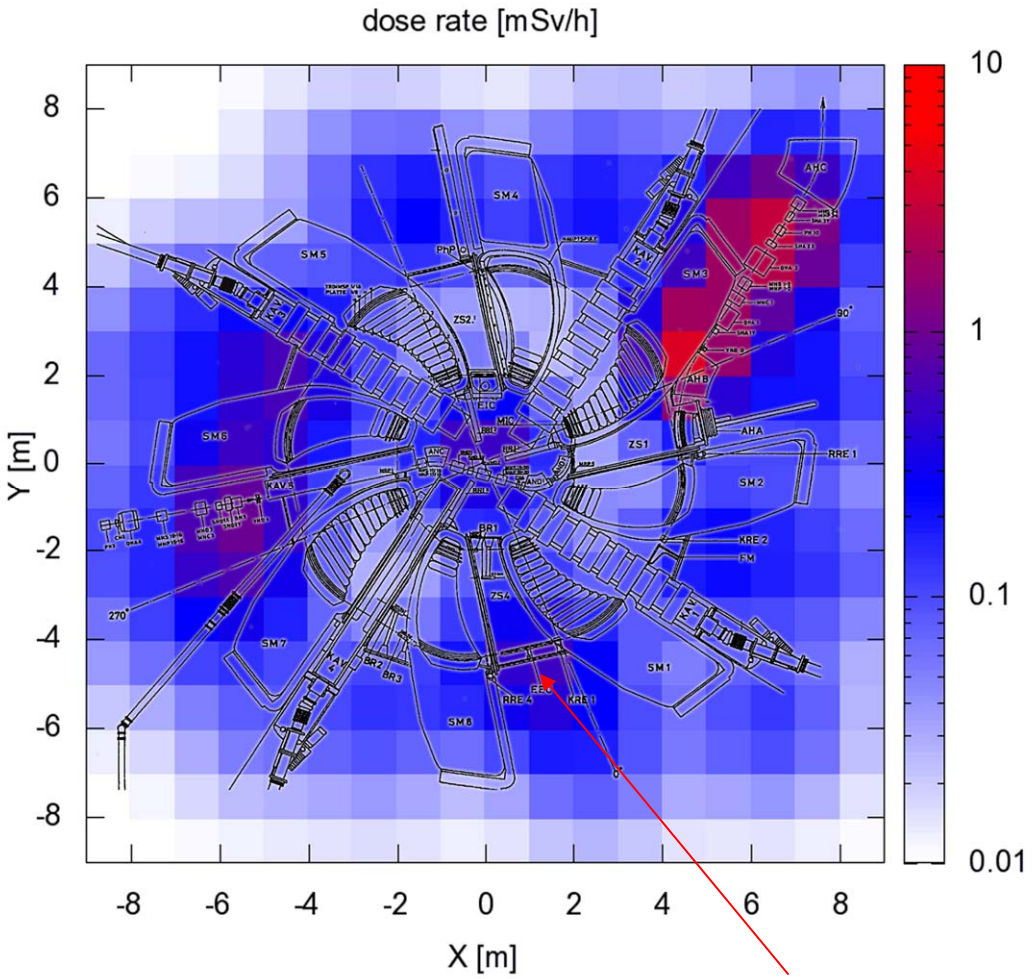
Th. Stammbach et al. NIM B 113 (1996) I-7

Electrostatic extraction channel



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 (850 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)**

Component activation – Ring Cyclotron (interpolated)



individual dose for 3 month shutdown:

57 mSv, 188 persons
max: 2.6 mSv

cool down times for service:

2000 → 1700 μA for 2h

0 μA for 2h

electrostatic extraction channel

Minimize extraction losses

Increase turn separation at extraction:

Number of turns: 140

Energy gain: 7 MeV / turn

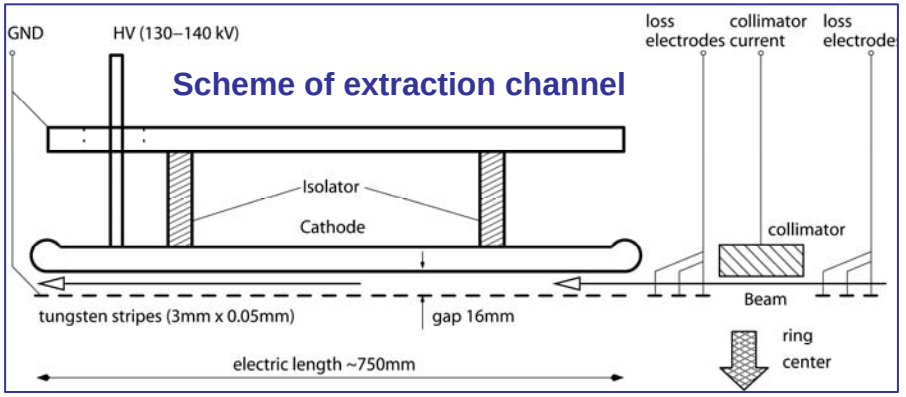
→ **1.2 MW power transfer to the beam per cavity is required for the proposed system**

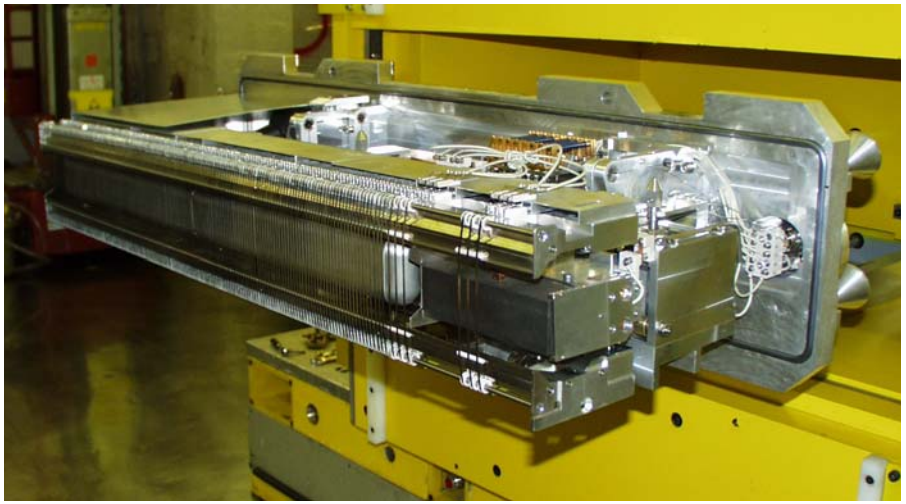
Critical: parameters of electrostatic elements

bending radius: 7 mrad

Electric field: 9 MV/m

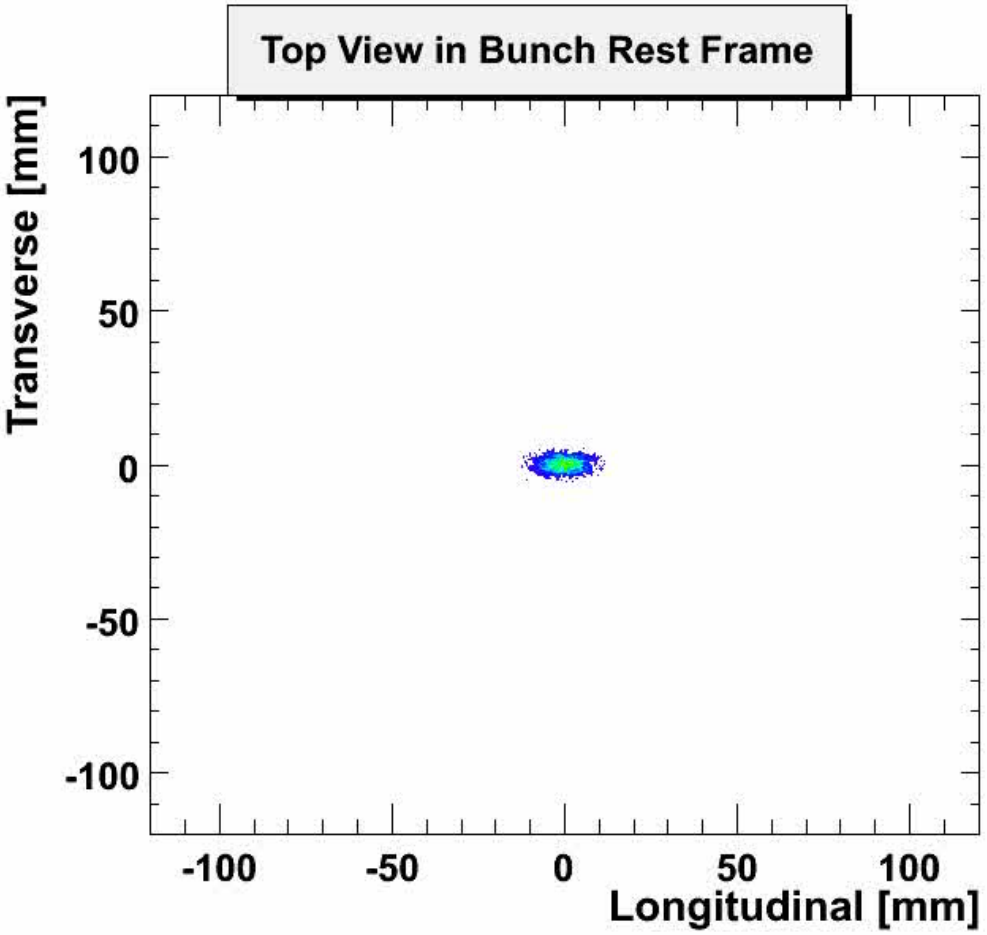
→ **150 kV between electrodes anode must be "invisible" for the beam**

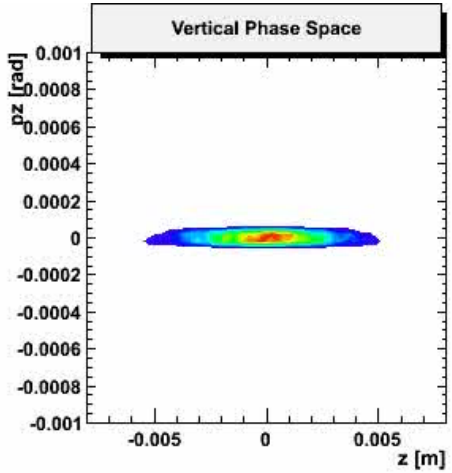


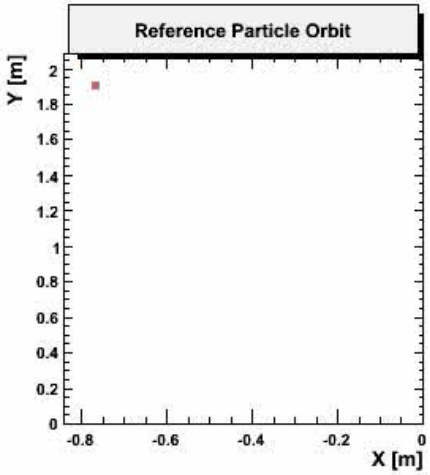


Modeling of High Intensity Beams in Cyclotrons

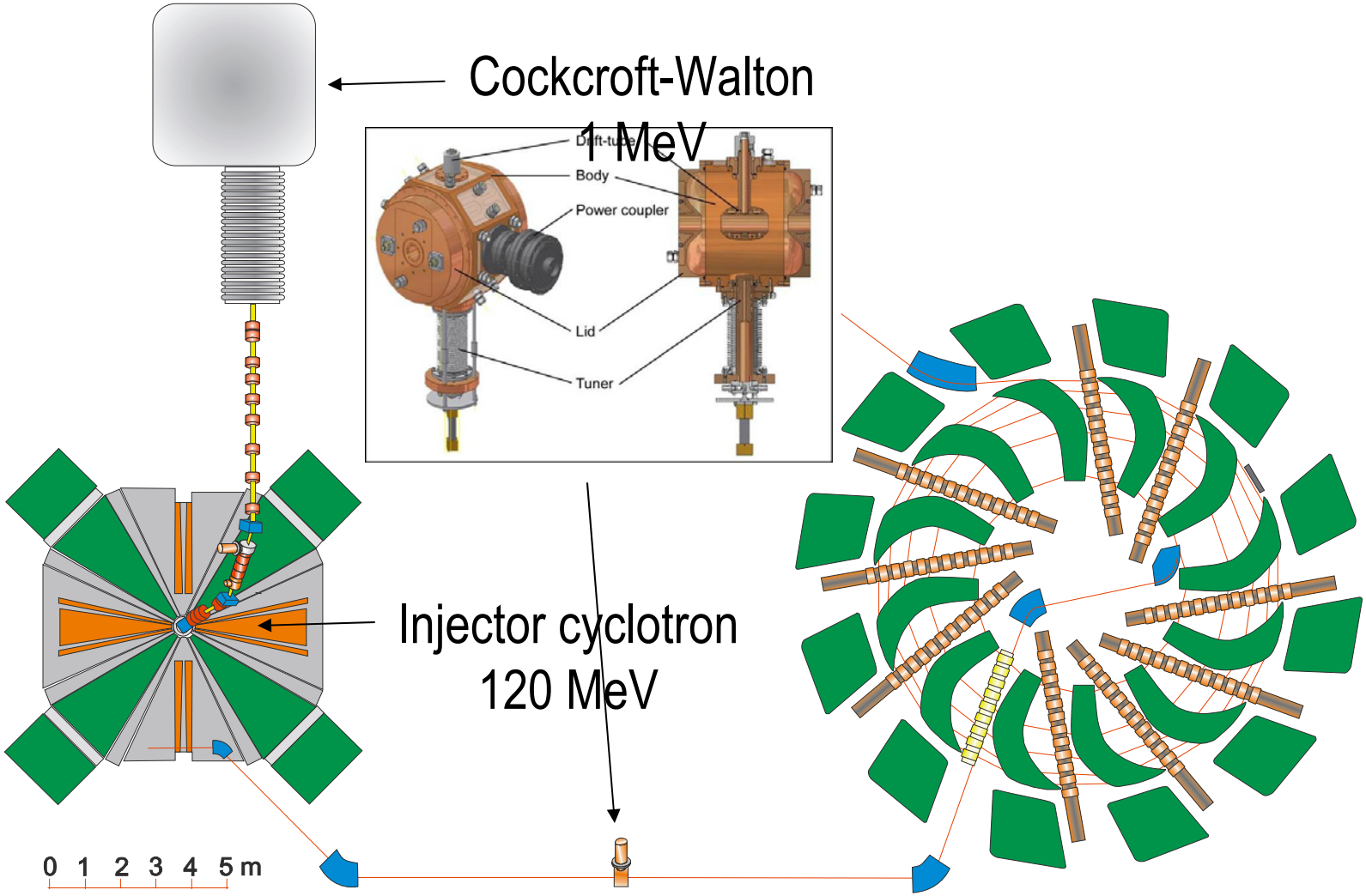
Courtesy: A. Adelmann







Avoid tail generation ⟶ 10th harmonic buncher in injection line



Therefore, we think that...

Why?

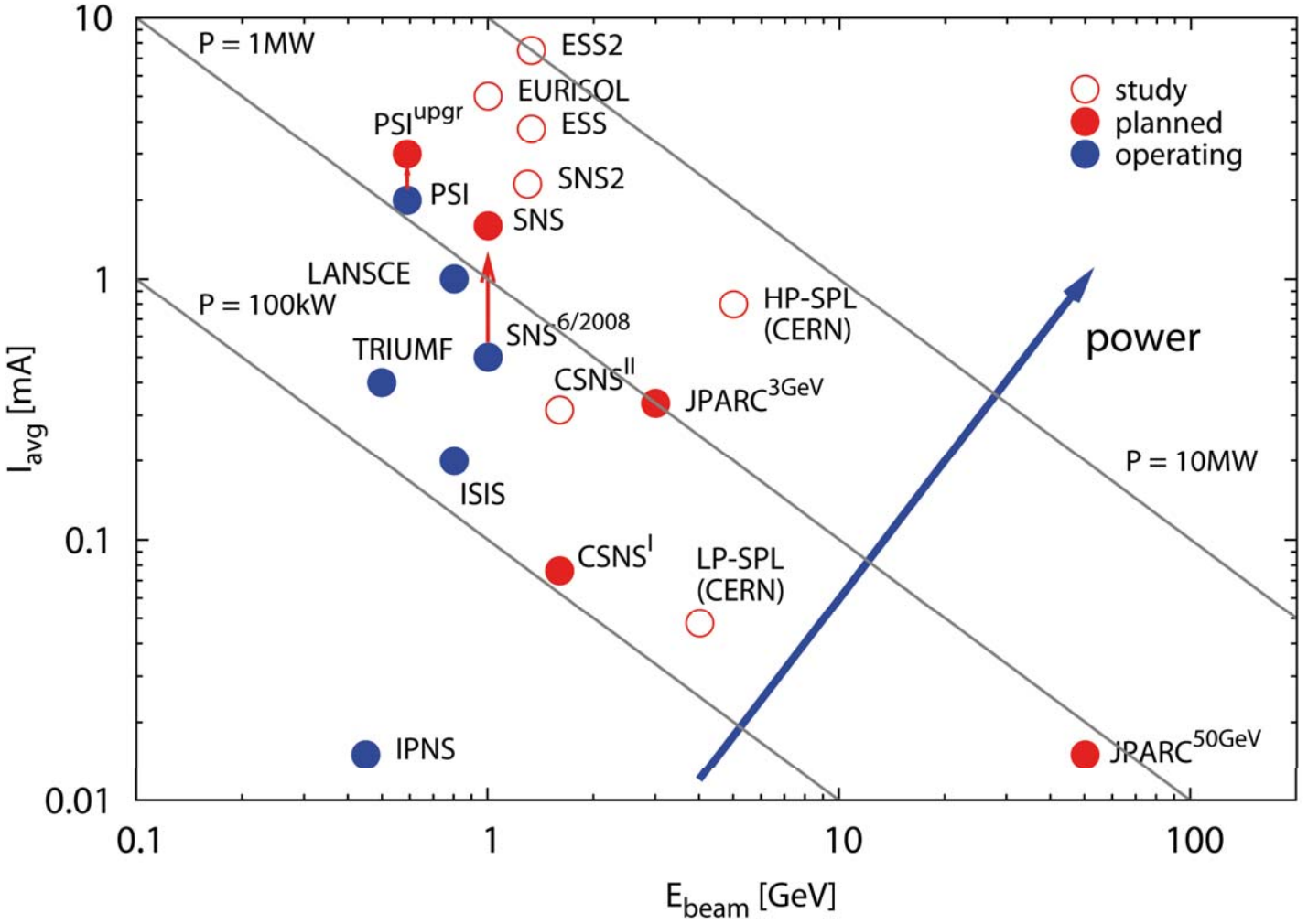
- sufficient beam-current and energy
- CW-operation
- low losses (sectors, cavities, bunchers)
- cost effective, efficiency >40%
- reasonable size
- modular design
- easy maintenance (individual dose)
- sound theoretical background

Important issues

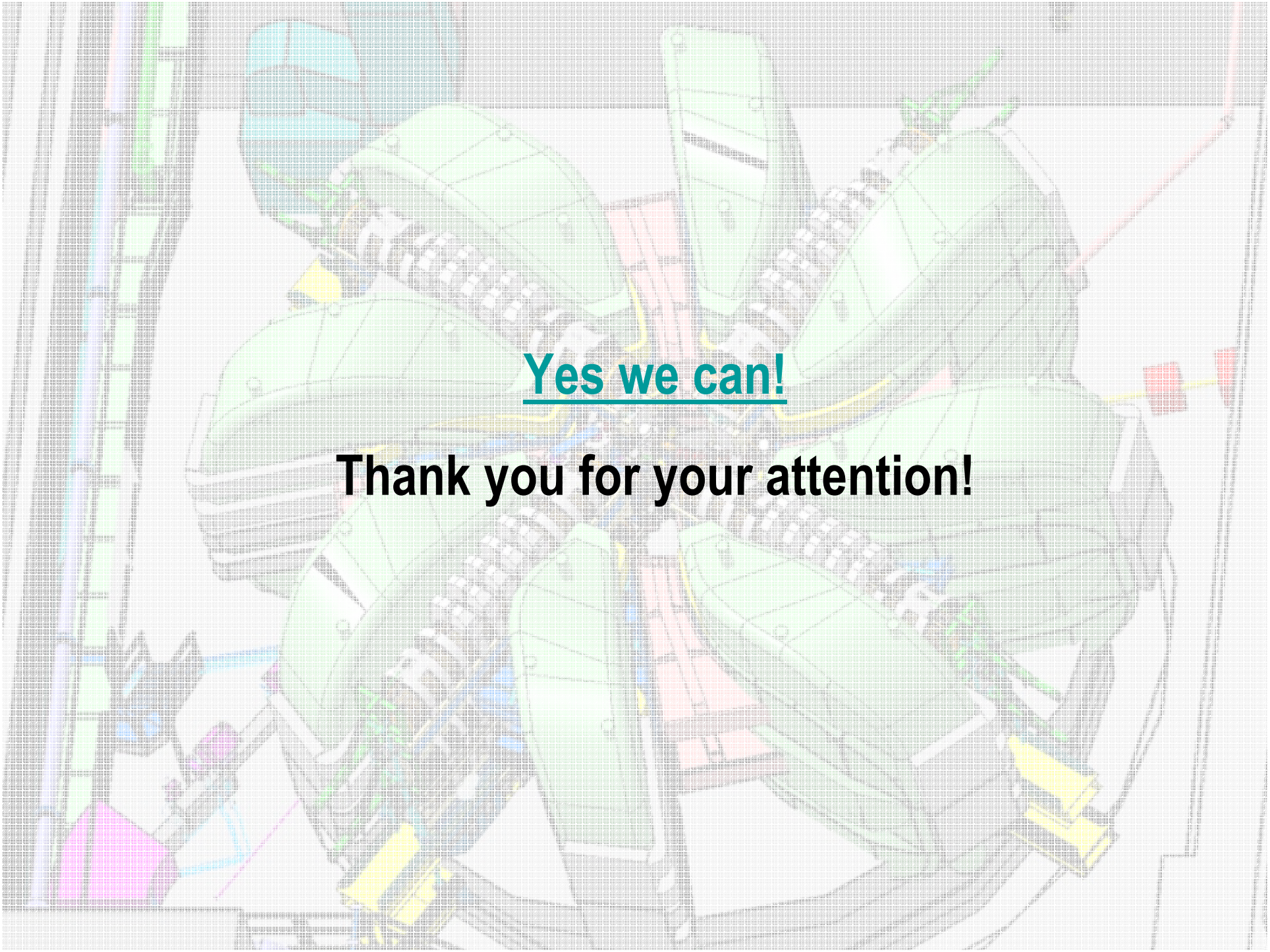
- extraction losses
- decrease number of trips (el. stat. elements)
- intercept component failure (redundancy)
- RF-design with reserve
- reliable ion source (solved: ECR)
- machine protection (diagnostics, collimators, targets)
- space charge limits (flat-tops or bunchers)
- Injector required

High Power Proton Accelerators

PSI Parameters: 2.2 mA ≙ 1.3 MW → 3mA ≙ 1.8 MW



The PSI cyclotron based facility still delivers the **highest average beam power**


Yes we can!
Thank you for your attention!