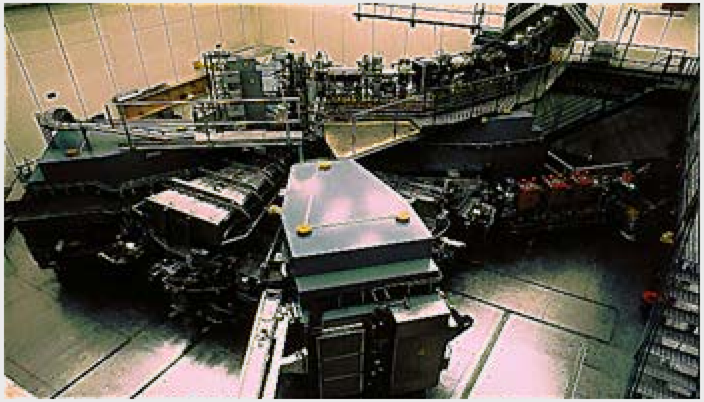
Upgrade of the PSI Proton Accelerator Facility to 1.8 MW

Pierre A. Schmelzbach for the PSI Accelerator Divisions



This talk:

- analyzes the potential for improvements from the ion source to the spallation target
- gives an overview of the work in progress

OVERVIEW

COCKCROFT-WALTON

870 keV TRANSFER LINE

INJECTOR 2

IP

72 MeV TRANSFER LINE

590 MeV CYCLOTRON

2 mA /1.2 MW

3 mA /1.8 MW

TARGET E

TARGET M

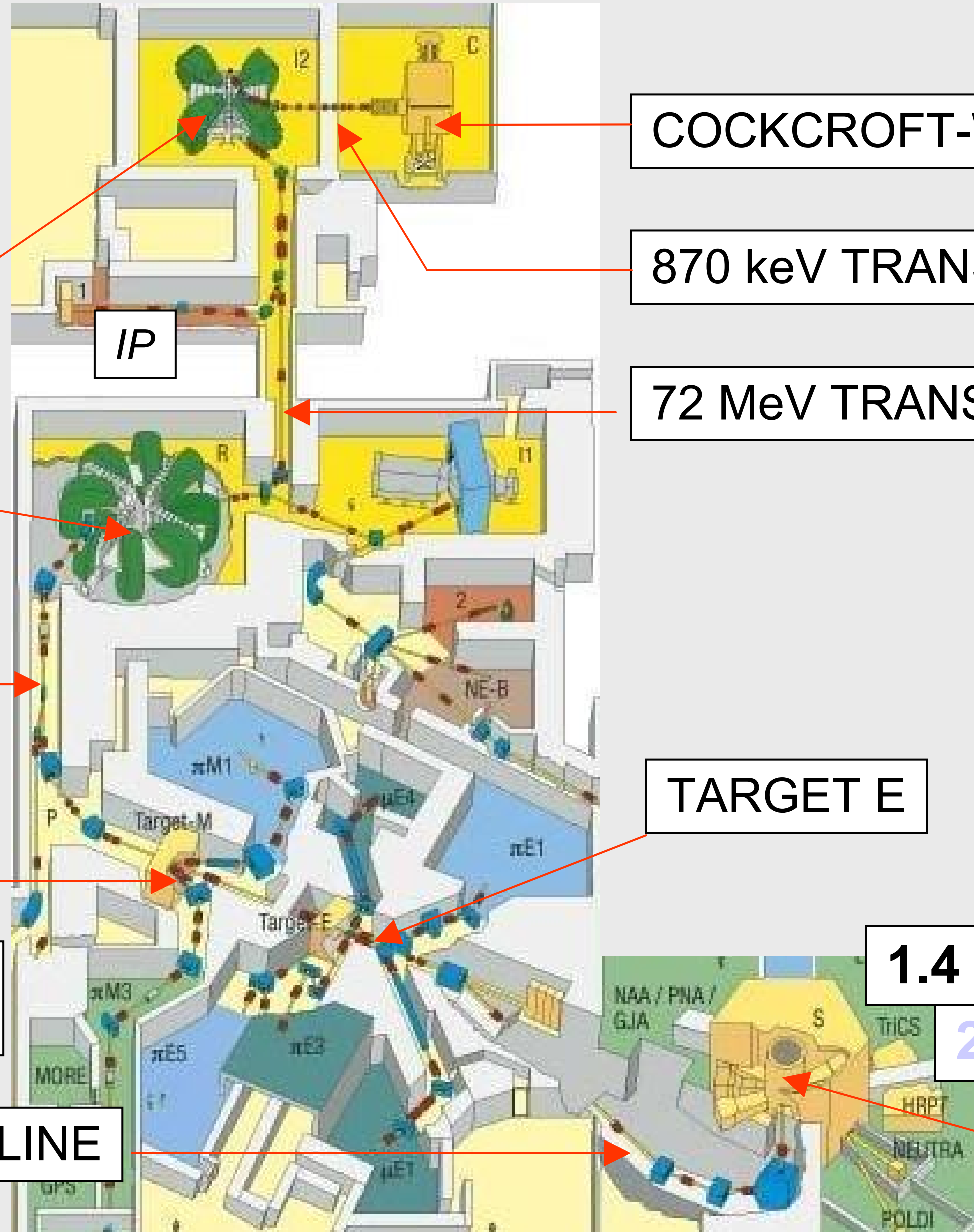
Protontherapy (+ 2006)
UCN (in construction)

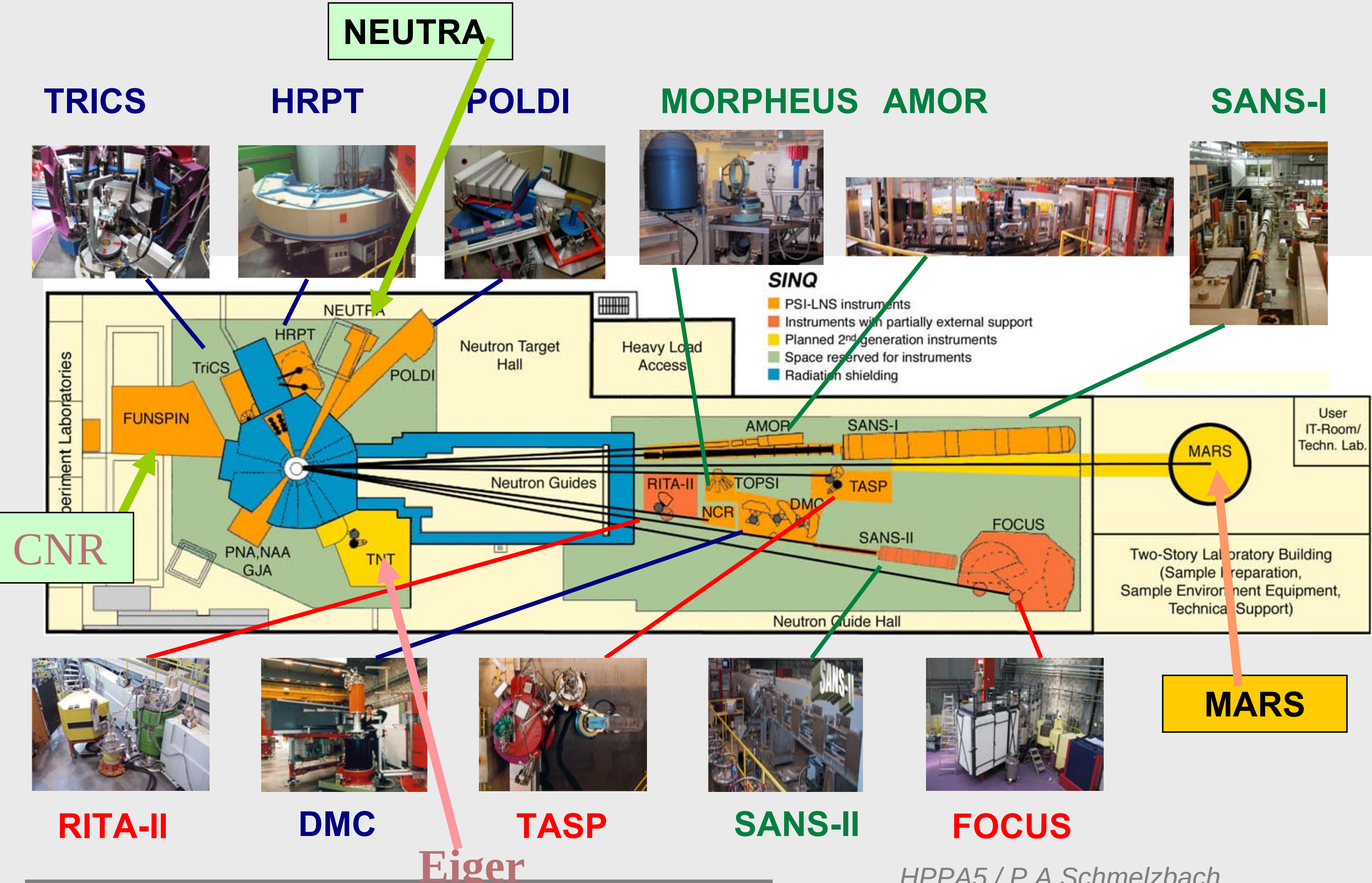
1.4 mA /.8 MW

2 mA /1.1 MW

SINQ TRANSFER LINE

SINQ




NEUTRA
TRICS
HRPT
POLDI
MORPHEUS
AMOR
SANS-I
SINQ
PSI-LNS instruments
Instruments with partially external support
Planned 2nd generation instruments
Space reserved for instruments
Radiation shielding
NEUTRA
HRPT
TriCS
POLDI
FUNSPIN
Experiment Laboratories
Neutron Target Hall
Heavy Load Access
Neutron Guides
AMOR
SANS-I
RITA-II
TOPSI
TASP
NCR
DMC
SANS-II
FOCUS
MARS
User IT-Room/ Techn. Lab.
Two-Story Laboratory Building (Sample Preparation, Sample Environment Equipment, Technical Support)
Neutron Guide Hall
PNA,NAA
GJA
TNT
CNR
RITA-II
DMC
TASP
SANS-II
FOCUS
MARS
Eiger

Basic Considerations for Design and Operation

Accelerators: Cyclotrons with large turn separation at the extraction

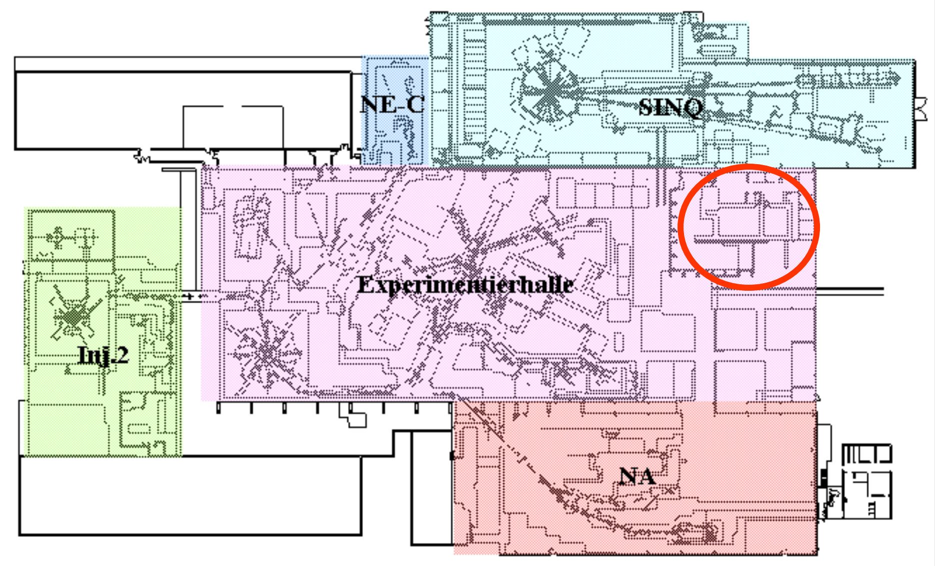
Losses: Extraction from Injector Cyclotron, injection and extraction from Ring Cyclotron: **< 0.5 μA** each

Beam lines: **< 1nA / m**

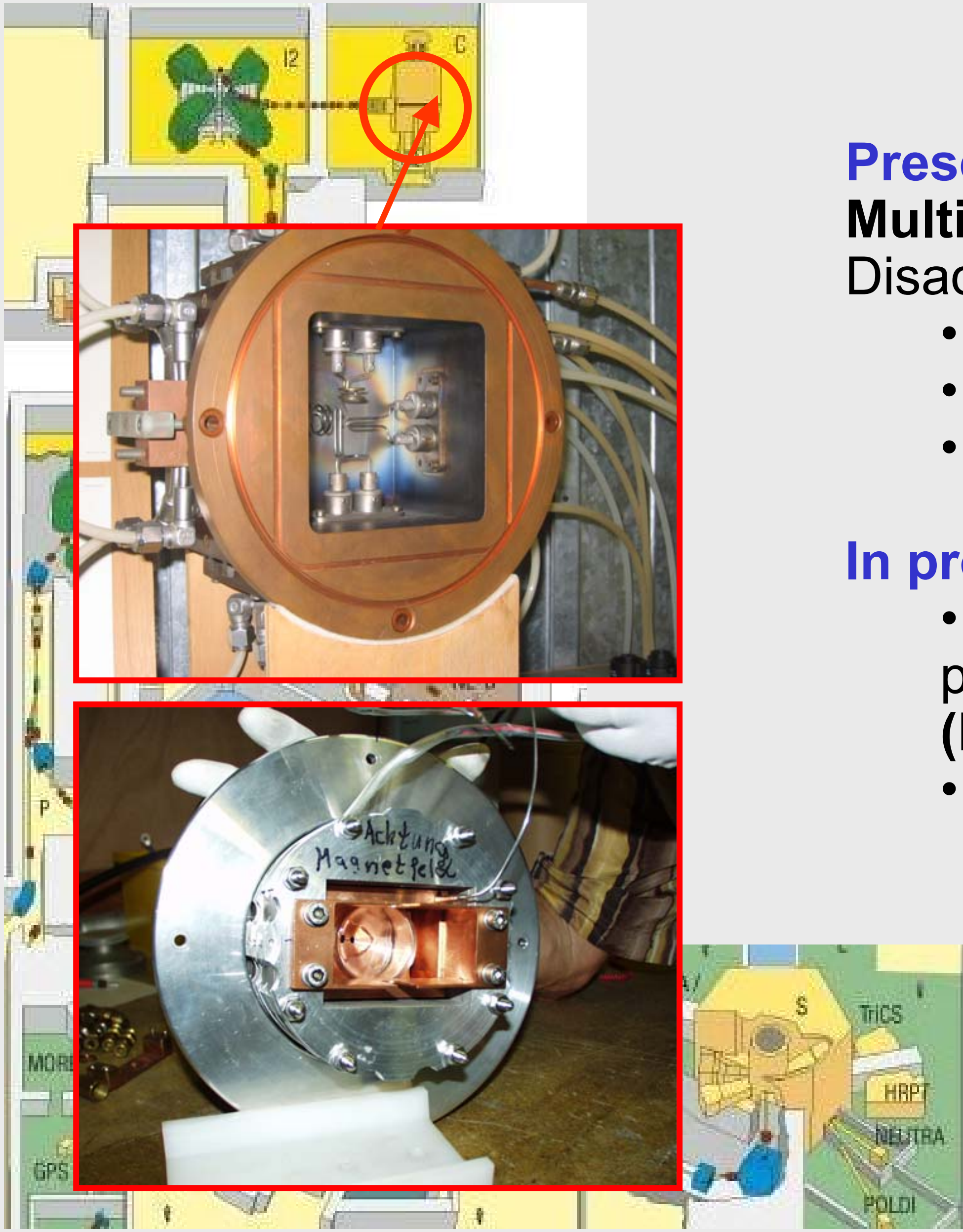
Local shielding

Remote handling

Repairs in hot cell located in machine / experimental hall



ION SOURCE



Present:

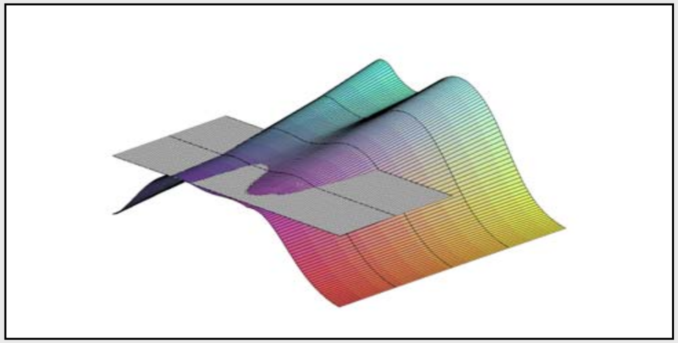
Multicusp ion source

Disadvantages:

- poor proton efficiency
- stability
- maintenance

In progress:

- development of a compact, permanent magnets, **microwave (ECR) ion source**
- will be installed in 2008

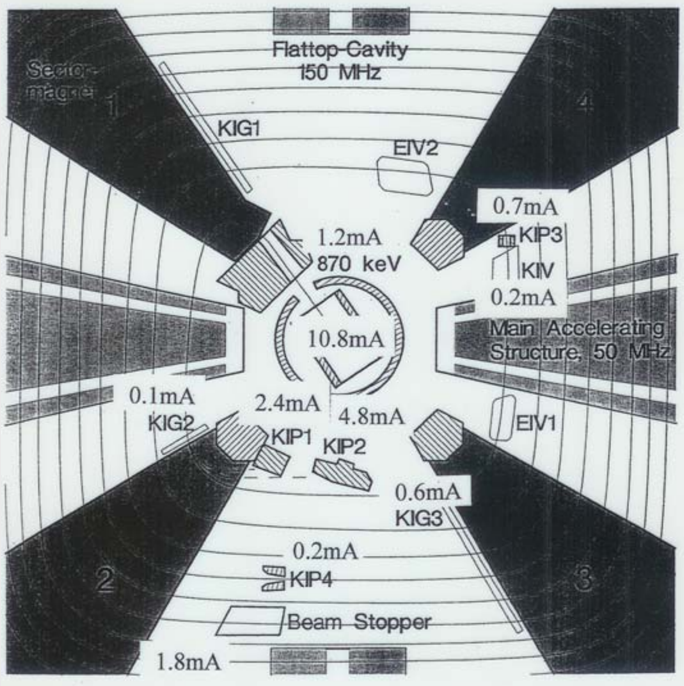


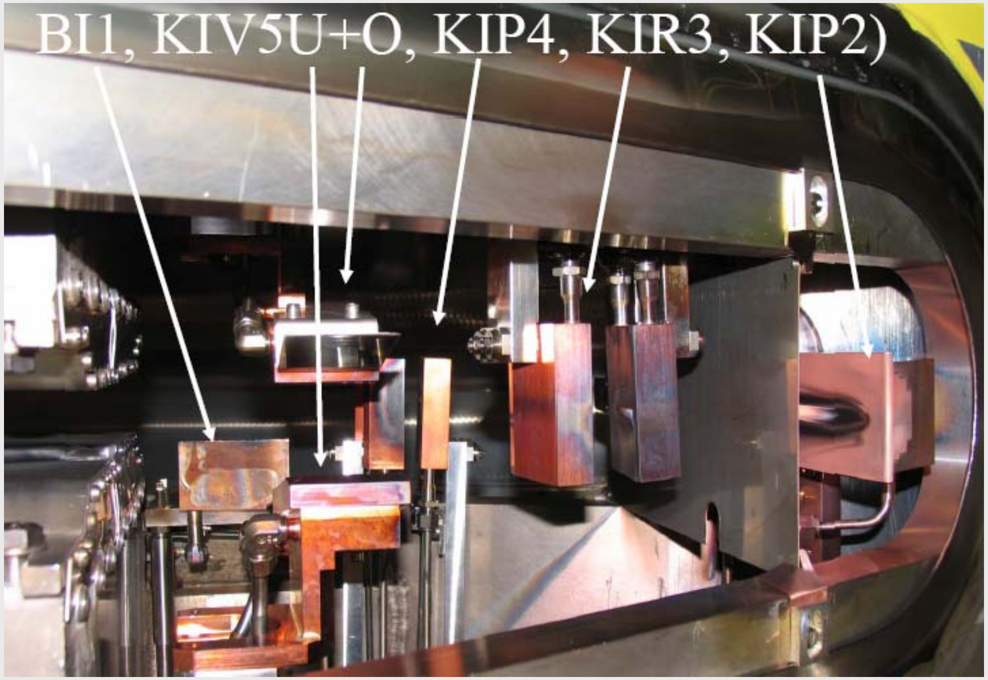
INJECTOR CYCLOTRON

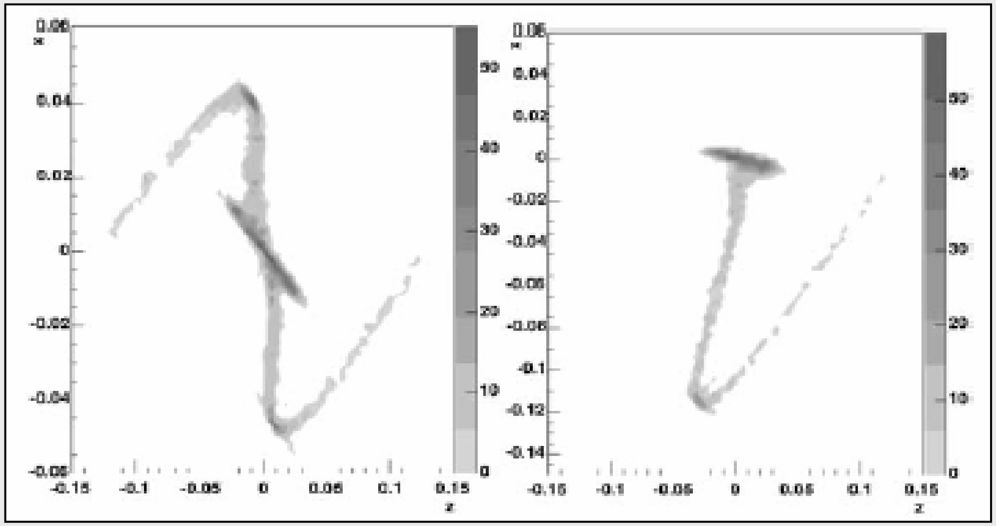
Beam Injection

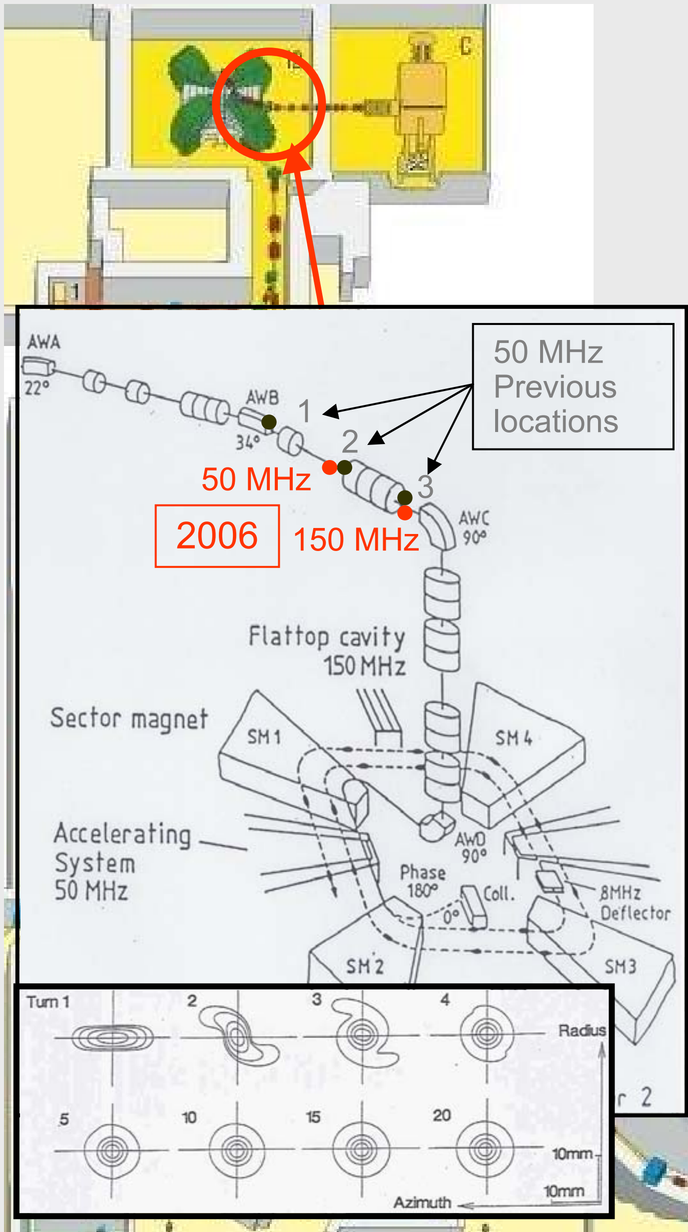
Beam collimation in the centre region Inj.2

- **ion source** DC beam current	**12.0mA**
collimators in the 870keV beam transport line	1.2mA
- **injected beam current**	**10.8mA**
phase defining collimator (KIP1 & KIP2)	7.2mA
- beam current **accepted on the 1st turn**	**3.6mA**
collimation of phase tails on the 1st turn (KIP3)	0.7mA
vertical collimation (KIG1,KIG2,KIG3,KIV)	0.9mA
radial collimation on the 4th turn (KIP4)	0.2mA
- **accelerated beam** current	**1.8mA**



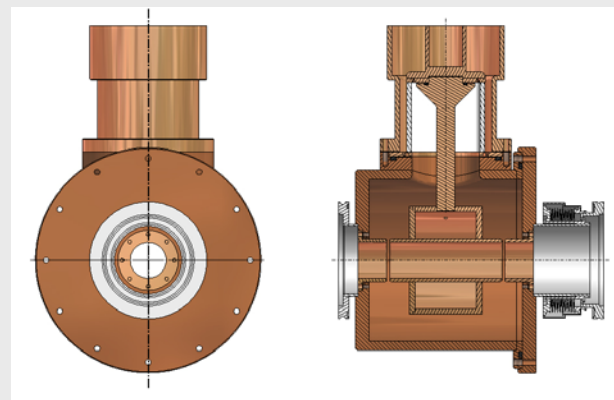






Goal: 2.2 mA >> 3.3 mA from Injector Cyclotron

First step: inject more beam
Implementation of a second buncher (3^{rd} harmonic → 150 MHz) in the horizontal line before the vertical deflection

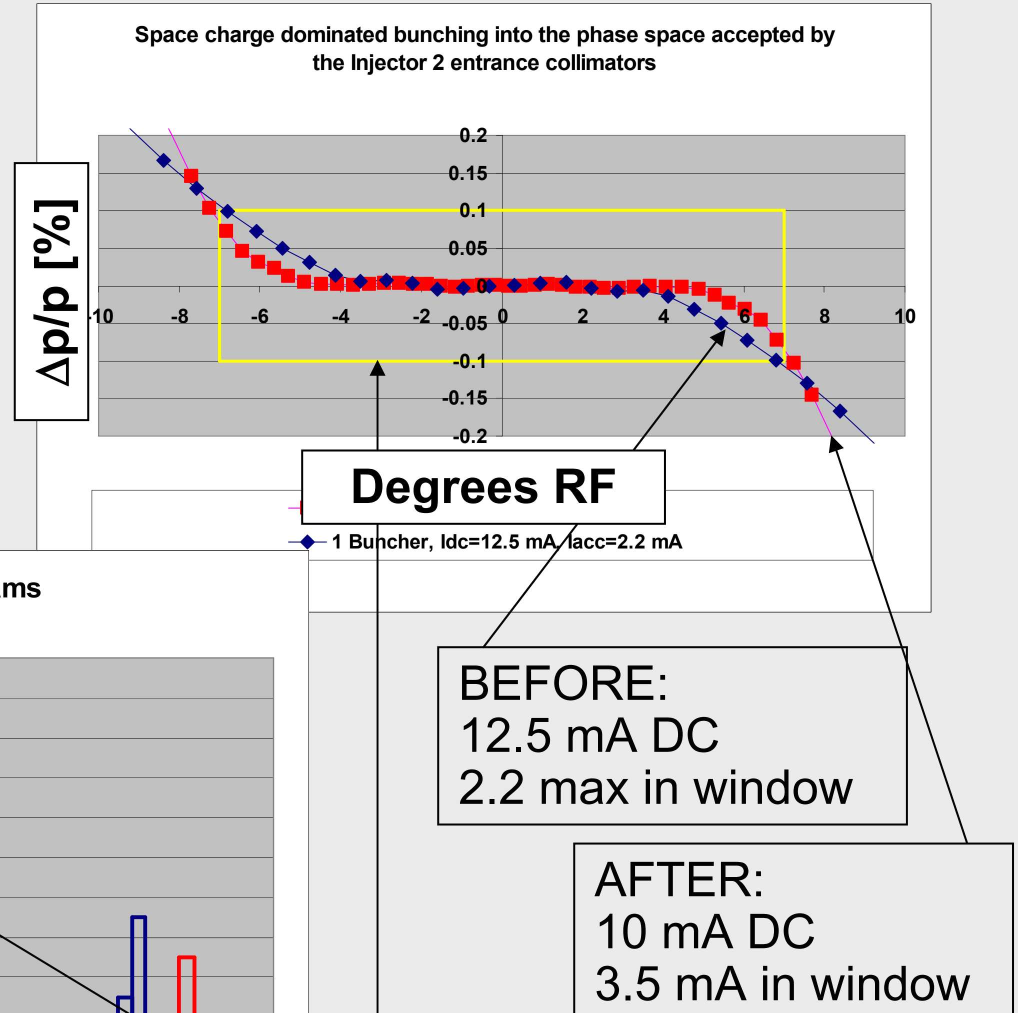


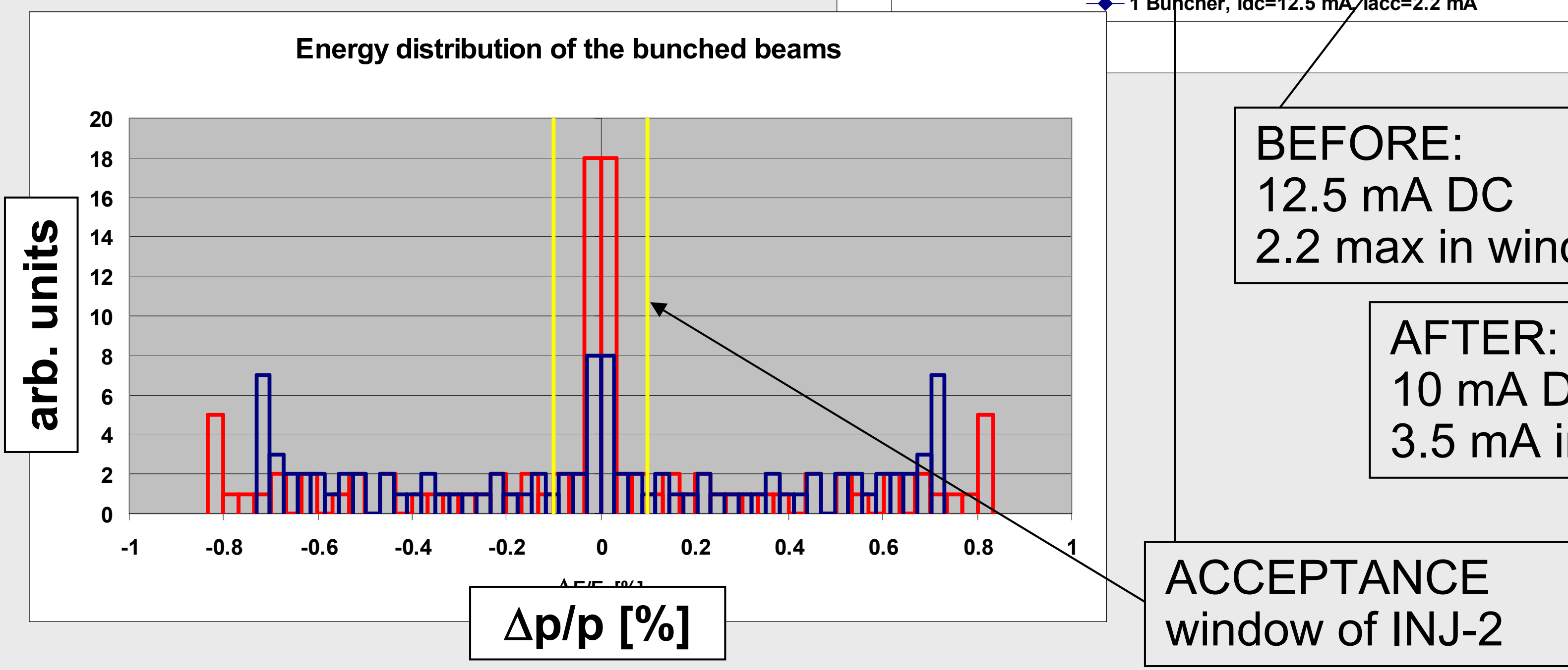
Status

- Installation in SD 2006, now in operation
- Beam width at extraction: for 2.4 mA same as previously at 2 mA ☺ ☺

870 keV TRANSFER LINE

The integration of the bunchers at available locations satisfies the requirements for a more efficient “round beam” injection into Inj. 2





INJECTOR CYCLOTRON

Step 2: acceleration / extraction >> simulation of space charge effects >> “round beam” acceleration mode >> current limit

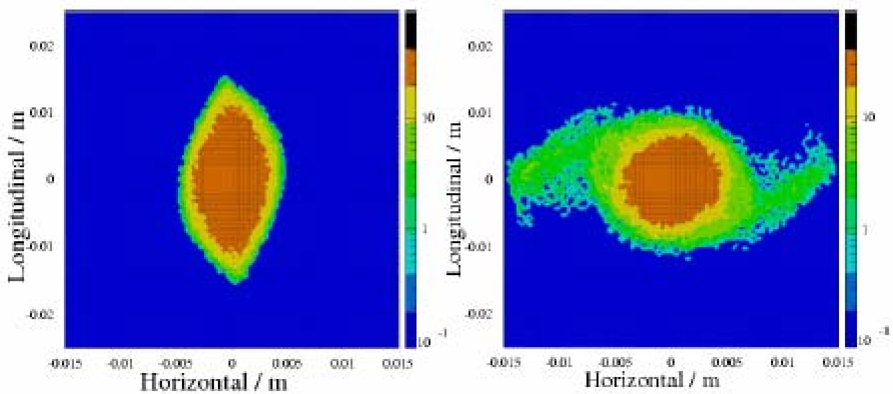


Figure 4 (color): Charge density in a.u.: Turn 1 and 6.

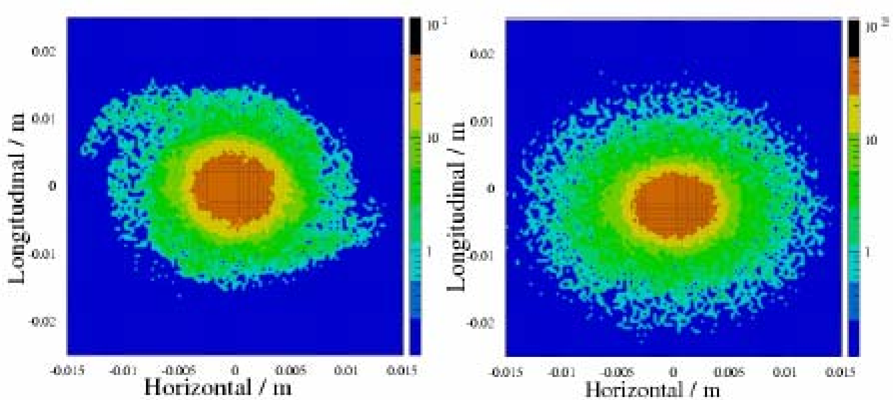
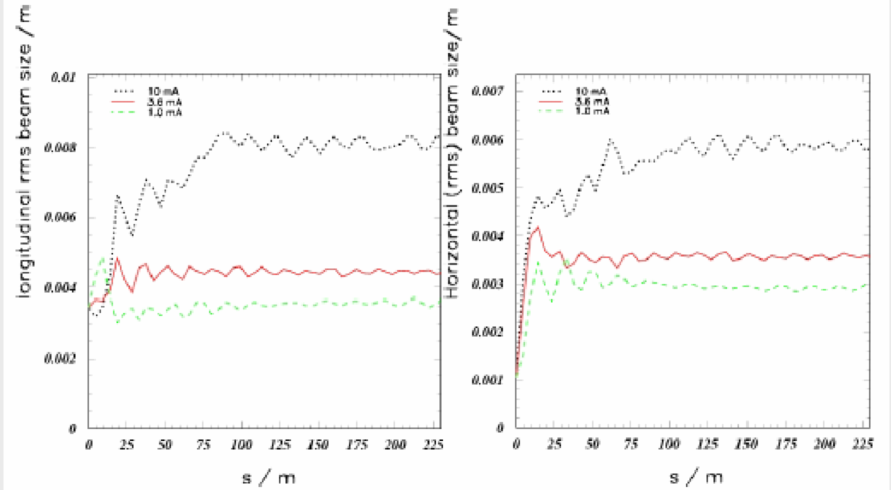
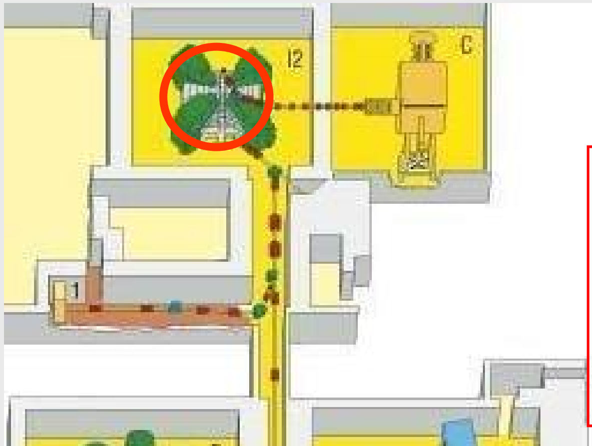


Figure 5 (color): Charge density in a.u.: Turn 10 and 60.

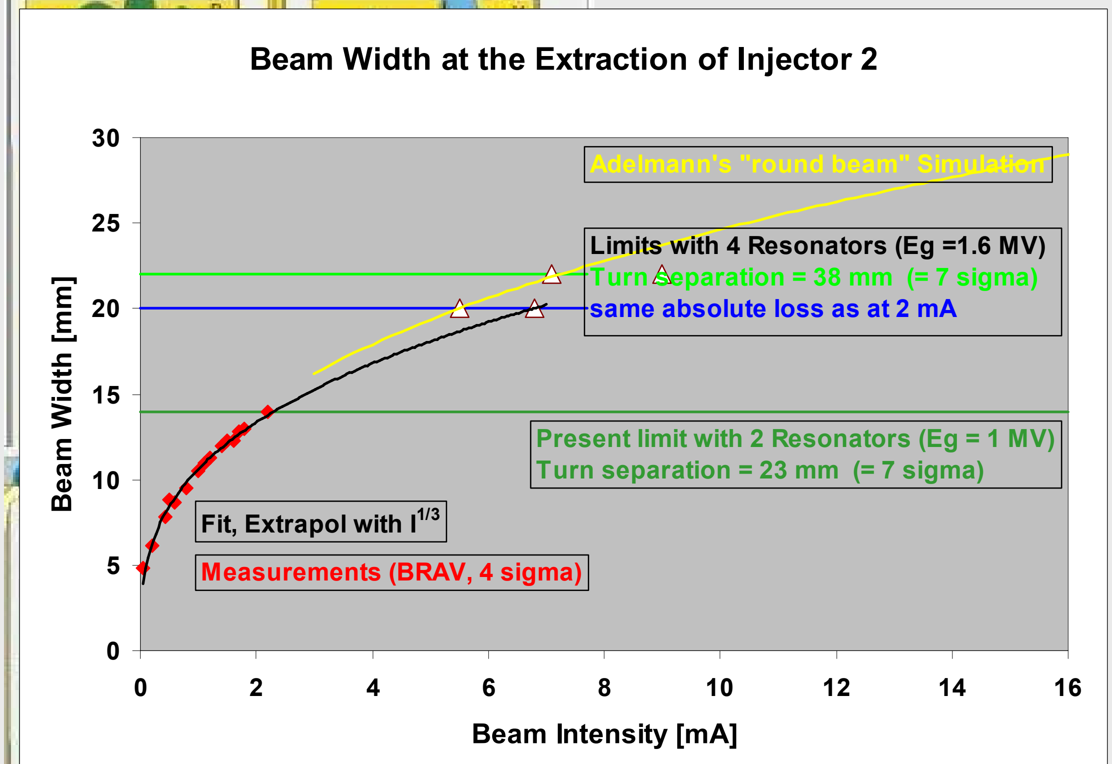


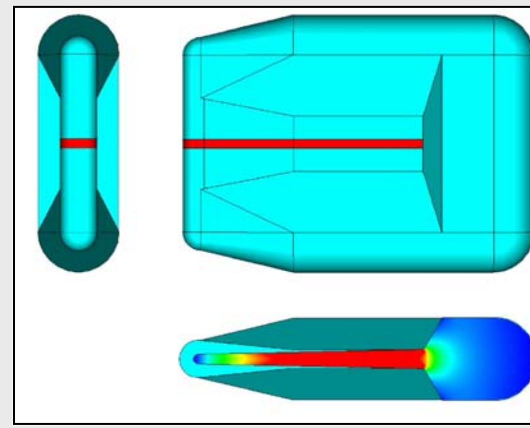
Phase width of the extraxted beam (after 90 turns) is about 2° rf
Good agreement between calculations and measurements

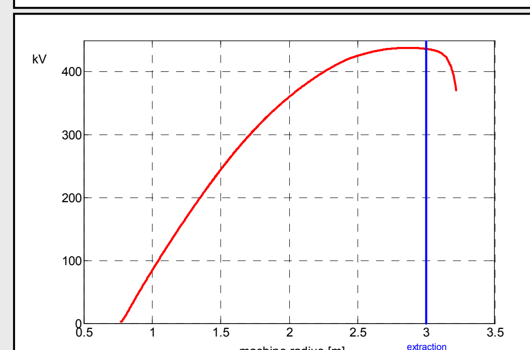
INJECTOR CYCLOTRON



In the “round beam” acceleration mode the flat-top cavities are obsolete → Replacement of the flat-top system by 50 MHz accelerating cavities

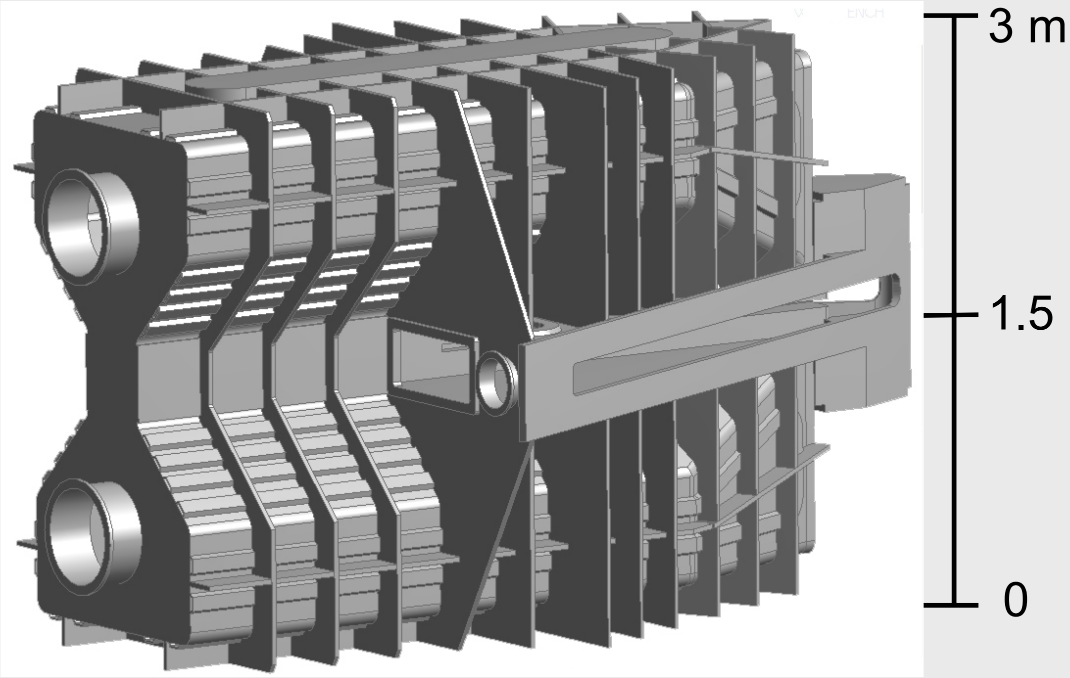


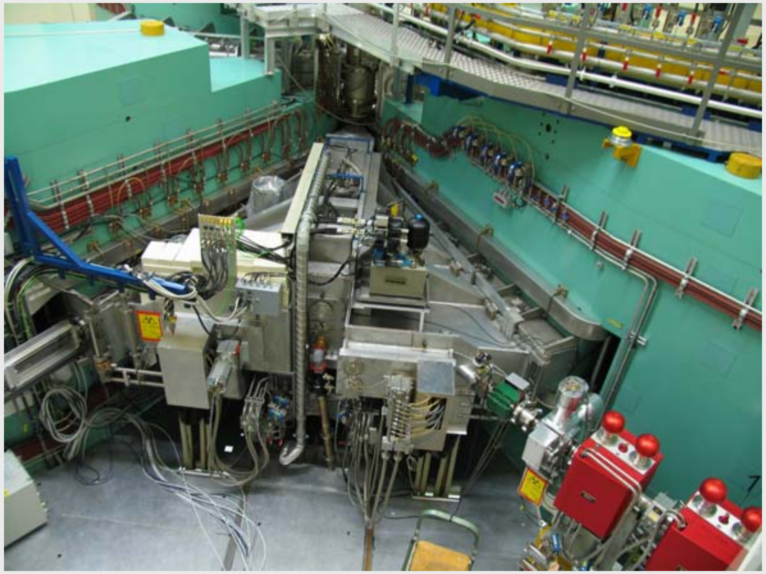




50 MHz RESONATOR for INJECTOR-2 (>2009)

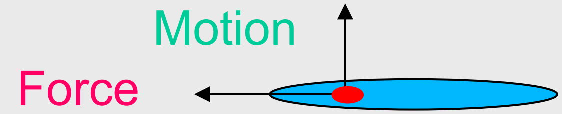
Frequency	50.6 MHz
Gap voltage	500 kV
Dissipated power	120 kW
Cavity wall	Alu 99.5



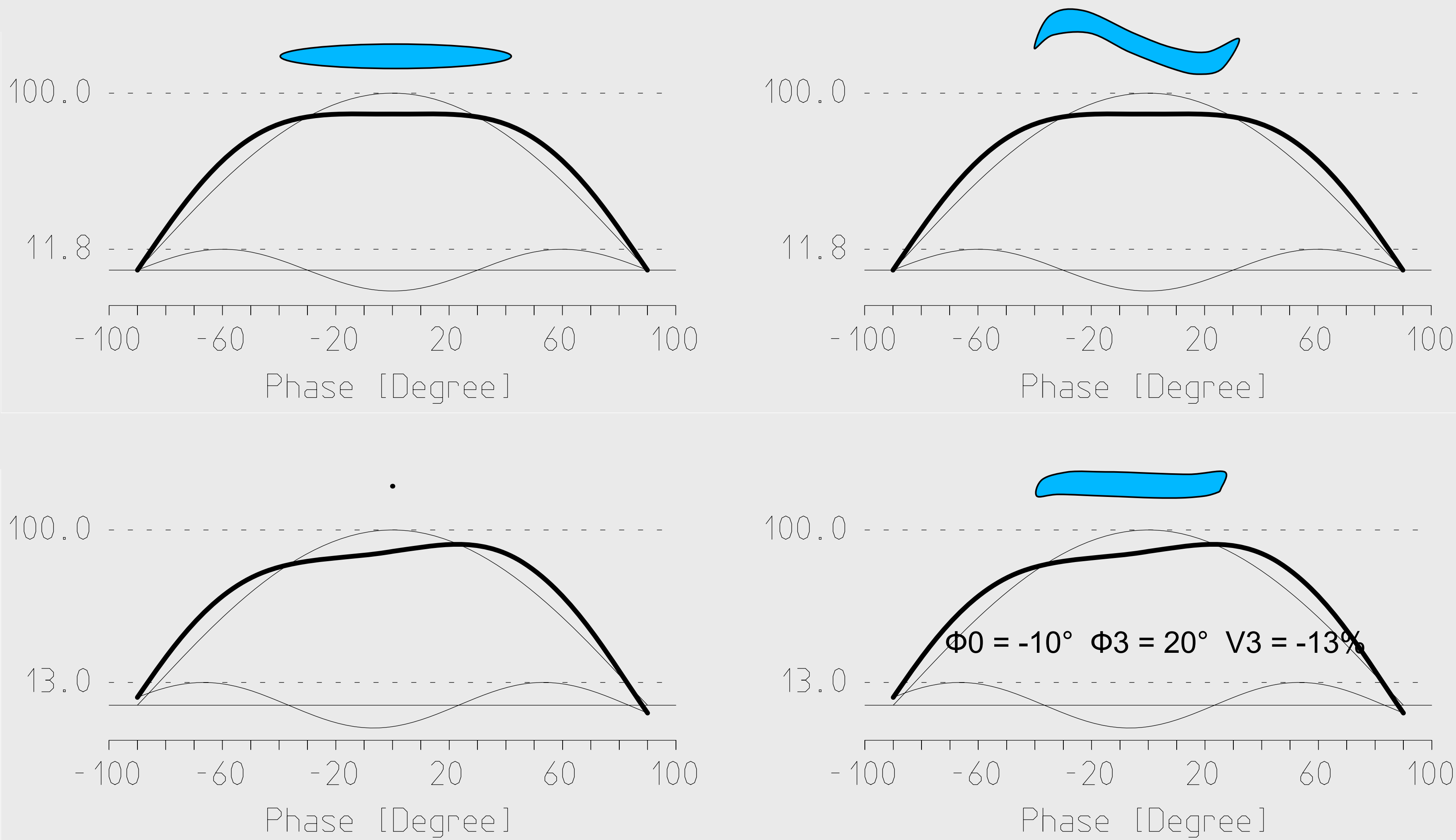


Injektor 2, Resonator 4

Flat-top and space charge



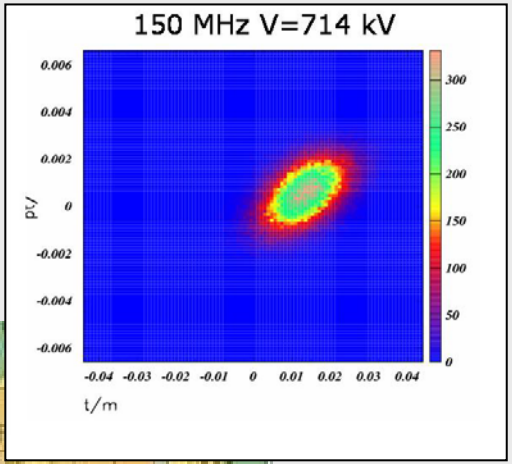
with SC

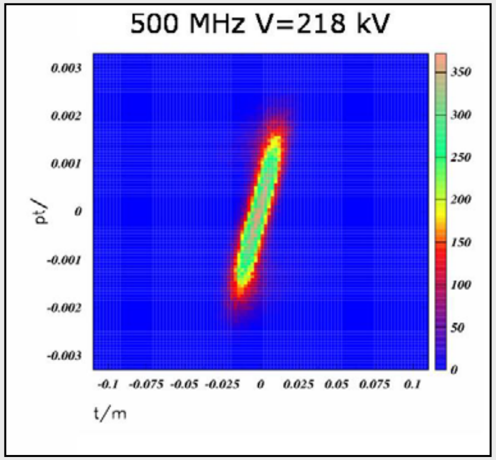


72 MeV TRANSFER LINE

Implementation of a buncher

- To optimize the phase width of the beam at the injection into the main cyclotron
- To allow for operation up to 2.5 mA with the present flat-top cavity
- To allow for "round beam" acceleration in the Ring Cyclotron (?)

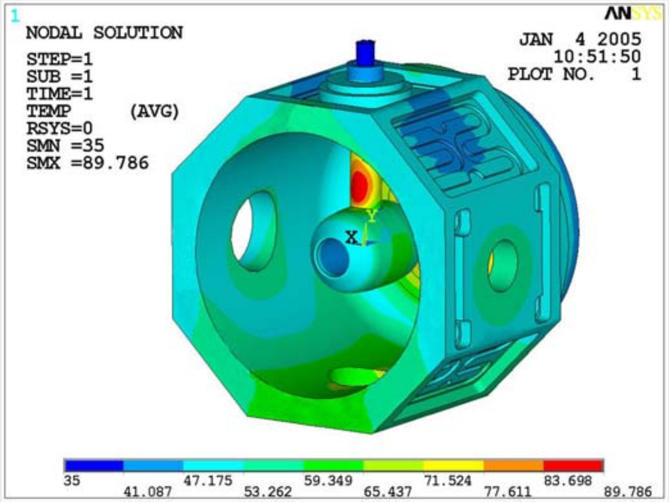


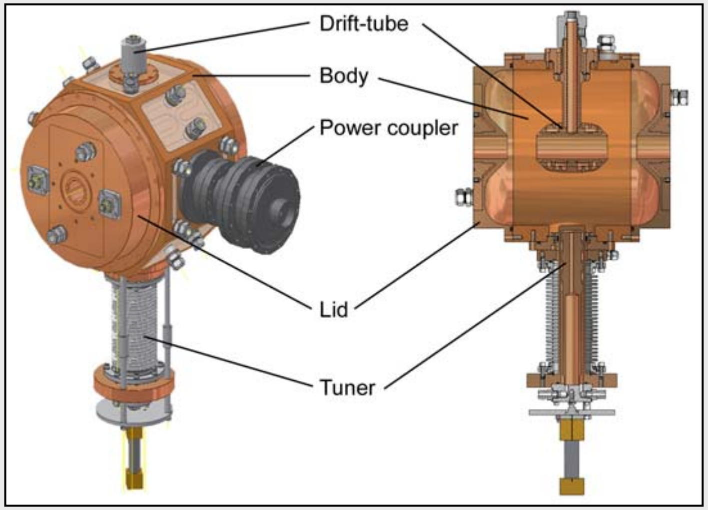


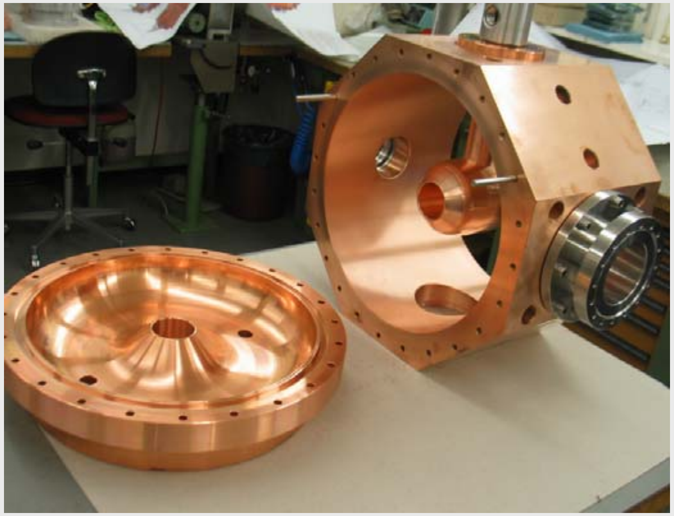
72 MeV BUNCHER

Status

♣Built, but no power tests yet
♣Infrastructure installed in SD 2006/7



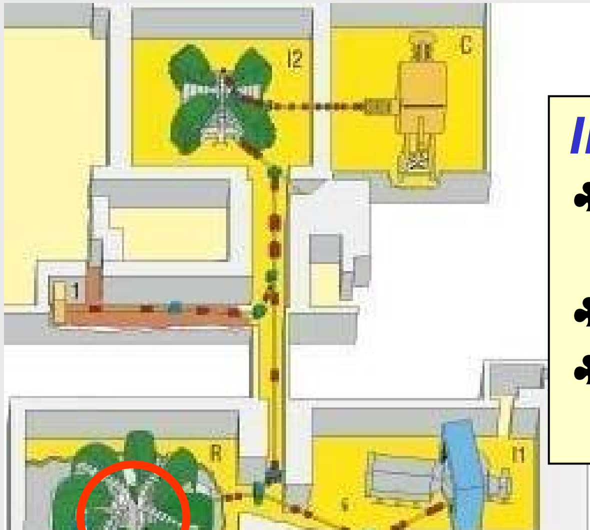




Technical data:

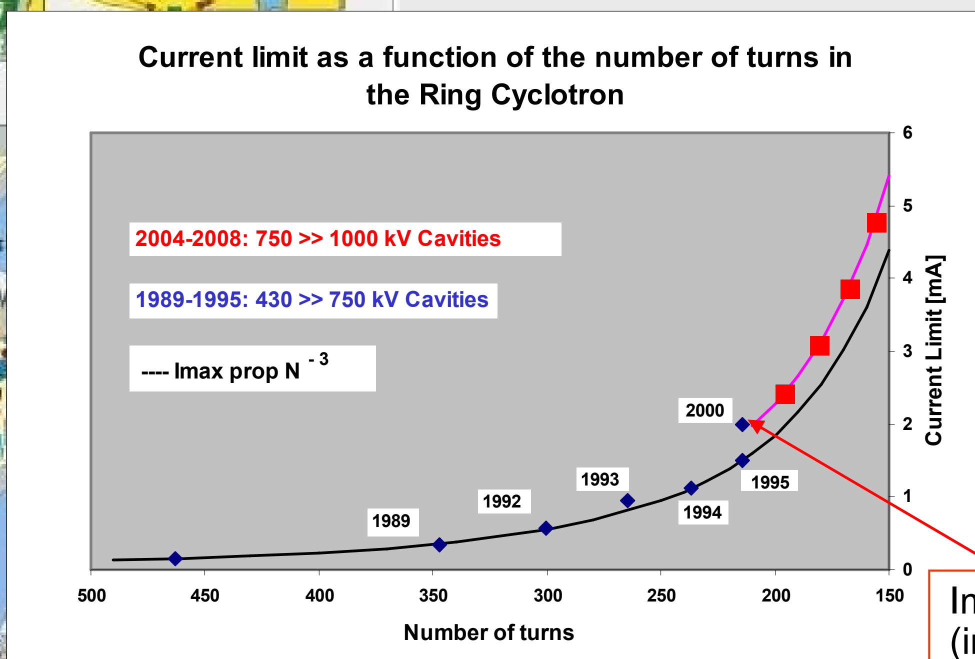
506 MHz 2-gap drift tube cavity
218 kVpp RF-voltage per gap
30 kW power (op. 10 kW)

RING CYCLOTRON



IN PROGRESS

- ♣Replacement of old cavities – 2 now installed. All four available in 2008.
- ♣Test of 180 kW amplifier for flat-top cavity
- ♣Investigation of the feasibility of the “round beam” mode of acceleration.



Joho: limit due to space charge prop. N^{-3}

General: Same dependence if emittance of injected beam included

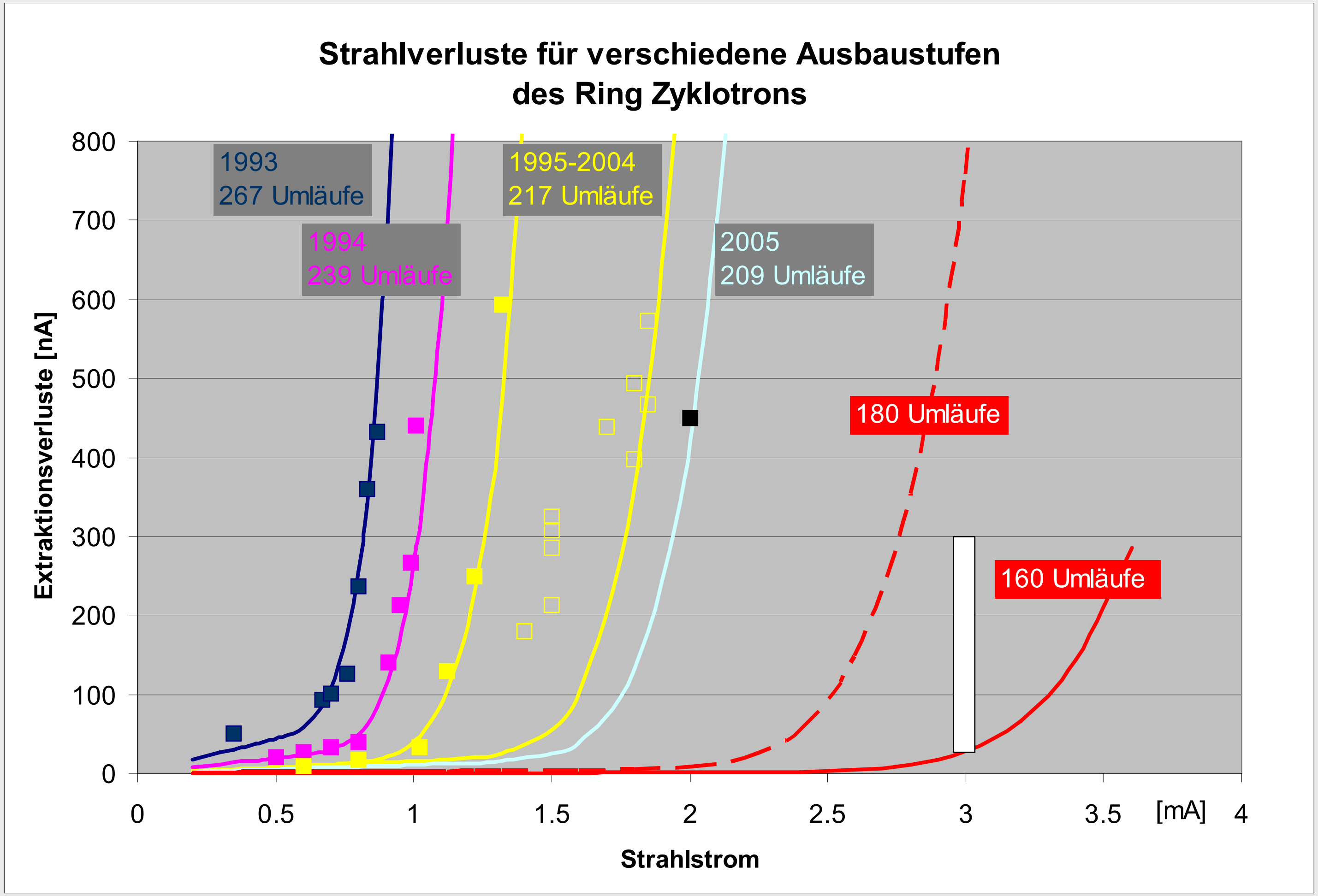
>> $dx/(dR/dn) = .6$ or $dR/dn = 7\sigma$

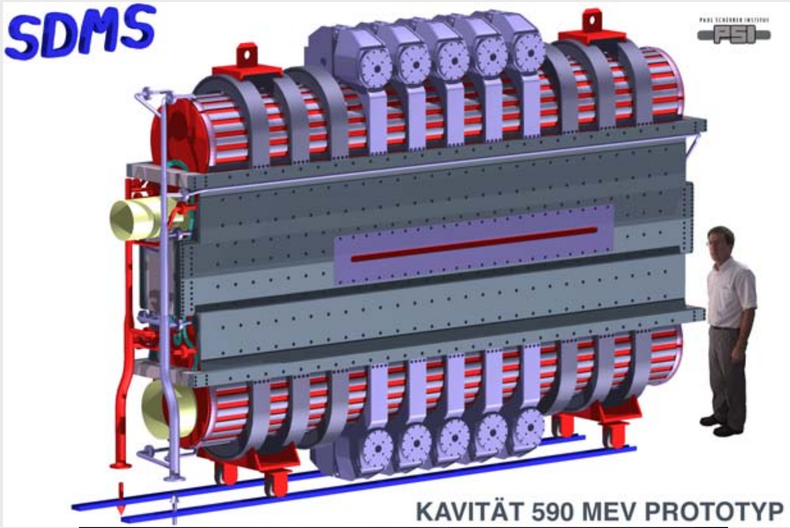
>> extraction losses (septum) 0.02%

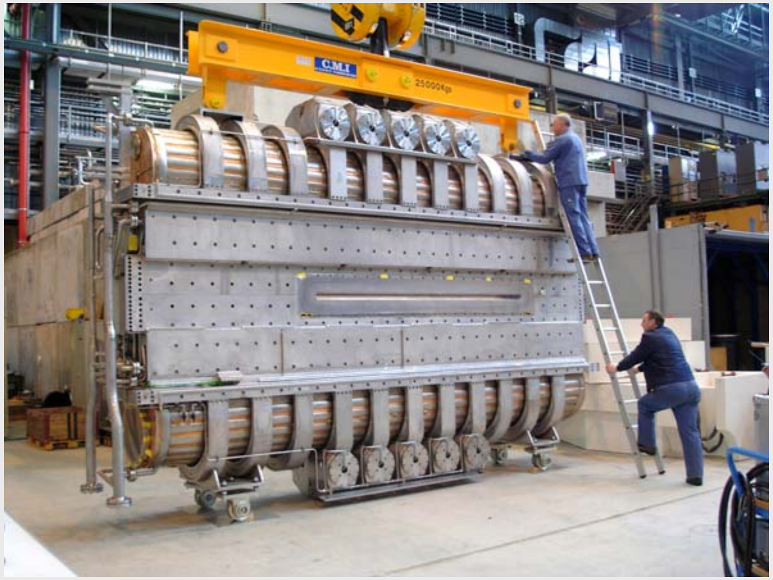
Improved beam quality from Injector (improved bunching in 870 keV line, „round beam“, cleaning slit after extraction)

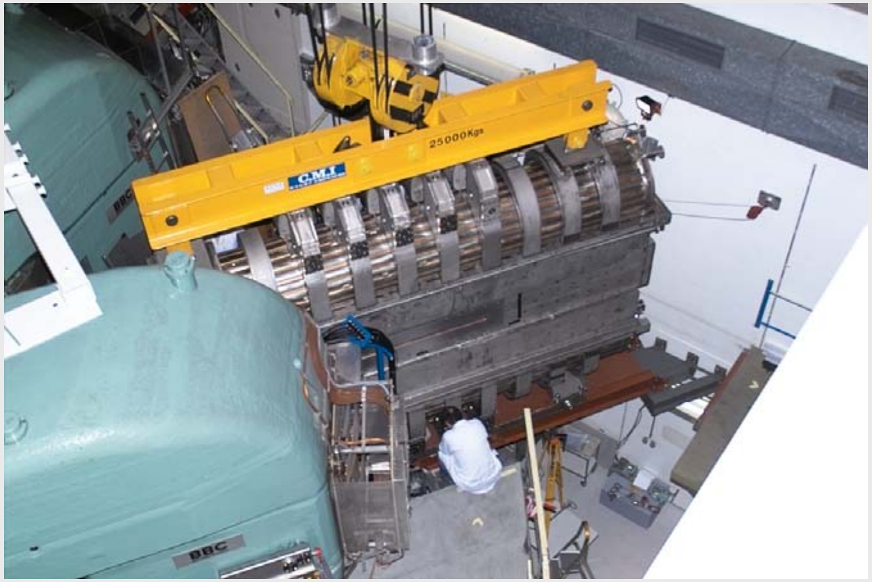
RING CYCLOTRON

Extraction losses: history and extrapolation




SDMS
KAVITÄT 590 MEV PROTOTYP


C.M.I
25000Kgs


25000Kgs
C.M.I
BBC

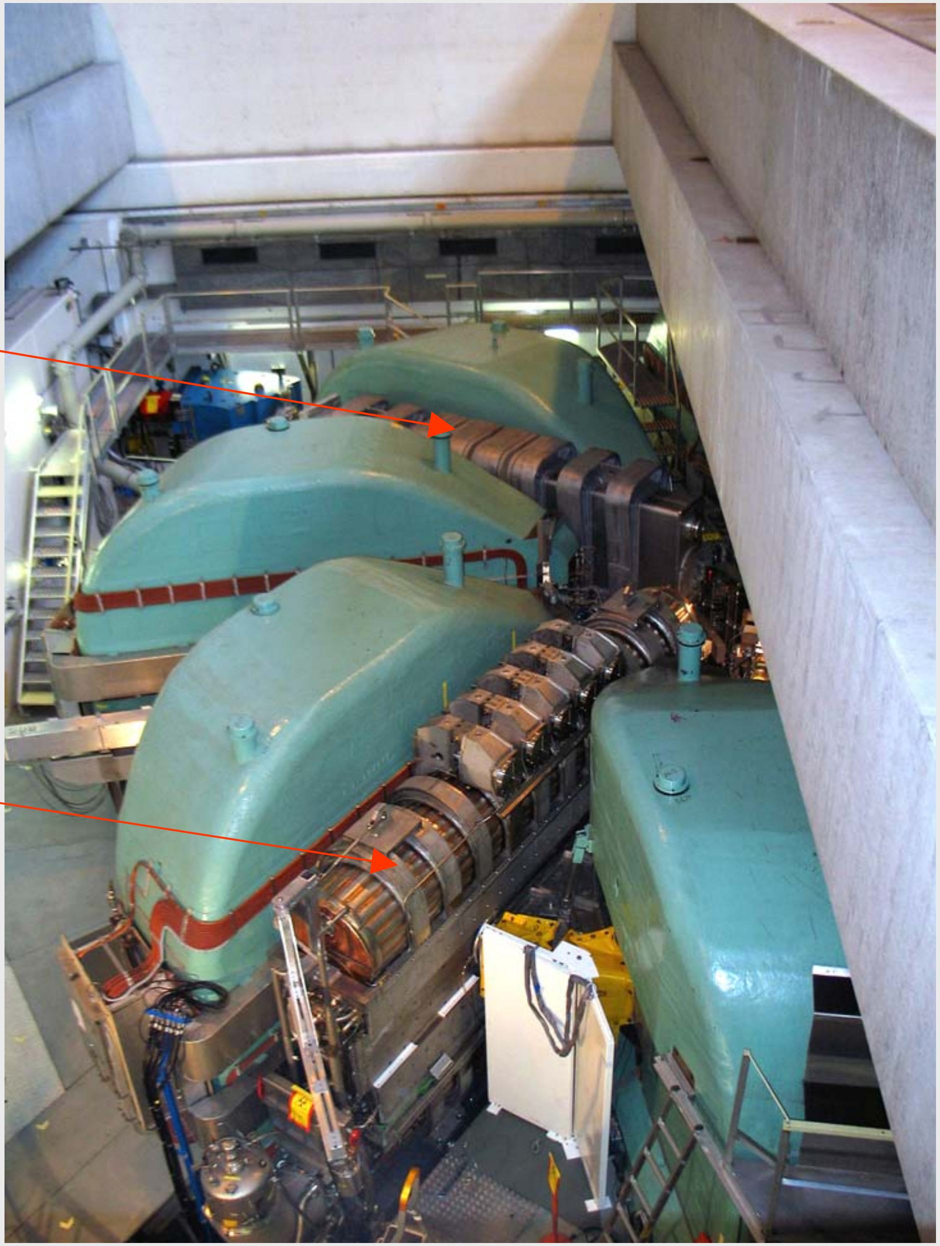
RING CYCLOTRON

OLD CAVITY

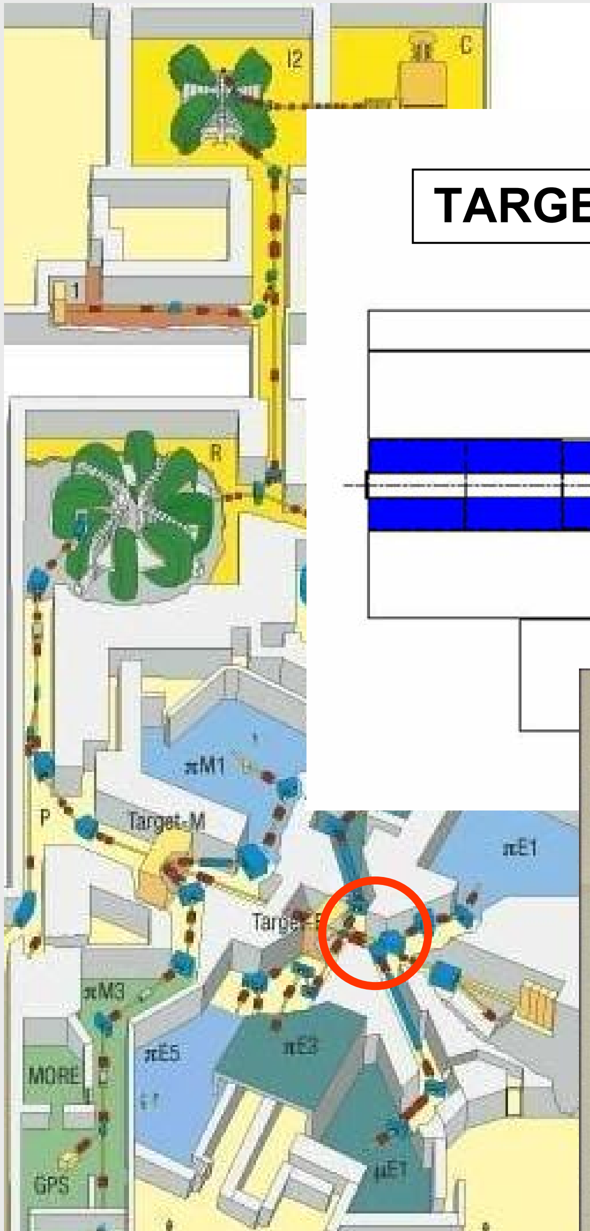
f_R = 50.6 MHz
Gap voltage = 750 kV
Q_o = 32’000
Dissip. Power = 300 kW
Power to beam = 350 kW

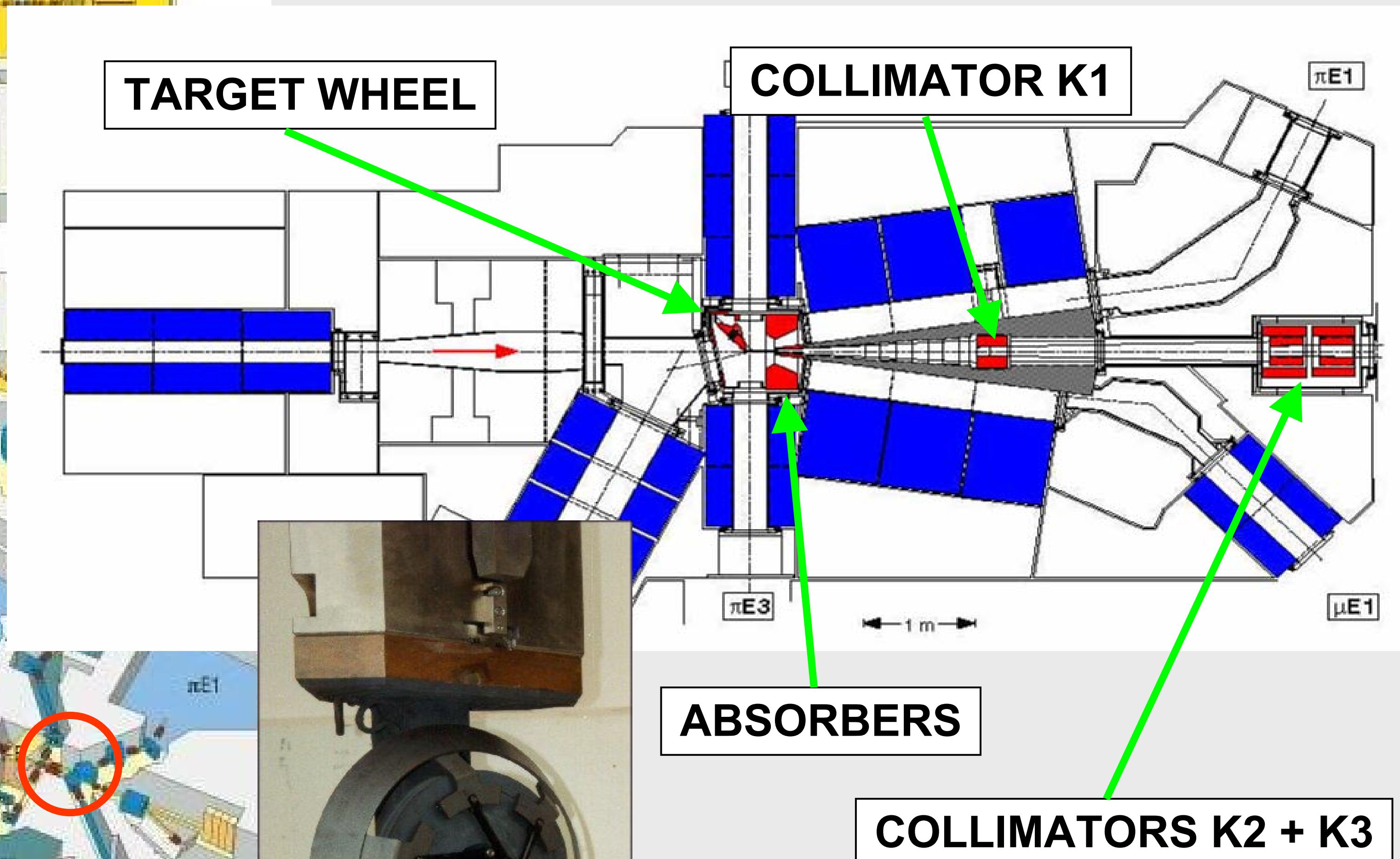
NEW CAVITY

f_R = 50.6 MHz
Gap voltage > 1 MV
Q_o = 48’000
Dissip. power = 300 kW
Power to beam = 500 kW



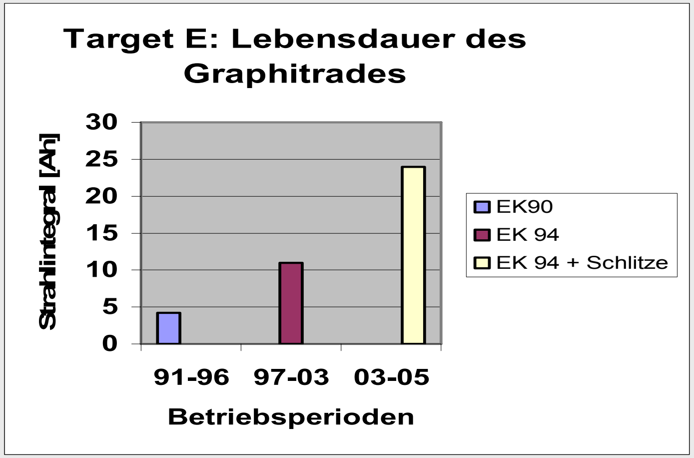
TARGET E

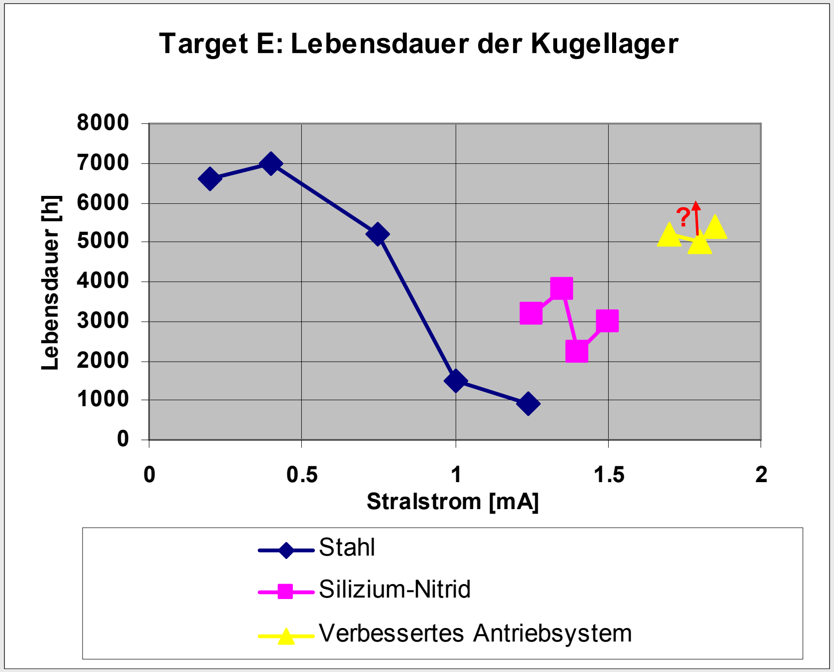

I2
C
1
R
πM1
Target-M
P
πE1
πM3
πE5
πE3
MORE
GPS
μE1

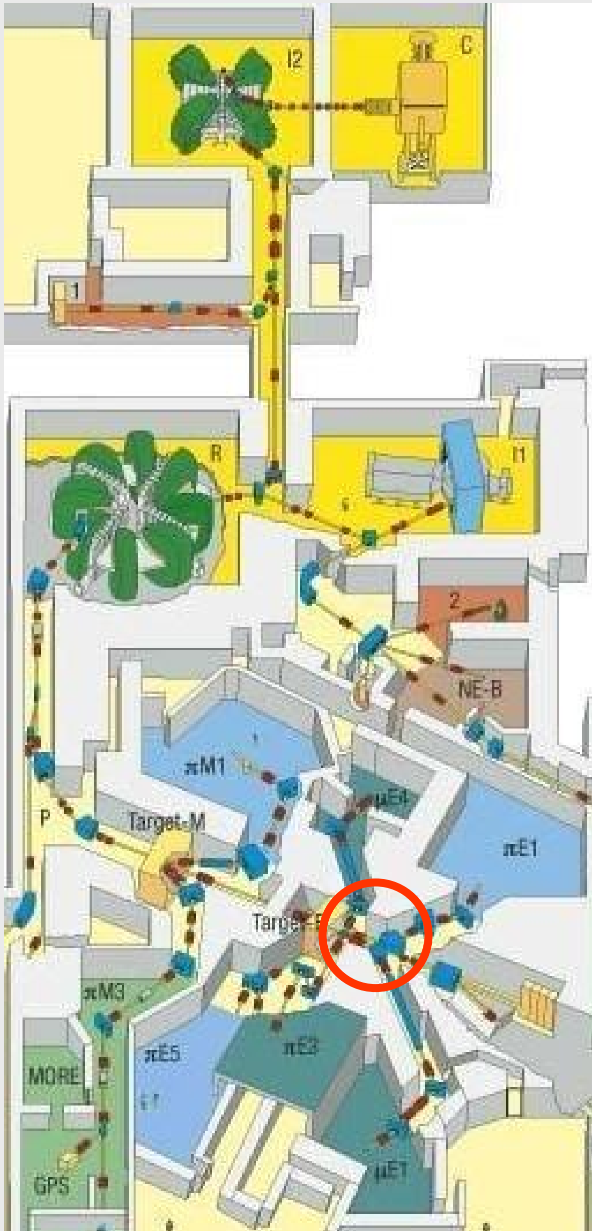

TARGET WHEEL
COLLIMATOR K1
πE1
πE3
1 m
μE1
ABSORBERS
COLLIMATORS K2 + K3

Status:

- became a very reliable component







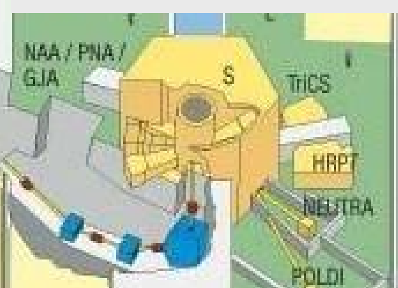
TARGET E

Thermal limits exist for the target and the subsequent collimators

2.0 mA - 2.6 mA
- OK for target with 4 cm length

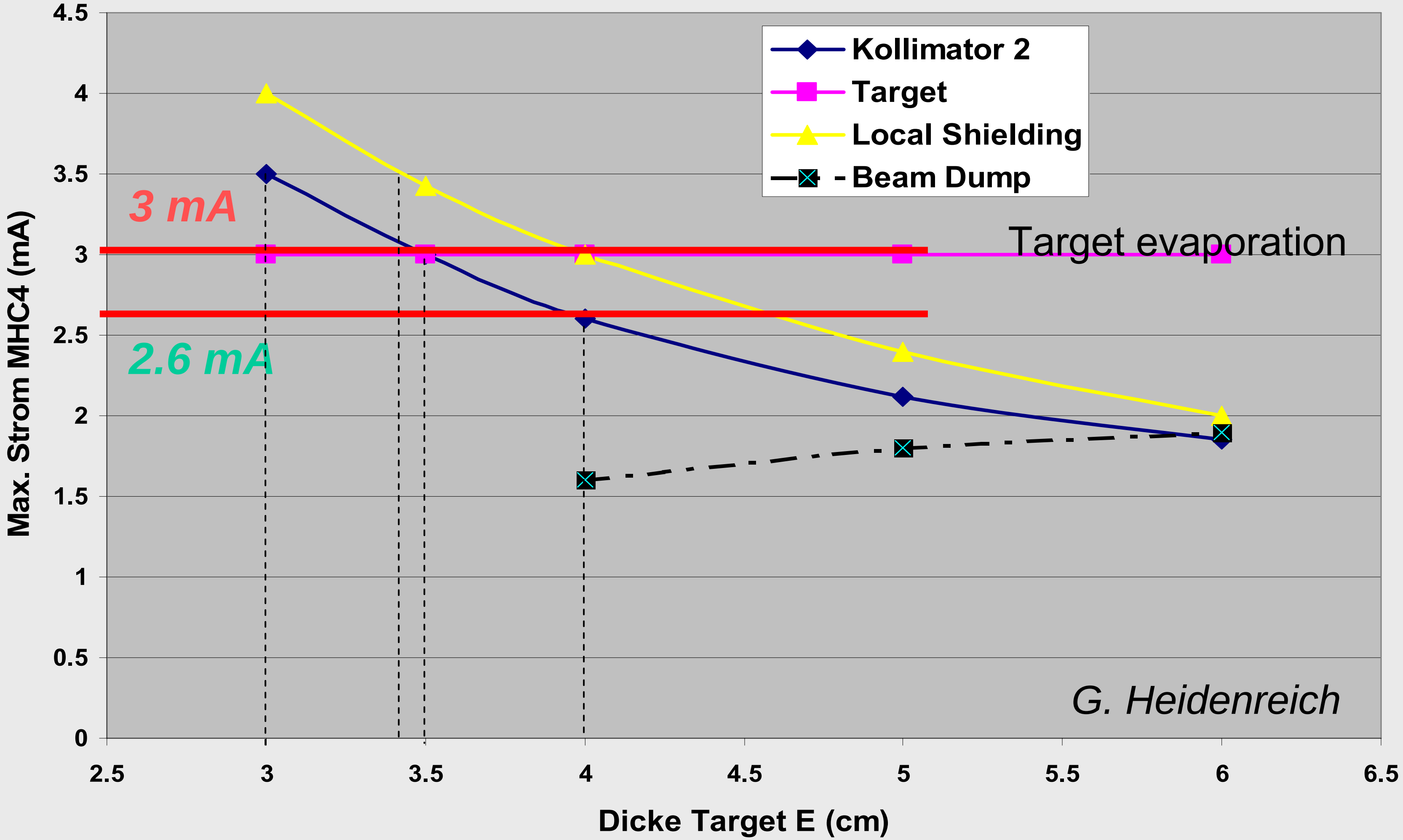
2.6 mA - 3.0 mA
- OK for target with 4 cm length
- Collimators K2 and K3 must be replaced or shorter target without replacement
- SINQ target must be replaced

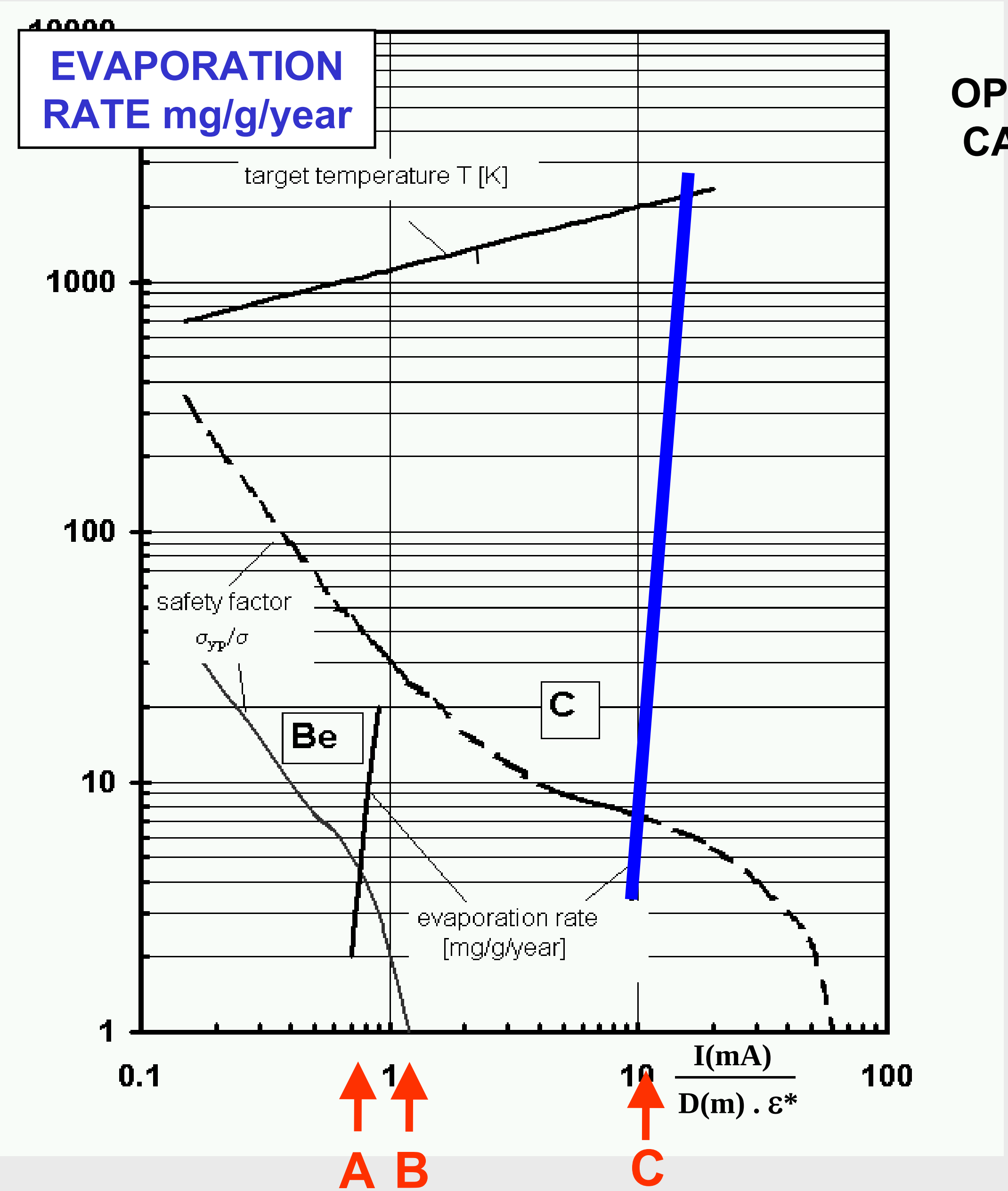
> 3.0 mA
- Target wheel radius must be increased
- Target chamber must be replaced
- SINQ Targetsystem must be redesigned



Target E sets the limit on the performance of the facility !

CURRENT LIMITS OF TARGET E COMPONENTS





OPERATIONAL LIMITS OF THE ROTATING CARBON & BERYLLIUM TARGET CONES

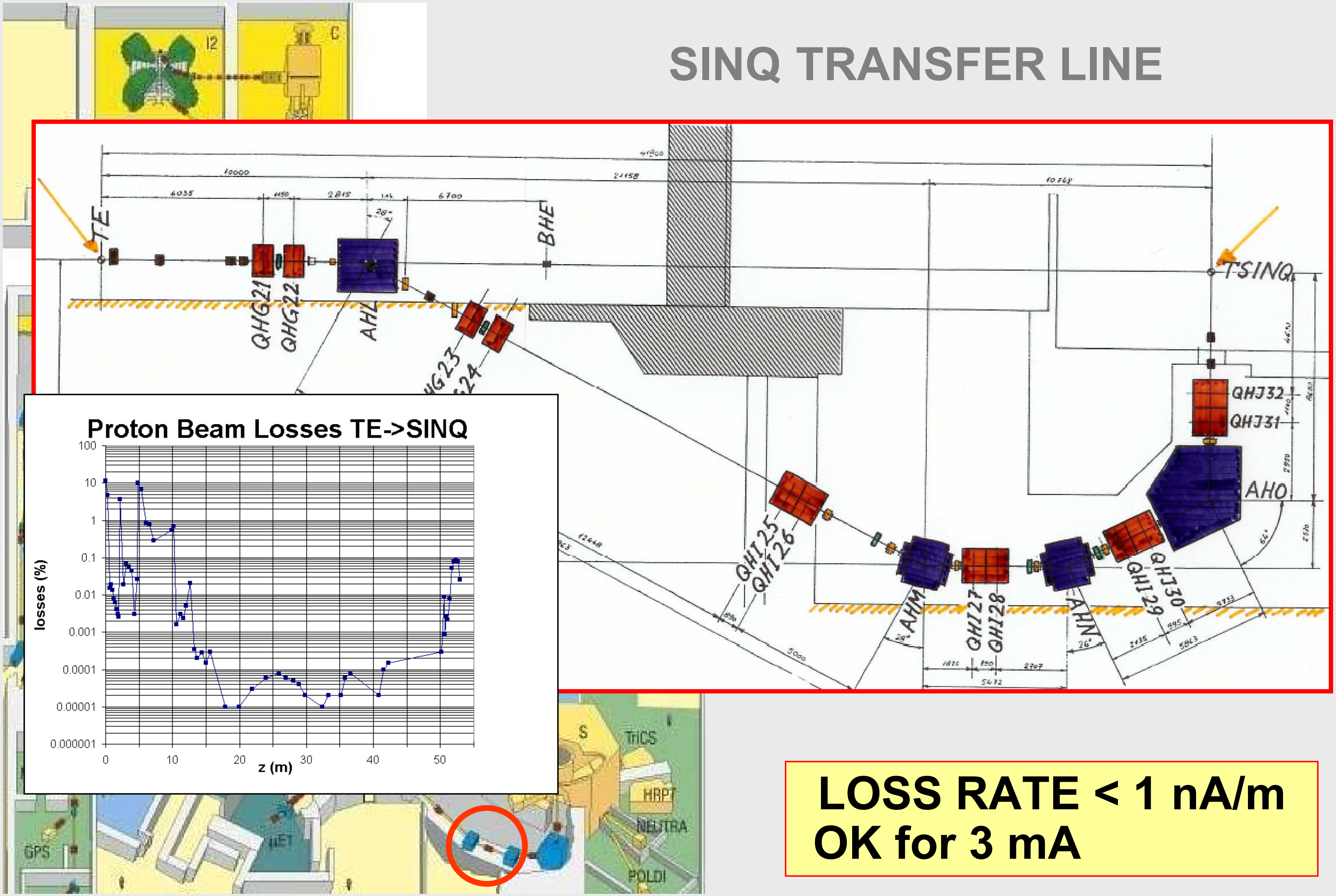
	A	B	C
D[m]	0.28	0.19	0.45
I[mA]	0.15	0.12	3.0
ε^*	0.6	0.6	0.75

I proton current

D mean target diameter

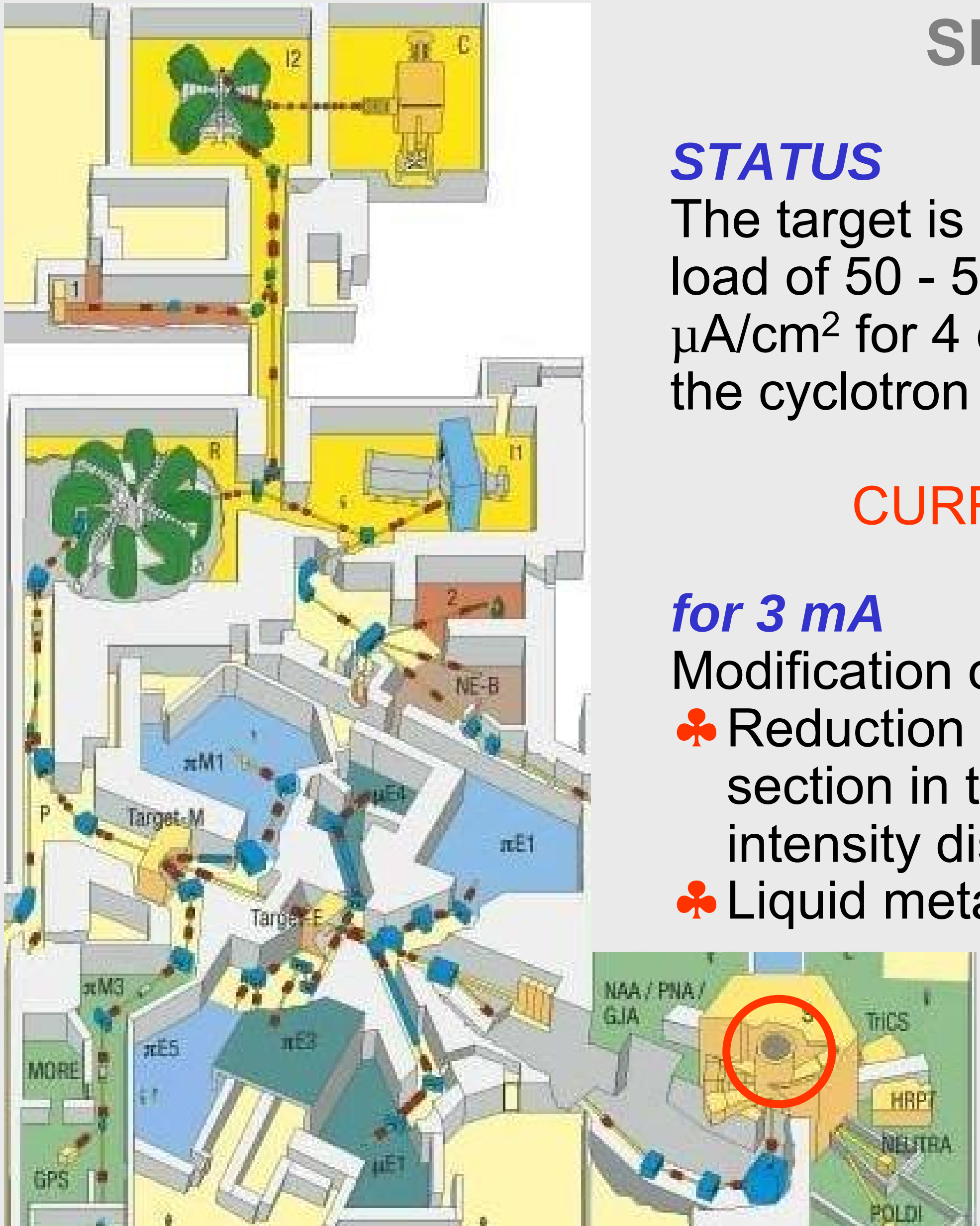
ε^* effective emissivity =
F (emissivity, view factors, areas of radiating surfaces)

SINQ TRANSFER LINE



LOSS RATE < 1 nA/m
OK for 3 mA

SINQ TARGET



STATUS

The target is designed for a maximum current load of 50 - 55 µA/cm². The actual load is 40 µA/cm² for 4 cm target length and 2 mA from the cyclotron (= 1.4 mA on SINQ).

CURRENT LIMIT: 2.5 – 2.7 mA

for 3 mA

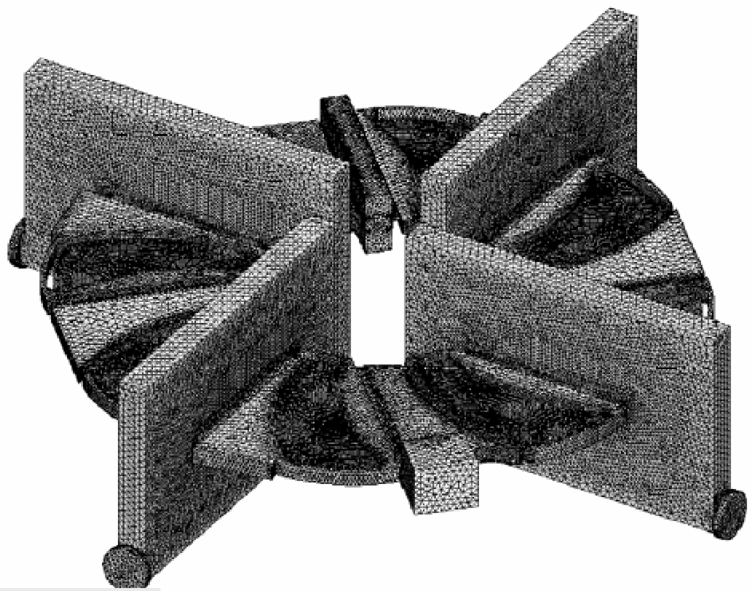
Modification of the SINQ target:

- Reduction of the ‚canelloni' cross section in the center of the beam intensity distribution (◊ Zirkalloy)
- Liquid metal / ceramic target (Al_2O_3)

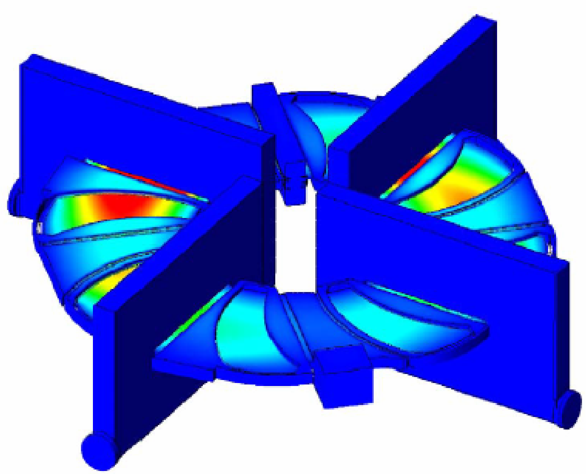
SIMULATIONS

Mesh of RF structures and vacuum chamber, created with tetrahedral elements, using CUBIT (Sandia Lab)

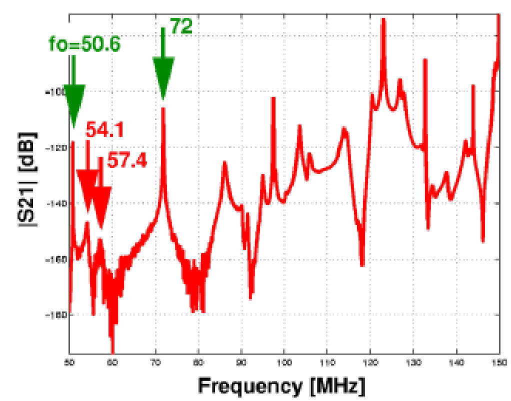
1.2 M 2nd order elements, 6.9 M degrees of freedom



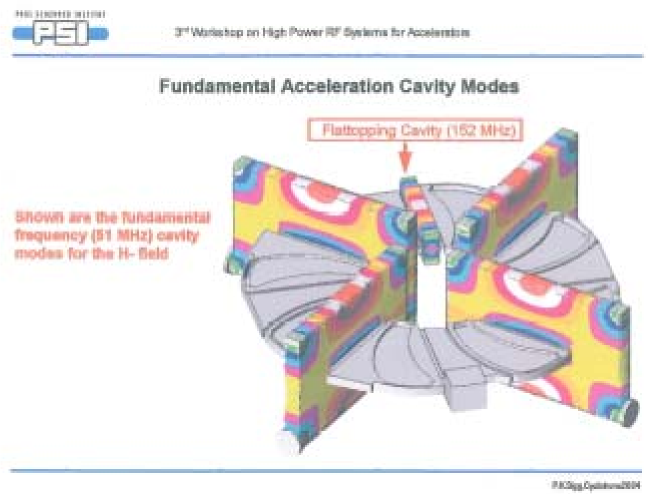
clotron Modes:

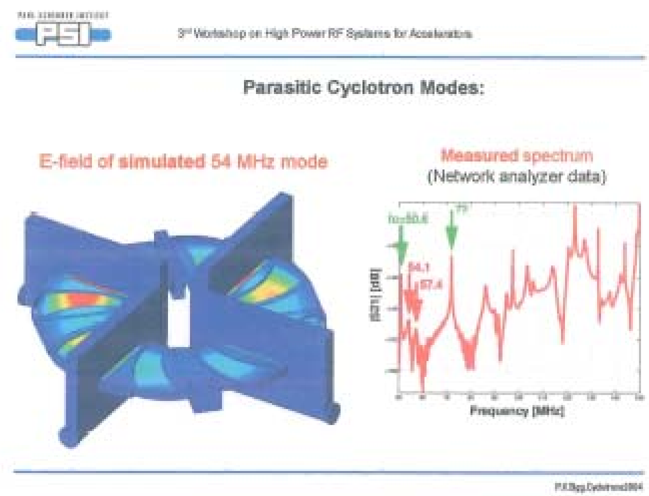


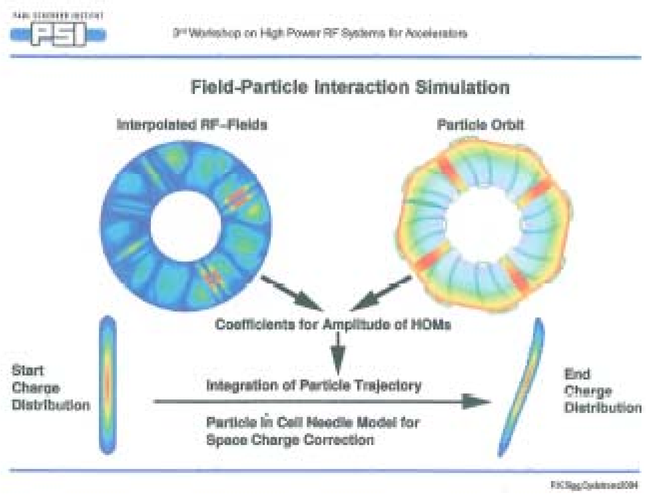
Measured spectrum
(Network analyzer data)

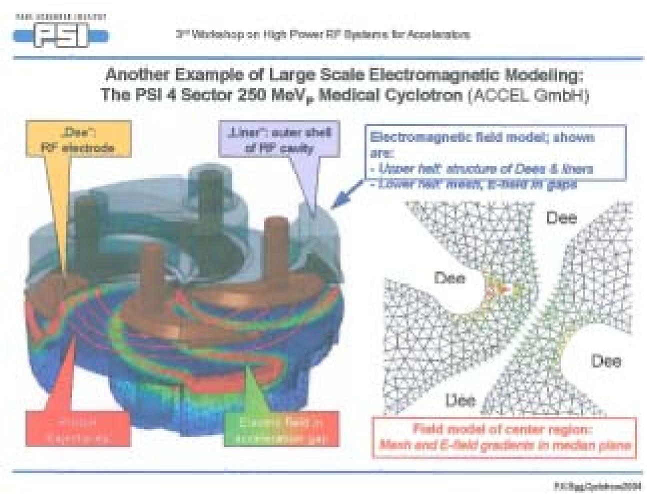


SIMULATIONS









SIMULATIONS

2.0 mA >> 3.0 mA

- Improved understanding of space charge compensation in simulations of 870 keV transfer line
- Beam dynamics with second 870 keV buncher

  1 D simulations ready
- **Injection + High intensities in INJ-2**
- Beam dynamics in 72 MeV transfer line (collimators / halo)

  Performance of the 72 MeV buncher
- Beam dynamics in the main cyclotron (**Higher Order Modes**, overlapping turns, “round beam” acceleration)
- **Optics in the SINQ transfer line**

Ideally: STS, source to target simulations‘

In progress / **DONE**

Bundesamt für Gesundheit
Office fédéral de la santé publique
Ufficio federale della sanità pubblica
Uffizi federal da sanadad publica

Original	Seite 1 von 1
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Strahlenschutz und Sicherheit
5232 Villigen PSI

Gesuchsteller/in, Bewilligungsinhaber/in

Paul Scherrer Institut (PSI)
Protonenbeschleunigeranlagen
5232 Villigen PSI

Bewilligung für den Betrieb der Beschleunigeranlagen und die damit verbundene Durchführung von Experimenten am Paul Scherrer Institut (PSI) in Villigen 20. Mai 2003

Gestützt auf Artikel 28 und 30 des Strahlenschutzgesetzes vom 22. März 1991 (StSG, SR 814.50) und auf Artikel 126 der Strahlenschutzverordnung vom 22. Juni 1994 (StSV, SR 814.501) wird dem/der Gesuchsteller/in die Bewilligung für den Umgang mit ionisierender Strahlung im beiliegend umschriebenen Rahmen und mit den aufgeführten Auflagen erteilt.
Verstösse gegen Vorschriften der Strahlenschutzgesetzgebung und das Nichteinhalten der Bestimmungen dieser Bewilligung bzw. die Nichterfüllung von Auflagen innerhalb der gesetzten Fristen unterliegen den Strafbestimmungen nach Art. 43 bis 46 StSG und Artikel 139 StSV (Haft/Busse). Zudem kann dies den Entzug der Bewilligung zur Folge haben (Art. 34 Abs. 1 StSG).
Diese Bewilligung ist gültig bis zum Widerruf durch die Bewilligungsbehörde oder längstens bis zum 01.07.2010.

Bern, 20.05.2003 — Bundesamt für Gesundheit

W. Zeller

Aufsichtsbehörde: Bundesamt für Gesundheit, Abteilung Strahlenschutz, 3003 Bern
Sachbearbeiter/in: Nicolas Stritt, Tel. 031/322 96 14, Fax 031/322 83 83
Inspektionsdatum: 19.05.2000

Rechtsmittelbelehrung
Gegen diese Verfügung kann innert 30 Tagen, vom Eingang der schriftlichen Ausfertigung an gerechnet, beim Eidgenössischen Departement des Innern, 3003 Bern, Beschwerde erhoben werden.
Die Beschwerdeschrift ist im Doppel einzureichen. Sie hat die Begehren, deren Begründung mit Angabe der Beweismittel und die Unterschrift der Beschwerdeführerin bzw. des Beschwerdeführers oder seiner Vertreterin bzw. seines Vertreters zu enthalten. Die angefochtene Verfügung und die als Beweismittel angerufenen Urkunden sind der Beschwerde beizulegen, soweit der Beschwerdeführer bzw. die Beschwerdeführerin sie in Händen hält.

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Seite 2 von 5 — AG-0444.12.001
Seite 3 von 5 — AG-0444.12.001
Seite 4 von 5 — AG-0444.12.001
Seite 5 von 5 — AG-0444.12.001