Upgrade of the PSI Cyclotron Facility to 1.8MW

M.Seidel, P.A.Schmelzbach
Paul Scherrer Institute

Outline

- present status and overview on the facility
- motivation to further raise the beam power
- components of the upgrade program:
  - new ion source
  - harmonic buncher (3x) and resonators for the **Injector II**
  - harm. buncher (10x), resonators for the **Ring Cyclotron**
  - impact on Meson production targets / spallation target
- beam losses and activation
- legal requirements
- time schedule and summary

Facility Overview

Injector II Cyclotron
72 MeV
2 new resonators

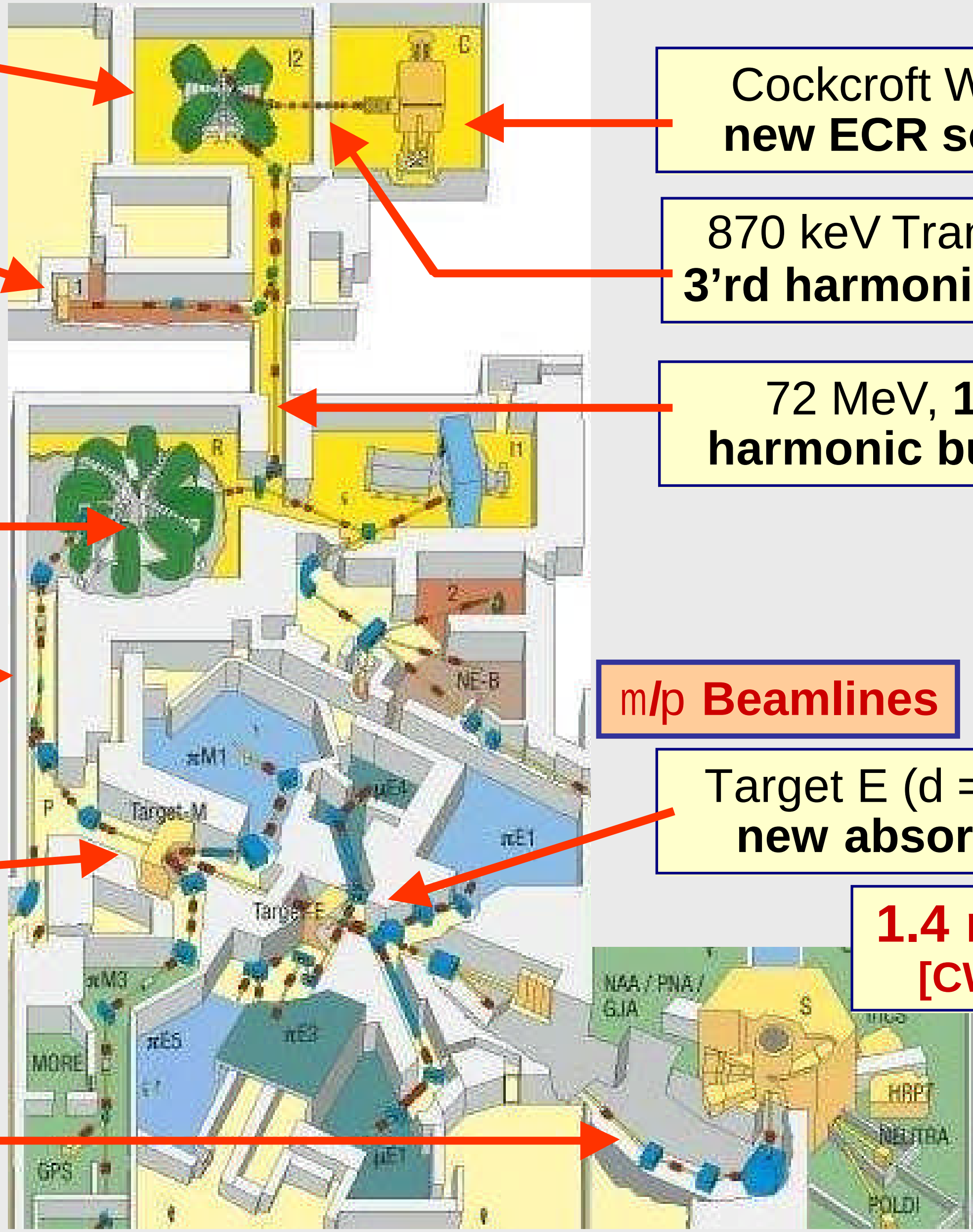
Isotope Production
(split beam <100µA)

Ring Cyclotron
590 MeV
4 new resonators

2 mA /1.2 MW

Target M (d=5mm)

SINQ Transfer Line



Cockcroft Walton
new ECR source

870 keV Transfer Line
3'rd harmonic buncher

72 MeV, **10`th harmonic buncher**

m/p Beamlines

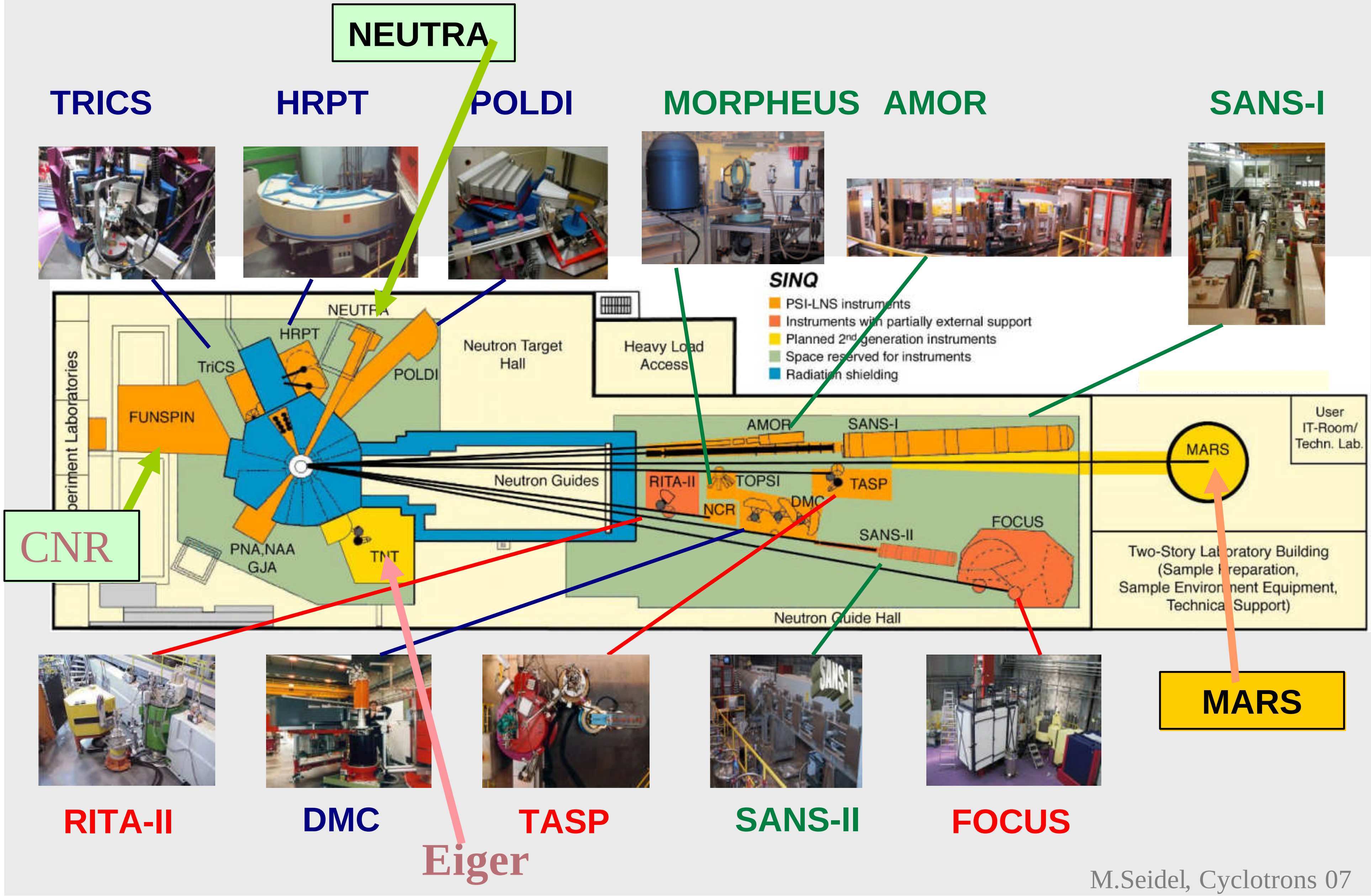
Target E (d = 4cm)
new absorbers

1.4 mA /0.8 MW
[CW operation]

SINQ spallation source

Spallation Source Experimental Area – 12 Beamlines, heavily overbooked

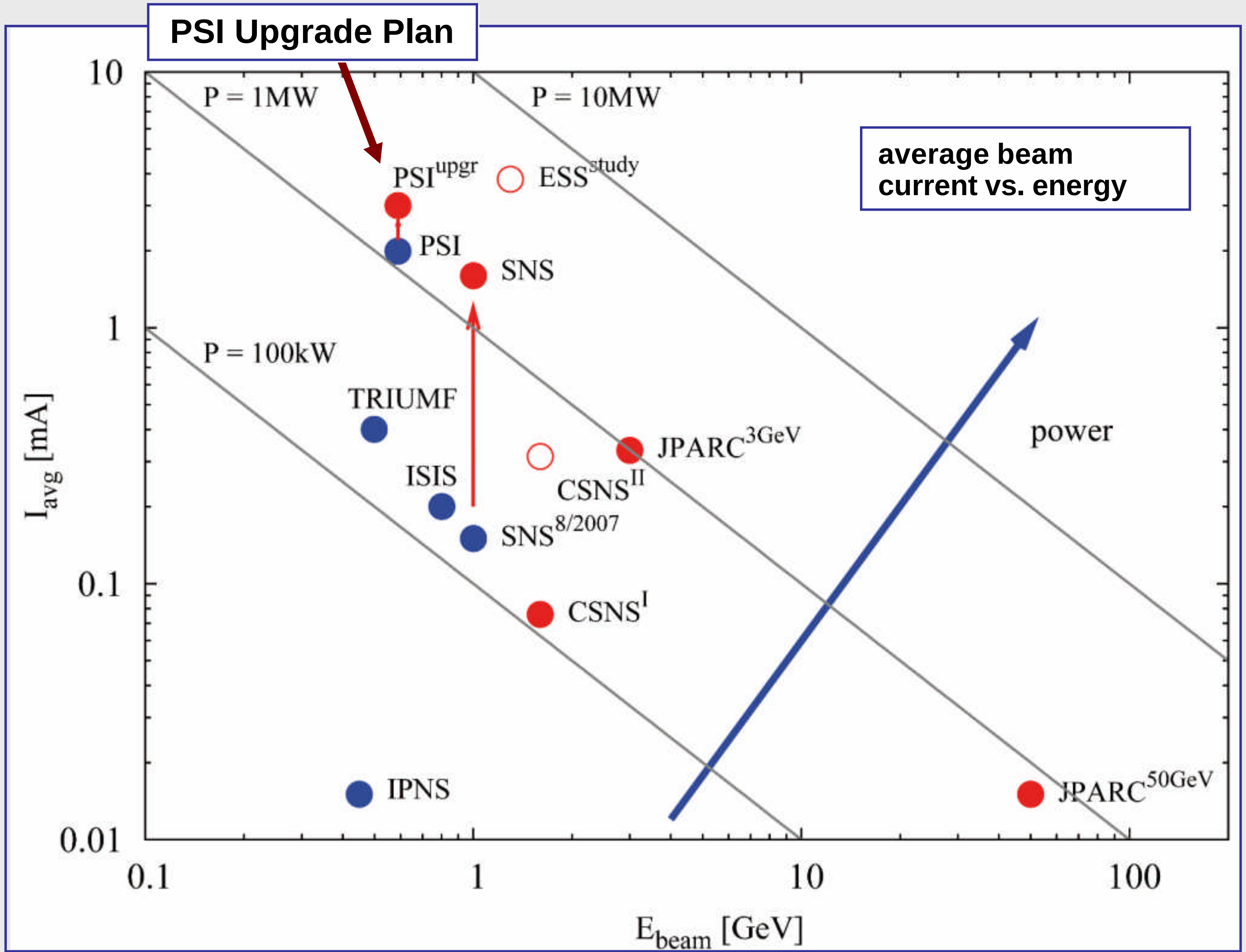
K. Clausen



PSI user laboratory key numbers **2006**

	 SLS	SINQ	SμS	 PSI total
Beamlines/instruments	**11**	**12**	**6**	**29**
Instrument days	**1076**	**1020**	**574**	**2670**
Experiments	**653**	**260**	**135**	**1048**
User visits	**1990**	**328**	**130**	**2448**
Individual users	**934**	**259**	**95**	**1288**
New proposals	**531**	**347**	**147**	**1025**
	γ	**n**	μ	**[courtesy of Stefan Janssen]**

High Power Proton Accelerators



plot: selected accelerators

current vs. energy

power ∝ current × energy

the PSI cyclotron based facility is still at the forefront with respect to the **average beampower**

(some experiments need **pulsed beam** though!)

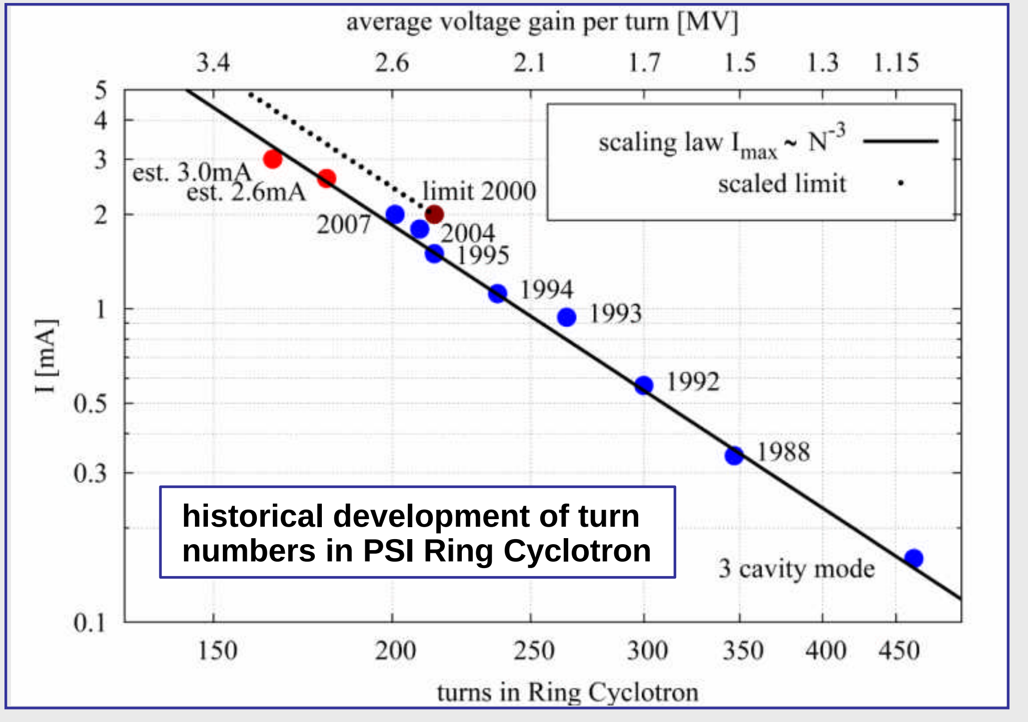
PSI Parameters: [2mA, 1.2MW] → [3mA, 1.8MW]

Cyclotron Facility Upgrade Path

- keep **absolute losses constant**; increase acceleration voltage and beam quality, better turn separation at extraction
- new components: **resonators** - 4 in Ring, 2 in Injector; **harmonic bunchers**: 3'rd harmonic for Injector; 10'th harmonic for Ring
- in addition: new ECR source; new absorbers for scattered beam at target E

planned turn numbers and voltages

	turns Ring	turns Injector
now (2.0mA)	**202** (U_{peak}≈3.0MV)	**81** (U_{peak}≈1.12MV)
inter. step (2.6mA)	**~180** (U_{peak}≈3.3MV)	**~73** (U_{peak}≈1.25MV)
upgrade (3.0mA)	**~165** (U_{peak}≈3.6MV)	**~65** (U_{peak}≈1.40MV)



historical development of turn numbers in PSI Ring Cyclotron

Components - New Ion Source

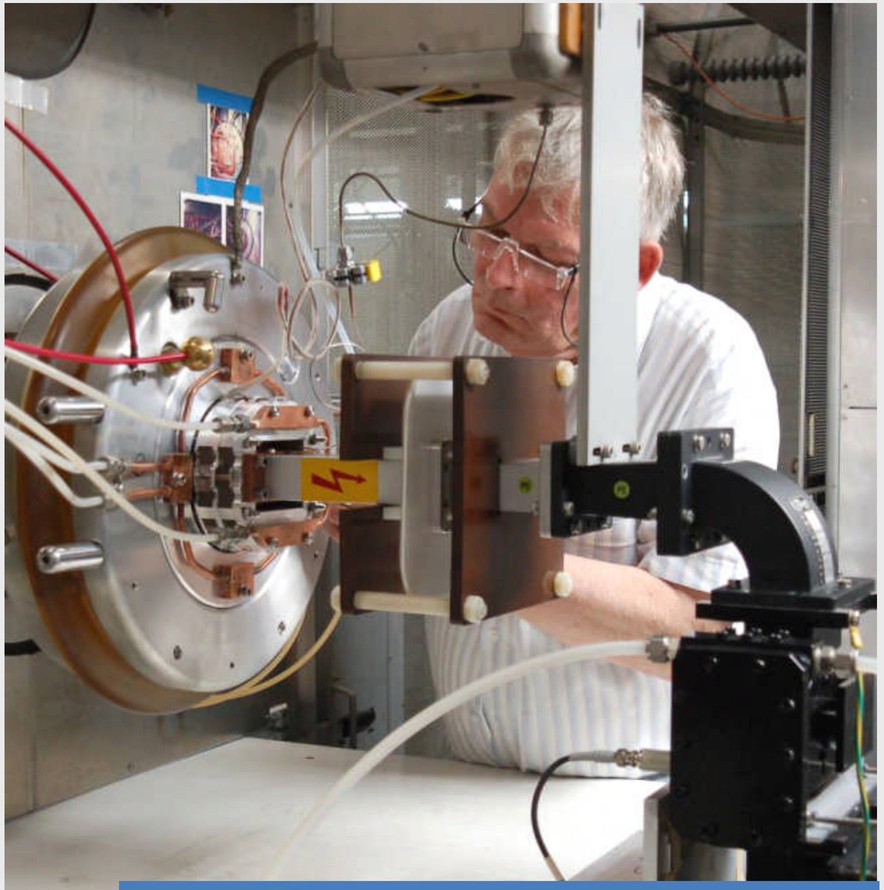
presently in use: **Multicusp Ionsource**

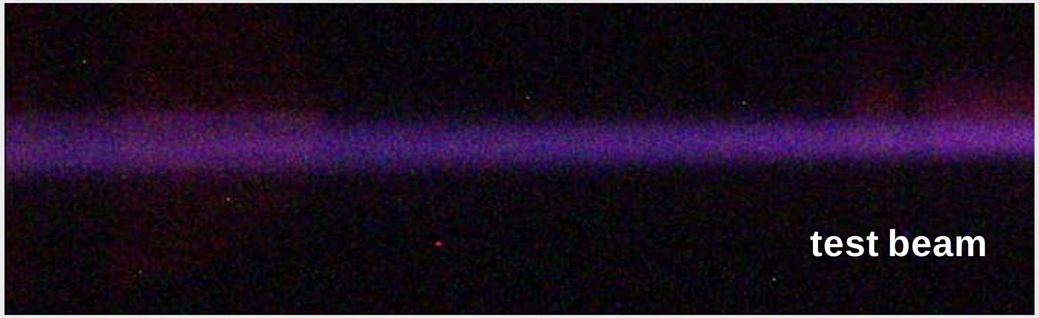
disadvantages:

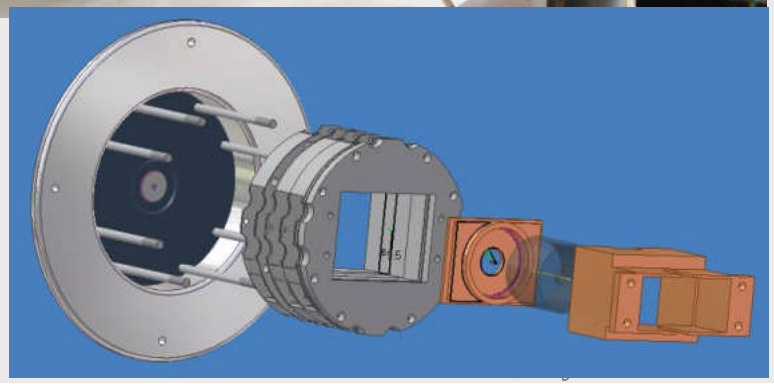
- relatively low fraction of p+ ions (<50%)
- stability not optimal
- service (filament exchange every 2 weeks)

under development:

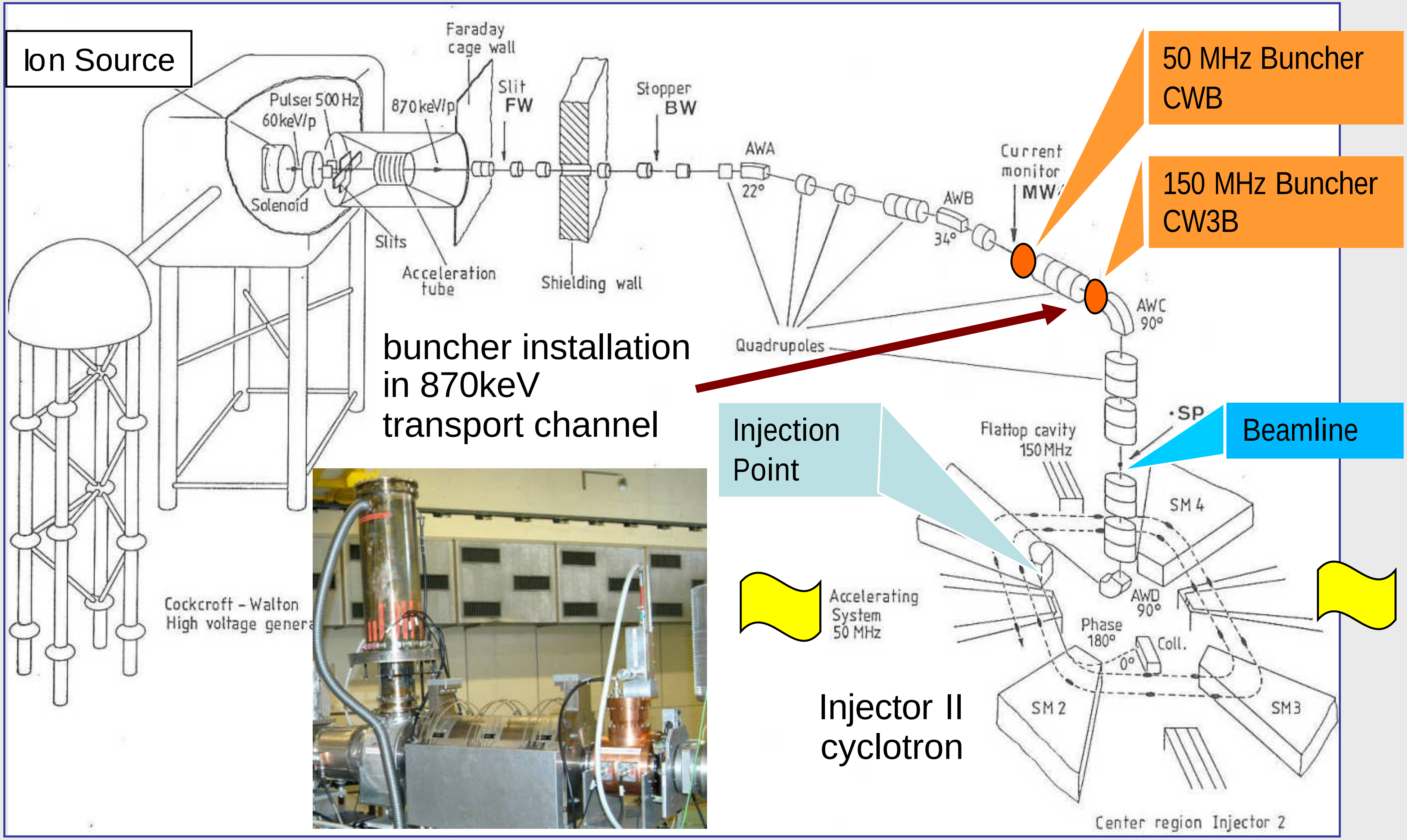
- compact **microwave ion-source** with permanent magnets
- ongoing tests; installation SD 2008
- expected: longer service periods, low emittance, improved stability **(see paper by P.Schmelzbach at this conference, WEPPRB04)**







components: 3'rd harmonic buncher for Injector II Cyclotron



Function of Harmonic Buncher

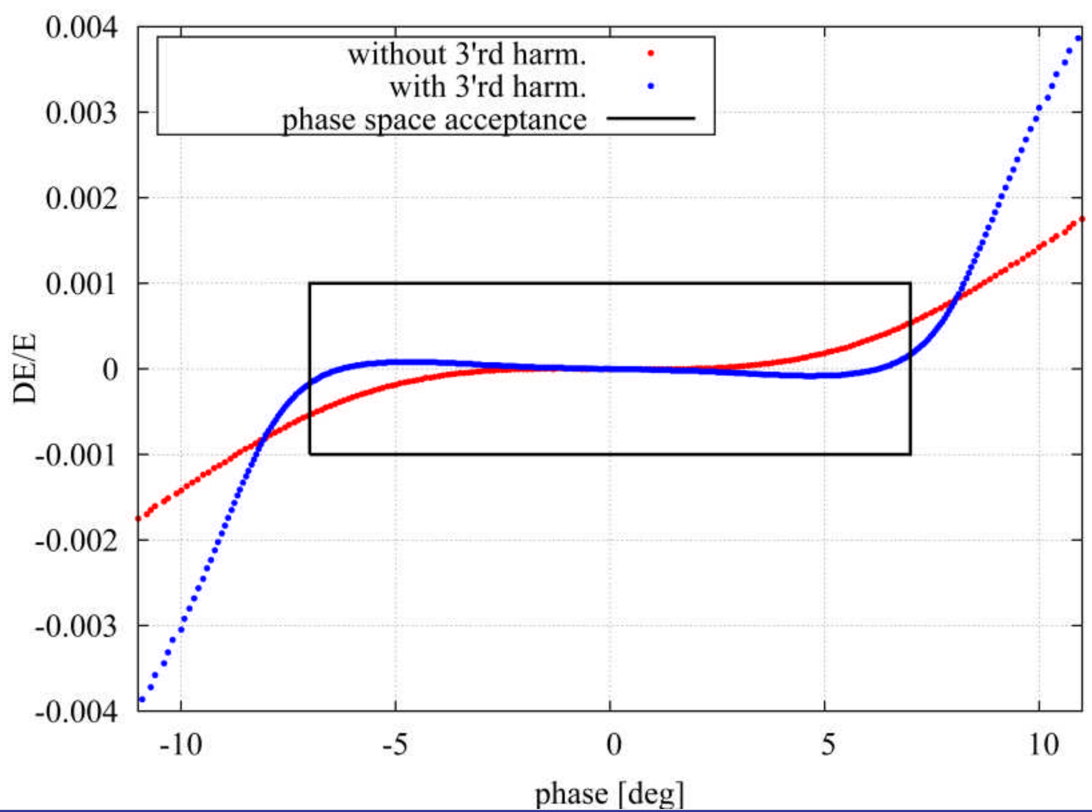
è third harmonic increases the linear range of effective buncher voltage

è impressed velocity modulation of beam in balance with repulsive space charge forces results in small energy spread at injection of the cyclotron

è higher capture efficiency in cyclotron; strong space charge effects result in formation of short round bunches • **2.7mA extracted in 2006!**

plot:

energy spread vs. phase of bunched beam at the injection of the injector cyclotron

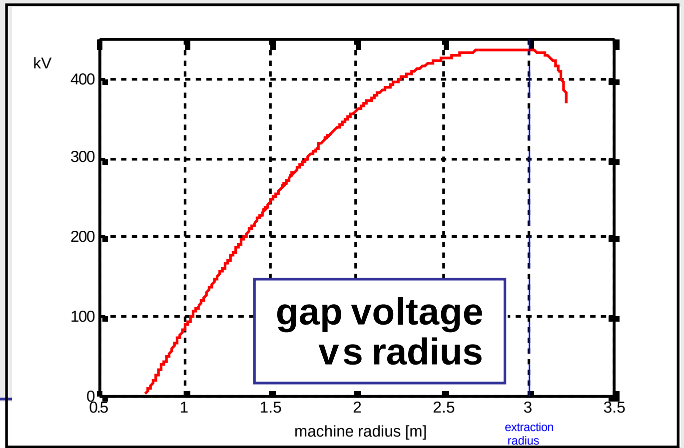


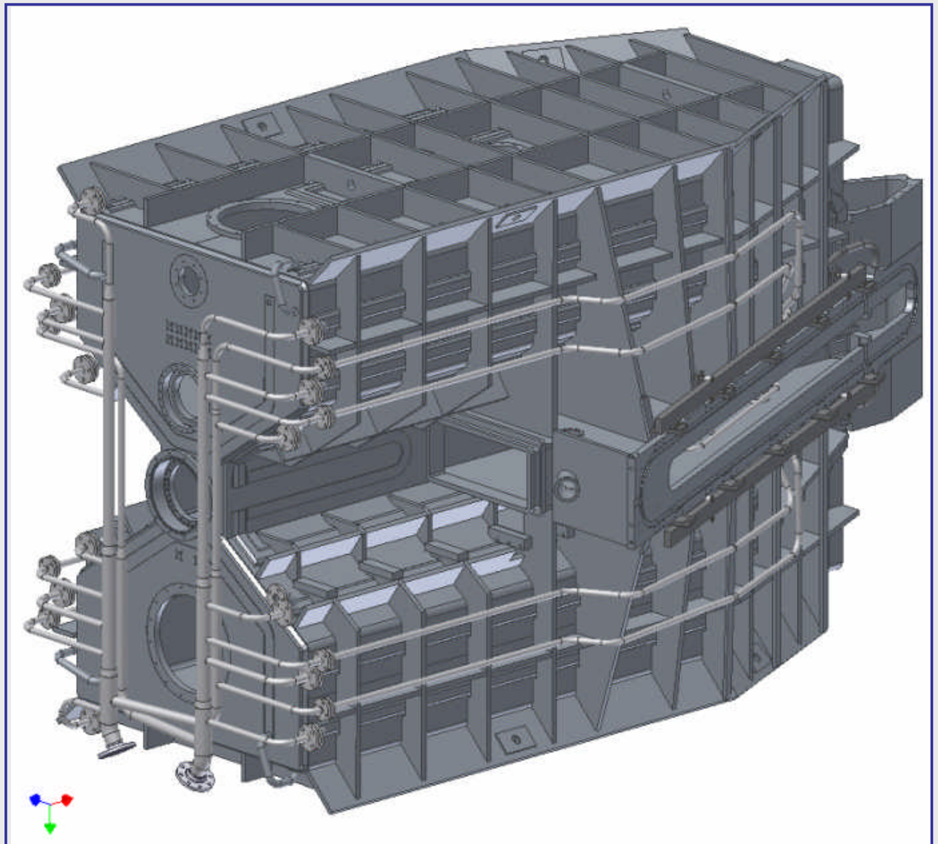
see poster by J.Grillenberger et al

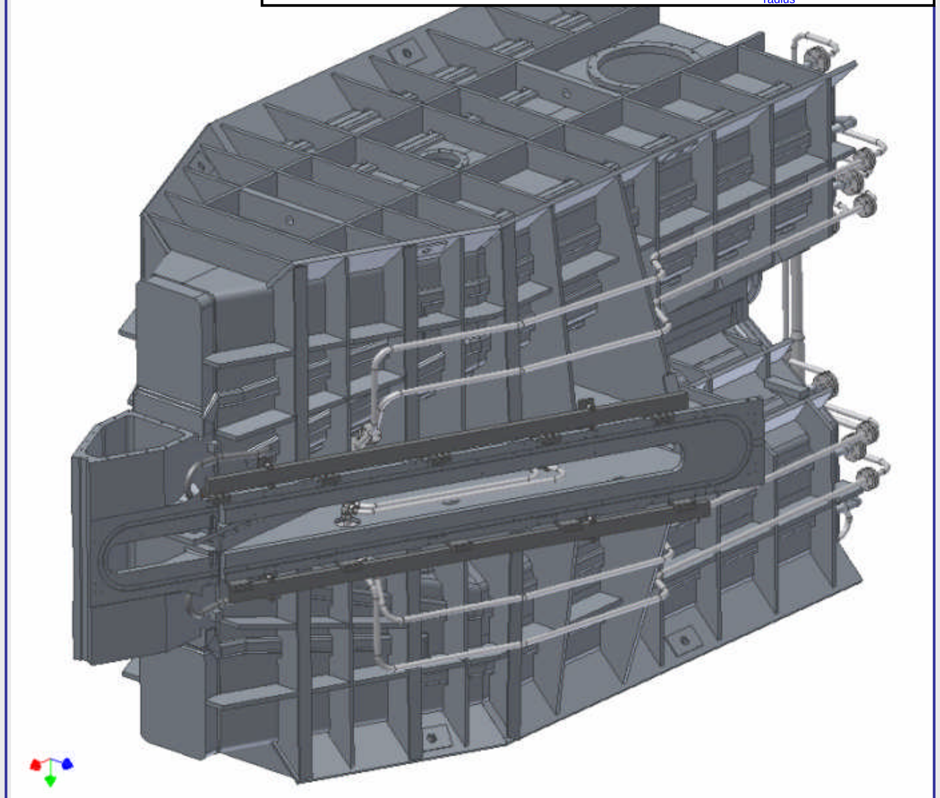
TUPPRA18

Components: Additional Cavities for the Injector II Cyclotron

- two new cavities planned for f **= 50.6MHz, U_{max} = 500kV**; **Q_0 = 28k**, Material: **Aluminum**; sector shape: tight mechanical tolerances on the position of sealing surfaces
- **replace two 150 MHz flat-top cavities**
- resonators on order from industry
- **contribution by L.Stingelin, TUPPRA19**

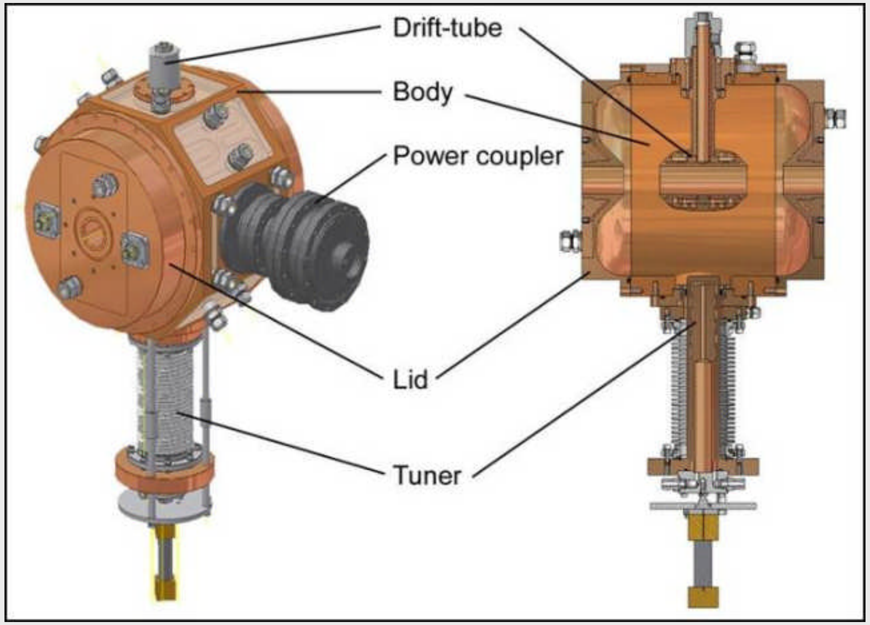


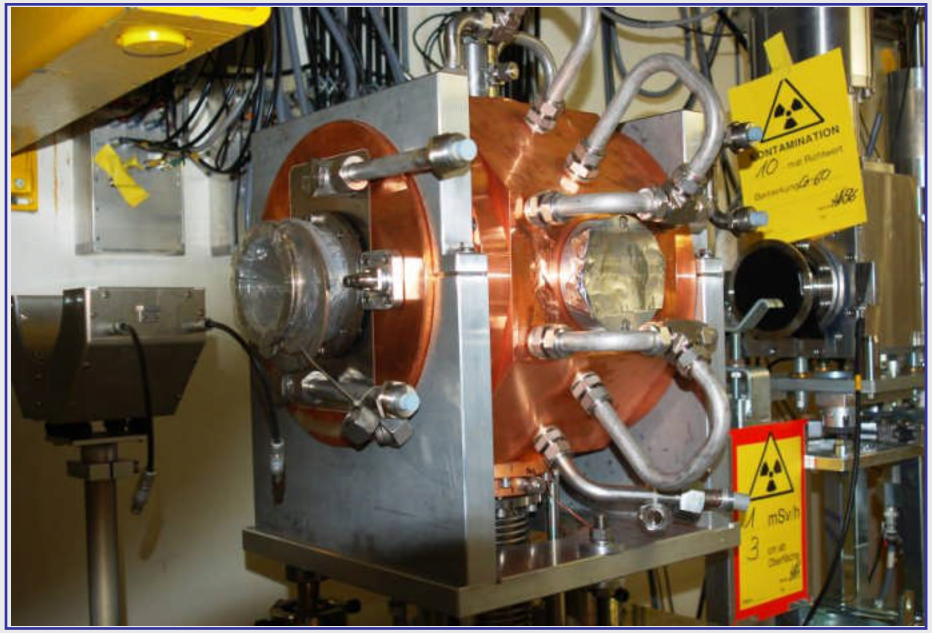




Components: 10'th harmonic Buncher between Injector and Ring

- operating frequency 506 MHz; U_{gap} = 220kV
- compress bunch length at injection in Ring-Cyclotron
- installation planned in SD 2008





“round beam” – space charge in cyclotrons

qualitative picture:

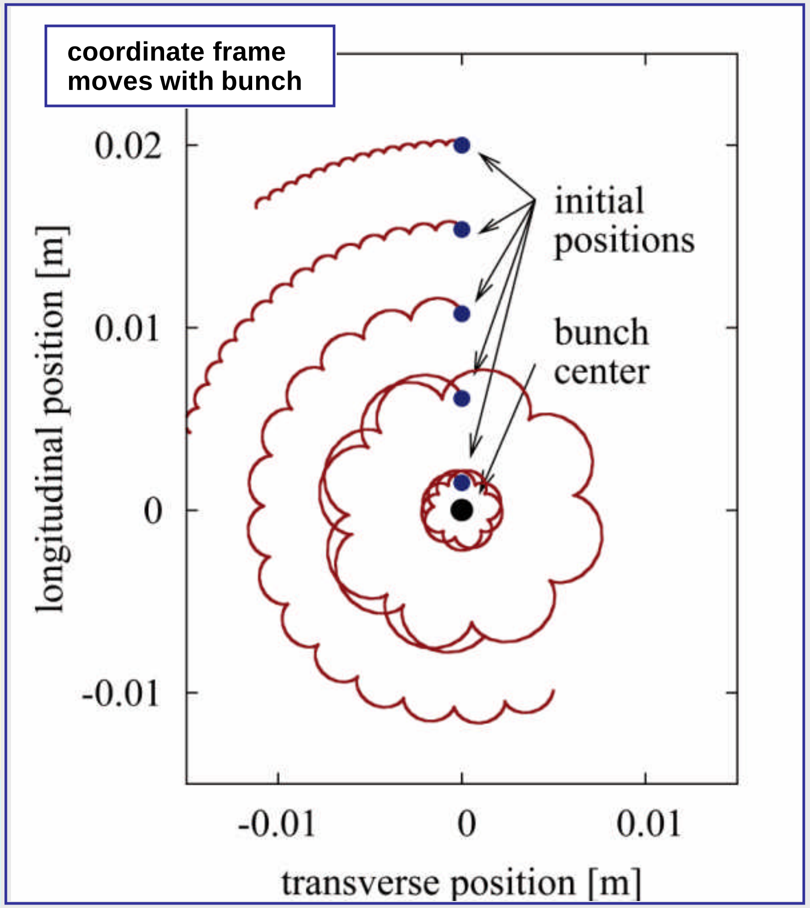
protons in the field of a round, short bunch + vertically oriented magnetic field (neglect relativistic effects and focusing)

[Chasman & Baltz (1984)]

though the force is repulsive a “*bound motion*” is established

→ for short bunches a round beam shape is formed

→ a round beam is observed in the Injector II cyclotron



Beam Dynamics Simulations

longitudinal dynamics in Ring Cyclotron

→ behavior of short bunches, generated by 10'th harmonic buncher

→ optimum parameters of flat-top cavity at these conditions

-multiparticle simulations

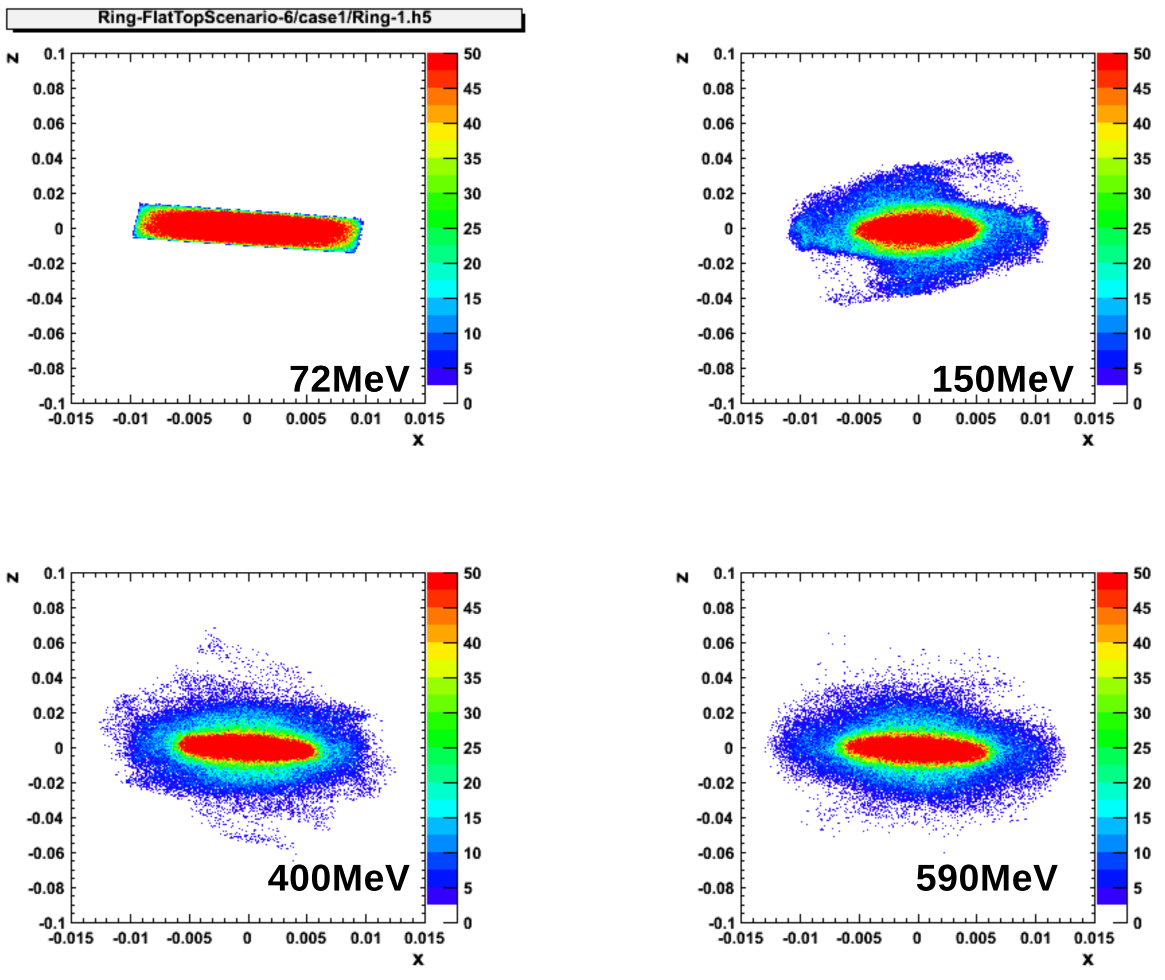
-10^6 macroparticles

- precise field-map

- bunch dimensions:

s_z **~ 5..25 mm**; σ_{xy} ~ 10 mm

→ operation with short bunches and reduced flattop voltage seems possible



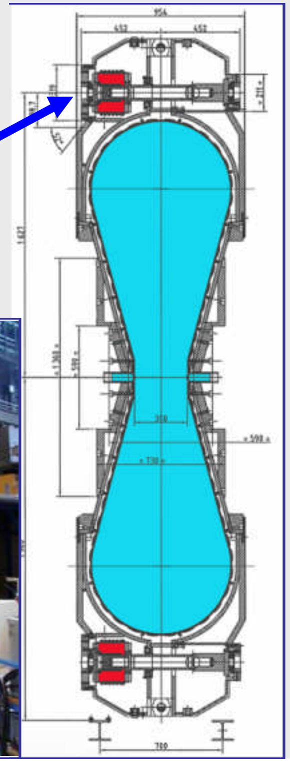
see talk by A.Adelmann this conference, Friday!

Components: new RF Resonators for Ring Cyclotron

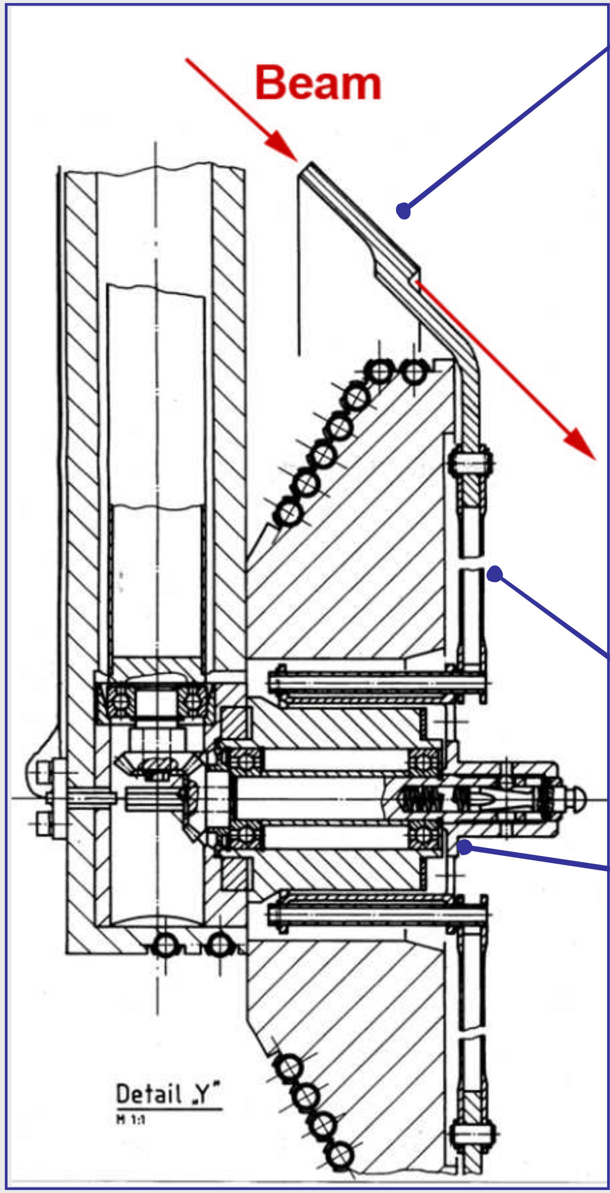
- **two new resonators installed and operated** (together with two old Al resonators); remaining two will be installed in SD 2008
- **f = 50.6MHz**; **$Q_0 = 4 \times 10^4$**; **U_{max}=1.2MV** (presently 0.83MV→202 turns in cyclotron)
- transfer of up to **400kW power to the beam** per cavity
- deformation from air pressure ~20mm; **hydraulic tuning devices** in feedback loop → regulation precision ~10µm
- new copper cavities have **less wall losses** (potentially saves ~100kW per resonator); **faster conditioning** observed; **better surfaces** for vacuum seals

resonator inside

hydraulic tuning devices (5x)



Components: High Power Meson Production Targets



TARGET CONE

3.0mA o.k., limit: sublimation

Mean diameter:	**450 mm**
Graphite density:	1.8 g/cm³
Operating Temp.:	**1700 K**
Irrad. damage rate:	0.1 dpa/Ah
Rotation Speed:	**1 Turn/s**
Target thickness:	**60 / 40 mm**
	10 / 7 g/cm²
Beam loss:	18 / 12 %
Power deposit.:	30 / 20 kW/mA

SPOKES

To enable the thermal expansion of the target cone

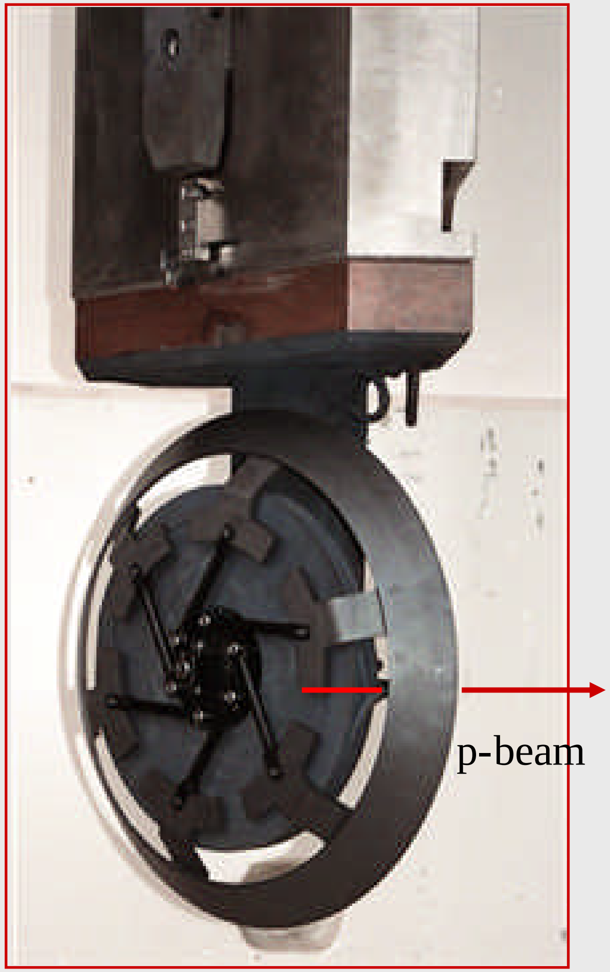
BALL BEARINGS *)

Silicon nitride balls

Rings and cage silver coated

Lifetime 2 y

*) GMN, Nürnberg, Germany



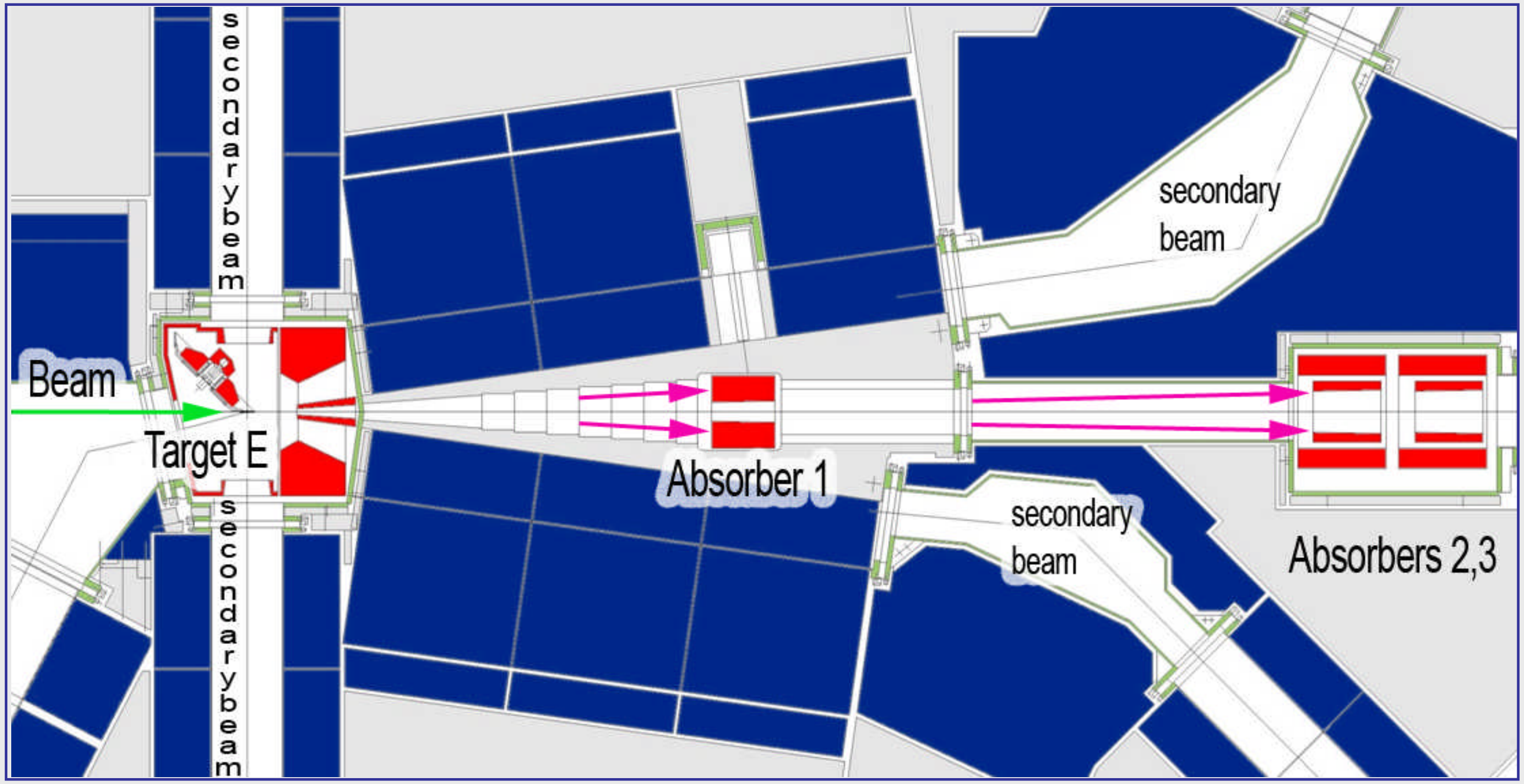
G.Heidenreich et. al.

Absorbers behind the Target need Upgrade

è absorbers capture scattered protons, up to 30% of the beam power

è at 3mA the uniformity of the losses on the three units has to be improved, as well as the cooling capacity

è absorbers are exchangeable without dismantling the vacuum system



side note on Spallation Target

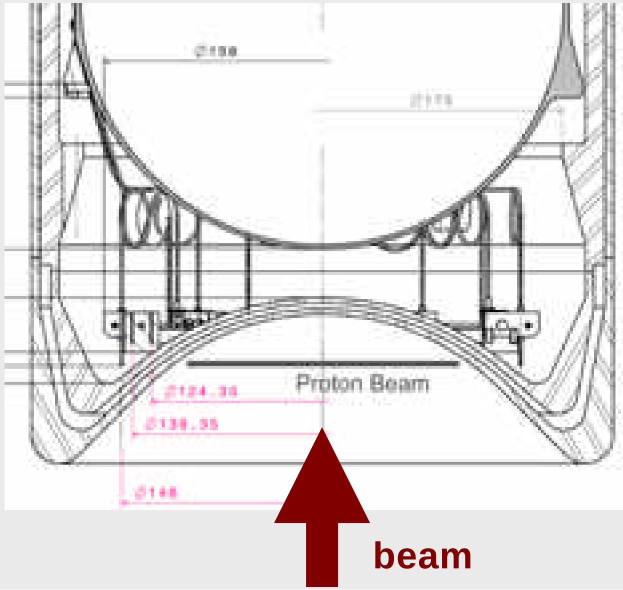
[ultimate goal – more neutrons • which spallation target?]

- in 2006 test of liquid metal target **MEGAPIE** (lead/bismuth) → neutron flux raised by **80%**; R&D program for production target under way (not before 2011)
- also: improvements on **solid target** may gain **~40%**
- **significant potential with target development, equivalent with more current**

the future – liquid metal target?

beam window and assembled **target of MEGAPIE**;

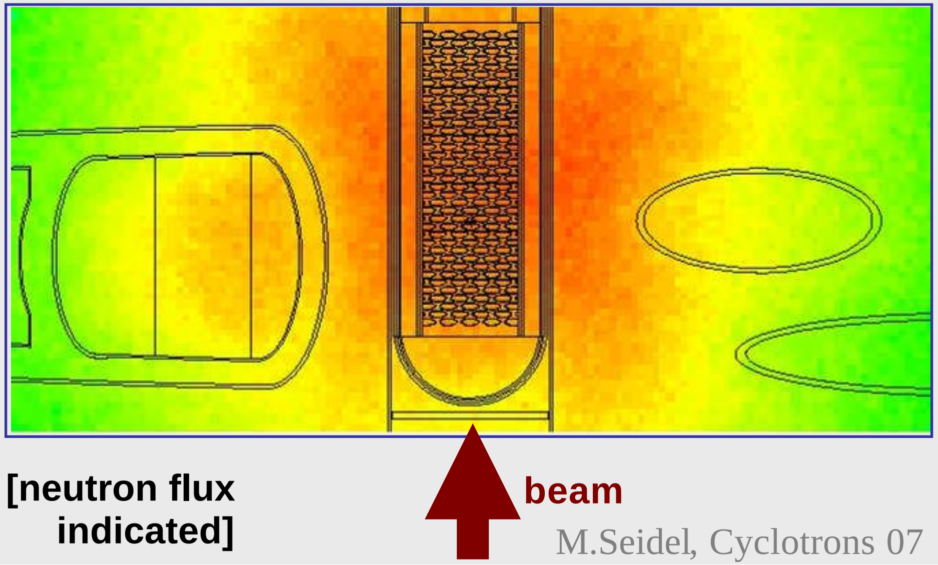
~~**[talk by F.Gröschel, Monday]**~~



presence: D_2O cooled solid target

side view of **presently used solid target** (Zircaloy tubes filled with lead)

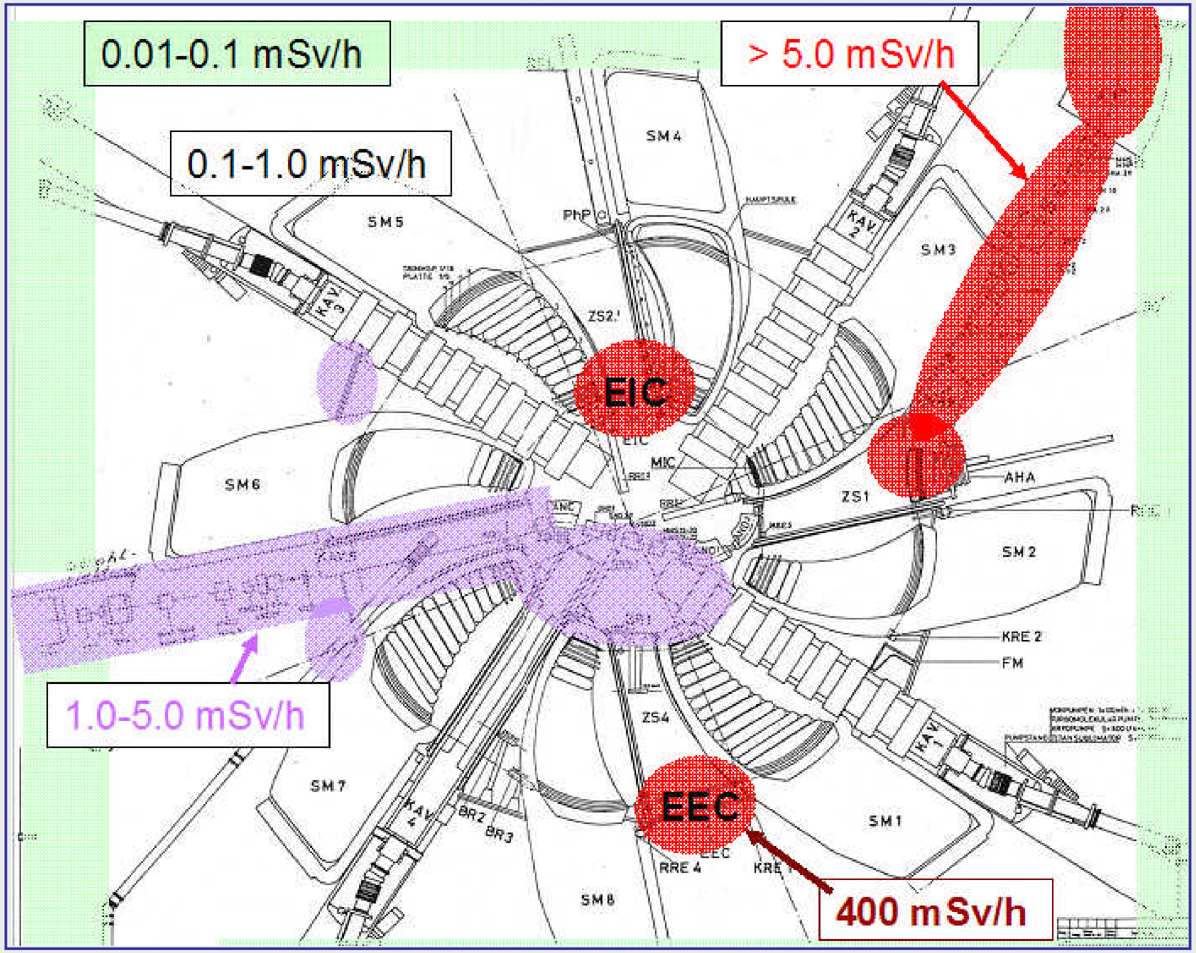
also **this scheme has improvement potential!**



[neutron flux indicated]

Controlling Beam Loss

Instrumentation:
- loss monitors: ionization chambers
- segmented collimators → measure loss current
- transmission monitors → difference between two current monitors
- many technical interlocks → magnet currents, cavity voltages etc.



activation map of Ring Cyclotron

(EEC = electrostatic ejection channel)

Interlock levels:

Injector II - 5µA

Ring Extr. - 2µA (**typ. 0.4**)

Transport Line - 100nA

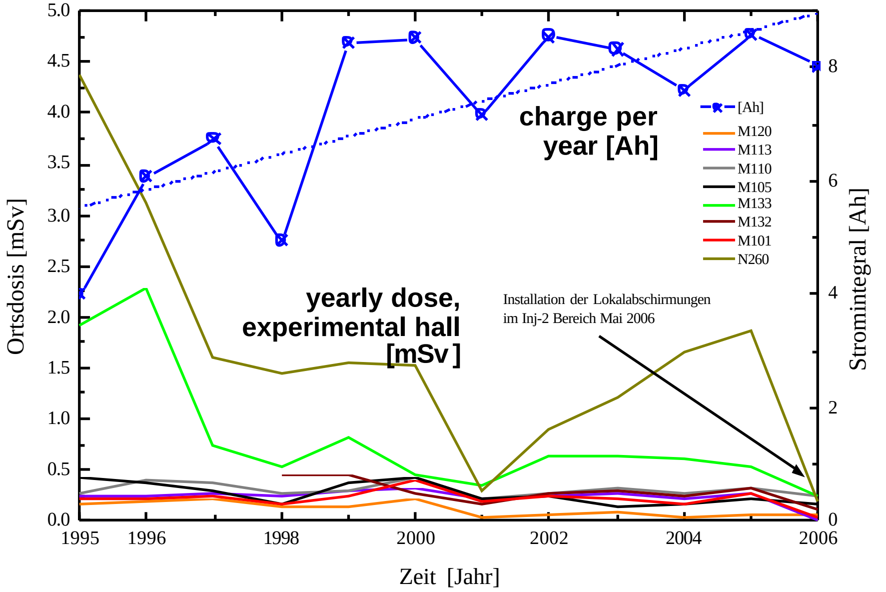
courtesy: A.Mezger

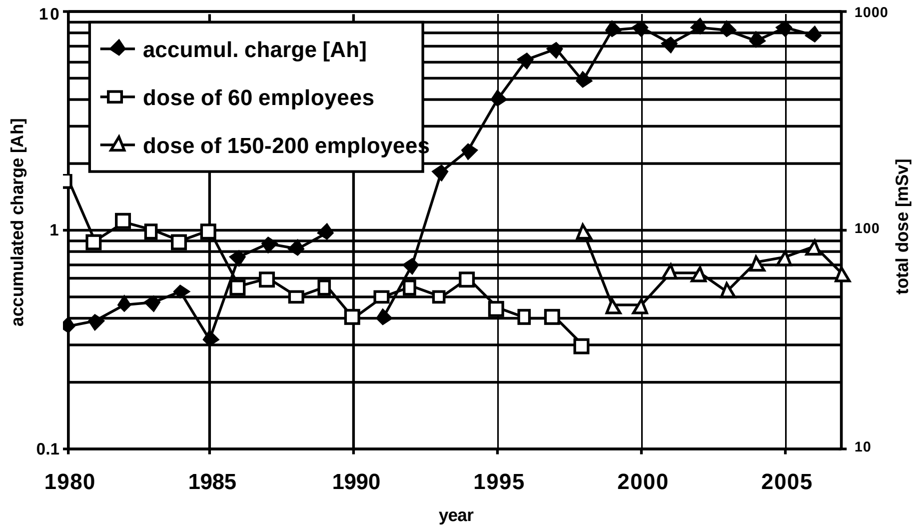
Legal Requirements for Upgrade

- present license allows for **2.0mA**
  (actually losses are key parameter, but license specifies current)
- licensing process for 3.0mA under work!
- **required:** re-evaluation of shielding • direct radiation; emission of radio nuclides; activation of components • radiation exposure of personnel

radiation dose monitored in experimental hall; accumulated charge vs. time; no correlation visible!

personnel radiation dose shows no correlation between beam current and dose!

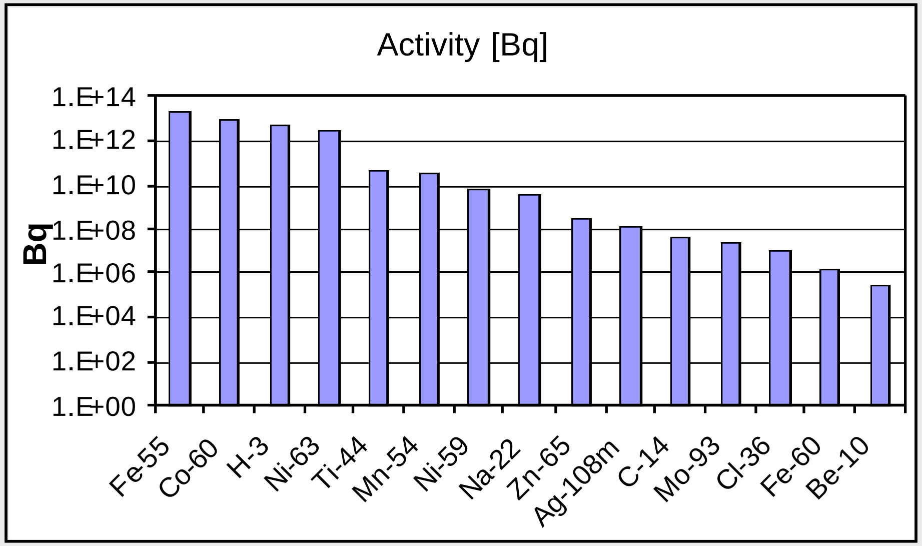




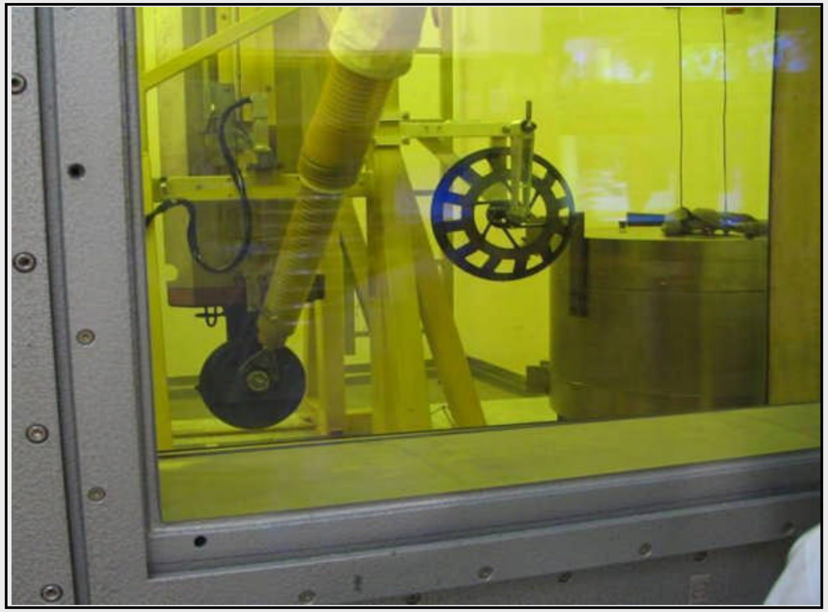
additional Infrastructure

- totally ~ 1200 employees radiologically monitored at PSI
- radiation monitoring network, contamination detectors, interlock systems, analytical equipment; facilities for dealing with radioactive components
- legally required: radioactive waste management – prediction of nuclide content, decay time, professional storage etc.
- licensing through specialized and knowledgeable Swiss authorities

example: nuclide inventory of beam dump; numerical prediction; legally required for disposal in Switzerland



example: hot cell: C-target wheel (several Sv/hour) in remote handling



Milestones of the Upgrade Project

7 / 2007	place order for new resonators injector II
9 / 2007 **new:**	authorization for short time operation at 2.2mA given **[21.9.: auth. received; 28.9.: 2.15mA achieved; acceptable losses!]**
12 / 2007	**parameters 500MHz-buncher/flattop fixed (experiment + simulation)**
3 / 2008	audit with Swiss authorities on licensing of operation at 3mA
4 / 2008	install two new resonators in ring cyclotron → completed! 500MHz (10'th harm.) is installed
11 / 2008	new building for injector II RF system incl. infrastructure completed
3 / 2009	resonator 2 for injector II delivered and controls for RF system installed
3 / 2010	resonator 4 for injector II delivered
4 / 2011	**operation at 2.6mA (1.5MW)**
12 / 2011	new collimators at target E installed (power limitation); extension of cooling capacity; improvement of SINQ cooling
4 / 2012	**operation at 3.0mA (1.8MW)**

Summary

- the PSI cyclotron facility has significant further potential → an upgrade of the beam power **from 1.2 to 1.8 MW** is in progress
- the essential ingredients are **improved resonators** with higher gap voltages in the cyclotrons and **harmonic bunchers** that allow to inject short bunches in the cyclotrons

  [® round bunch scheme]
- for high power CW beam production **cyclotrons present a very valid and cost efficient option!**

Thank you for your attention!

Thanks to the colleagues at PSI from GFA/LOG/NUM, who contribute to the project and provided material for this presentation!