The Heavy Ion Storage Ring TSR

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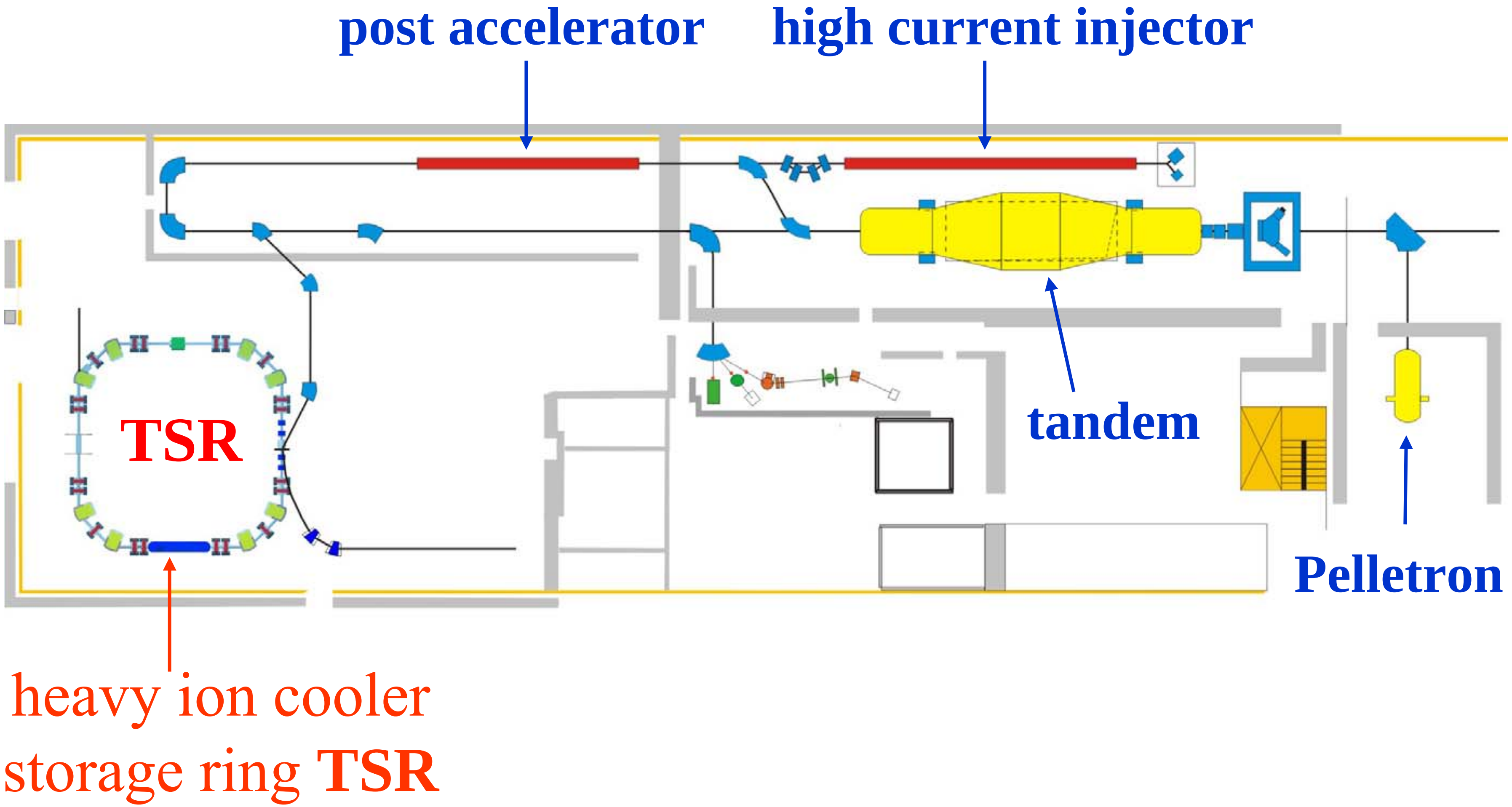
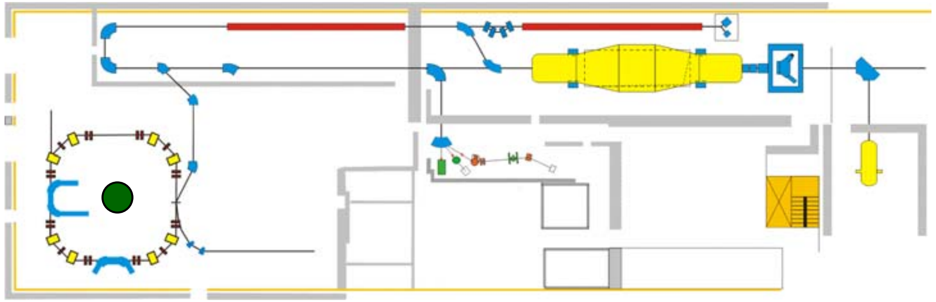
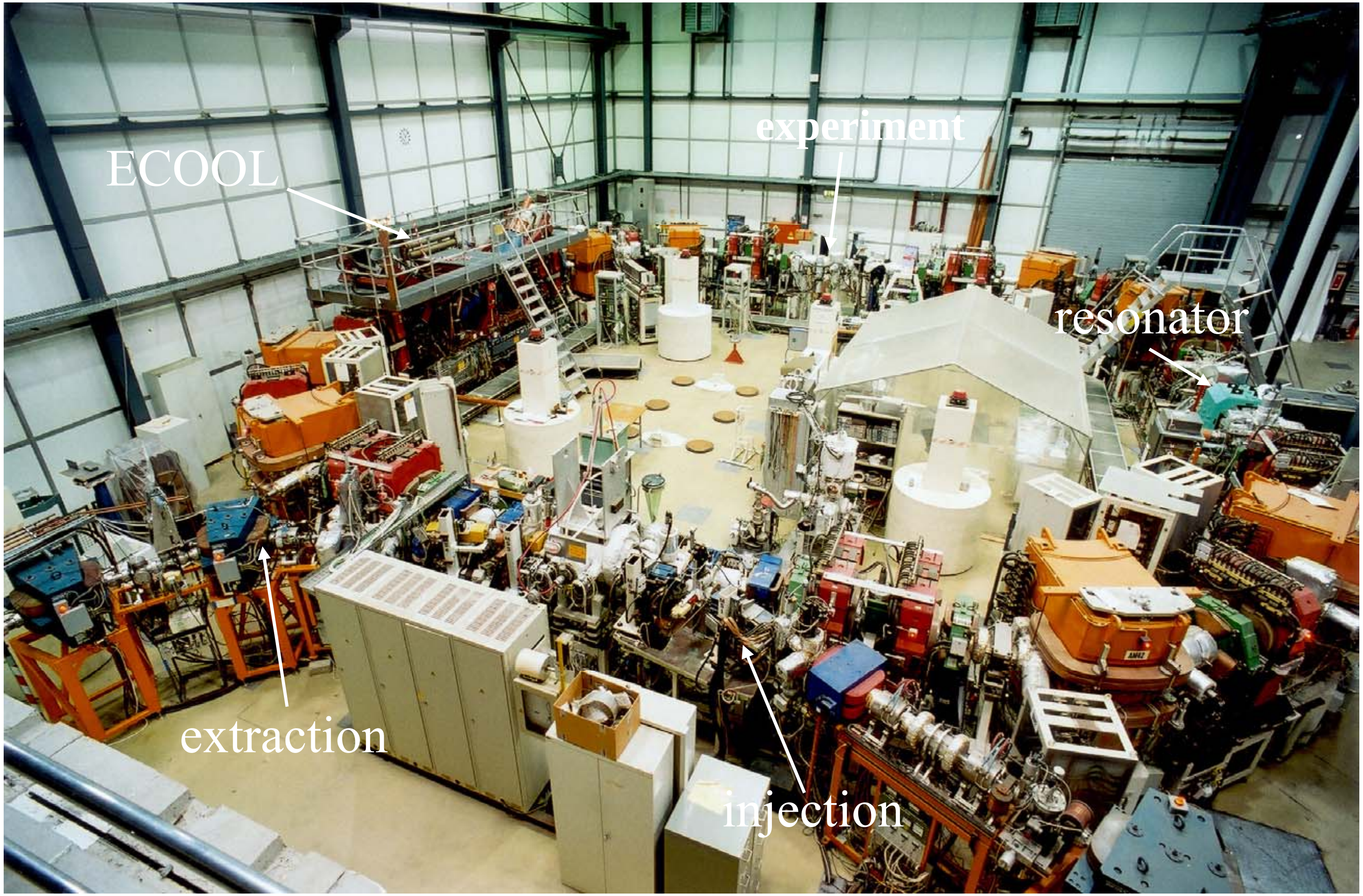
ISCC meeting, CERN, July 3rd 2012

The accelerator facilities at MPIK



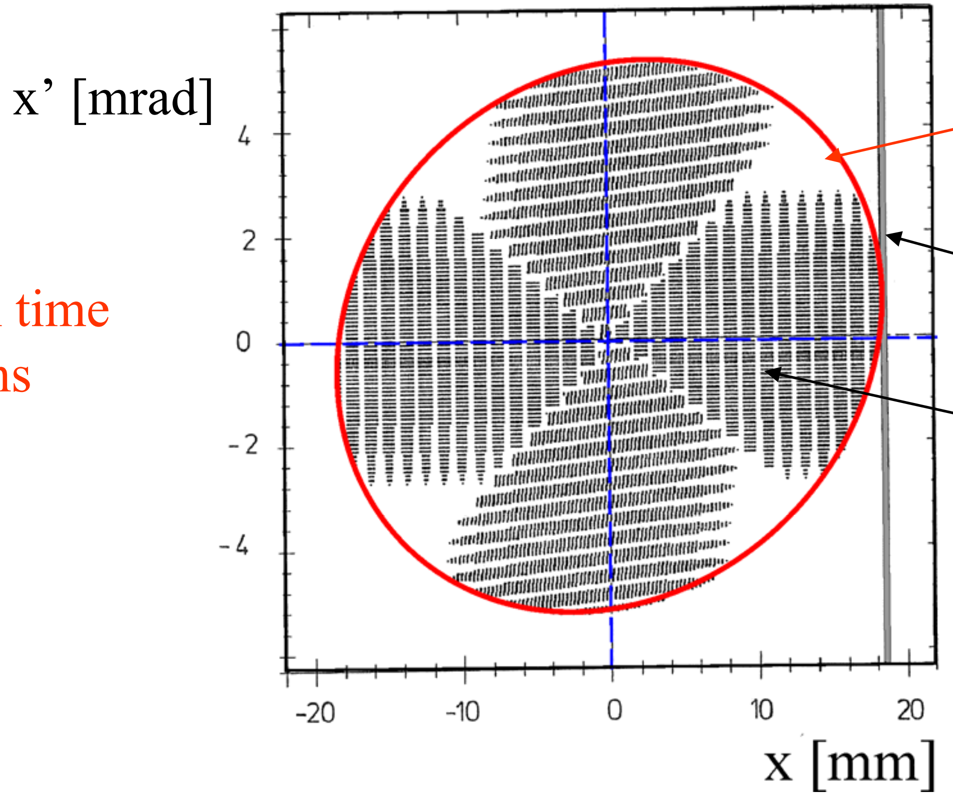
The heavy ion storage ring TSR





With multiturn Injection filled transverse phase space

Simulation for the heavy ion storage ring TSR



acceptance ellipse
A=120 mm·mrad

septum thickness

phase space
injector beam
(tandem)
ε=1.5 mm·mrad

injection time
≈ 70 turns

intensity multiplication factor M:

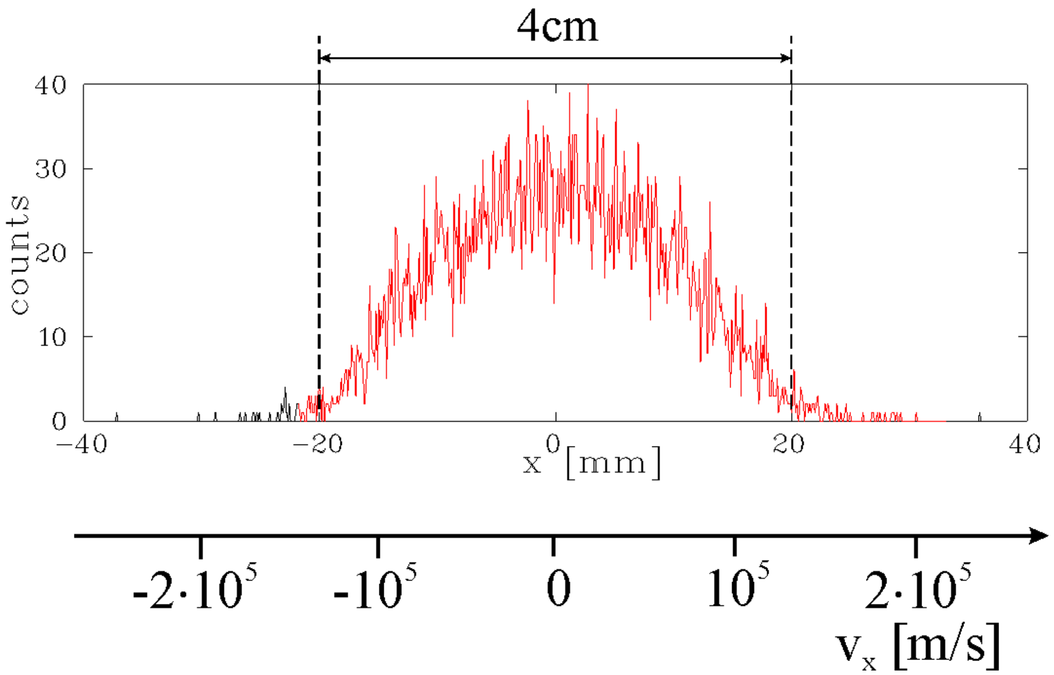
$$M = \frac{I_0}{I_{inj}} = \frac{A}{d \cdot \varepsilon}$$

I_0 stored intensity , I_{inj} injector intensity

d- phase space dilution factor, simulation d ≈2 ⇒ M ≈ 40

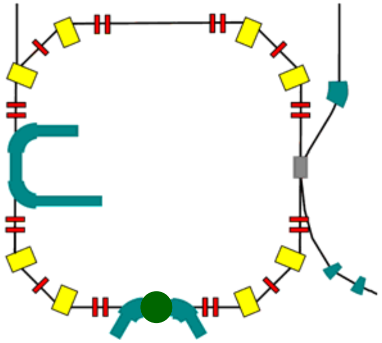
Beam profile after multi turn injection

beam: $^{12}C^{6+}$ E=73.3 MeV

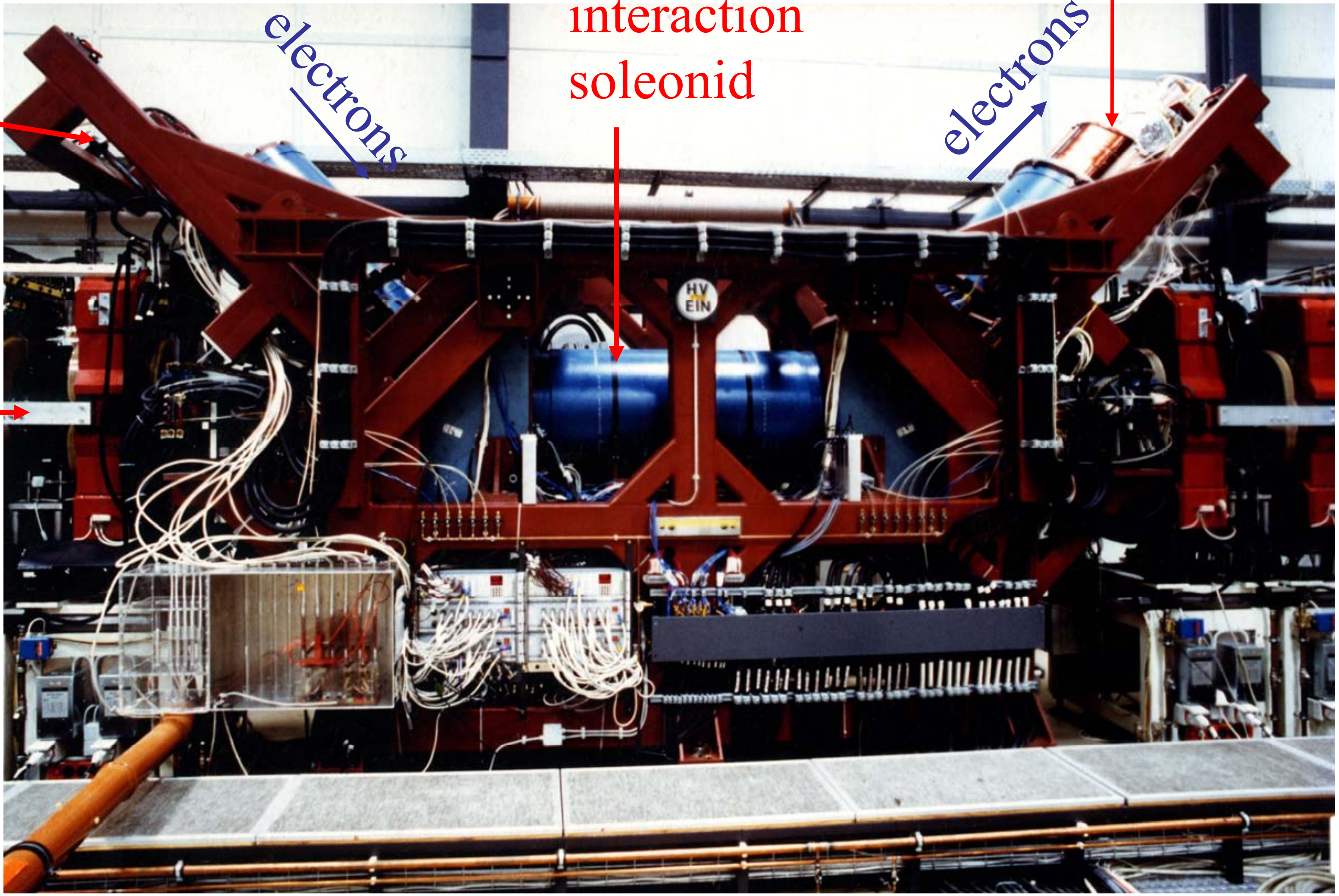


velocity distribution $n(v_x) = \frac{N}{\sqrt{2\pi}\sigma_{v_x}} e^{-\frac{1}{2}\frac{v_x^2}{\sigma_{v_x}^2}}$ $\sigma_{v_x} \approx 6\cdot 10^4 \, m/s$

beam temperature: σ_{v_x} with $\frac{1}{2} k \cdot T = \frac{1}{2} m \cdot \sigma_{v_x}^2$ $\Rightarrow T \approx 5\cdot 10^6$ K



The electron cooler



gun

electrons

interaction soleonid

electrons

collector

ions

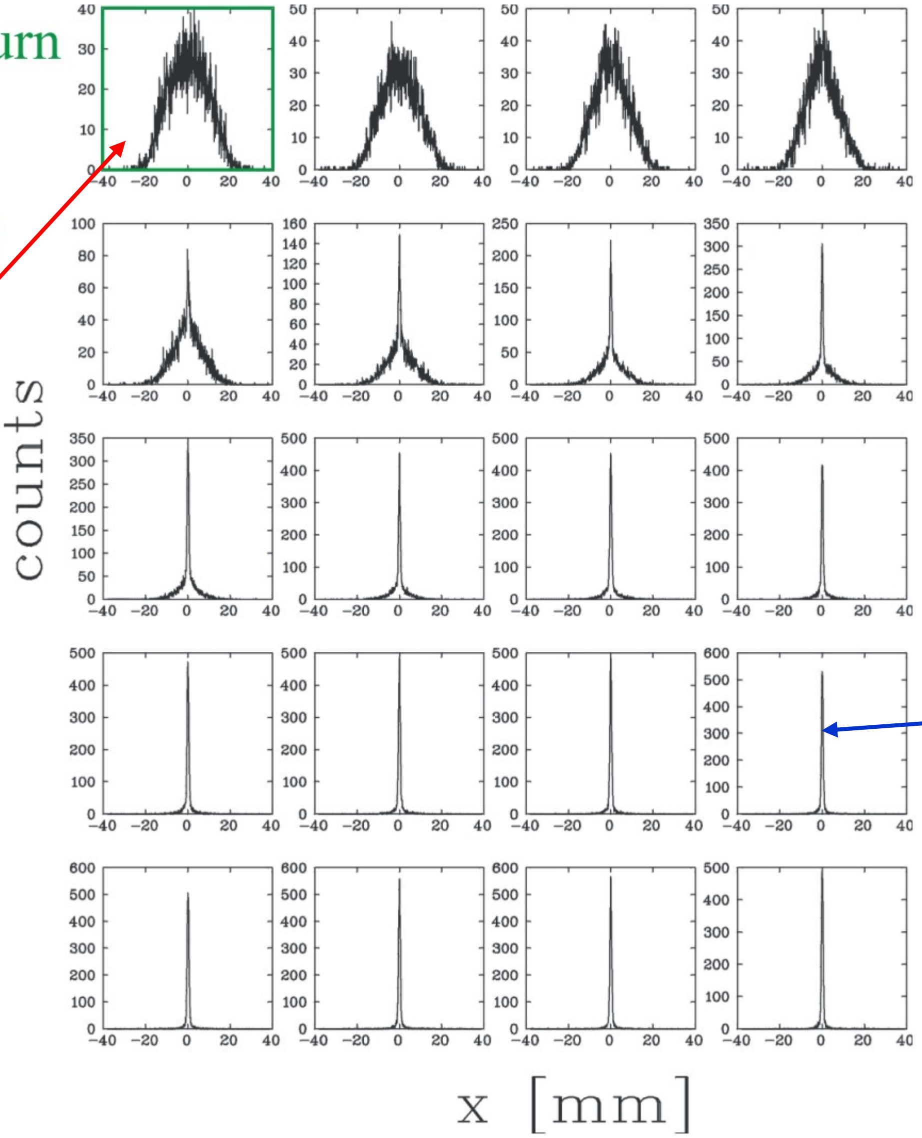
ions

Transverse electron cooling

after multiturn injection

Δt=100 ms

hot ion beam



example
horizontal beam profile
$^{12}C^{6+}$ (E=73.3 MeV)

$\Rightarrow$ transverse cooling time:
$T \approx 1s$

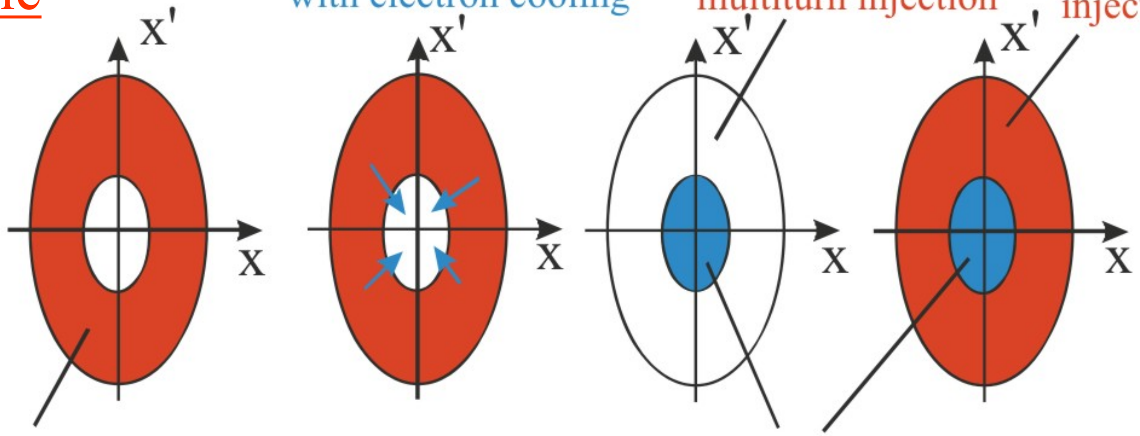
for α_{ex}= 7.7
and $n_e=1.53\cdot10^7$ 1/cm^3

cold ion beam

measuring time: 2s

ECOOL Stacking

principle



compression of transverse phase space with electron cooling

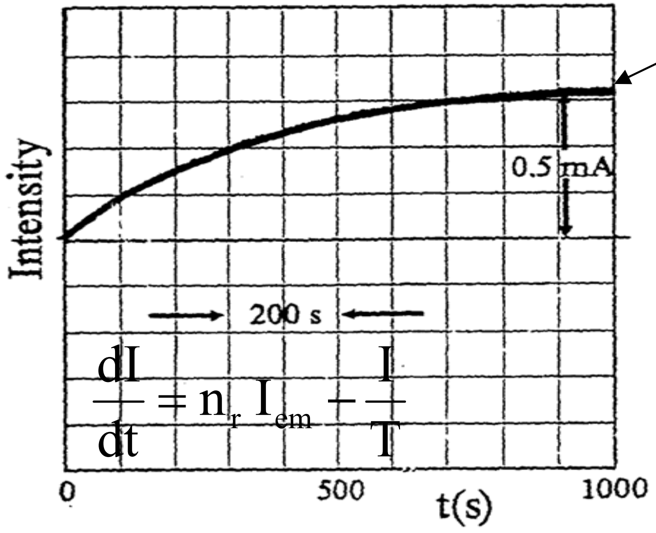
phase space made available for the next multiturn injection

next multiturn injection

filled transverse phase space with multiturn injection

phase space containing the electron cooled ion beam

measured I(t) for $^{35}Cl^{17+}$ ions



$$\frac{dI}{dt} = n_r I_{em} - \frac{I}{T}$$

equilibrium intensity I_0

$$I_0 = n_r \cdot T \cdot M_{eff} \cdot I_{inj}$$

$$n_r = \begin{cases} 1/T_{cool} & T_{cool} > 0.2s \\ 5\ 1/s & T_{cool} \leq 0.2s \end{cases}$$

I_{em} effective intensity increase with multiturn injection

I_{inj}-Injector intensity

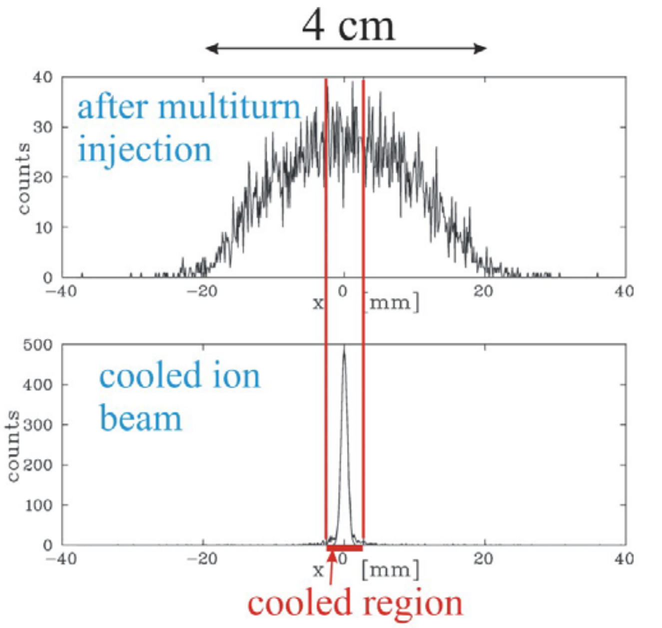
M_{eff}- effective intensity multiplication factor : $M_{eff} = \frac{I_{em}}{I_{inj}}$

T- beam lifetime

n_r-injection rate

T_{cool}- electron cooling time

Cooling time T_{cool} of a multiturn injected ion beam



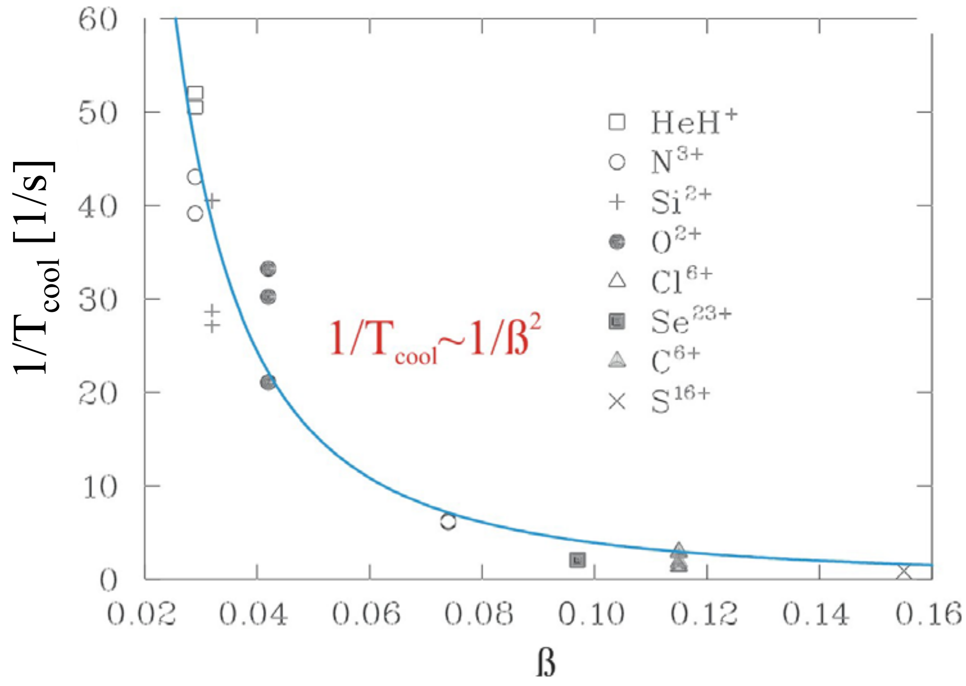
definition of transverse cooling time

The cooling time is the time it takes to cool 80% of the particles outside the cooled region into the marked region

$$T_{cool} \approx const \cdot \frac{A\,ß^2}{q^2\,n_e} \quad (\,0.03<ß<0.16\,)$$

inverse cooling time $1/T_{cool}$ as a function of ß

normalized to q^2/A and $n_e=10^8$ cm^{-3}



$\Rightarrow$ for $\alpha_{ex}=9.6$ and per $=1$ µperv

$$T_{cool} \approx \frac{A}{q^2} \cdot 3\,s \quad \text{because} \quad n_e \propto \beta^2$$

Beam life-time T for some ions

60 h

Ion	Energy	Pressure	cooled	uncooled	cooled	expl.	uncooled	expl
	[MeV]	[10^{-11} mbar]	[s]	[s]	[s]		[s]	
p	21	4	220000		180000	REC		
HD^{+}	2	7		5				DIS
^{7}Li^{+}	13	6		48	41	ST	41	ST
^{9}Be^{+}	7	6	16	16	12	ST	12	ST
^{12}C^{6+}	73	6	7470		5519	REC	5630	MS
^{28}Si^{14+}	115	6	540	260	424	CAP	493	CAP
^{32}S^{16+}	196	5	450		554	REC	1200	CAP
^{35}Cl^{15+}	157	6	366		306	CAP	375	CAP
^{35}Cl^{17+}	202	6	318	366	402	REC	735	CAP
^{56}Fe^{22+}	250	5	77		90	REC	278	CAP
^{58}Ni^{25+}	342	5	60		89	REC	374	CAP
^{63}Cu^{26+}	510	6	122		166	REC	622	CAP
^{74}Ge^{28+}	365	5	45		59	REC	162	CAP
^{80}Se^{25+}	480	5	204		179	REC	384	CAP
^{197}Au^{51+}	710	5	23	51				

Intensities for a few ions achieved with ECOOL stacking

I≈1 mA →
inchoherent tune shift limit

Ion	E [MeV]	life time[s]	Intensity [μA]
p	21	220000	1000
$^{16}O^{8+}$	98		750
$^{12}C^{6+}$	73	1700	1000
$^{32}S^{16+}$	195	450	1500
$^{35}Cl^{17+}$	293	318	1000
$^{45}Sc^{18+}$	178		380
$^{56}Fe^{22+}$	250	77	70
$^{56}Fe^{23+}$	260	74	128
$^{58}Ni^{25+}$	342	60	600
$^{63}Cu^{25+}$	290	49	280
$^{63}Cu^{26+}$	510	122	100
$^{74}Ge^{28+}$	365	45	110
$^{80}Se^{25+}$	480	204	100
$^{80}Se^{31+}$	506	50	<1
$^{197}Au^{50+}$	695	3	3

$N \approx 4000$ $^{32}S^{16+}$

$$N = \frac{I_0}{I_{inj}} = M \cdot \varepsilon_m \cdot n_r \cdot T$$

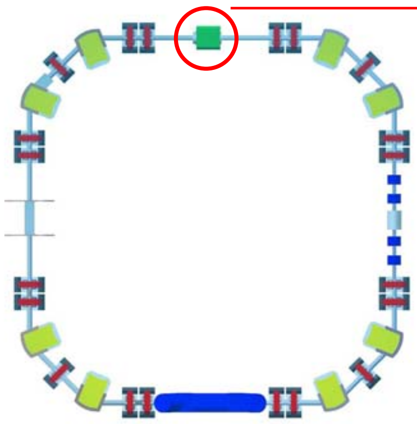
$$n_r = \begin{cases} 1/T_{cool} & T_{cool} > 0.2s \\ 5\,1/s & T_{cool} \le 0.2s \end{cases}$$

$$\varepsilon_m = \begin{cases} 0.8 & n_r = 1/T_{cool} \\ 1 & n_r < 1/T_{cool} \end{cases}$$

I_0	equilibrium intensity
I_{inj}	injected intensity
T-	life time
T_{cool}	cooling time of a multiturn injected ion beam
M	intensity multiplication factor multiturn injection ECOOL Stacking $M \le 10$

RF acceleration and deceleration

RF resonator

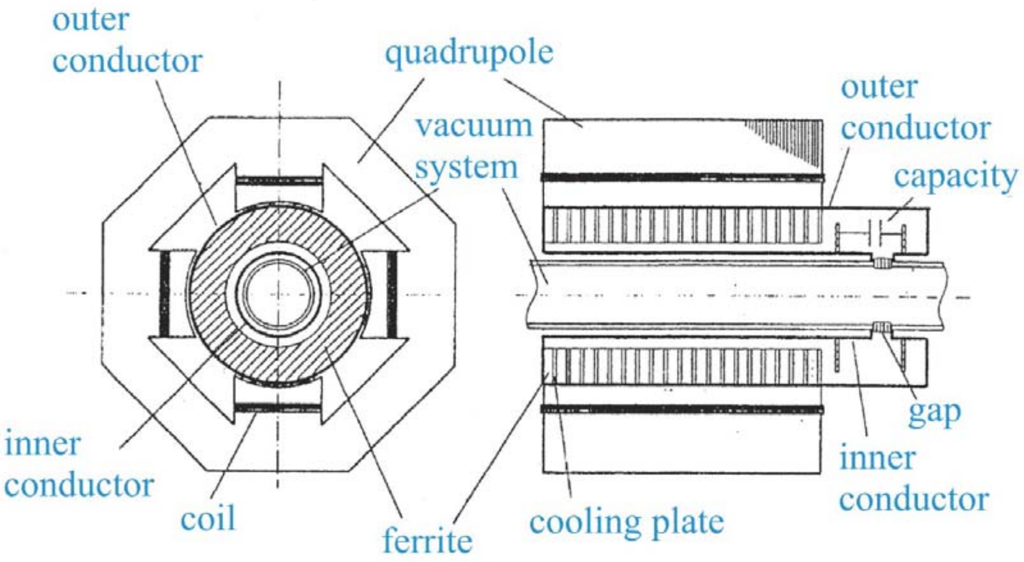


quadrupole coil resonator

frequency range: 0.5-7 MHz
only with magnetization:
factor ≈ 7 I_{mag}=0-150 A
rf voltage: max 5 kV
rf power: max 10 kW
ferrite: Philips FXC 8C12
ferrite size: 498x270x25 mm^3
number of ferrites: 20
cooling: 21 water cooled Cu disks

quadrupole

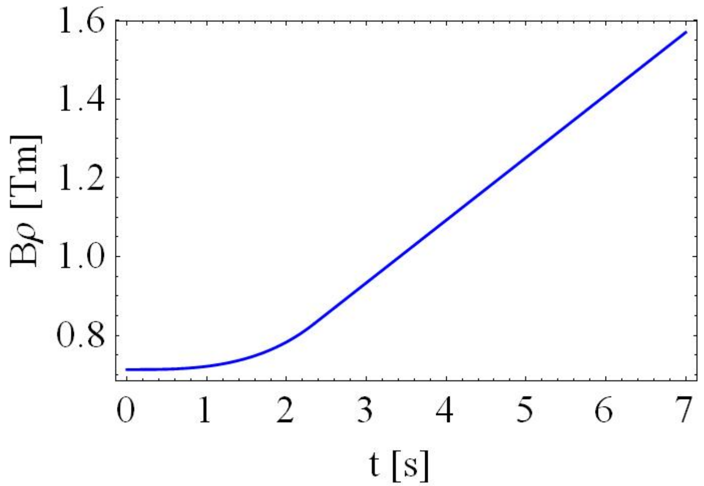
- magnetization of the ferrites
- decoupling of rf field and magnetization field



Acceleration tests with $^{12}C^{6+}$ ions

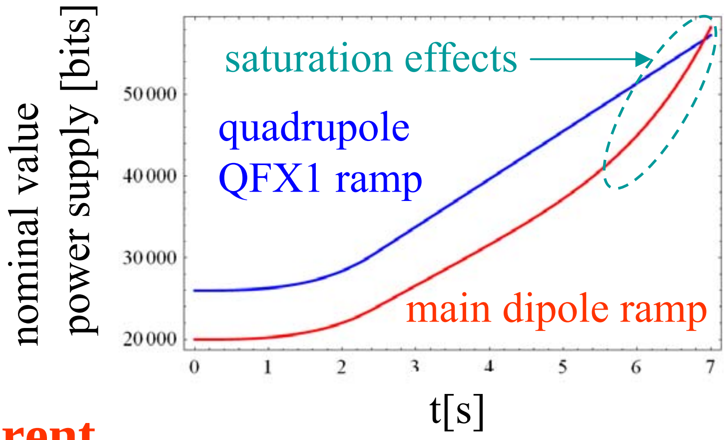
energy E= 73.3 MeV→ 362 MeV ⇔ $B\cdot\rho = 0.71$ Tm → **1.57 Tm**

rigidity



⇒

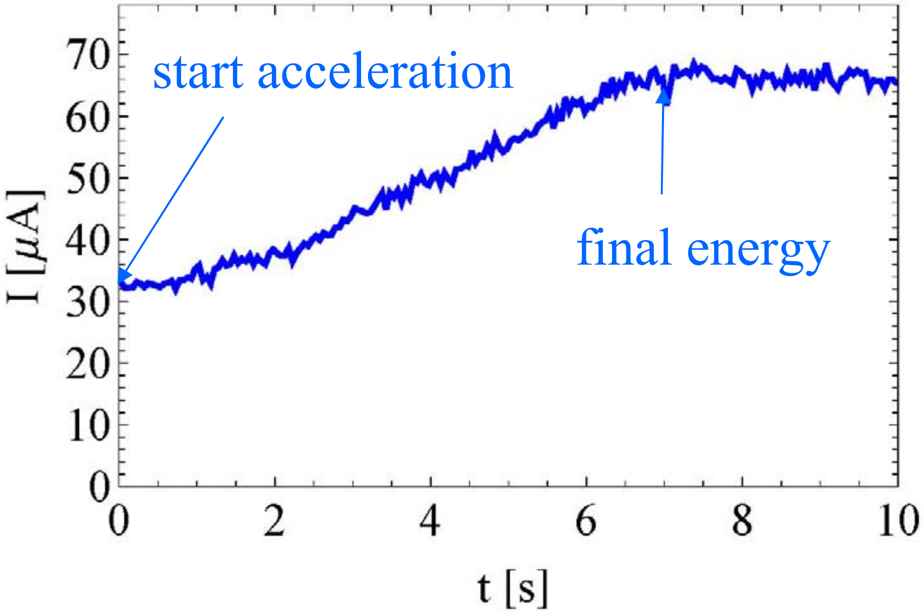
nominal value power supplies



ion current

ion current

$$I = Q \cdot N \cdot f_0$$



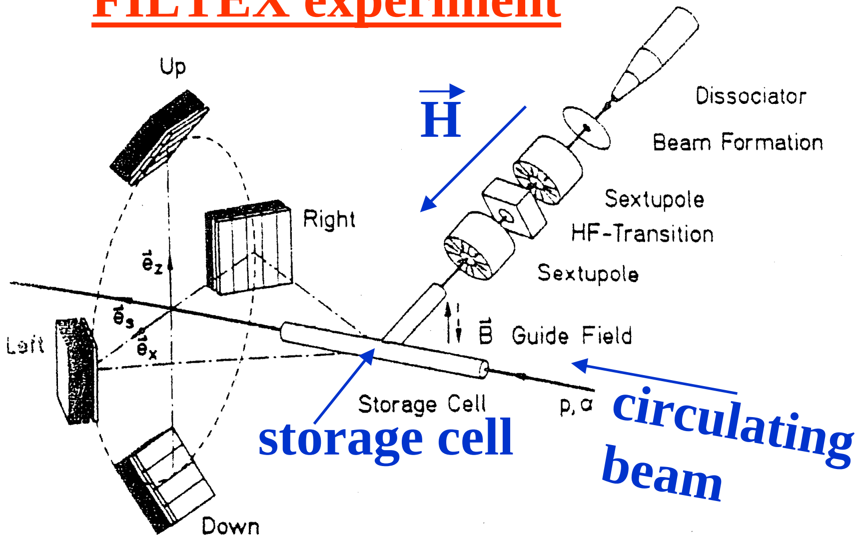
efficiency

$$\eta = \frac{N_{final}}{N_{start}}$$

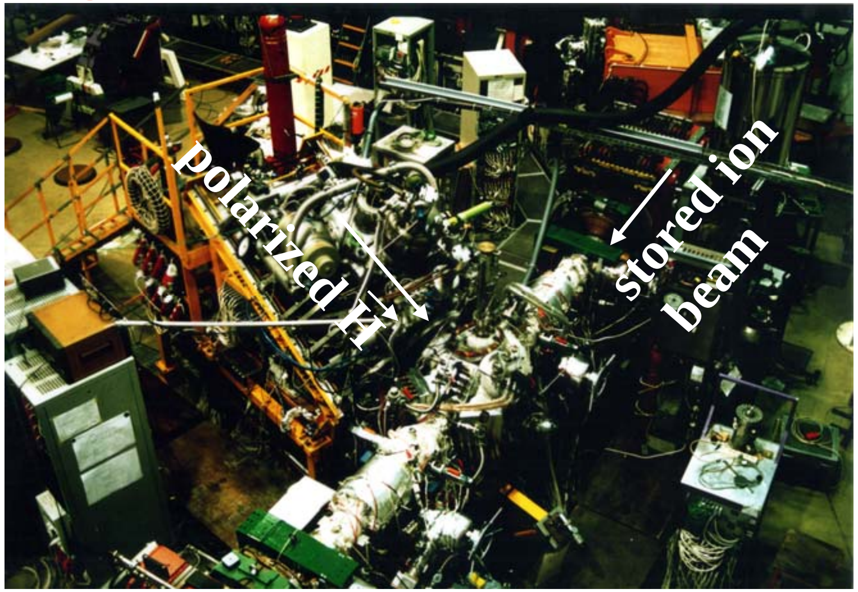
η=98 %

Internal target experiments at the TSR

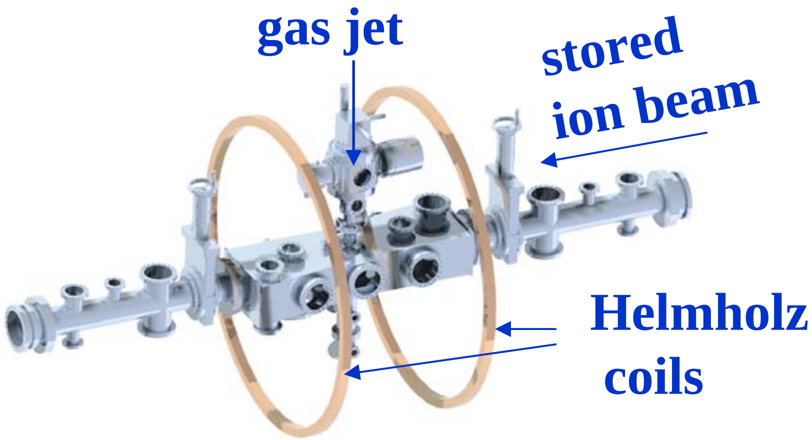
FILTEX experiment

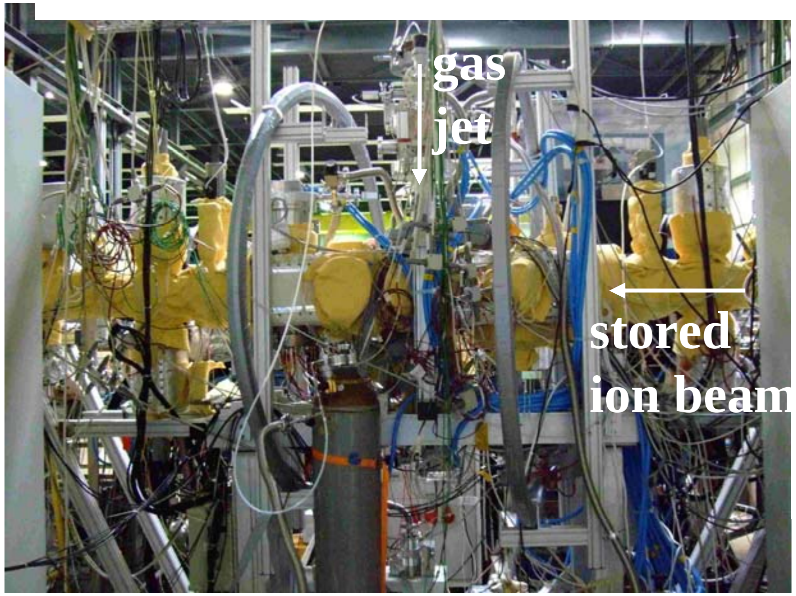


target thickness: 5·10^{13} atoms/cm^2



Reaction microscope



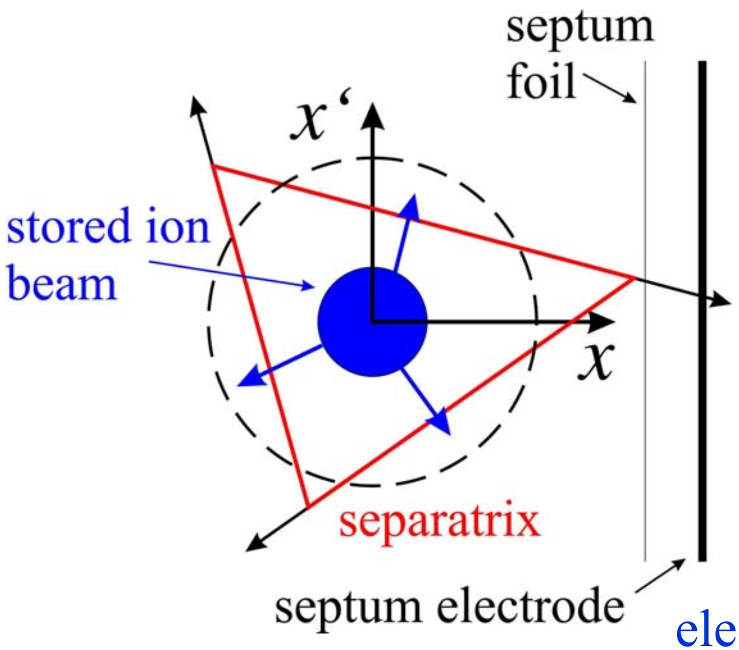


Slow extraction

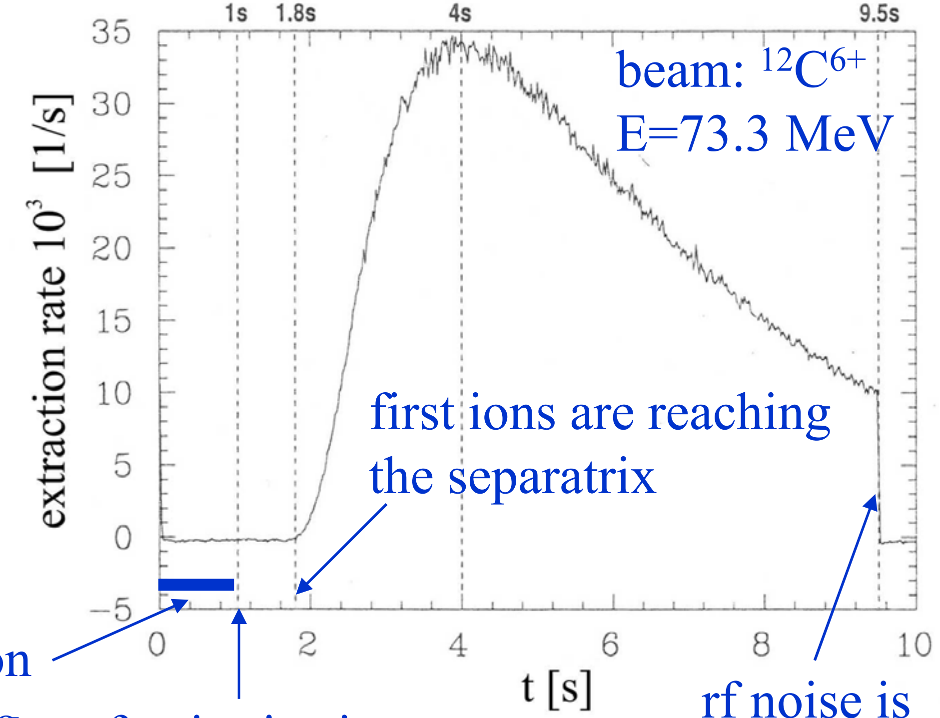
slow extraction process

- ion beam is cooled with electron cooling
- horizontal working point is shifted close to the third order resonance: $Q_x \rightarrow 2.66\ldots$
- rf noise is given to a horizontal kicker to blow up the horizontal phase space

extraction scheme



extraction rate



beam: $^{12}C^{6+}$
E=73.3 MeV

first ions are reaching the separatrix

electron cooling

rf noise is given to a horizontal kicker

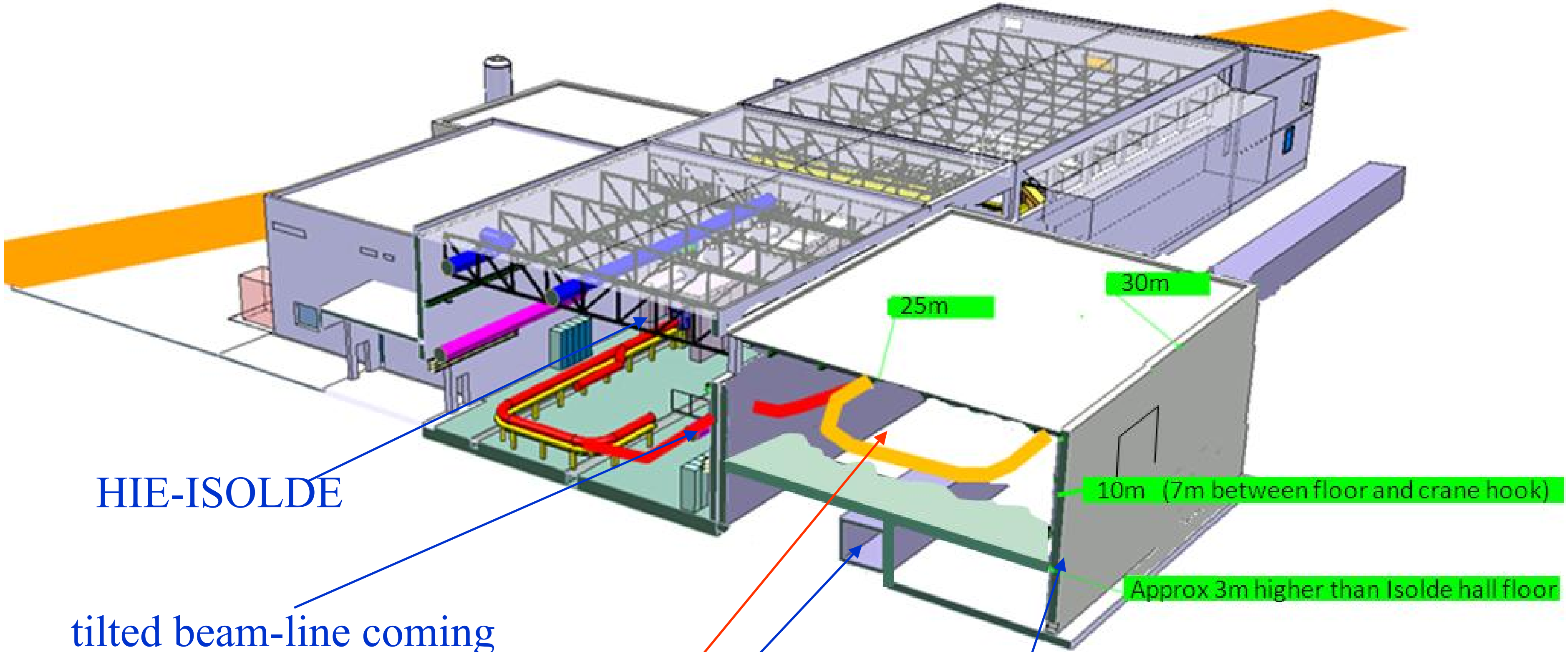
rf noise is switched off

efficiency:
without electron pre-cooling: ≈25 %
with electron pre-cooling: ≈90 %

Status of the TSR ring

- TSR is routinely used at MPI up to the end of 2012
- end of 2012: shut down of the whole accelerator facility at MPIK, including TSR
- TSR will kept at MPI until TSR can be reassembled at ISOLDE (scheduled 2015)
- between 2013-2015 some modification at the TSR can be done to fulfill the requirements from CERN
- in 2015: disassembly and reassembly by specialists from MPIK and CERN,ISOLDE
- commissioning of the TSR at ISOLDE can be done in a joined effort with experts from MPIK and CERN,ISOLDE

TSR @ HIE-ISOLDE



HIE-ISOLDE

tilted beam-line coming
from the HIE-ISOLDE machine.

possible TSR installation
above the CERN cable-tunnel.
(E. Siesling)

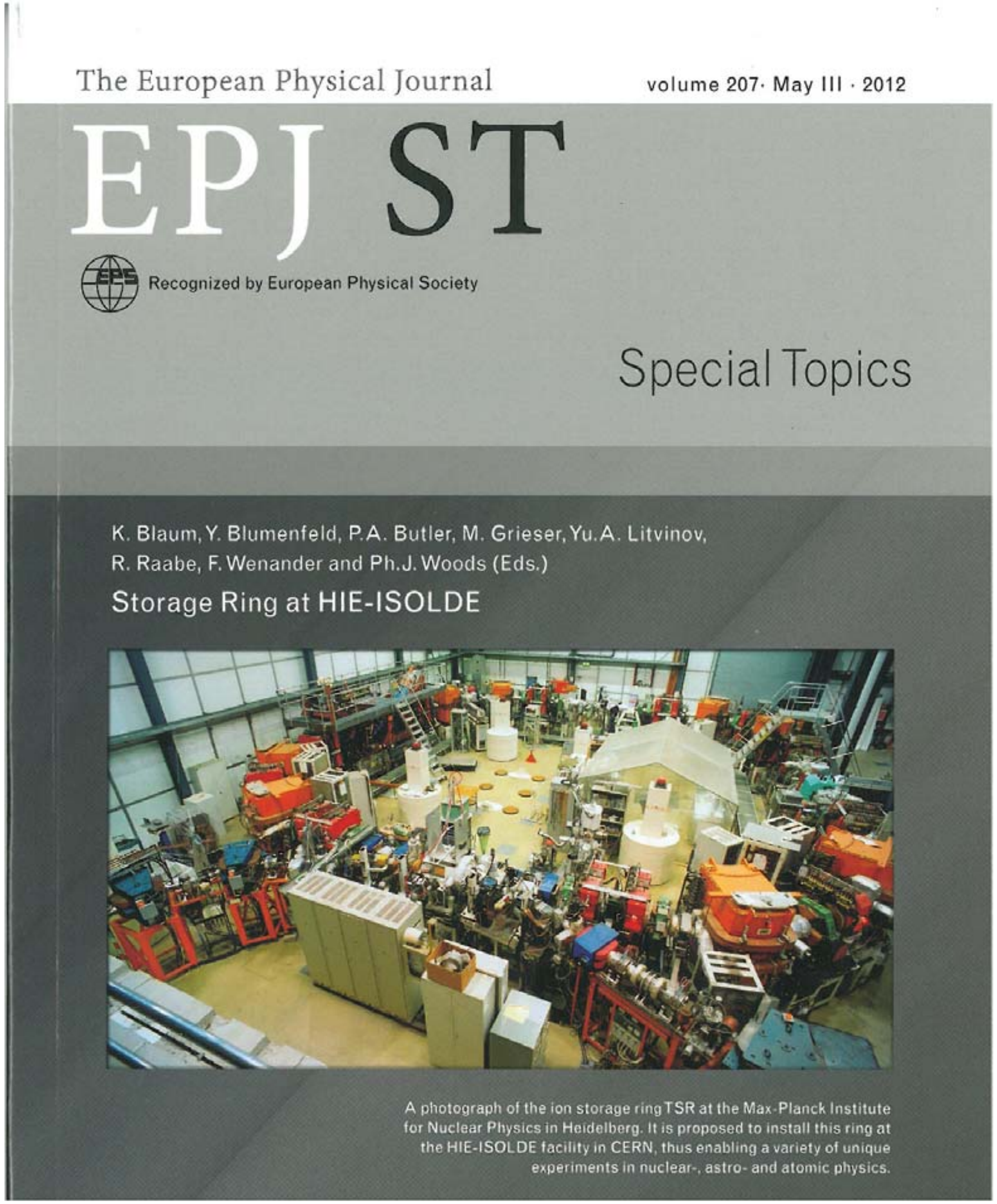
TSR@HIE-ISOLDE building

Technical Design Report

Storage Ring at Hie-Isolde

K. Blaum, Y. Blumenfeld,
P. A. Butler, M. Grieser,
Y. Litvinov, R. Raabe,
F. Wenander and Ph. J. Woods
(Eds.)

Published at the European Physical Journal
Volume 207   May 3 2012



The European Physical Journal

volume 207· May III · 2012

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Special Topics

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Storage Ring at HIE-ISOLDE

A photograph of the ion storage ring TSR at the Max-Planck Institute
for Nuclear Physics in Heidelberg. It is proposed to install this ring at
the HIE-ISOLDE facility in CERN, thus enabling a variety of unique
experiments in nuclear-, astro- and atomic physics.