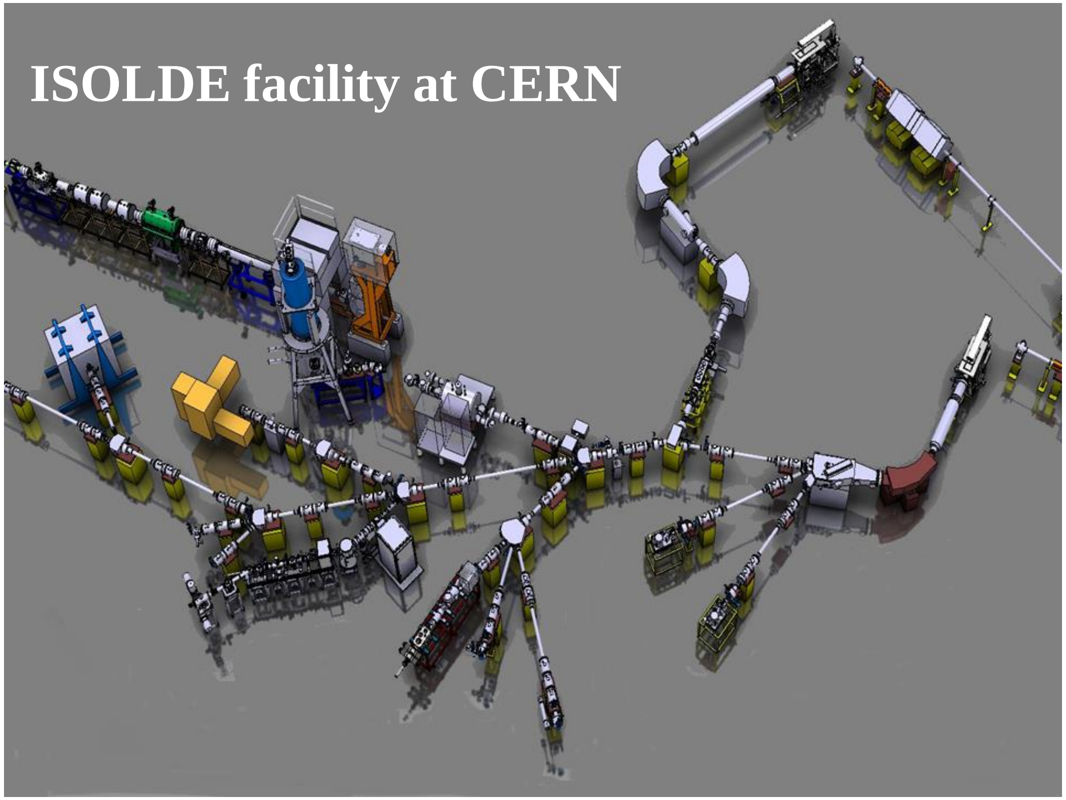
A preliminary design for a compact storage ring and possible integration into the HIE-ISOLDE hall

Manfred Grieser

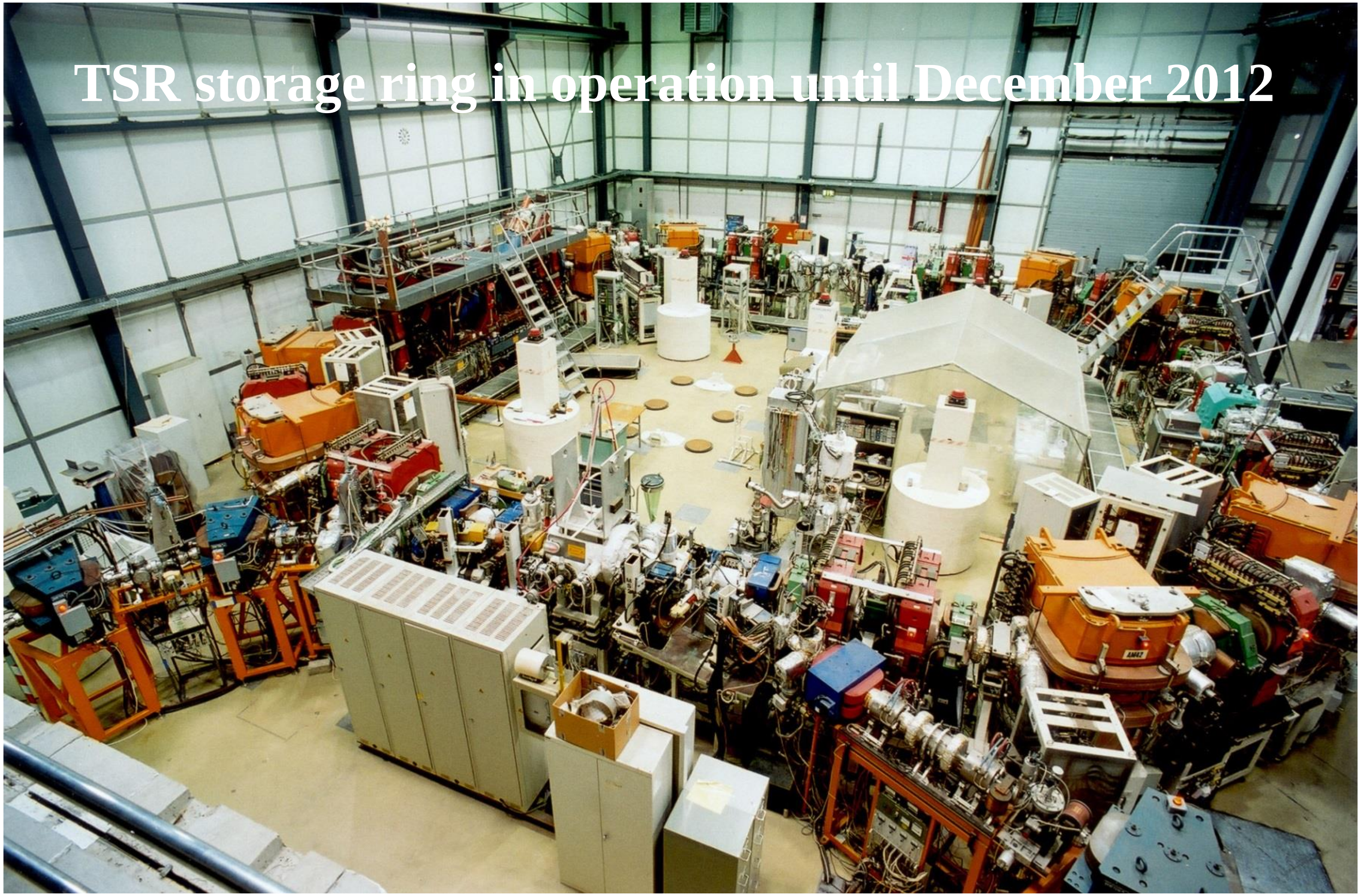
Max Planck Institut für Kernphysik, Heidelberg



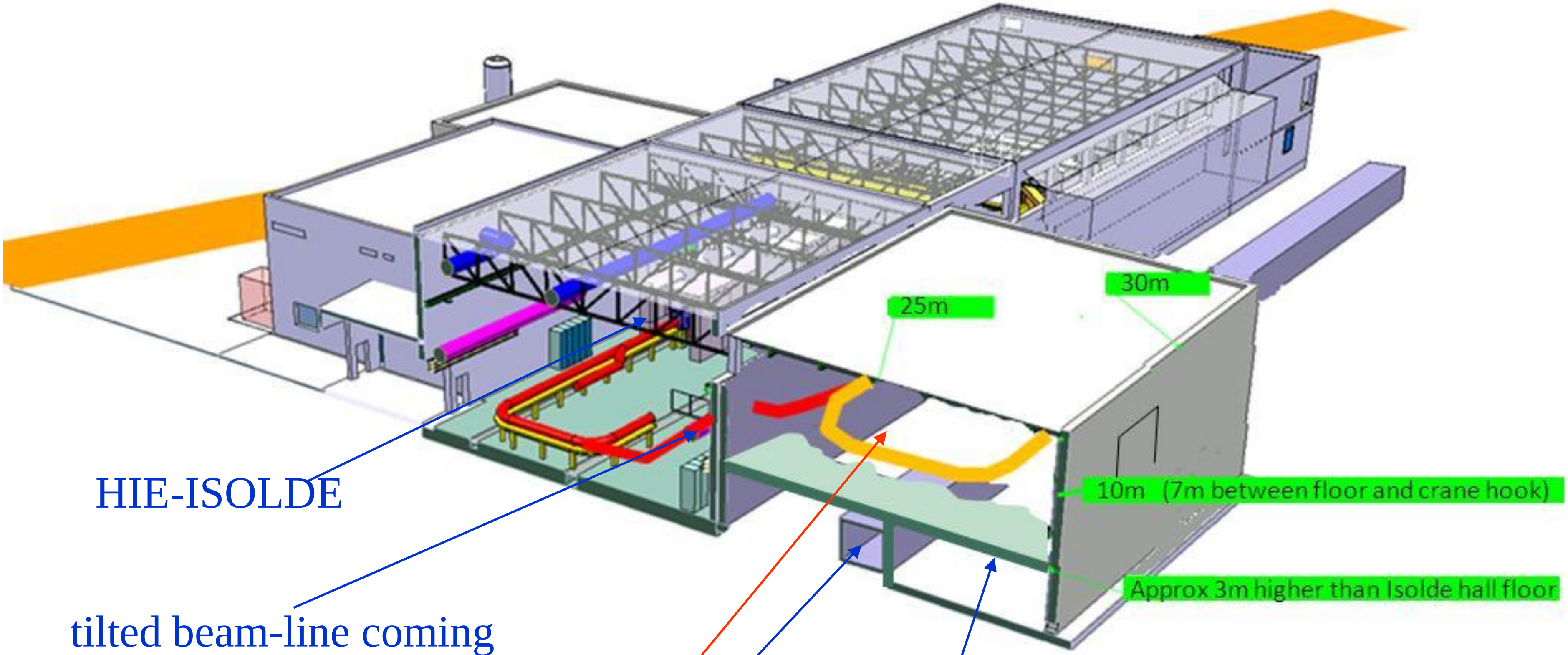
82nd ISOLDE Collaboration Committee meeting, 26th June 2018

Proposed TSR@ISOLDE project

to store radioactive ions for nuclear physics experiments it was proposed to move TSR located at MPI for nuclear physics to 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

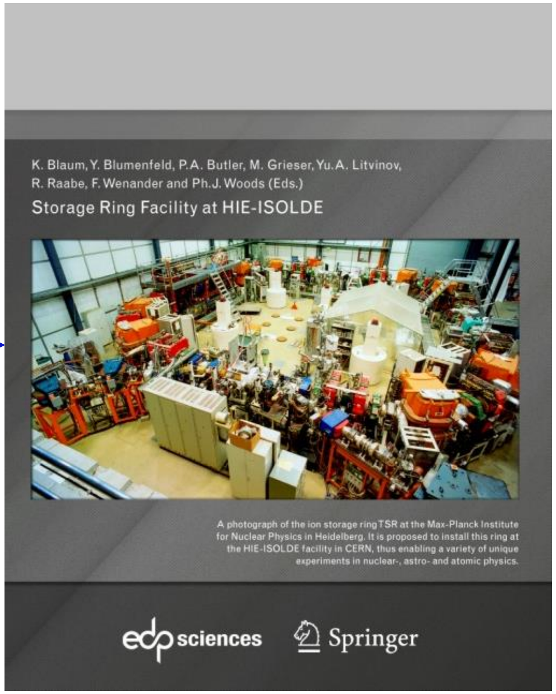
Time-line of the TSR@ISOLDE project

TSR@ISOLDE workshop at MPI-K Heidelberg
evaluated the future for TSR Oct 2010

ISOLDE and Neutron Time-of-Flight Committee endorsed Jan 2012

TSR technical design report **129 co-authors (47 institutions)**

EPJ Special Topics **207** 1-117 May 2012 →



Approved by CERN Research board, May 2012

"The installation of TSR, as an experiment to be included in the HIE-ISOLDE programme, was approved by the Research Board.

The timescale will be defined once the study of its Integration has been completed."

Presentation of the integration study to the CERN Research Board Nov 2013

Several TSR@ISOLDE workshops at CERN: 2012, 2014, 2015

Updated CERN integration study with report to the CERN directorate 2016

CERN director general: decision about the TSR@ISOLDE project is postponed until 2020/2021 (after second LHC upgrade) August/September 2016

MPIK cannot hold TSR at MPIK until 2020/2021 without getting green light from CERN

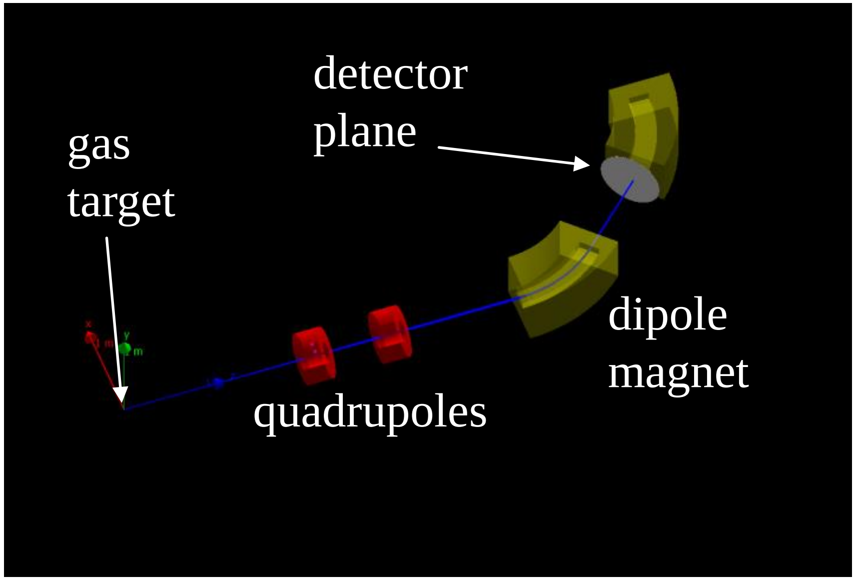
Design Criteria of the new storage ring

a) storing ions up to ^{238}U with 10 MeV/u.
⇒ maximum rigidity of the ring: $B\rho_{max} \approx 1.5$ Tm.

b) storing of heavy daughter nuclei up to a certain rigidity deviation ($\Delta B\rho/B\rho$) created in nuclear reactions should be possible.

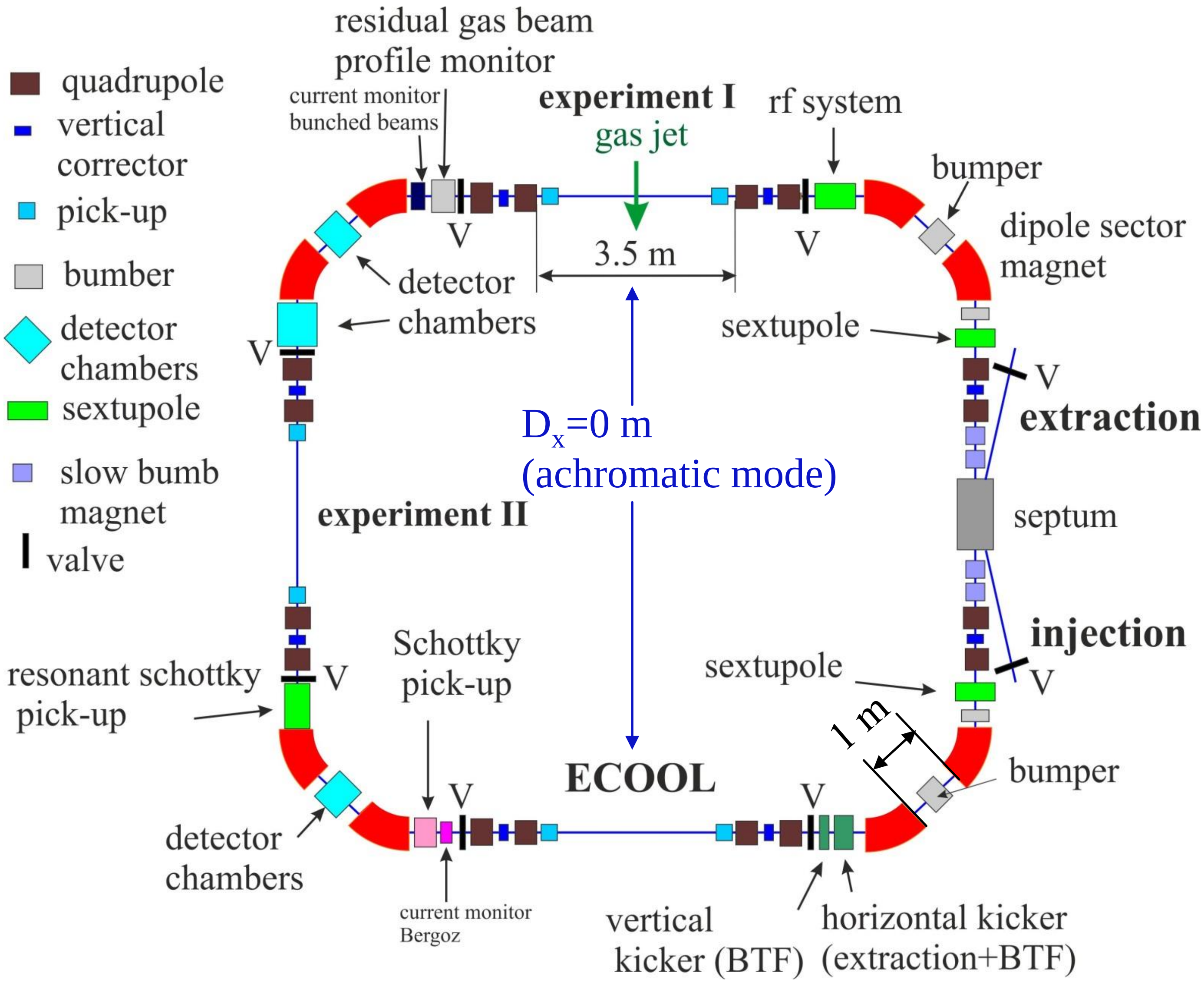
c.) daughter nuclei with large transversal momenta focused at the detector position.

d.) storing ring should be compact to fit in the present HIE Isolde hall.



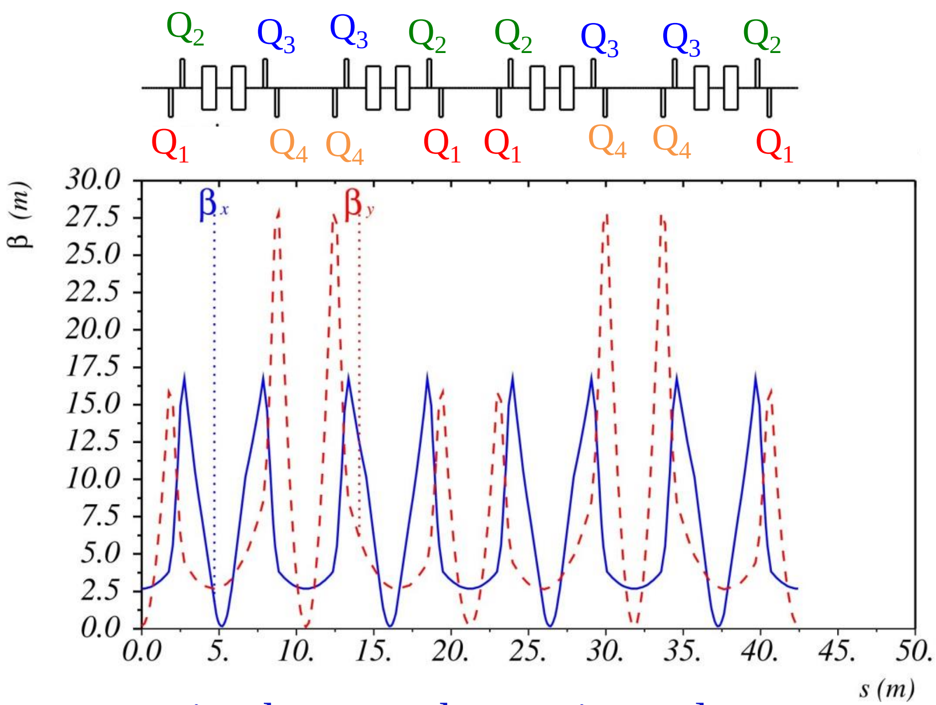
Layout of the new storage ring

with straight section Length L=3.5 m and circumference C=42.4 m



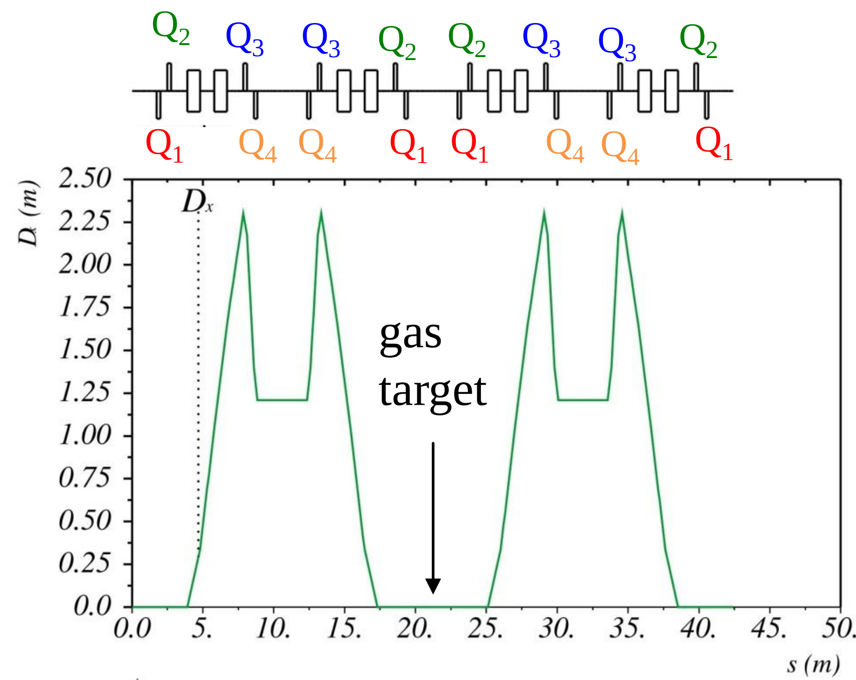
Twiss parameter of the storage ring (S=2)

ß-function



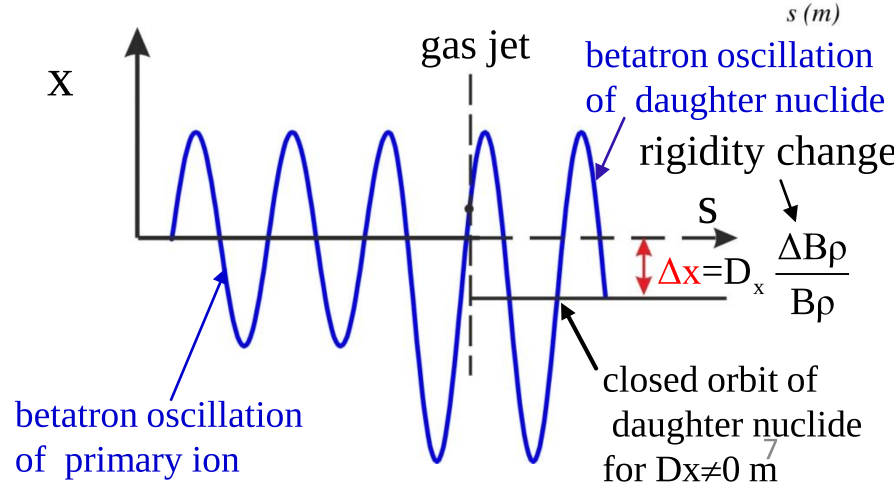
dispersion

achromatic mode



storage ring has an achromatic mode with D_x=0 m in the gas target to avoid excitation of betatron oscillations of the daughter nuclei produced in nuclear reactions

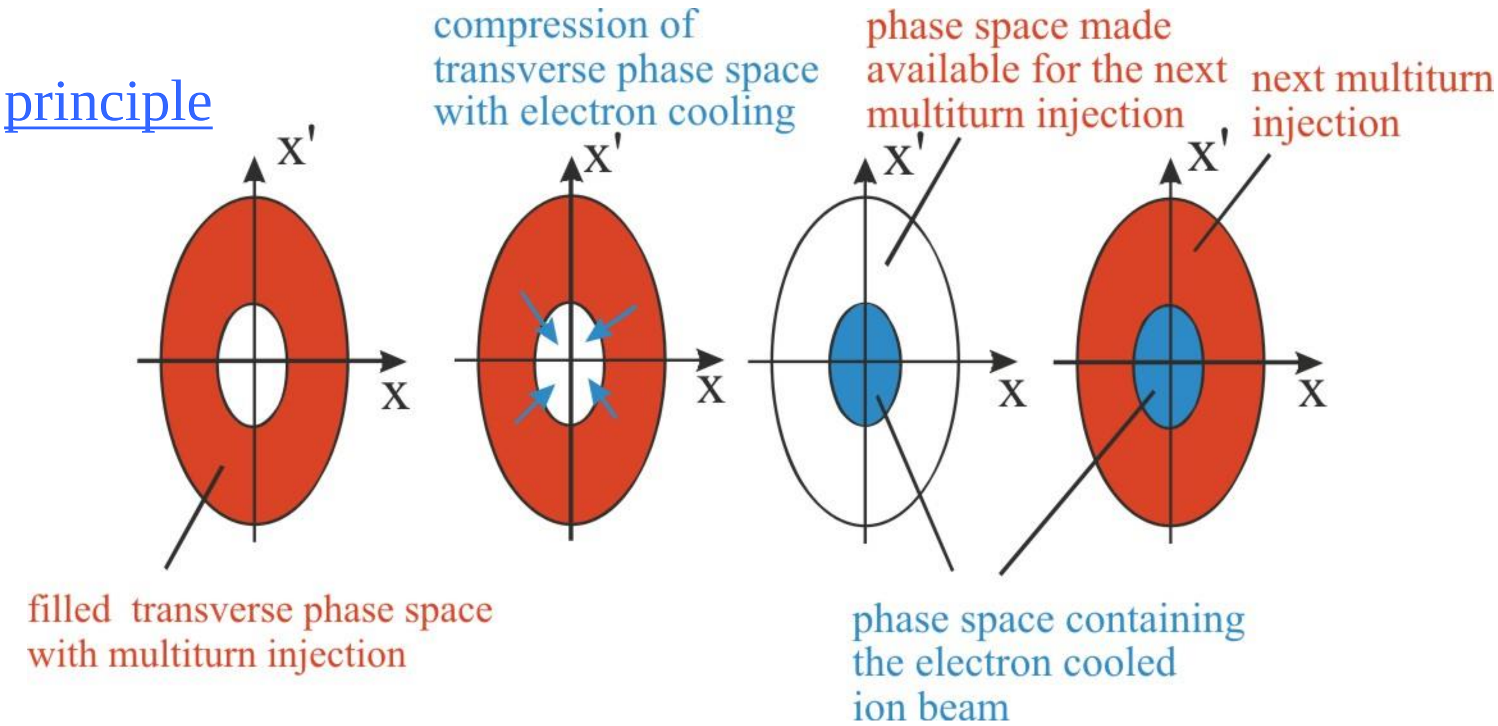
⇒ open-up the possibility to store daughter nuclei produced in nuclear reactions



ECOOL Stacking

A combination of multi-turn injection and electron cooling stacking will be used to fill the storage ring with particles

principle



particle number N(t):

$$\frac{dN(t)}{dt} = n_r N_i - \frac{N(t)}{\tau}$$

N_i-injected particle number per injection

n_r- injection rate

τ- total lifetime

N_s-space charge limit

In the equilibrium: $dN(t)/dt = 0$

number of stored ions N_0 ($N_0 \leq N_s$): $N_0 = n_r \, \tau \, N_i$

Space charge limit due to incoherent tune

maximum possible stored ion number: $N_s = \frac{A}{q^2} \frac{2\pi}{r_p} \cdot B \cdot \beta^2 \cdot \gamma^3 \cdot \varepsilon \cdot (-\Delta Q)$

$-\Delta Q$ - possible incoherent tune shift for B=1 at TSR: $-\Delta Q \approx 0.065-0.1$

Isolde storage ring (ISR) has similar possible incoherent tune shifts

for an electron cooled ion beam:

$$\varepsilon \propto \left(\frac{q^4}{A^2} \frac{N_s}{\lambda_{Cool}} \frac{1}{\beta^3} \right)^{0.44} \qquad \lambda_{cool} \propto n_e \frac{q^2}{A} \qquad n_e \propto \beta^2$$

incoherent tune shift for an electron cooled ion beam

$$N_s = \text{const} \frac{(A^{33}/E^5)^{1/28}}{q^2}$$

E-ion energy in MeV

A-ion mass

q-ion charge state

TSR experiments: const≈$7 \cdot 10^9$

Measured space charge limit of an electron cooled ion beam at the TSR

Ion	E (MeV)	measured N_s	calculated N_s
p	21	$5.4 \cdot 10^9$	$4.1 \cdot 10^9$
$^{16}O^{8+}$	98	$9.4 \cdot 10^8$	$1.3 \cdot 10^9$
$^{12}C^{6+}$	73	$1.7 \cdot 10^9$	$1.7 \cdot 10^9$
$^{32}S^{16+}$	195	$9.5 \cdot 10^8$	$6.3 \cdot 10^8$
$^{35}Cl^{17+}$	293	$5.1 \cdot 10^8$	$5.8 \cdot 10^8$

approximately valid for ISR

$\Rightarrow$ maximum possible Luminosity ($L = \frac{R}{\sigma}$) for $N_0 = N_s$

Effective Luminosity of some selected ions

$L_{eff} = \eta N_0 f_0 n_t$ calculated for the space charge limit ($N_0=N_s$) and a beam life time τ=1-1.5s

$\eta=0.5$

beam	Energy (MeV/u)	q_s	N_s	target	n_t (atoms/cm^2)	τ (s)	N_i/T (1/s)	L_{eff} (1/cm^{2}s)	
$^{86}Kr^{36+}$	10	36+	$3\cdot10^8$	H_2	$9\cdot10^{14}$	1.5	$3\cdot10^8$	$2\cdot10^{29}$	proton capture reactions
$^{96}Ru^{39+}$	10	39+	$3\cdot10^8$	H_2	$4\cdot10^{14}$	1	$3\cdot10^8$	$8\cdot10^{28}$	
$^{196}Hg^{64+}$	10	64+	$2\cdot10^8$	H_2	$5\cdot10^{13}$	1.5	$2\cdot10^8$	$8\cdot10^{27}$	
$^{232}Th^{71+}$	10	71+	$2\cdot10^8$	H_2,D_2	$5\cdot10^{13}$	1	$2\cdot10^8$	$8\cdot10^{27}$	fission reactions
$^{238}U^{72+}$	10	72+	$2\cdot10^8$	H_2,D_2	$3\cdot10^{13}$	1.5	$2\cdot10^8$	$5\cdot10^{27}$	
$^{232}Th^{71+}$	10	71+	$2\cdot10^8$	He	$3\cdot10^{12}$	1	$2\cdot10^8$	$4\cdot10^{26}$	
$^{238}U^{72+}$	10	72+	$2\cdot10^8$	He	$2\cdot10^{12}$	1	$2\cdot10^8$	$3\cdot10^{26}$	

injection charge state
green: bare ion
black: equilibrium charge state after HIE-ISOLDE stripper

N_s-space charge limit of an electron cooled stored ion beam

n_t -target thickness calculated for a beam life time: τ=1-1.5s

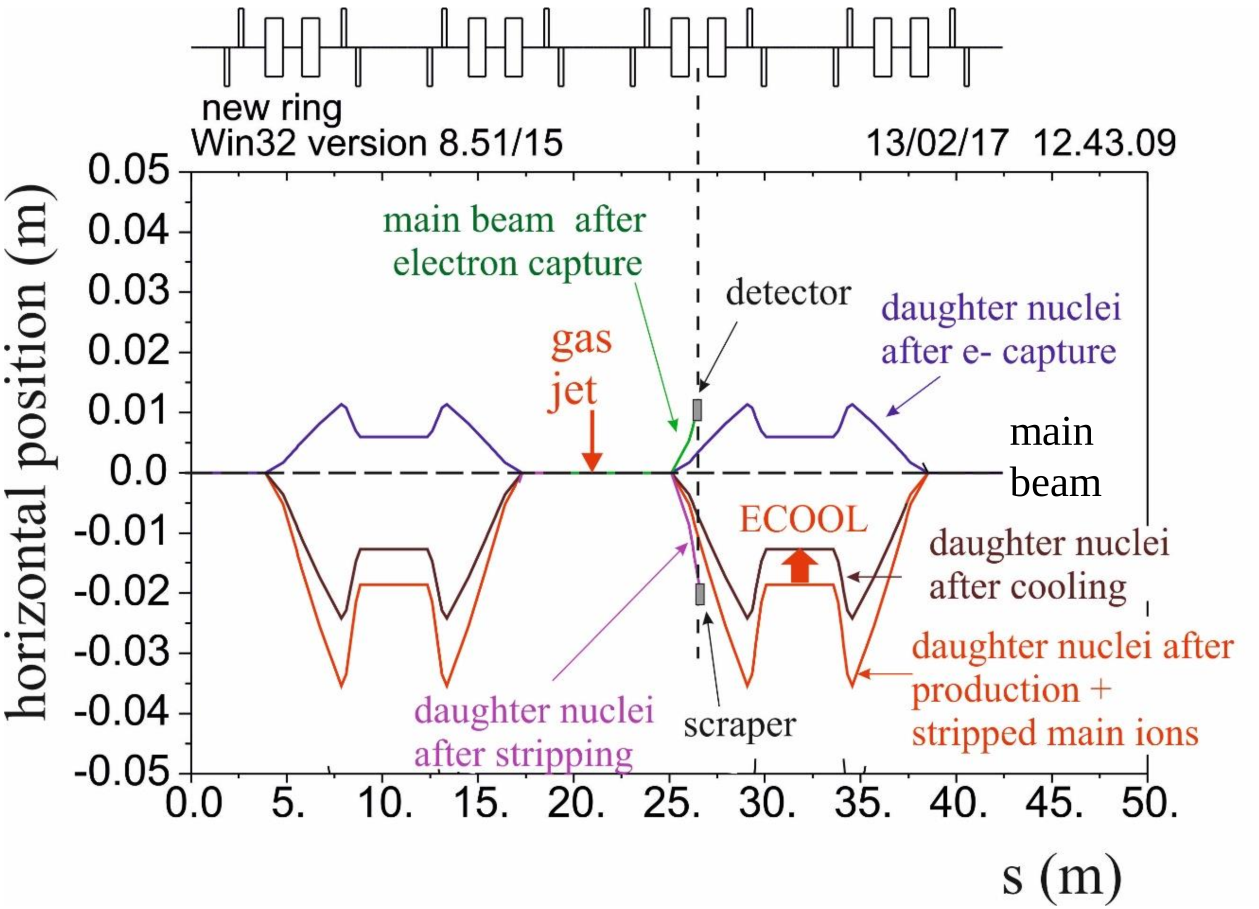
required injection rate (ions/s) for $N_0=N_s$

remark: H_2, D_2, He target: limitation of $n_t \approx 10^{14}$ atoms/cm^2
all required injection rates N_i/T for the space charge limit N_s maybe can not be reached

Storing of daughter nuclei produced in nuclear reactions

Electron cooling separates the daughter nuclei from the stripped ion beam and main ion beam.

example proton pick-up reaction: $Hg^{64+} + p \rightarrow Tl^{65+} + \gamma$



L- luminosity

s- cross section

τ_d- life time of daughter nuclei

<u>In the equilibrium:</u>

number of daughter nuclei:

$$N_{d,0} = \sigma L \tau_d$$

example:

$^{196}Hg^{64+}$, E/A=10 MeV/u

$N_0 \approx N_s/6 = 3 \cdot 10^7$

$n_t = 2 \cdot 10^{13}$ atoms/cm^2

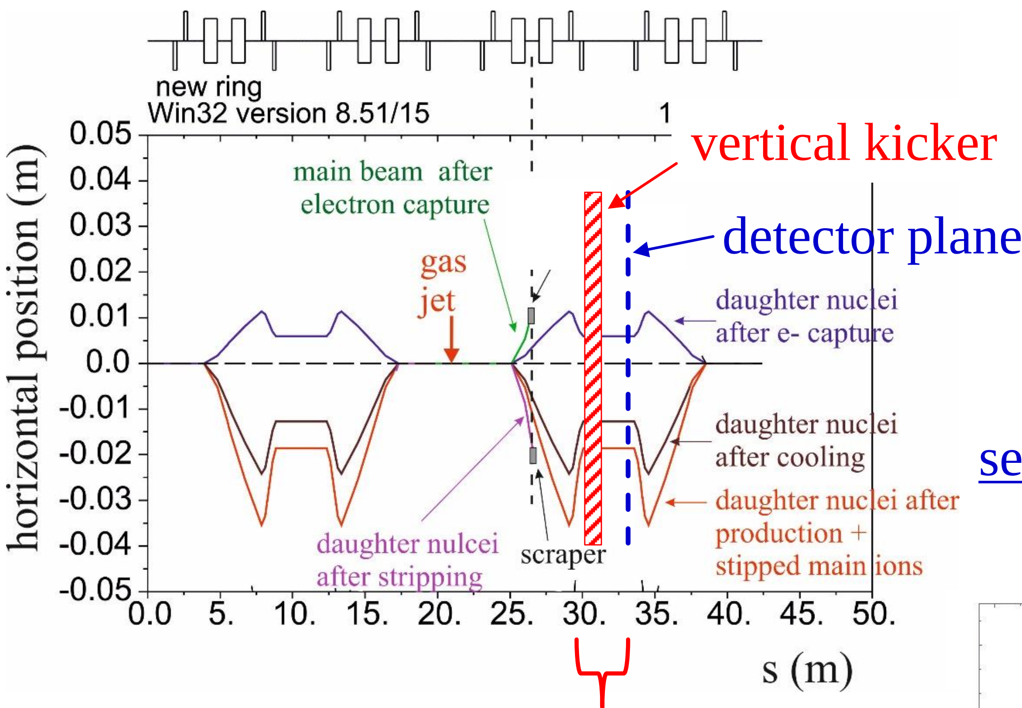
$$\Rightarrow L = 2.2 10^{27} 1/cm^2 s,$$

$$\tau_d \approx 3.5\,s$$

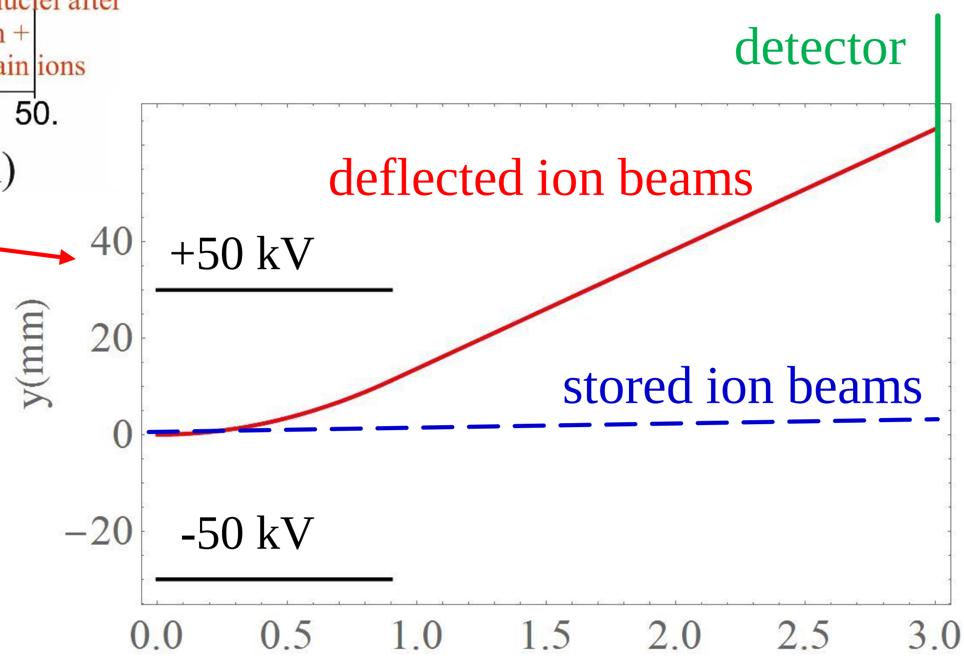
for: σ=0.01 barn :

$N_{d,0} \approx 80$

Direct detection of produced daughter nuclei



second experimental straight section II



A vertical kicker can be used to kick the stored ion beam towards the detectors

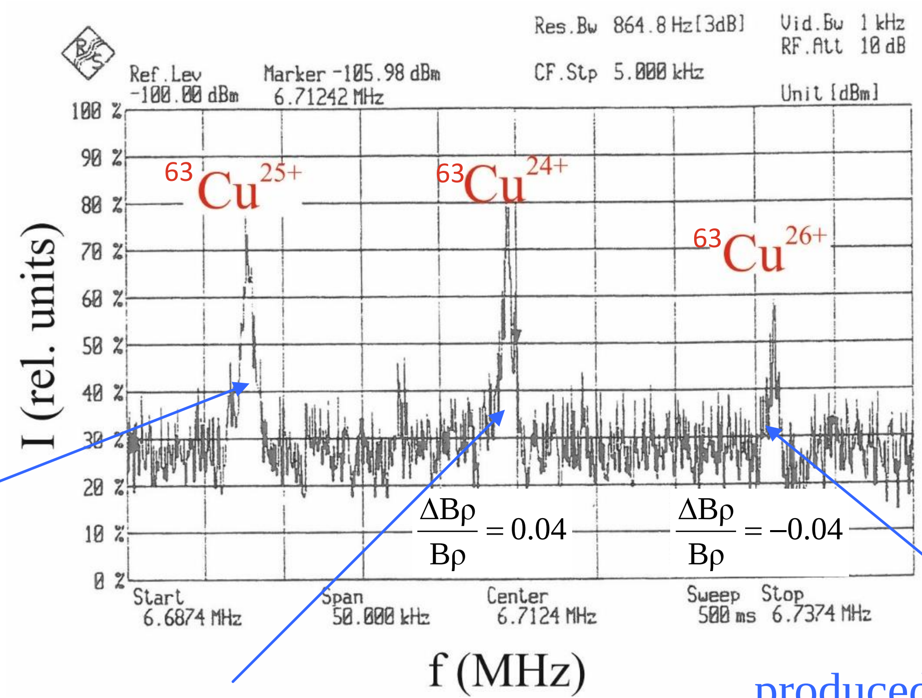
Multi Charge operation of the TSR

- Storing also daughter nuclei after production needs a relative large momentum acceptance of the storage ring
- At the TSR it was shown that several beams with different rigidities can be stored at the same time

Confirmation of the multi charge operation at the TSR

Schottky noise measured 12 s after injection

dispersion in the cooler:
D_x=0.3 m



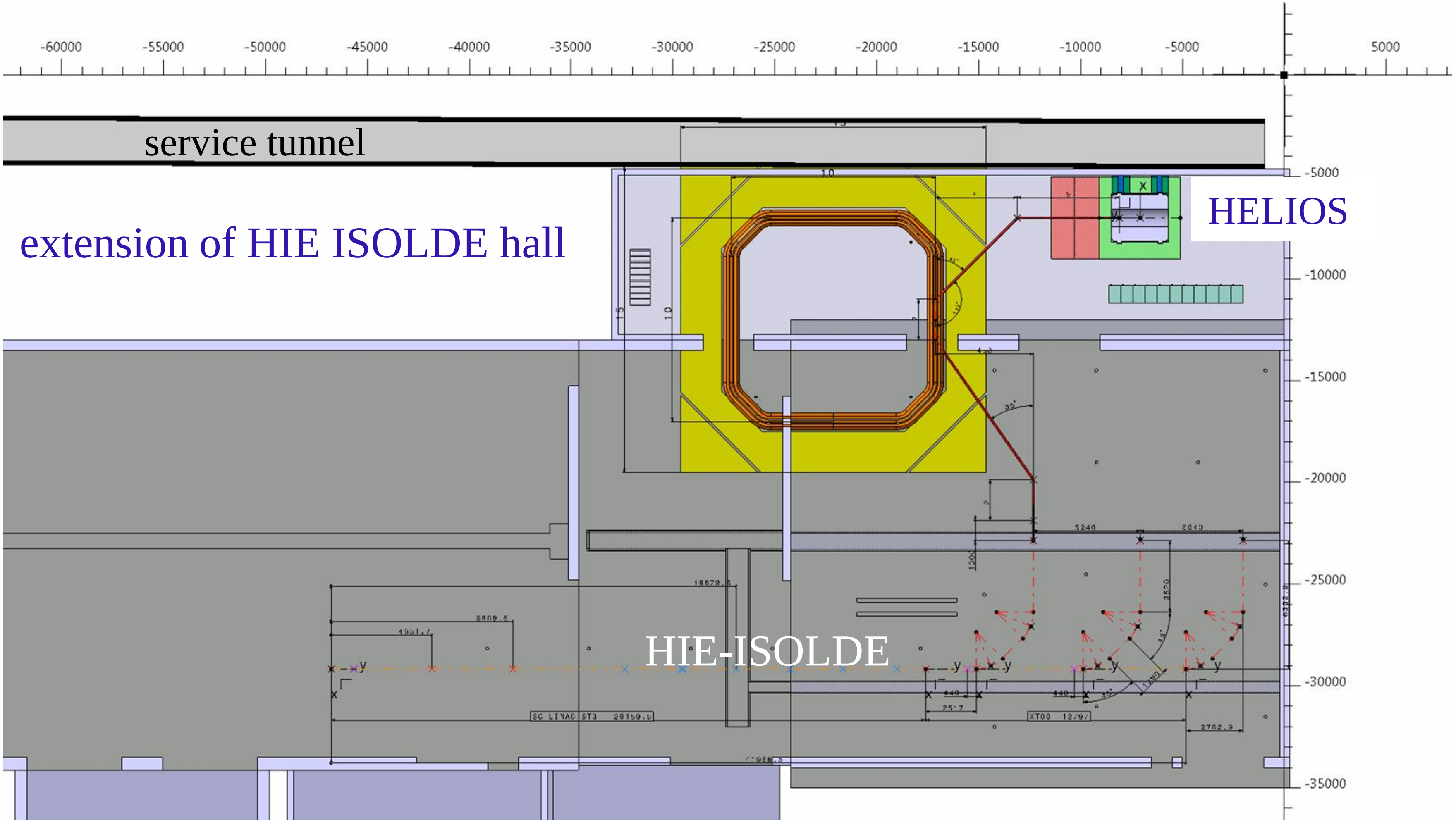
injected ion beam
E=266 MeV

produced by electron capture
visible already 2-3 s after injection

produced by stripping
detectable 8 s after injection

Possible location of the new storage at HIE-ISOLDE

transparency from Erwin Siesling and Stephane Maridor, CERN



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Appendix

Preliminary cost table

	Cost	Manpower	remark			
	kCHF	FTE				
Infrastructure						
Civil engineering (hall extension)	1000	1				
Ventilation	1700	1				
Water cooling system	1200	1				
Cabling and electrical infrastructure	500	0.5				
Compressed air	15	0.05				
Fire detection system	120	0.1			costs kCHF	Manpower FTE
Crane+tooling	0	0		infrastructure	4535	3.65
Storage Ring						
Alignment and survey	170	0.35				
Beam diagnostics	2500	5				
Applications	300	1				
Control system	100	1				
Project management		3				
E-cooler	1500	4	based on ELENA cooler			
General safety	0.5	0.5				
Injection line	200	0.5				
Injection-Extraction septum	200	1				
Magnets	2500	5				
Magnet Interlocks	100	0.1				
Power supplies	2777	10				
Radiation protection	100	0.05				
RF	274.2	2.8				
Stepper motor and Scrapers	2	0.1				
Vacuum System	3500	6				
Commissioning		2		storage ring costs	14223.7	42.4
In-ring experiments covered by the ISOLDE collaboration						
Extraction line covered by the ISOLDE collaboration						
total	**18758.7**	**46.05**				

ISR Spectrometer

example

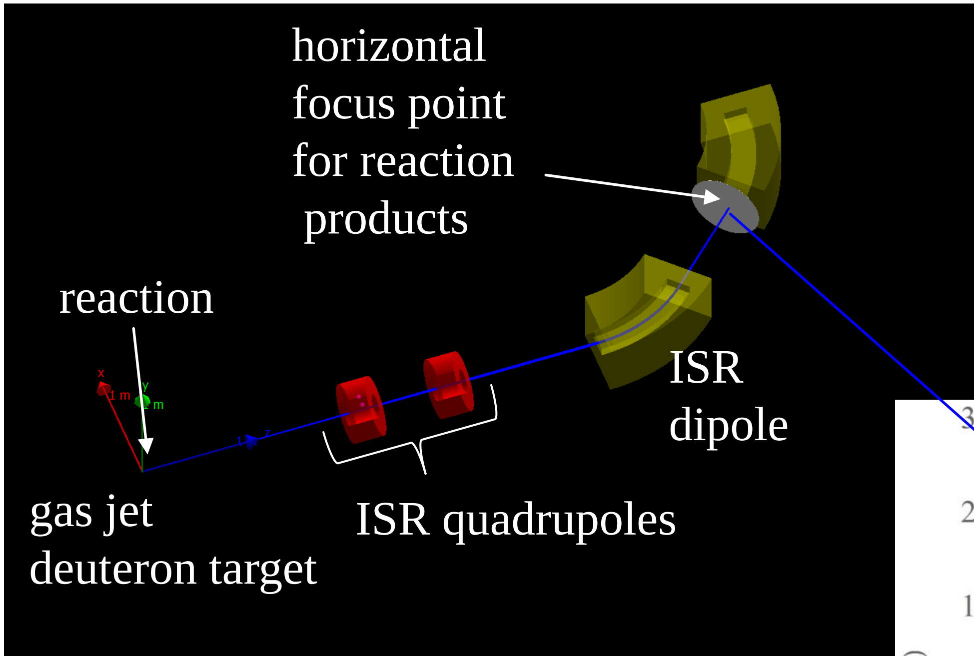
investigation of nuclear reaction
(reaction data: B. Jurado)

$^{238}U^{72+}(d,d')^{238}U^{72+}$

$^{238}U^{72+} \rightarrow {}^{238}U^{72+} + \gamma$

$^{238}U^{72+} \rightarrow {}^{237}U^{72+} + n$

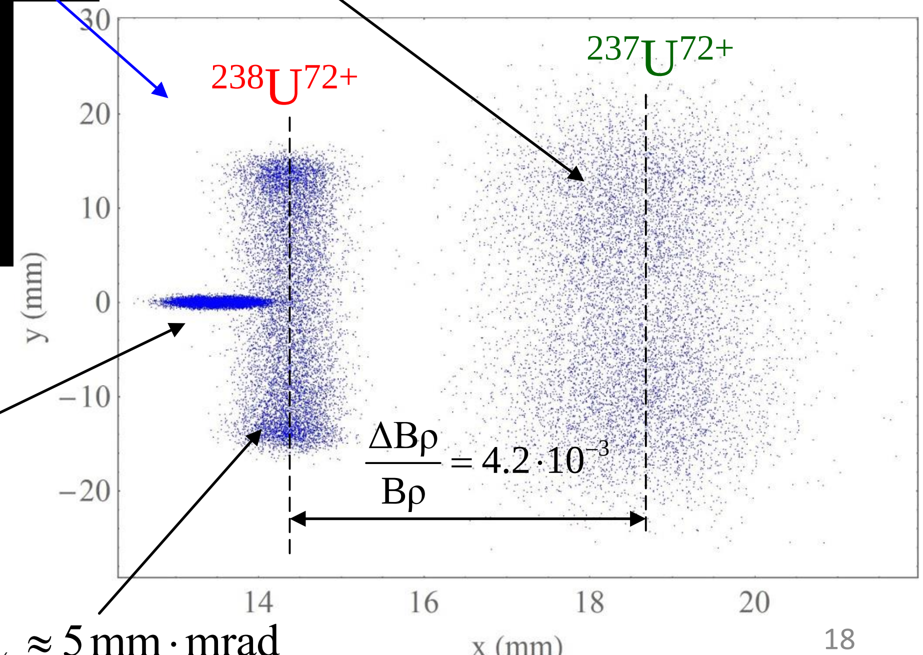
reaction daughter nuclei with relative large emittances



primary beam:
$^{238}U^{72+}$ E= 10 MeV/u

detector plane

$\varepsilon_{90\%} \approx 15\,\mathrm{mm\cdot mrad}$ ejectile angle= 10^0



in the target stripped ions

$\varepsilon_{90\%} \approx 5\,\mathrm{mm\cdot mrad}$