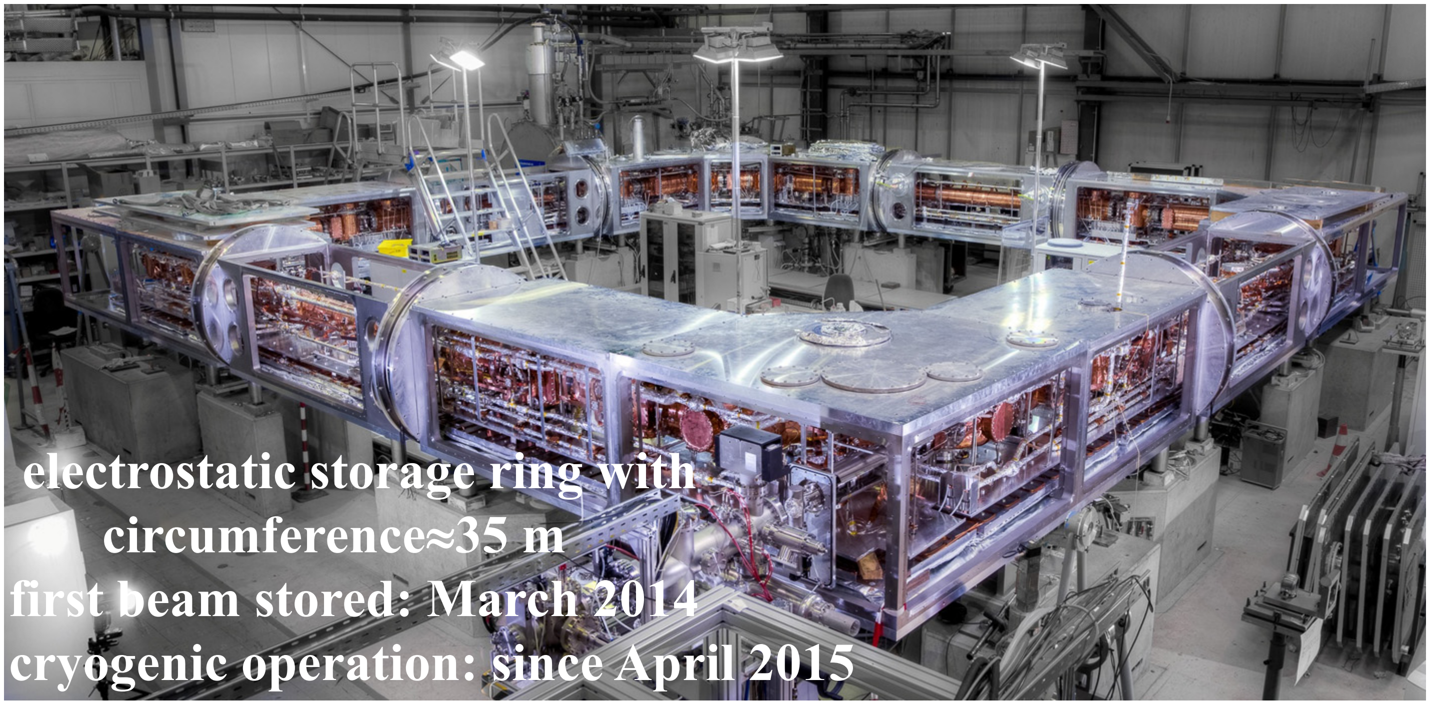
The **C**ryogenic **S**torage **R**ing **CSR**



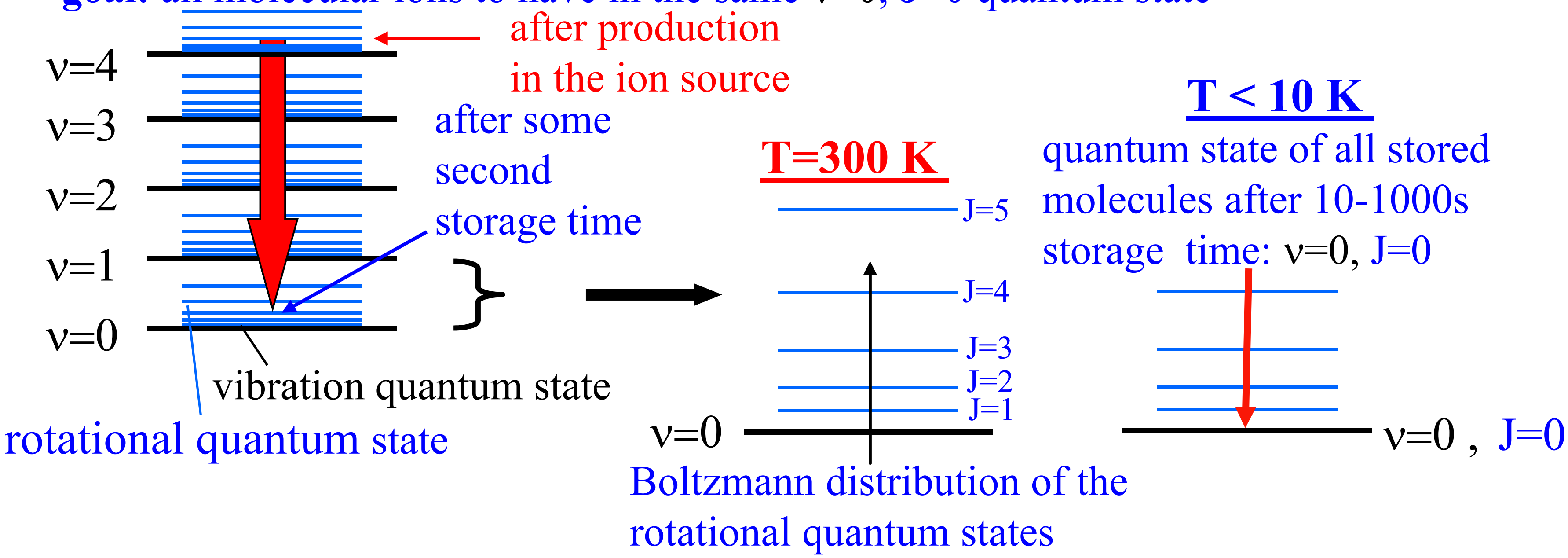
Manfred Grieser
Max Planck Institute for Nuclear Physics

HIAT2015 , September 8, 2015

Purpose of the CSR

main research field: molecular ion physics

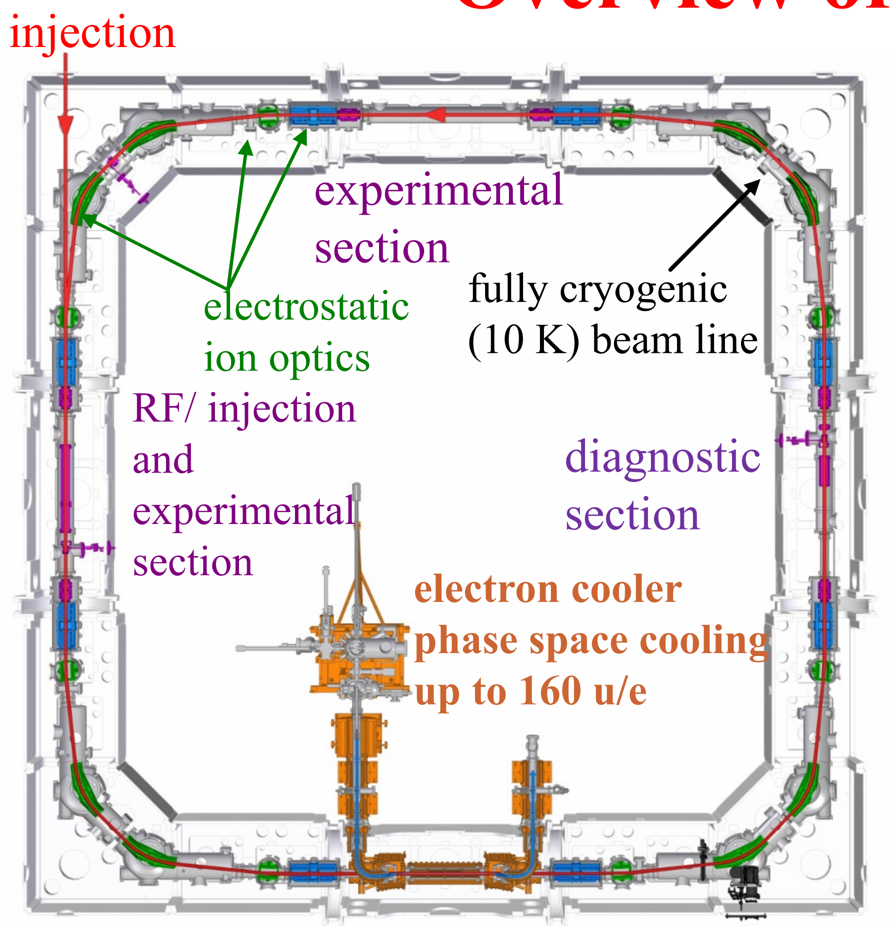
goal: all molecular ions to have in the same **ν=0**, **J=0** quantum state



to get all molecular ions in the same molecular quantum state (ν=0, J=0) the molecular ions have to be stored at **T<10 K**

⇒ a new **C**ryogenic **S**torage **R**ing (**CSR**) at MPIK Heidelberg
in opposite to other storage rings it is an **electrostatic storage ring**

Overview of the CSR

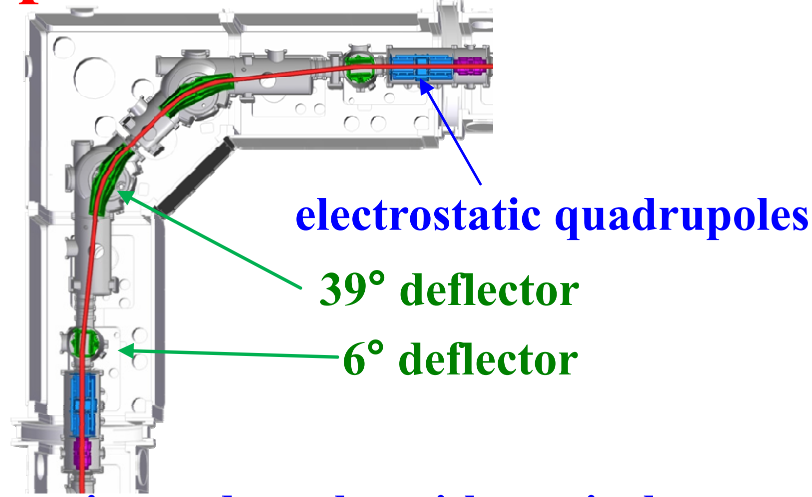


circumference: ≈ 35 m
beam energy: (20-300)·q keV
temperature: 10-300 K
residual gas densities:
(at T< 10 K): <20 molecules/cm^3

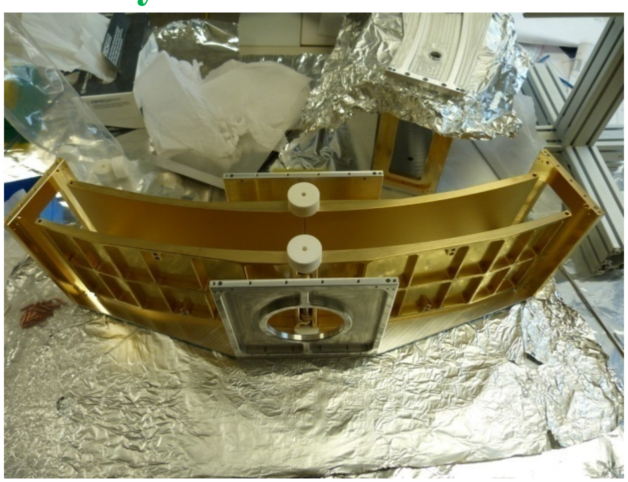
with electron cooling
m/q range: 1 -160
(at E/Q=300 kV)
lowest rigidity: p^+, H^- at E/Q= 20 kV
Bρ=0.02 Tm

Electrostatic beam optics Elements

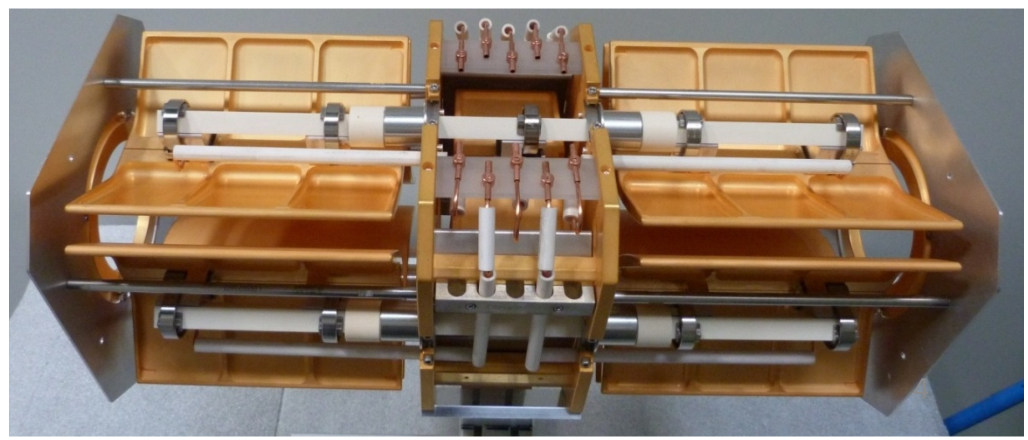
- 4-fold symmetric storage ring
  all CSR corner sections identical
- 4 x 2 pairs of **quadrupoles** (±10 kV, ∅ =100mm)
- 4 x 2 **6°-deflector** electrodes (±30 kV, d=120mm)
- 4 x 2 **39°-deflector** electrodes (±30 kV, d=60mm)
- 4 long free straight sections (≈ 2.8 m each)



39^0 cylindrical deflector

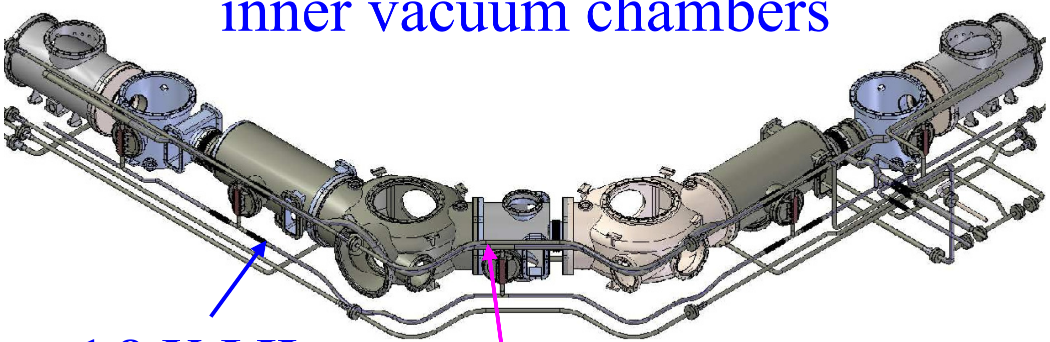


electrostatic quadrupoles with vertical steerer



Cryogenics

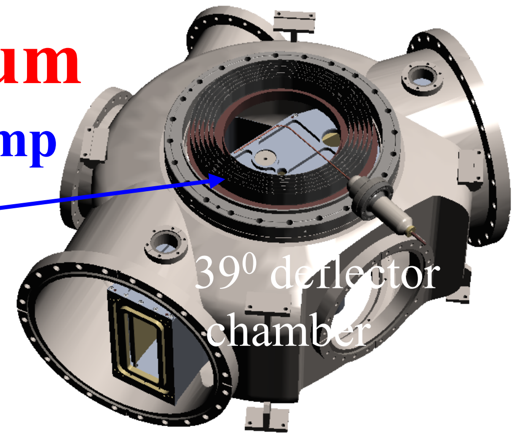
- inner vacuum chamber (≤ 10 K) cooled by superfluid He (20 W).
- isolation vacuum chamber
- 2 radiation shields (40 and 80 K) cooled by 5-K He (600 W)
- super-insulation



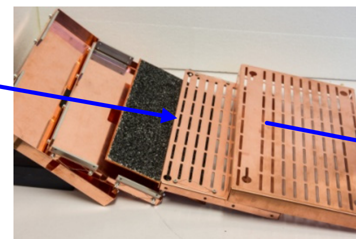
XHV: Extremely High Vacuum

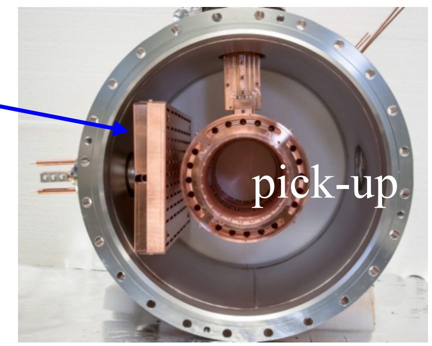
In 300-K-operation:
250°C bake-out,
Ion-getter pumps,
NEG pump (strips),
bake-able charcoal cryo-pumps

NEC pump



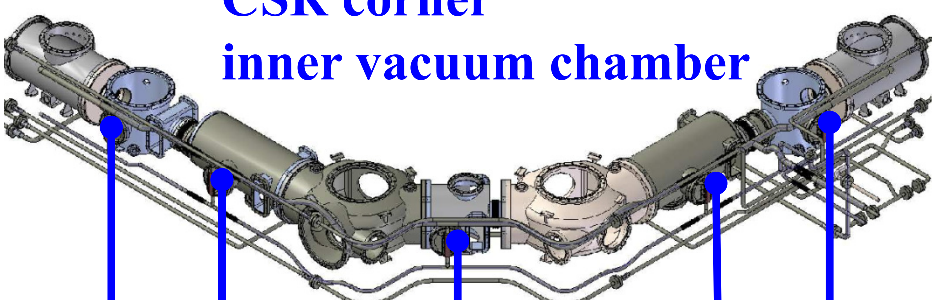
cryo pump

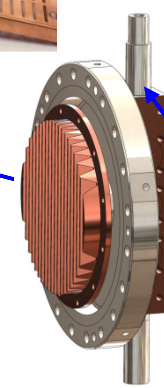




In < 10-K-operation:
cryo adsorption at 10-K-walls,
2-K cryo condensation pumps

CSR corner
inner vacuum chamber





He gas

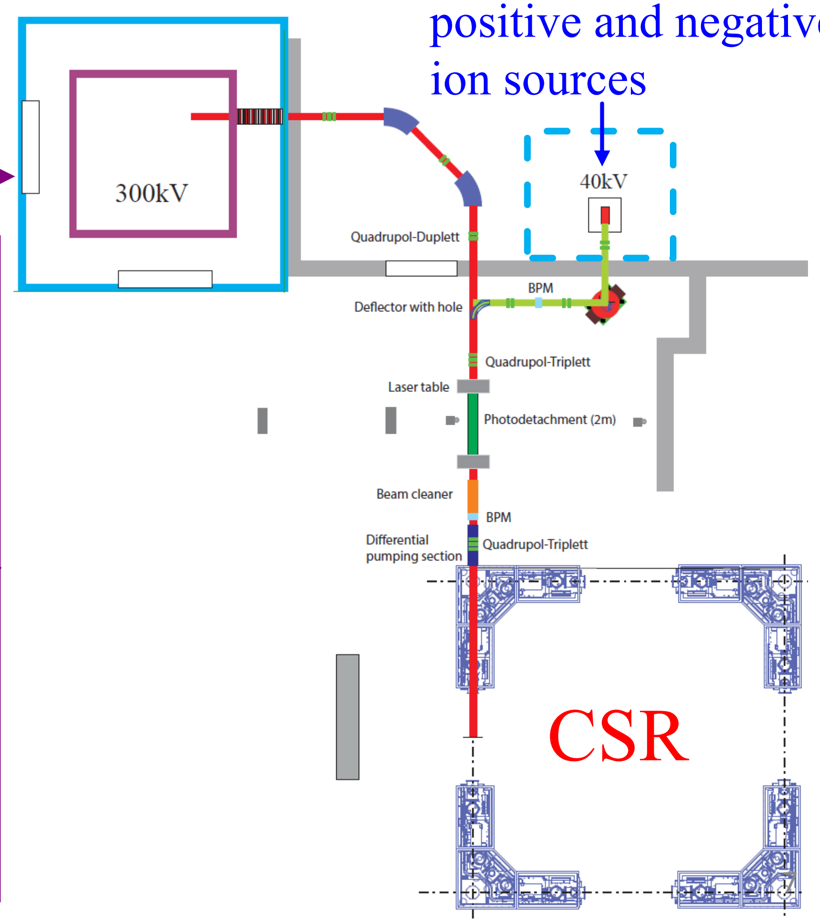
cold unit

liquid helium

High Voltage platforms

CSR main injector:
ion sources on a high
voltage plat form of **±300 kV**

± 40 keV platform with
positive and negative
ion sources



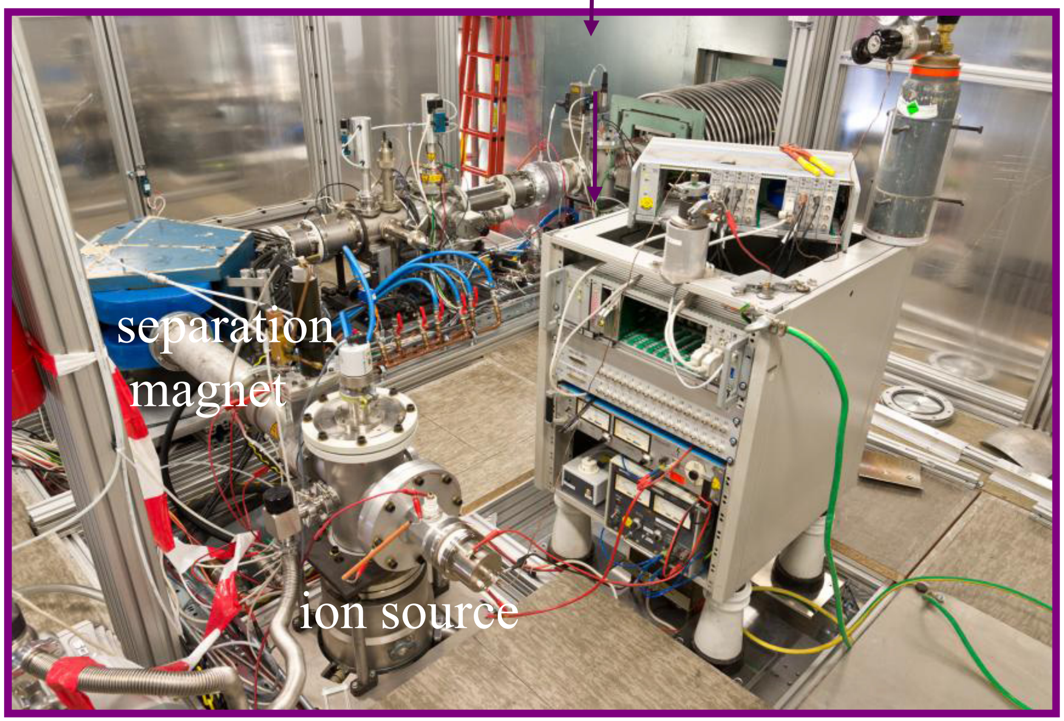
Ion sources

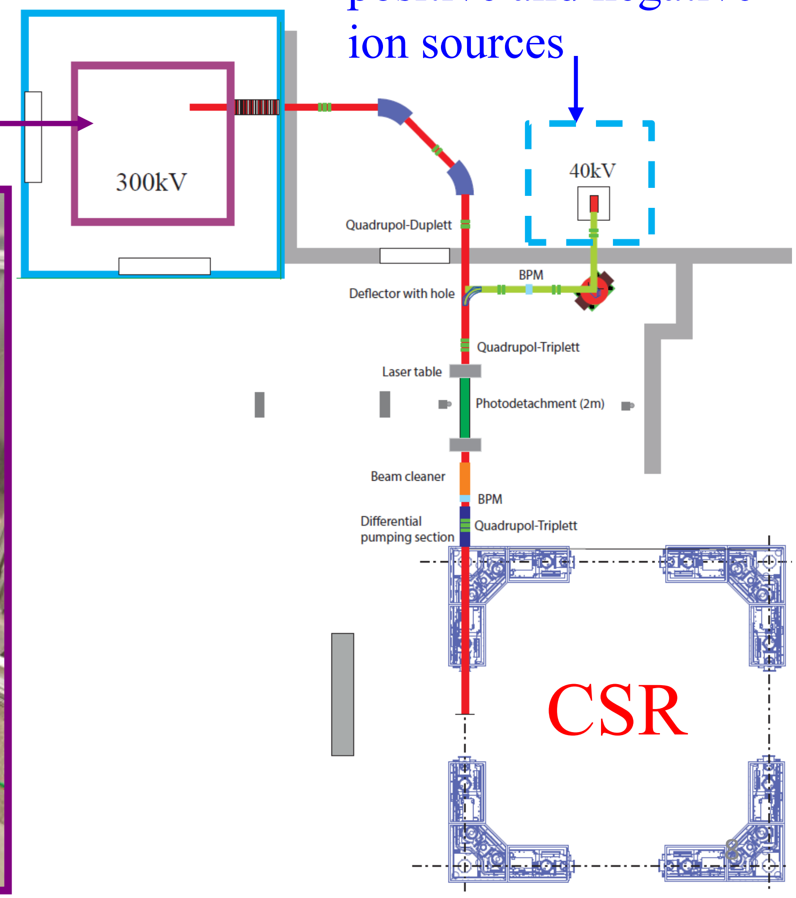
±300 kV high voltage platform

positive and negative
ion sources

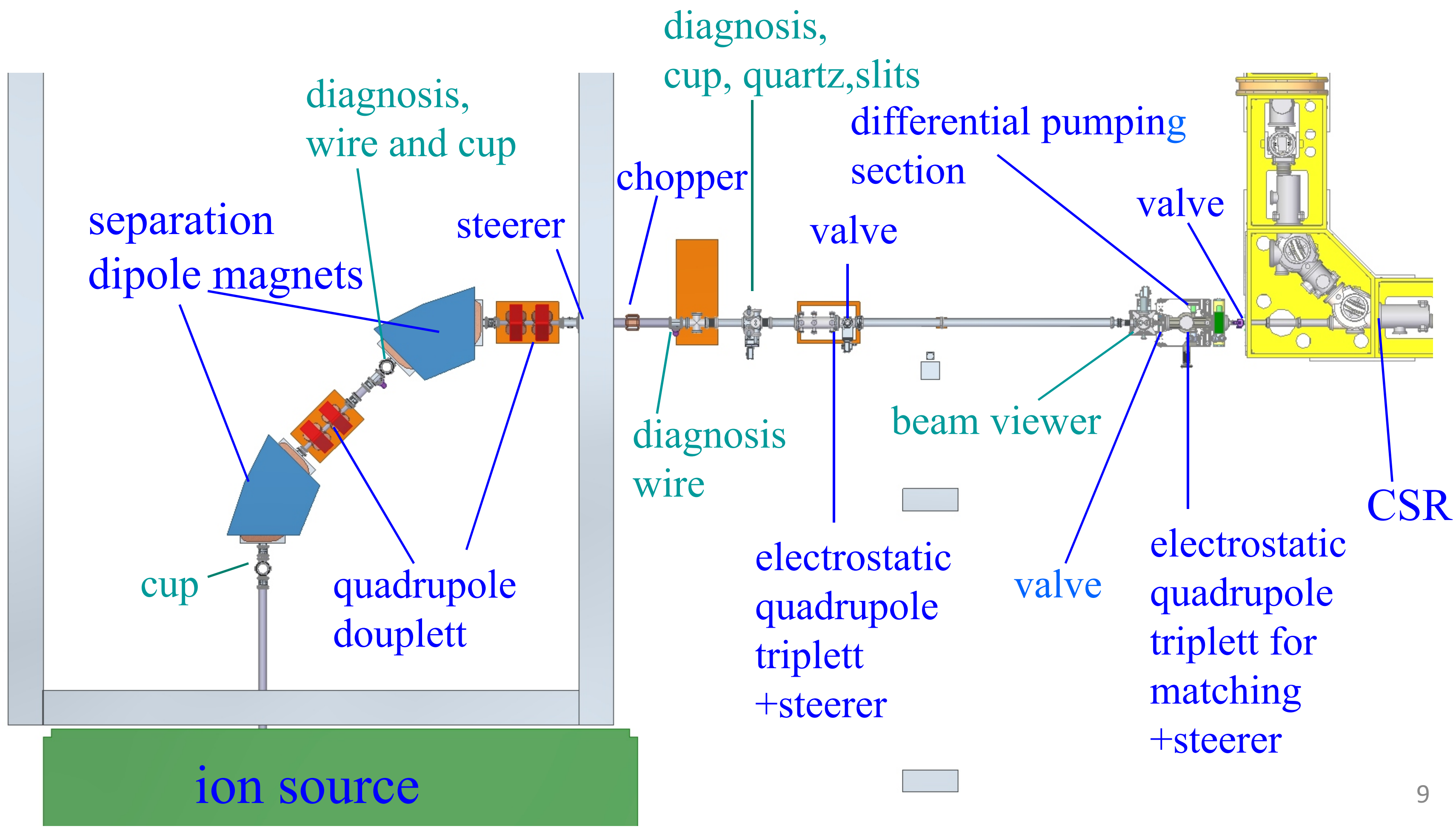
CSR main
injector: ±300 kV

± 40 keV platform with
positive and negative
ion sources



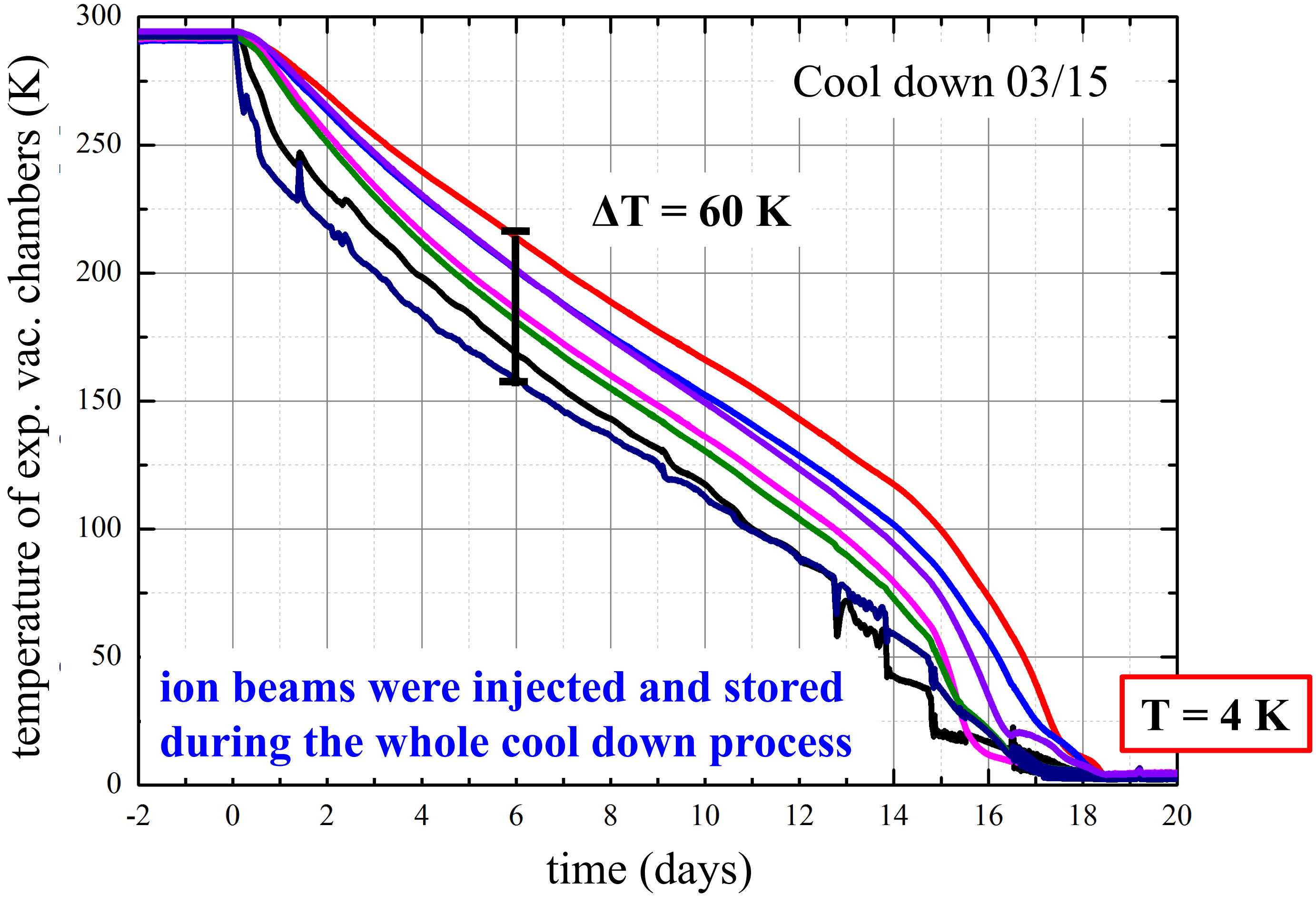


Transferline between ion source and CSR

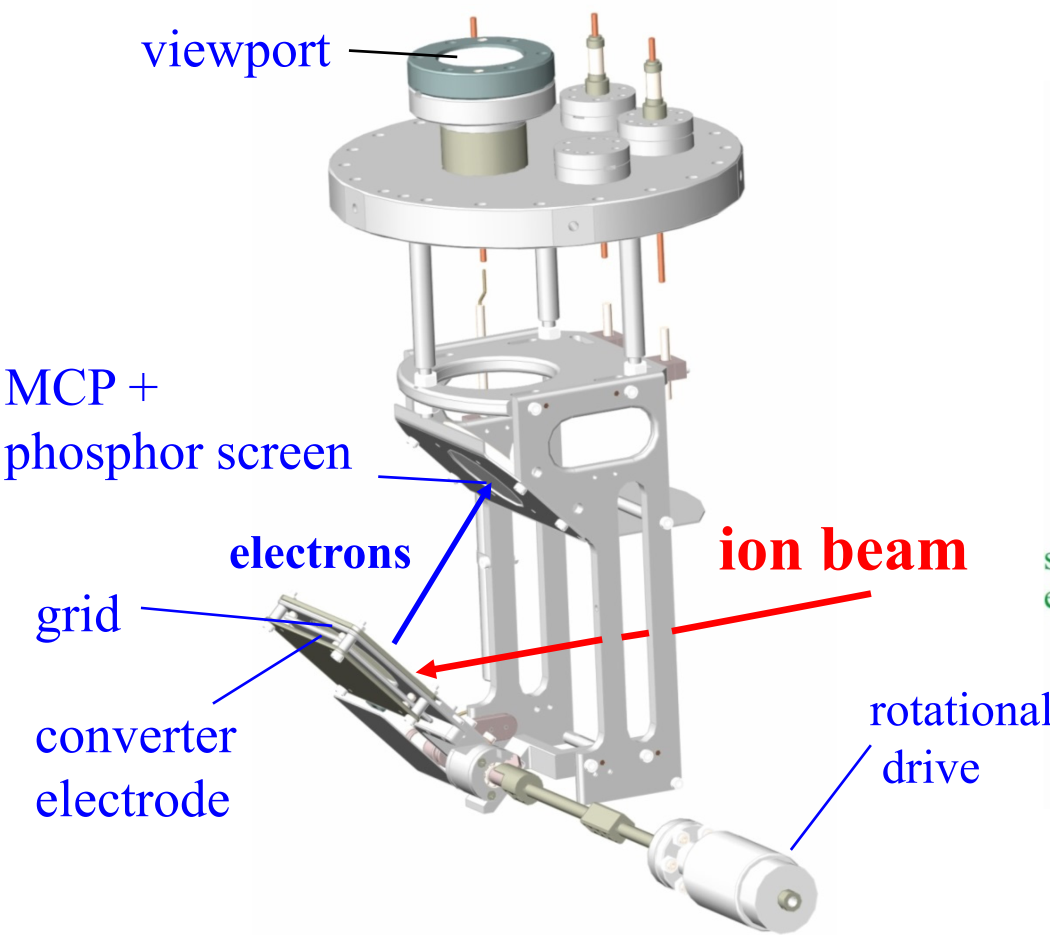


Cryogenic operation

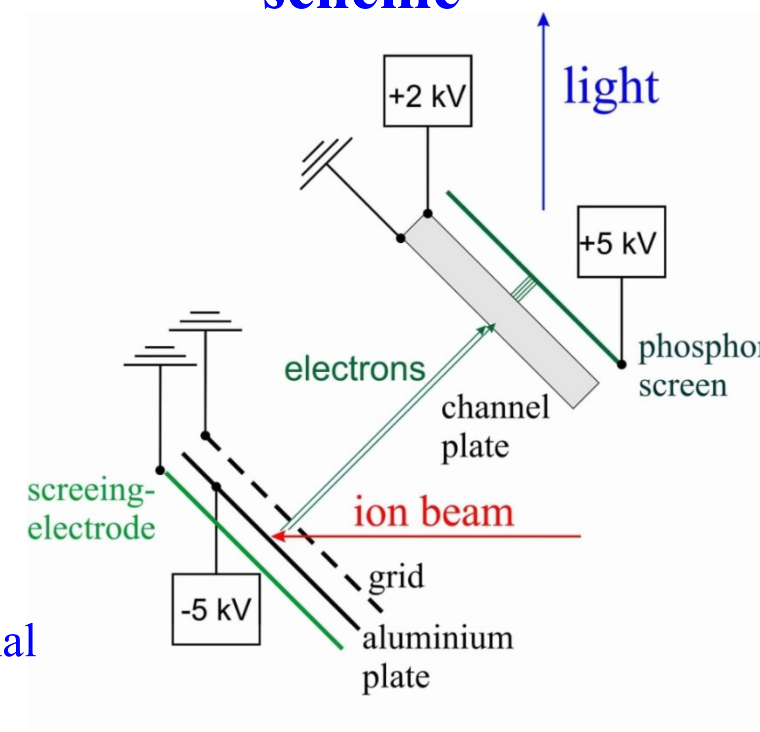
Cool down of the CSR



Beam profiler for first turn diagnosis



scheme

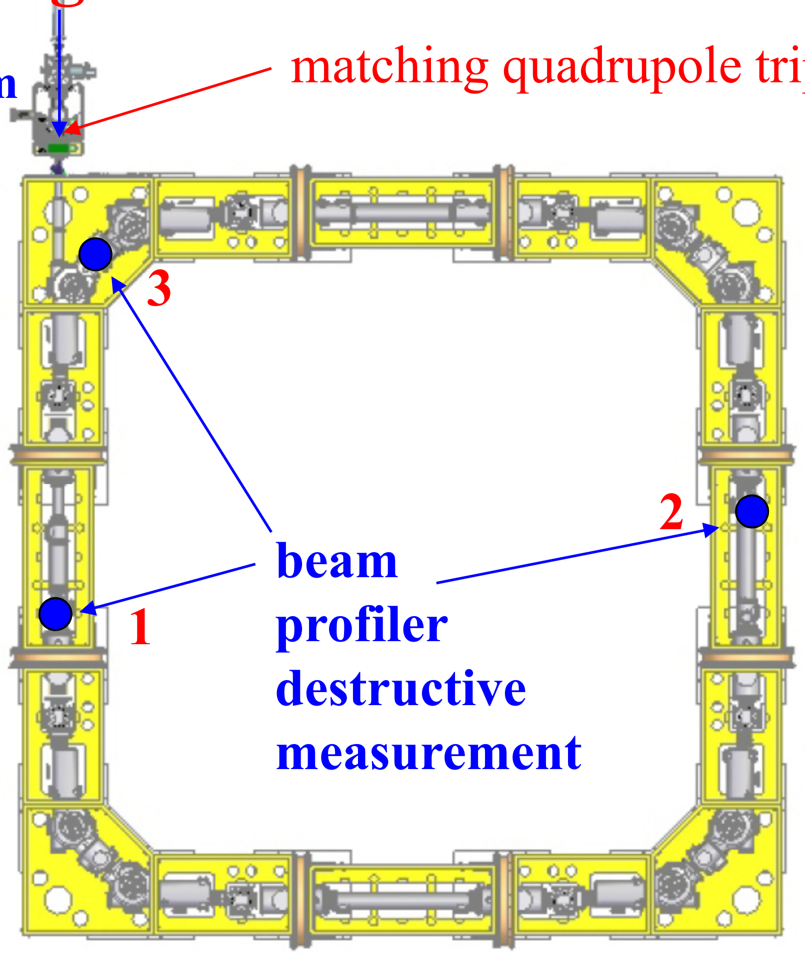


Diagnostics for ion beam injection

injected
ion beam

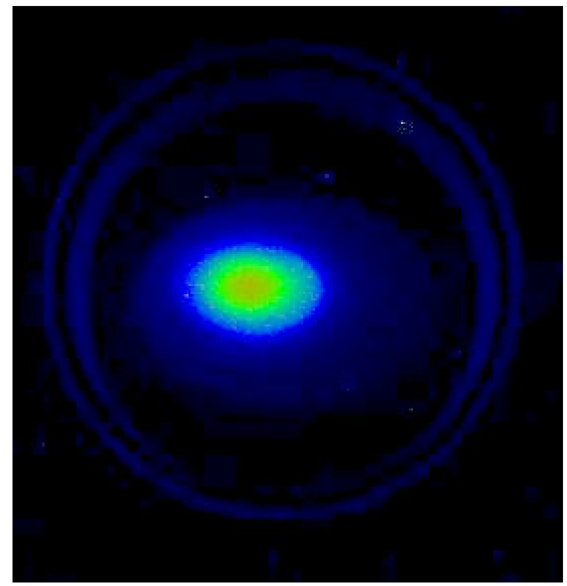
matching quadrupole triplet

beam profiler

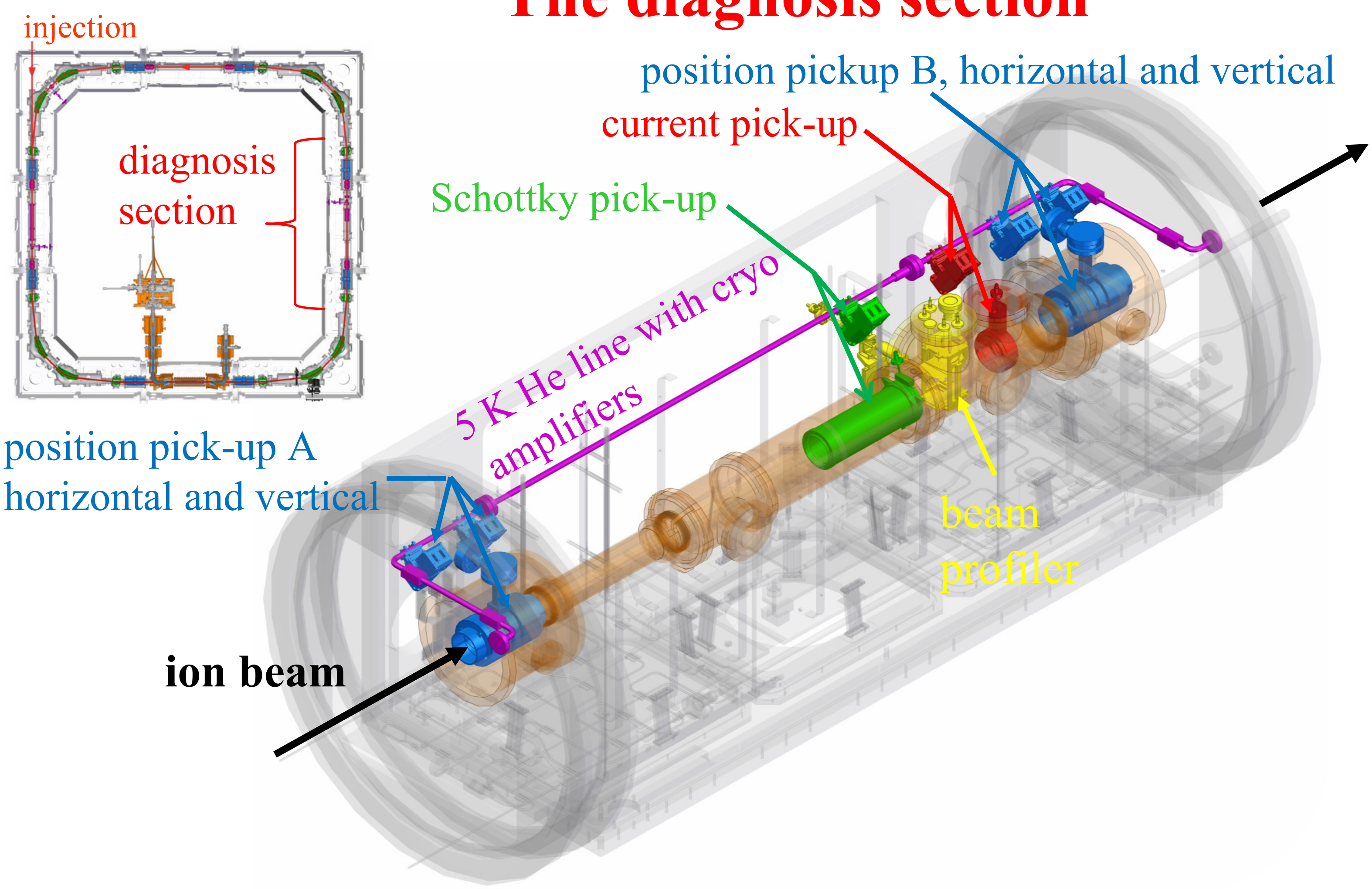


beam
profiler
destructive
measurement

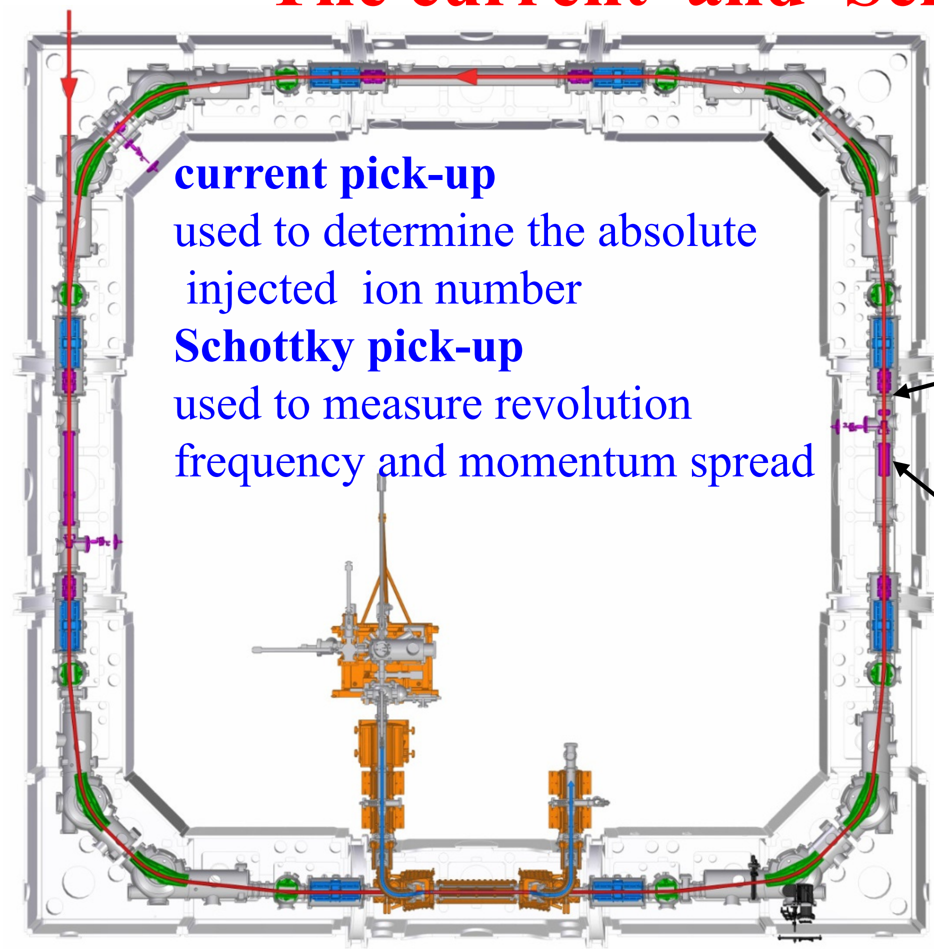
beam image



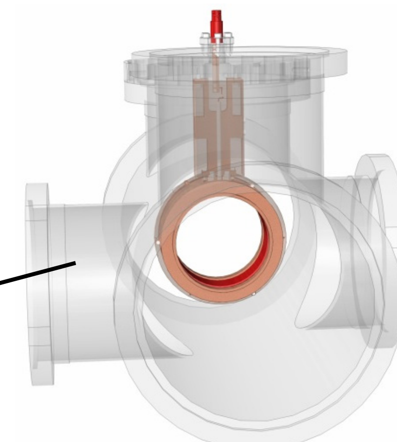
The diagnosis section



The current and Schottky pick-up

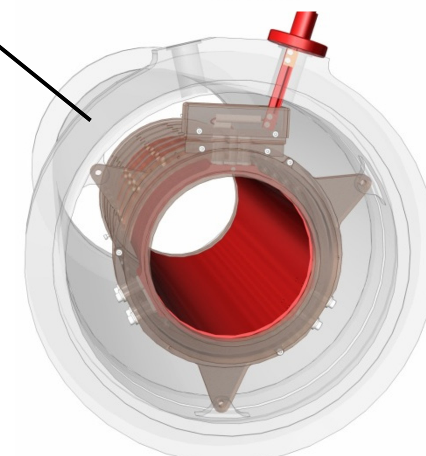


current pick-up
used to determine the absolute
injected ion number
Schottky pick-up
used to measure revolution
frequency and momentum spread



current pick-up

tube:
L= 3.5 cm
ψ=10 cm



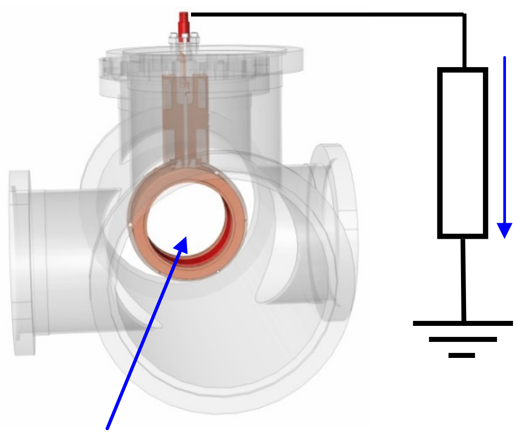
Schottky pick-up

tube:
L= 35 cm
ψ=10 cm

Current pick-up

-used to measure the **absolute number** of the injected ion number (pulsed beam)

-sensitivity 10^6 singly charged ions



$$U(t) = \frac{X_u}{C}\frac{L}{v}I(t)$$

X_u- signal amplification

L- pick-up length

v-velocity

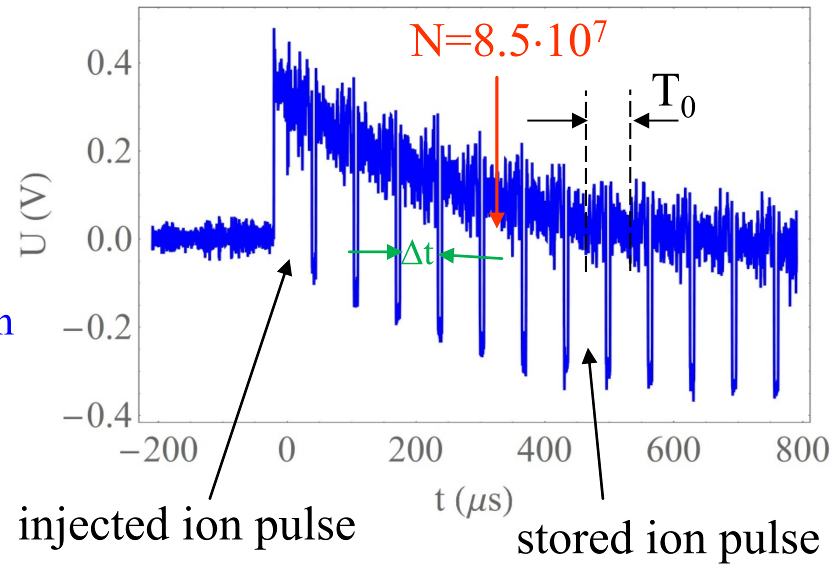
C- capacity

tube: ψ=10 cm, L=3.5 cm

integration over one pulse

$$N = \frac{1}{qe}\int_{t_1}^{t_2} I(t)dt = \frac{1}{qe}\frac{Cv}{L}\int_{t_1}^{t_2}\frac{U(t)}{X_u}dt$$

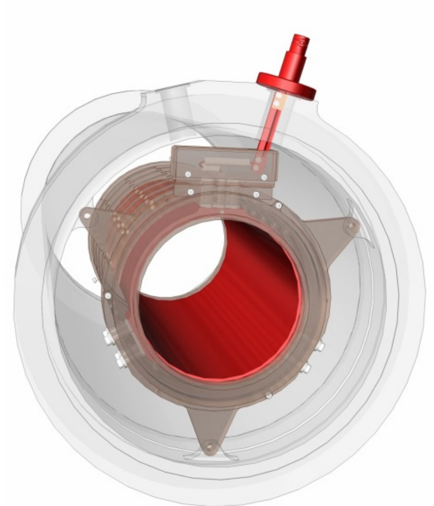
measured current signal of an $^{40}Ar^{+}$ ions (E= 60 keV)



T_0- revolution time

pulse length Δt is set up with an chopper in front of the CSR

Schottky noise spectrum



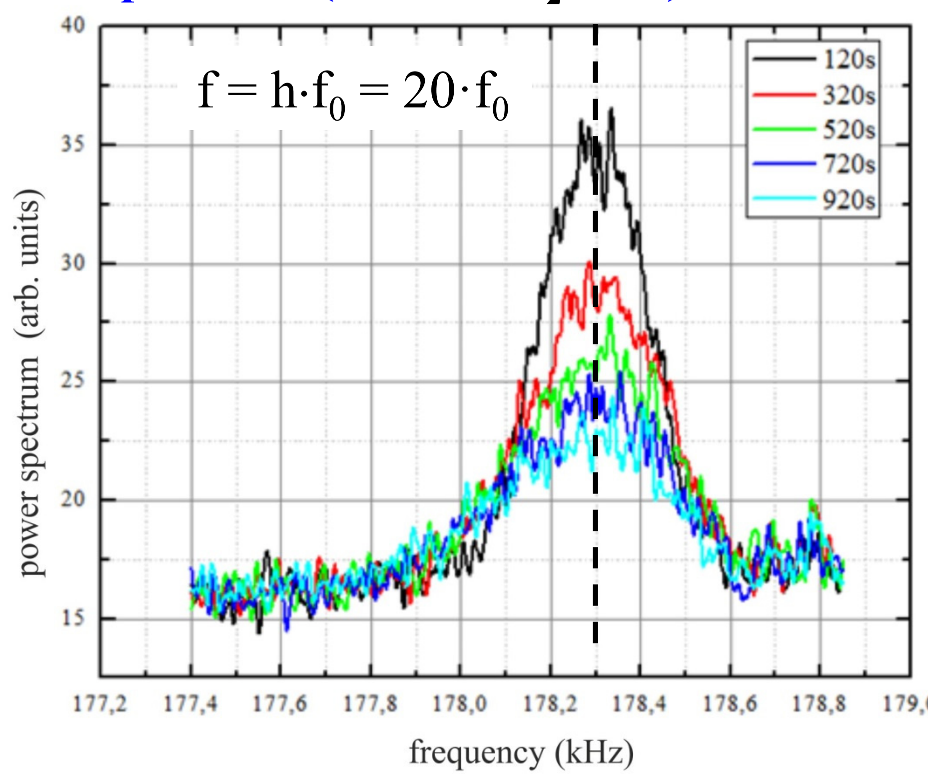
Schottky pick-up

slip factor

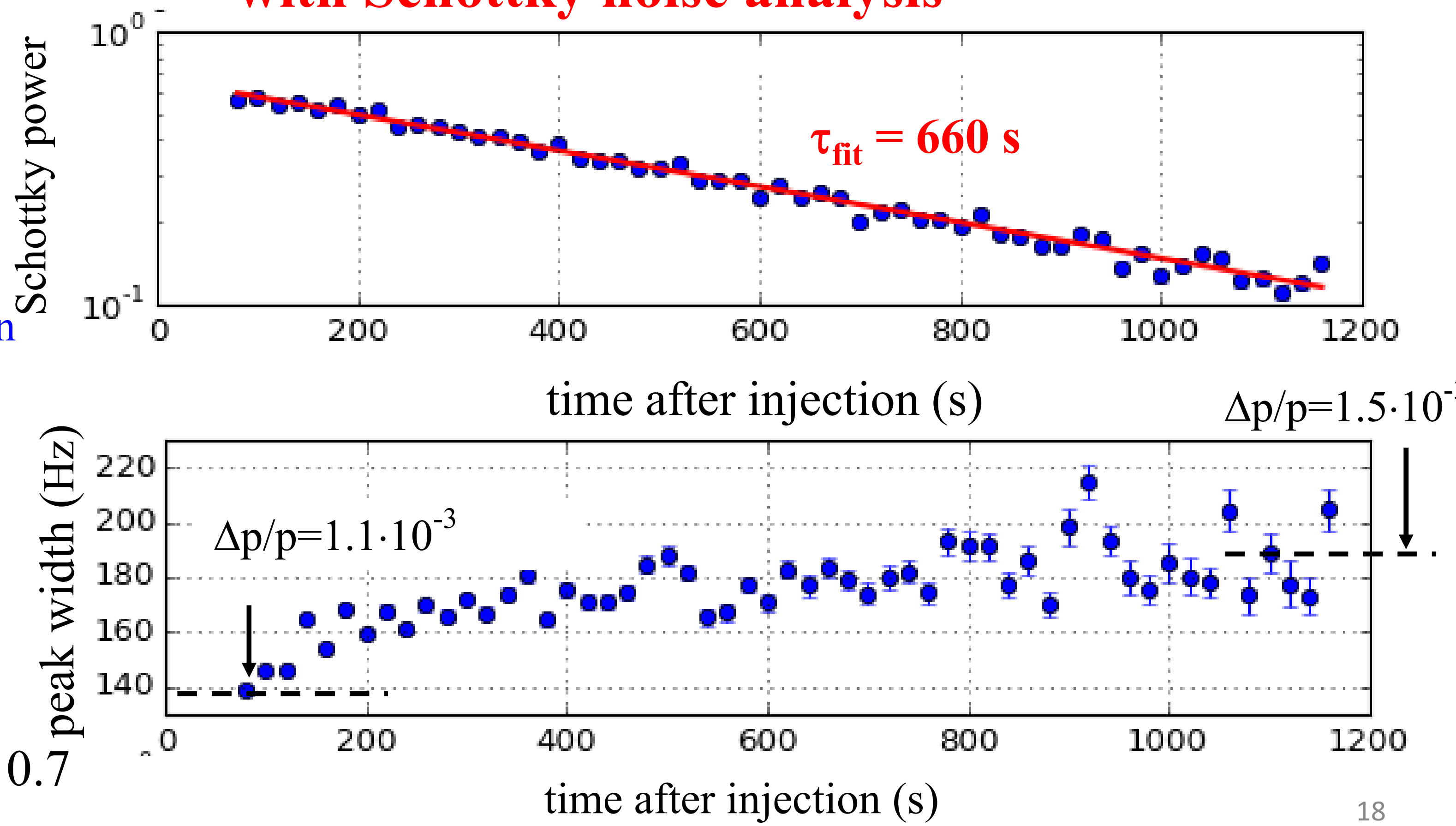
$$\eta = \frac{\Delta f / f}{\Delta p / p} = 1 - \frac{1}{\gamma_{th}^2} = 0.7$$

standard mode

Time development of the Schottky noise spectrum (60 keV Co_2^- ions)



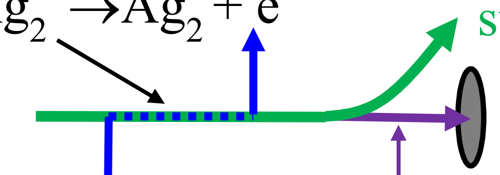
Lifetime Measurements of a stored Co_2^- beam with Schottky noise analysis



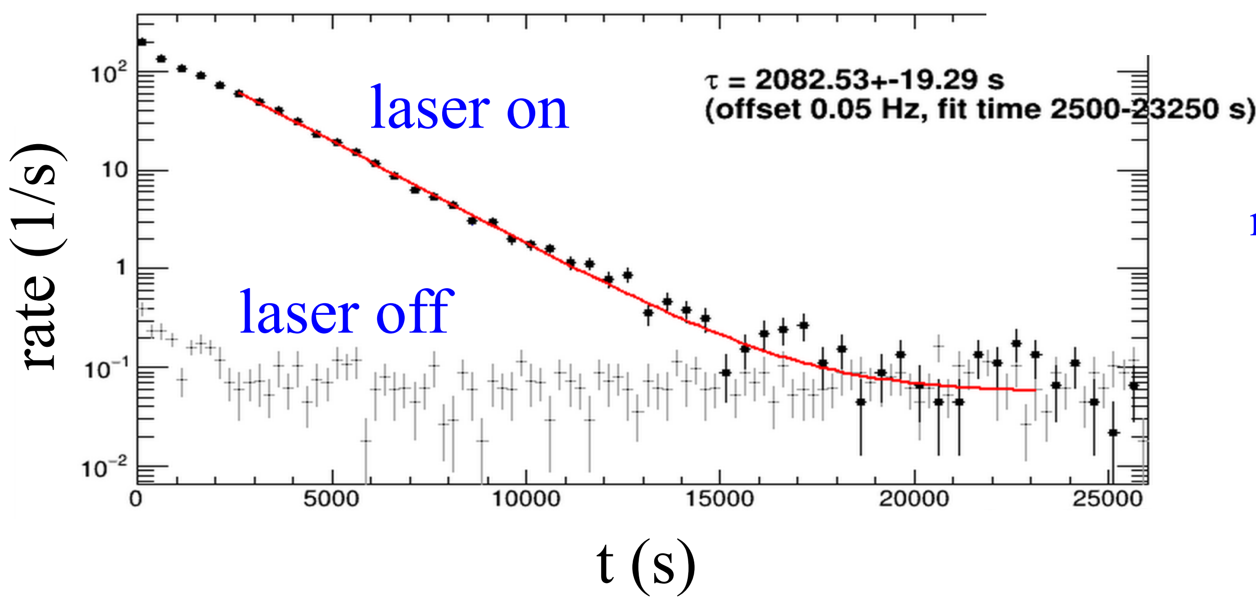
due to noise on the electrodes increasing of $\Delta p/p$

$$\eta = \frac{\Delta f / f}{\Delta p / p} = 1 - \frac{1}{\gamma_{th}^2} = 0.7$$

Lifetime Measurement of stored Ag_2^- ions (E=60 keV)



neutral rate on the detector



measured life time:

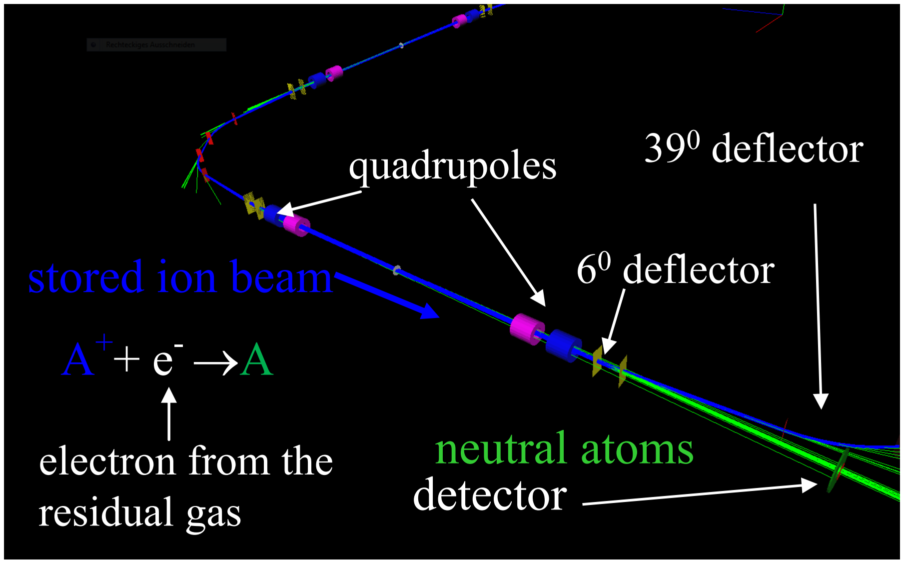
τ =2082 s

corrected for laser depletion:

τ=2500 s

Measurement of the residual gas density

simulation of the neutralization process **with g4beamline**



$$R(t) = \eta_f \cdot \frac{N(t)}{\tau_c} \qquad \tau_c = \frac{1}{n \cdot v \cdot \sigma}$$

measurement:

$^{40}Ar^{+}$ (E=60 keV) and N=$2 \cdot 10^{8}$:

R<10 1/s ⇒ **n< 20 H_2 molecules/cm³** !!!

⇒ vacuum life time: $\tau_v > 10^{6}$ s ≈ 280 h

simulation results

fraction of ions η_f hitting the detector

$\varepsilon_{x,90\%}$ (mm mrad)	η_f
0.5	0.126
9.1	0.119
23.0	0.118

average value $\eta_f = 0.121$

σ- cross section for neutralization

singly charged 50-60 keV ions (for H_2):

Ar^{+}: $\sigma = 5.3 \cdot 10^{-16}$ cm² O^{-}: $\sigma = 3.4 \cdot 10^{-16}$ cm²

v- velocity

n- residual rest gas density

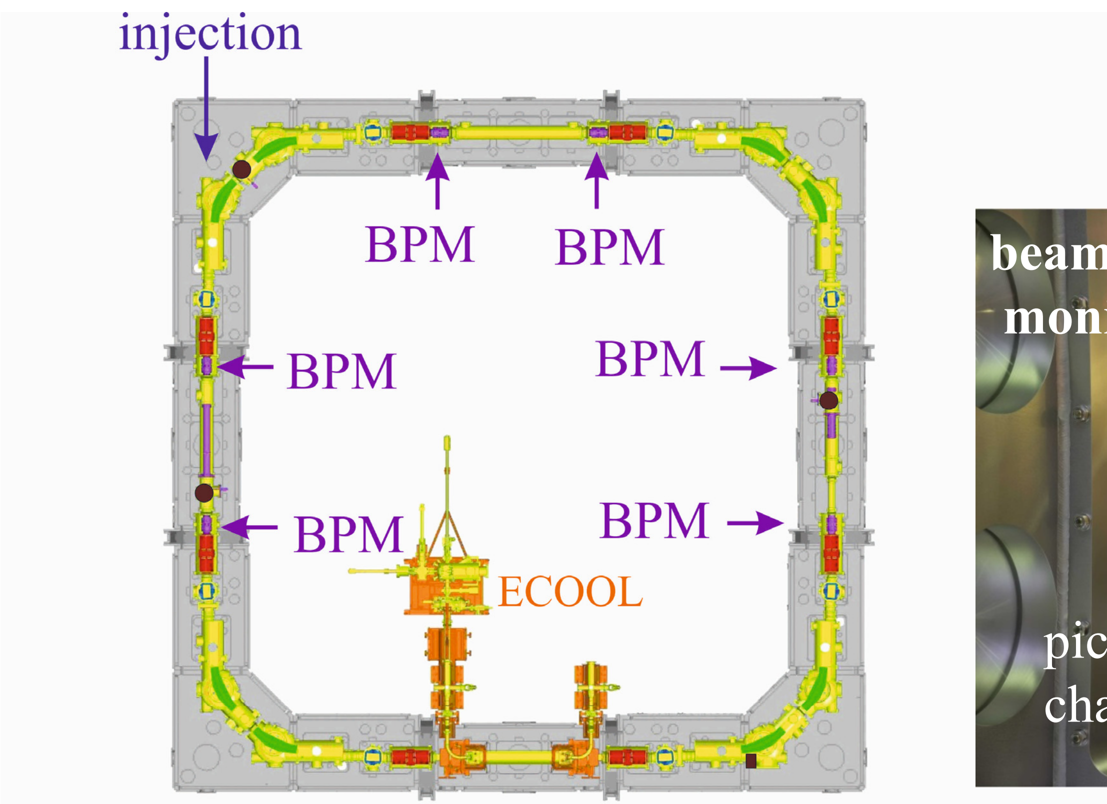
R(t)- detector rate

N(t)- number of stored particles

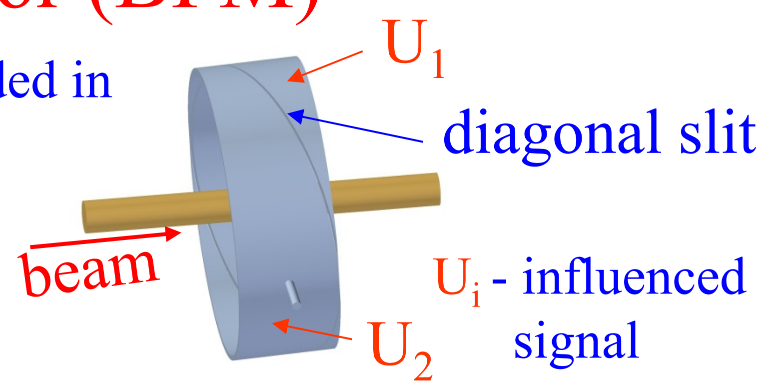
⇒ lifetime is not residual gas dependent !!!

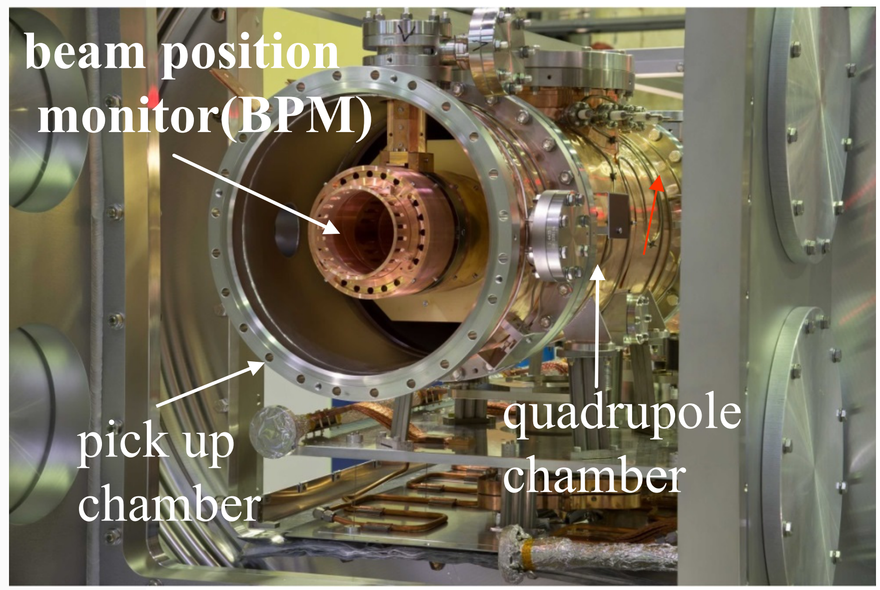
Beam Position Monitor (BPM)

CSR has 6 horizontal and
6 vertical position pick ups (BPM)



tube divided in
two parts

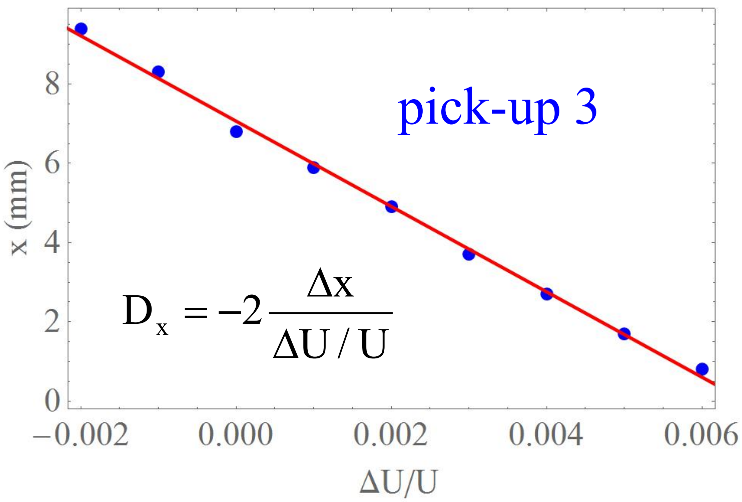




Dispersion in the straight section

pick-up measurements

closed orbit change x via variation of all potentials by ΔU/U



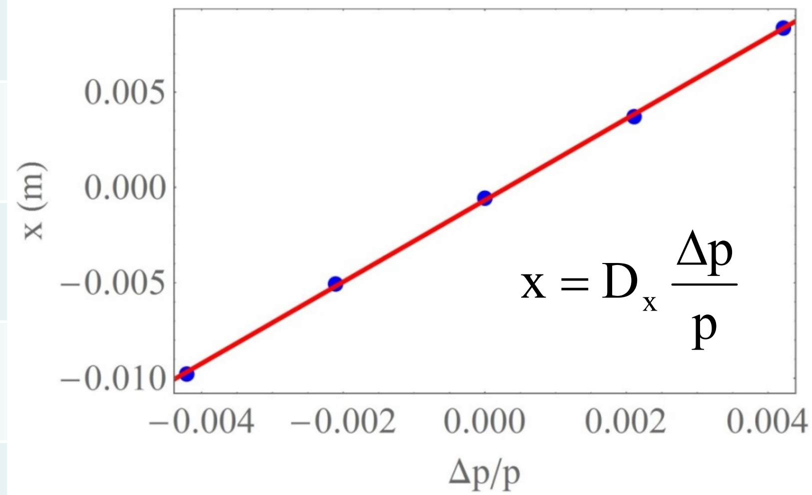
average value

$$\overline{D}_x = 2.17\,\text{m}$$

pick-up	D_x (m)
1	2.19
2	2.23
3	2.15
4	2.17
5	2.16
6	2.09

g4beamline simulation

tracking of particles with different momenta and plotting the closed orbit position x as a function of Δp/p



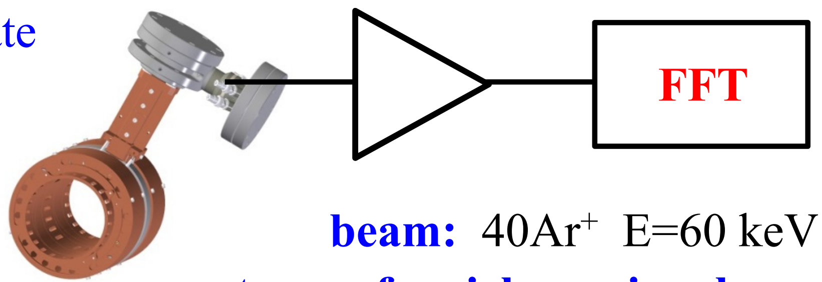
D_x=2.14 m

remark: D_x=2.14 m is the maximum dispersion in the standard mode

Application of pick-up measurements

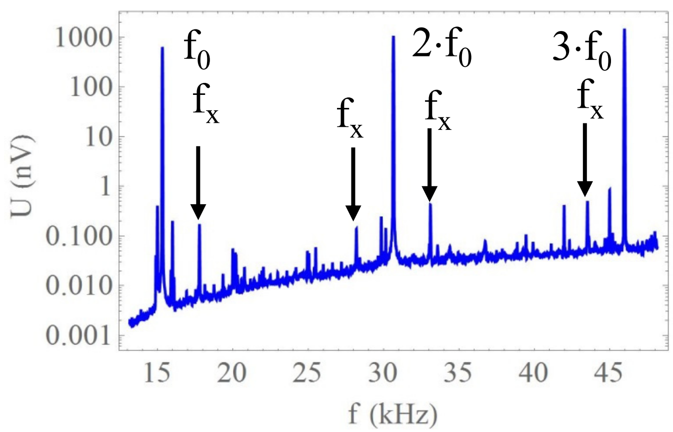
determination of the horizontal and vertical tune

one pick-up plate amplification



beam: 40Ar^{+} E=60 keV

spectrum of a pick-up signal induced on a horizontal plate



f_0- revolution frequency

f_x - betatron side band

$$f_x = f_0(n \pm q_x)$$

n- integer number

q_x- non integer part of the tune

effective quadrupole length

The effective quadrupole length are determine by matching the measured tunes with the calculated tunes.

result:

calculated with **TOSCA**: l_{eff}=0.211 m

measurement:

quadrupole family 1: l_{eff}=0.208 m

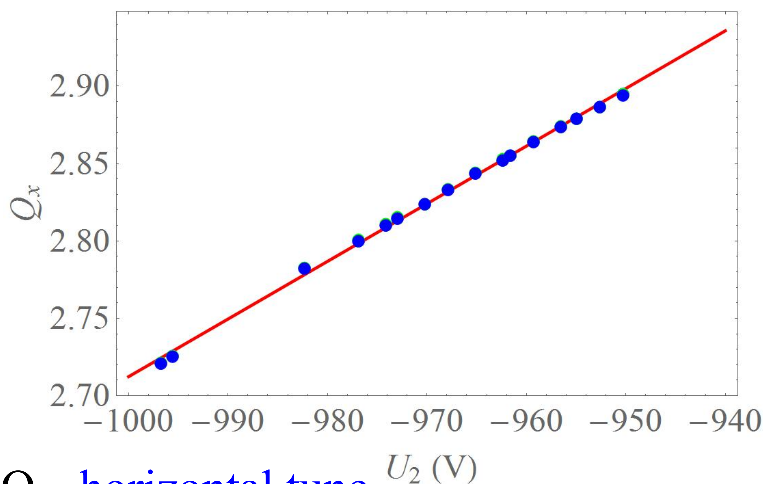
quadrupole family 2: l_{eff}=0.209 m

Determination of horizontal ß$_x$ and vertical ß$_y$ functions

$$\Delta Q_x = \frac{1}{4\pi}\int \beta_x(s)\cdot \Delta K(s)\,ds$$

$$\Rightarrow \quad \vec{\beta}_x = \frac{\pi}{2}\frac{1}{\alpha}\frac{\Delta Q_x}{\Delta U}\frac{1}{L_m} \text{ with } \alpha = \frac{K}{U}$$

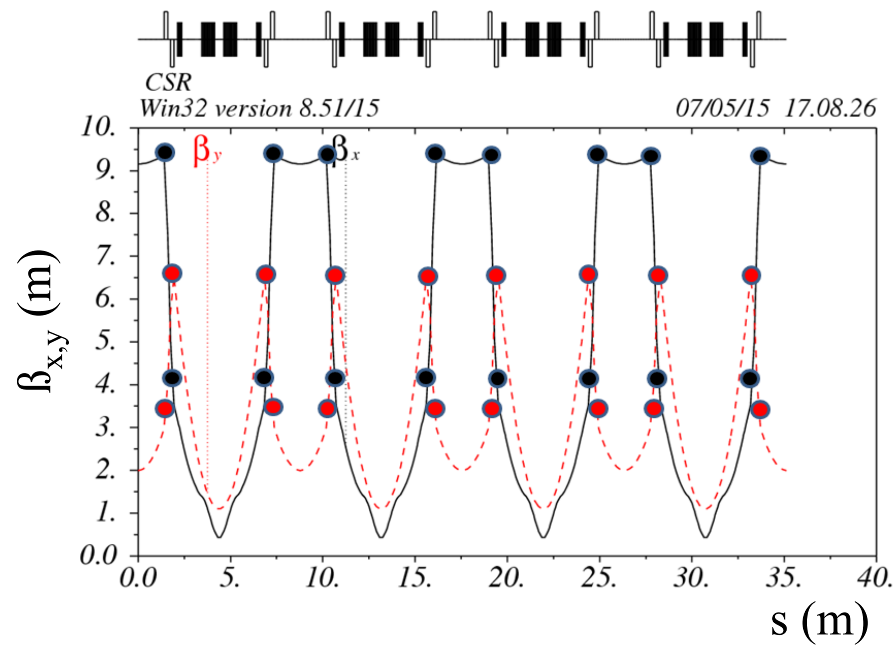
horizontal tune as a function of voltage of quadrupole family 2



Q_x- horizontal tune

U_2 -voltage of quadrupole family 2

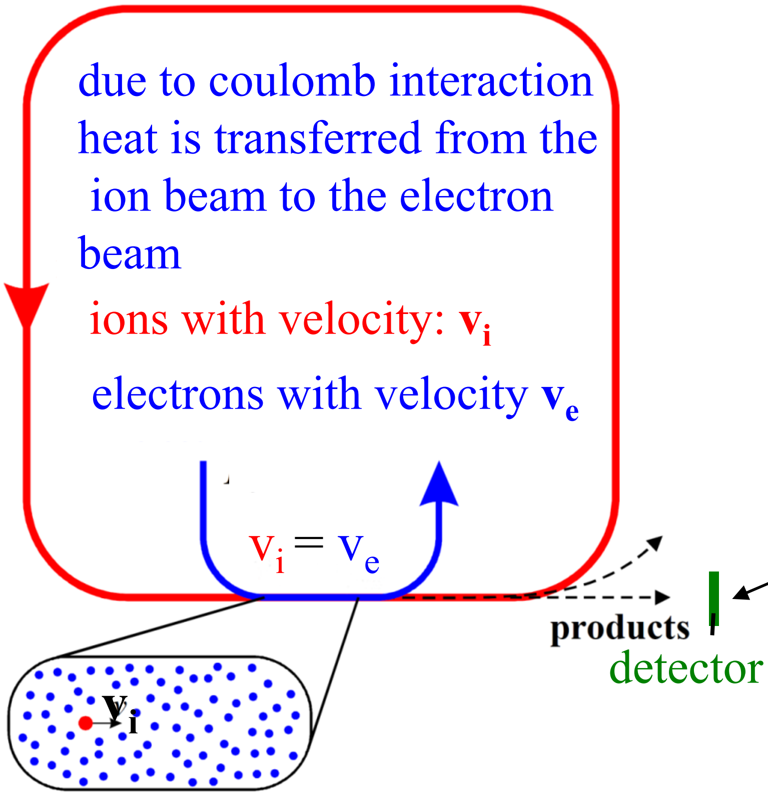
MAD calculation of horizontal and vertical β function (standard mode)



- measured horizontal ß$_x$ function
- measured vertical ß$_y$ function

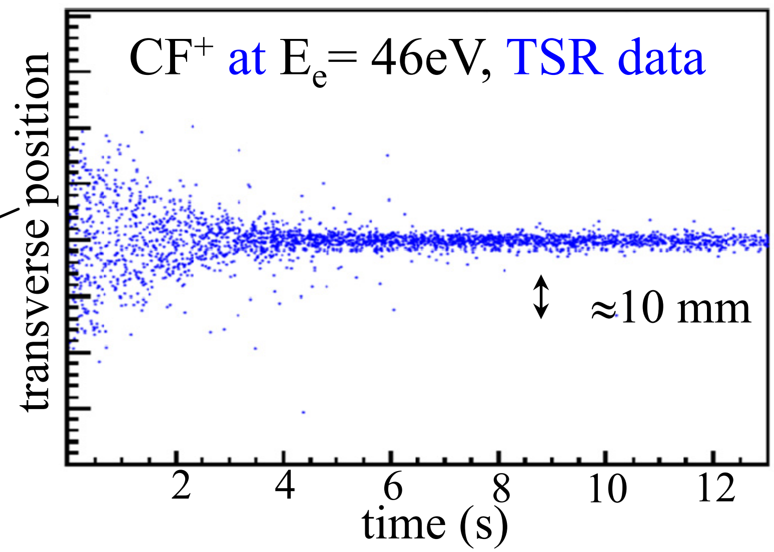
CSR electron cooler – principle

principle of electron cooling:

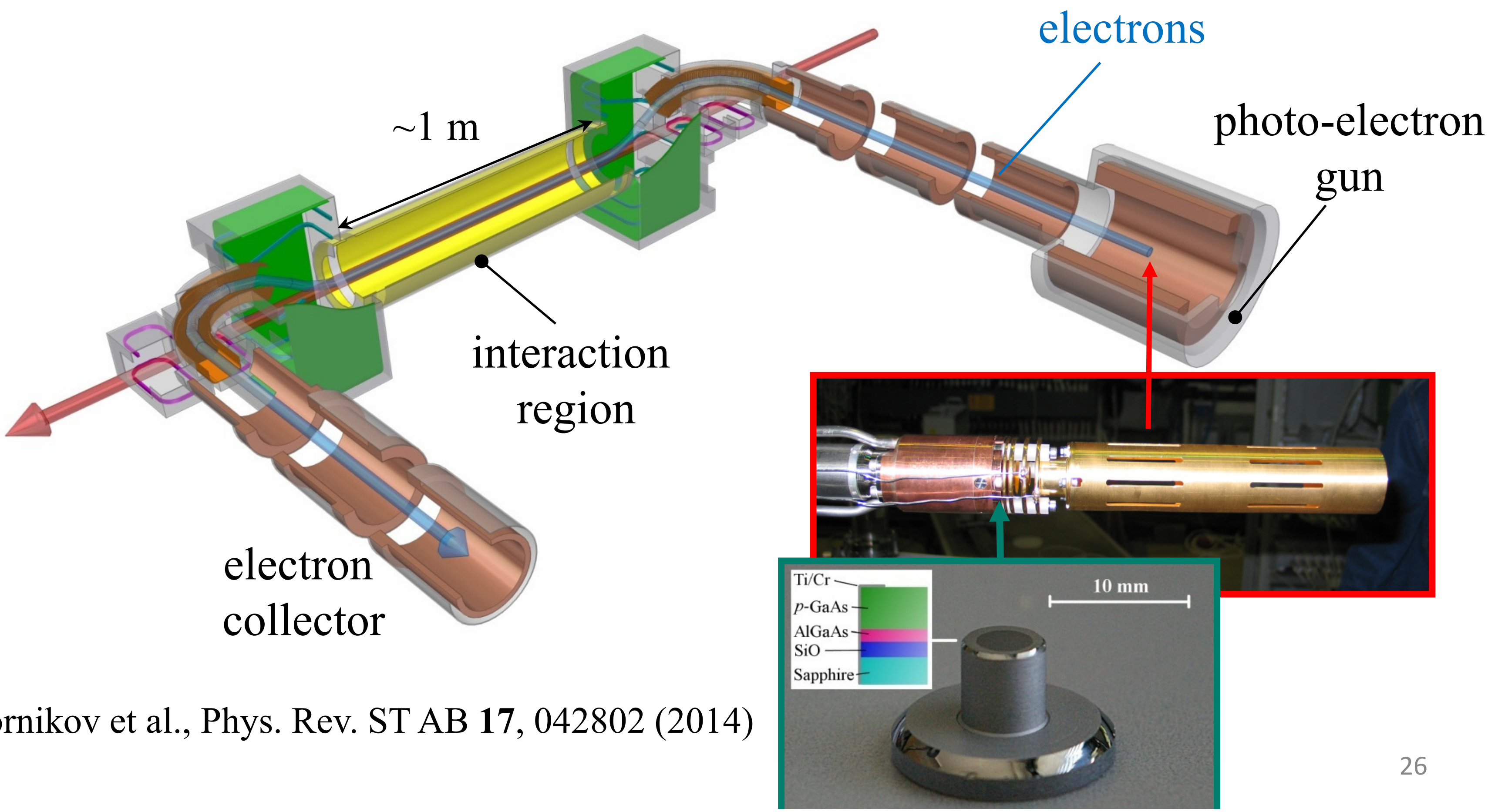


E_e (eV)	ion
163	for 300 keV p^+
~10	for most ions
1	for M_{ion} = 160 u

electron cooling experiment at the TSR

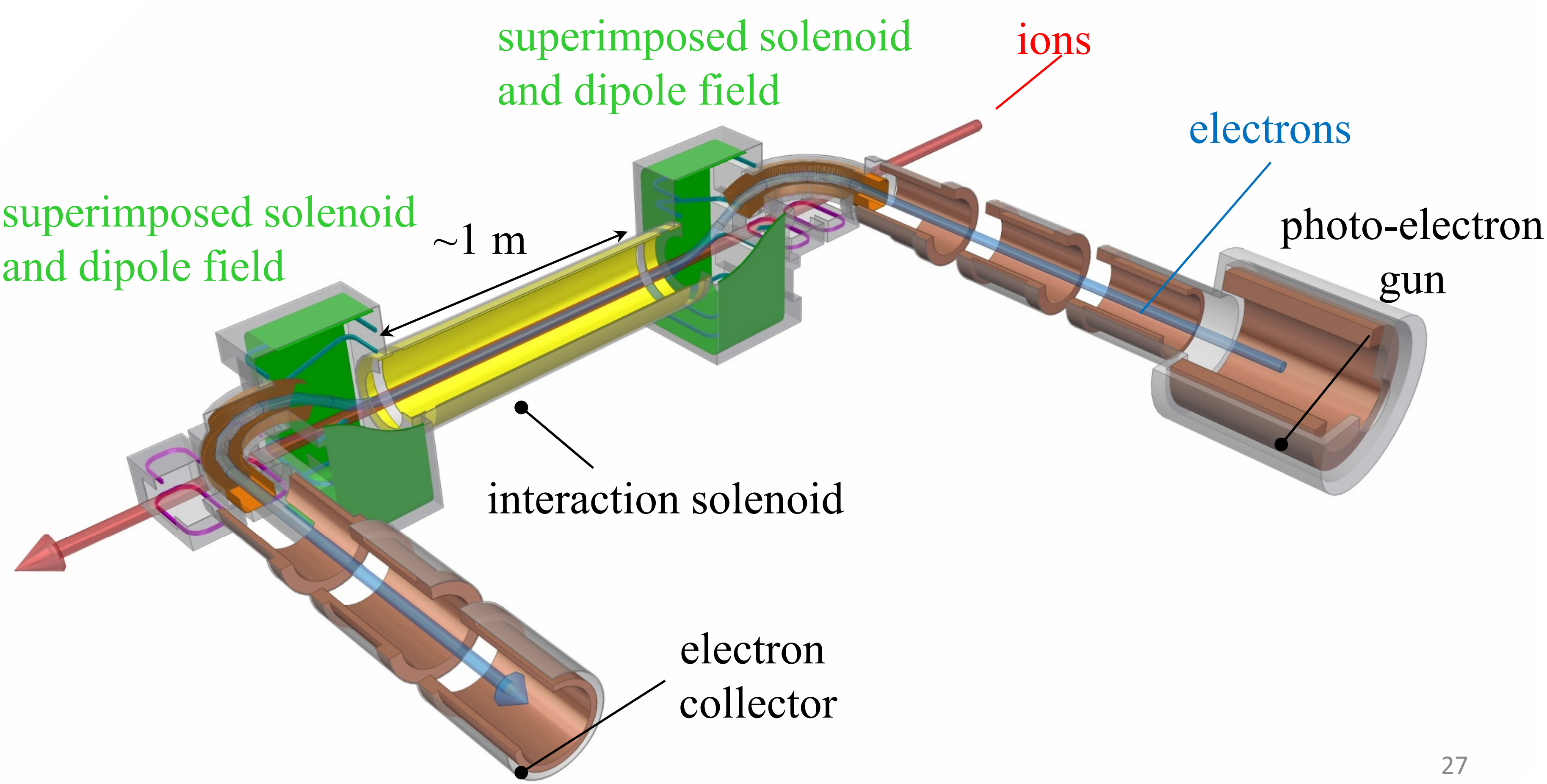


CSR electron cooler – photo-cathode

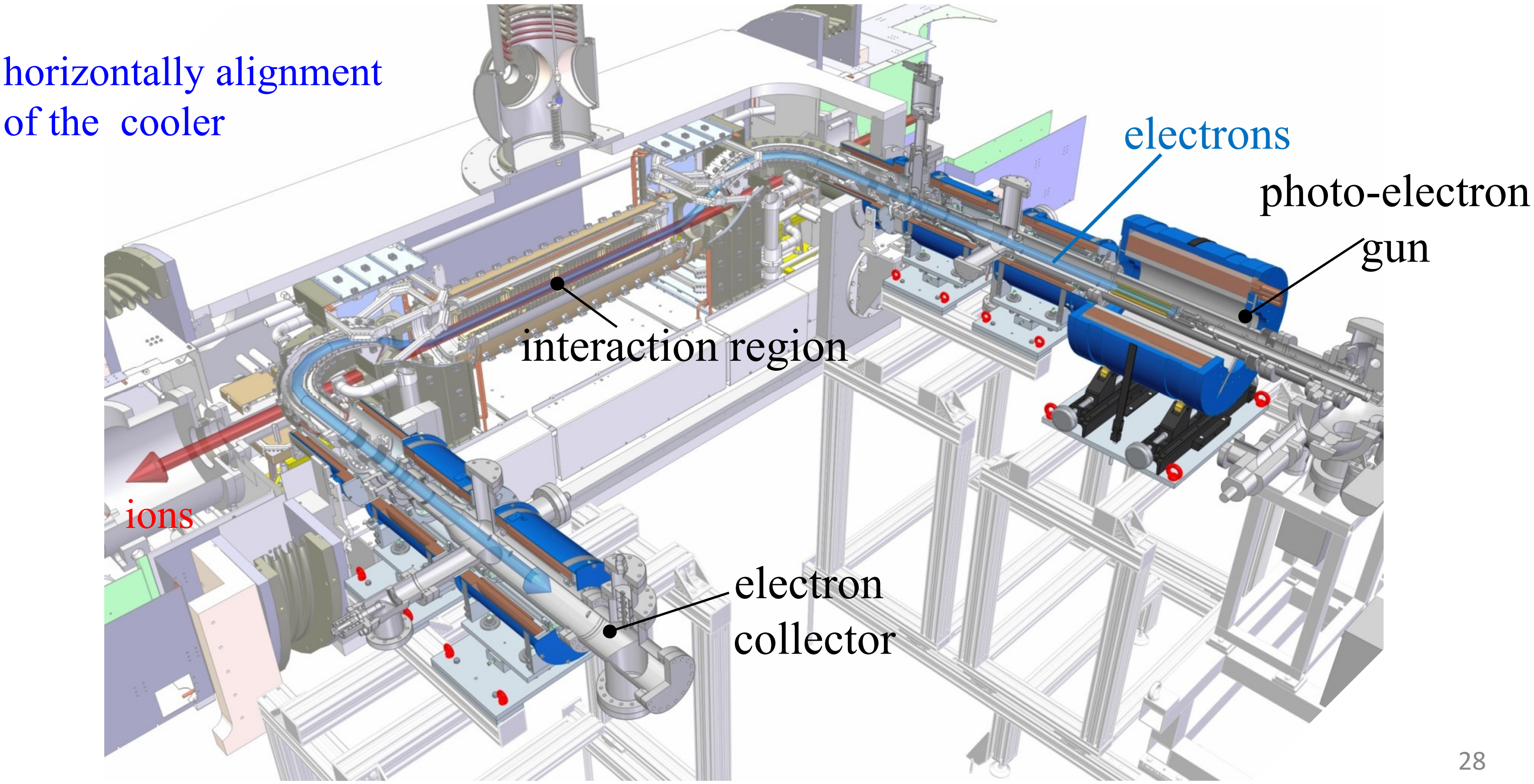


Shornikov et al., Phys. Rev. ST AB **17**, 042802 (2014)

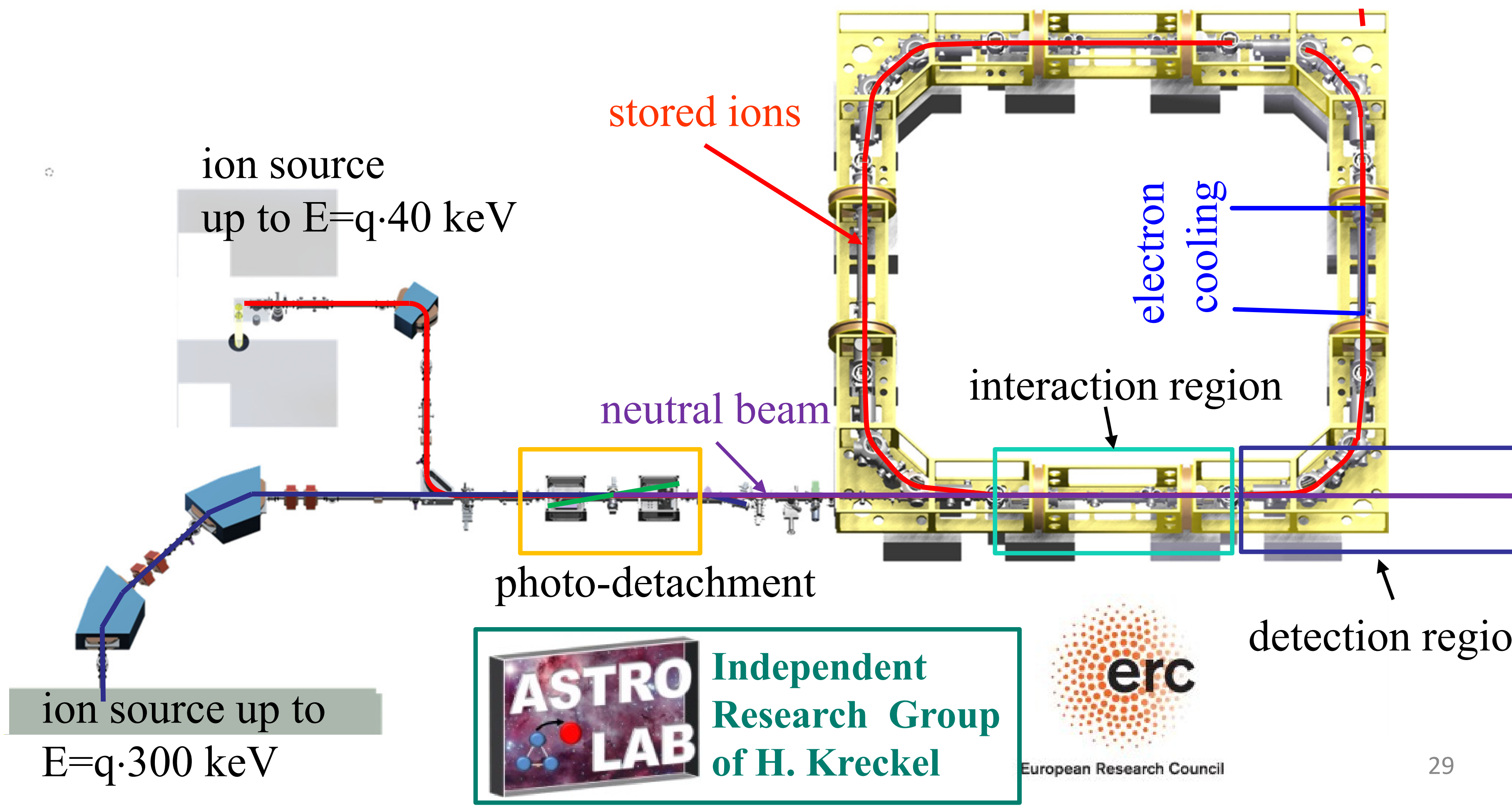
CSR electron cooler – magnetic guiding field



CSR electron cooler – Design

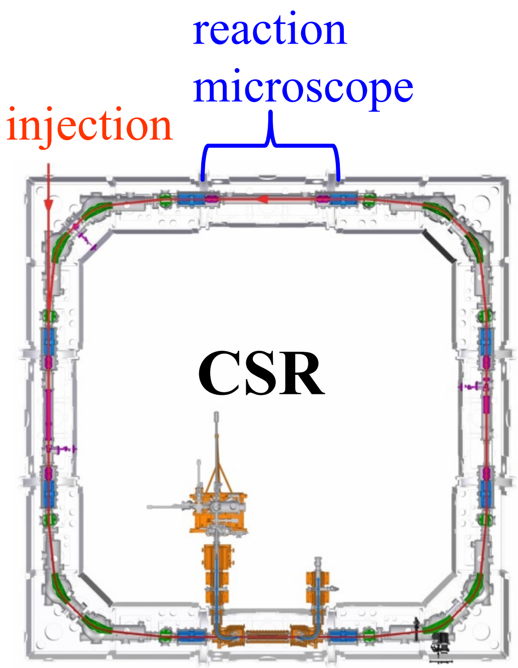


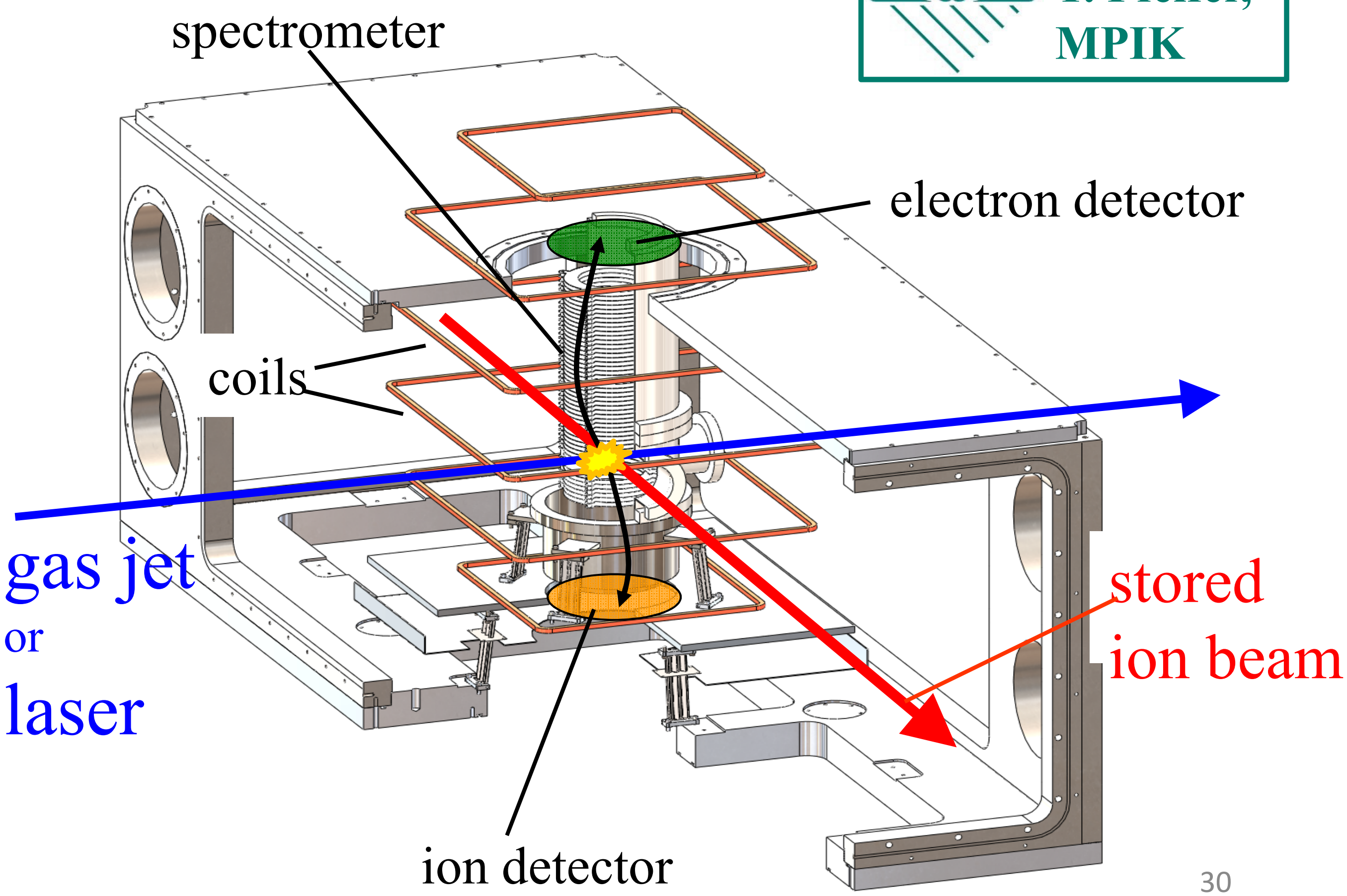
Neutral beam experiment



The reaction microscope

Division of T. Pfeifer, MPIK





Thanks for your attention!

A. Becker
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M. Grieser
F. Grussie
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J. Karthein

C. Krantz
H. Kreckel
S. Kumar S.
M. Lange
J. Lion
S. Lohmann
C. Meyer
P. M. Mishra
O. Novotný
P. O'Connor
R. Repnow

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