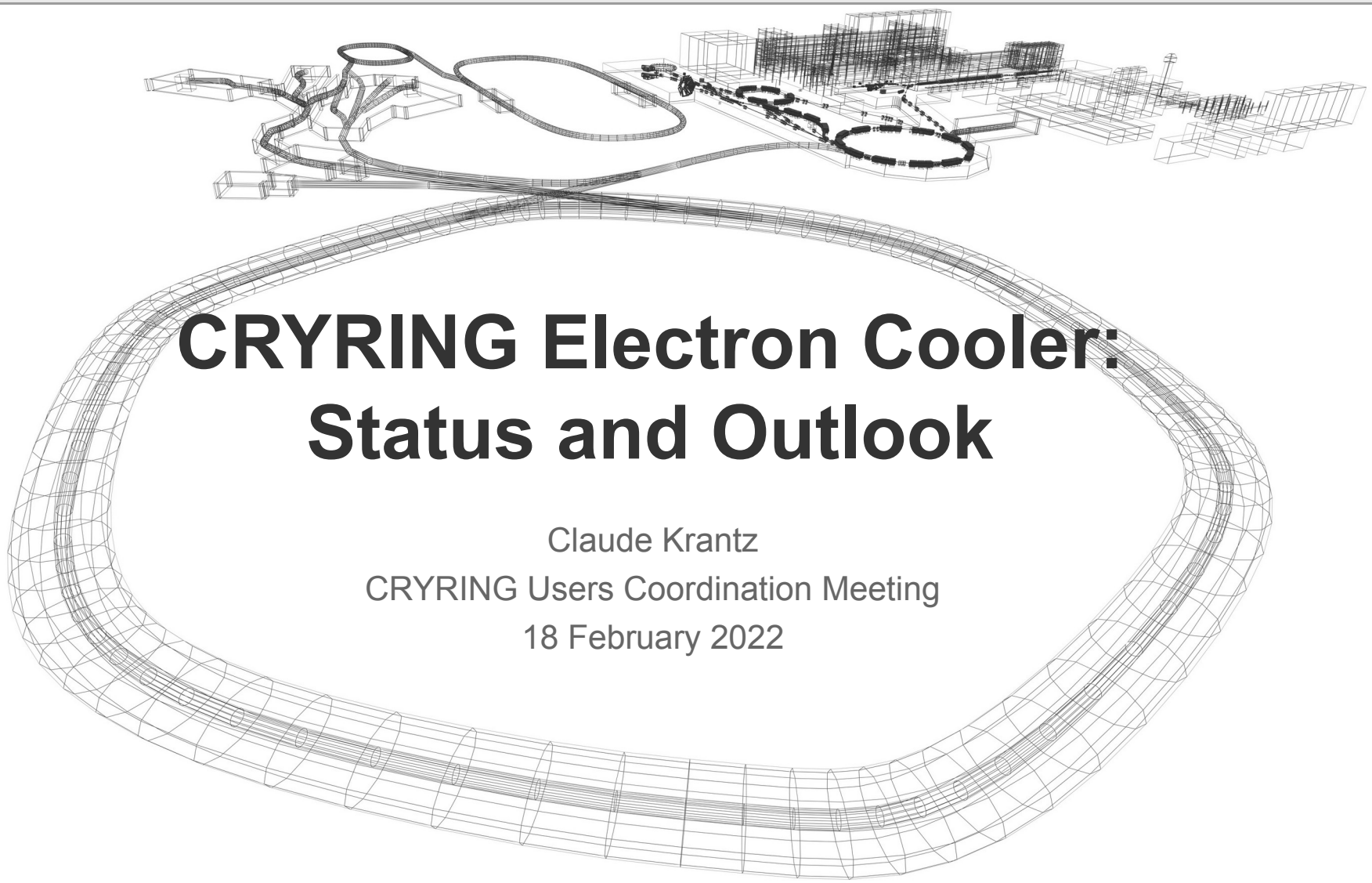


# CRYRING Electron Cooler: Status and Outlook

Claude Krantz

CRYRING Users Coordination Meeting

18 February 2022

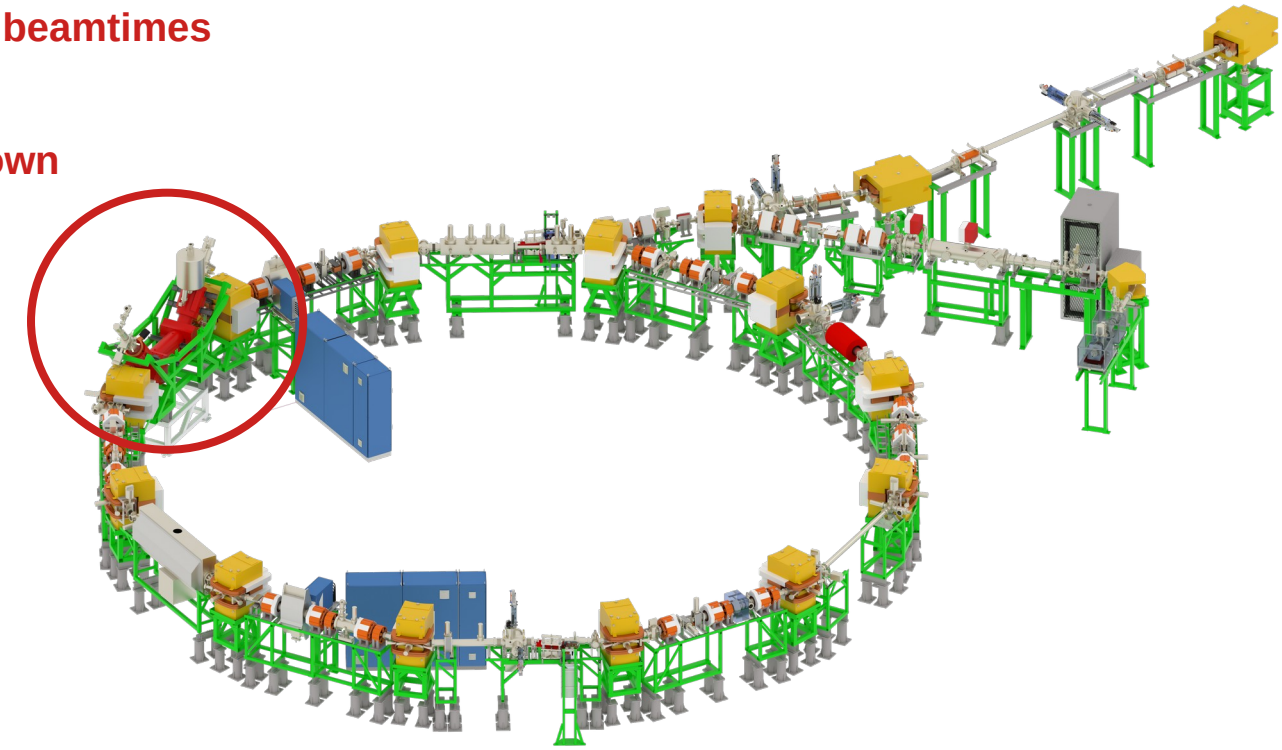
# CRYRING Electron Cooler: Status and Outlook

## Outline

**Highlights from 2020 / 2021 beamtimes**

**Upgrades in 2022/23 shutdown**

**Possible further upgrades**



# The CRYRING electron cooler

18 years of successful operation and successive improvements at MSL.

→ Pioneered strong expansion of e-beam

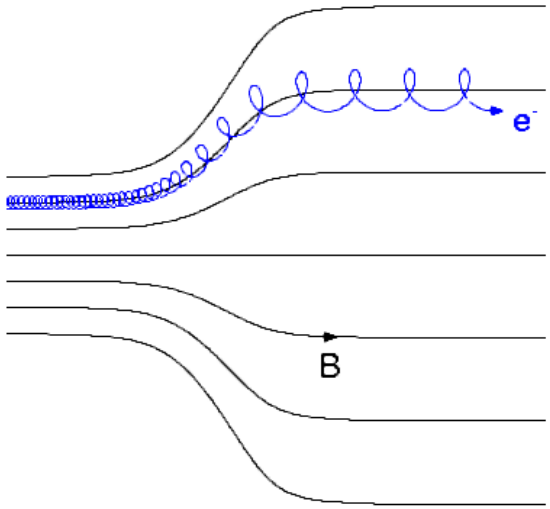
$$T_{\text{trans}} = T_{\text{cath}} \frac{B_{\text{cooler}}}{B_{\text{gun}}}$$

with s.c. gun solenoid: $B_{\text{gun}} / B_{\text{cooler}} = 100$

msi.se

Contributed significantly to our understanding of electron cooling!

(… besides enabling countless experiments on atomic and molecular physics.)




First cooled beam at GSI/FAIR in 2018.

“Routine” operation since 2020 beamtime.

# The CRYRING electron cooler

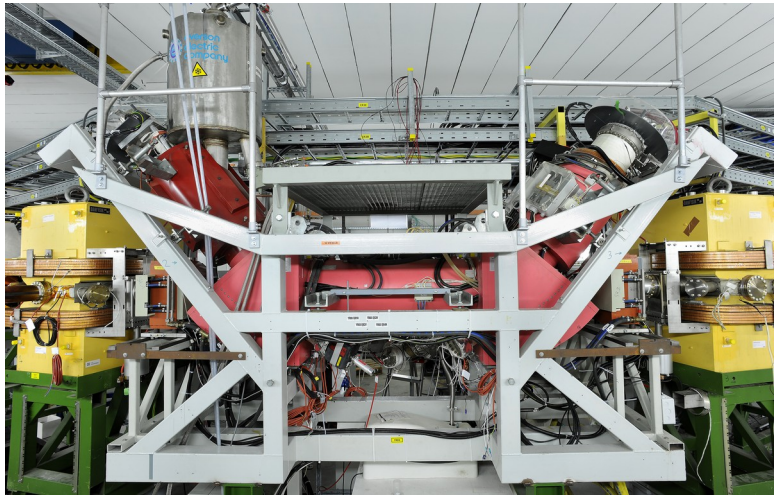
Transverse electron temperature at max. expansion:

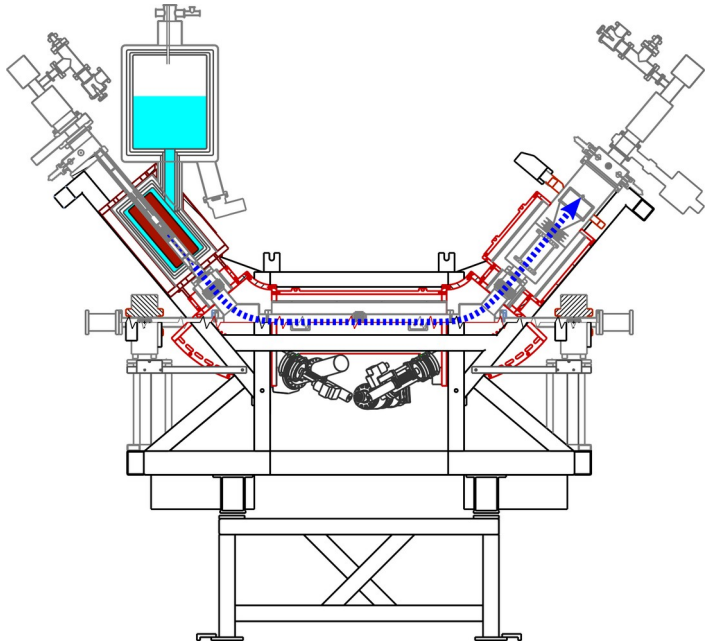
*Theory:*

$T_{cath}$ ~ 100 meV/$k_B$ (1200 K) → $T_\perp$ ~ 1 meV/$k_B$

*Various MSL experiments:*

$T_\perp$ = 1.5 … 3 meV/$k_B$





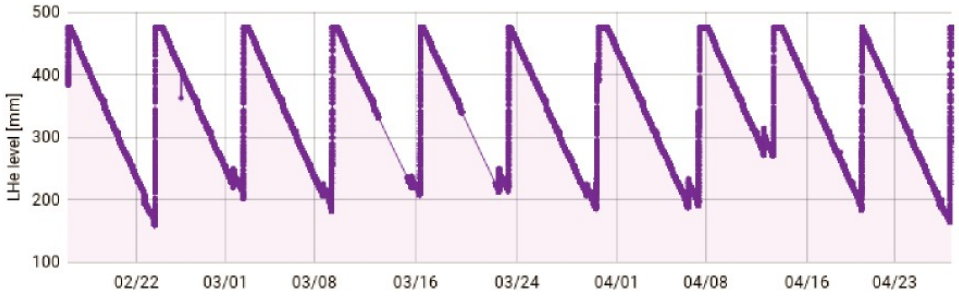
| | |
|---|---|
| electron energy | ≤ 8 keV (~14.6 MeV/u) |
| electron current | ≤ 110 mA |
| cathode diameter | 4 mm |
| mag. expansion factor | ≤ 100 (≤ 3 T → 0.03 T) |
| e-beam diameter | ≤ 40 mm |
| cooler solenoid length | ≈ 1.1 m (~ 2% $C_{ring}$) |

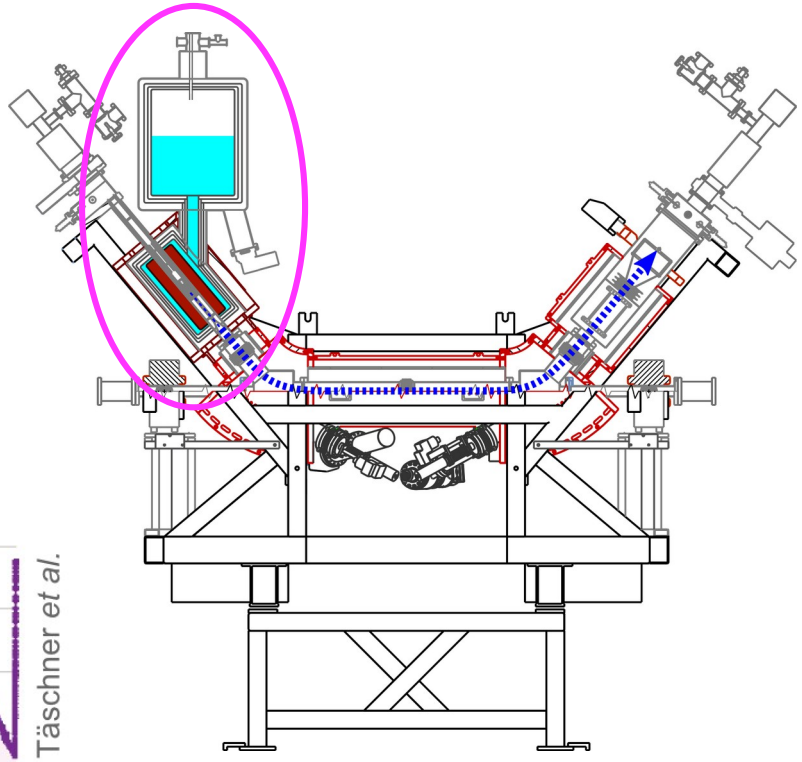
# Results from 2020 / 2021 beamtimes

Superconducting gun solenoid
has been operating very reliably since 2020!

1 LHe refill per week.

Several months of continuous cooler operation.



A. Täschner *et al.*

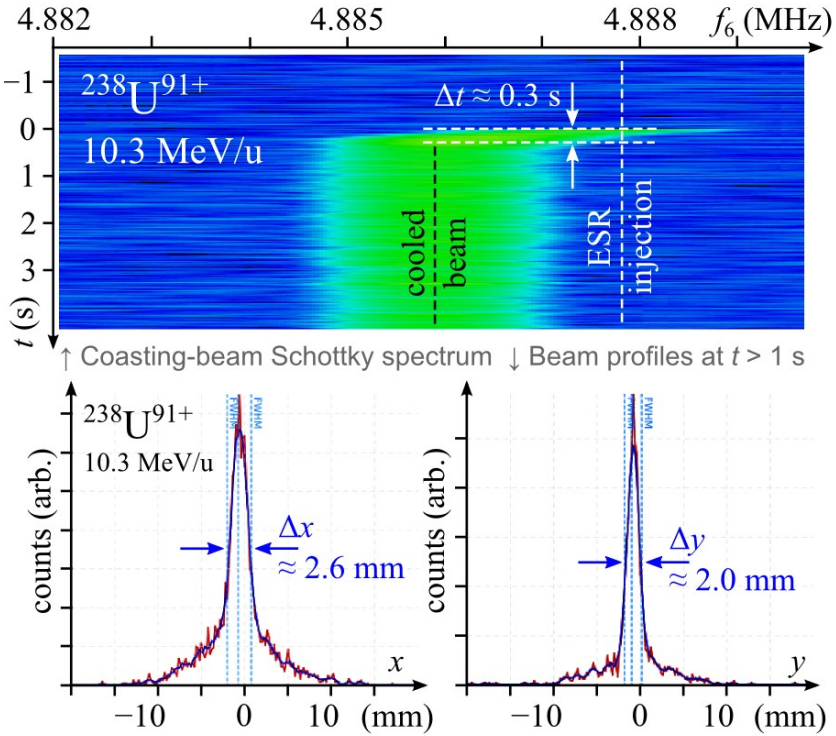
# Results from 2020 / 2021 beamtimes

Highly-charged ions from SIS18 via ESR

**Cooler parameters:**
Acc. voltage: 5.63 kV
current: 30 mA
expansion: 33.3

**Example: $^{238}U^{91+}$**

Stripped after SIS18 at 300 MeV/u
decelerated (and cooled) in ESR to 10.3 MeV/u
injected into CRYRING and re-cooled < 1s



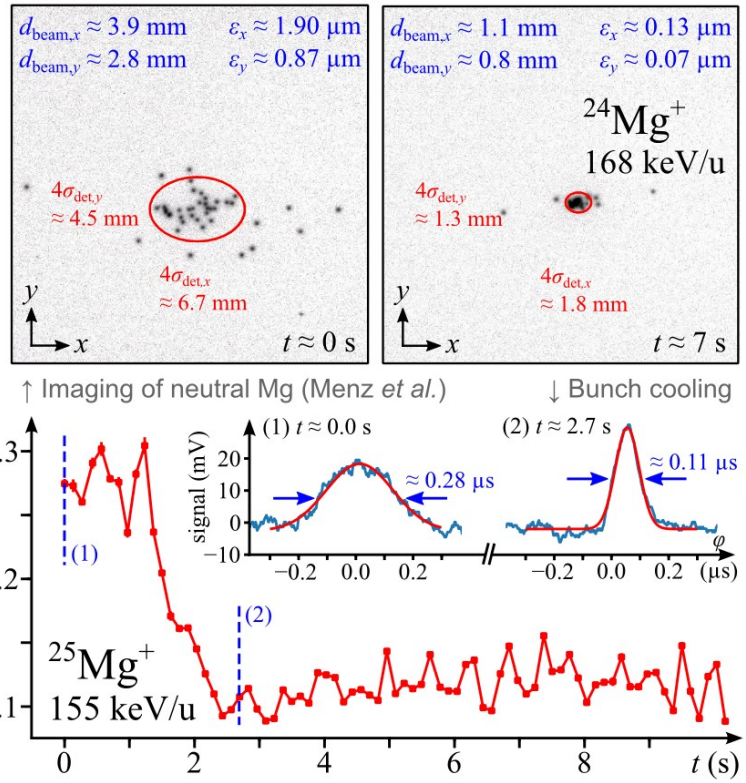
# Results from 2020 / 2021 beamtimes

Weakly-charged ions from local injector

**Cooler parameters:**
Acc. voltage: ~ 100 V
current: 1.7 mA
expansion: 33.3

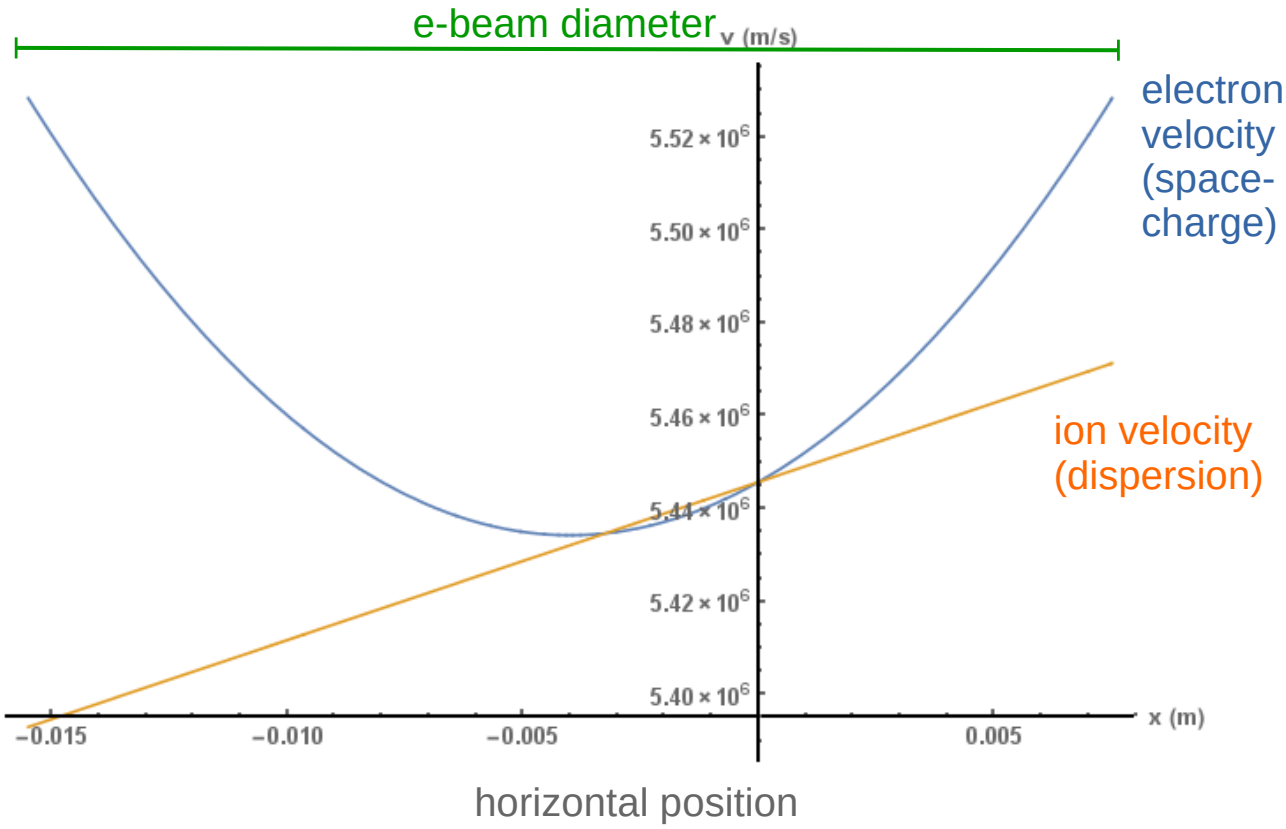
**Example: $^{24/25}Mg^{+}$**

*m*/*q* too high for acceleration in RFQ.
Injected at 35 keV (1.4 keV/u).
Acceleration to max. rigidity: $^{24}Mg^{+}$: 168 keV/u
$^{25}Mg^{+}$: 155 keV/u
Cooled in ~2 s (long.) / ~6 s (transv.)



# Results from 2020 / 2021 beamtimes

Weakly-charged ions from local injector: **Dispersive coupling effects in electron cooling**



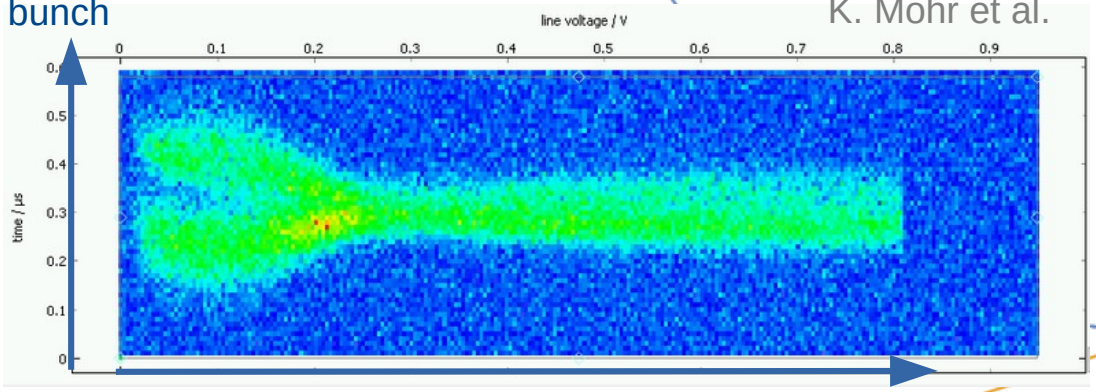

**Cooler parameters:**
Acc. voltage: ~ 100 V
current: 1.7 mA
expansion: 33.3

# Results from 2020 / 2021 beamtimes

Weakly-charged ions from local injector: **Dispersive coupling effects in electron cooling**

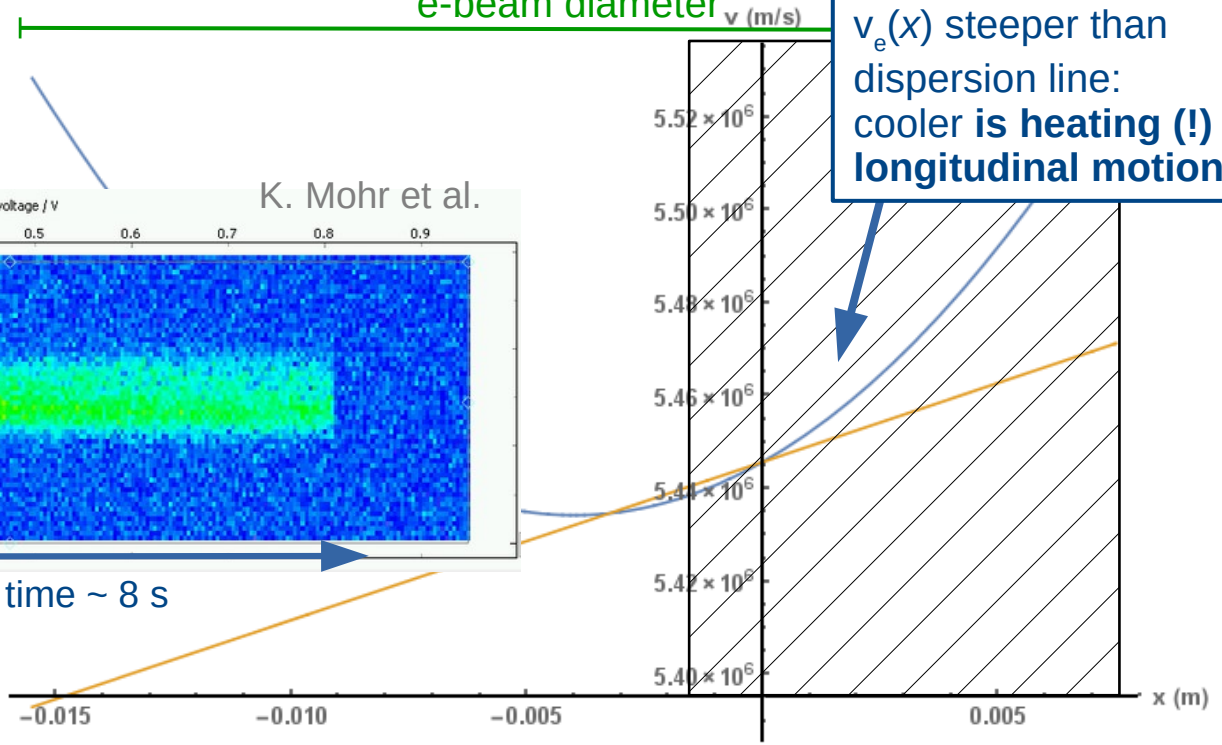
e-beam diameter

Time structure of bunch




K. Mohr et al.

storage time ~ 8 s




$v_e(x)$ steeper than dispersion line: cooler **is heating (!) longitudinal motion**

horizontal position

**Cooler parameters:**
Acc. voltage: ~ 100 V
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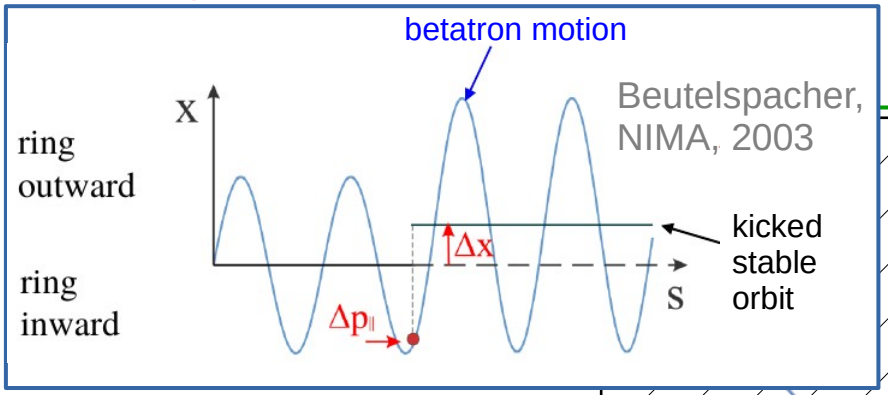
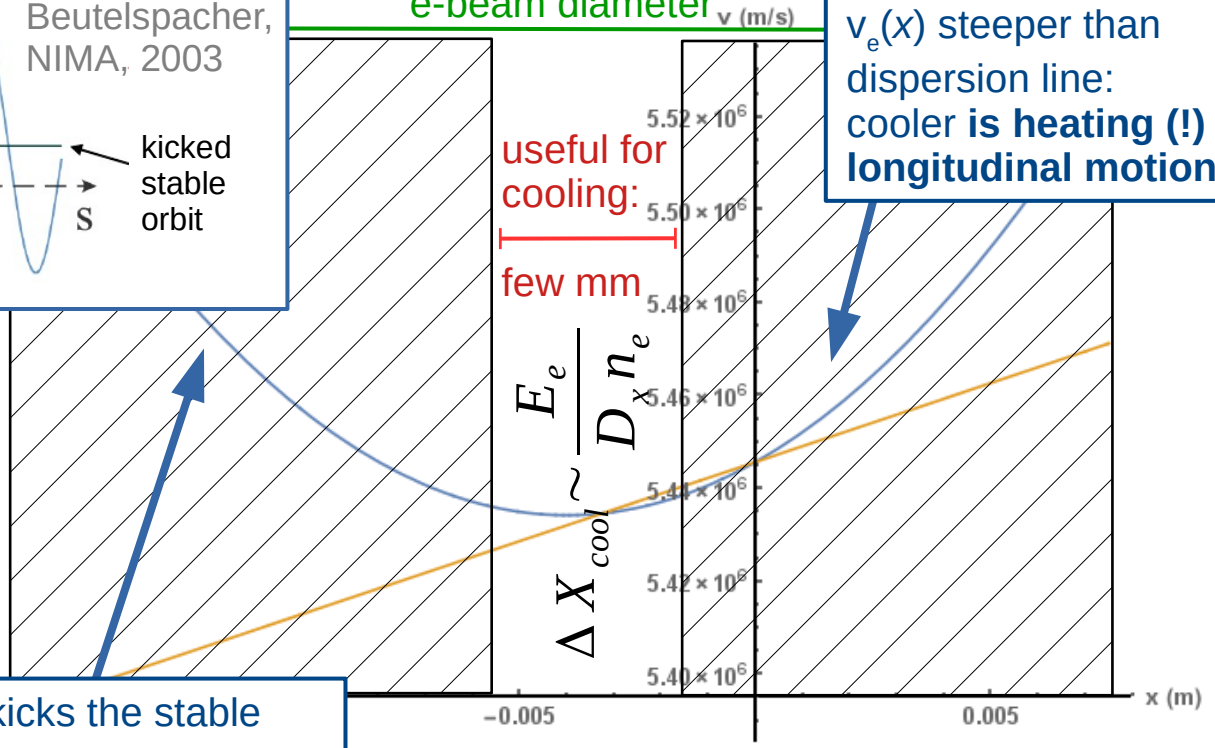
# Results from 2020 / 2021 beamtimes

Weakly-charged ions from local injector: **Dispersive coupling effects in electron cooling**




Beutelspacher, NIMA, 2003




useful for cooling:

few mm

$$\Delta X_{cool} \sim \frac{E_e}{D_x n_e}$$

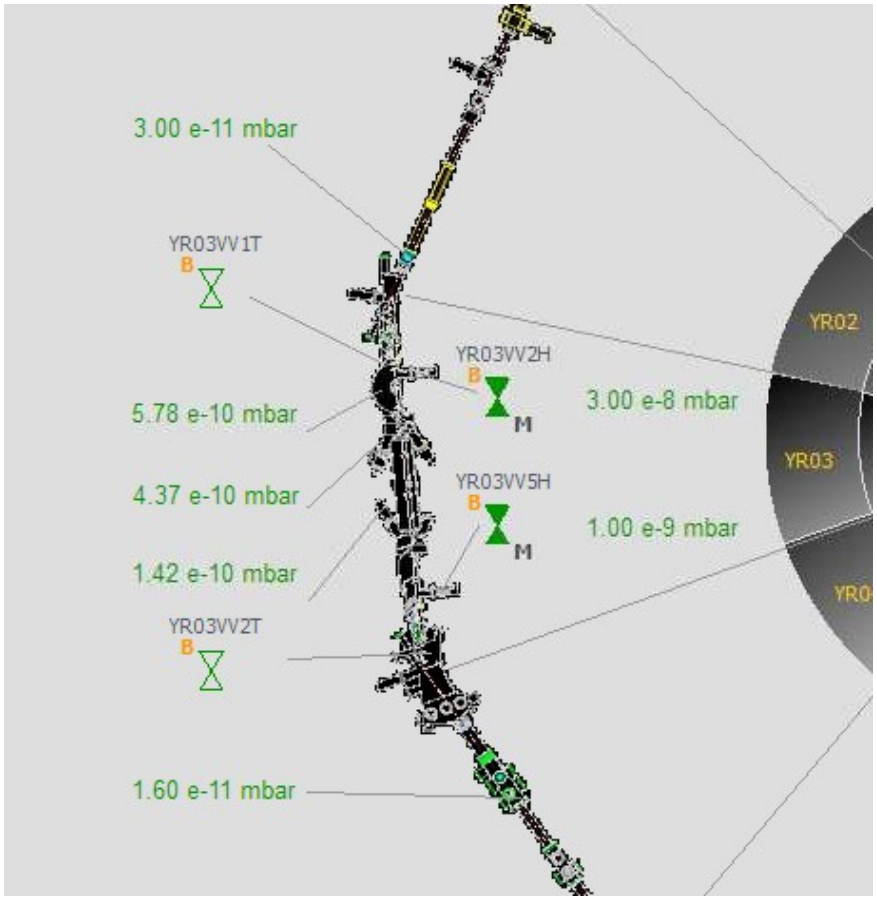
$v_e(x)$ steeper than dispersion line: cooler **is heating (!) longitudinal motion**

horizontal position

**Cooler parameters:**
Acc. voltage: ~ 100 V
current: 1.7 mA
expansion: 33.3

$v_e(x)$ kicks the stable orbit *away* from the ion position: cooler **heats betatron motion!**

# Major issue: Vacuum




Vacuum in the merged-beams section of the cooler is not well known.

(Extractor gauges are far away and shaded by in-vacuum structures.)

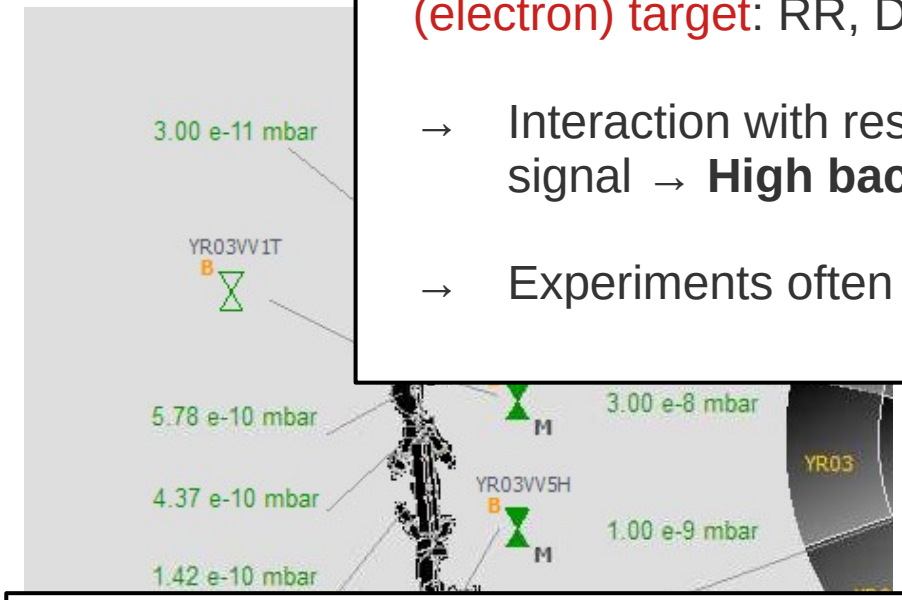
It is reasonable to assume the cooler has the worst vacuum in all of CRYRING!

# Major issue: Vacuum

Particularly bad for experiments that use the cooler as internal (electron) target: RR, DR.

→ Interaction with residual gas competes with electron-induced signal → **High background rates**.

→ Experiments often favour higher **e-density over expansion**.

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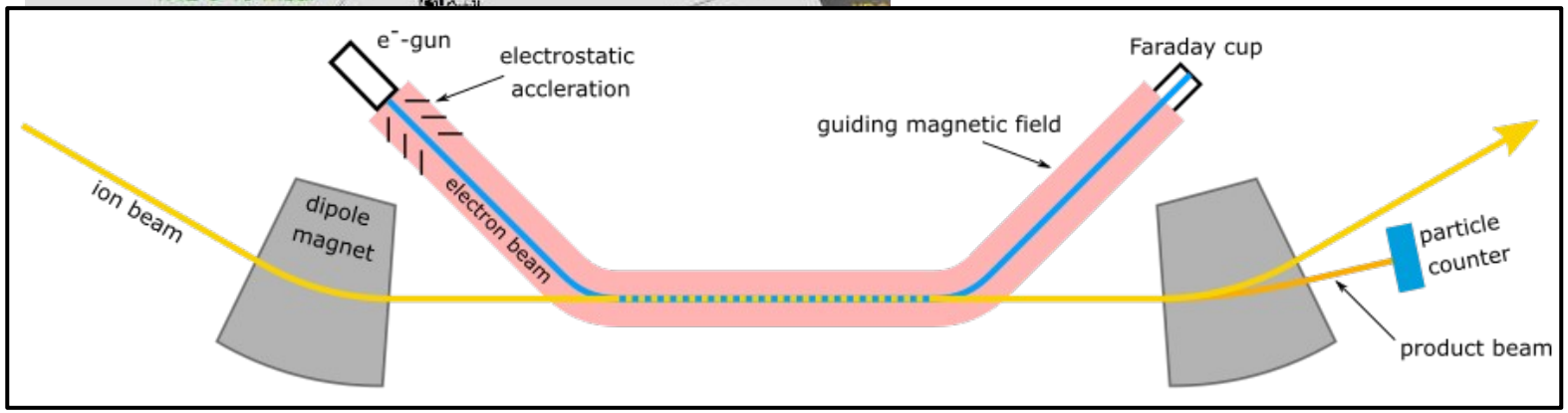

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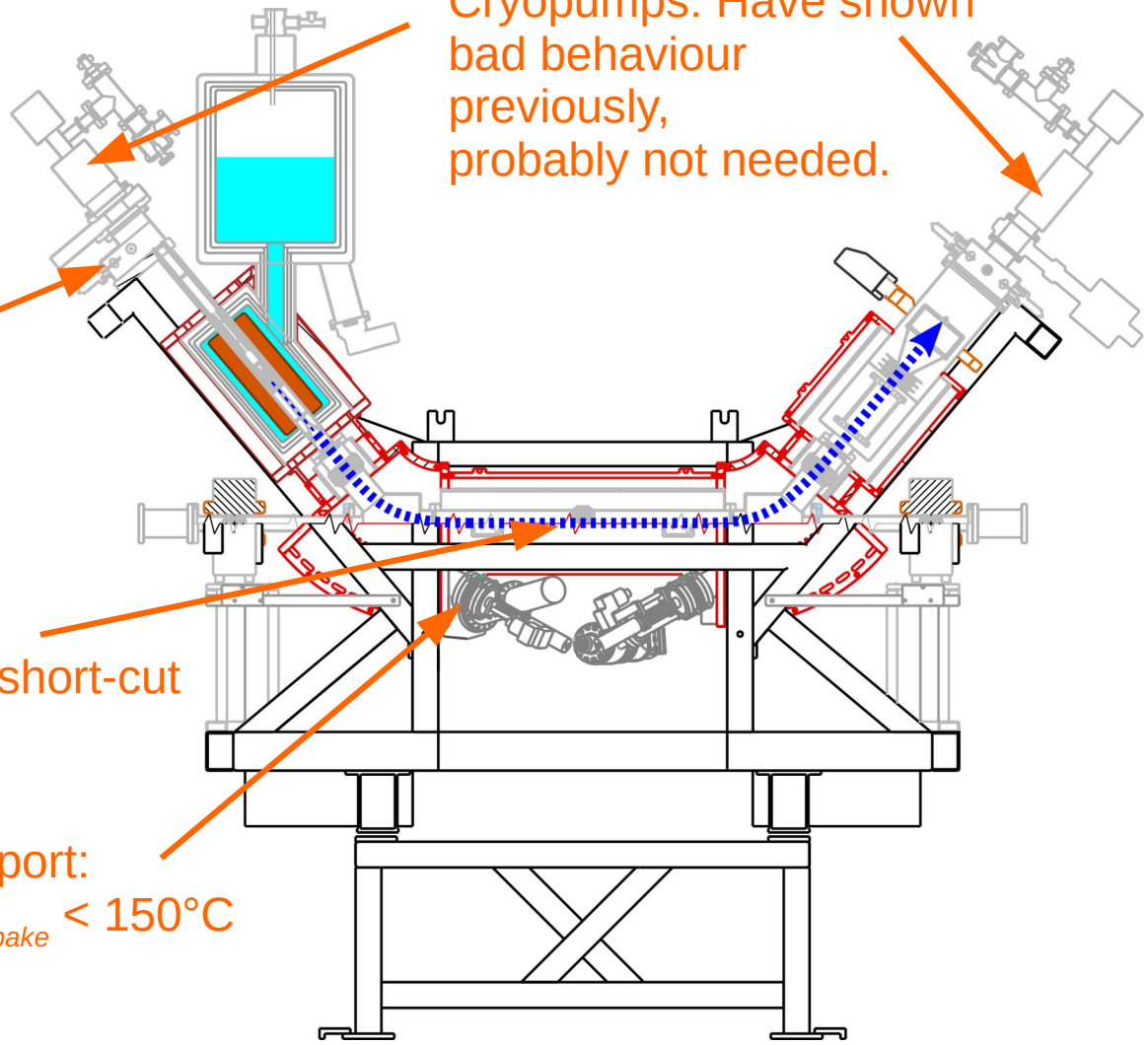

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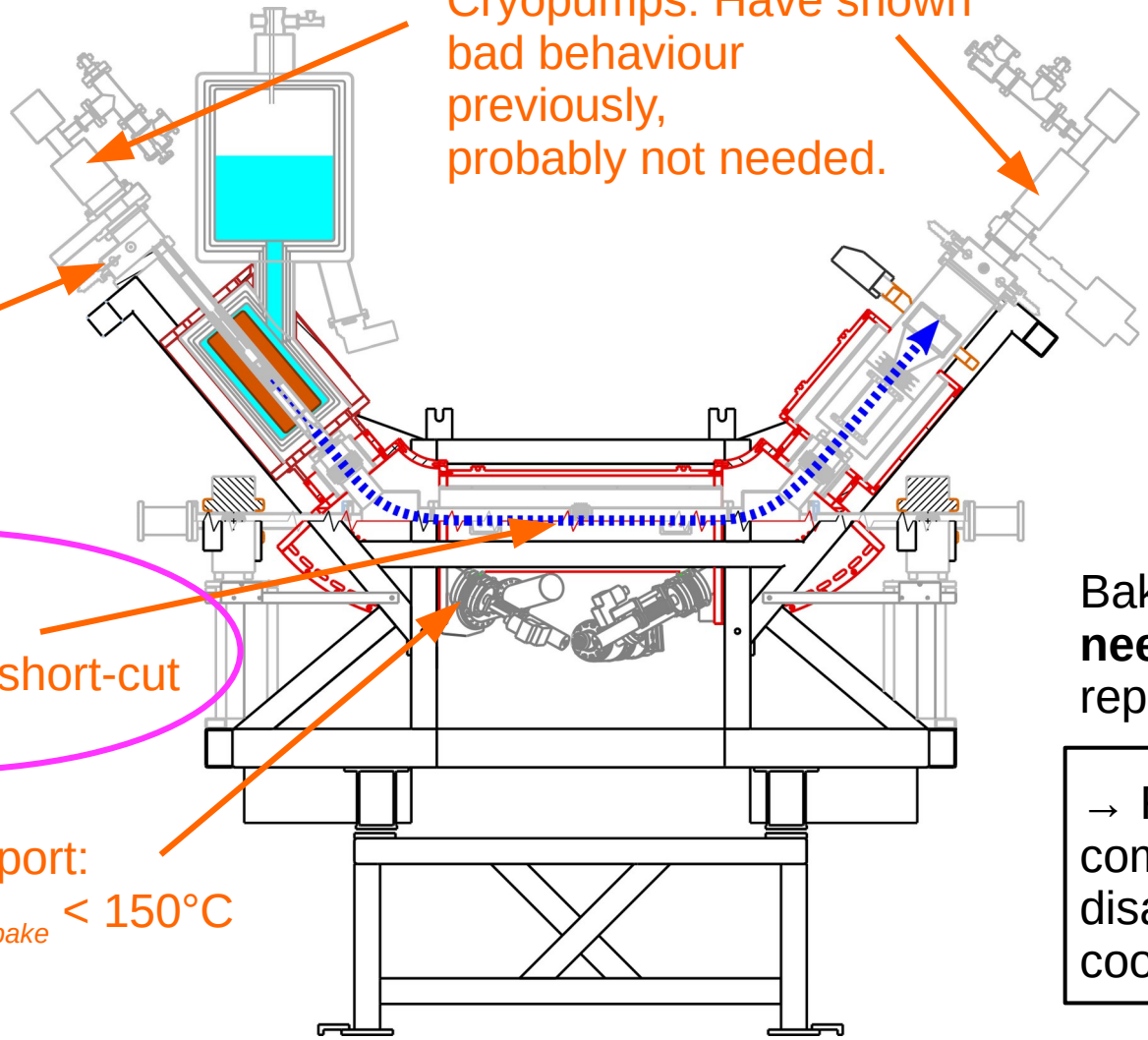


Cryopumps: Have shown bad behaviour previously, probably not needed.

Valve cryo-gun: broken, leaking (strongly)

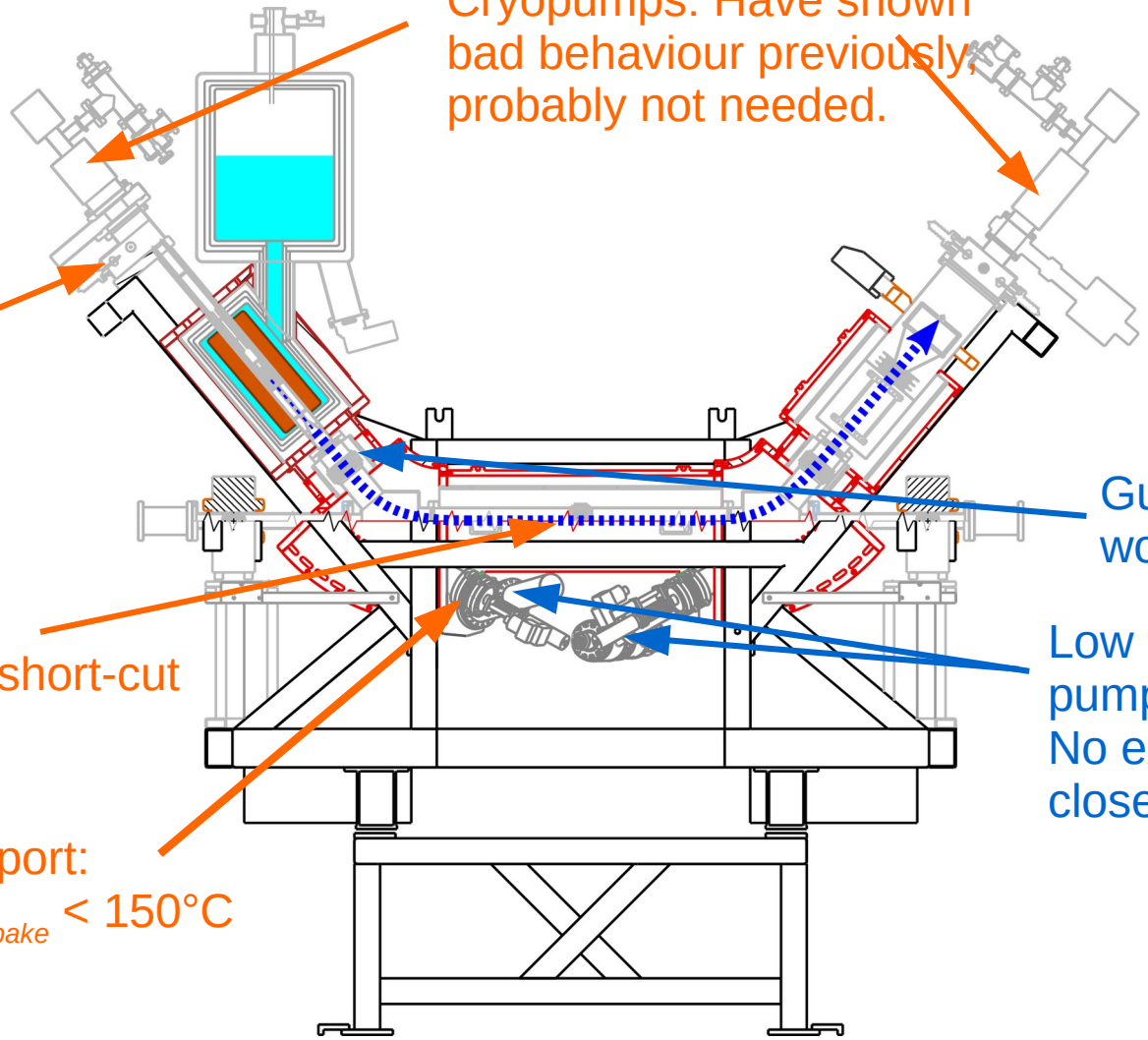
Cooler section: Bakeout jacket short-cut

CF16-viewport: Vacseal, $T_{bake}$ < 150°C

Bakeout heater **needs** to be repaired!

→ Requires almost complete disassembly of the cooler.

# Major issue: Vacuum



Cryopumps: Have shown bad behaviour previously, probably not needed.

Valve cryo-gun: broken, leaking (strongly)

Gun alignment not working properly.

Cooler section: Bakeout jacket short-cut

Low installed pumping speed. No extractor gauges close to ion beam.

CF16-viewport: Vacseal, $T_{bake}$ < 150°C

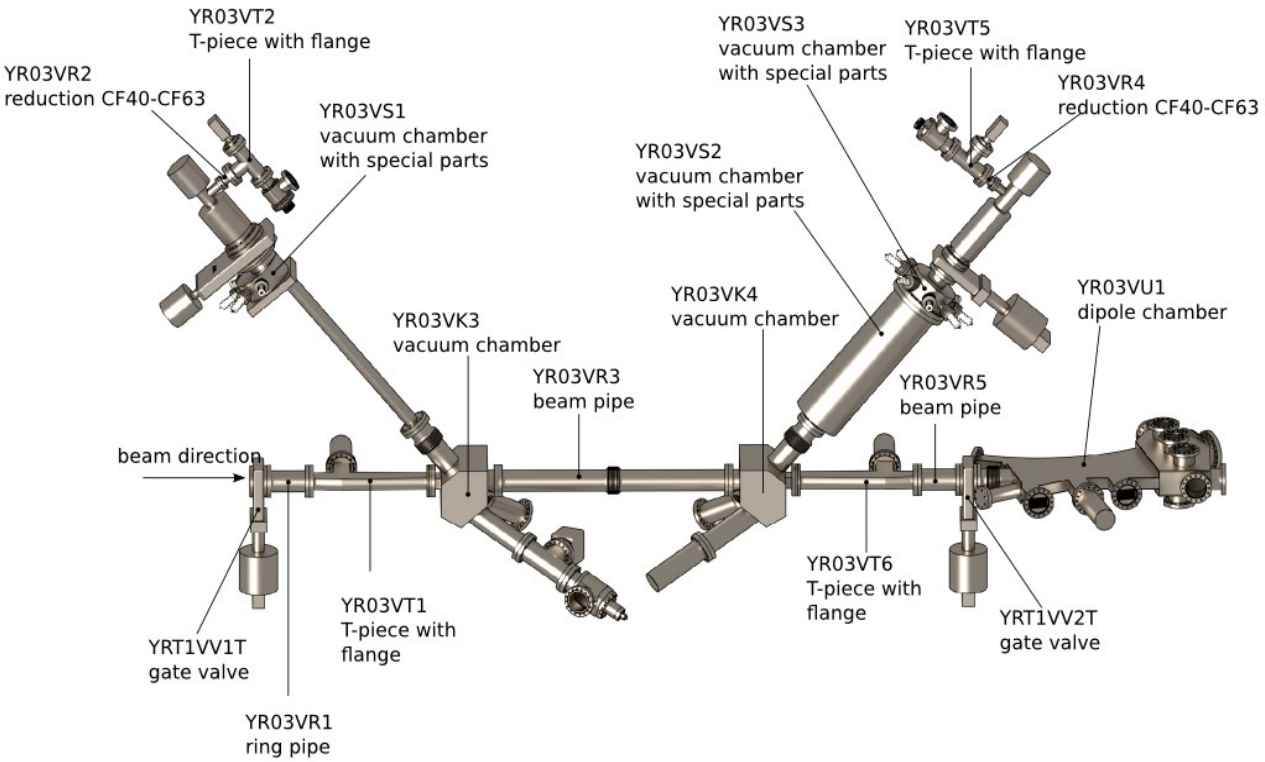
# Planned repairs in 2022/23 shutdown

Replace bakeout heating
in merged-beams section.

Repair viewport:
Vacseal → Welding

Exchange broken valve
cryopump - e-Gun

Replace cryopumps by
StarCell / NEG Units
(next slide)




***Additional improvements:***

Replace all bakeout heaters
(almost all are leaking current to ground).

Fix electron gun alignment.

Install larger ion-getter-pumps at toroid chambers.

Install extractor gauge close to merged-beams section.

# Planned repairs in 2022/23 shutdown

* Remove cooler from CRYRING.

* Unmount gun and collector chambers.

* Unmount gun and collector magnets.

* Disassemble toroid magnets.

* Remove toroid chambers.

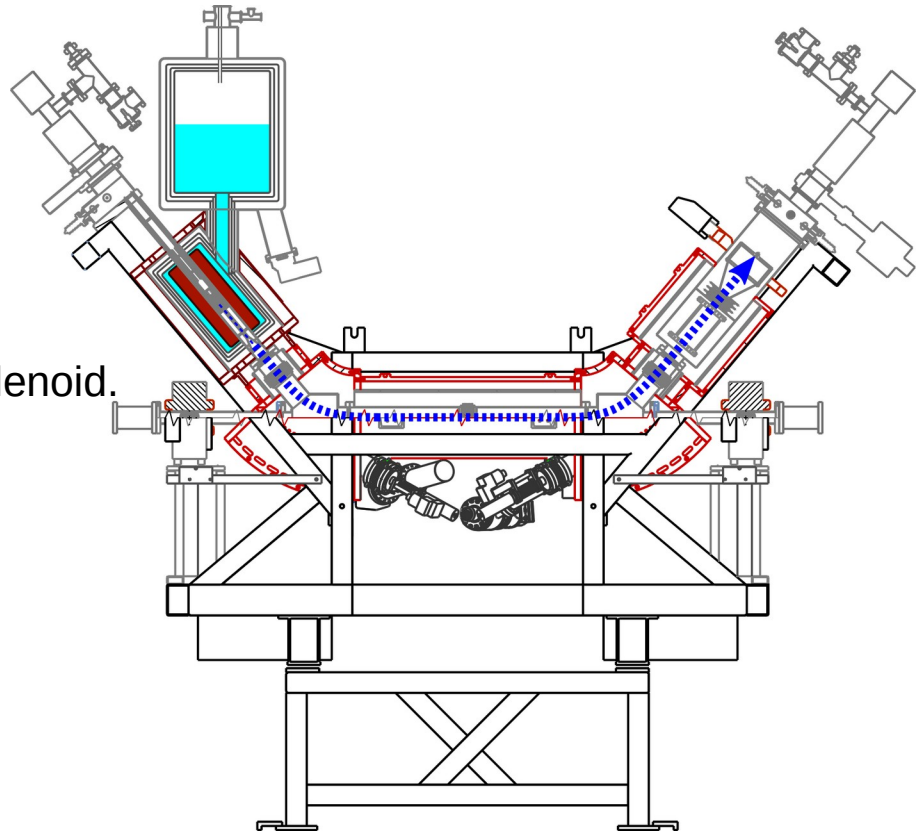
* Remove merged-beams pipe from cooler solenoid.

* Exchange bakeout heaters

* Repair leak at viewport.

* Repair gun alignment.

* … re-assemble everything ...



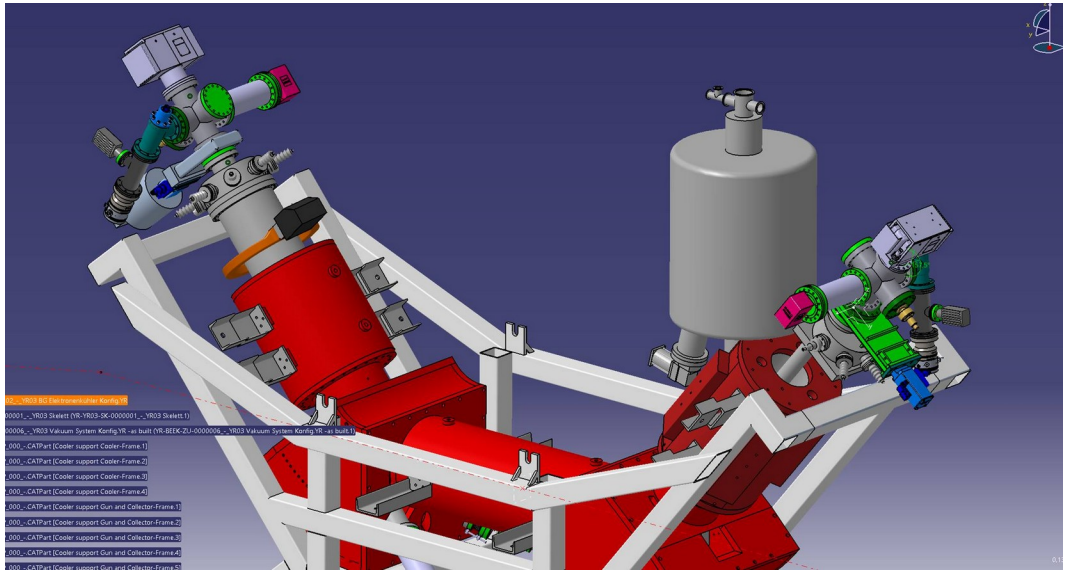
# Planned repairs in 2022/23 shutdown

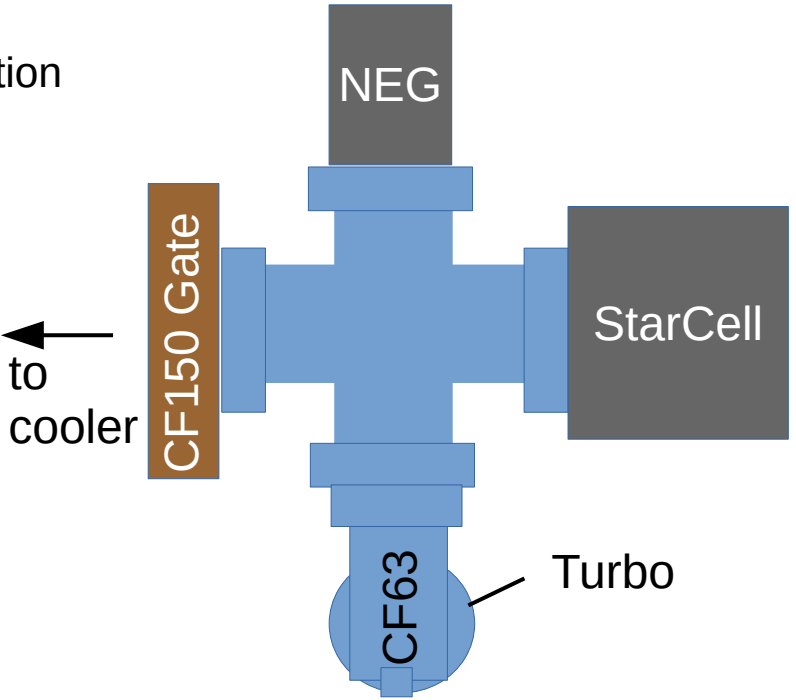
***Replace cryopumps by ion-getter / NEG units***

*One pumping unit at gun and collector, respectively, including*

* StarCell 75
* SAES NEG module
* turbo-pump for independent bakeout + NEG activation

(inspired by MPIK cooler which had a similarly small cathode)



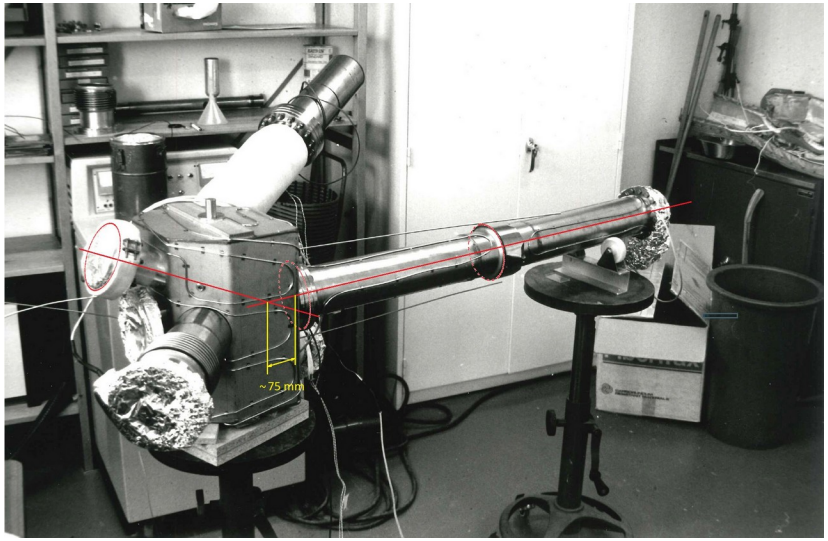


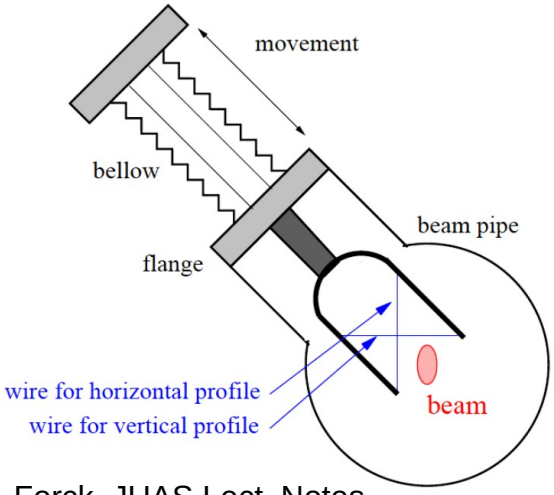
# Further possible upgrades (post-2023?)

**Wire scanners as electron beam diagnostics**

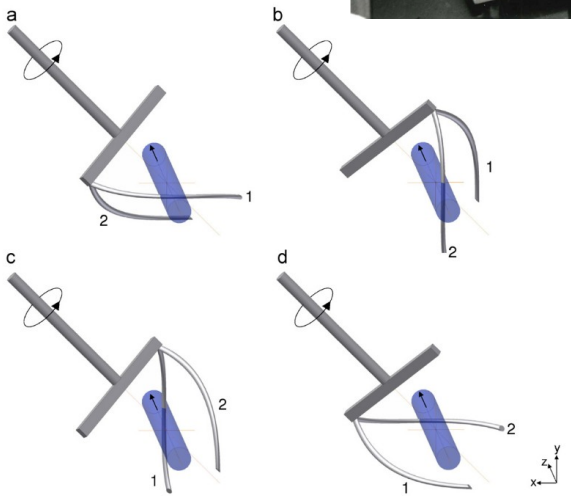
→ Provide information about transverse e-current distribution.

→ Recently „rediscovered“ ports at toroid chambers may be a possibility for installation.




Forck, JUAS Lect. Notes



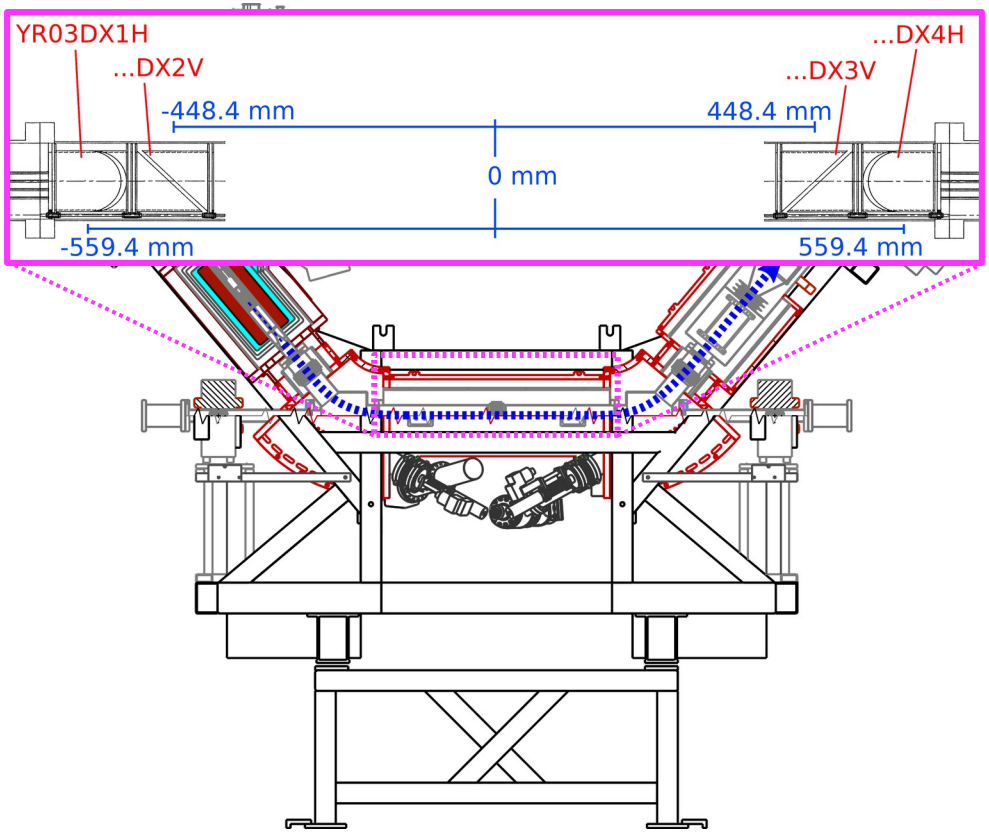

Seely, NIM A 585 (2008) 69

# Further possible upgrades (post-2023?)

***Install drift-tube in-between BPMs***

BPMs reduce the clear aperture of the cooler section from 10 cm to ~ 7.7 cm.

→ Requires a bias voltage to be applied to the BPMs to correct for changes in e-beam space charge.



# Further possible upgrades (post-2023?)

***Install drift-tube in-between BPMs***

BPMs reduce the clear aperture of the cooler section from 10 cm to ~ 7.7 cm.

→ Requires a bias voltage to be applied to the BPMs to correct for changes in e-beam space charge.

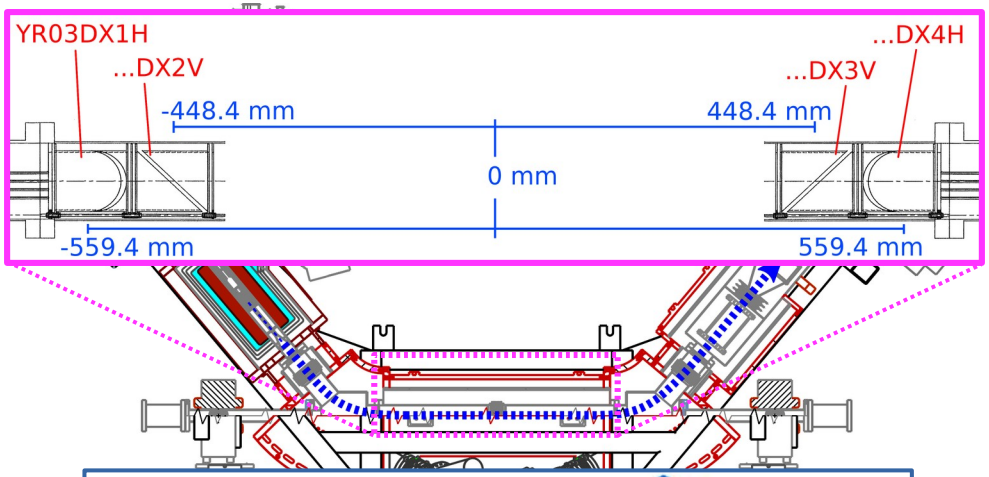
Idea:

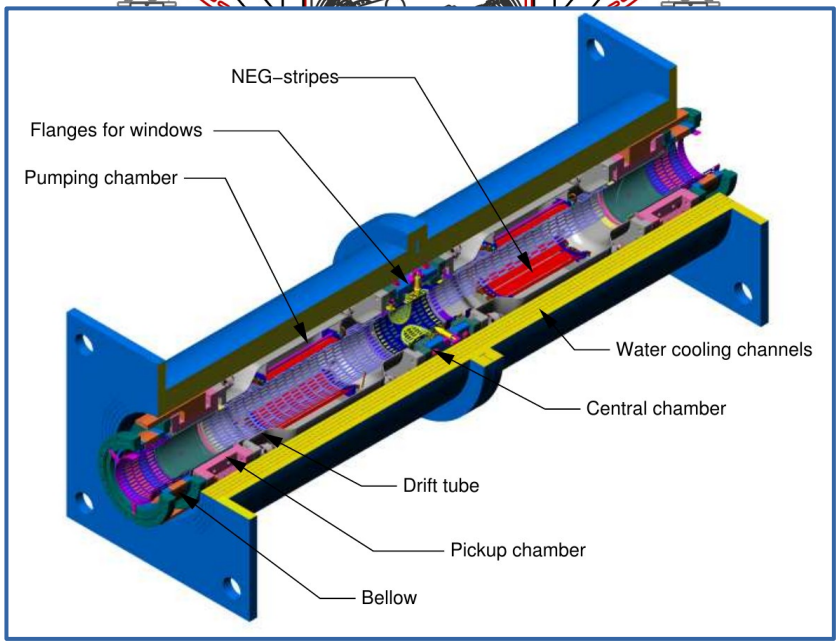
Fill up the space in-between the BPMs by a drift tube electrode (equal diameter).

→ Makes s.c. correction obsolete.

→ Allows the beam pipe to be NEG-coated

→ If floatable to HV:
* Additional means for energy variation.
* Allows higher current at low energies („*effective perveance*“).




Sprenger, PhD, Heidelberg, 2003

# Further possible upgrades (post-2023)

***Design and purchase a new superconducting gun magnet***

Present magnet works, but ...

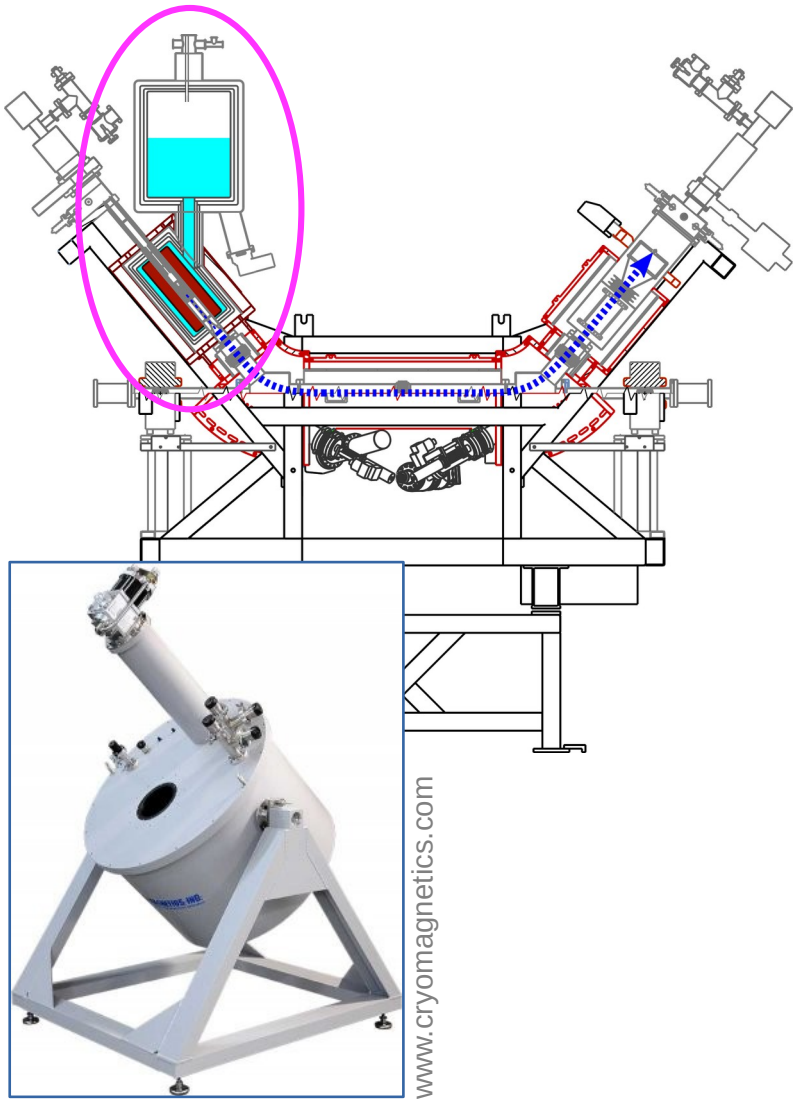
… high cost of operation (money, resources).

… never reached its design field.

… ordering a new magnet takes very long.

Crogen-free superconducting magnet systems are now available!

(HT superconductors + pulse-tube coolers)



# Thank you!

Z. Andelkovic, C. Dimopoulou, W. Geithner, T. Hackler,
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*(Uni Münster)*