MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

The Cryogenic Storage Ring CSR: Stored and cooled ions in a 10 K environment

Claude Krantz

Max Planck Institute for Nuclear Physics

The Cryogenic Storage Ring **CSR**

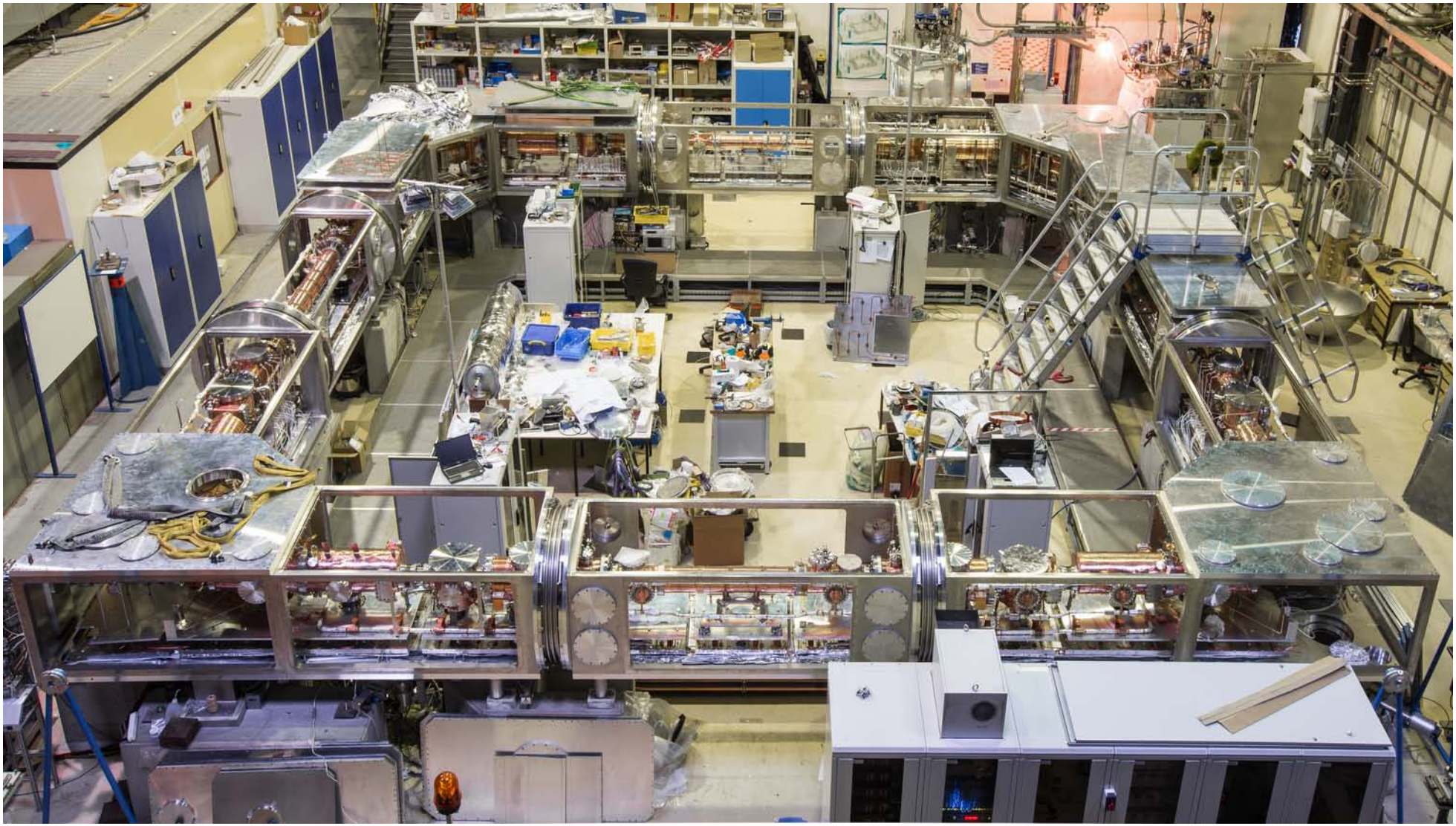
Status of the CSR

Electron **Cooler**

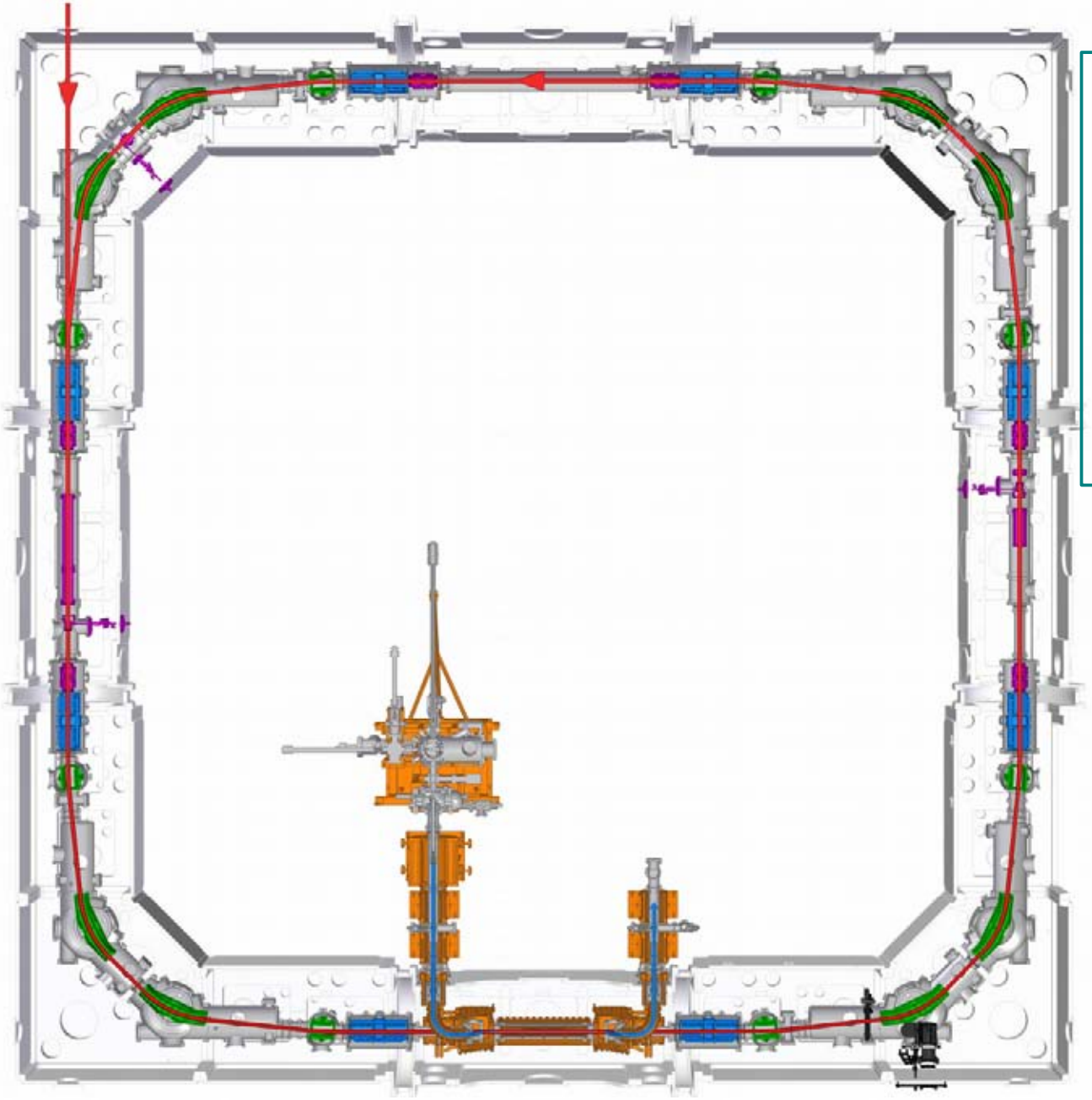
(Some) experimental **perspectives**

The CSR

The CSR



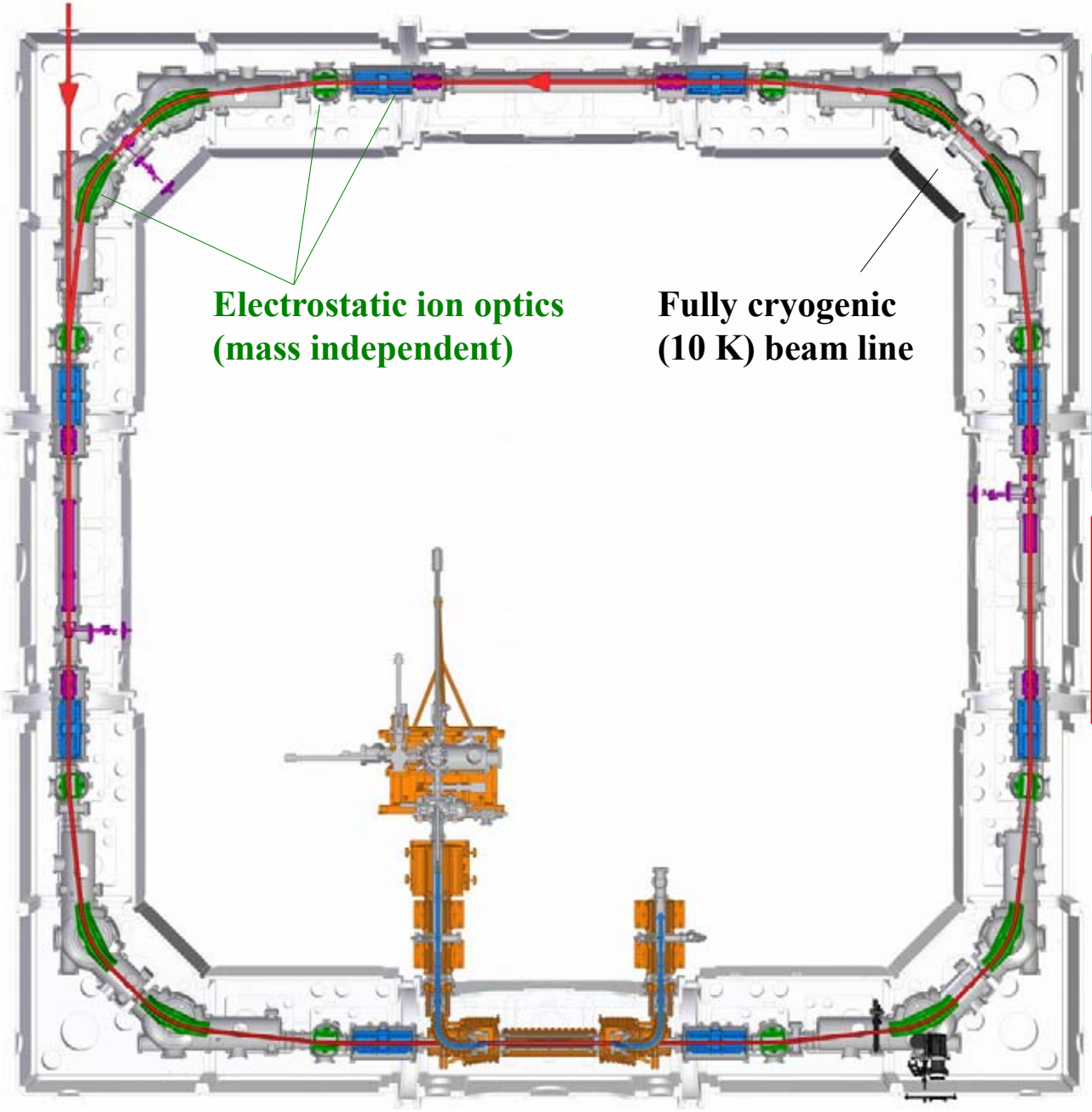
The CSR



circumference:	**35 m**
beam energy:	**20 keV × q ...** **300 keV × q**
temperature:	**10 … 300 K**
res. gas press. (@ < 10 K):	**10^{-13} mbar** **(~ 1000 cm^{-3})**

The CSR

injection energy: 20 … 300 keV



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lowest rigidity	**p^+, H^-** **@ 20 keV**

The CSR

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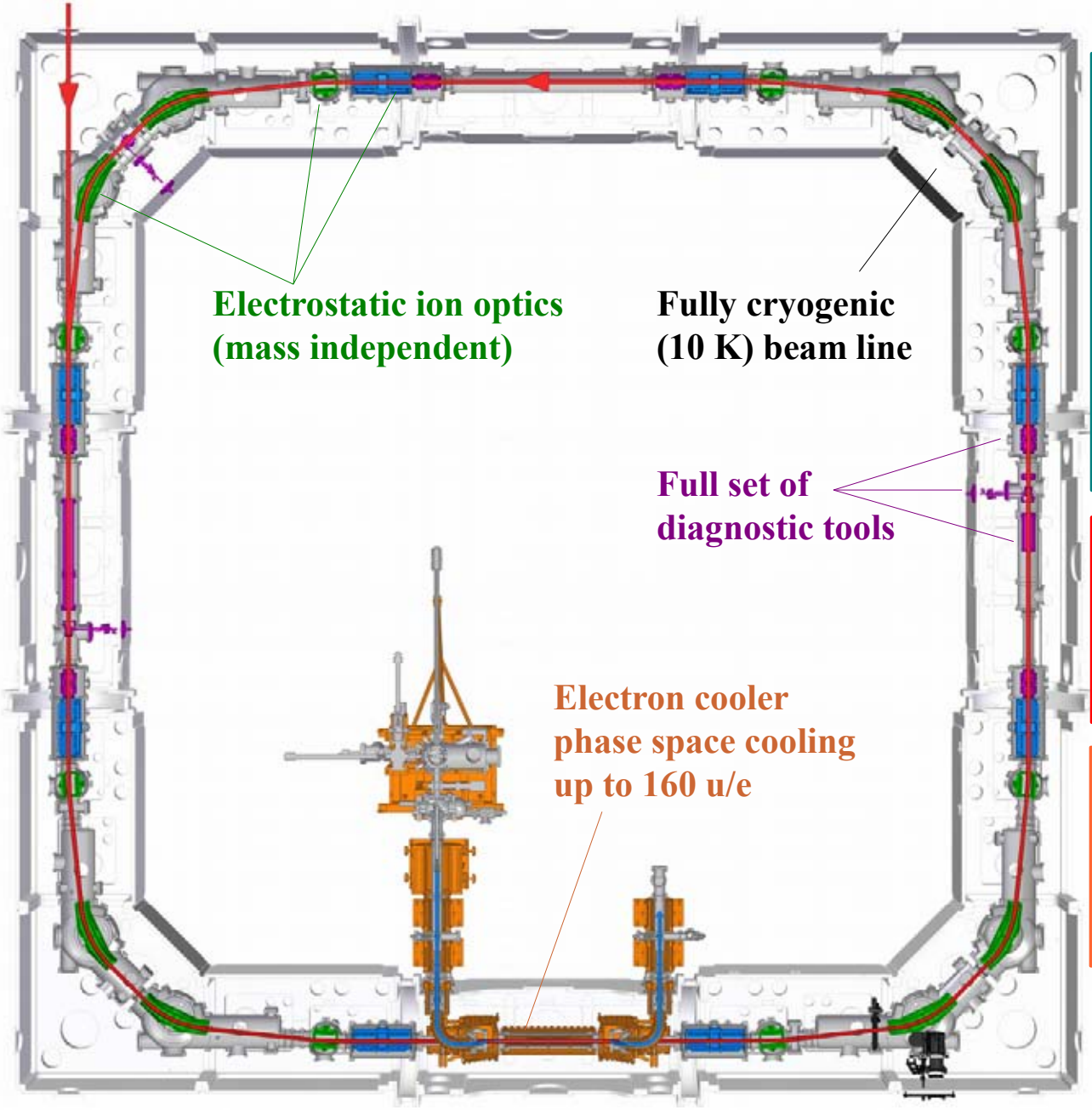

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res. gas press. (@ < 10 K):	**10^{-13} mbar** **(~ 1000 cm^{-3})**

m/q range:	**1 ... "∞" u/e**
lowest rigidity	**p^+, H^-** **@ 20 keV**

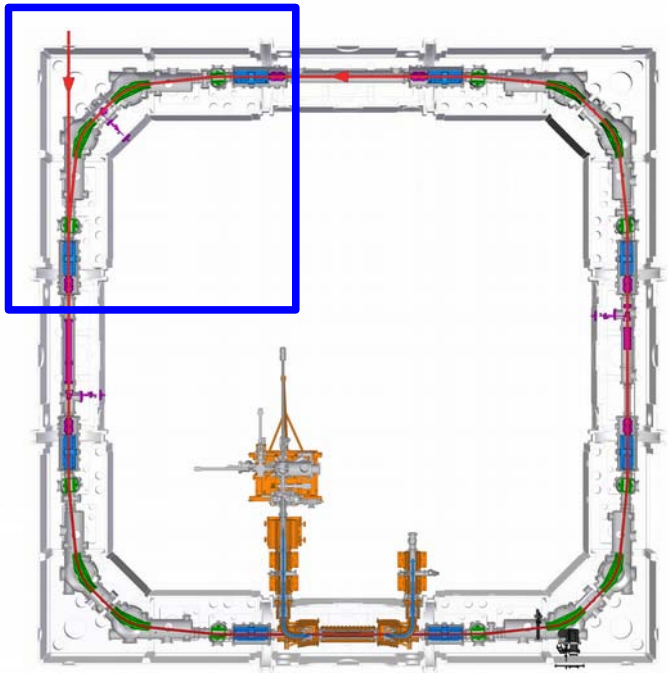
... with electron cooling

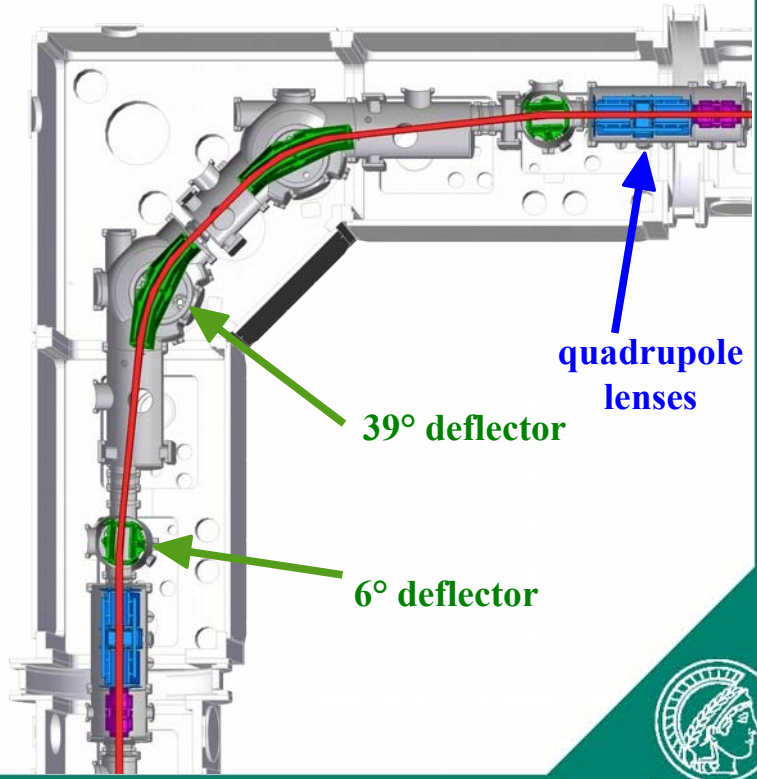
m/q range:	**1 ... 160 u/e** **(@ 300 kV)**
lowest rigidity	**p^+, H^-** **@ 20 keV**

The CSR

Electrostatic beam optics

- 4-fold symmetric storage ring
  All CSR corner sections identical
- 4 x 2 pairs of **focussing quadrupoles**
- 4 x 2 **6°-deflector** electrodes (20 kV)
- 4 x 2 **39°-deflector** electrodes (20 kV)
- 4 free straight sections (2.4 m each)





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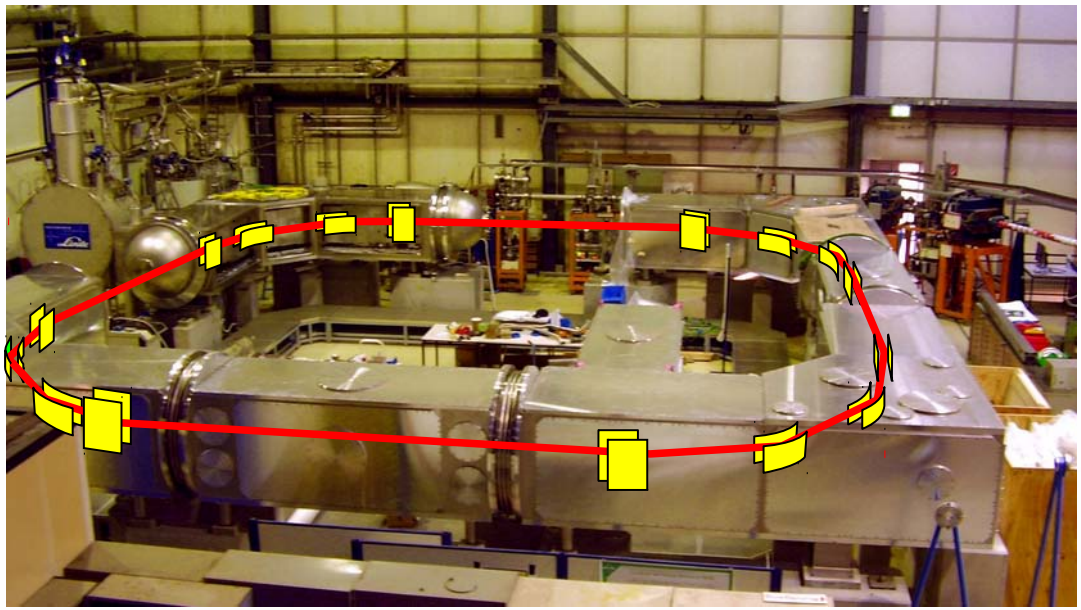
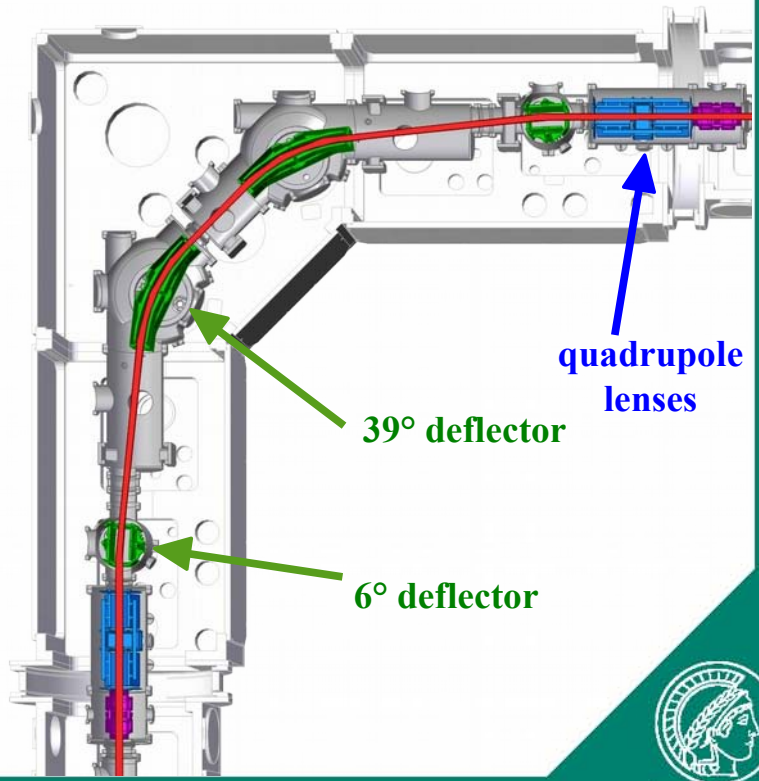
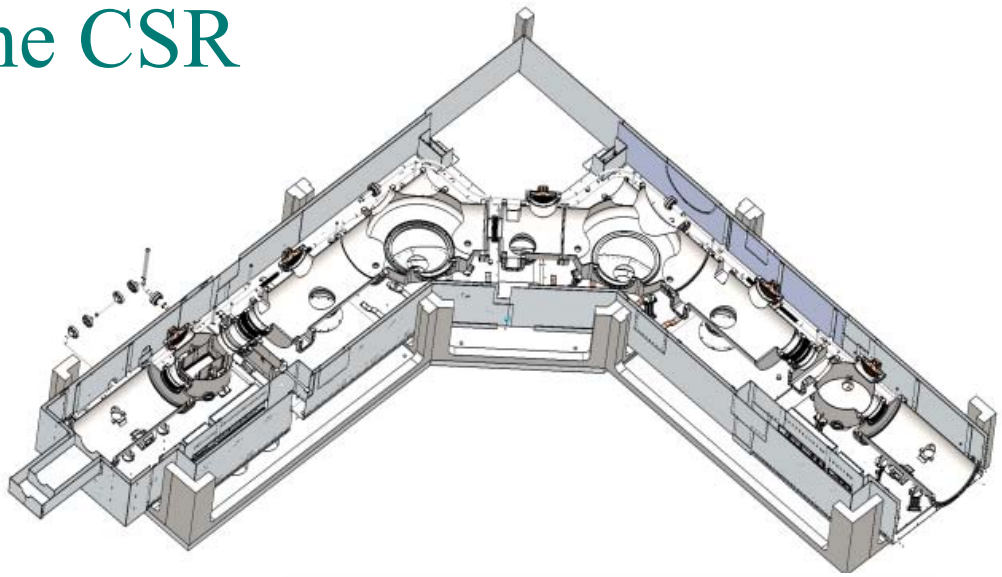


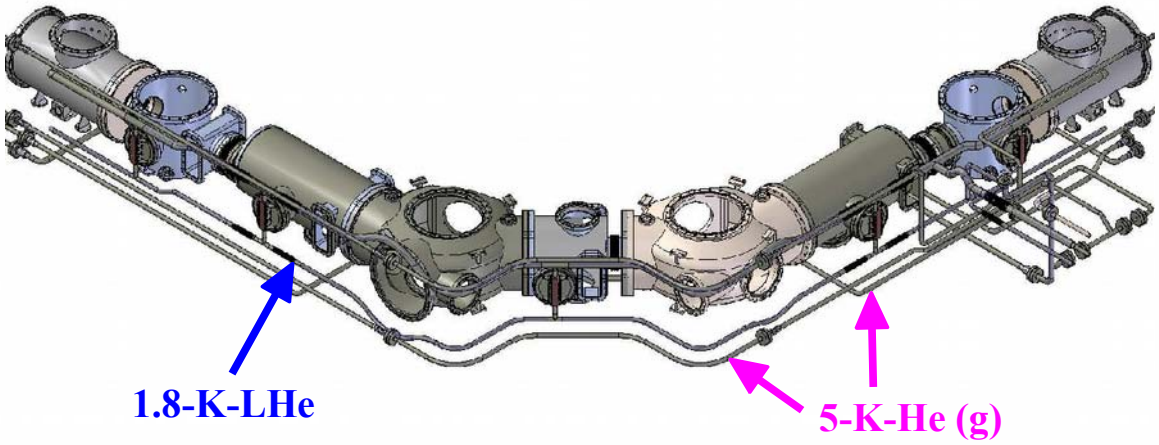


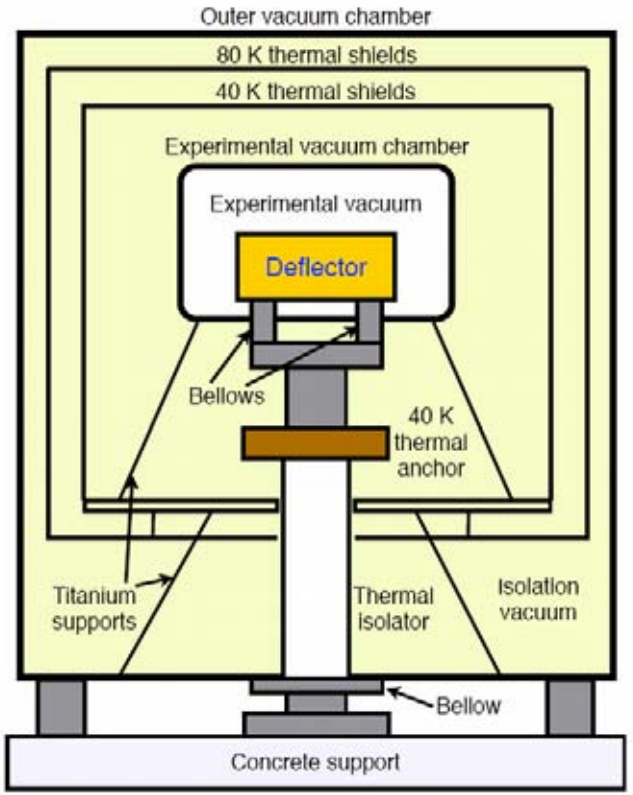
The CSR

Cryogenics

- Multi-layer cryostat
- Inner vacuum chamber (≤ 10 K)
  cooled by superfluid He (20 W).
- 2 radiation shields (40 and 80 K)
  cooled by 5-K He (600 W)
- Superinsulation
- Isolation vacuum chamber







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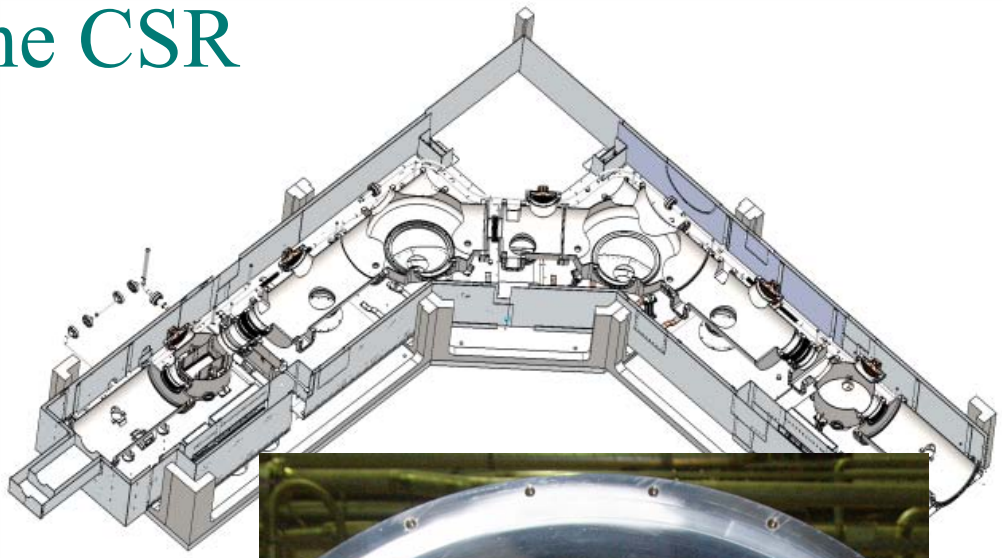
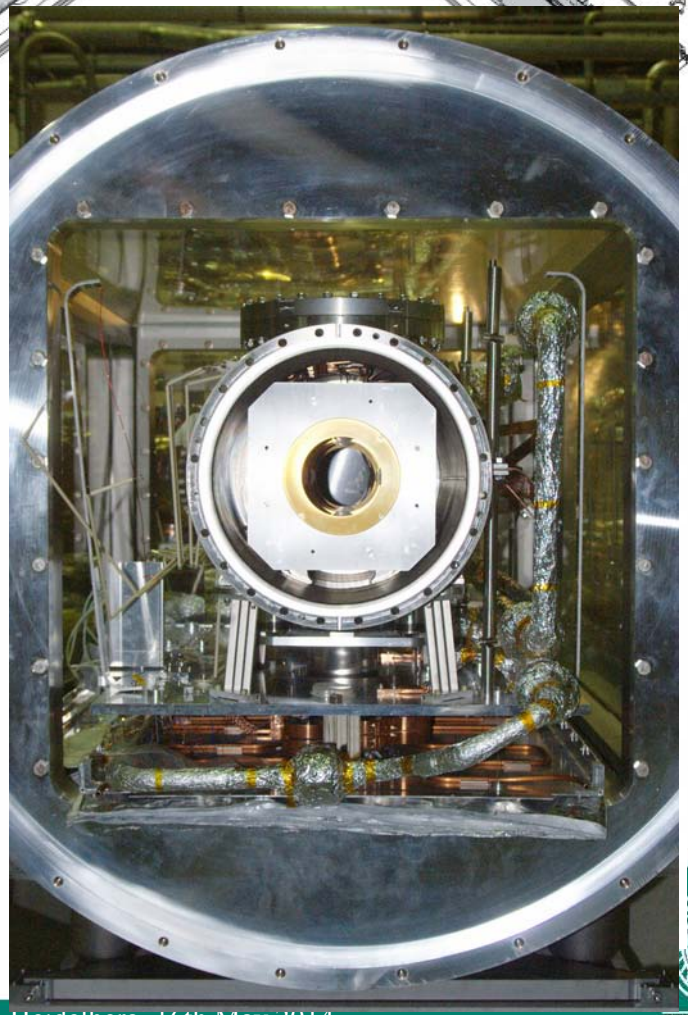
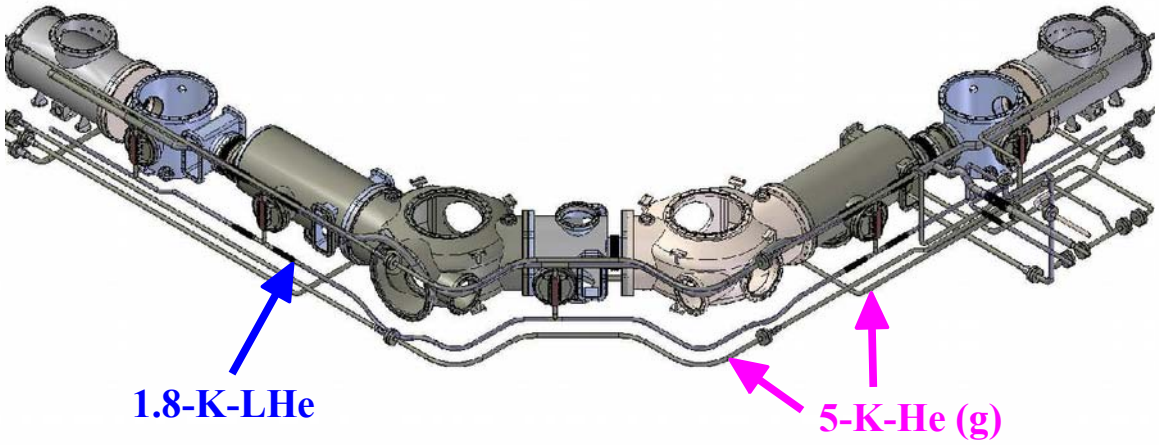


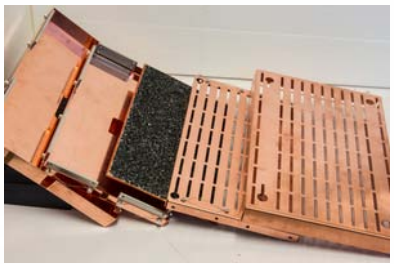


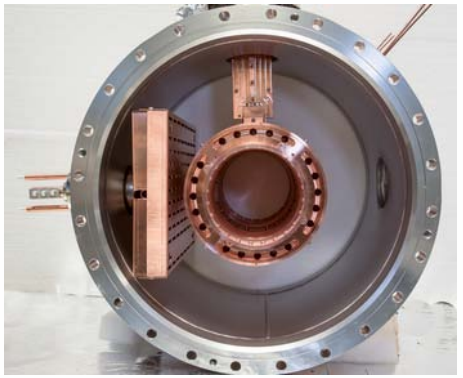


The CSR

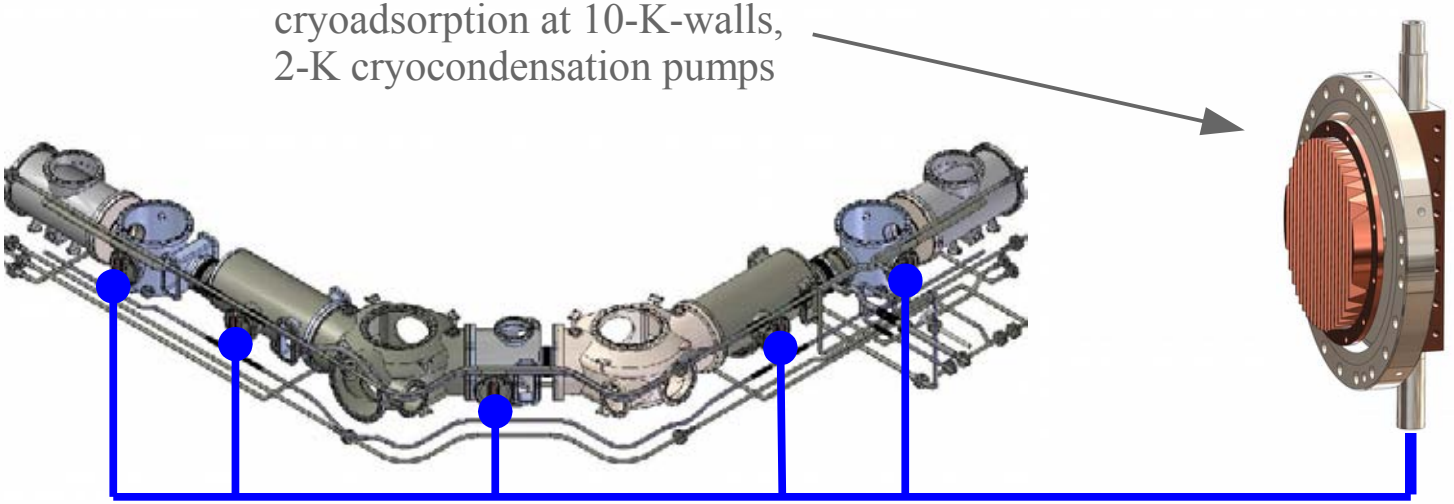
XHV: Extremely High Vacuum

- In 300-K-operation: **~ 10^{-11} mbar**
  250°C bakeout,
  Ion-getter pumps,
  NEG surfaces,
  bakeable charcoal cryopumps

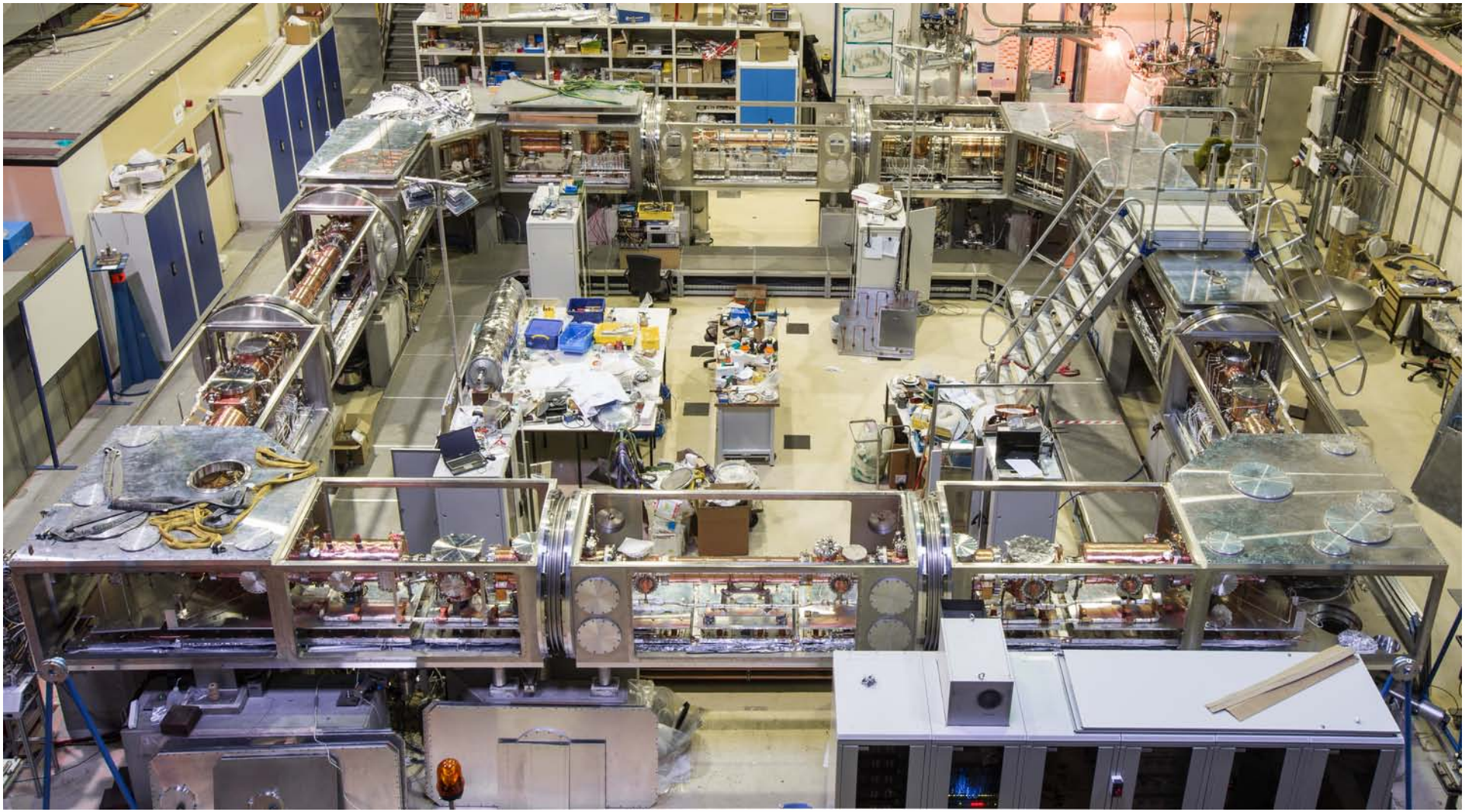




- In < 10-K-operation: **≈ 10^{-13} mbar RTE**
  cryoadsorption at 10-K-walls,
  2-K cryocondensation pumps

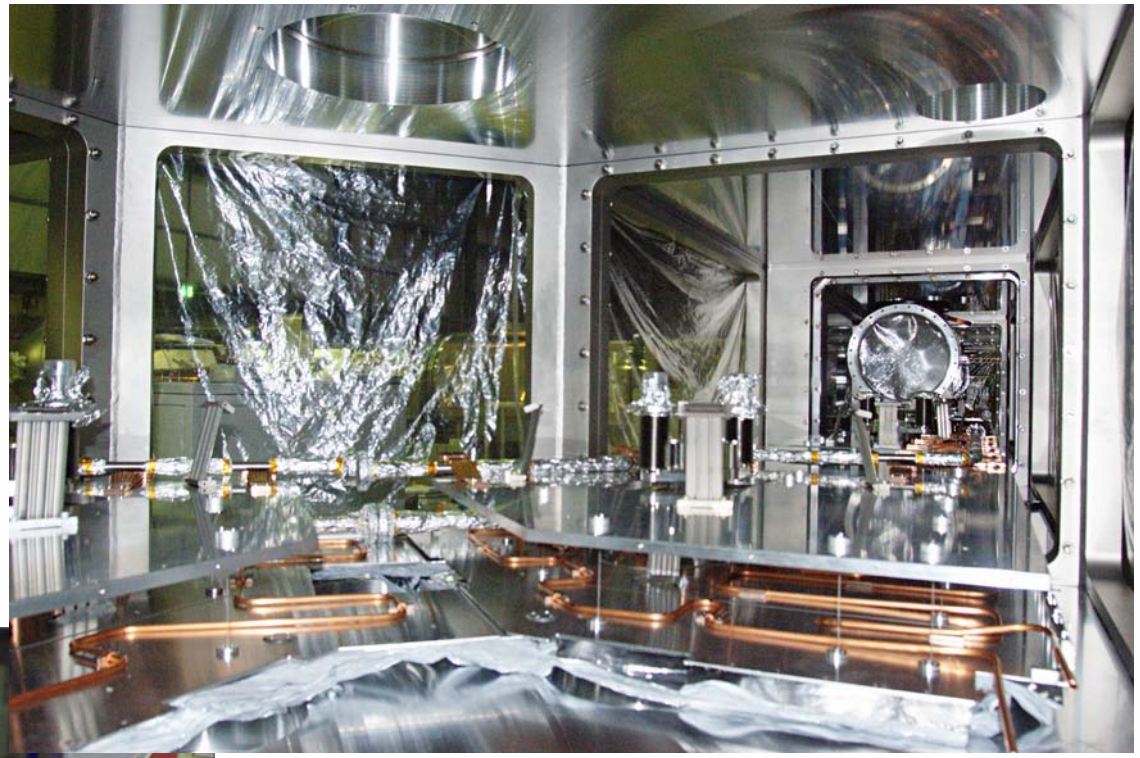


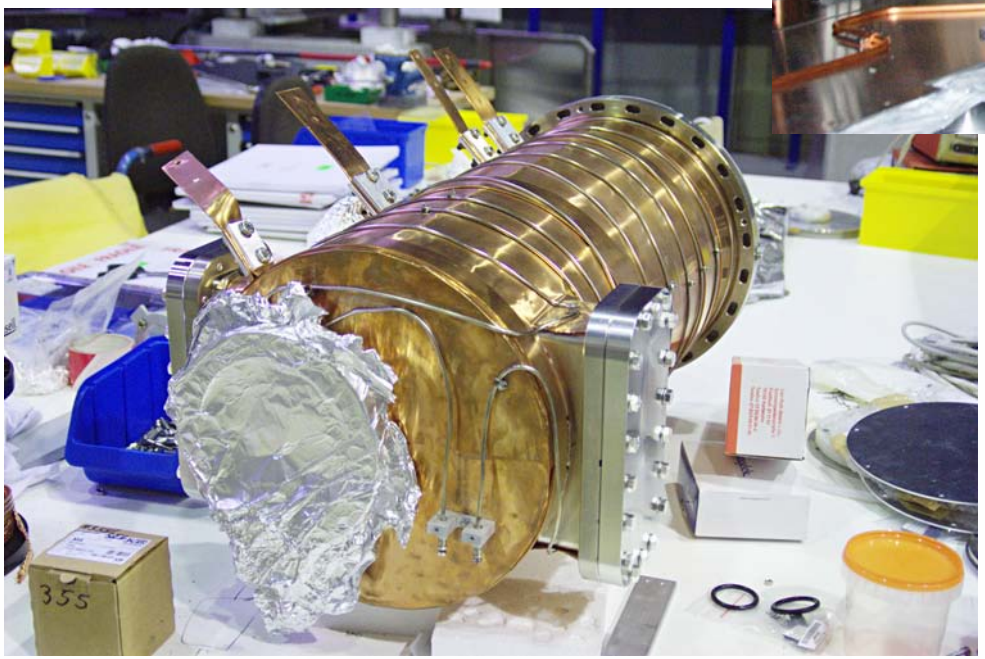
Present Status



Present Status

Assembly of **inner chambers and ion optics.**





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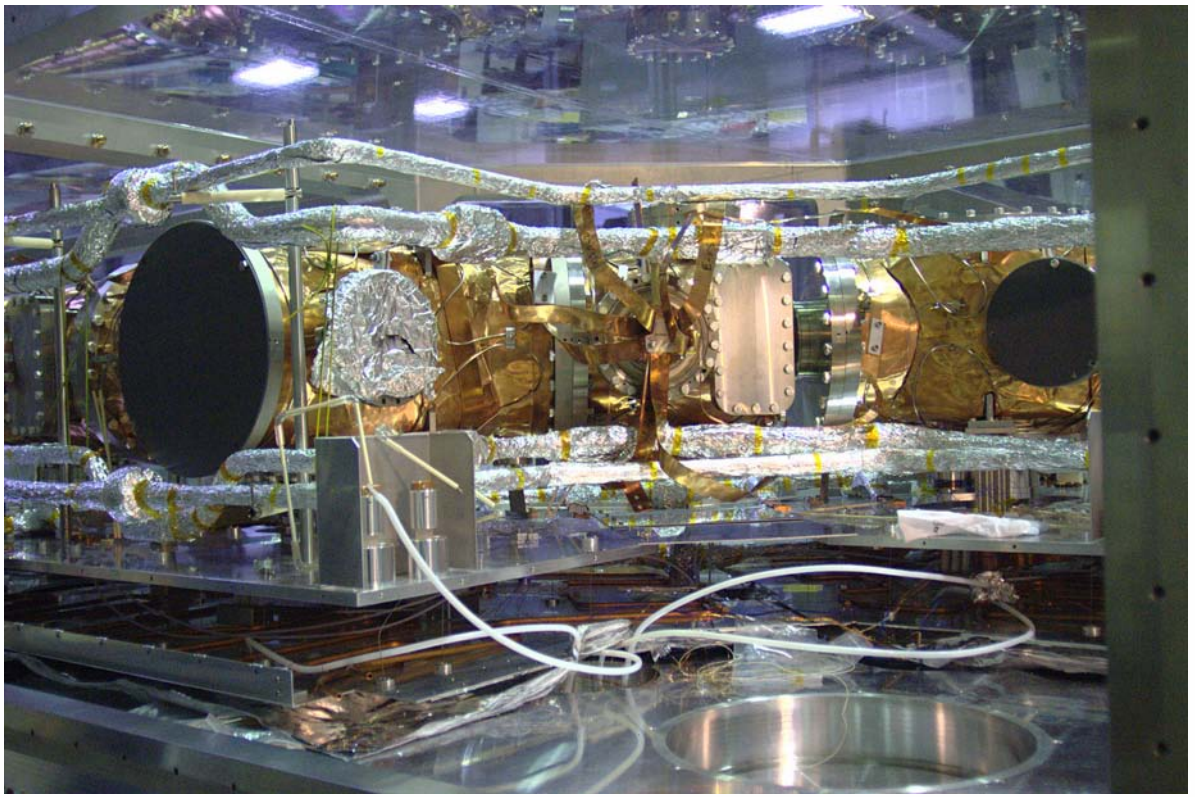

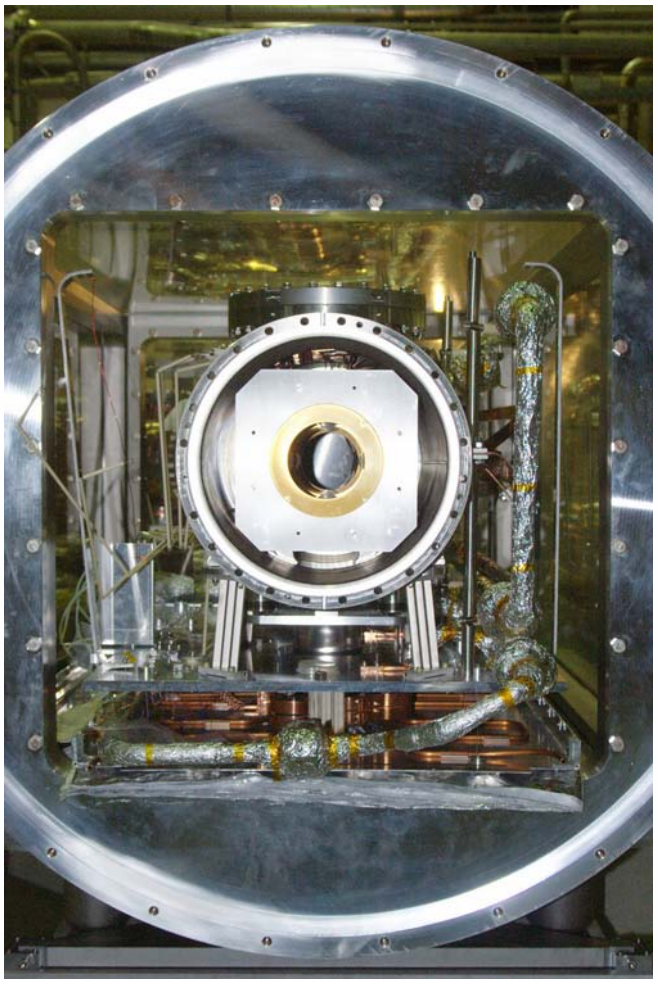

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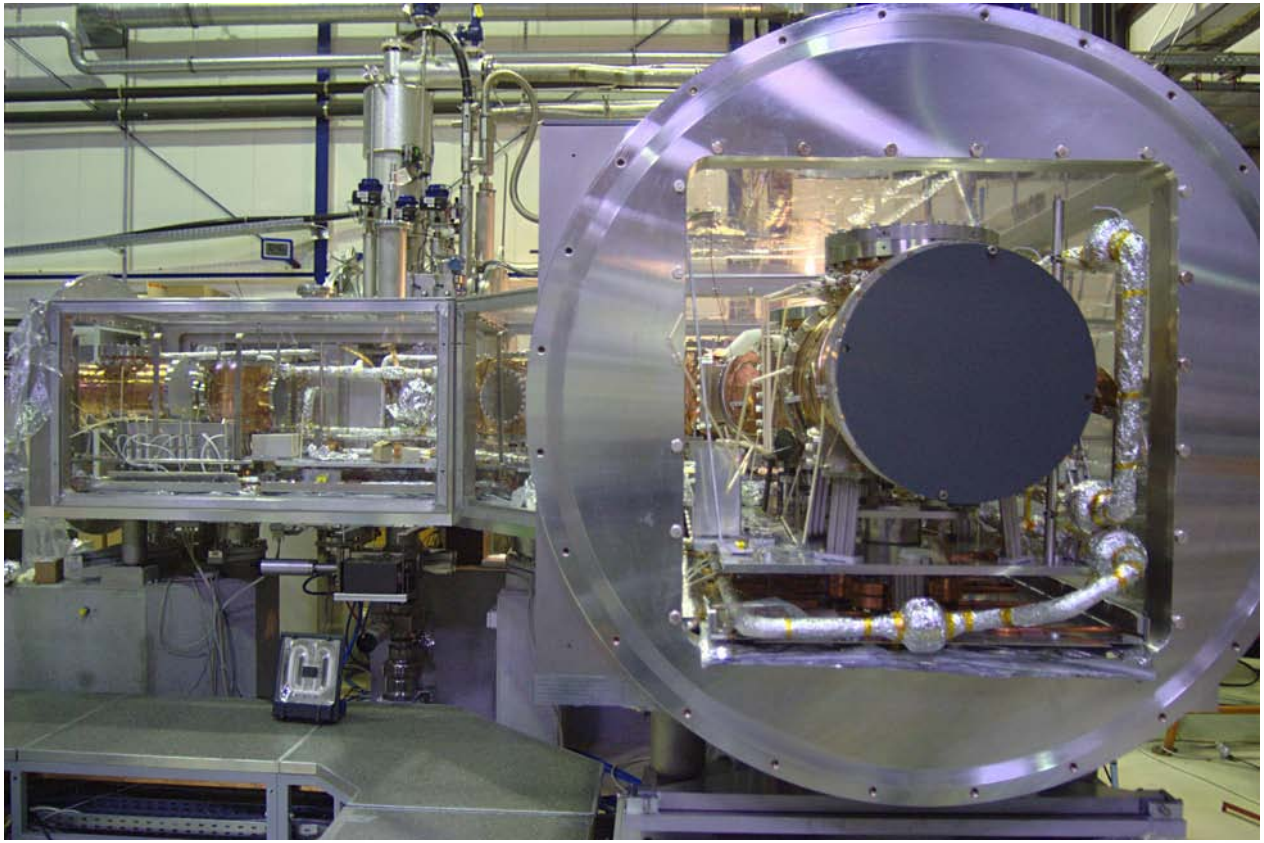

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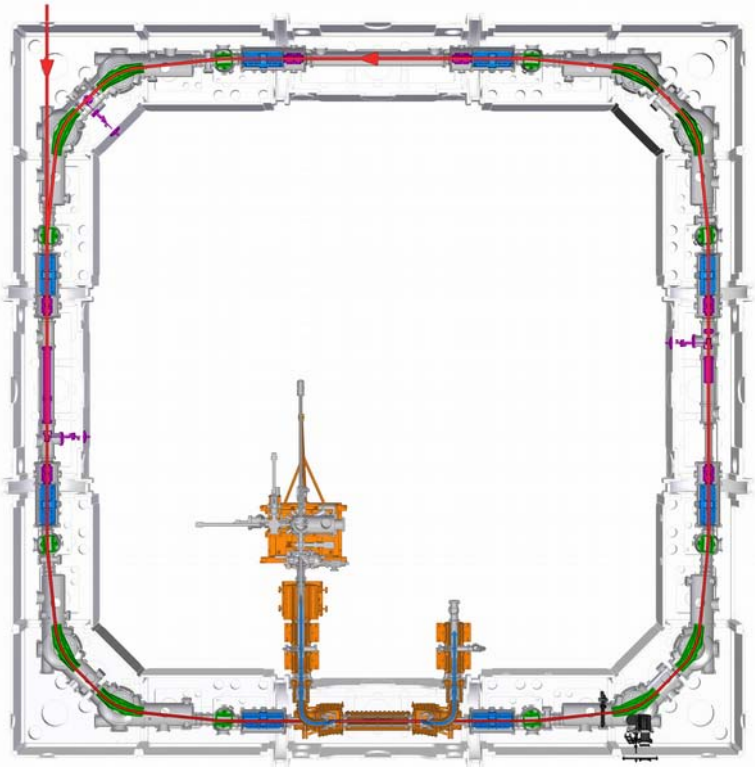

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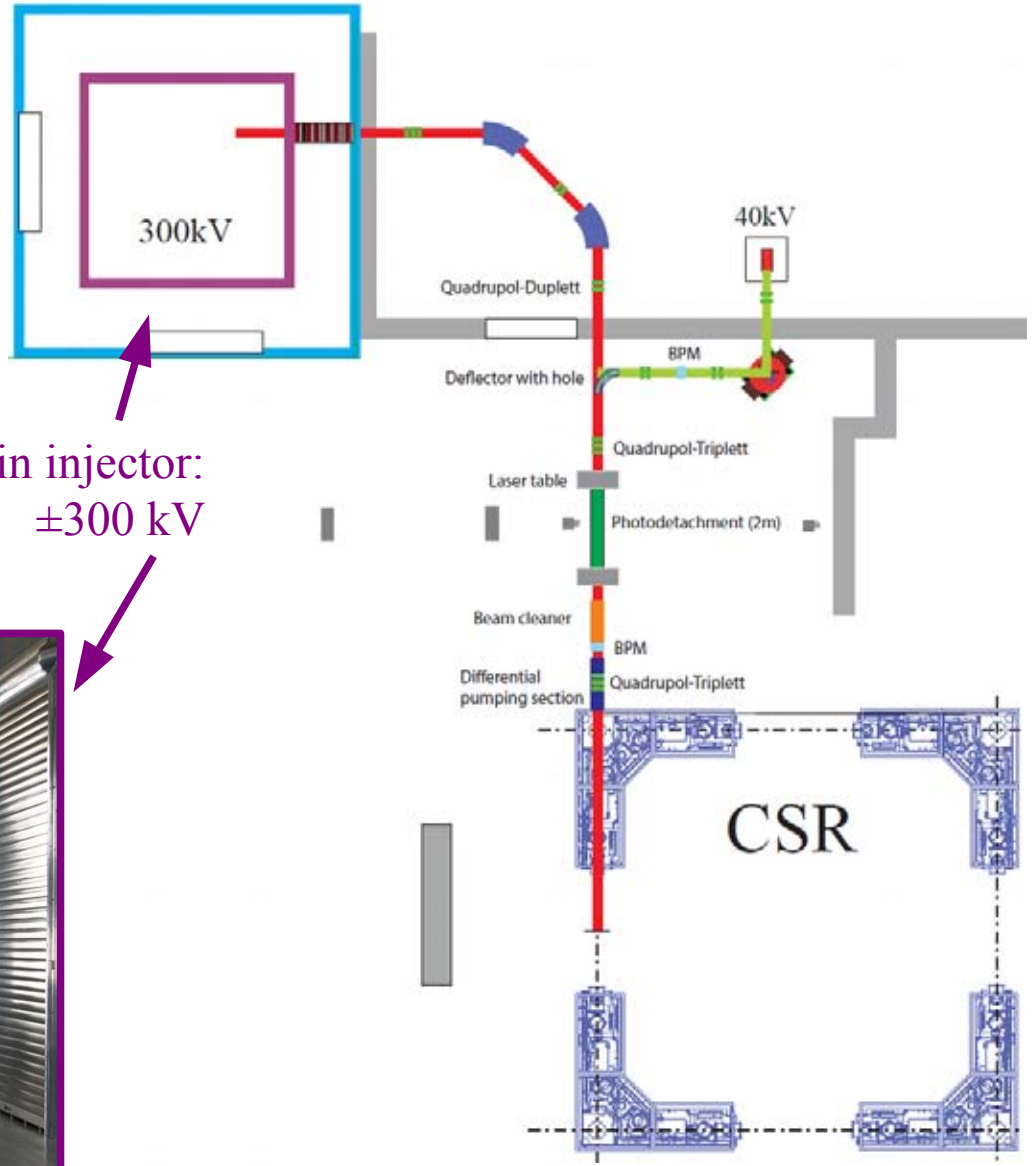

CSR main injector: ±300 kV

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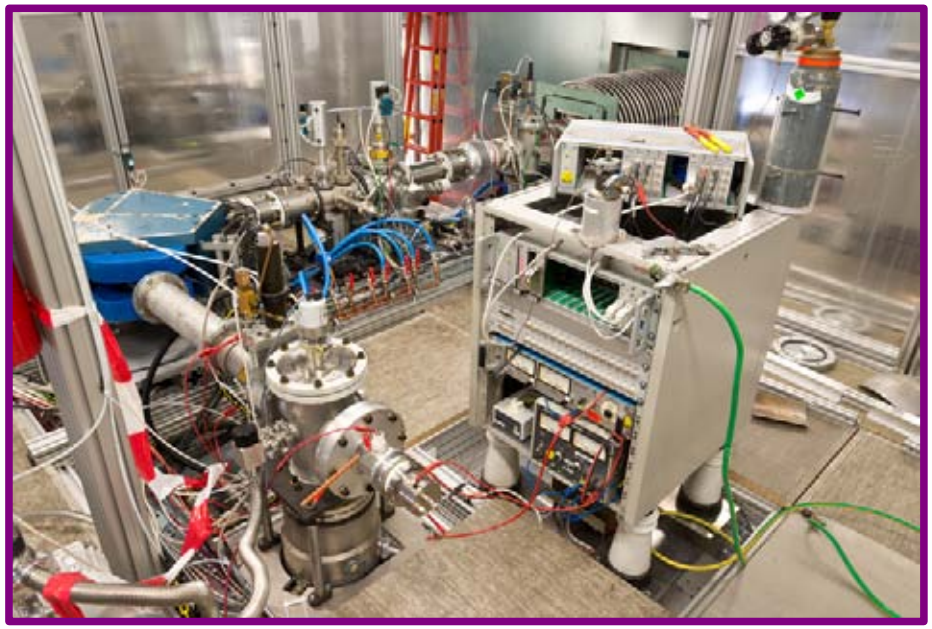

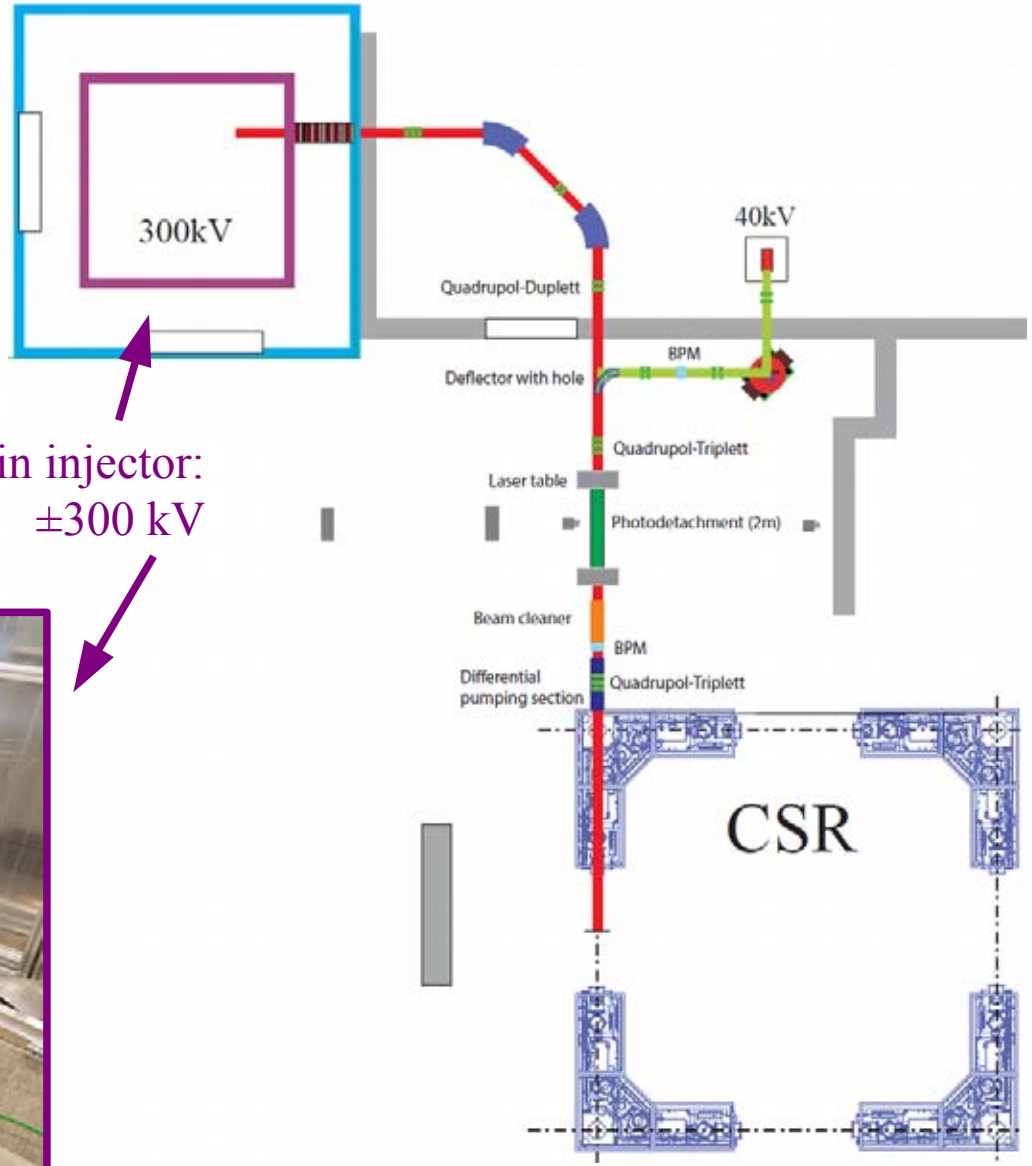

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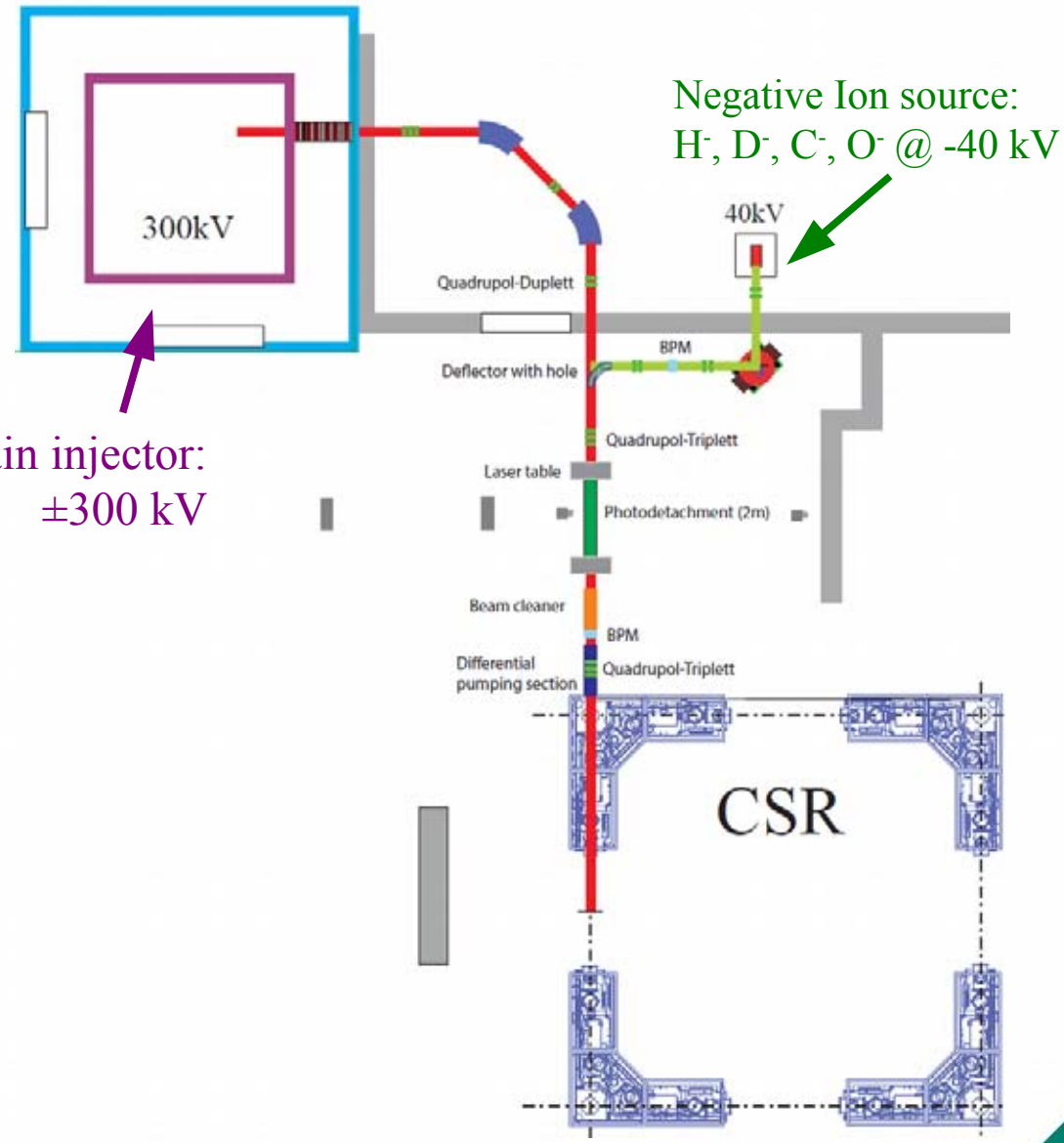

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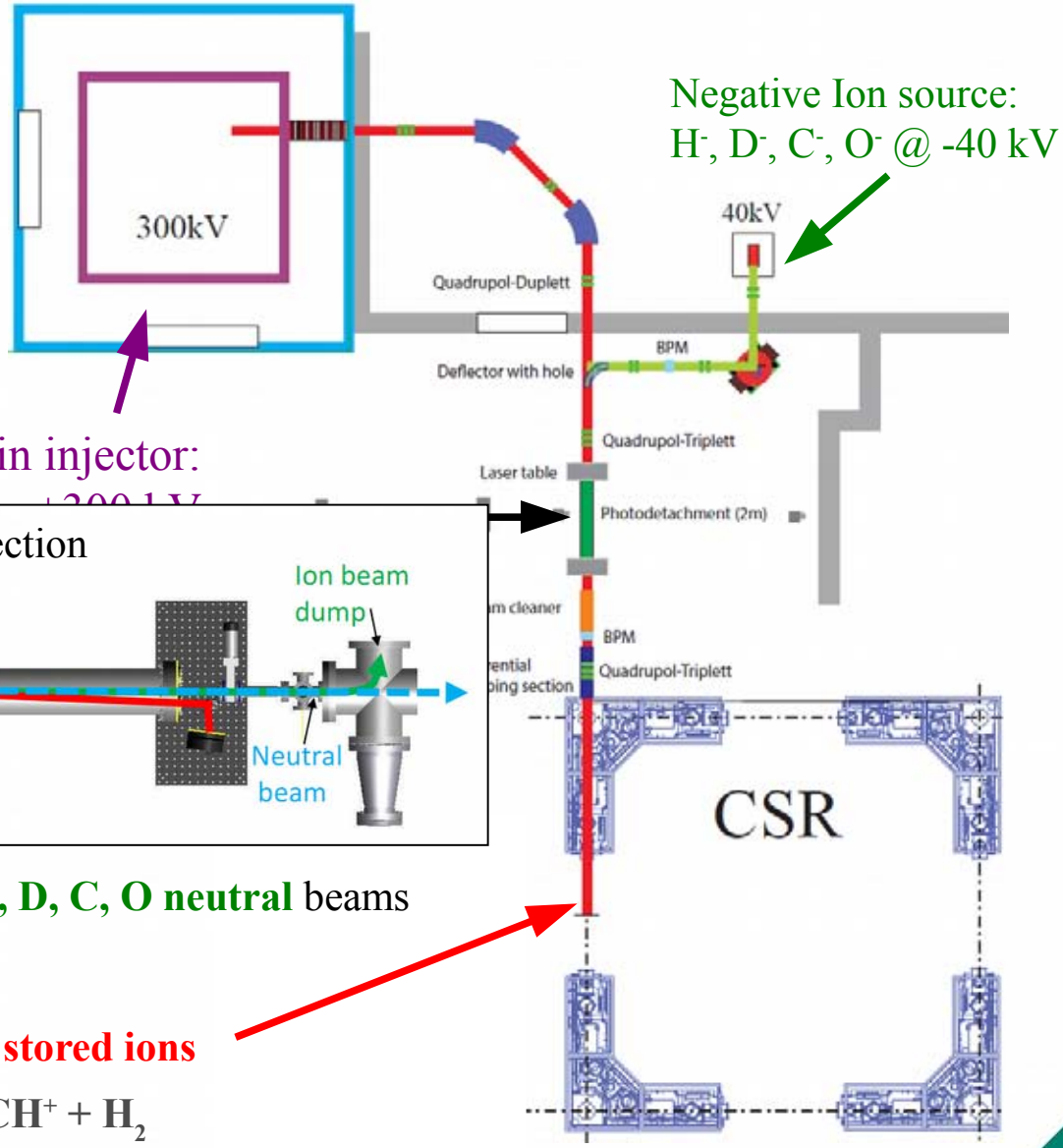
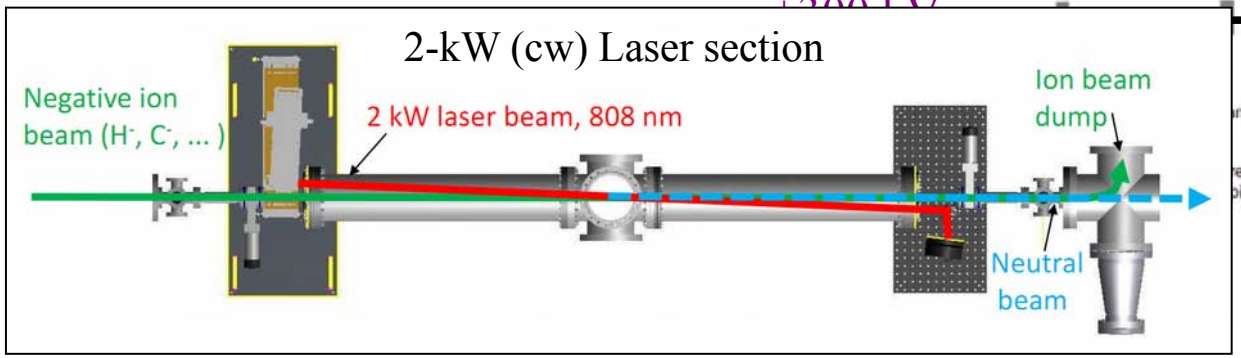


H. Kreckel et al.



Create ground-state **H, D, C, O neutral** beams by photo-detachment

superimpose the to the **stored ions**

e.g. $C + H_3^+ \rightarrow CH^+ + H_2$

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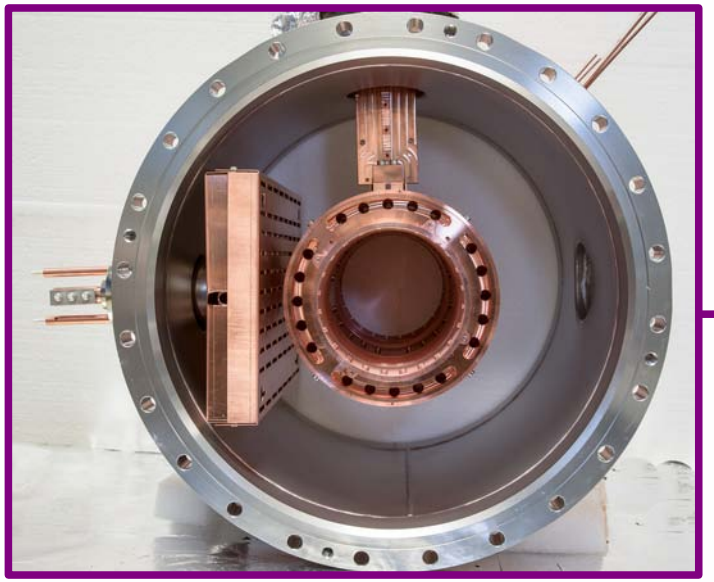
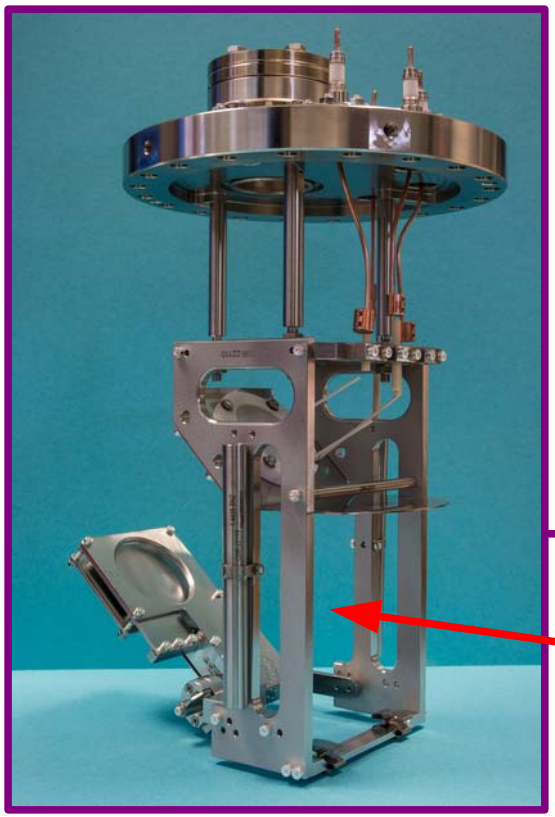
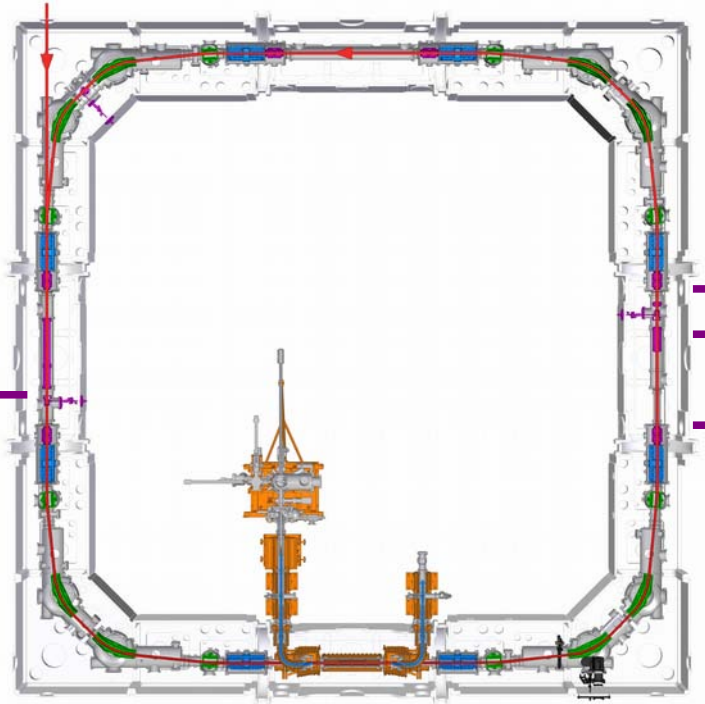
Beam **diagnostics**



position-, Schottky-, current-pickups



beam imaging system



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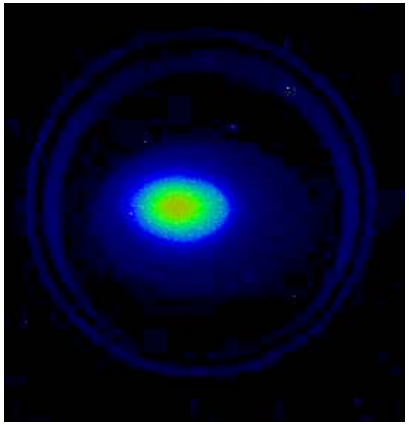
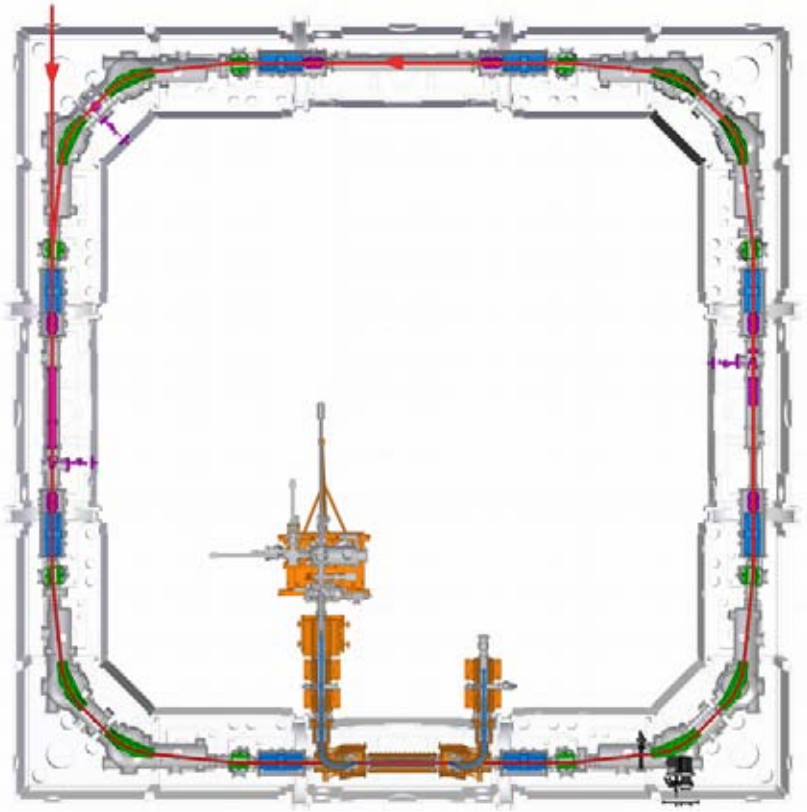
300 kV **injector.** ✓
Beam **diagnostics** ✓
Commissioning (room temperature):
Inject $^{40}Ar^{+}$ at 50 keV



Ar+ (50 keV)



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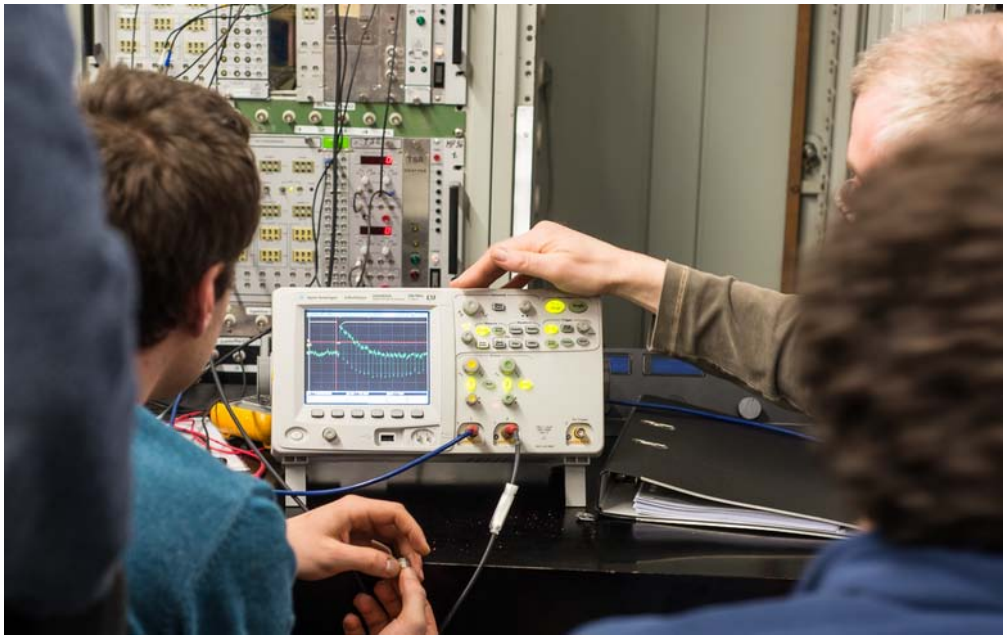
Beam **diagnostics** ✓

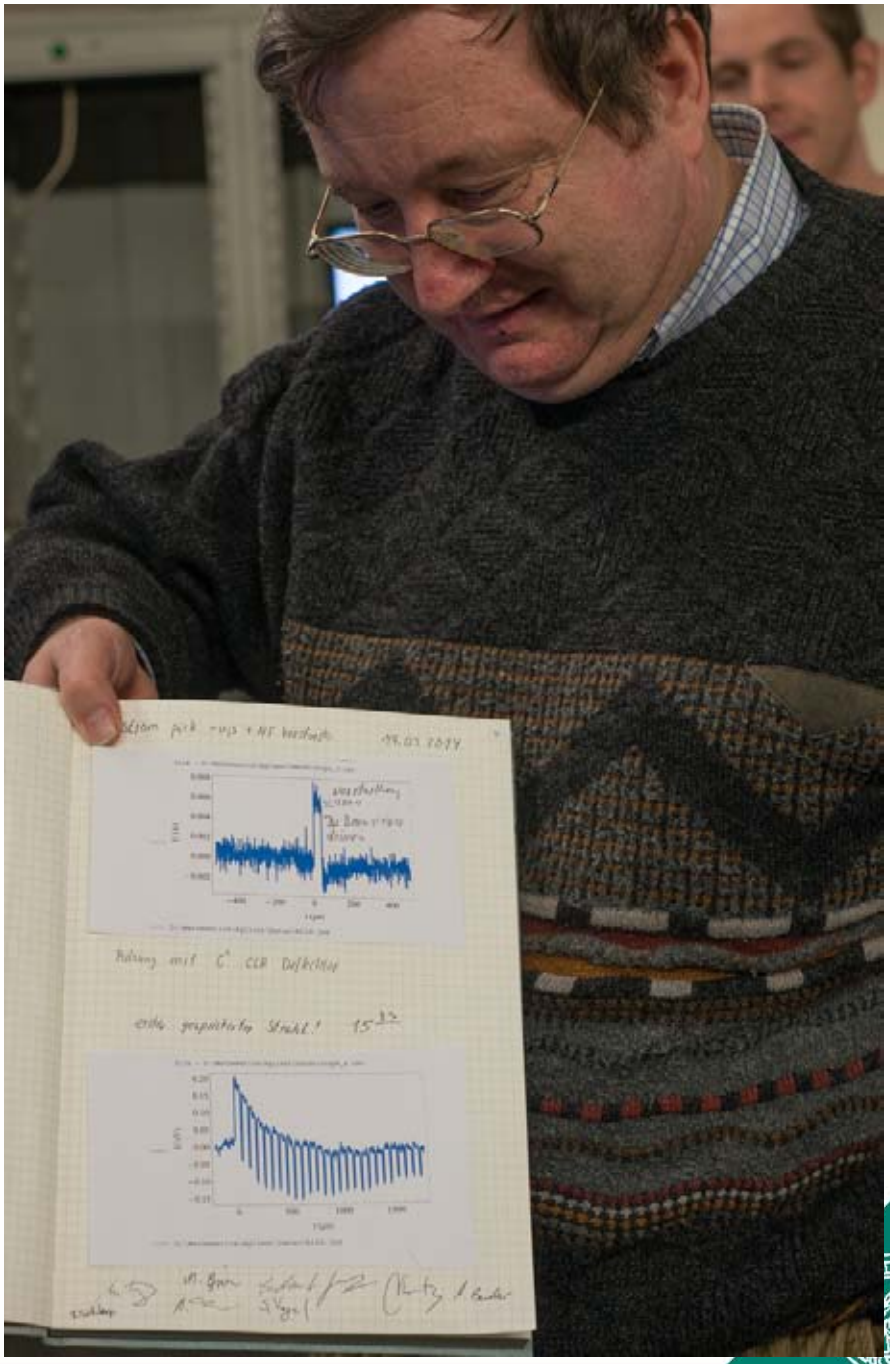
Commissioning (room temperature):

Inject $^{40}Ar^{+}$ at 50 keV ✓

17th March 2014 (15:33)

First **stored** beam!





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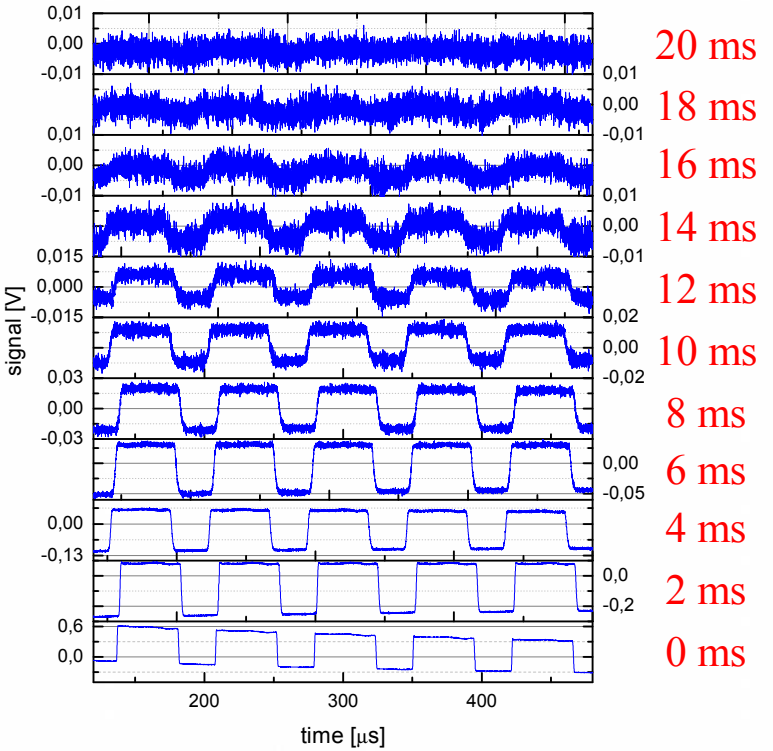
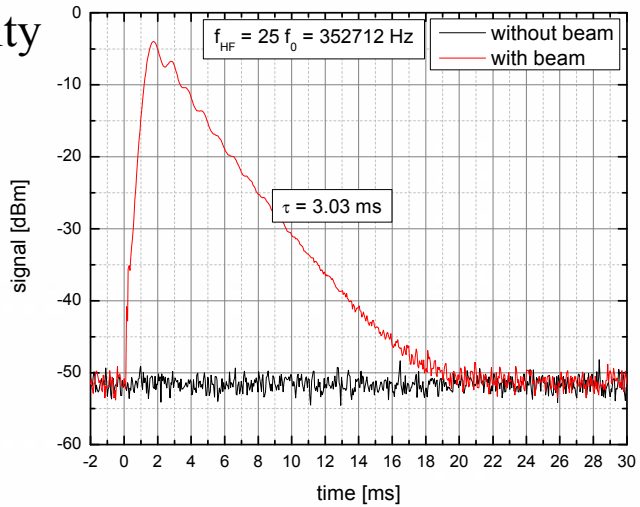
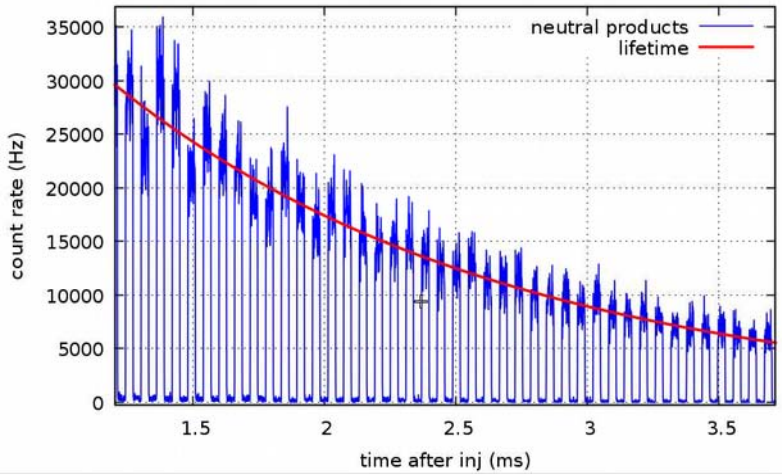
Commissioning (room temperature):

- **Inject** $^{40}Ar^{+}$ at 50 keV ✓
  - 17th March 2014 (15:33)
    - First **stored** beam! ✓
  - Beam lifetime
    - **(~3 ms @ ~ 10^{-7} mbar)**
  - Detector tests
  - Betatron stability
  - rf bunching
  - ...



~ 300 revolutions (10 km)





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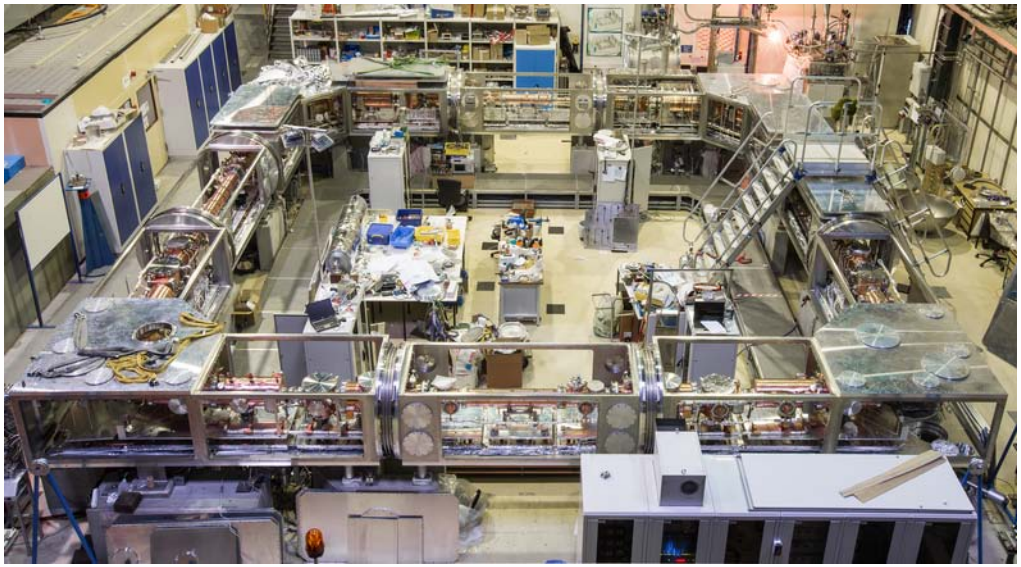
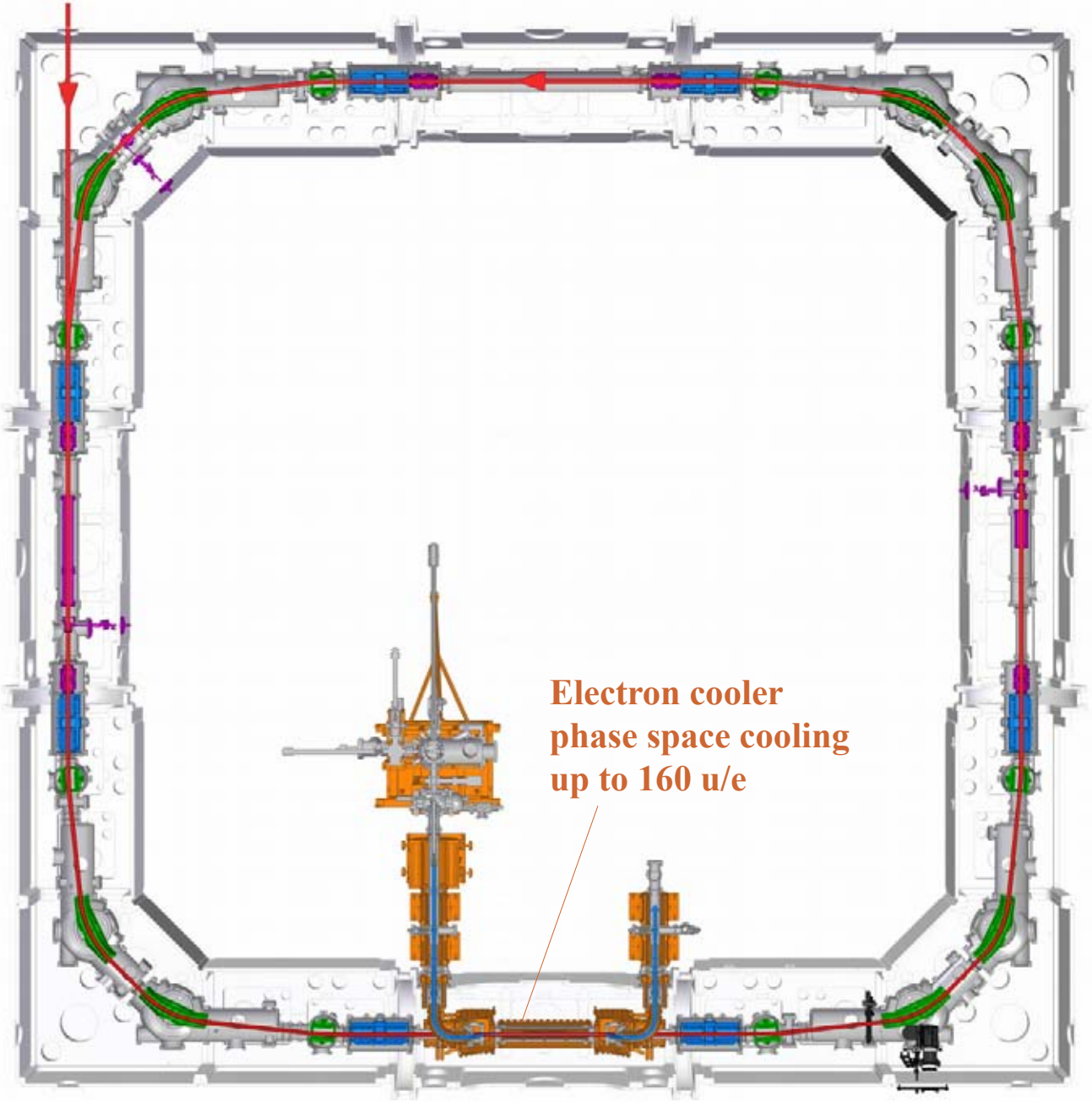


Next step:

Cryogenic operation

Electron Cooler



Electron Cooler

Principle of ecooling: $v_{electron} = v_{ion}$

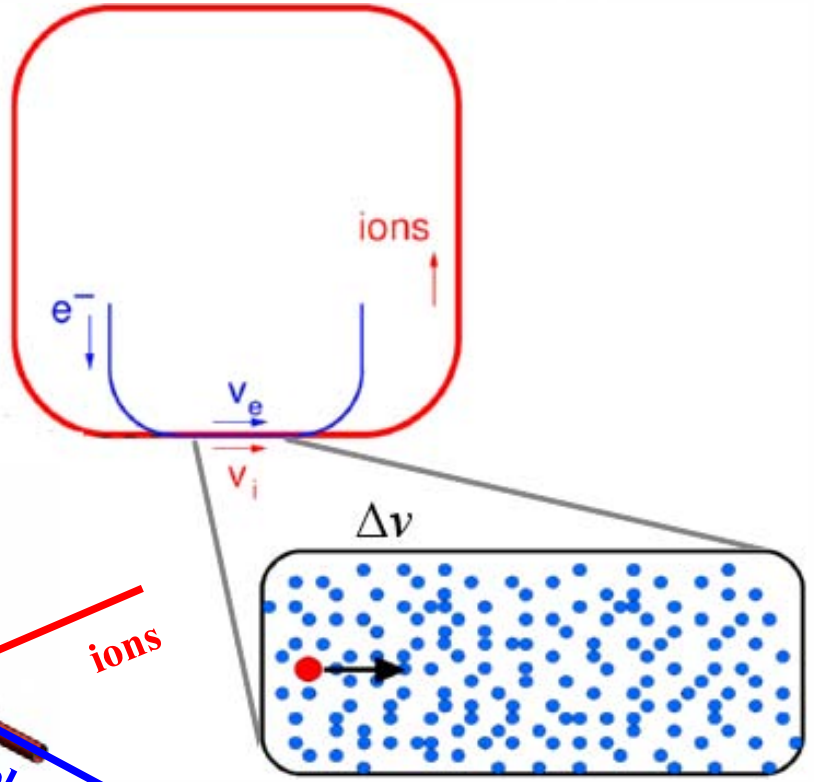
CSR energy limit: → Need **very** slow electrons

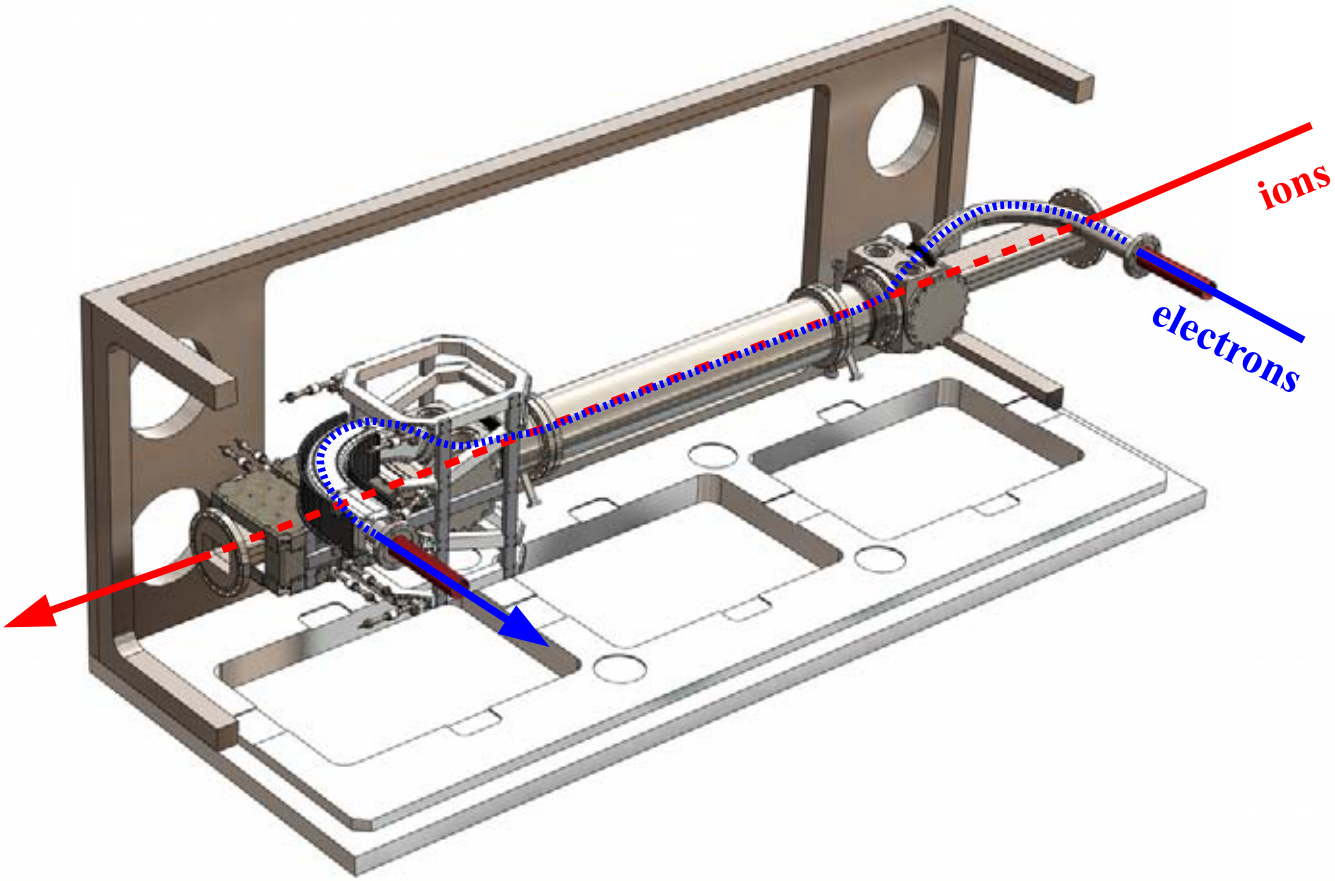
E_{ion}/Z_{ion} = 300 keV

160 eV for p^+

< 20 eV for most ions

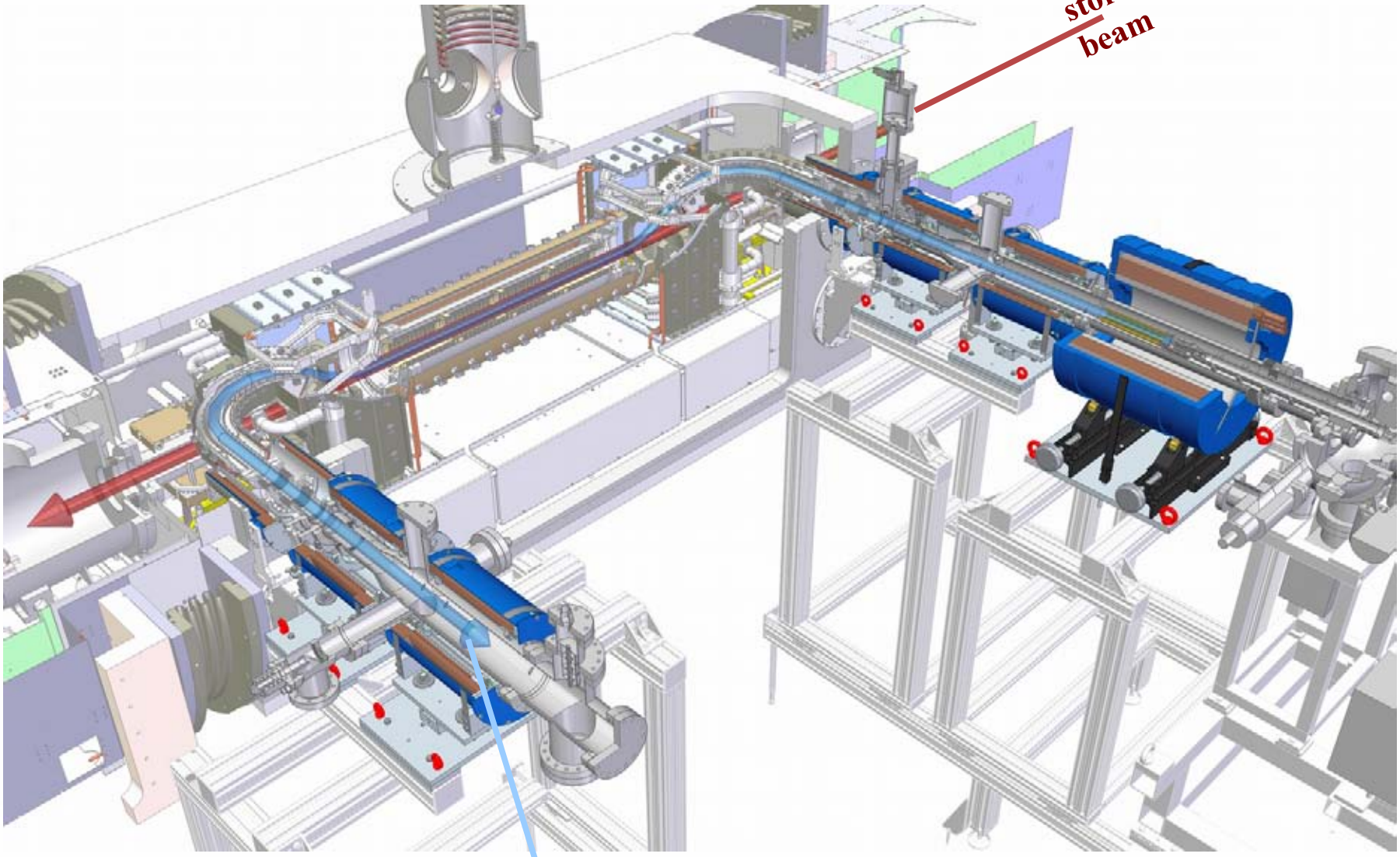
1 eV for M_{ion} = 160 u





600 km/s

Electron Cooler



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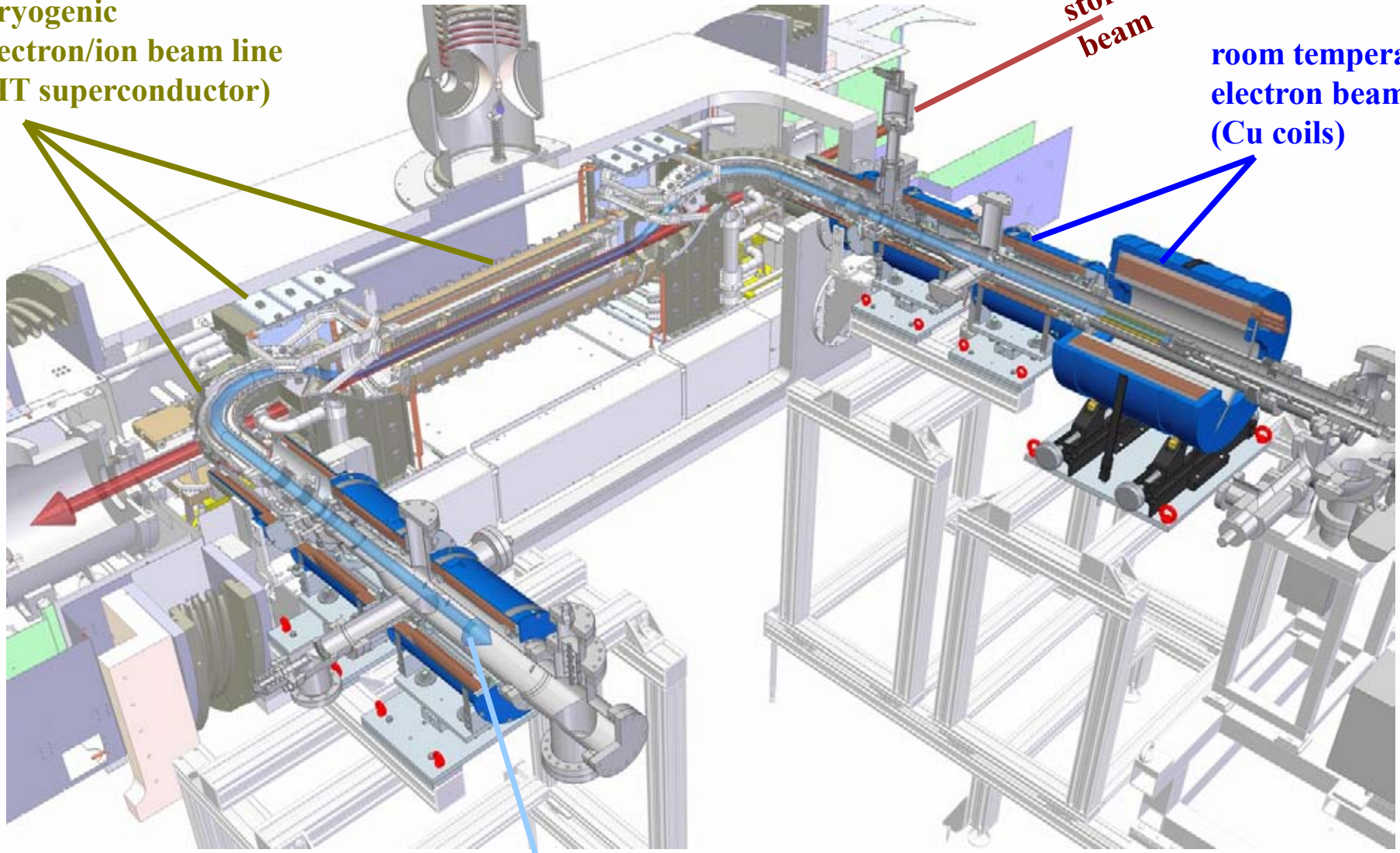

Electron Cooler

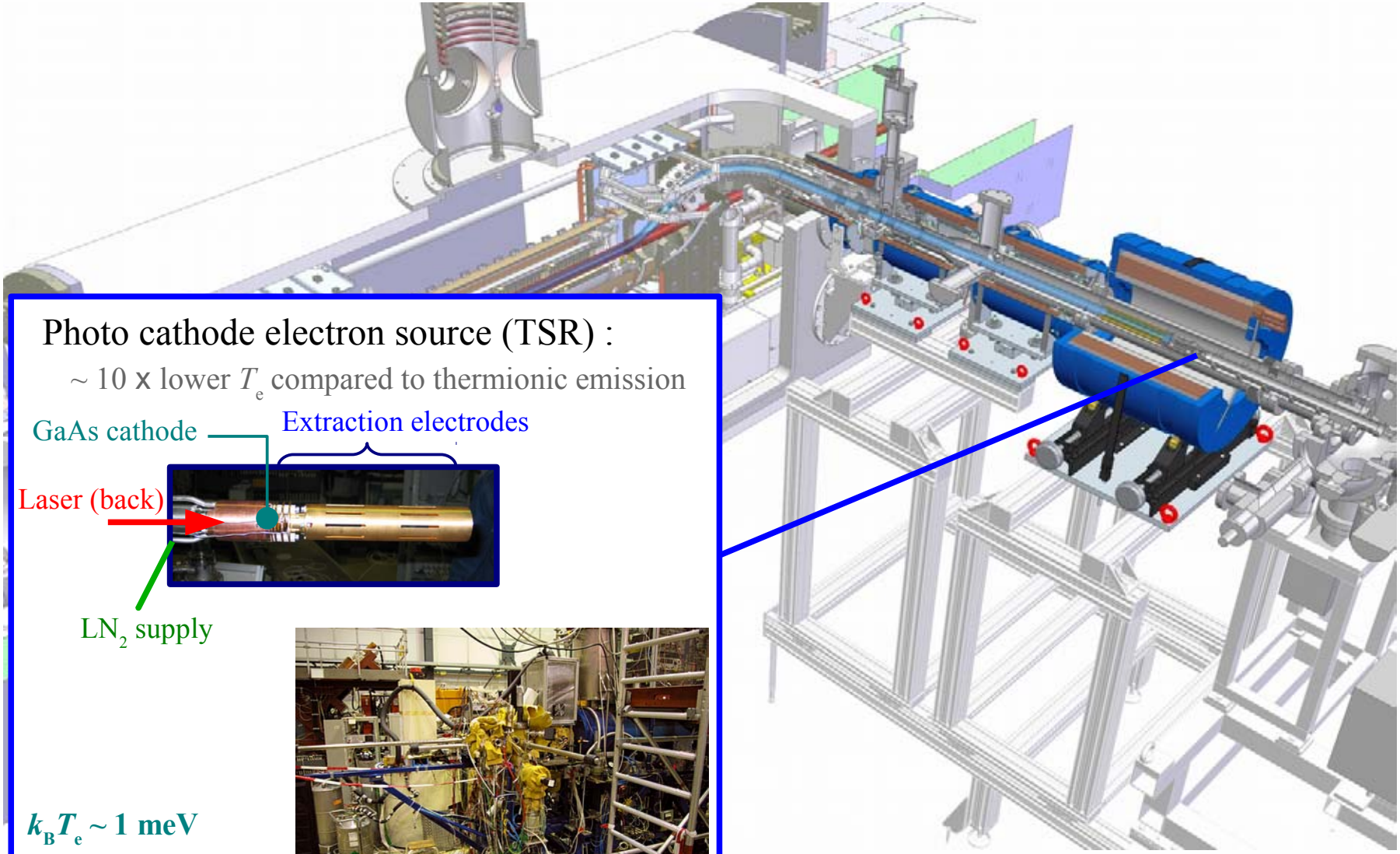

Photo cathode electron source (TSR) :

~ 10 x lower T_e compared to thermionic emission

GaAs cathode

Extraction electrodes

Laser (back)

LN_2 supply

$k_B T_e \sim 1$ meV

$n_e \sim 10^5$ cm^{-3} @ 1 eV

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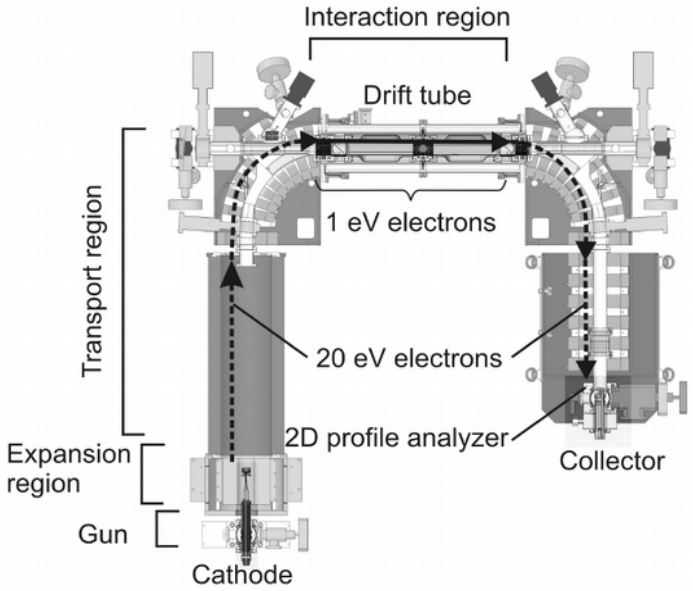
Electron Cooler

Electron energy: towards 1 eV and below …



- Calibration of E_e against cathode potential
  taking beam **space charge** and
  work function differences into account

- Current:
  few µA at E_{cool} = 1 eV

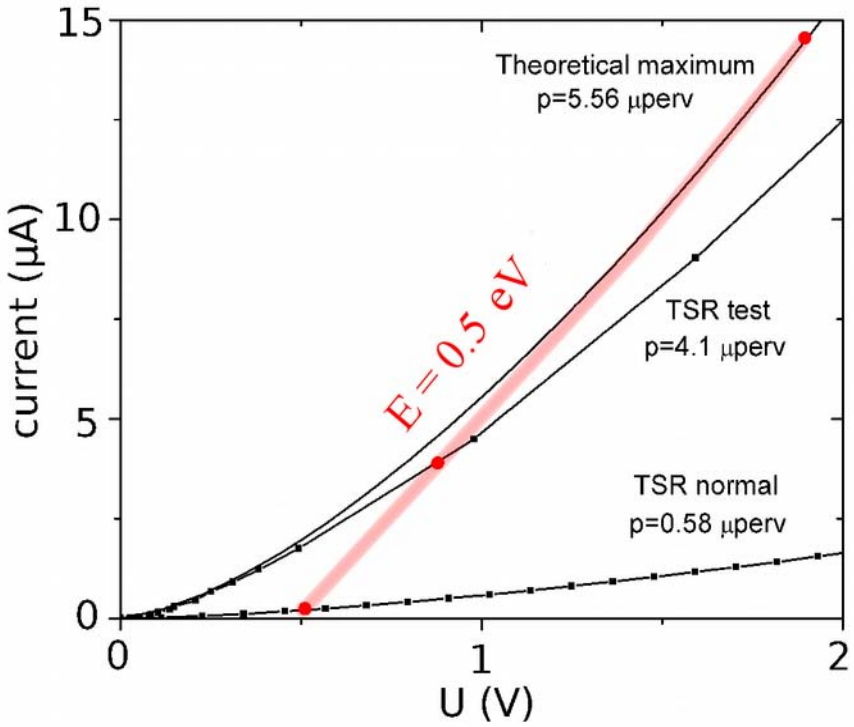
  $n_e \sim 10^5$ cm^{-3}

- Cooling times

$$\tau \sim \frac{M_{ion} T_e^{3/2}}{Z_{ion}^2 n_e}$$

  up to ~ 100 s …

  … but: ion lifetime ~ 1000 s



A. Shornikov et al., Phys. Rev. ST Accel. Beams 17 (2014) 042802

Electron Cooler

Electron energy: towards 1 eV and below …

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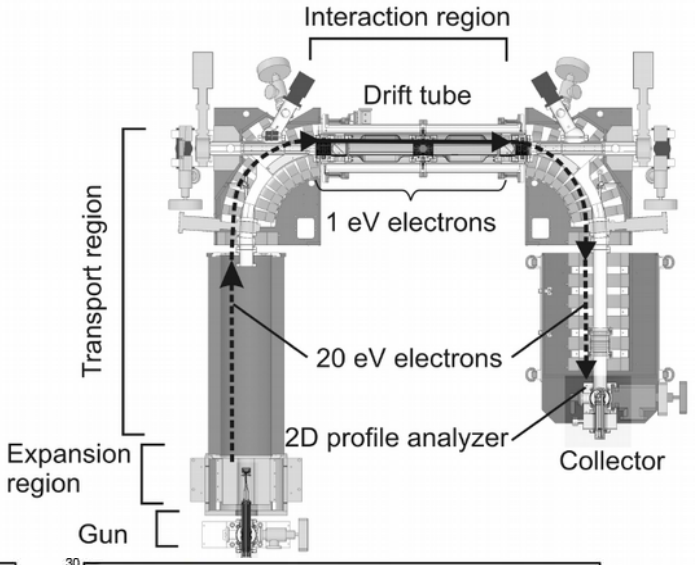

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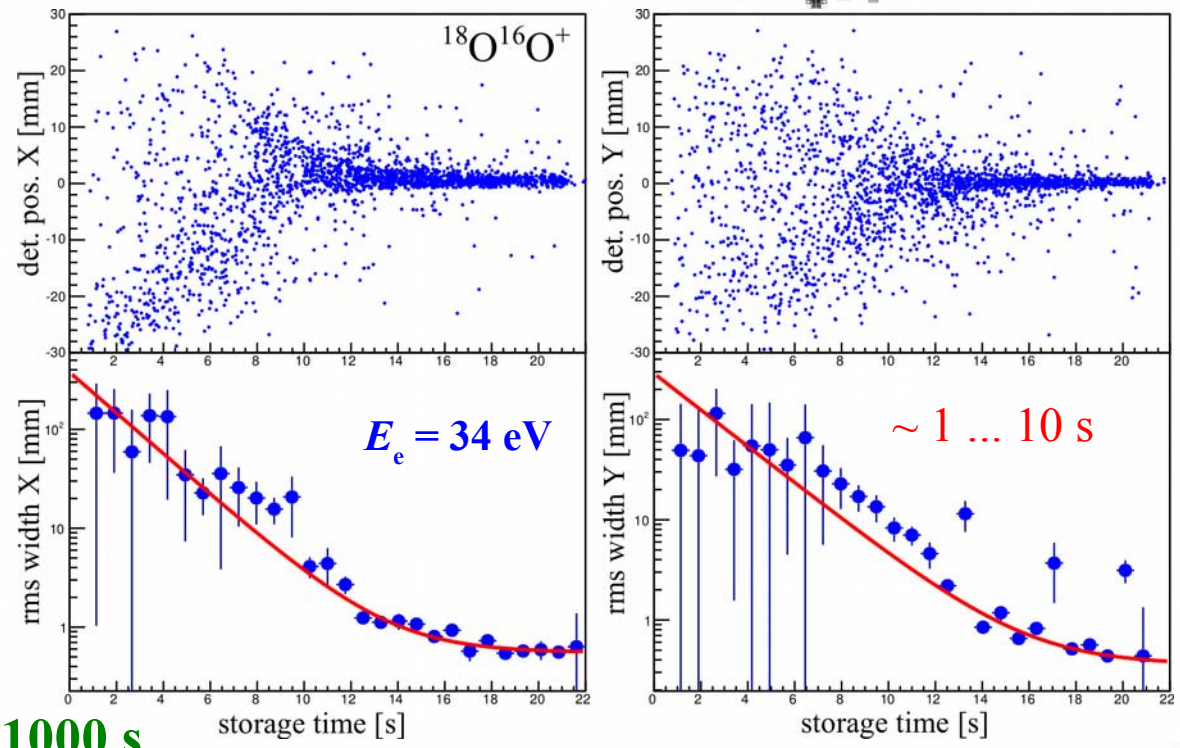
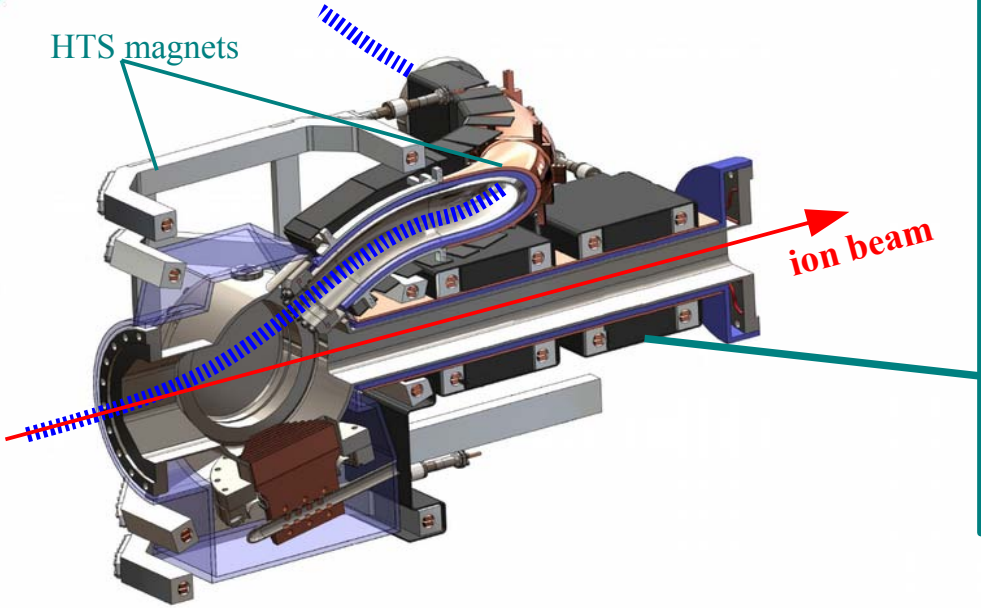
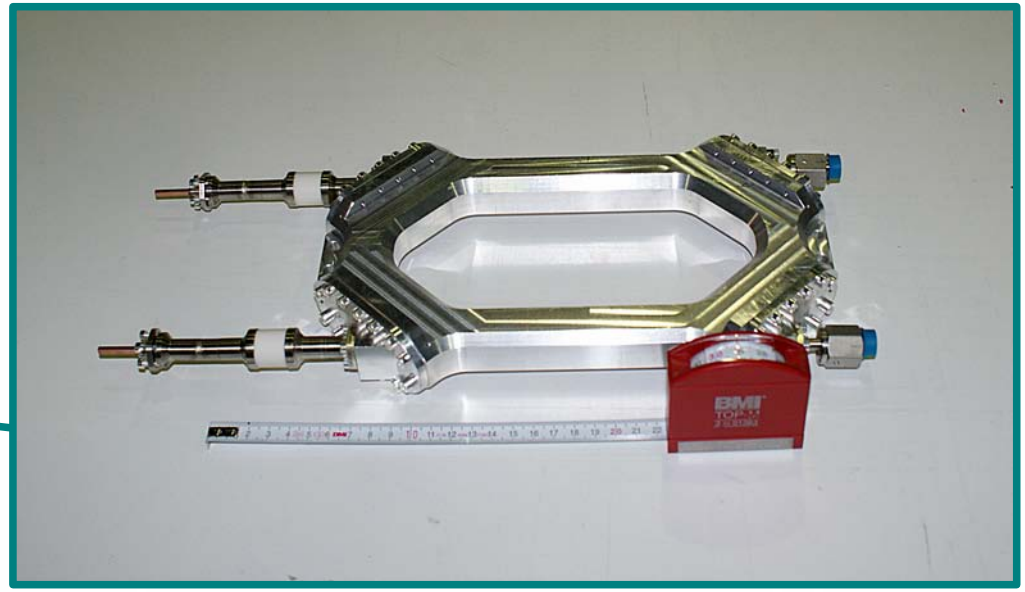


TSR data, C. K. et al., in prep.

Electron Cooler - Status

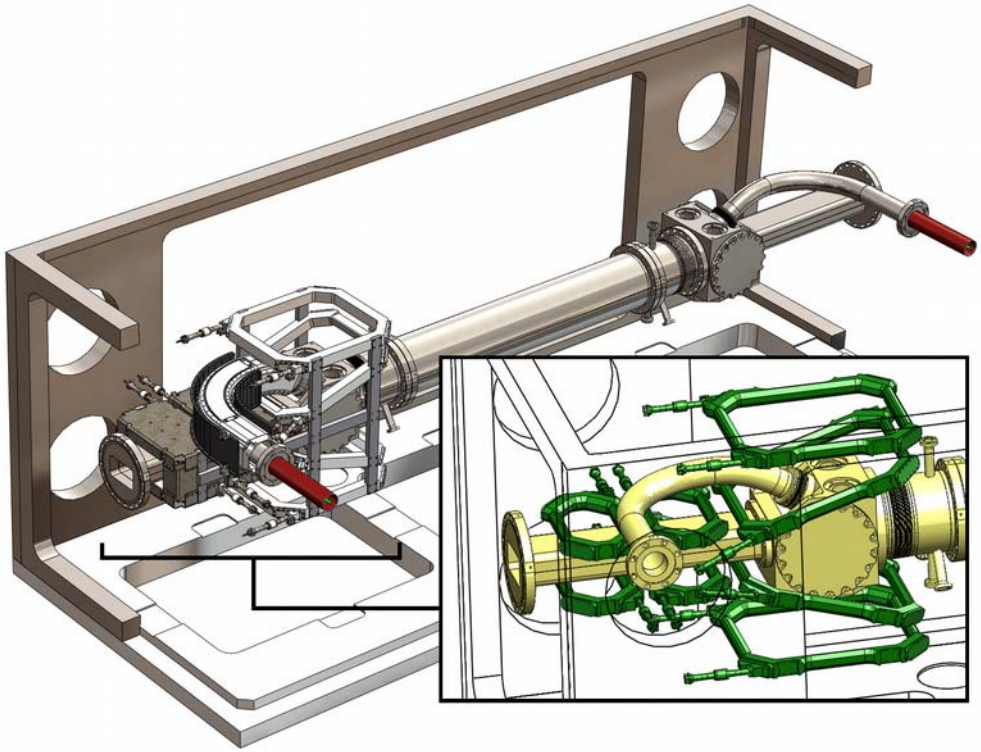




Superconducting ring coils have been built and tested

(LNe, approx. 30 K)

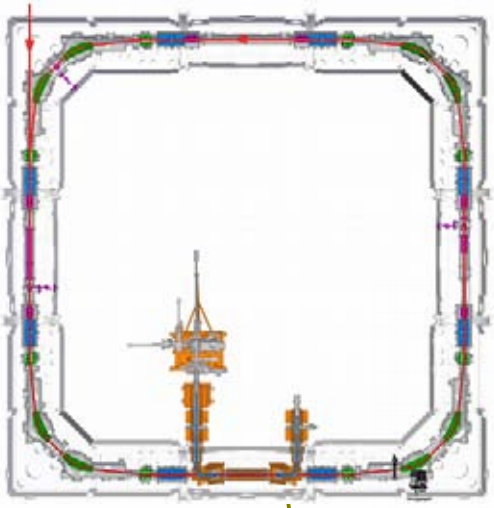
10-K vacuum chambers are in manufacturing process ...

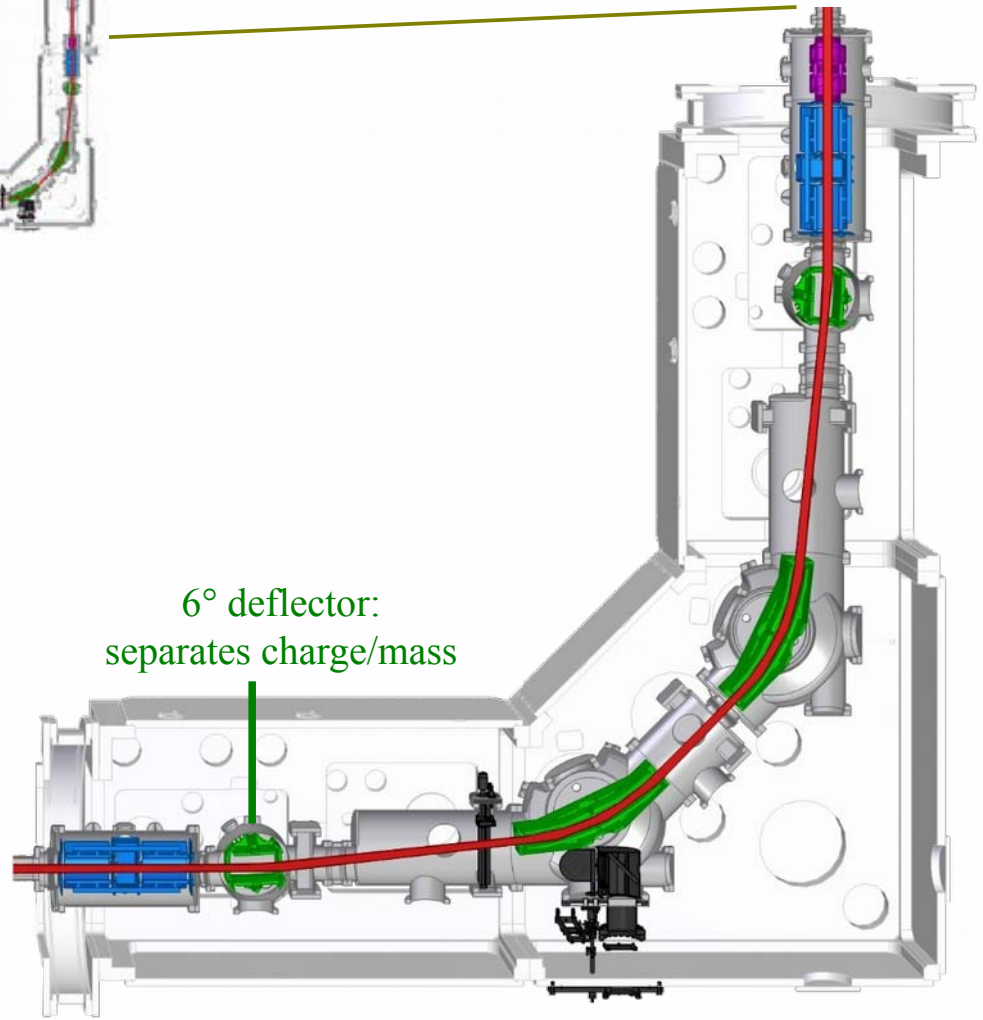


Electron Cooler - Status

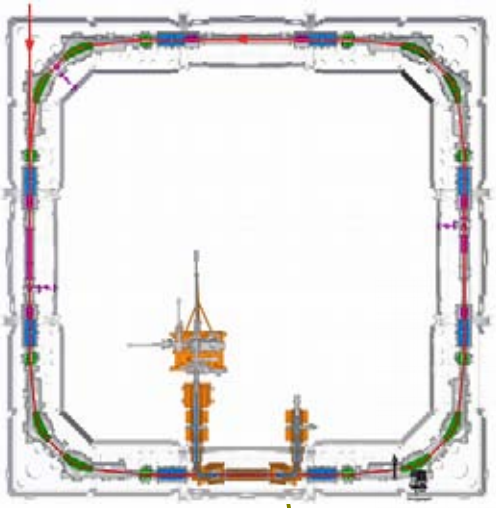
assembly of 300 K beamlines ...

Electron Cooler - Detectors



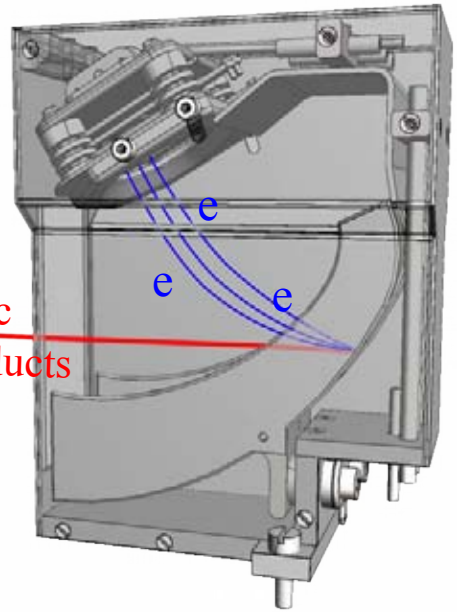


Electron Cooler - Detectors



COMPACT

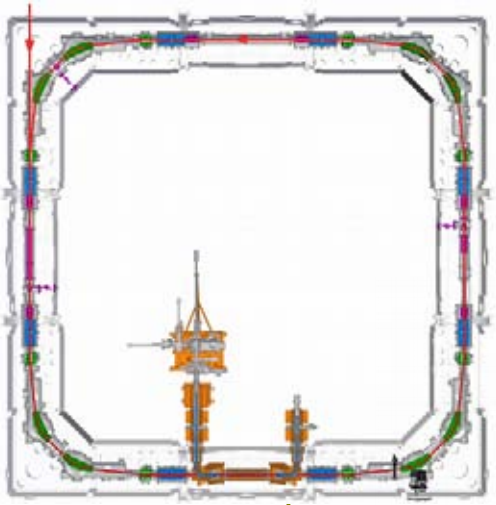
"Cold Movable Particle Counter"



ionic products

from experiment

Electron Cooler - Detectors



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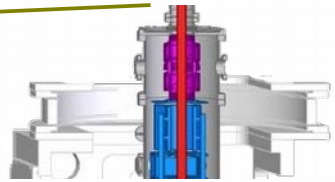
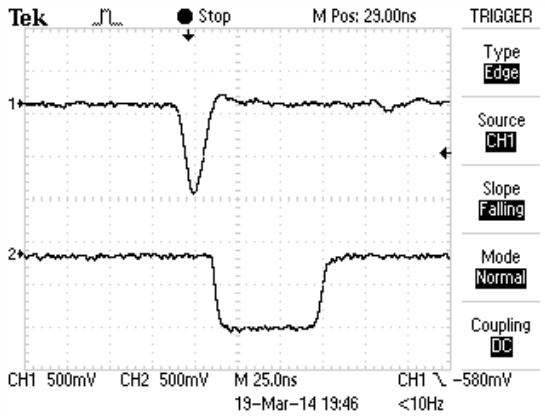
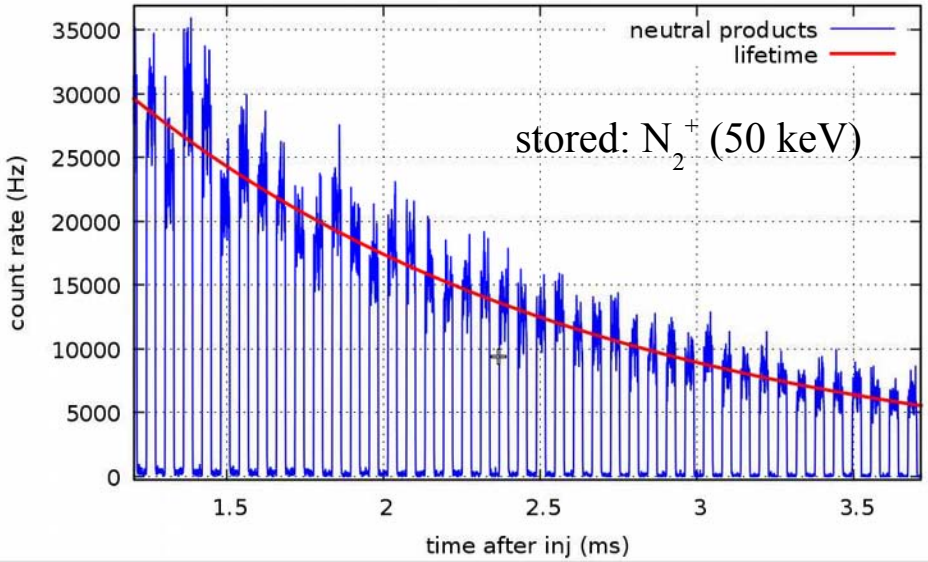
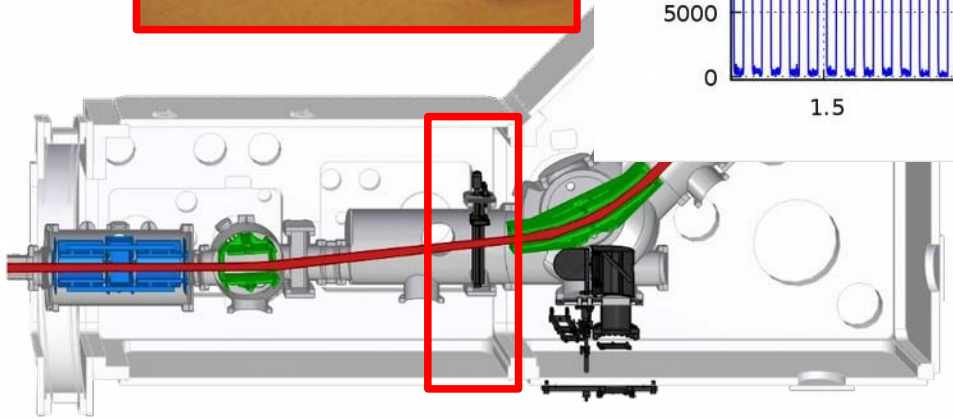


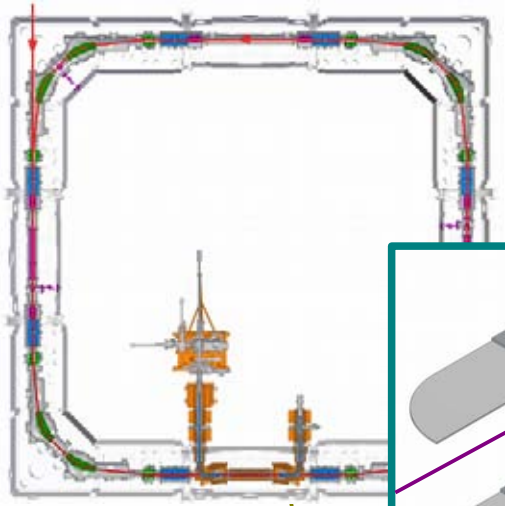




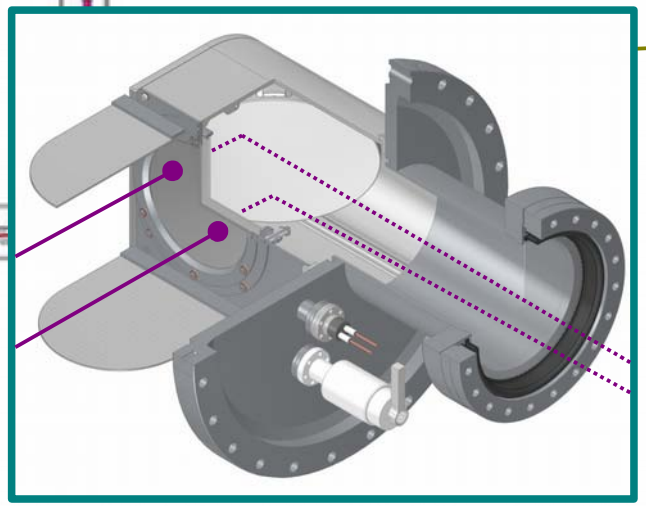


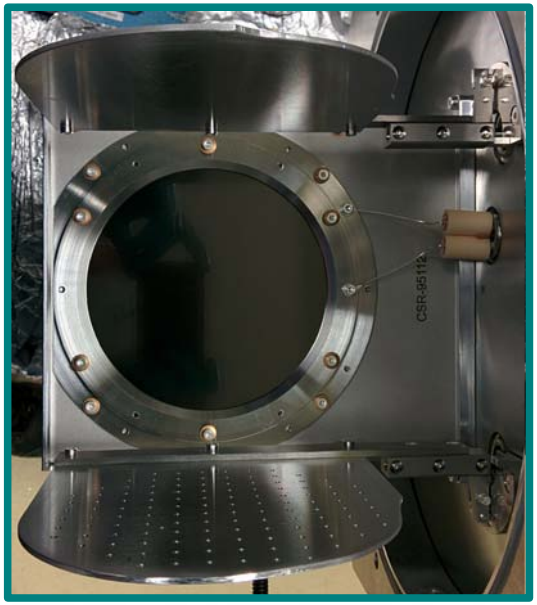
from experiment

Electron Cooler - Detectors

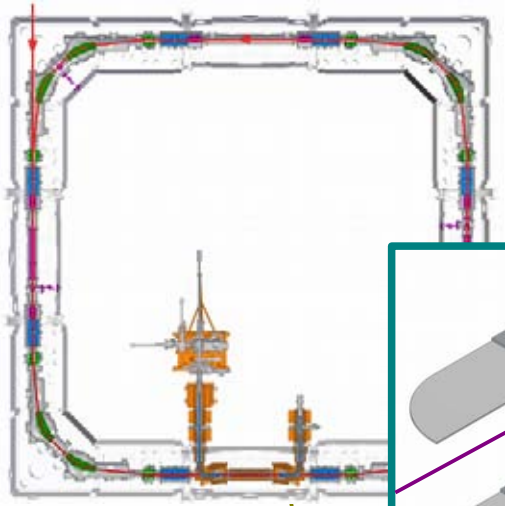


NICE "Neutral Imaging in Cryogenic Environment"





Electron Cooler - I



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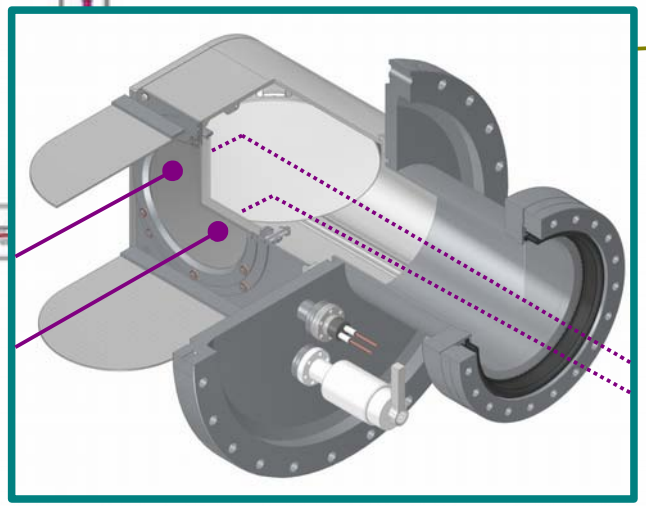
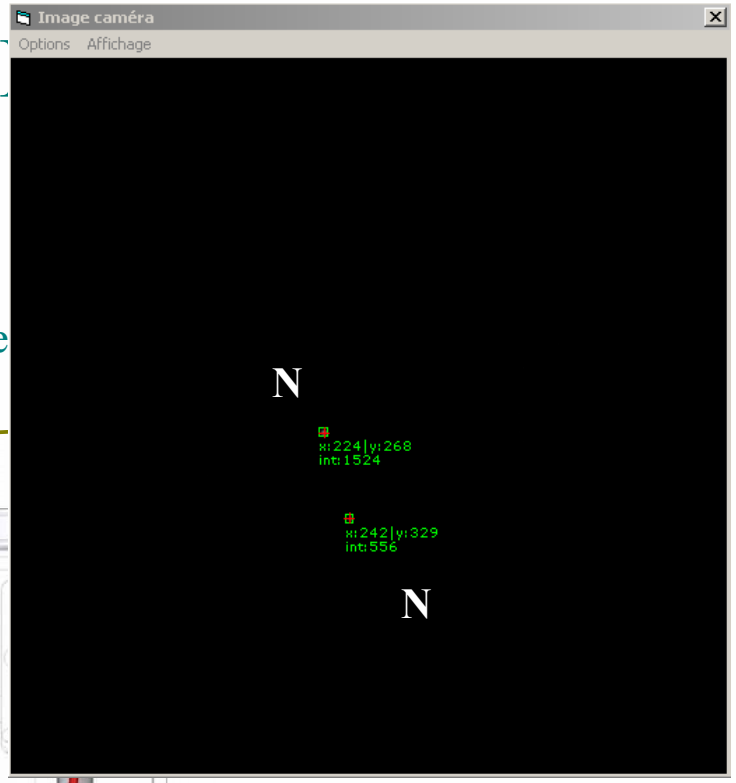
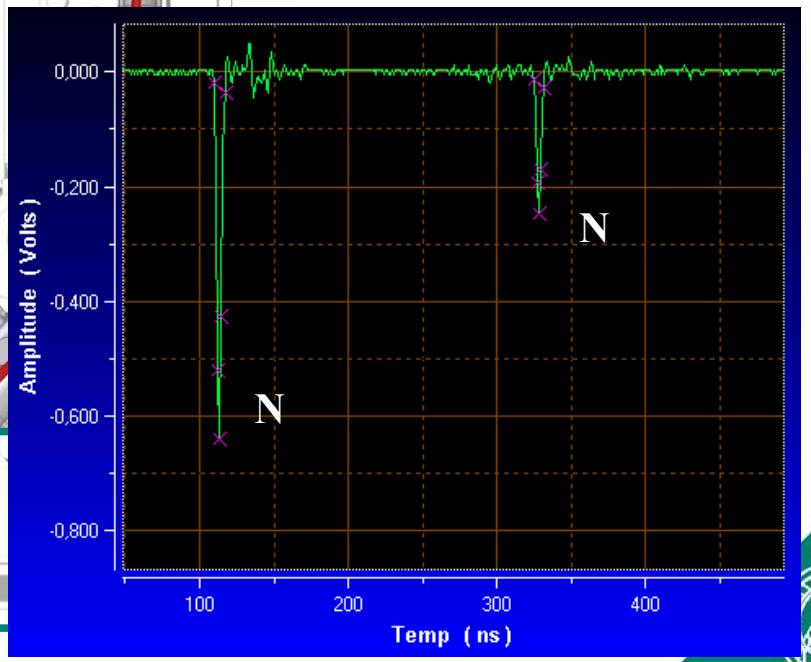
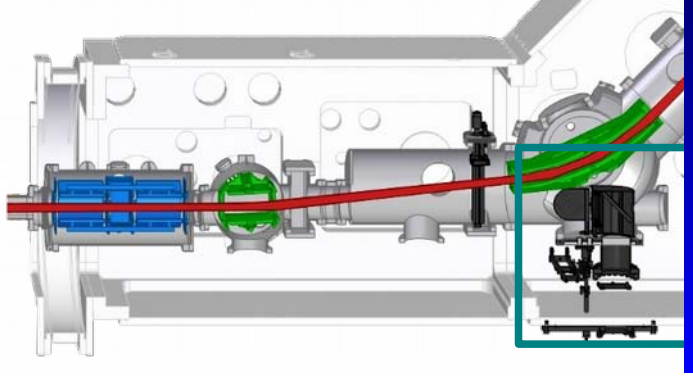




X. Urbain, A. Becker et al.



X. Urbain, A. Becker et al.



N_2^+ (50 keV) **from experiment**

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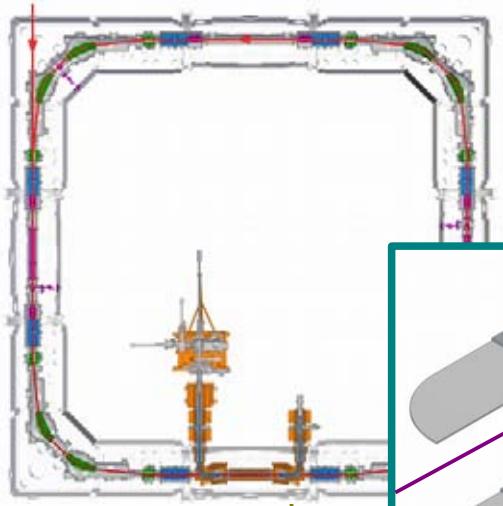
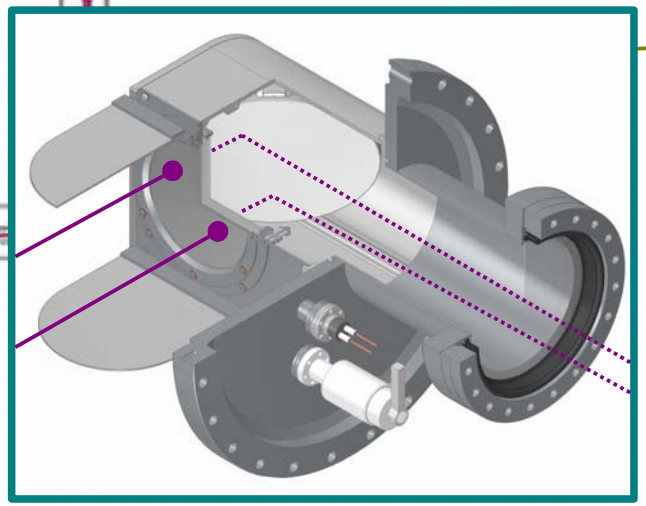
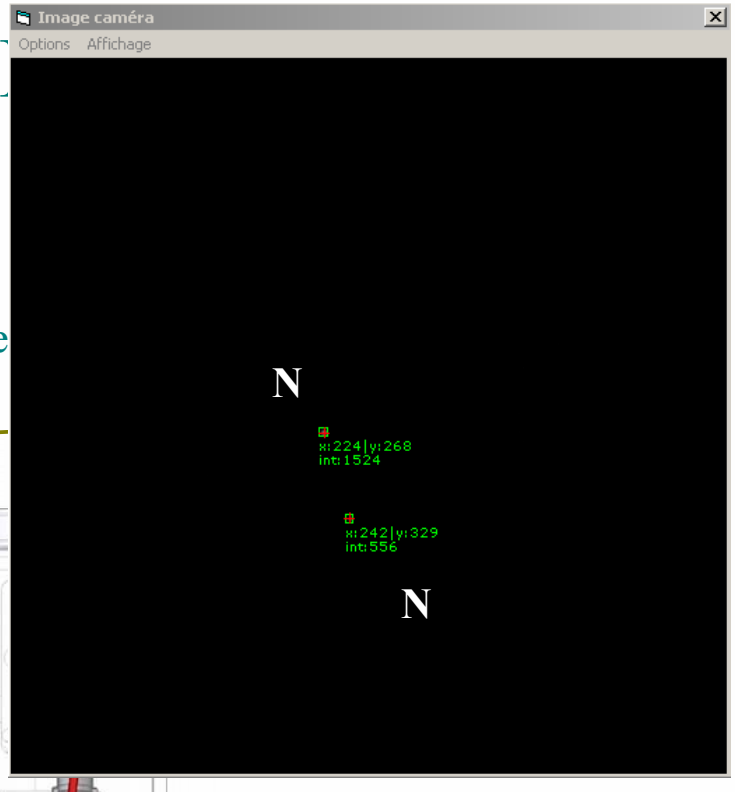
Electron Cooler -

NICE "Neutral Imaging in Cryogenic Environme

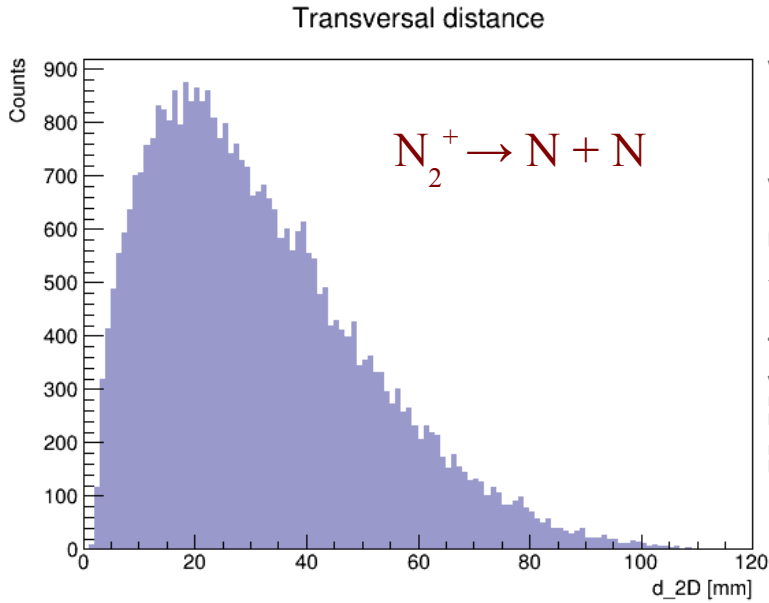






X. Urbain, A. Becker et al.

N_2^+ **from experiment**
(50 keV)



X. Urbain, A. Becker et al.

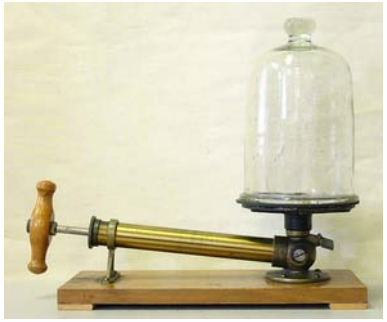
(A few) Experimental Perspectives

Electrostatic optics (300 keV/q)

Well-suited for low charge/mass-ratio
(e.g. complex molecules, clusters, low-charge atomic ions)

Extremely High Vacuum (10^{-13} mbar)

Storage of large or heavy (= slow) ions for long times (~ 1000 s)



Internally and kinematically cold ions

10 K environment: Internal cooling of molecules

Electron cooler: phase space cooling

(A few) Experimental Perspectives

Phase 1 (2014):

Commissioning of CSR (300 K) ✓

Storage at 10 K

→ Experiments with uncooled beam
(but: **radiative cooling!)**

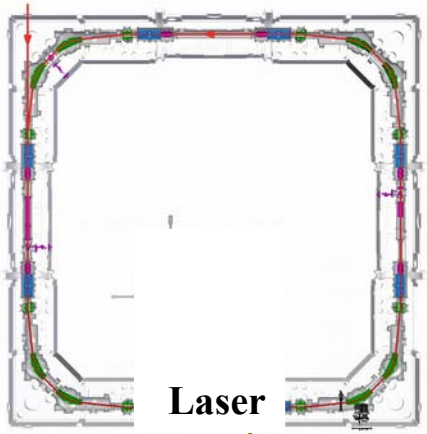
Phase 2 (2015 → …):

Installation of **electron cooler**

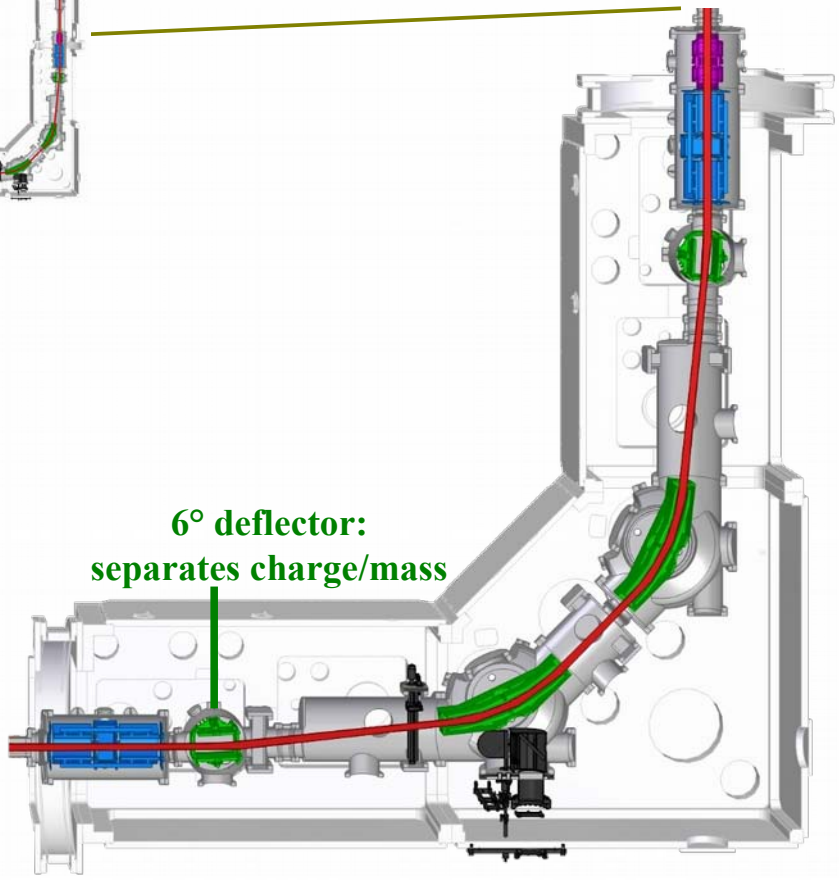
→ Experiments with cooled beams (internal AND external!)

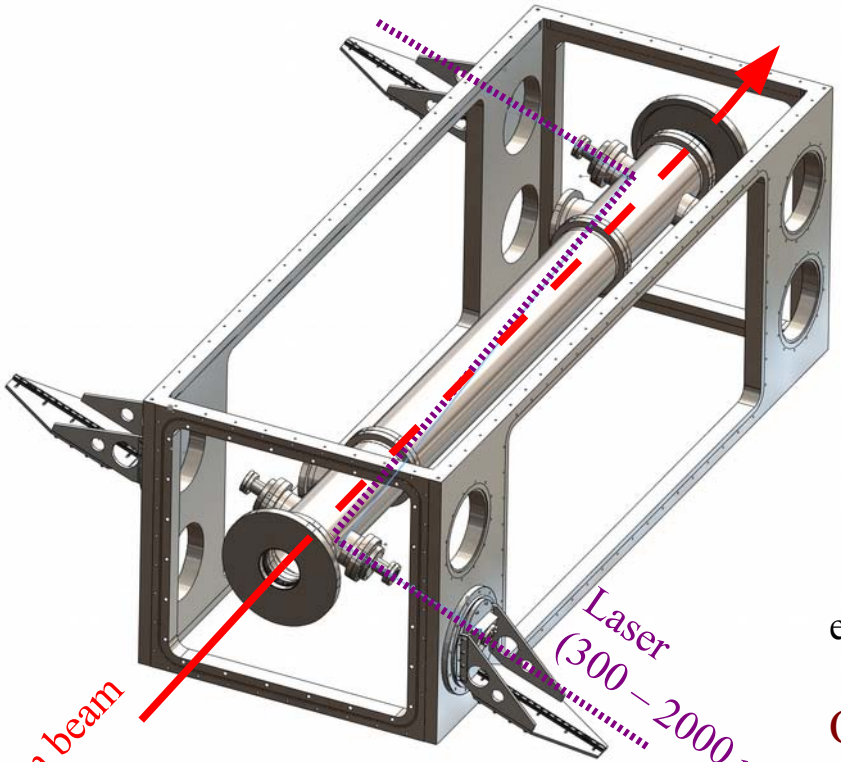
→ Experiments on electron-ion interaction (DR et al ...)

Phase 1 Experiments



Laser





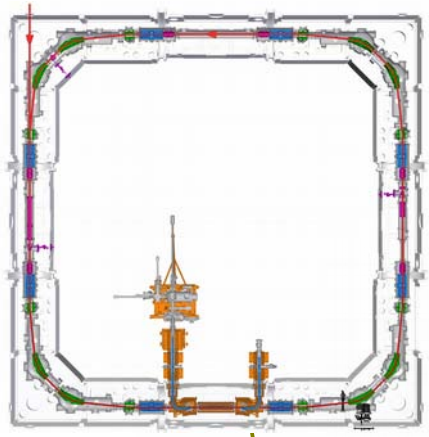
Laser interaction section
instead of electron cooler

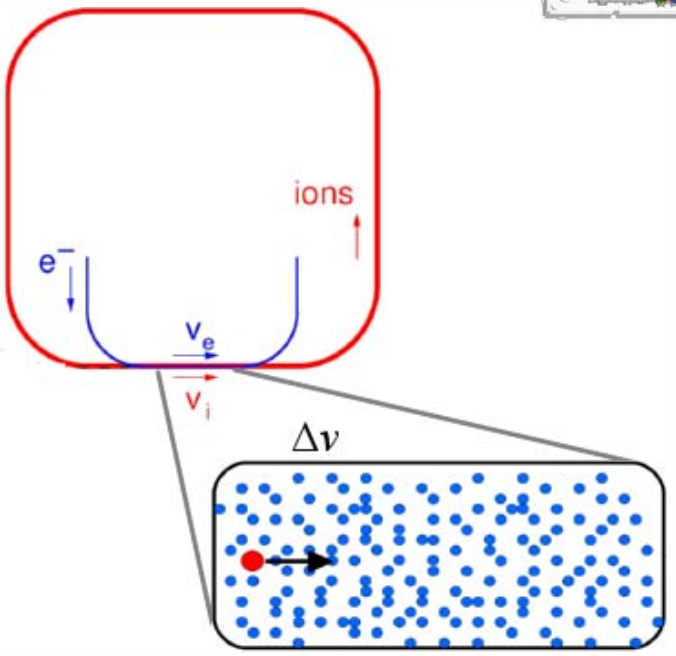
e.g.

$OH^- + \gamma \rightarrow OH + e$

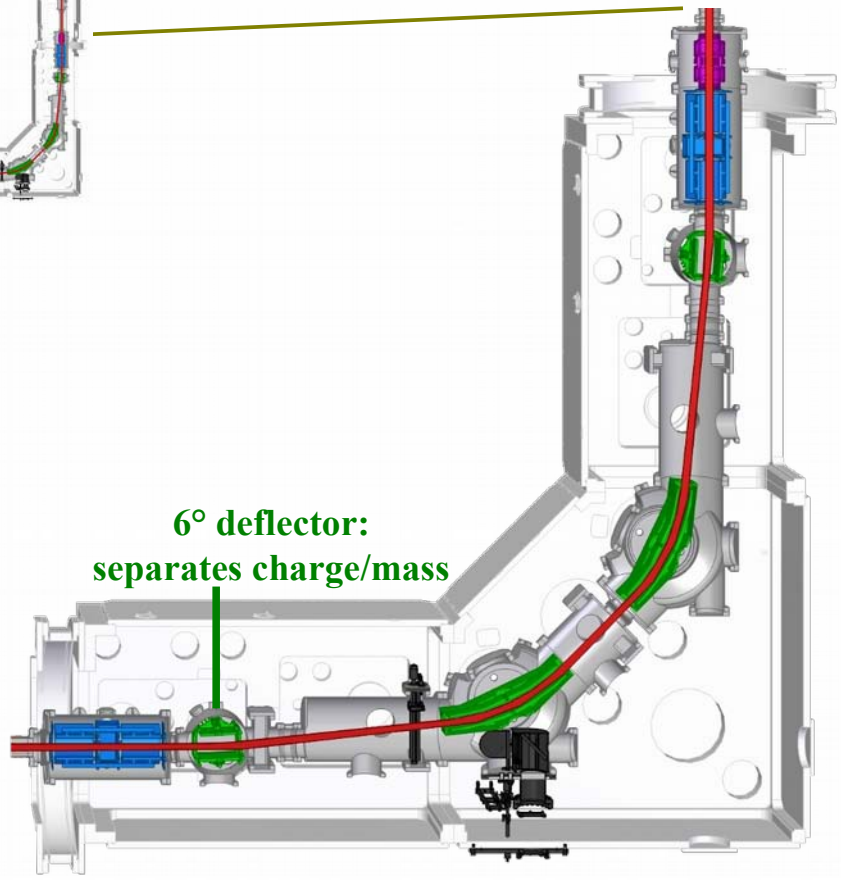
$CH^+ + \gamma \rightarrow C^+ + H$

Phase 2 Experiments: Recombination

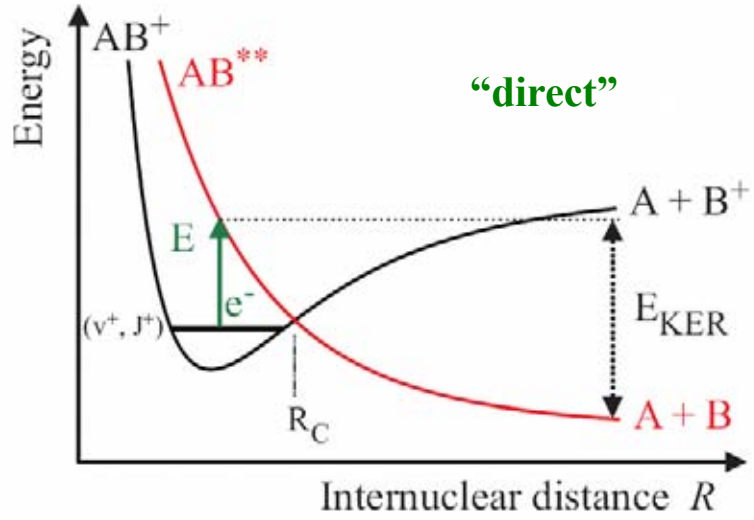


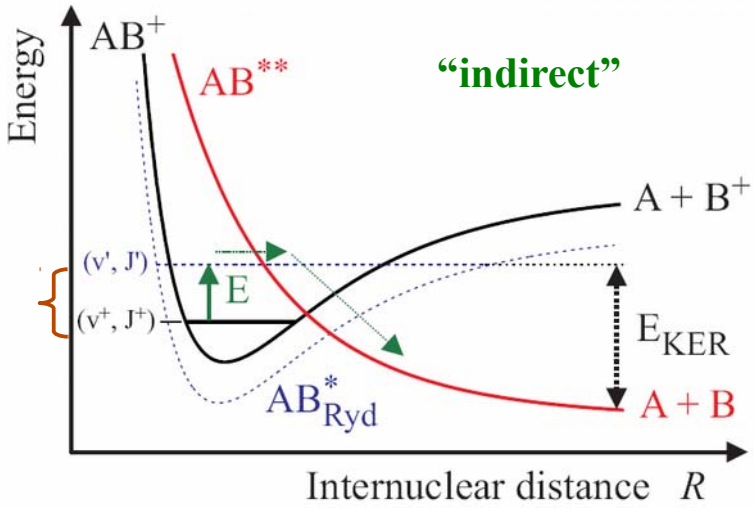


from experiment

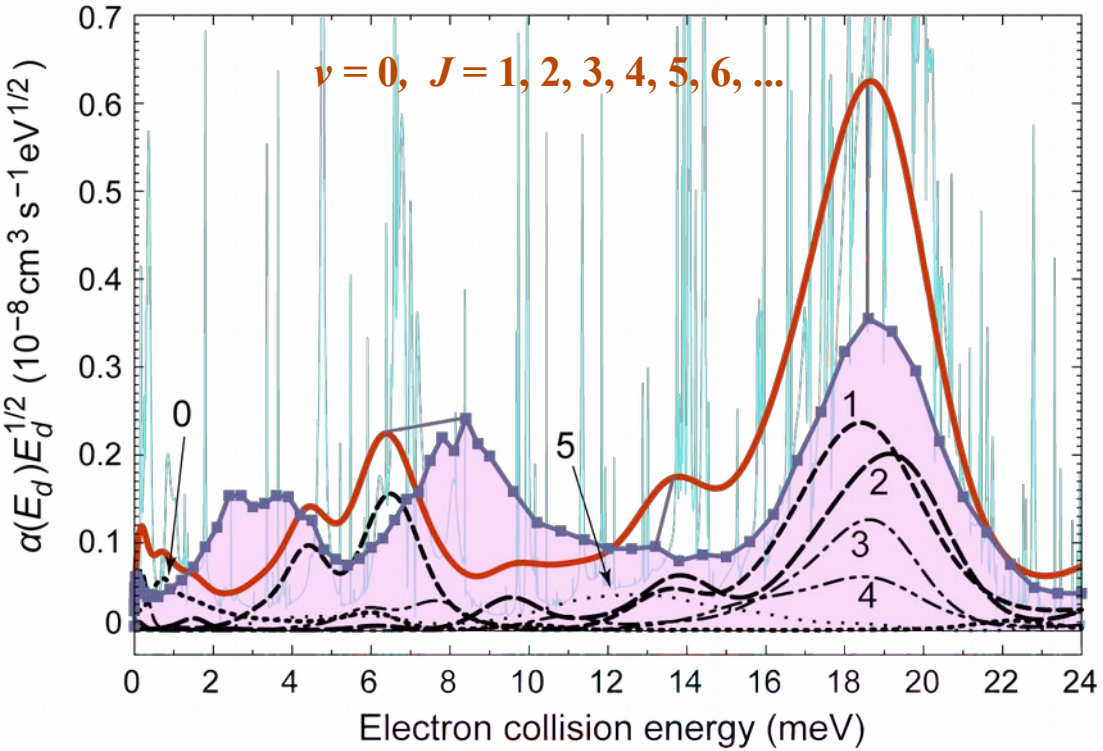


DR Experiments: "Benchmarks"





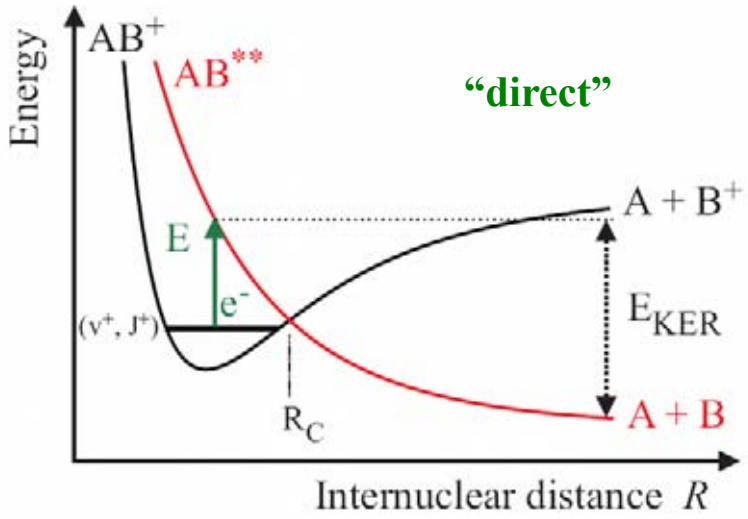
$HD^+ + e \rightarrow H + D$

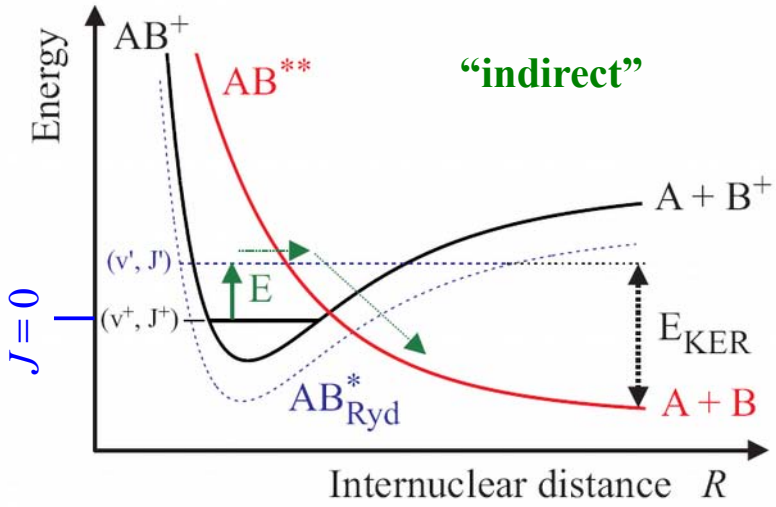


Waffeu-Tamo *et al.*, PRA 84 (2011) (0 K)

TSR data (kT_e ~ 1 meV, T_{ion} ~ 300 K)

DR Experiments: "Benchmarks"





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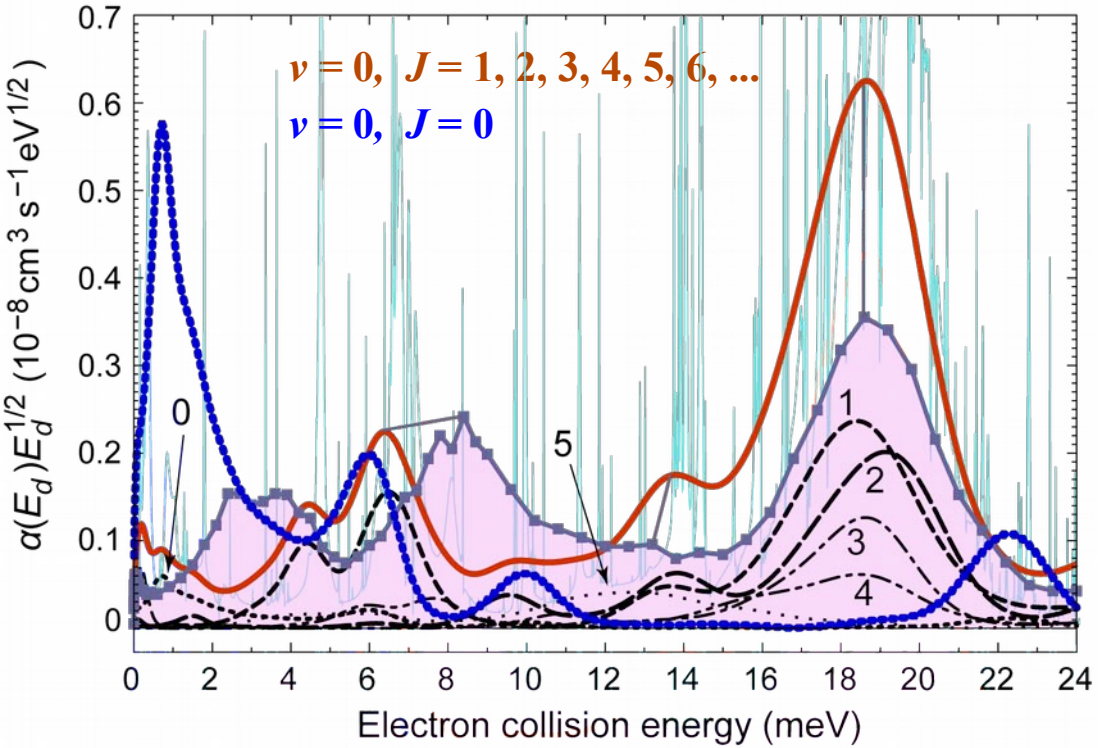


Waffeu-Tamo *et al.*, PRA 84 (2011) (0 K)

TSR data ($kT_e \sim 1$ meV, $T_{ion} \sim 300$ K)

CSR prediction ($T_{ion} = 10$ K)

at CSR: $E_{cool} = 54$ eV

$10\ \text{K} \rightarrow J = 0$

DR Experiments: Complex Systems

- Polyatomics: H_3^+, H_3O^+, HNO^+/HON^+, CCN^+/CNC^+ ...
- Recombination of large organic molecules $C_xH_y^+$, $C_xH_yOH^+$ ...
- Dielectronic Recombination of atomic monoions: C^+, N^+, F^+, Si^+, P^+, Cl^+, Fe^+

  Contribute to cold astrochemistry [Bryans et al., ApJ 694 (2009)]

  $C^+ (^2P_{1/2}) + e^- (< 8\ meV) \rightarrow C^{**} (^2P_{3/2}, nl) \rightarrow C^* + \gamma$

  (Not measurable in TSR due to field ionisation and non-DR background!)
- Electron cooled cluster anions …
- Ion-photon interactions / ion-neutral collisions with cooled/cold ions.

Summary

CSR, a next-generation electrostatic storage ring has been been commissioned in 2013.

It will be all-cryogenic, providing very low residual gas density and IR background radiation.

It will feature a fully-functional electron cooler.

It provides unique opportunities for a multitude of experiments stored and cooled low energy ions.

Thank You!

Max Planck Institute for Nuclear Physics, Heidelberg

Klaus Blaum
Robert von Hahn
Florian Fellenberger
Sebastian George
Sebastian Menk
Holger Kreckel
Florian Grussie
Philipp Herwig
Arno Becker
C. K.
Aodh O'Connor
Stephen Vogel
Robert Repnow
Manfred Grieser
Andreas Wolf

Université Catholique, Louvain-la-Neuve

Xavier Urbain

Justus-Liebig University, Gießen

Kaija Spruck
Stefan Schippers

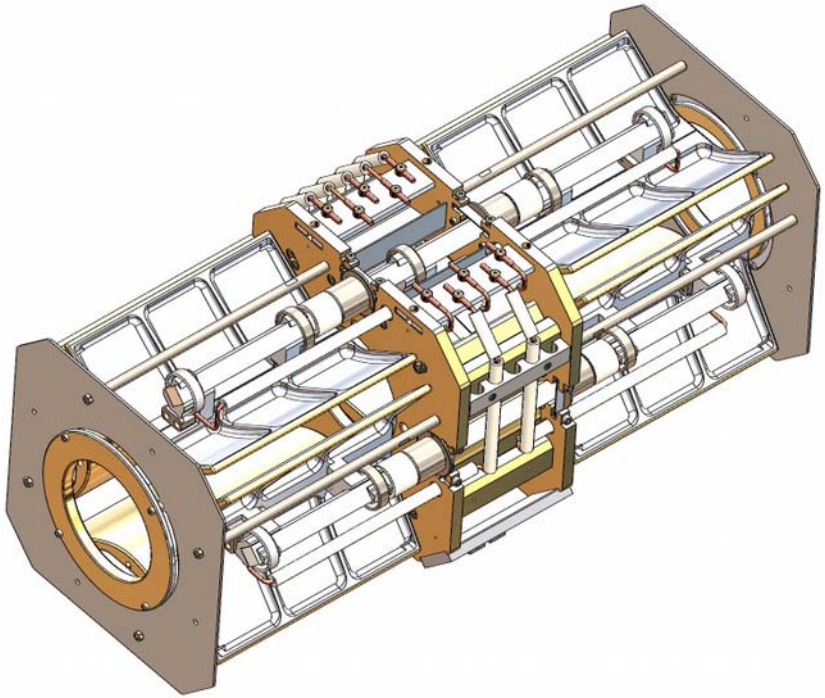
Columbia University, New York

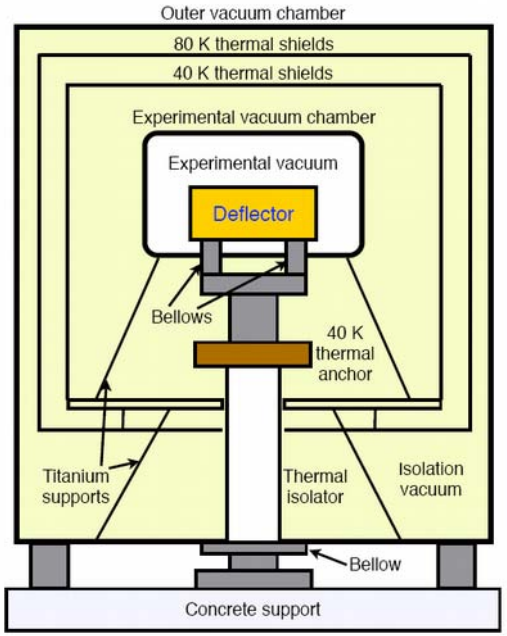
Oldřich Novotný
Daniel W. Savin

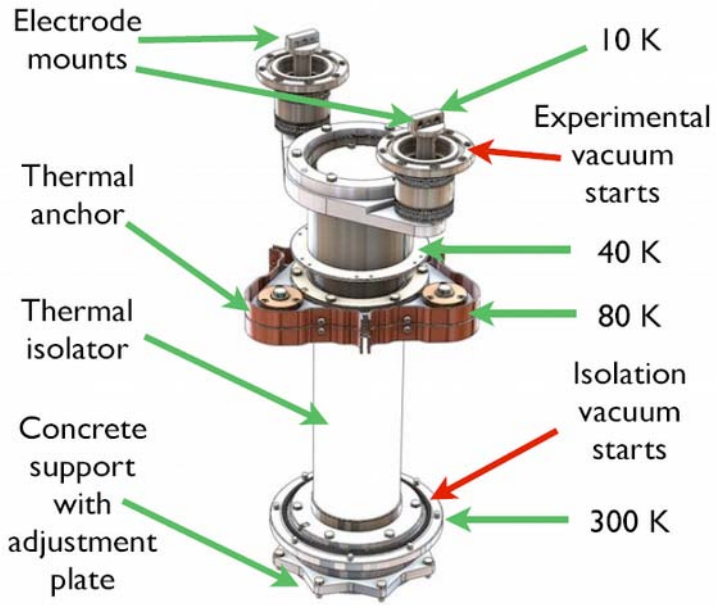
The CSR

Electrostatic beam optics

- Electrodes thermally anchored to cold chamber walls (≤ 10 K) …
- … but mechanically decoupled from them.
  (thermal shrinking of beam pipe)







The CSR

Electrostatic beam optics

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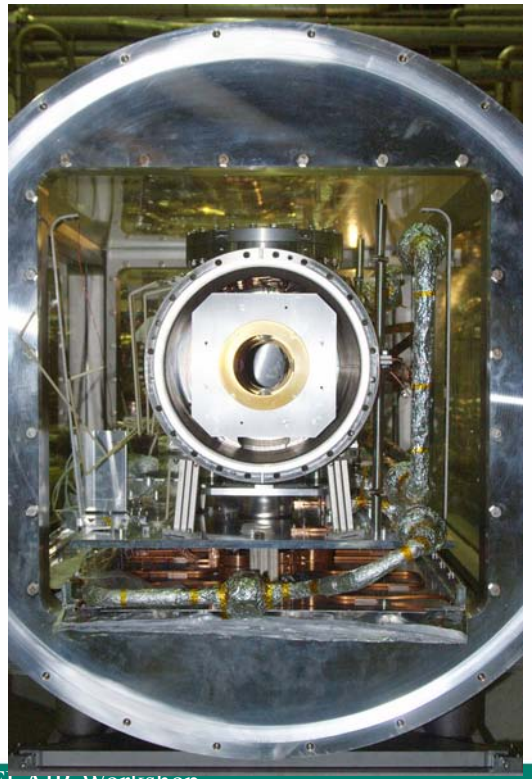
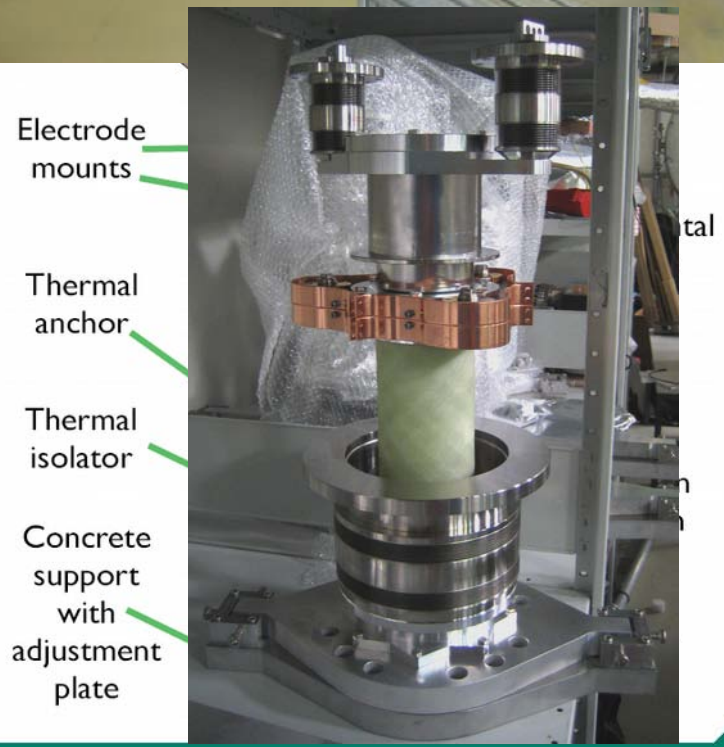
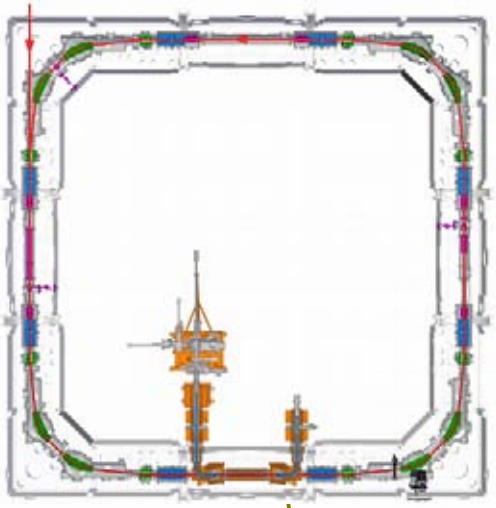


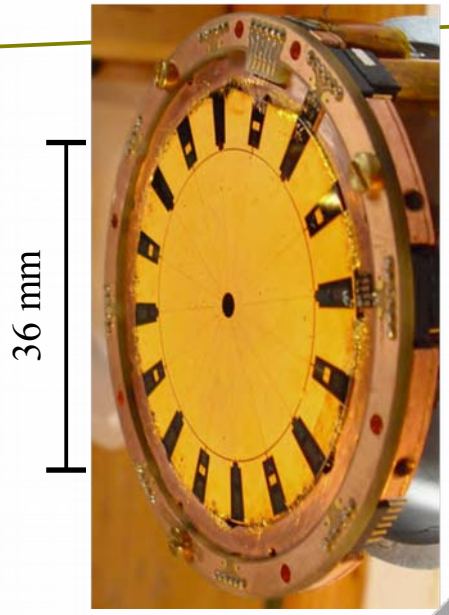


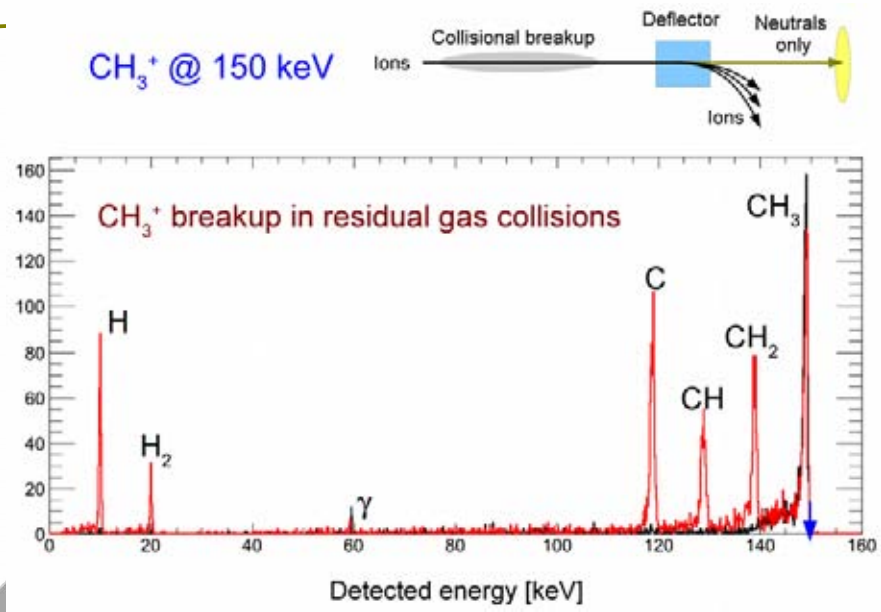
Electron Cooler - Detectors

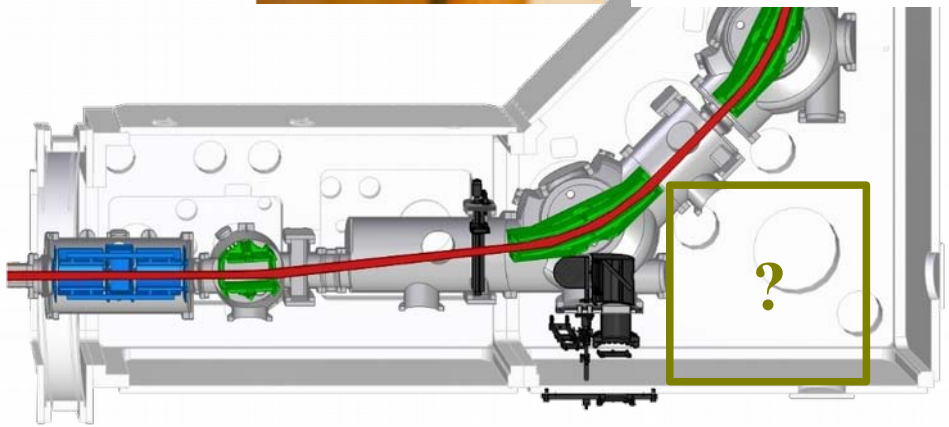


future upgrade:

PIZZA
segmented microcalorimeter







A. Fleischmann, C. Enss et al.
KIP, University of Heidelberg