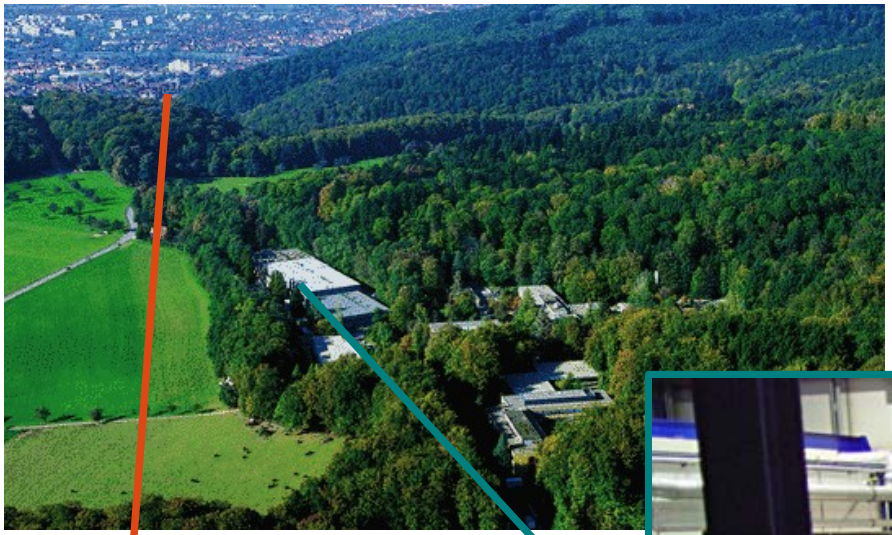
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

The Cryogenic Storage Ring

Claude Krantz

Max Planck Institute for Nuclear Physics

The CSR



Max Planck Institute for Nuclear Physics
(MPIK, Heidelberg, Germany)

The CSR, picture of 2/2/2013

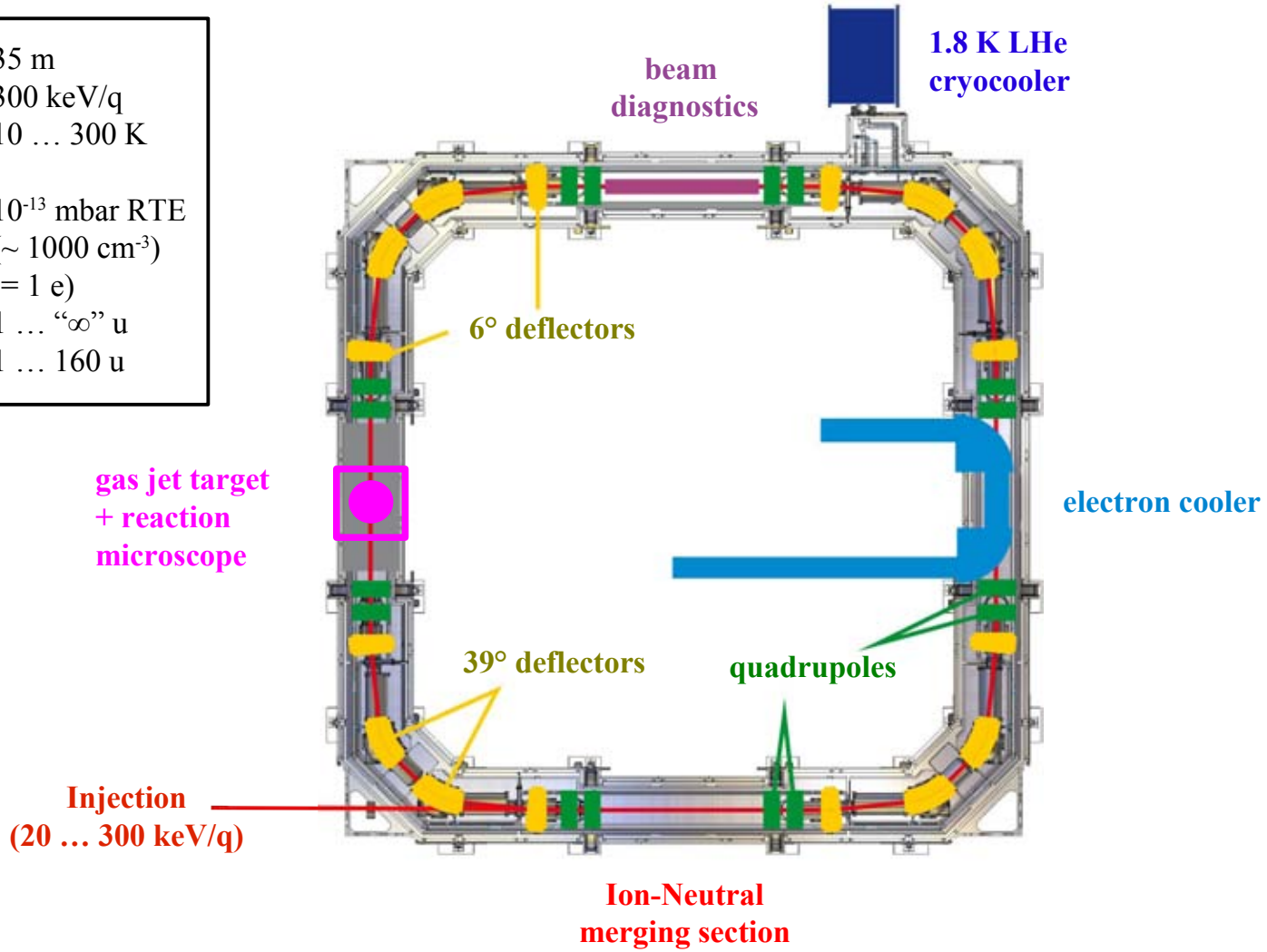
The Castle of Heidelberg

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

The CSR

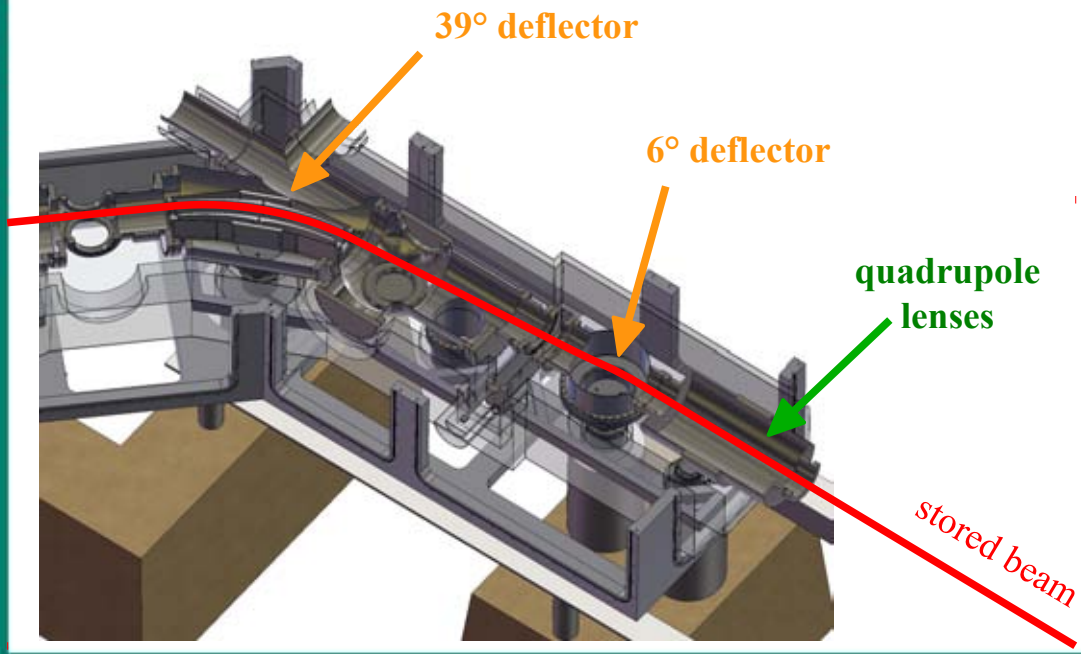
- CSR: a full-featured next generation storage ring

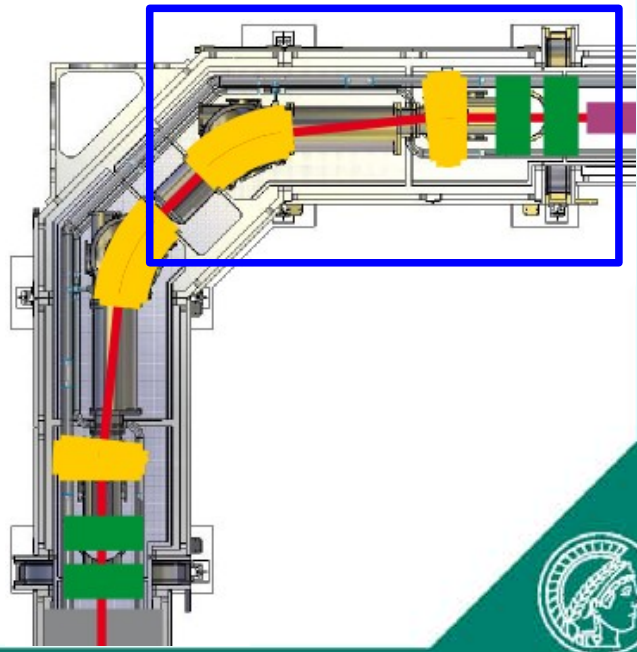
circumference:	35 m
beam energy:	300 keV/q
temperature:	10 … 300 K
res. gas press. (@ < 10 K):	10^{-13} mbar RTE (~ 1000 cm^{-3})
ion masses (for q = 1 e)	
no cooling:	1 … "∞" u
with cooling:	1 … 160 u



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 (30 kV)
  - 4 x 2 **39°-deflector** electrodes (30 kV)
  - 4 free straight sections (2.6 m each)





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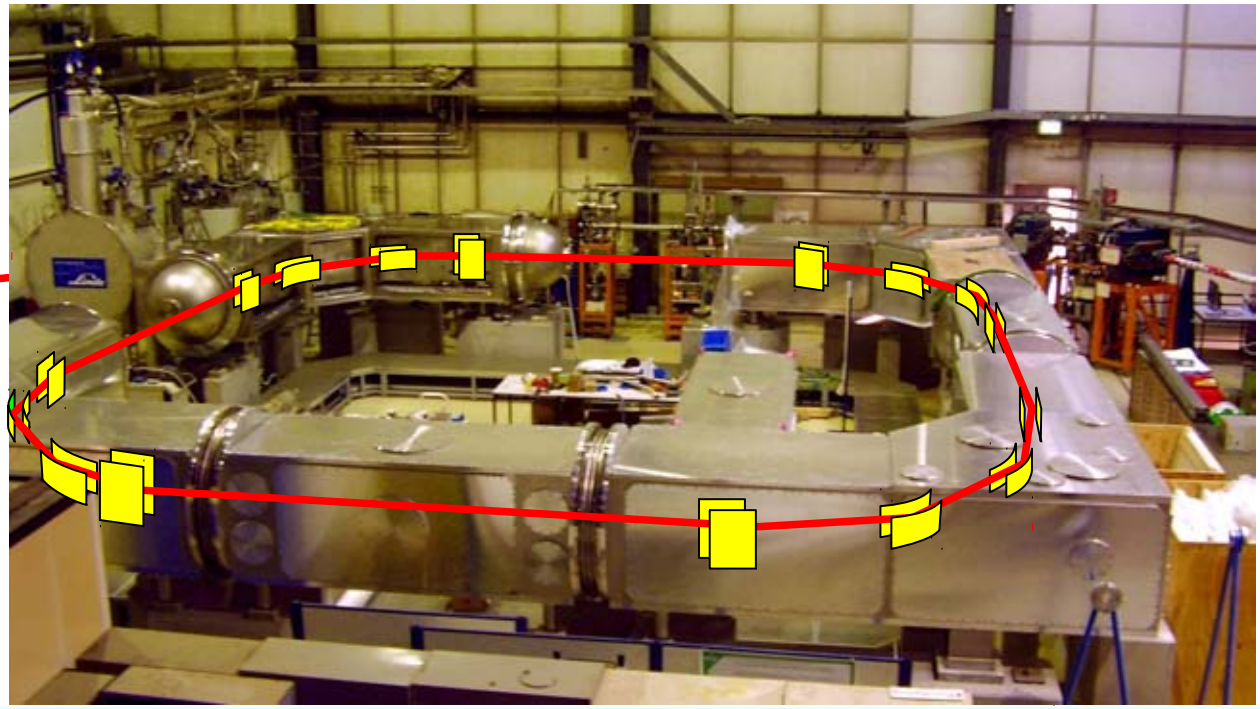

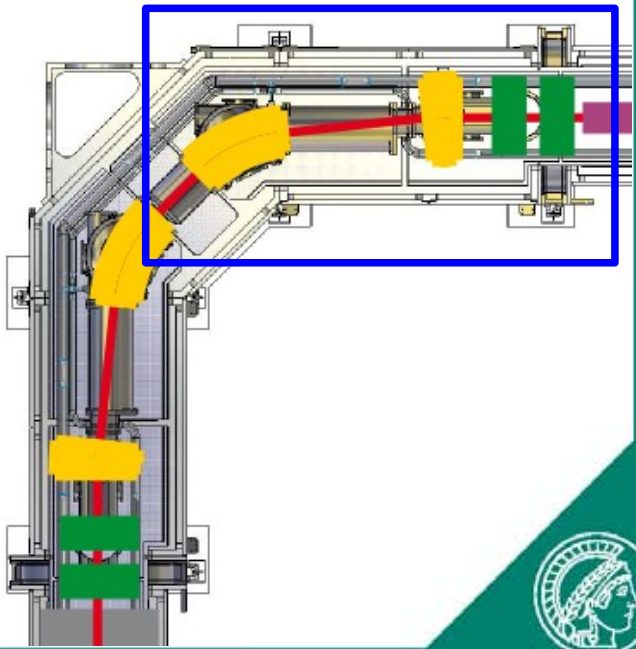

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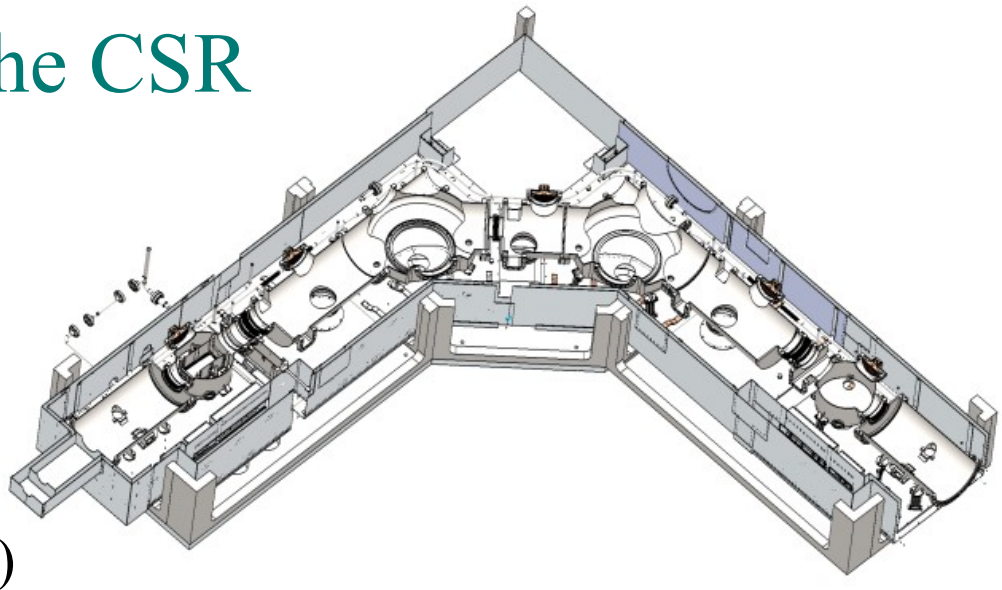
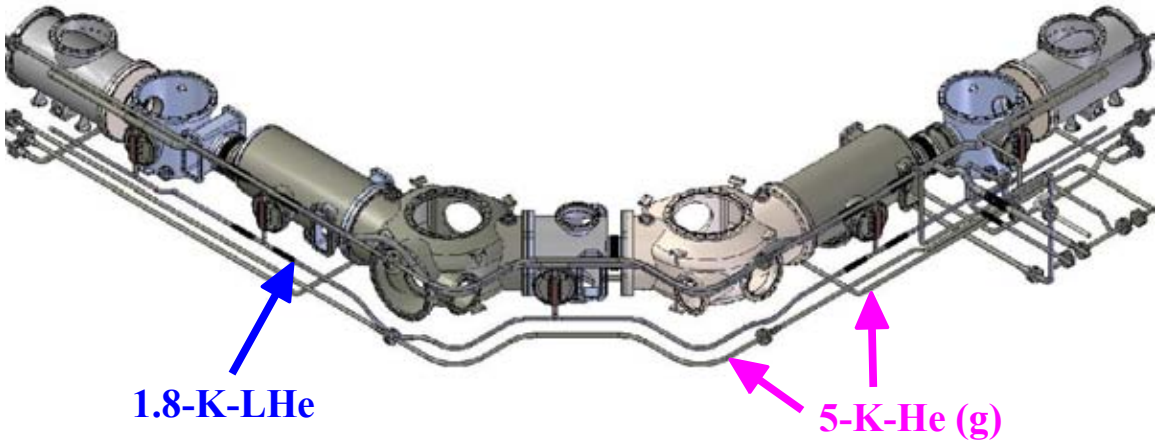
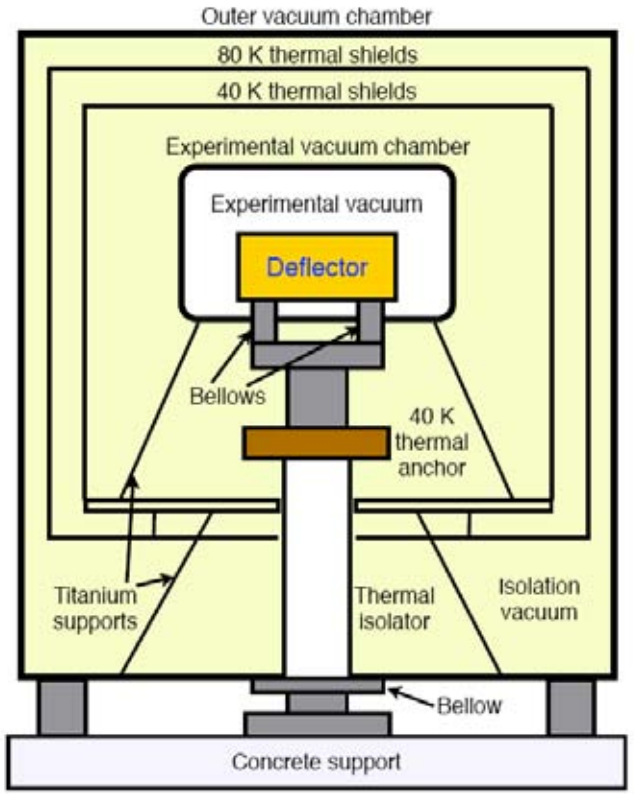


- Cryogenics
  - Multi-layer cryostat
  - Inner vacuum chamber (≤ 10 K)
    cooled by superfluid He (20 W).
  - 2 radiation shields (40 and 80 K)
    cooled by 5-K He (600 W)
  - Superinsulation
  - Isolation vacuum chamber





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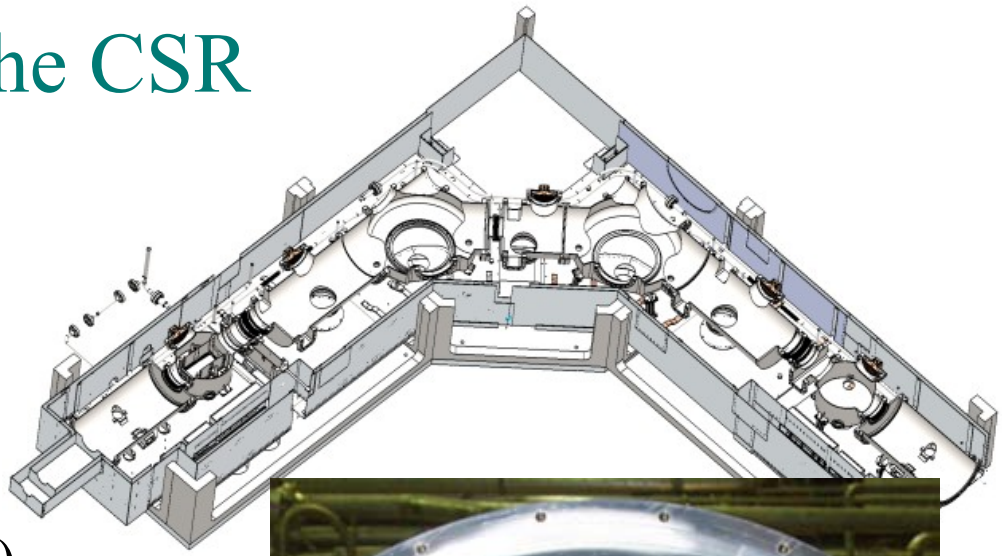
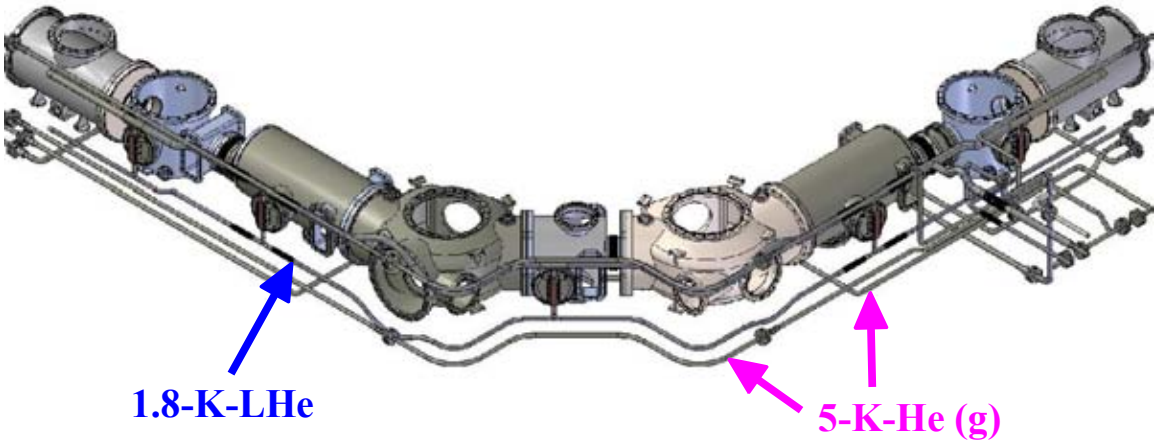
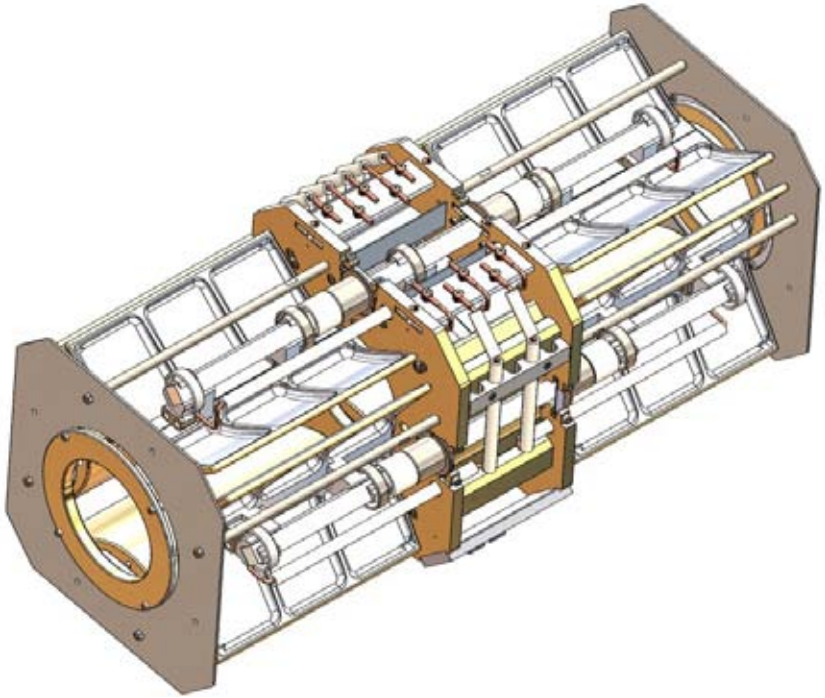
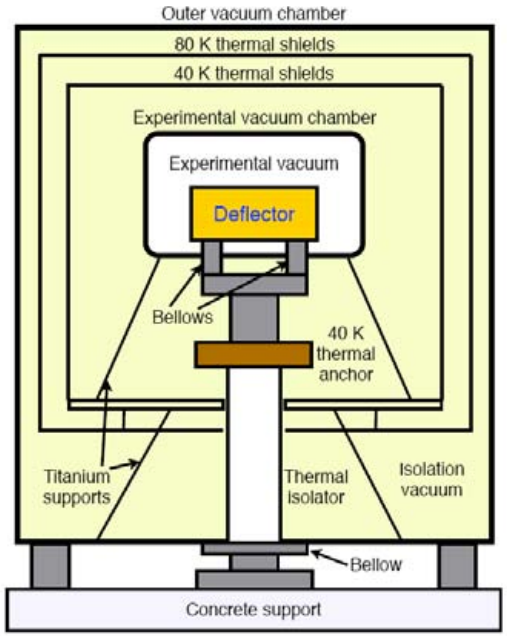


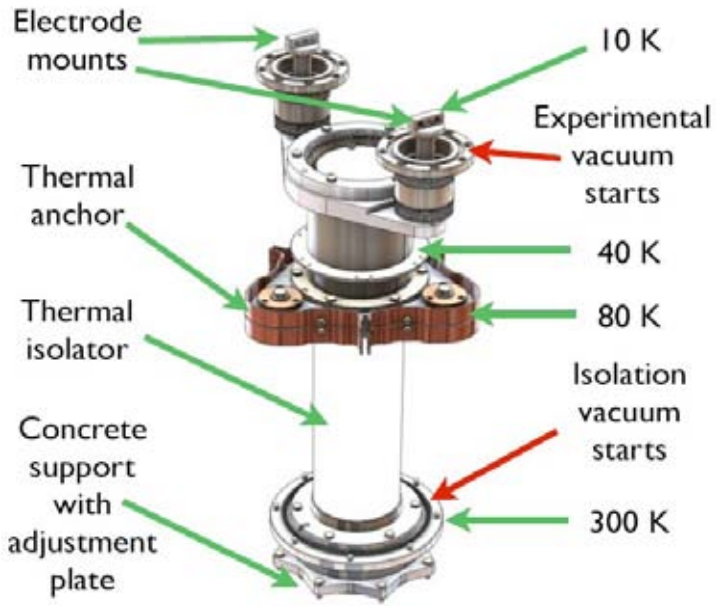


The CSR

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







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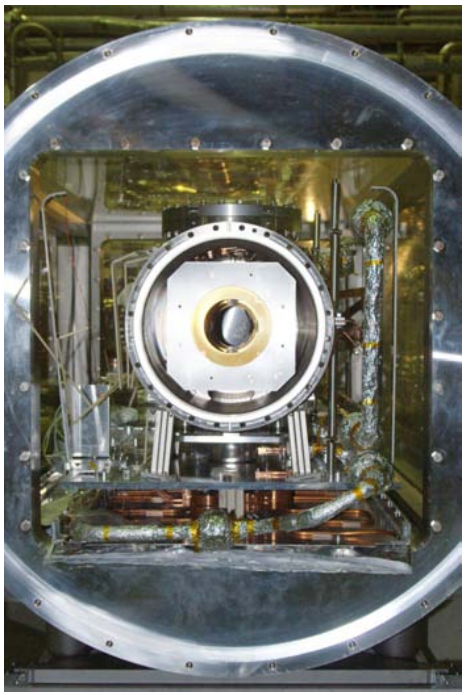
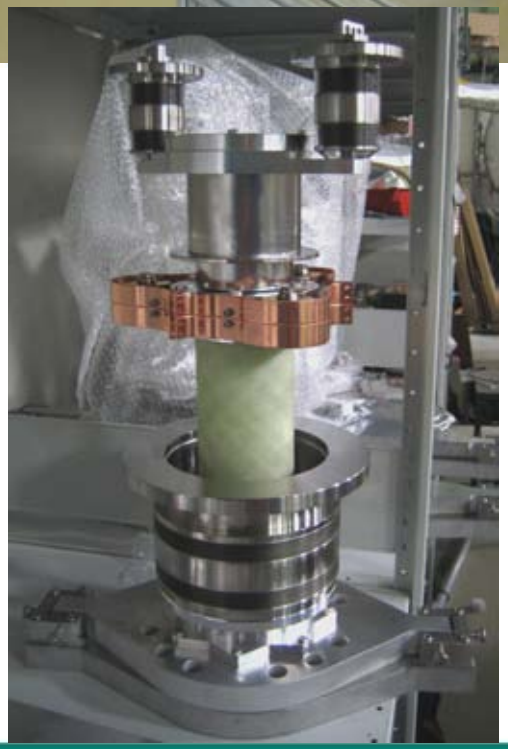
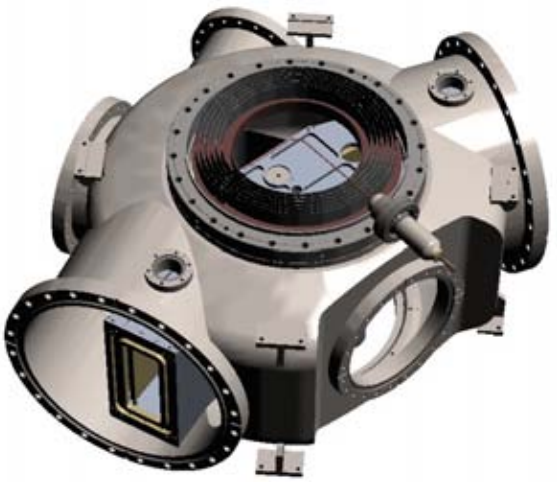
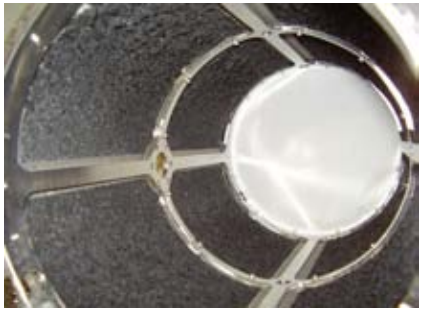


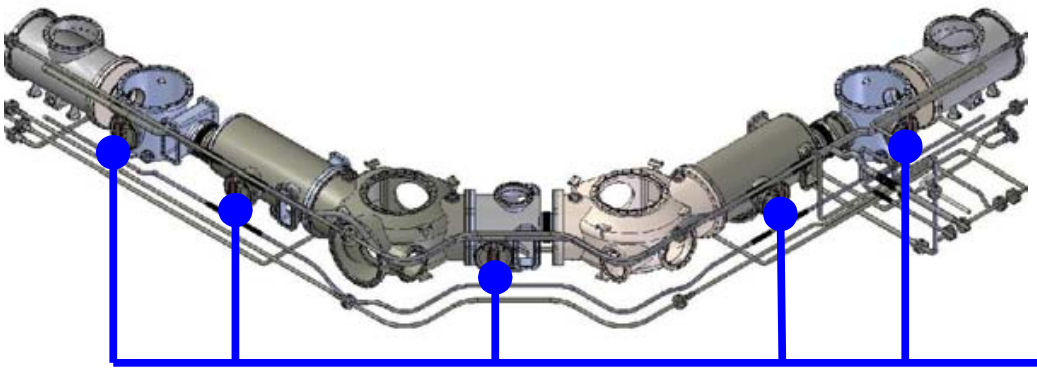


The CSR

- XHV: Extremely High Vacuum
  - In 300-K-operation: **~ 10^{-11} mbar**
    200°C – 300°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

First corner: **completed + tested**

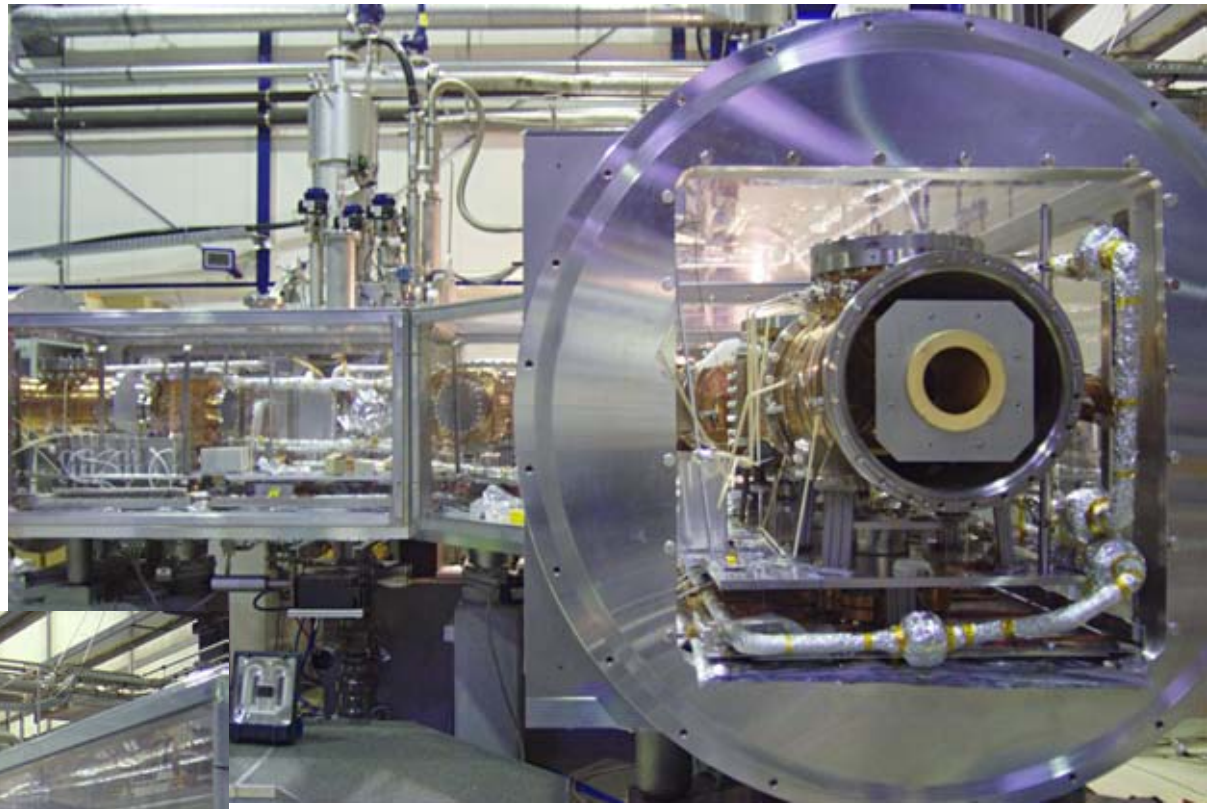
Remaining 3 corner sections: **To be completed by summer 2013**

Present Status

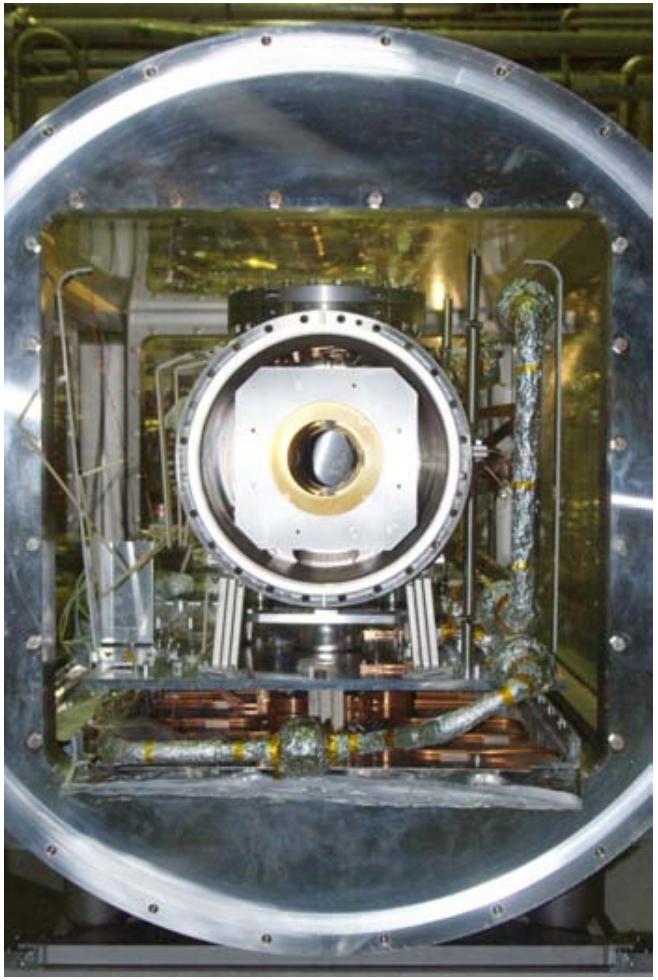
First optics corner:

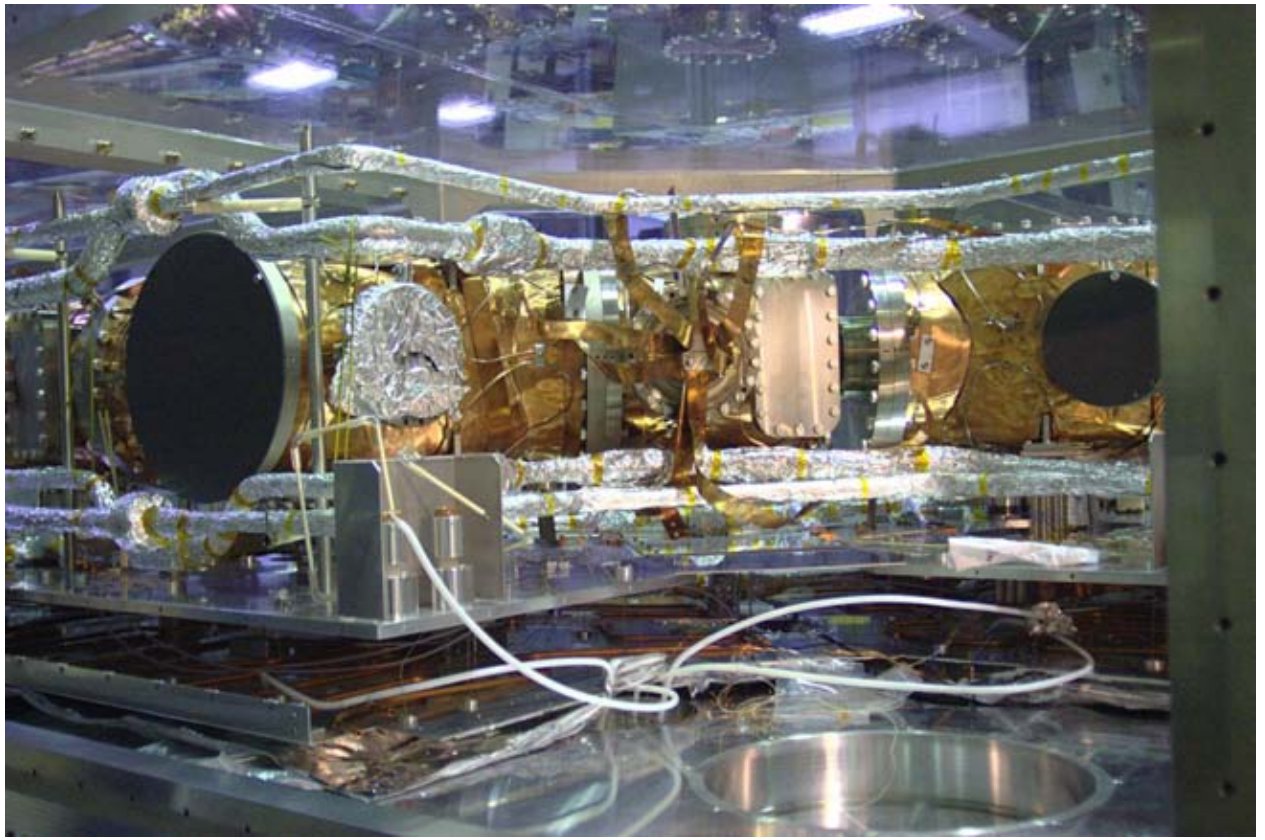
… reached **< 10 K** in 2012 √

… **bakeout** test scheduled for March. •



Present Status

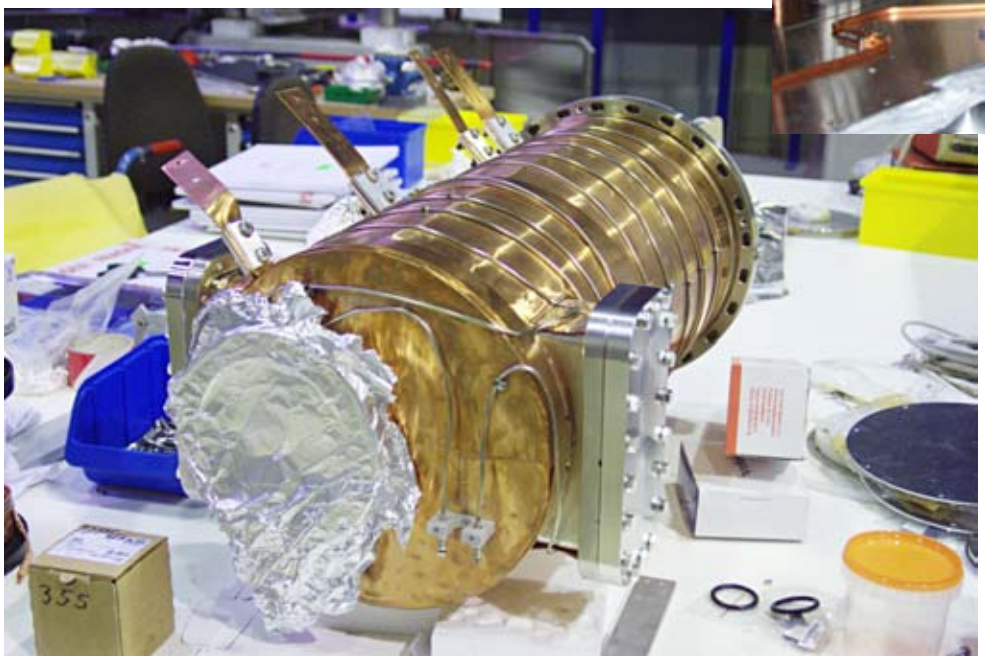




first optics corner

Present Status

assembly of remaining
corner sections



Timeline

Phase 1 (2013):

Commissioning of CSR (300 K)

Storage at 10 K

Experiments with uncooled beam

(but: **radiative cooling!)**

Phase 2 (2014 → …):

Installation of **electron cooler**

Experiments with cooled beams (internal AND external!)

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)**

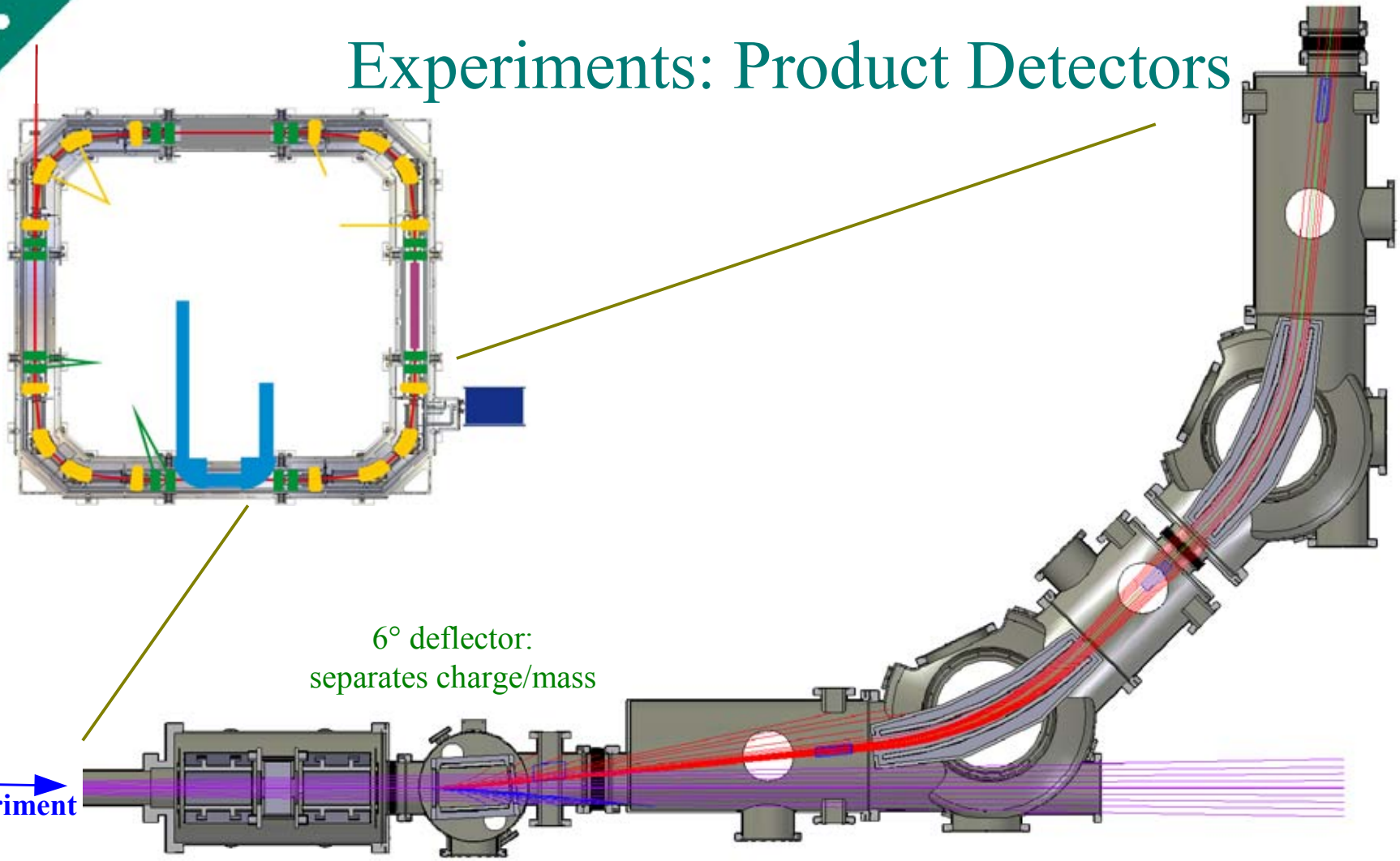
  Storage of large or heavy (= slow)
  ions/molecules for long times (~ 1000 s)

  (from 2014)
  Phase-space cooling with
  CSR electron cooler

- **Cold environment (10 K)**

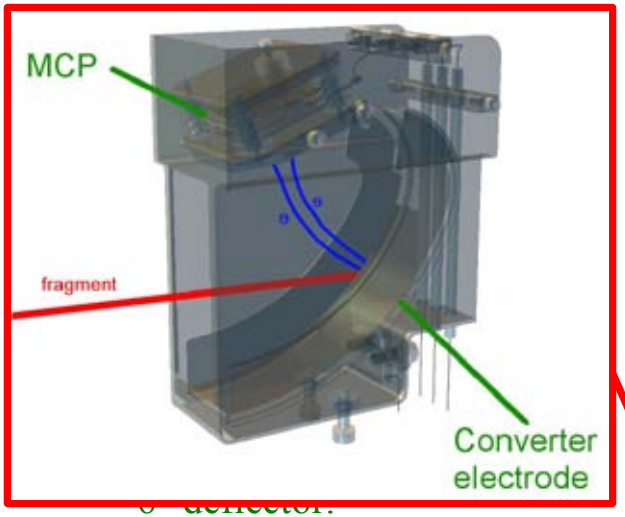
  Internal cooling of
  IR-active species

Experiments: Product Detectors



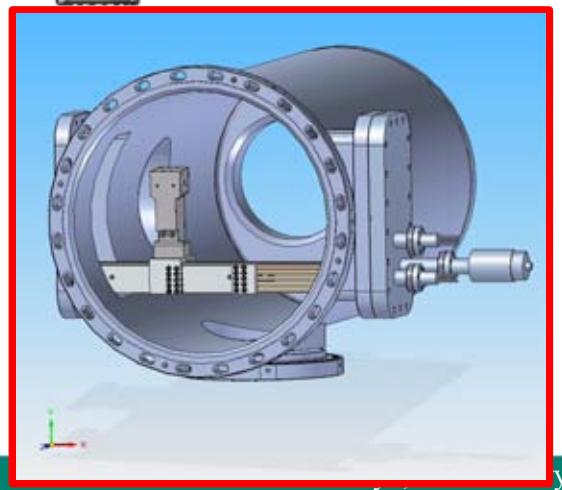
Experiments: Product Detectors

charge-changed product detectors



separates charge/mass

from experiment



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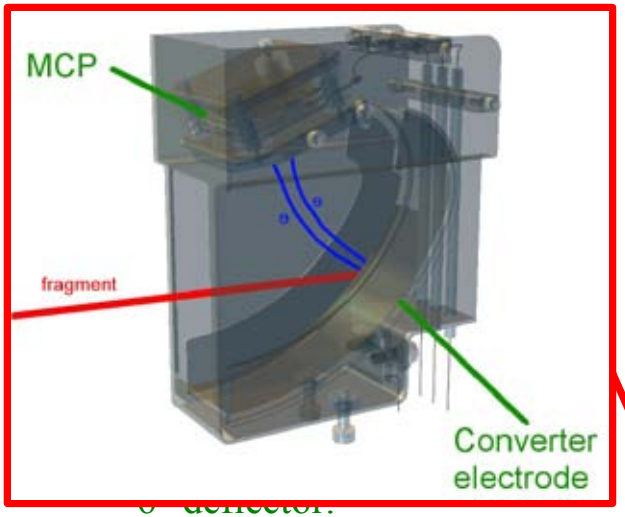
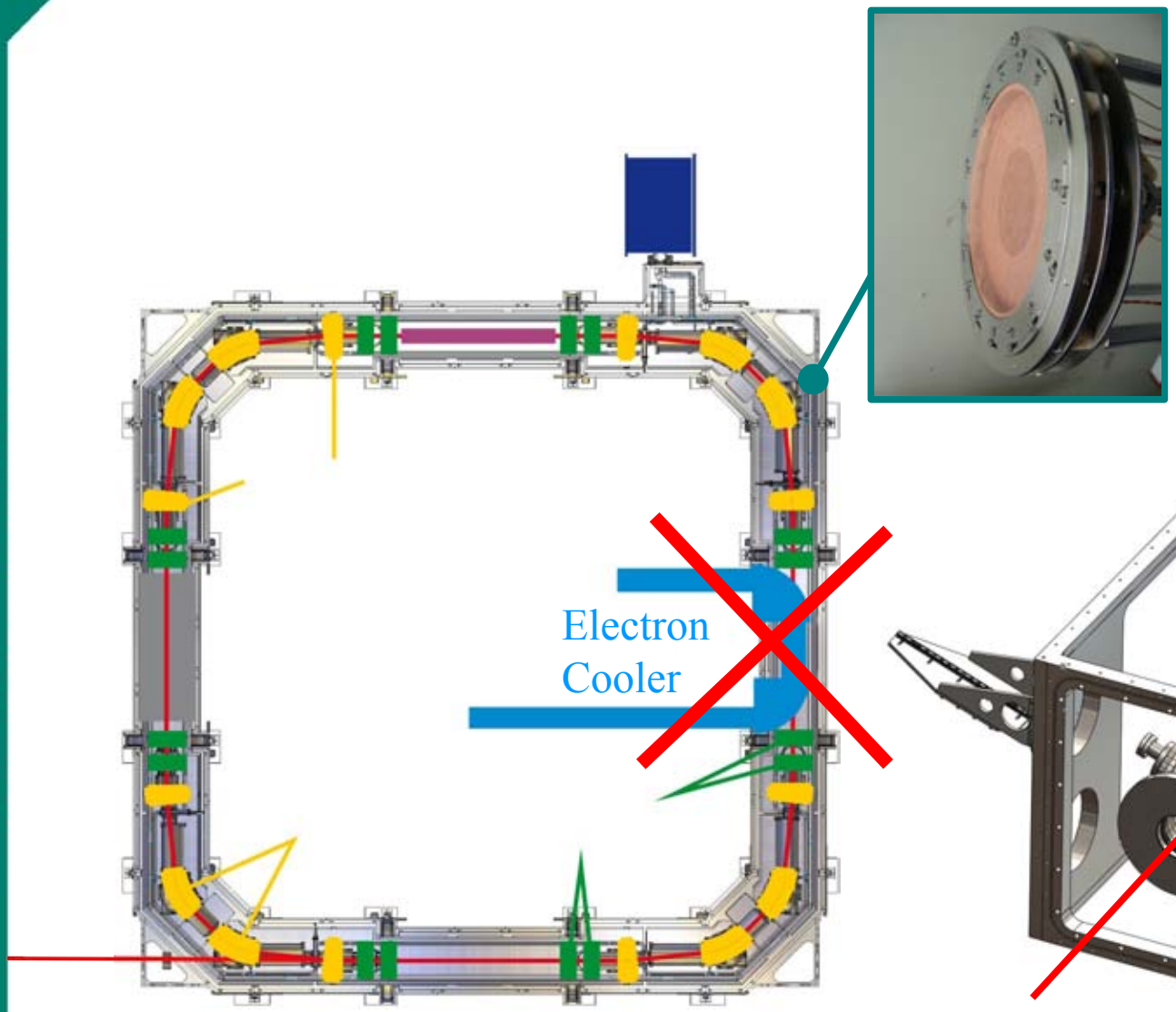


separates charge/mass

from experiment

neutral product detectors: MCP, phosphor screen + pulse timing

Phase 1 Experiments: Laser Interactions



Laser interaction section
instead of electron cooler

Phase 2 Experiments: Electron Cooled Ions

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

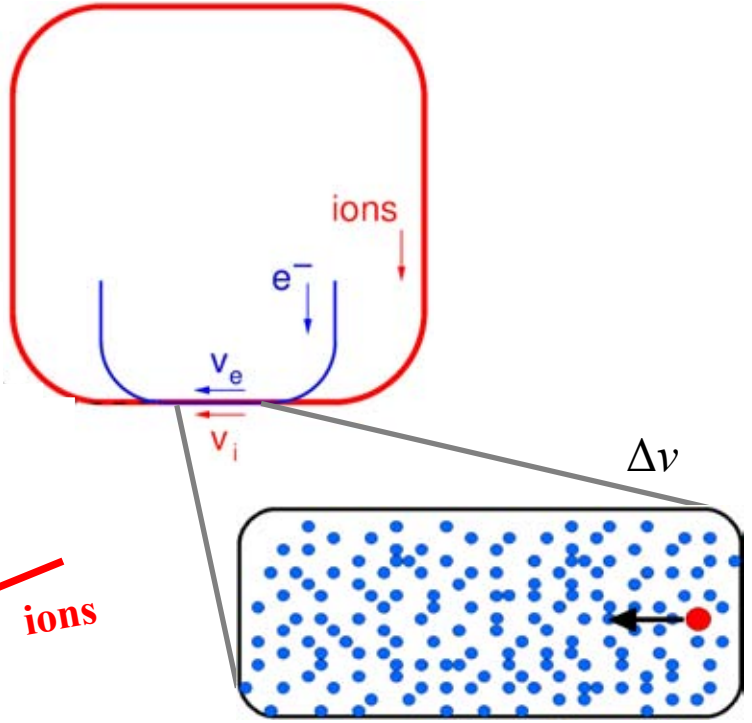
CSR energy limit: → Need **very** slow electrons

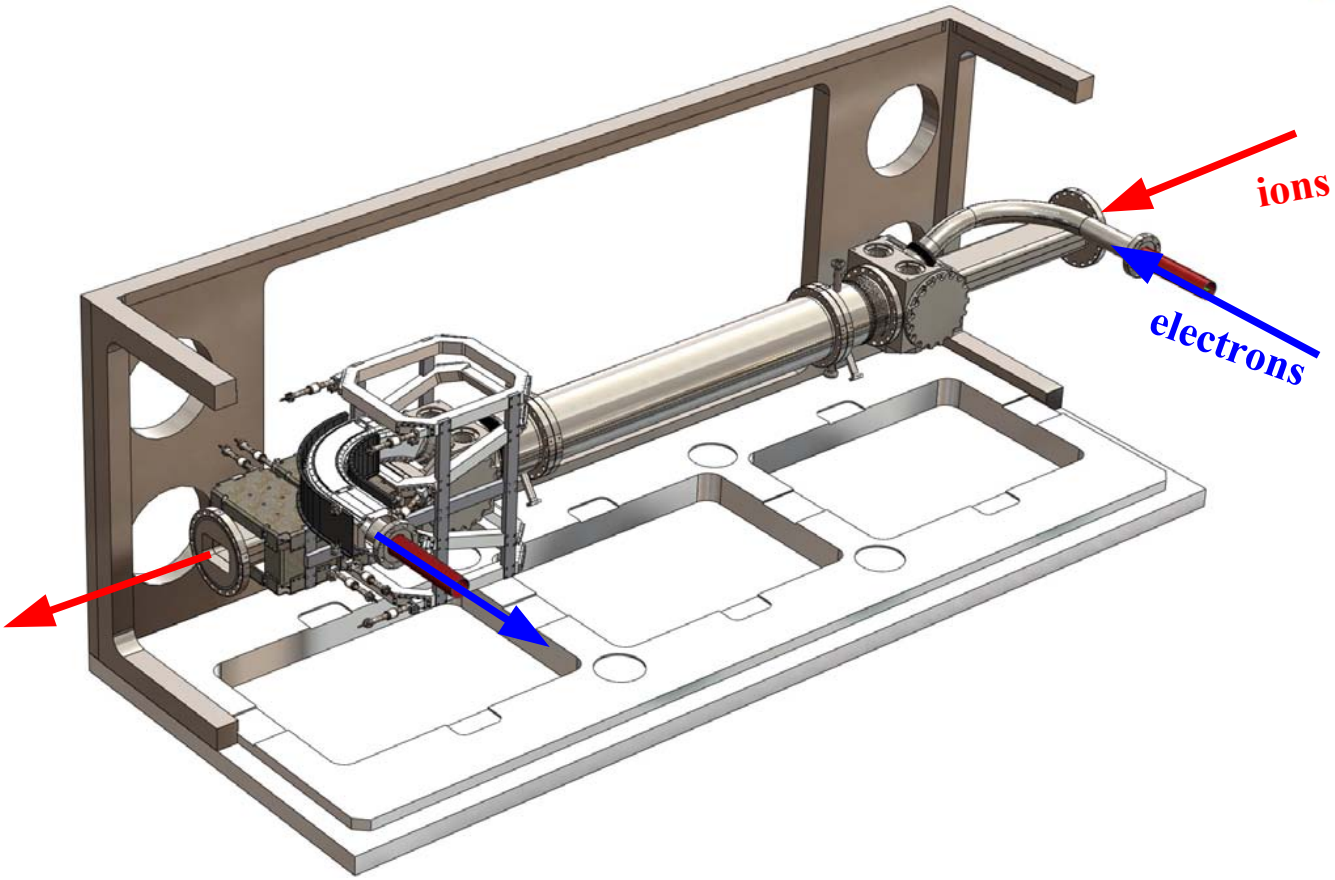
E_{ion}/Z_{ion} = 300 keV

160 eV for p^+

< 20 eV for most ions

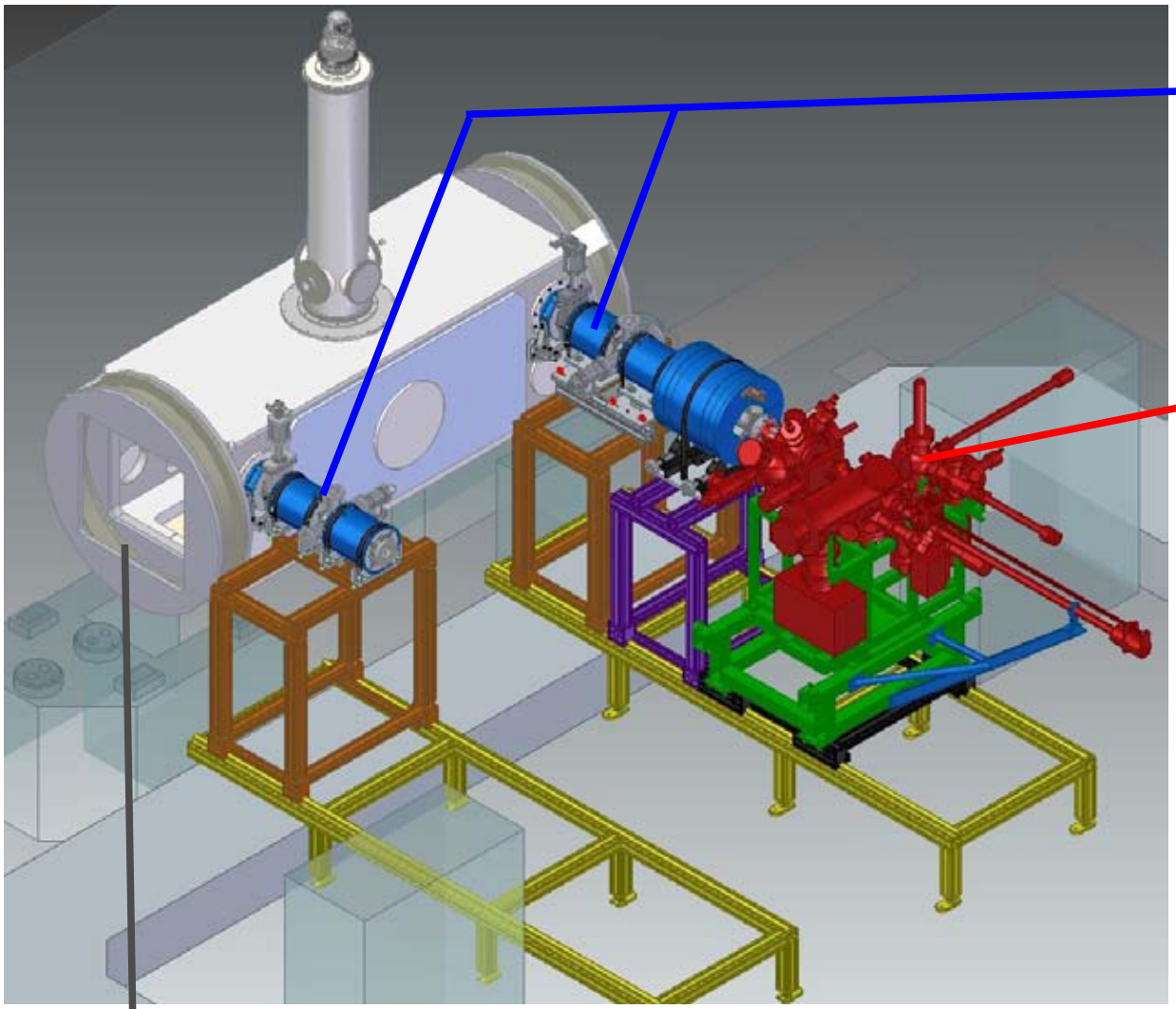
1 eV for M_{ion} = 160 u





500 km/s

Electron Cooler

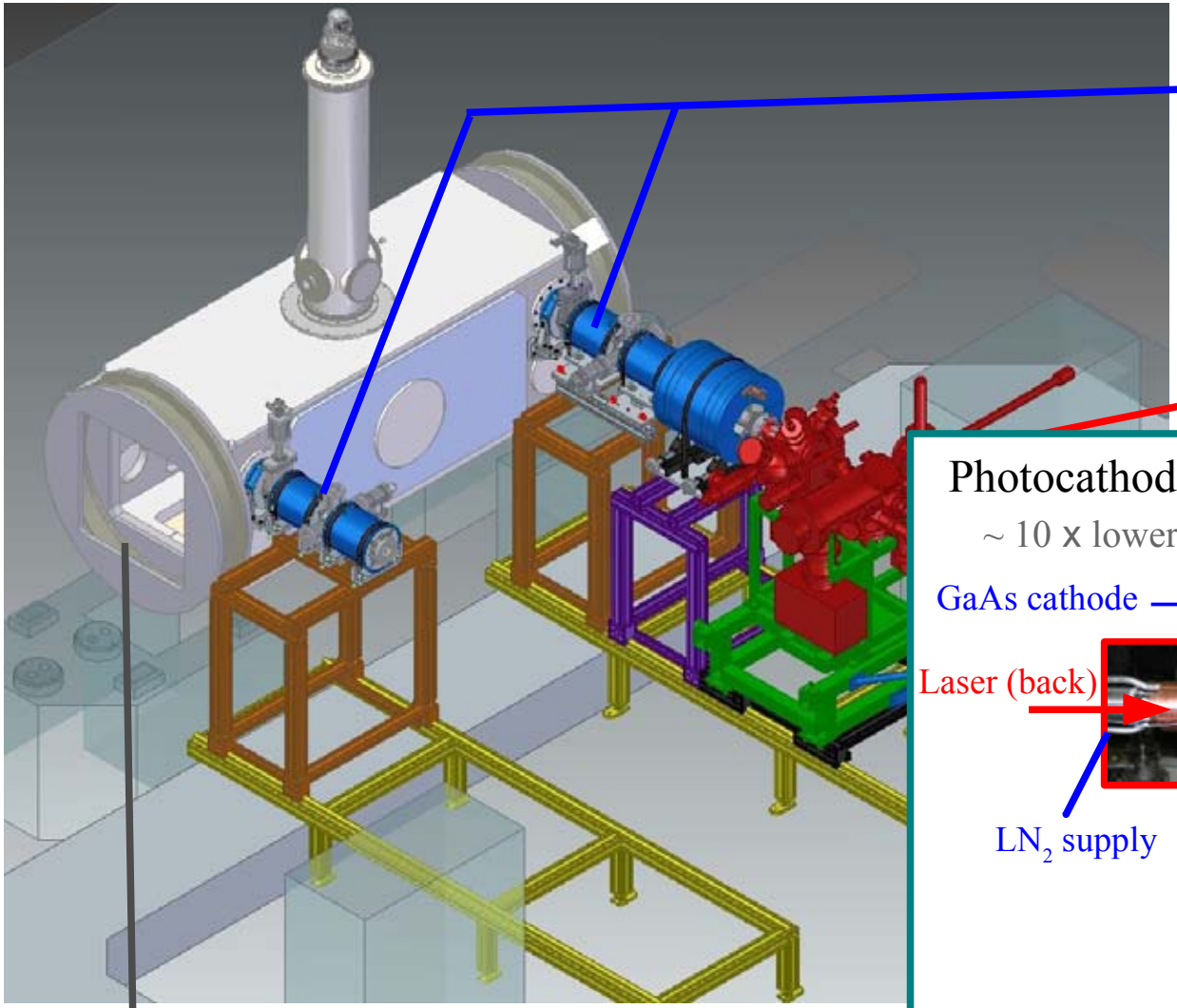


Warm electron beam lines

TSR E-Target photocathode e-gun (T_e ~ 10 K)

CSR

Electron Cooler



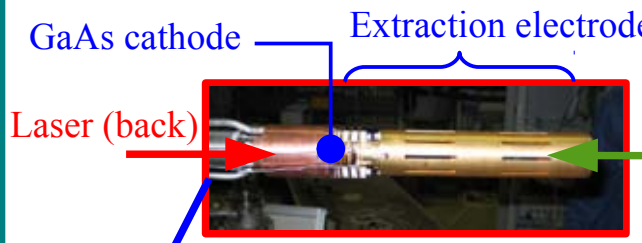
Warm electron beam lines

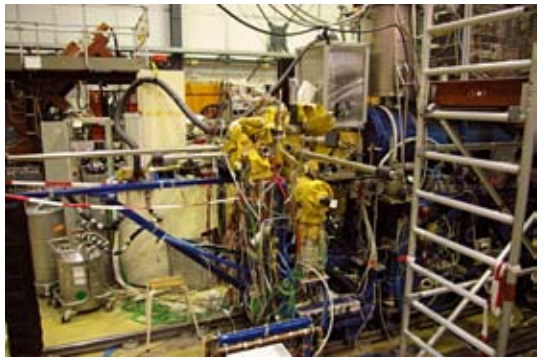
TSR E-Target photocathode e-gun (T_e ~ 10 K)

CSR

Photocathode electron source (TSR) :

~ 10 x lower T_e compared to thermionic emission



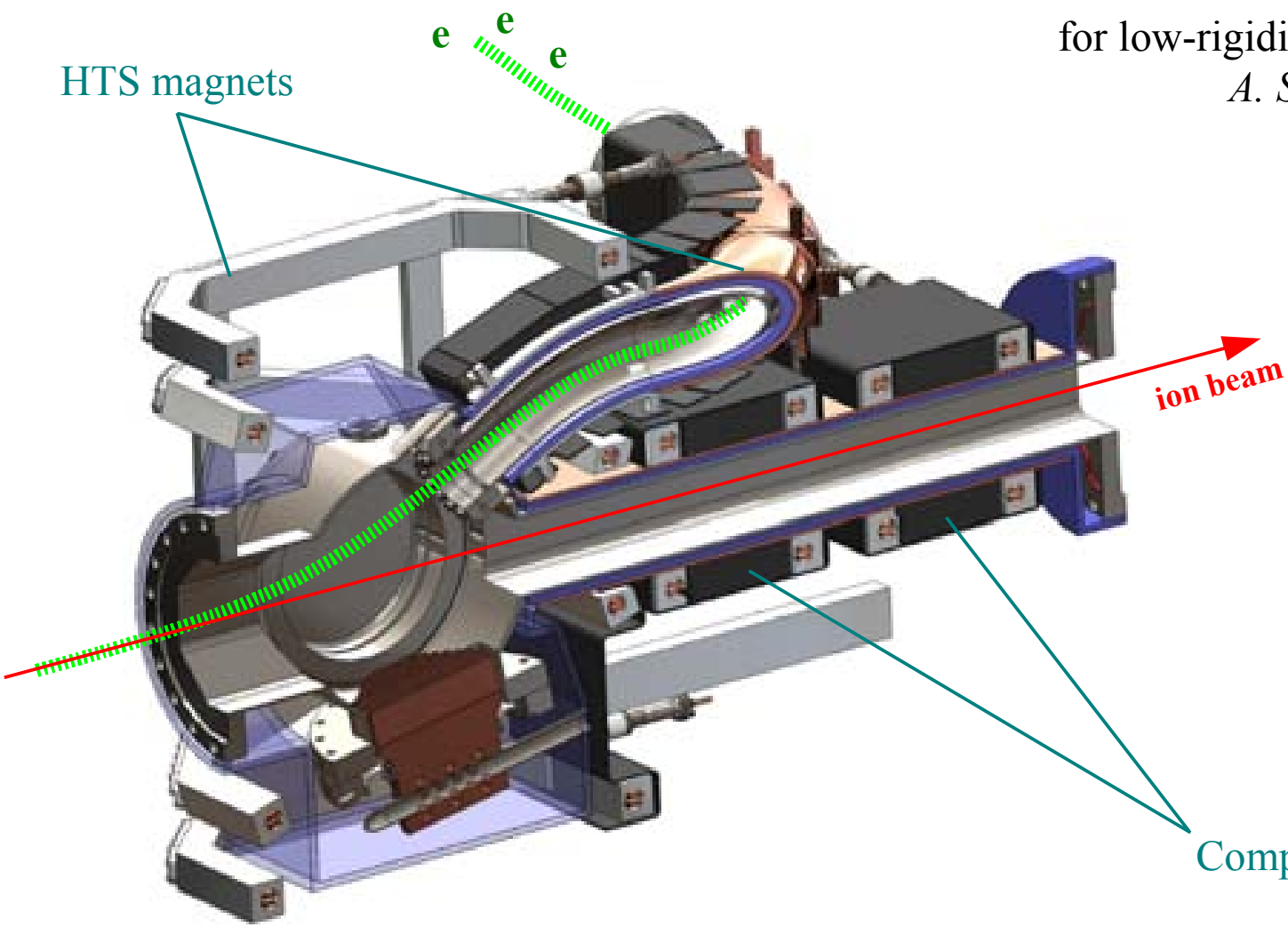


$k_B T_e$ ~ 1 meV

n_e ~ 10^5 cm^{-3} @ 1 eV

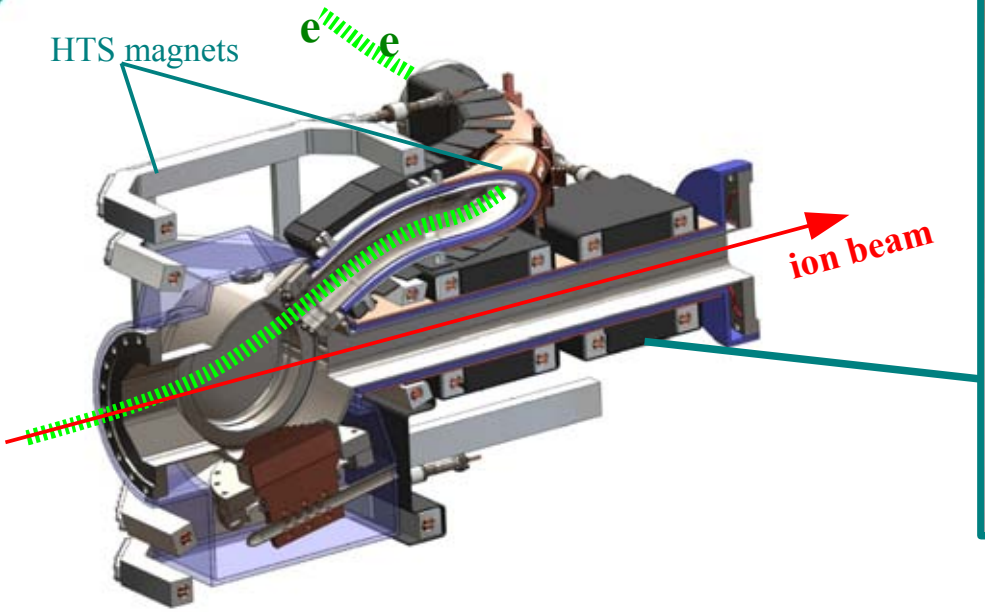
Electron Cooler

"horizontal-vertical" merging scheme
for low-rigidity ion beams
A. Shornikov, PhD thesis



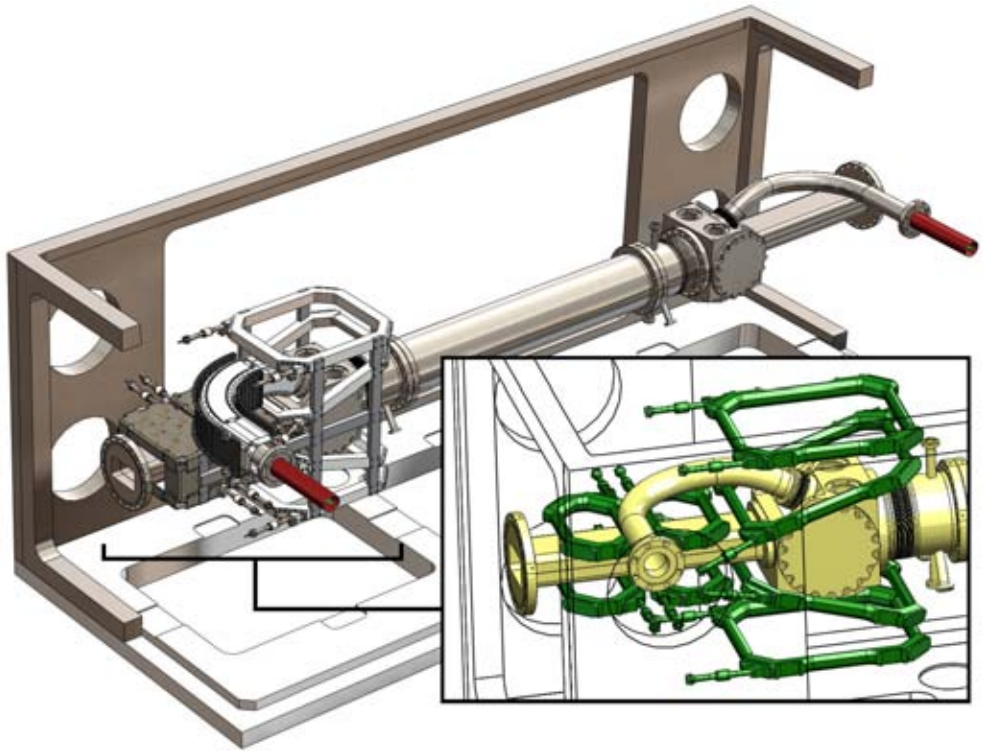
A. Shornikov, PhD

Electron Cooler



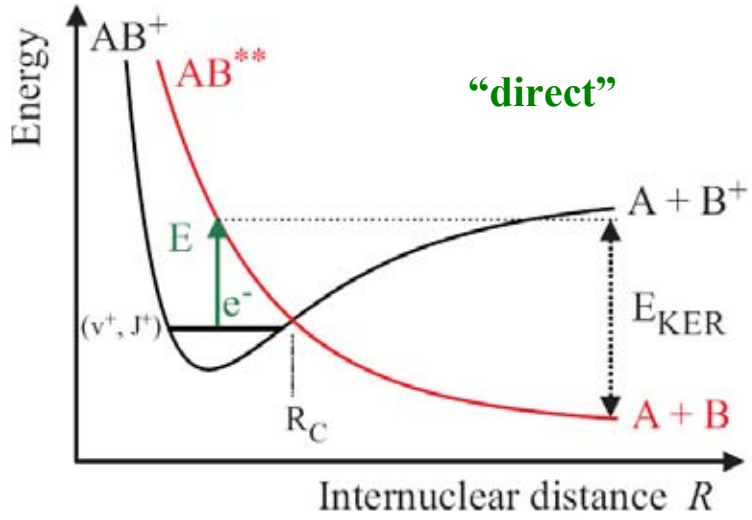
Superconducting coils have been tested

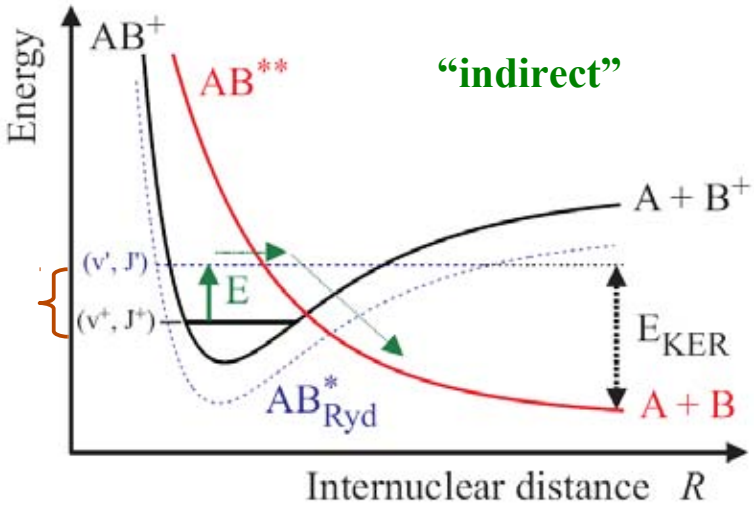
(LNe, approx. 30 K)



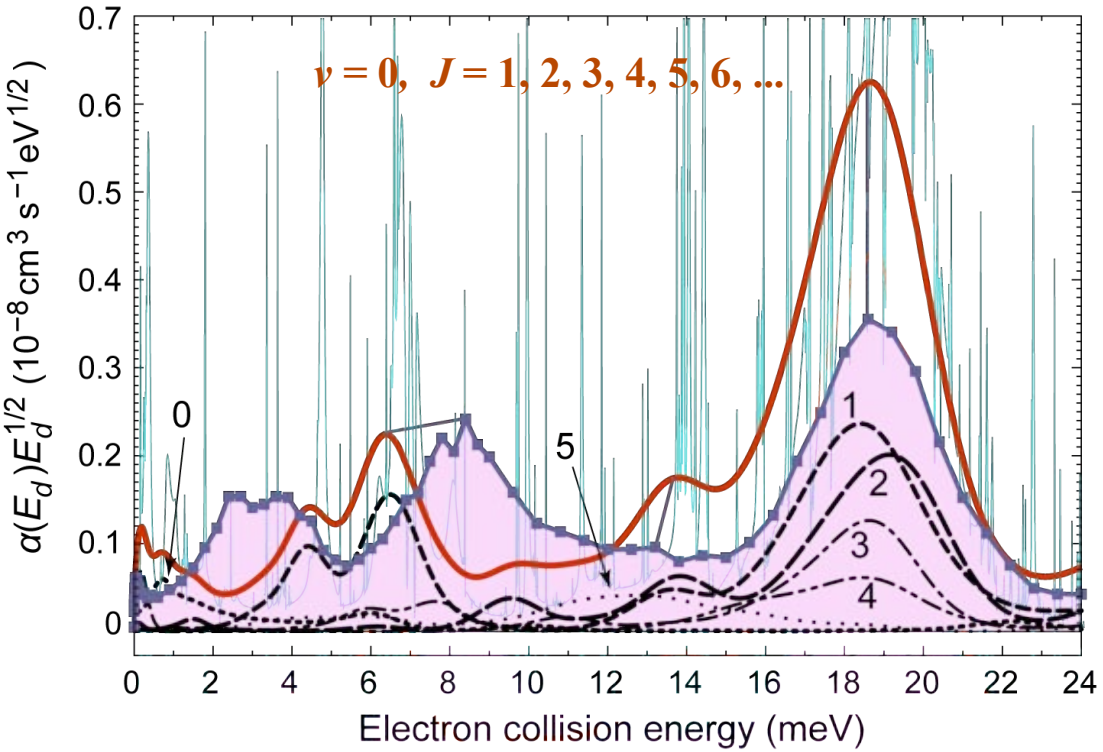
Merging magnets and chambers are being manufactured.

Phase 2 Experiments: Electron Collisions





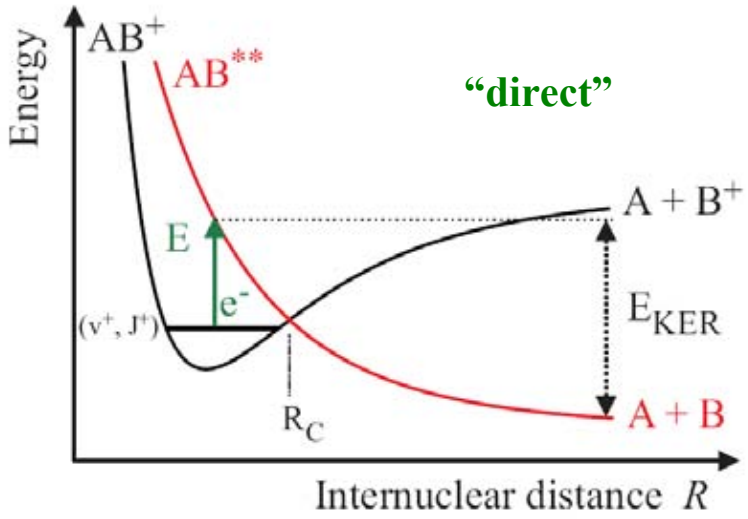
$HD^+ + e \rightarrow H + D$

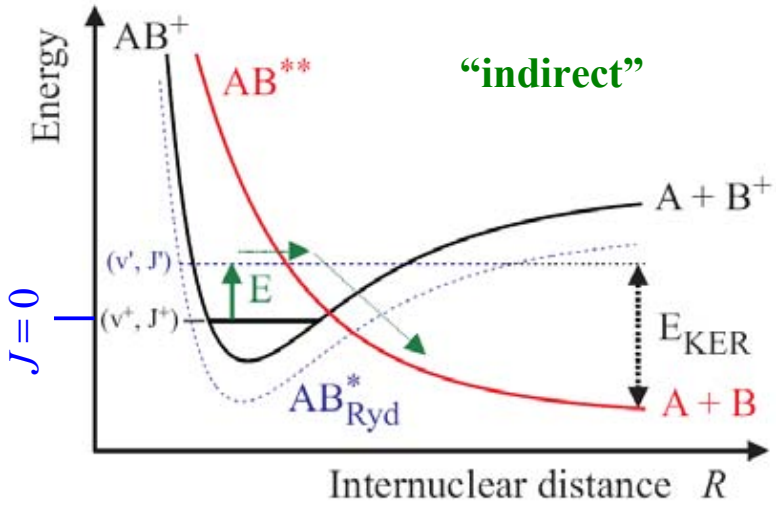


Waffeu-Tamo *et al.*, PRA 84 (2011) (0 K)

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

Phase 2 Experiments: Electron Collisions





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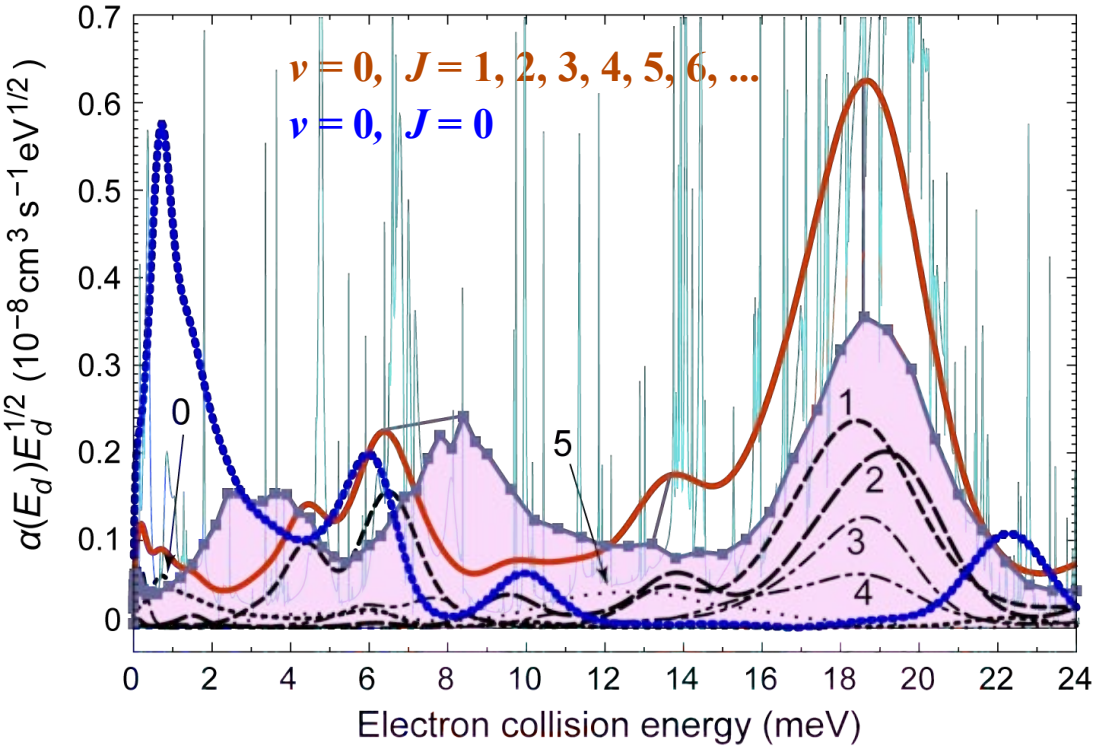


Waffeu-Tamo *et al.*, PRA 84 (2011) (0 K)

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 K → $J = 0$

Phase 2 Experiments: Electron Collisions

- Slow, heavy/complex ions

  - Singly-charged atomic ions: C^+, N^+, F^+, Si^+, P^+, Cl^+, Fe^+
    Contribute to cold astrochemistry [Bryans et al., ApJ 694 (2009)]
    Dielectronic recombination via fine-structure excitation

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

    Not measurable in TSR due to field ionisation and non-DR background!

  - Electron collisions of Cluster ions …
    Dependence of rate coefficients on internal excitations ?

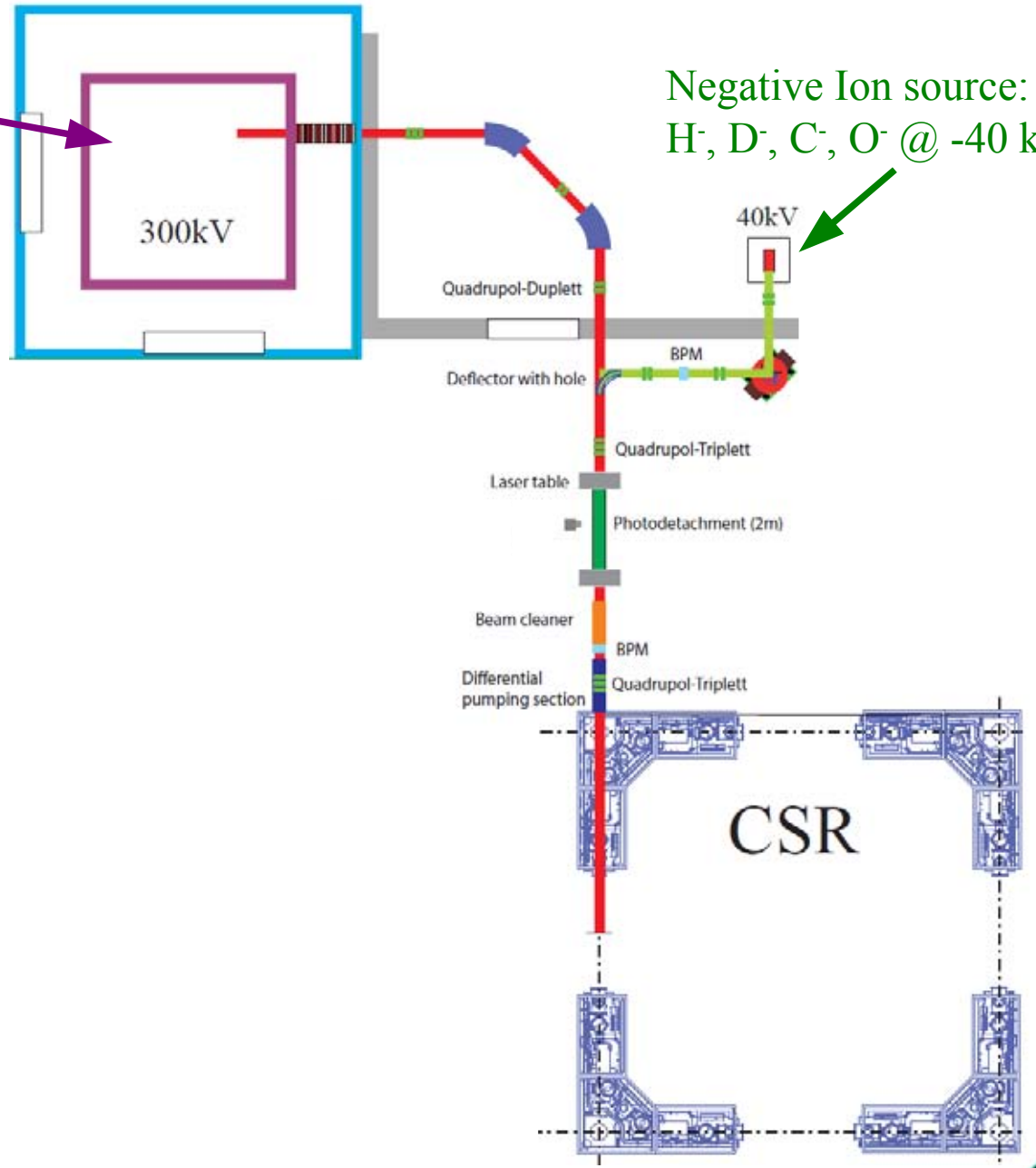
  - DR of large organic molecules $C_xH_y^+$, $C_xH_yOH^+$ ...
    Complex chemistry in cold interstellar media

  - Transition to non-dissociative recombination?
    Recombination by non-destructive intramolecular energy repartitioning.

Phase 2 Experiments: Slow Neutral Collisions

CSR main injector:
+300 kV

Negative Ion source:
H^-, D^-, C^-, O^- @ -40 kV



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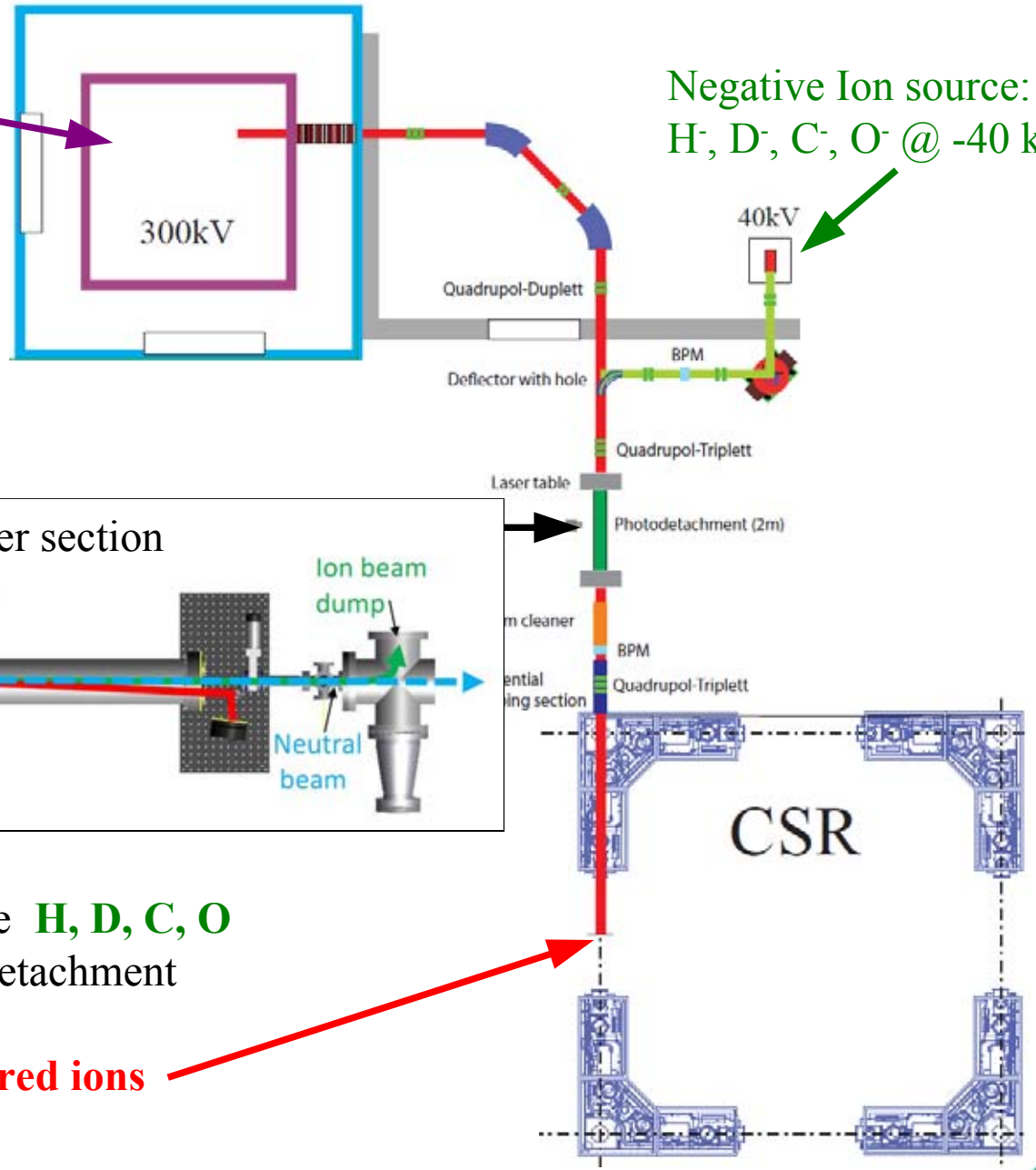
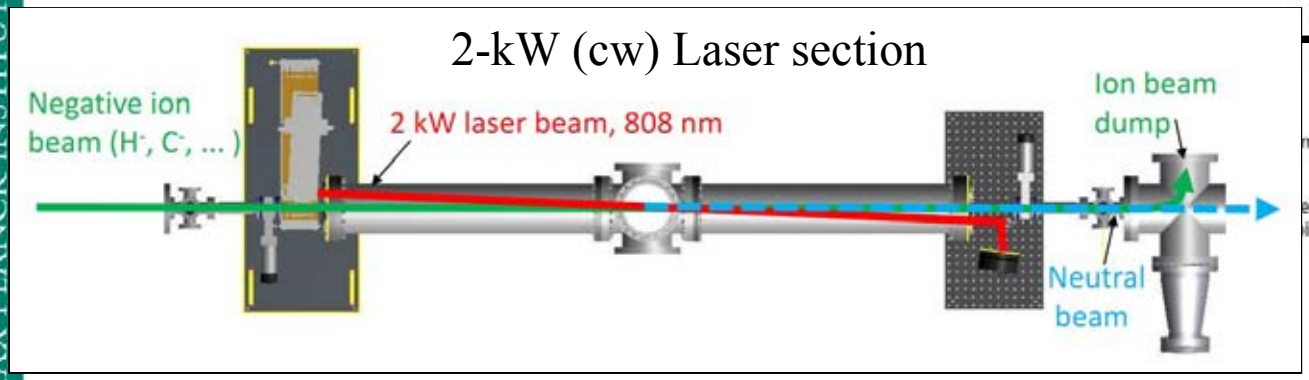


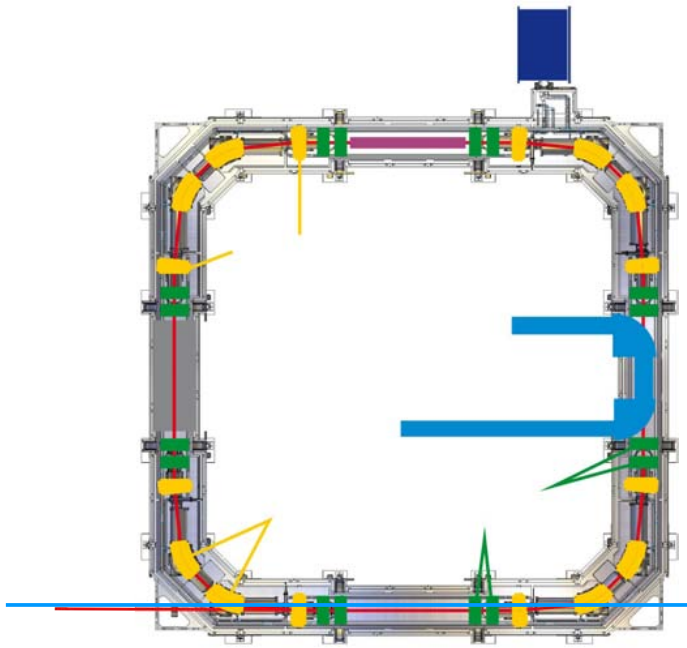
H. Kreckel et al.



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

superimpose the to the **stored ions**

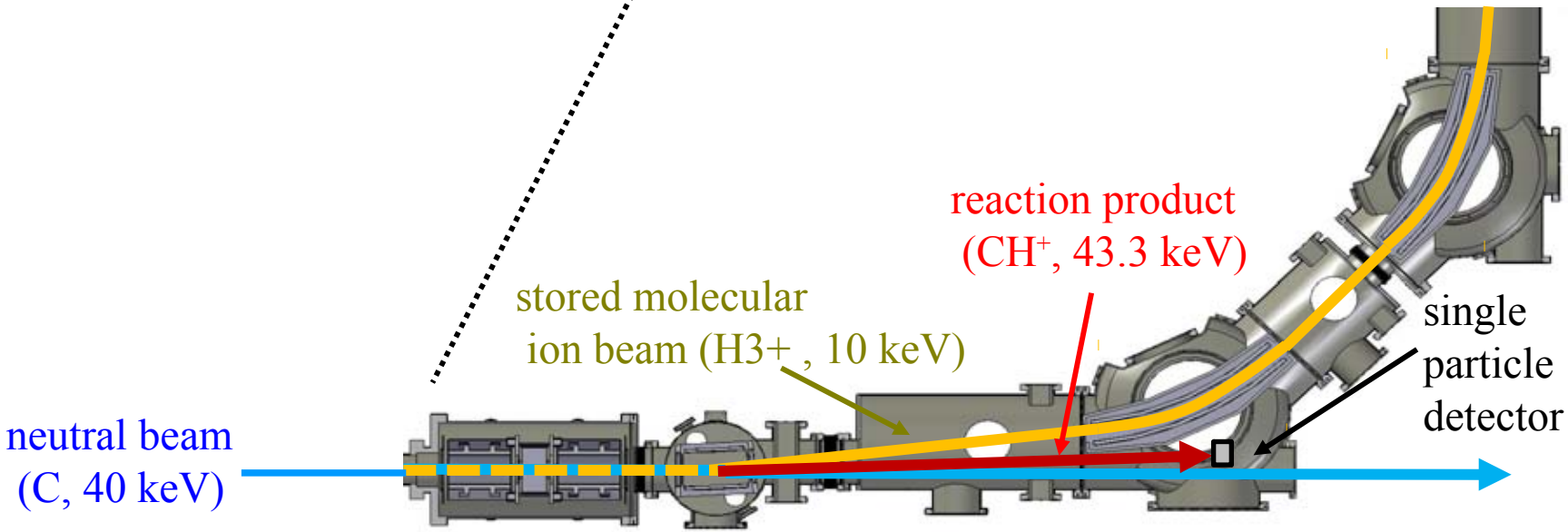
Phase 2 Experiments: Slow Neutral Collisions



Example:

Protonation of C by H3+
in Interstellar Space

$$C + H_3^+ \rightarrow CH^+ + H_2$$



H. Kreckel et al.

Summary

- CSR, a next-generation electrostatic storage ring will be 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 on molecular and other heavy 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.
Michael Lange
Stephen Vogel
Robert Repnow
Manfred Grieser
Andreas Wolf

Université Catholique, Louvain-la-Neuve

Xavier Urbain

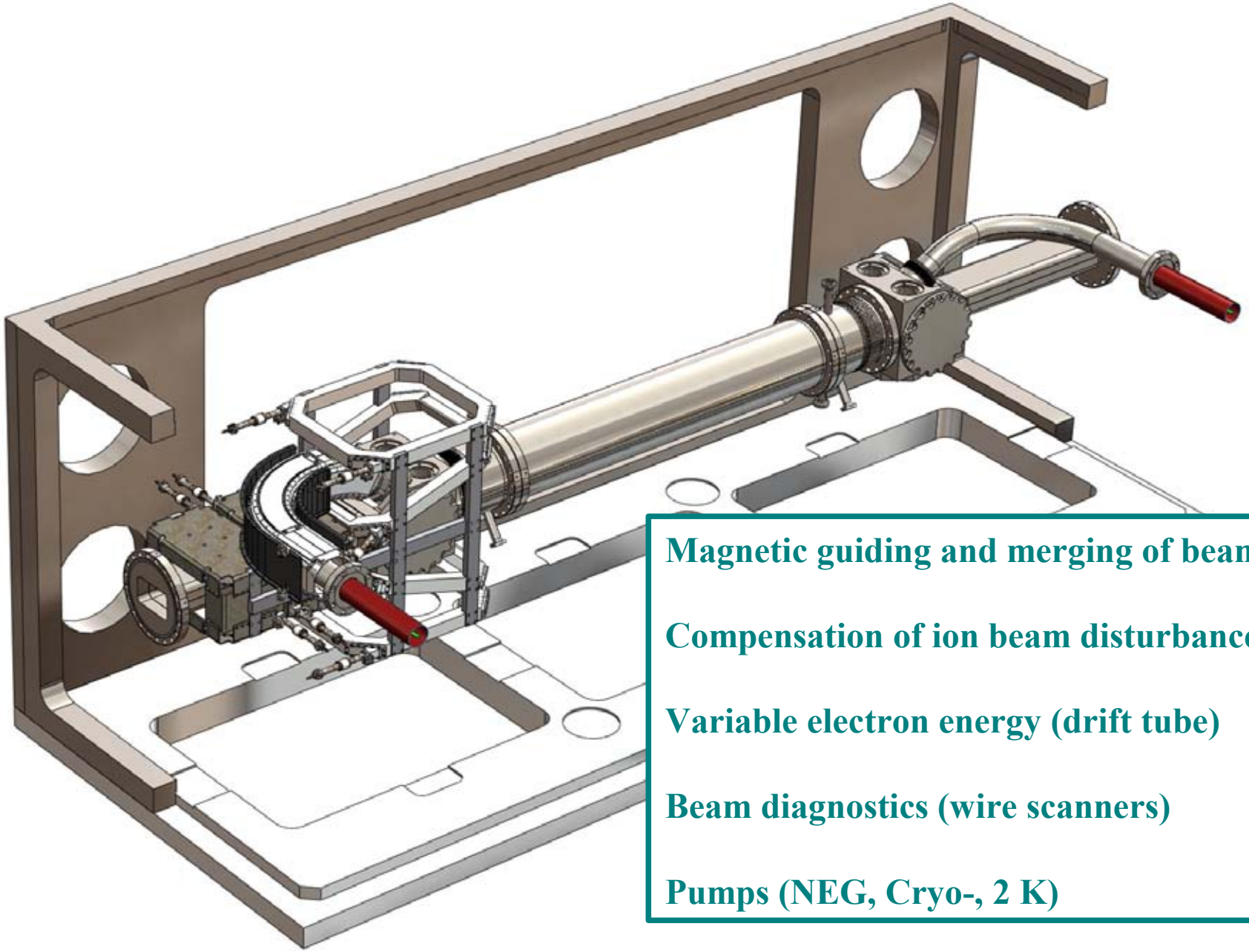
Justus-Liebig University, Giessen

Kaija Spruck
Stefan Schippers

Columbia University, New York

Oldřich Novotný
Daniel W. Savin

Electron Cooler



Magnetic guiding and merging of beams

Compensation of ion beam disturbance

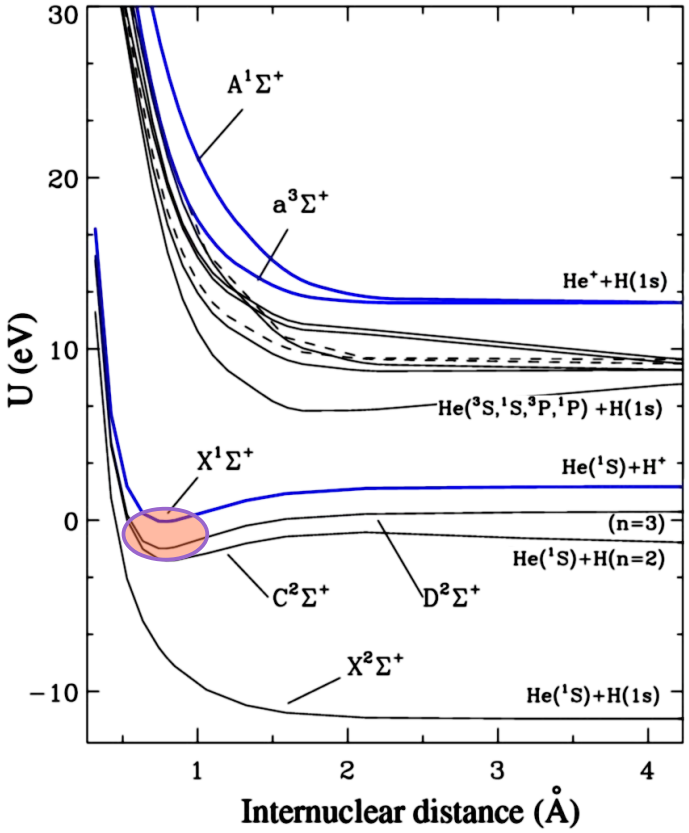
Variable electron energy (drift tube)

Beam diagnostics (wire scanners)

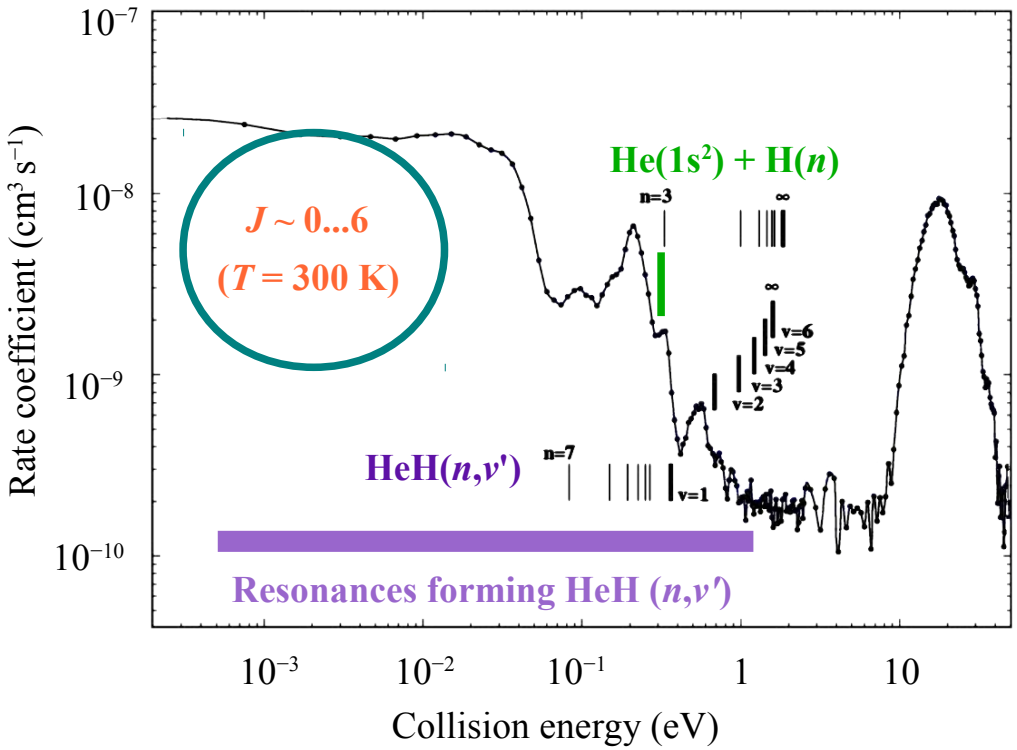
Pumps (NEG, Cryo-, 2 K)

Phase 2 Experiments: Electron Collisions

$HeH^+ (v = 0) + e \rightarrow He\ (1s^2) + H\ (n \geq 2)$

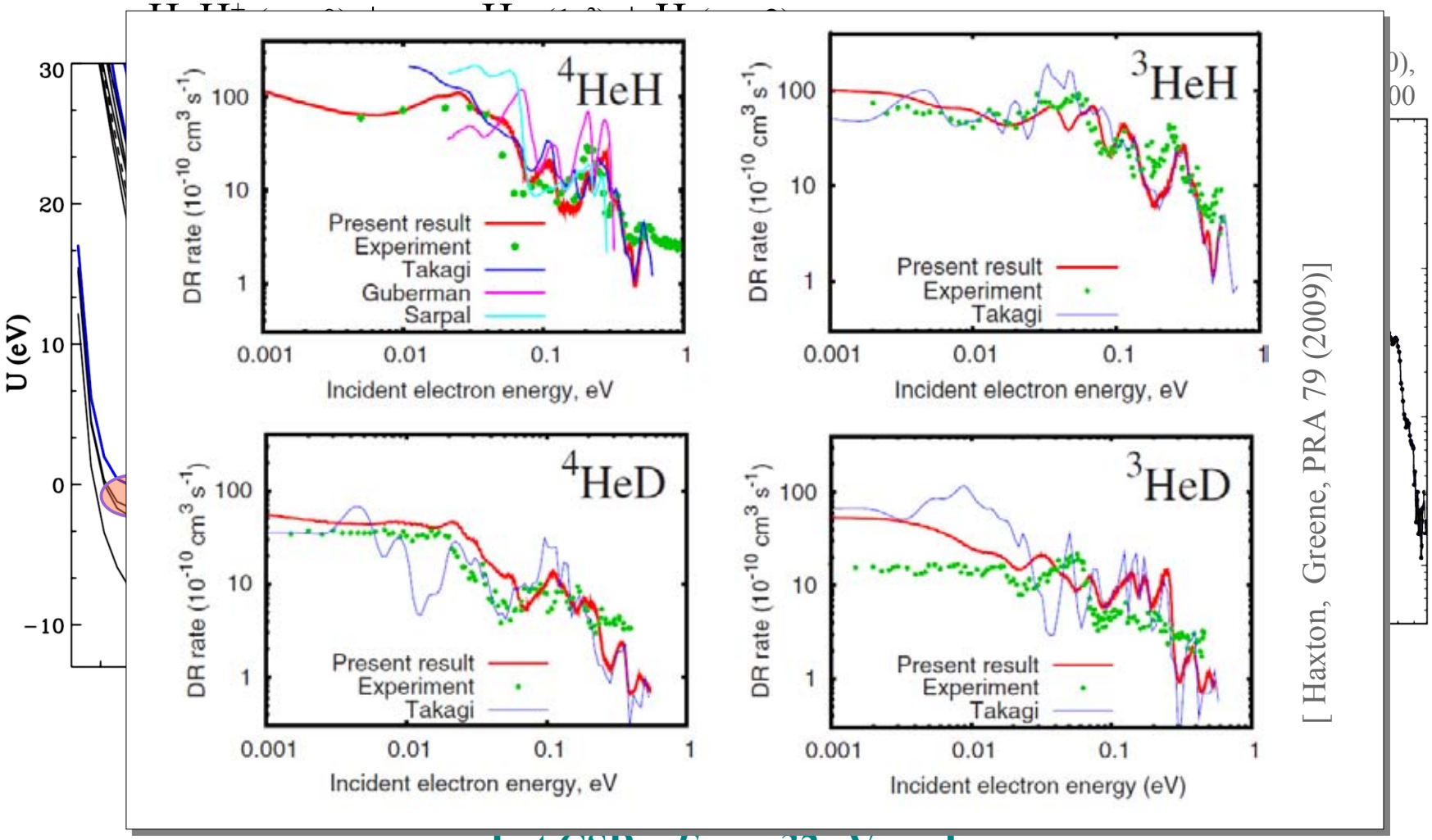


TSR (S. Krohn, 2000),
data scaled to Tanabe *et al.*, 2000



at CSR: E_{cool} = 32 eV
10 K → J = 0

Phase 2 Experiments: Electron Collisions



[Haxton, Greene, PRA 79 (2009)]

at CSR: E_{cool} = 32 eV

10 K → J = 0

CSR/eCool

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

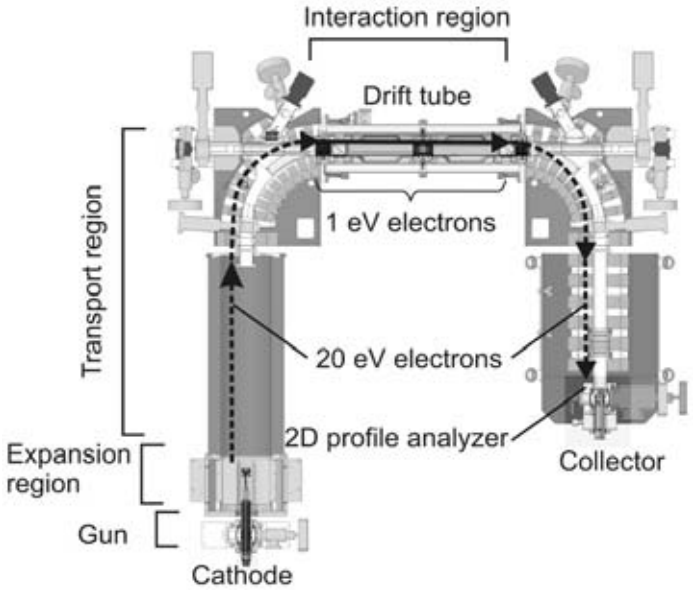
  $n_e \sim 10^5$ cm^{-3}

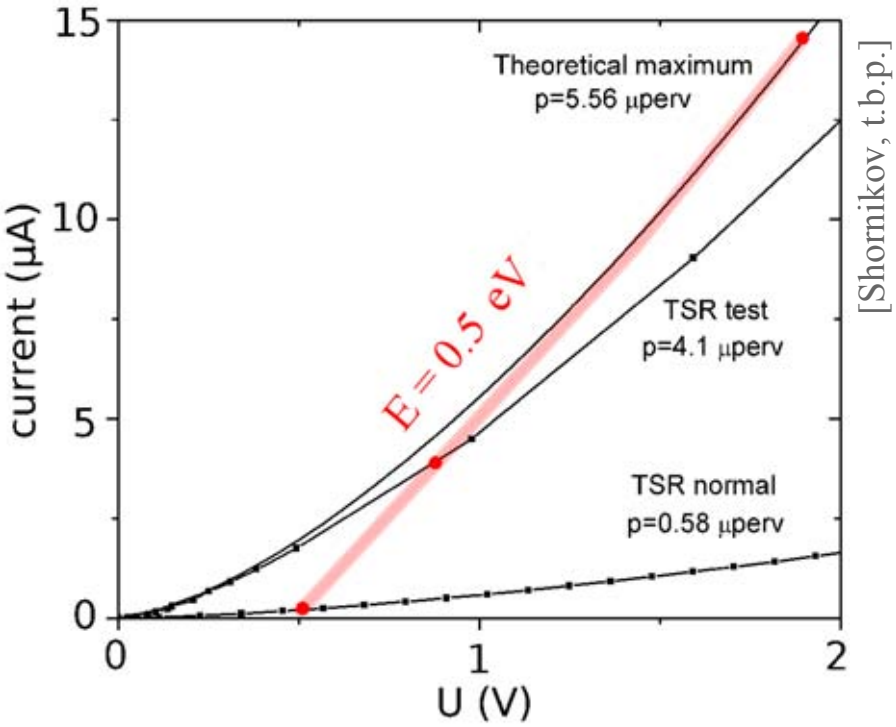
- Cooling times

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

  up to ~ 100 s …

  … but: ion lifetime ~ 1000 s





[Shornikov, t.b.p.]