MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

The DR Setup at the Cryogenic Storage Ring

Claude Krantz

Max Planck Institute for Nuclear Physics

From TSR to CSR ...

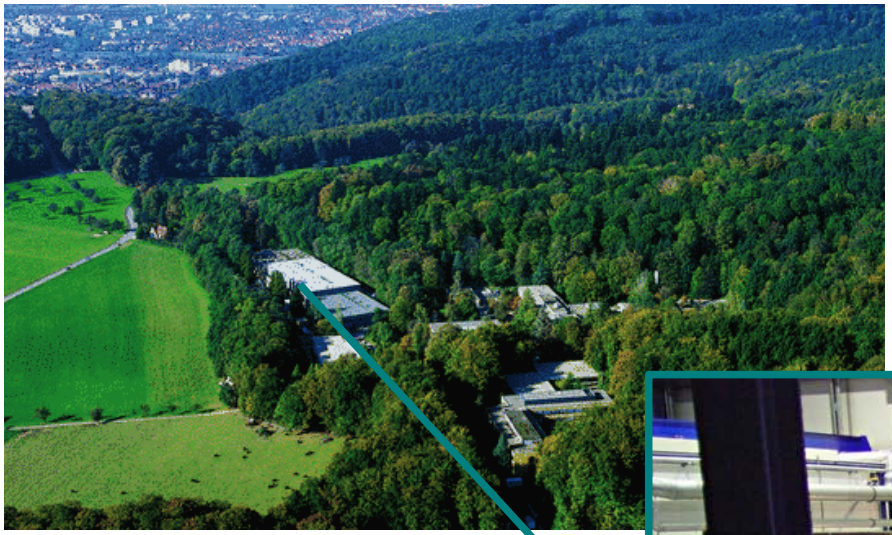
Max Planck Institute for Nuclear Physics
(MPIK, Heidelberg, Germany)

TSR (MPIK) 1988 - 2012

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

TSR (1988 - 2012)

From TSR to CSR ...



Max Planck Institute for Nuclear Physics
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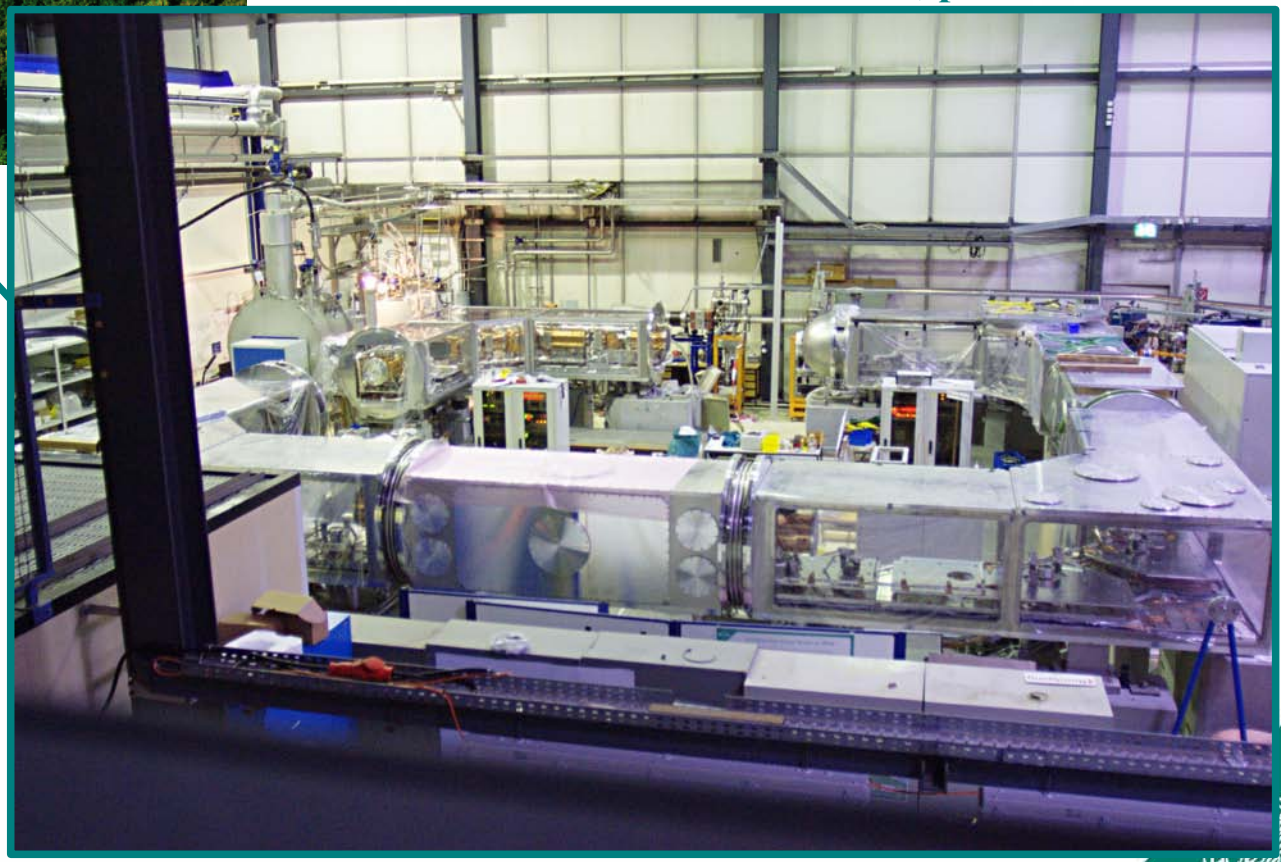
The CSR, picture of 2/2/2013



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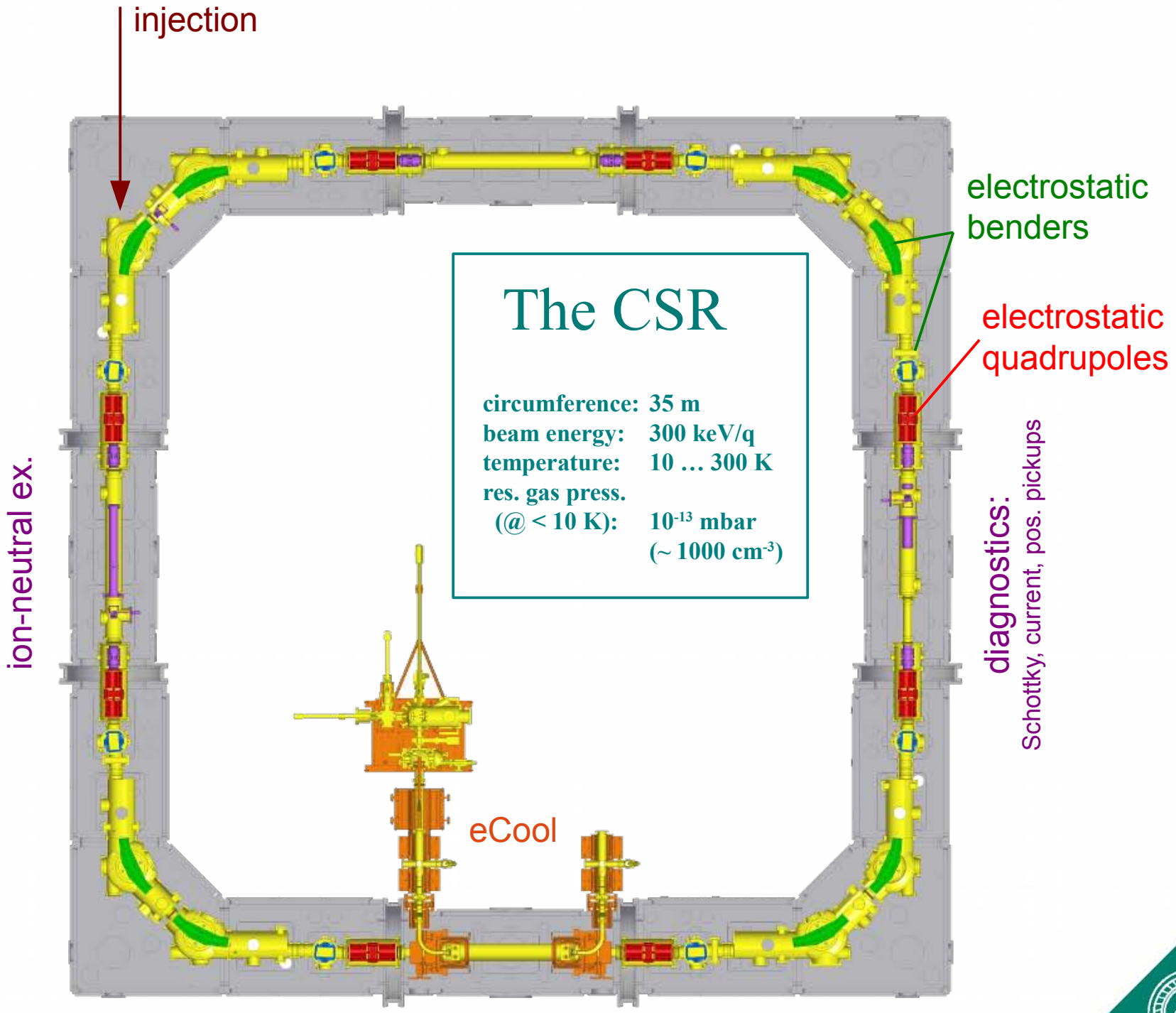
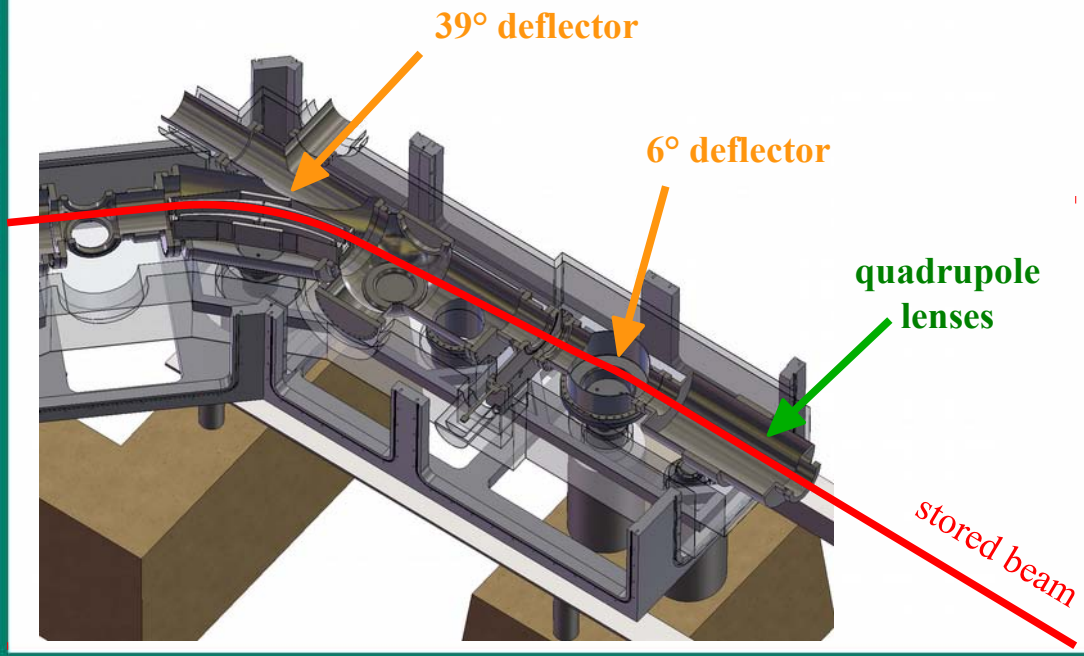


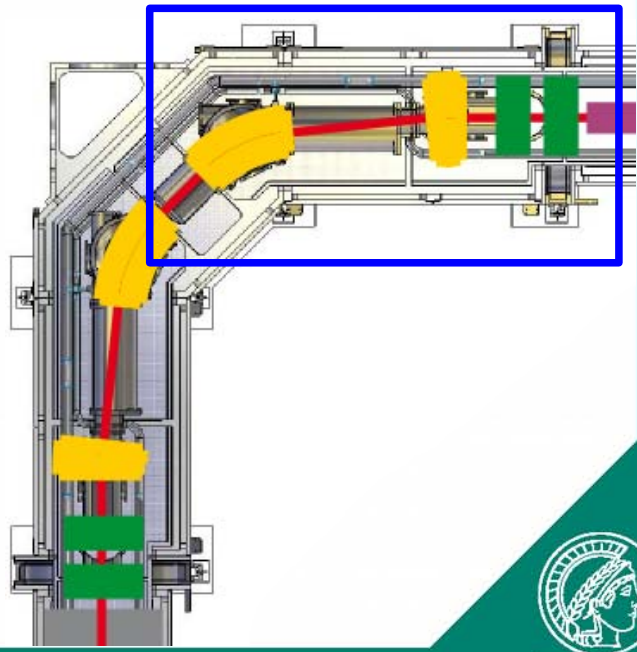
The CSR

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

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 (2.6 m each)





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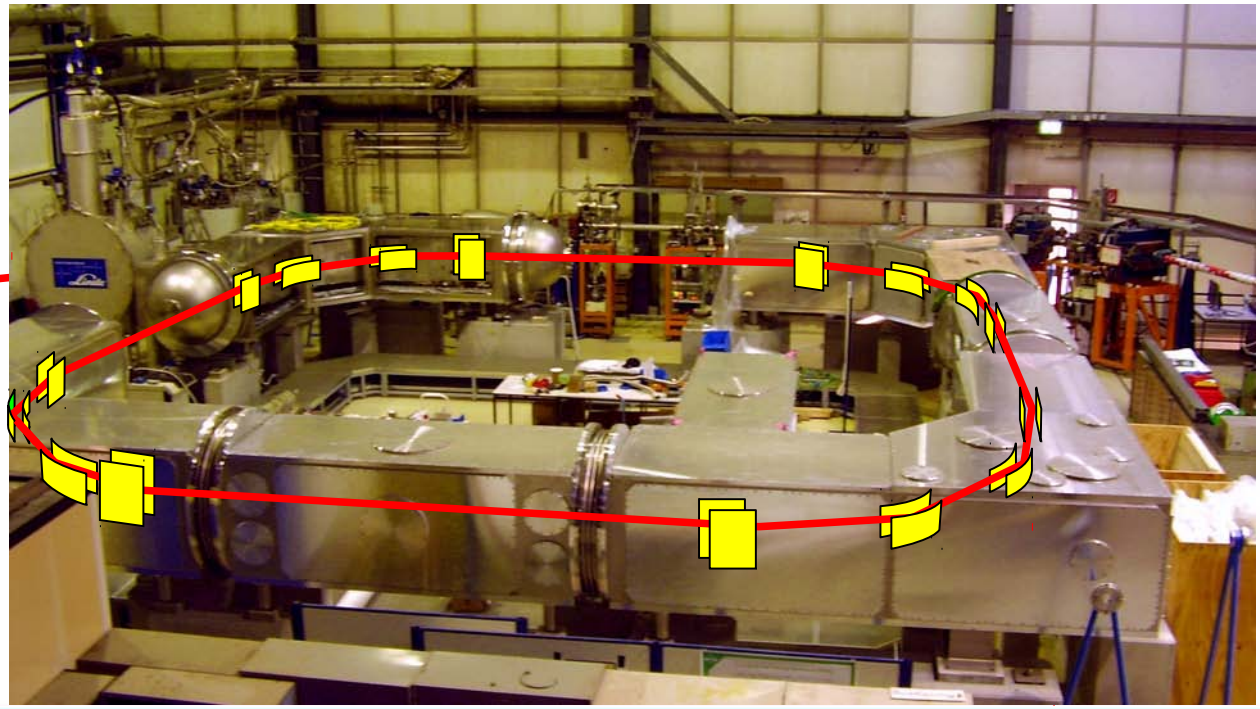
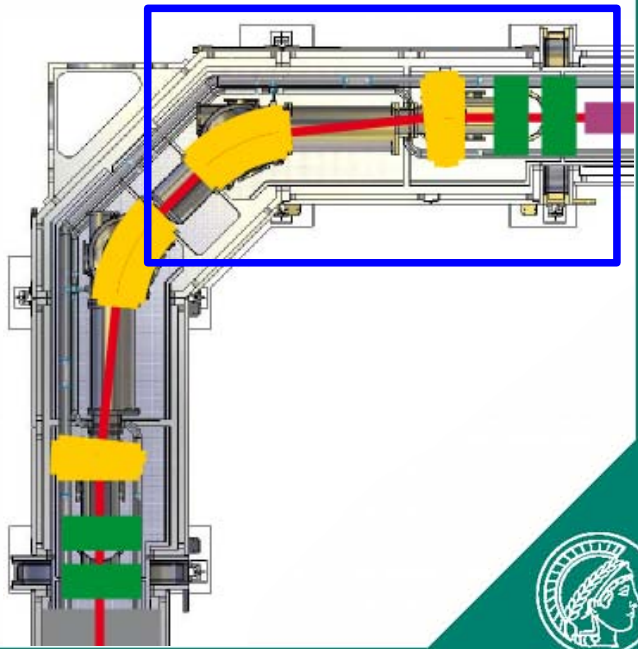
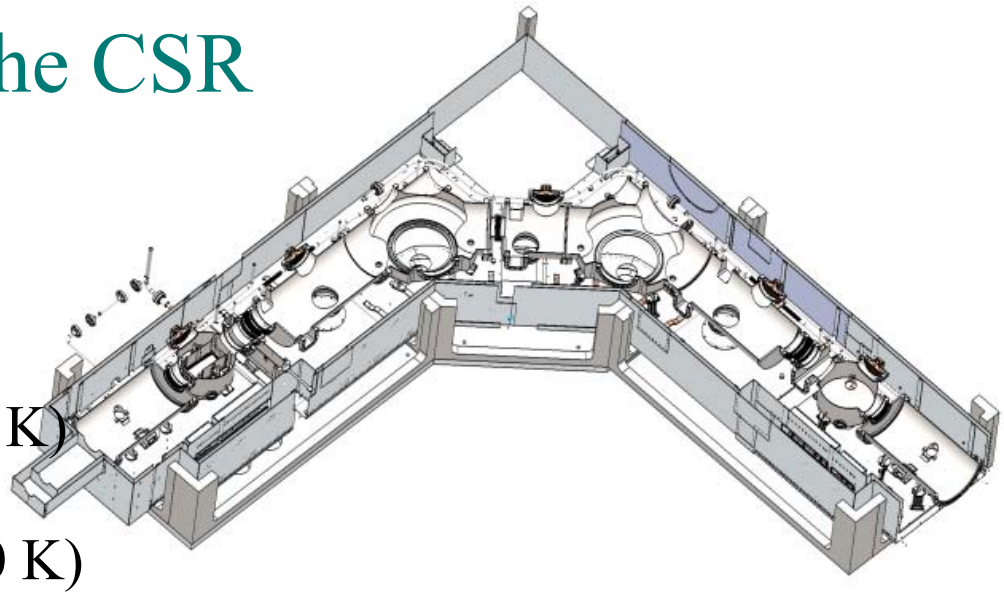
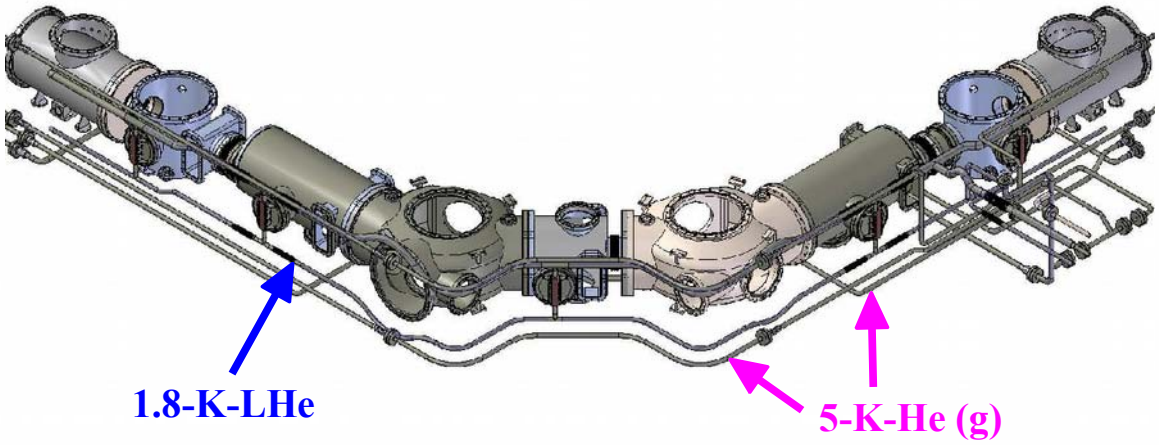


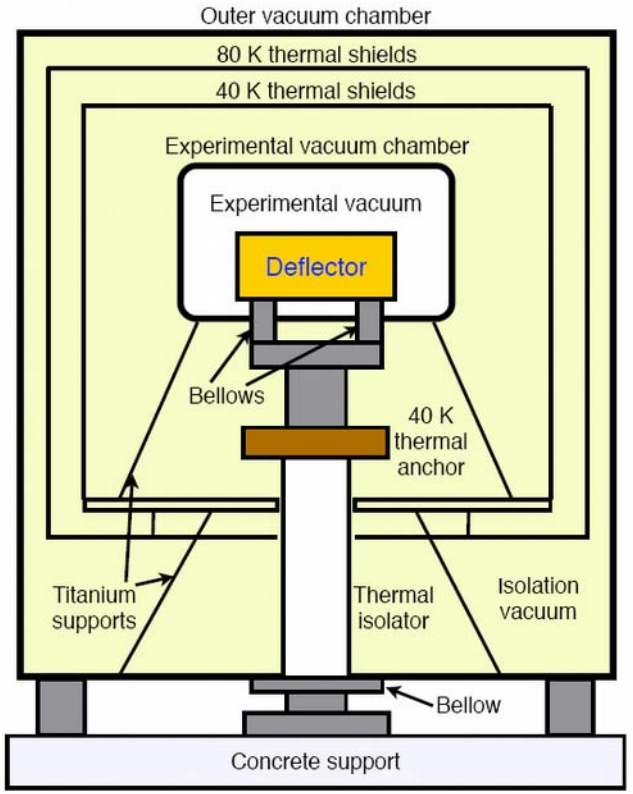


The CSR

- 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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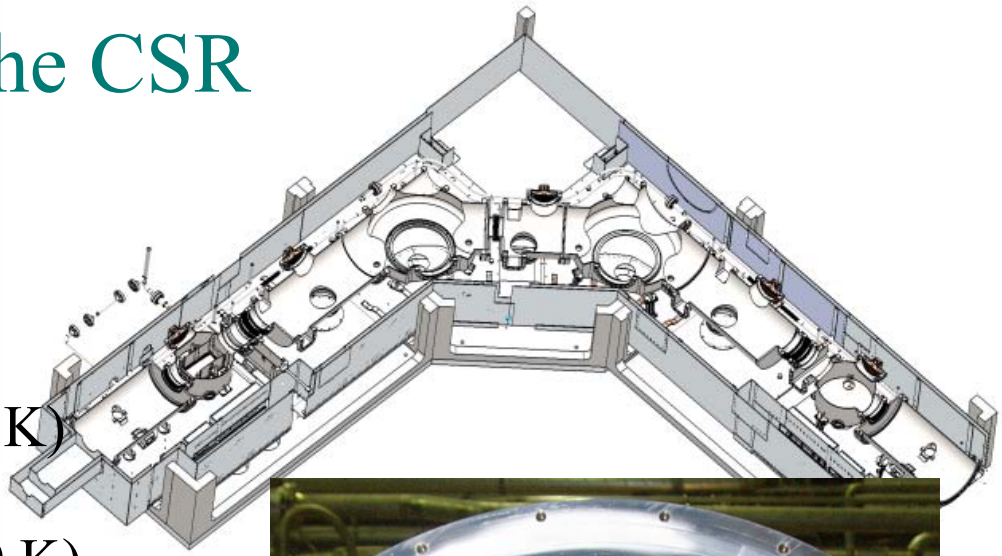
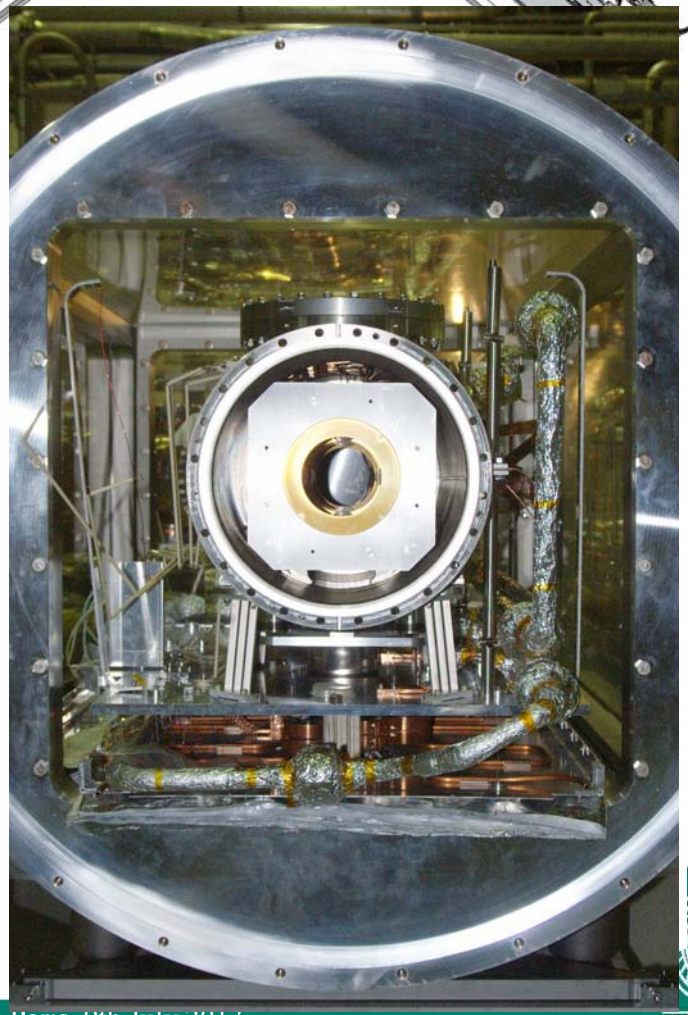
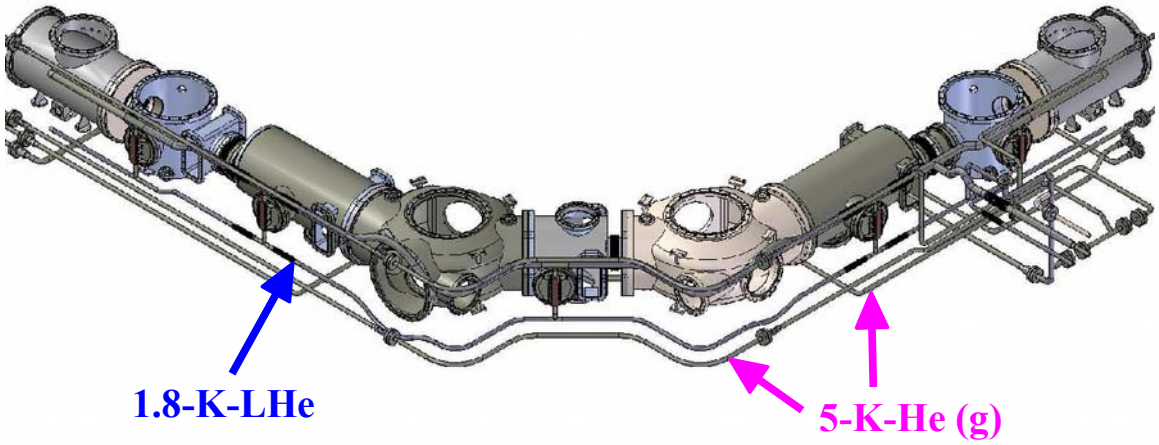
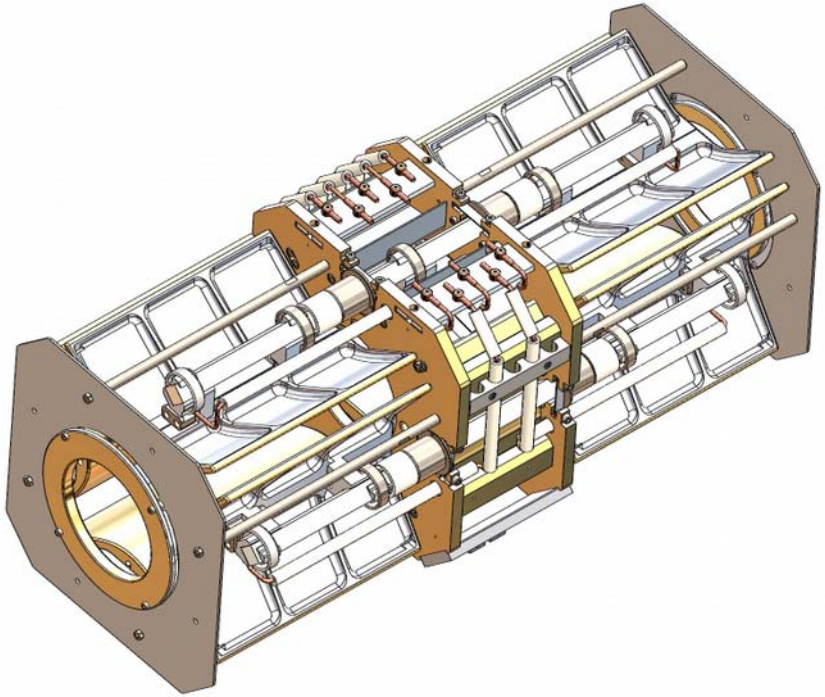


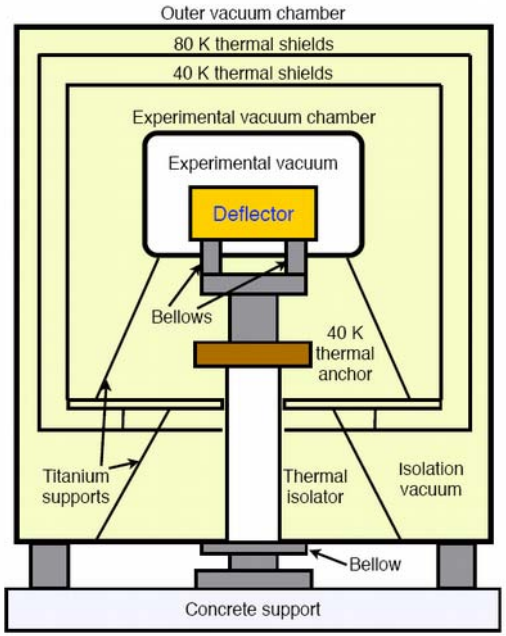


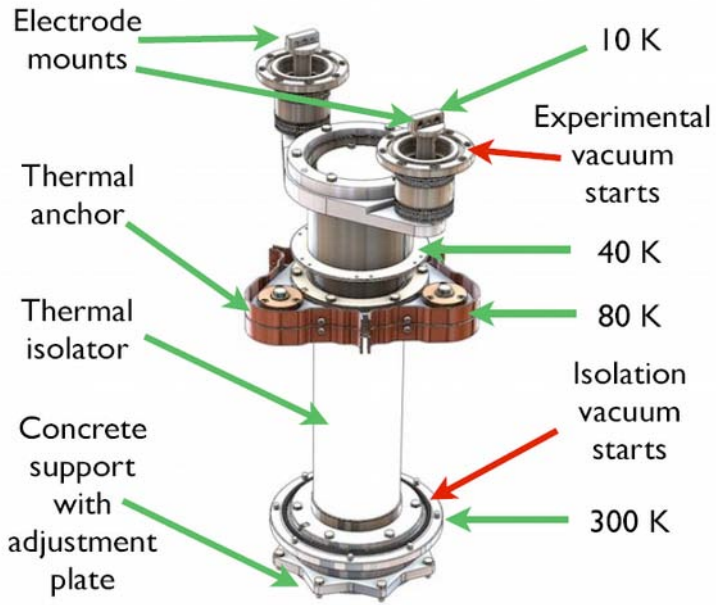


The CSR

- 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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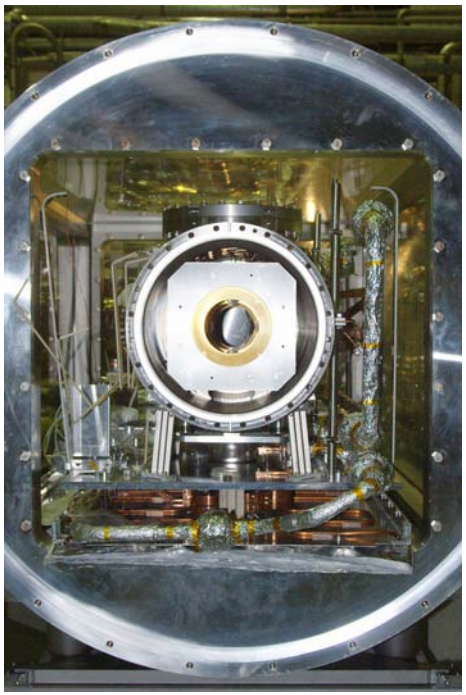
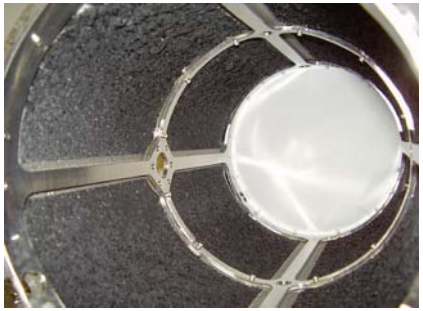


The CSR

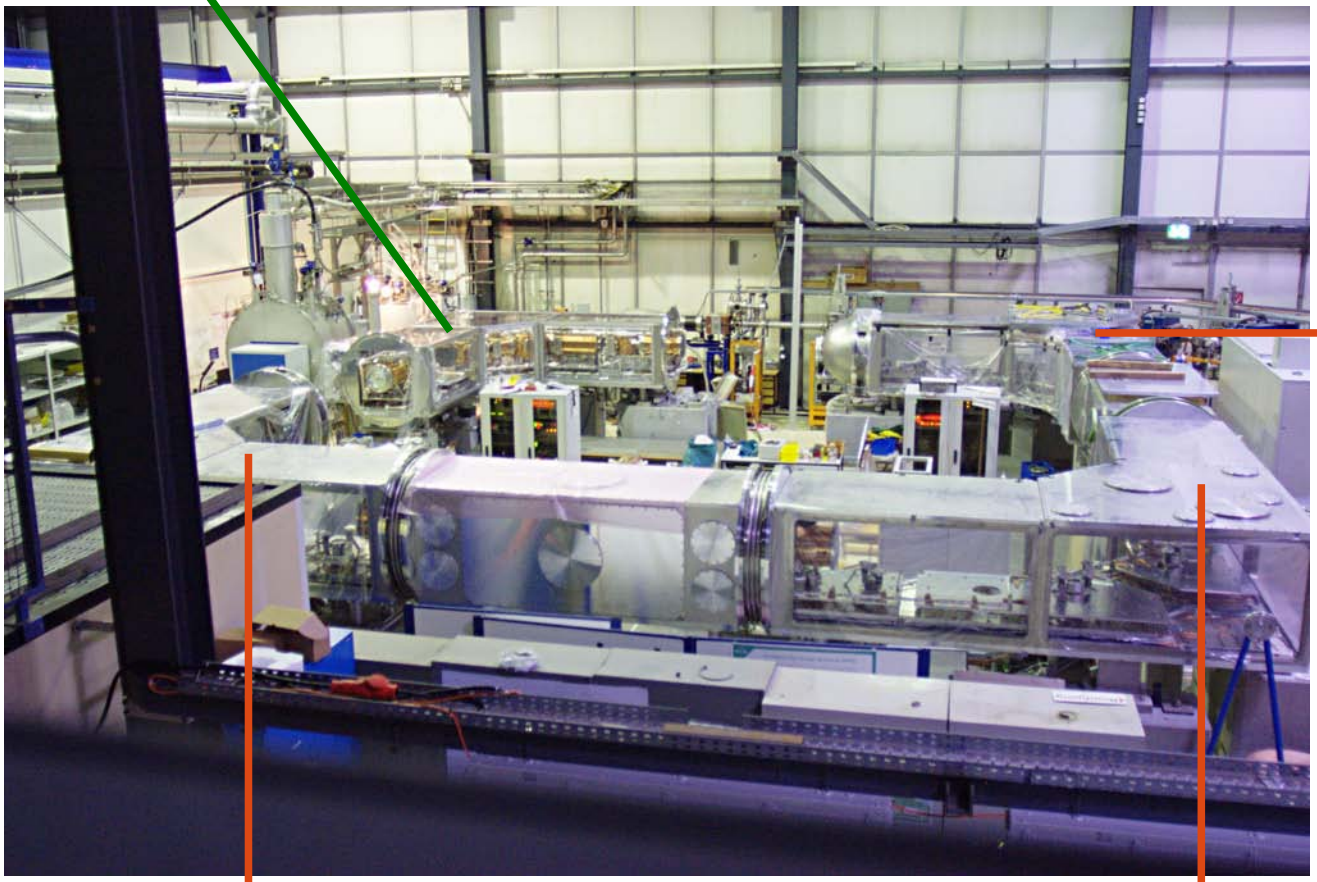
- XHV: Extremely High Vacuum
  - In 300-K-operation: **~ 10^{-11} mbar**
    250°C bakeout,
    Ion-getter pumps,
    NEG surfaces,
    bakeable charcoal cryopumps



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

Present Status

First corner: **completed.**



Remaining 3 corner sections: **To be completed in 2013**

Present Status

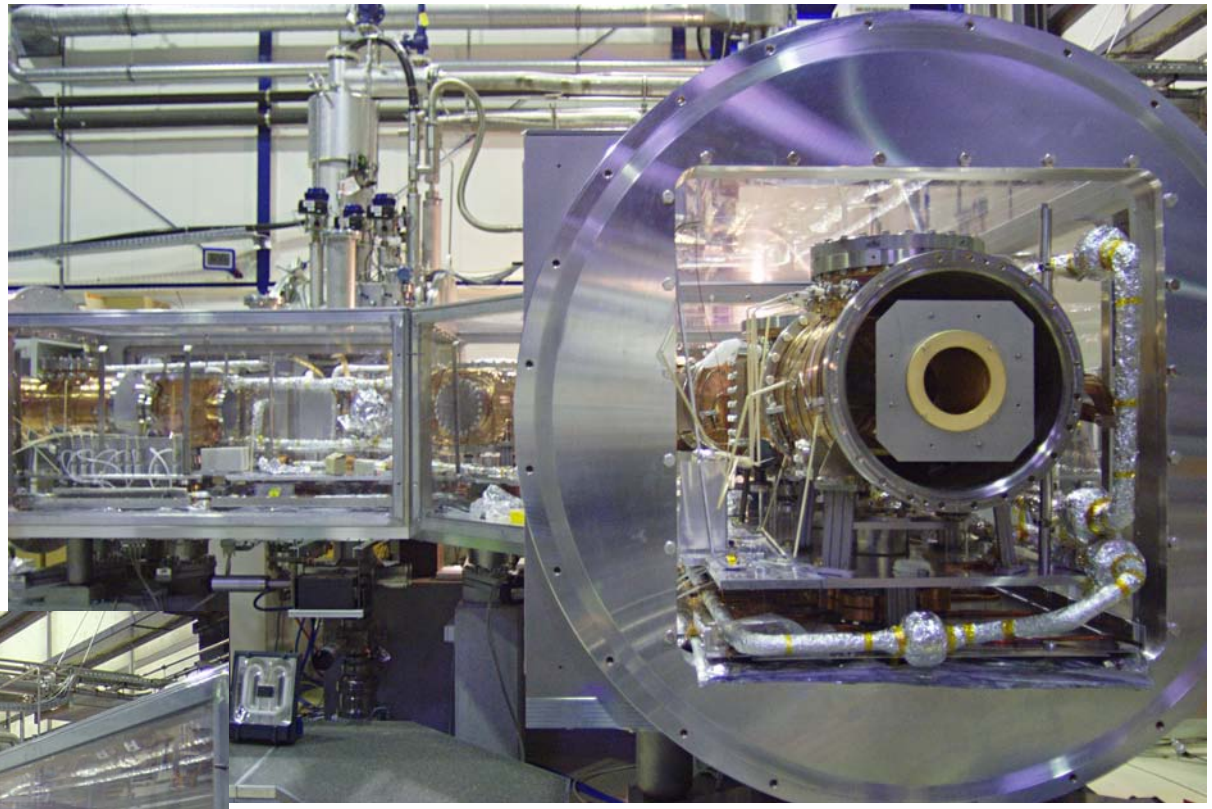
First optics corner:

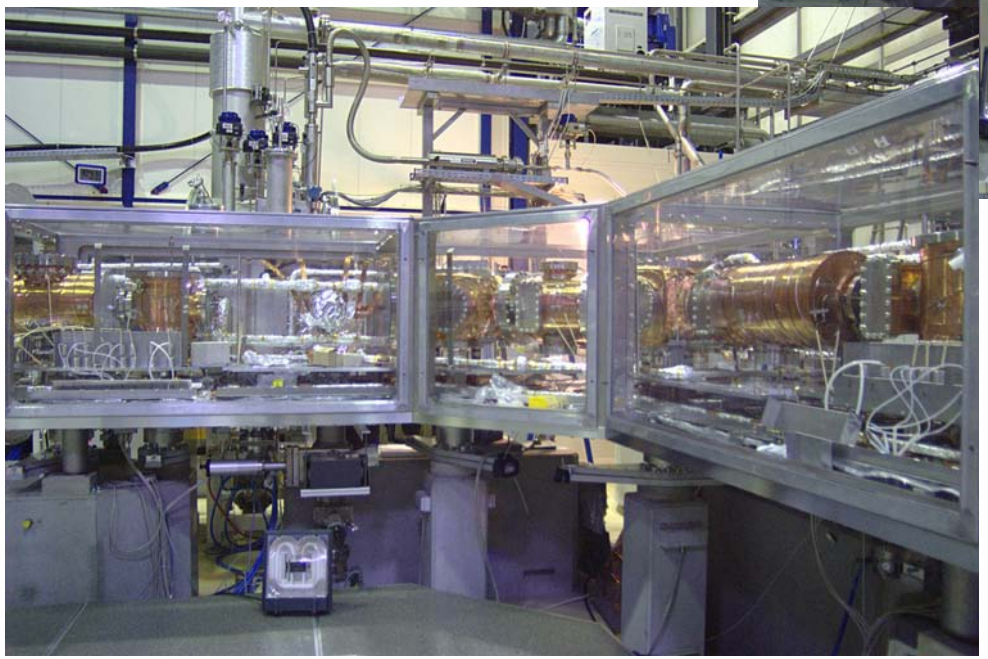
… reached **< 10 K** in 2012 √

… **bakeout** (250°C) and single NEG activation √

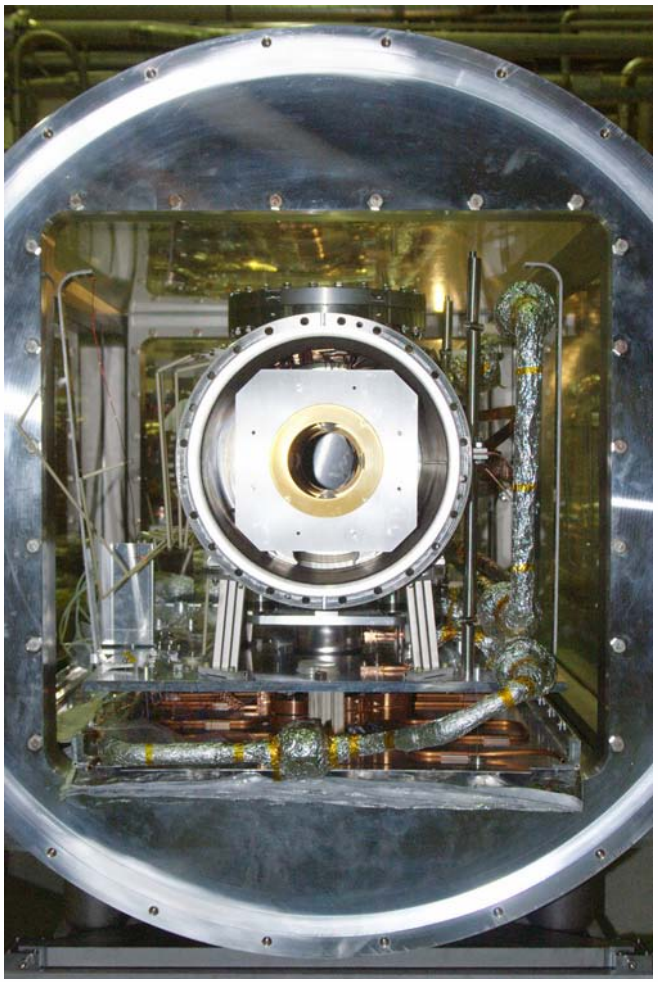
... $p = 1 \cdot 10^{-10}$ mbar

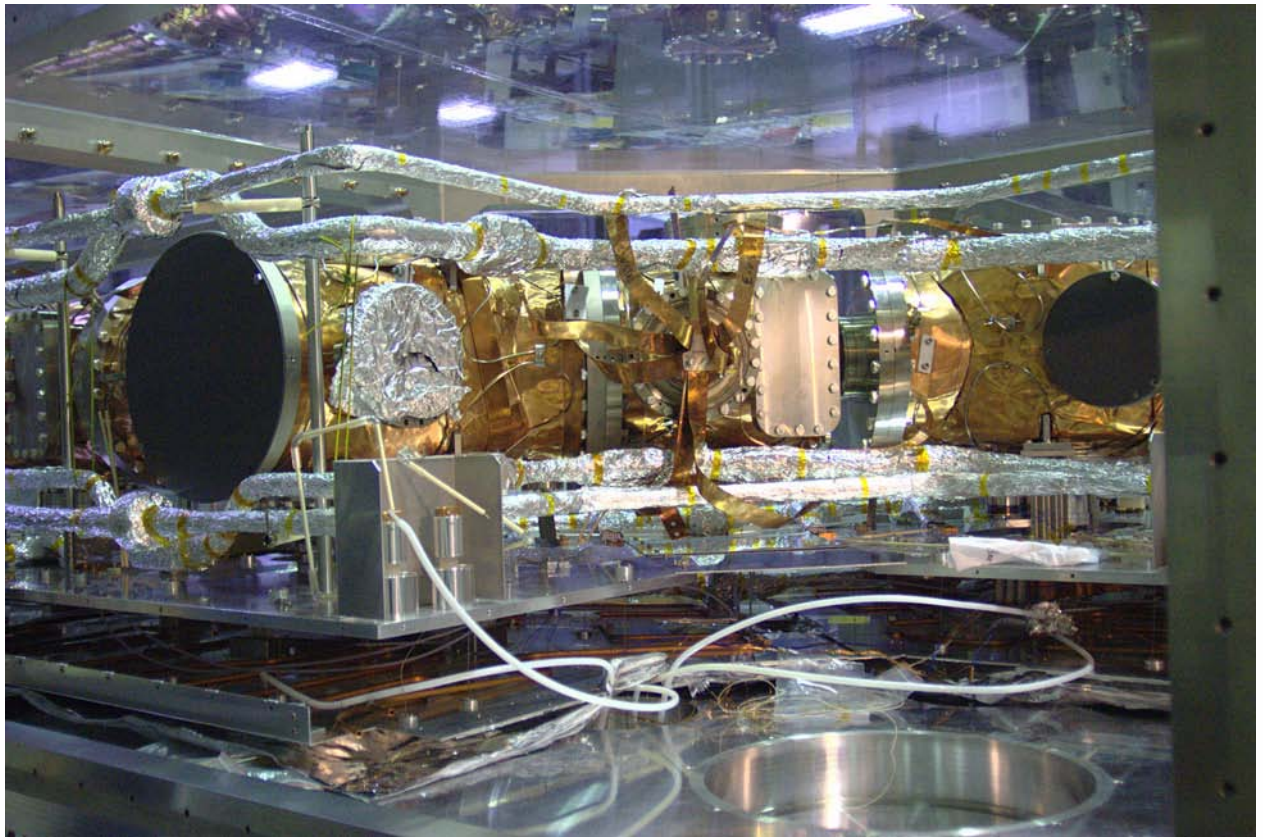
... HV test (±20 kV) ongoing





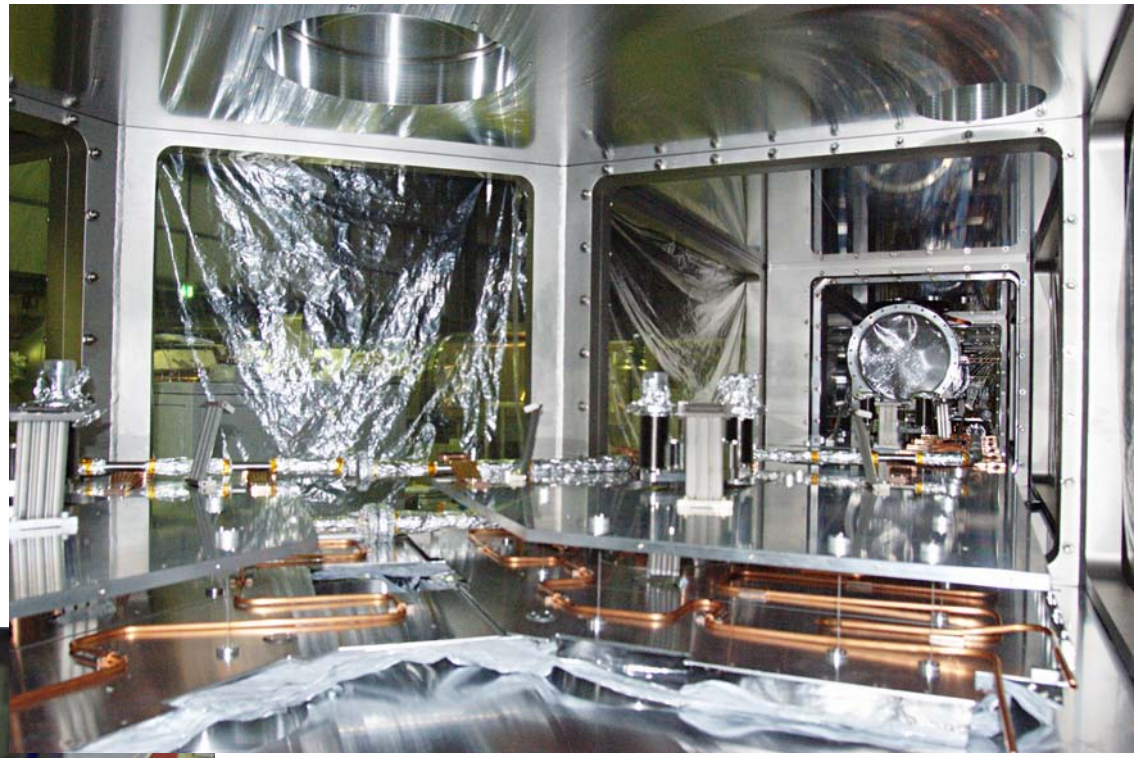
Present Status

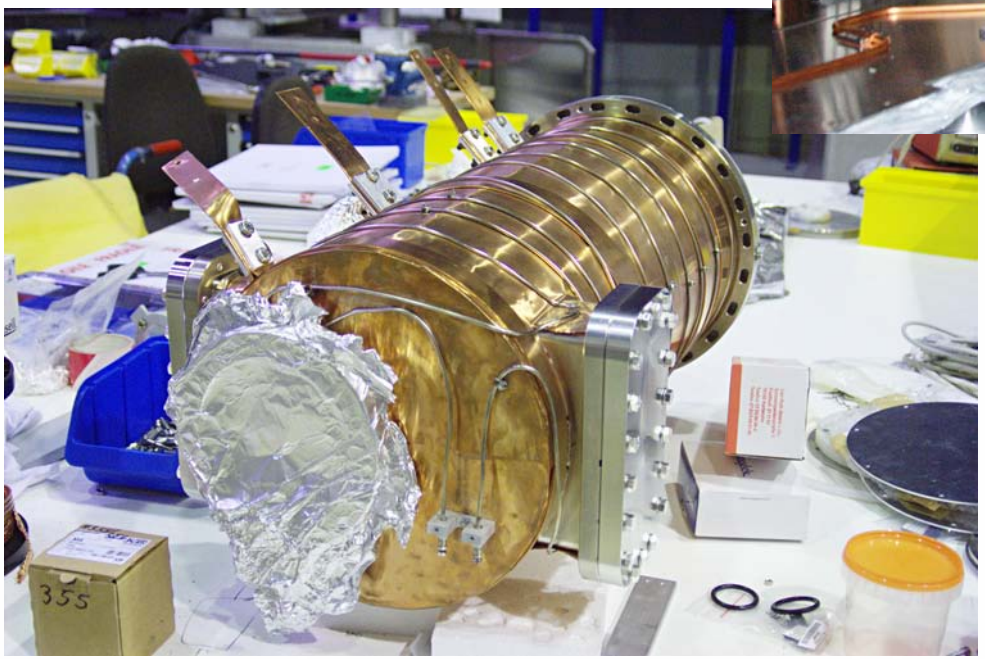




first optics corner

Present Status

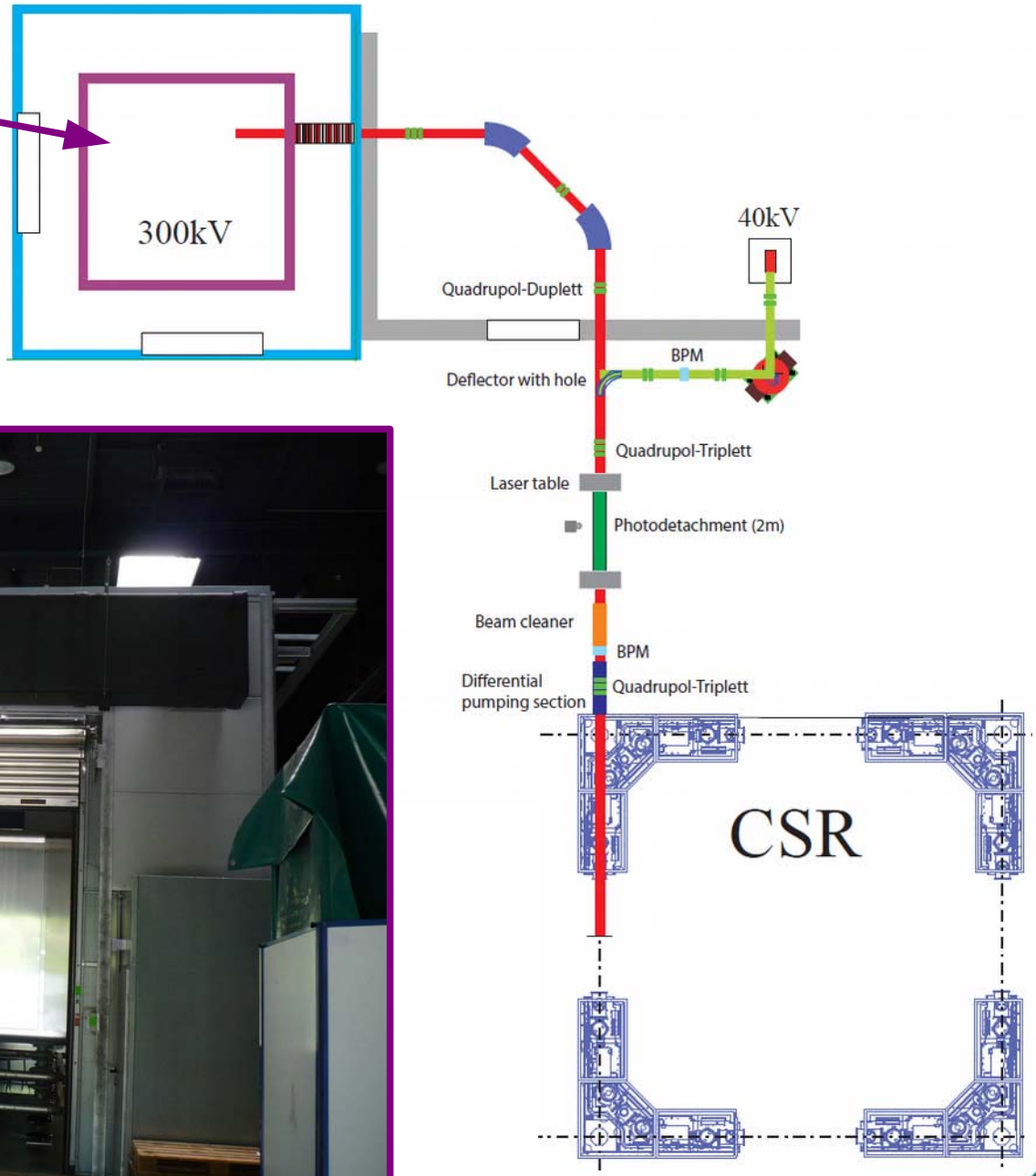




assembly of remaining
corner sections

300 kV Injector

CSR main injector:
±300 kV



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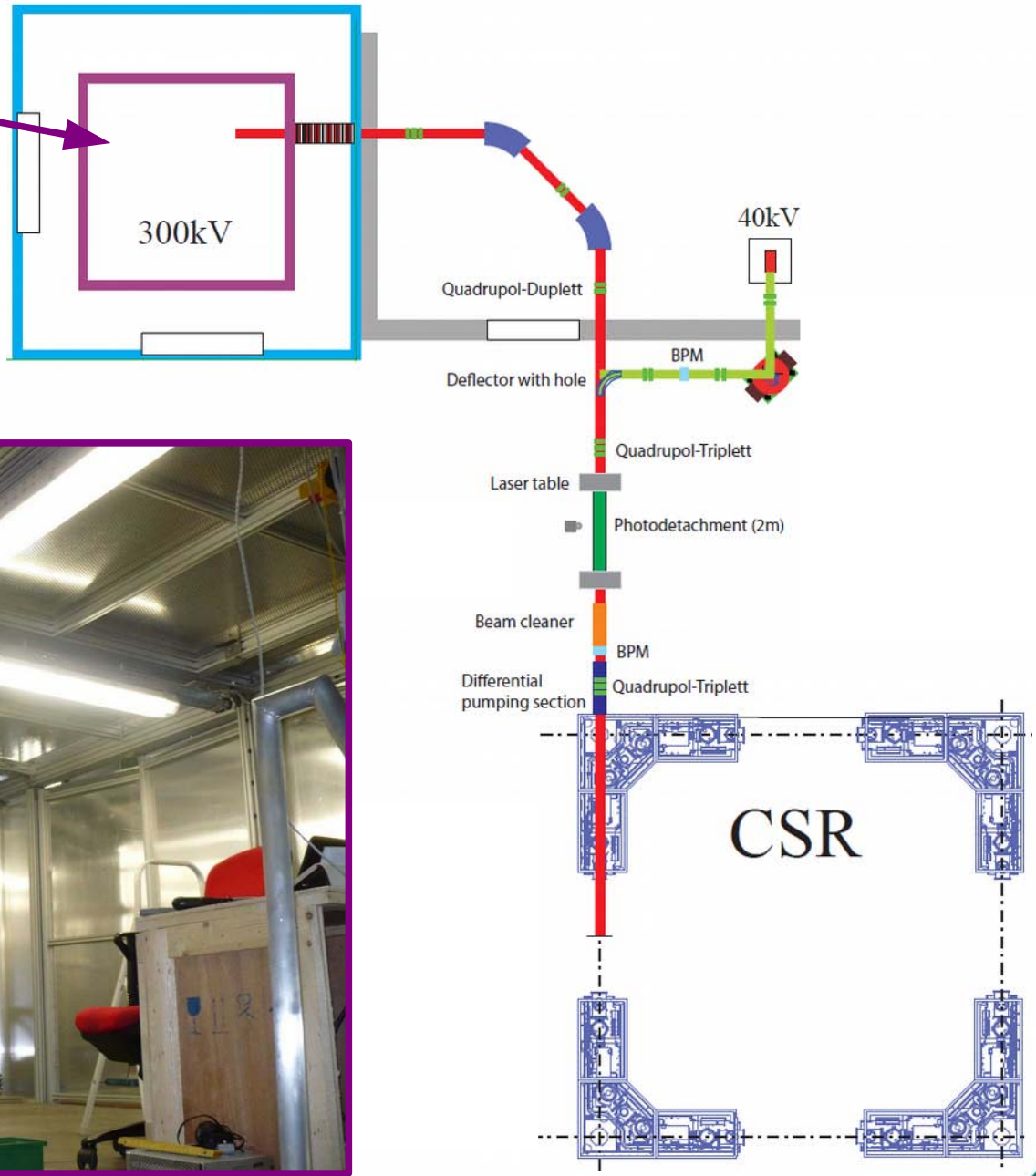


Experimental Perspectives

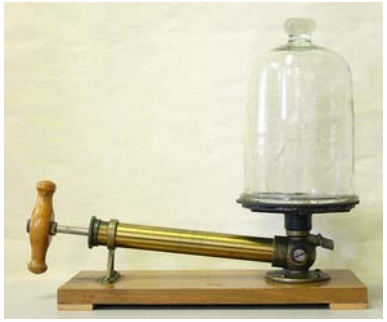
- **Electrostatic optics (300 keV/q)**

  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)
  (molecular) ions for long times (~ 1000 s)

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



  Slow electron collisions

- **Cold environment (10 K)**

  Internal cooling of
  IR-active species

Experimental Perspectives

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  Well-suited for low charge/mass-ratio
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- **Cold environment (10 K)**

  Internal cooling of
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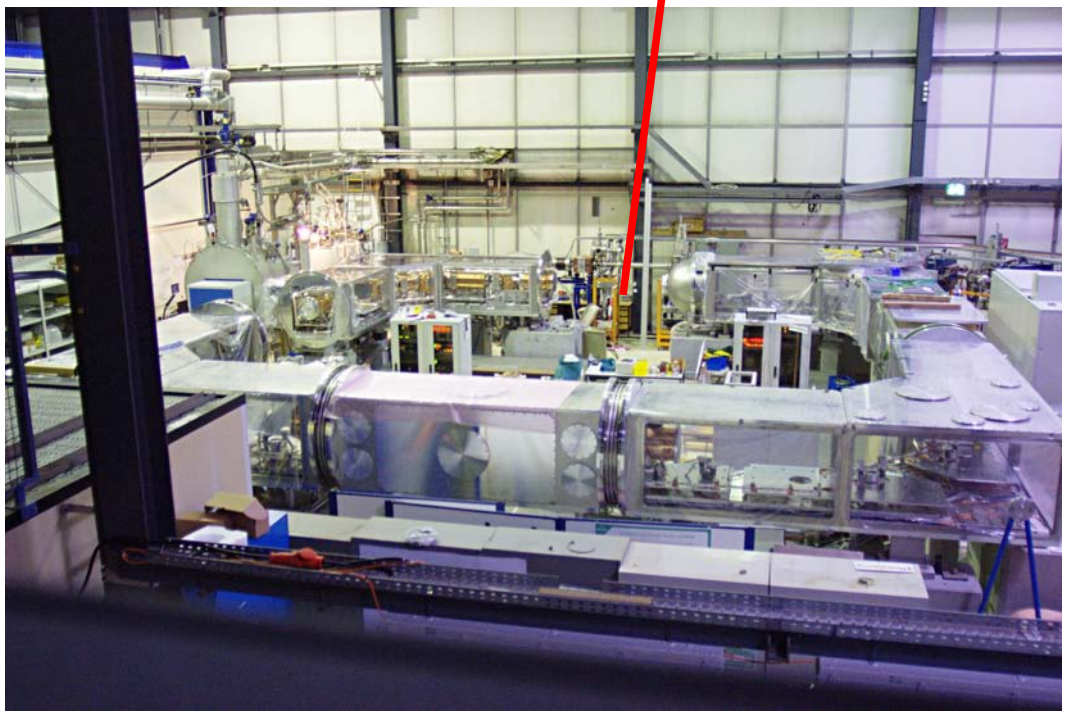
Timeline

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!)
→ DR experiments

Electron Cooler

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

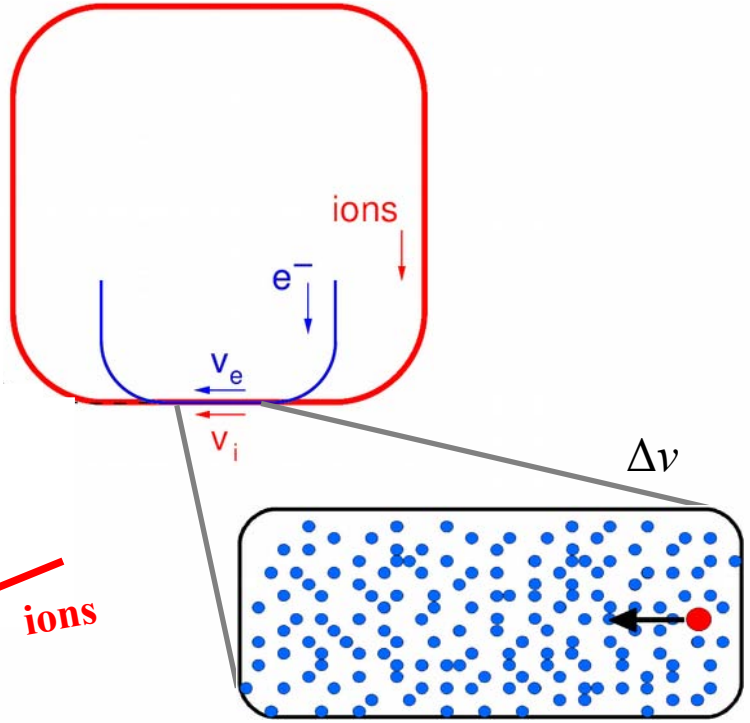
CSR energy limit: → Need **very** slow electrons

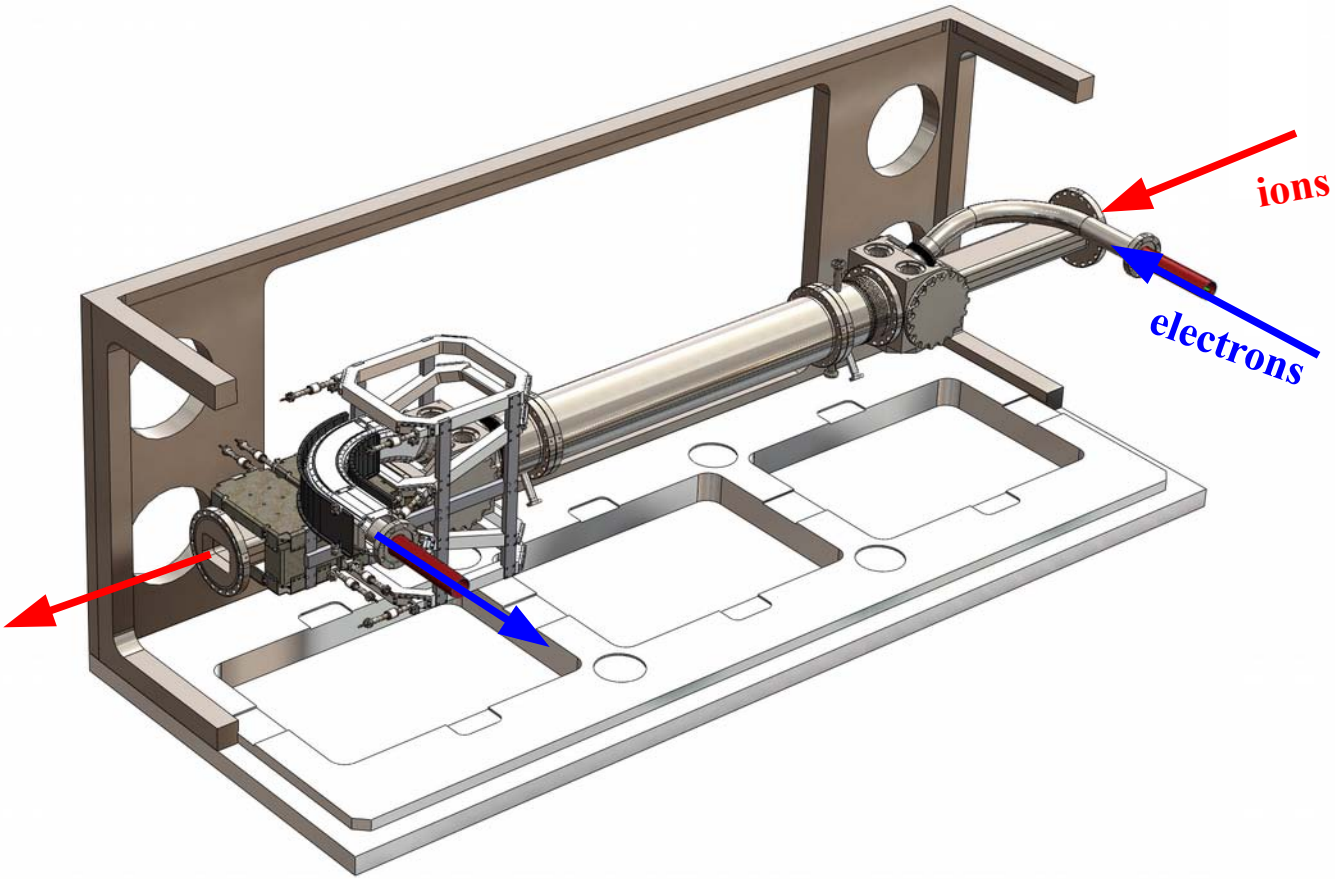
E_{ion}/Z_{ion} = 300 keV

160 eV for p^+

< 20 eV for most ions

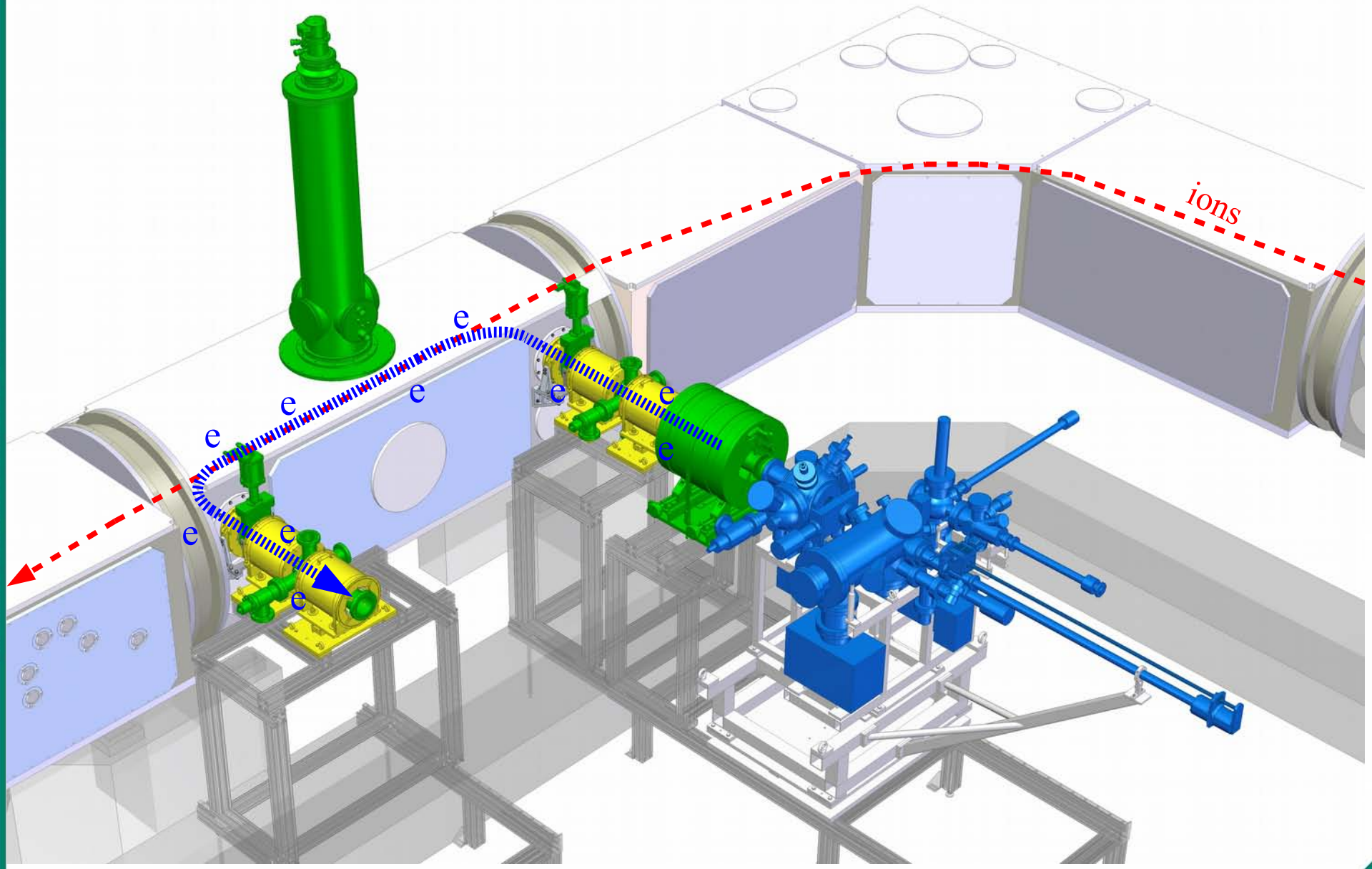
1 eV for M_{ion} = 160 u



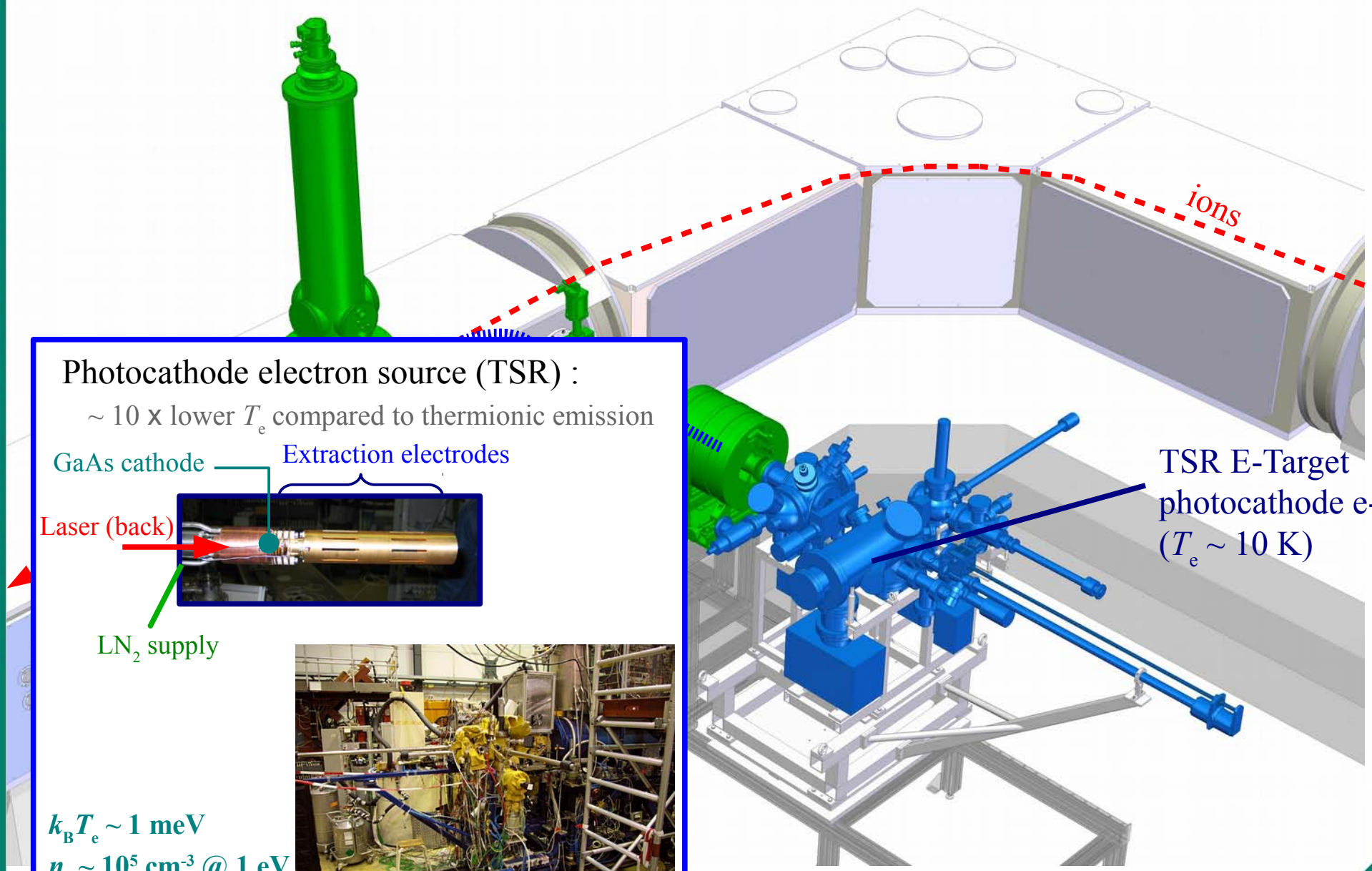


600 km/s

Electron Cooler



Electron Cooler



Photocathode electron source (TSR) :

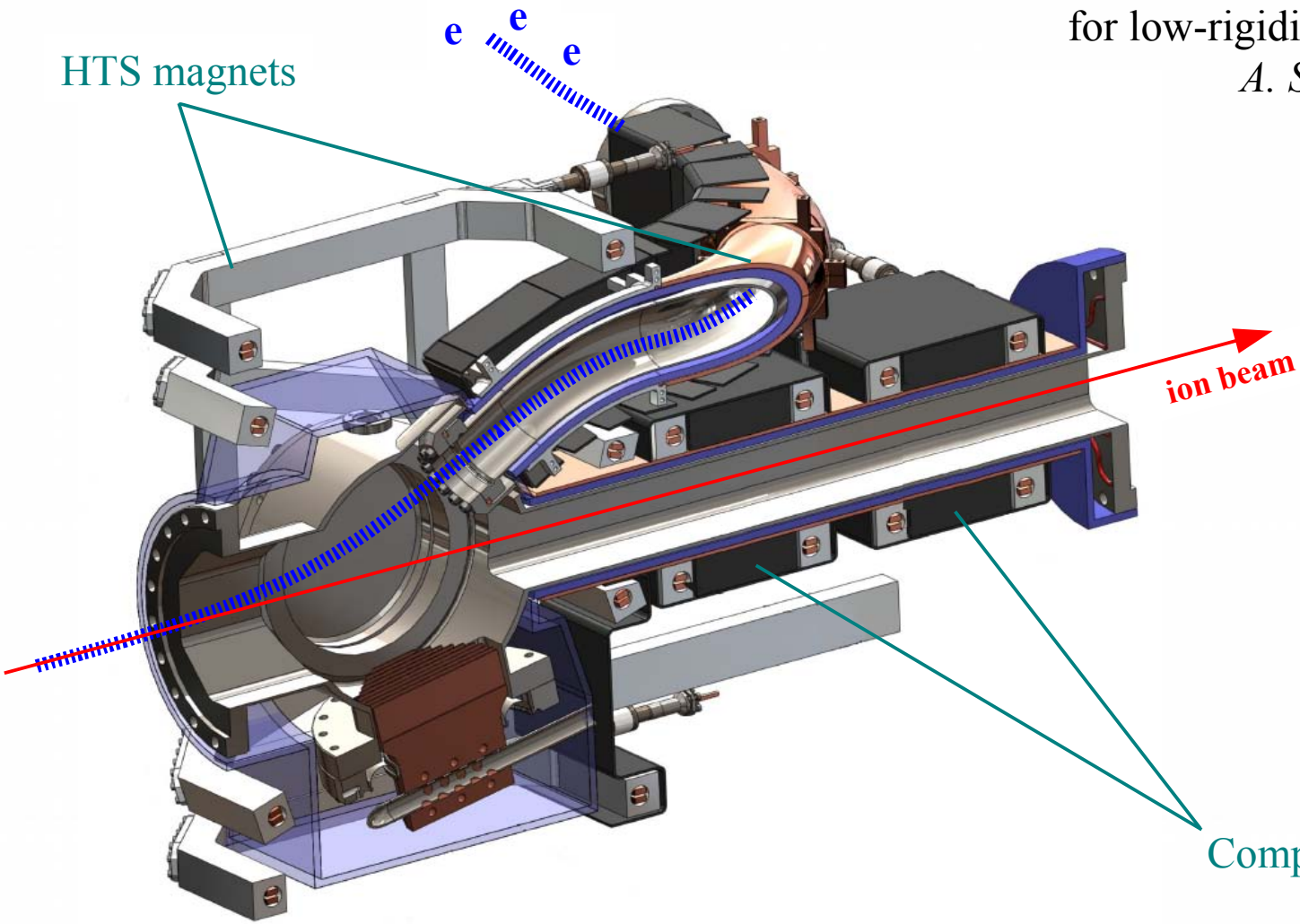
~ 10 x lower T_e compared to thermionic emission

$k_B T_e$ ~ 1 meV

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

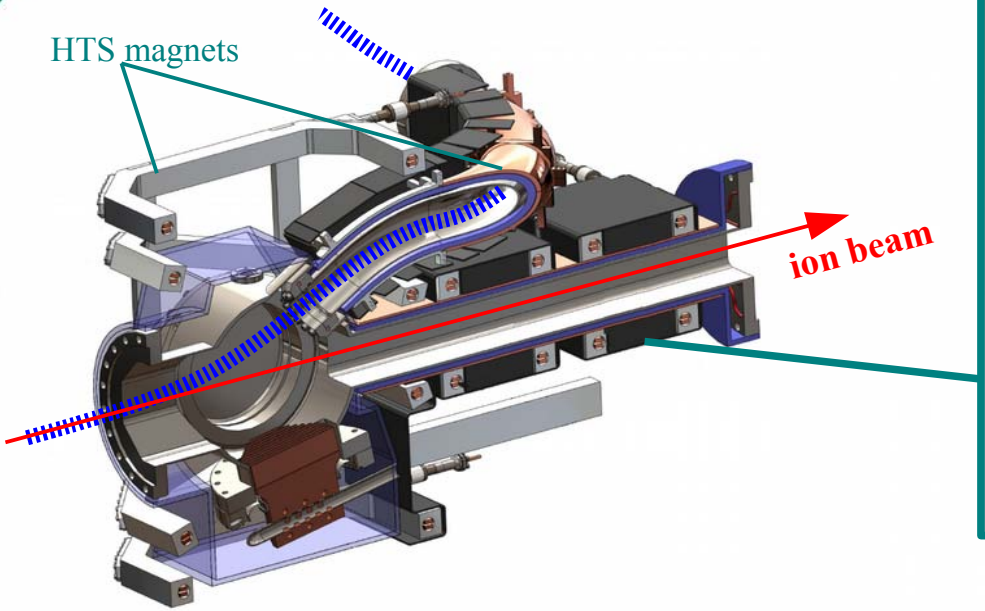
Electron Cooler

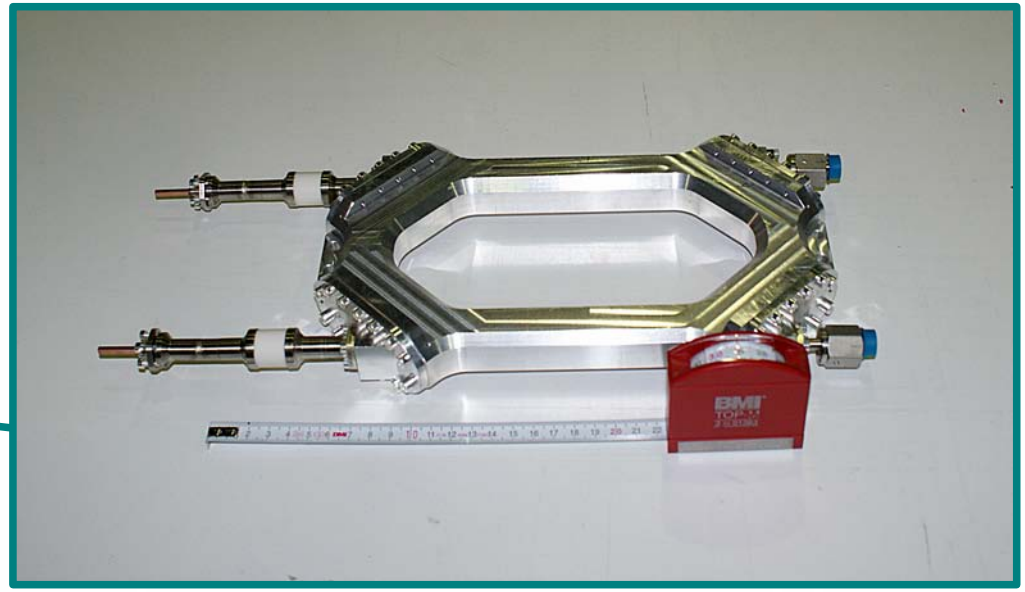
"horizontal-vertical" merging scheme
for low-rigidity ion beams
A. Shornikov, PhD thesis



A. Shornikov, PhD

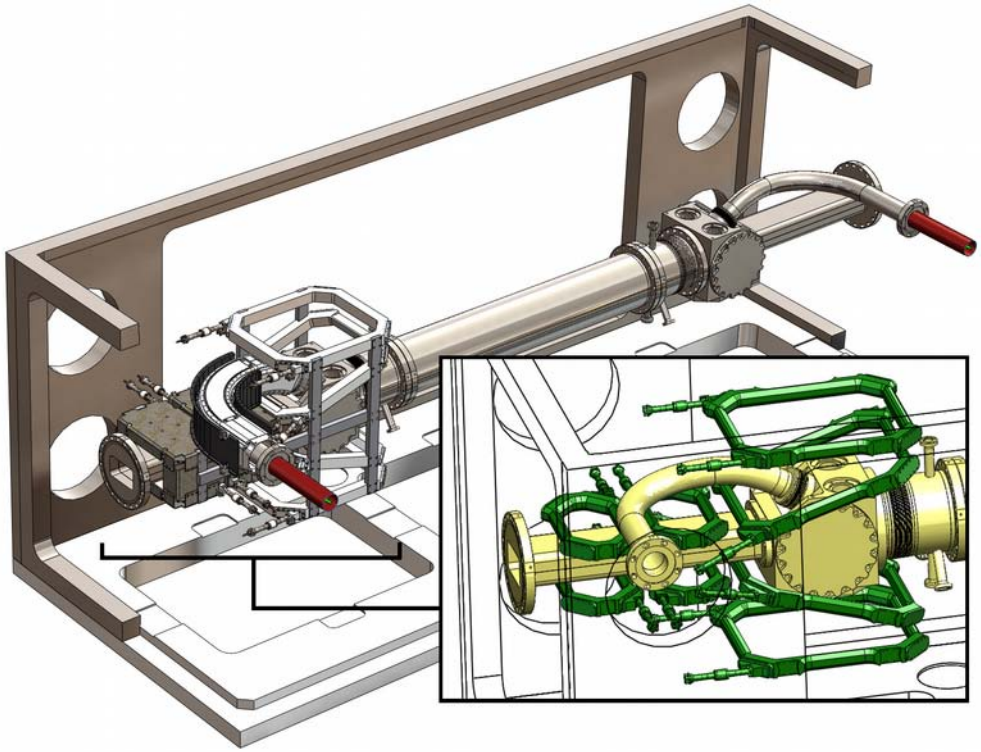
Electron Cooler





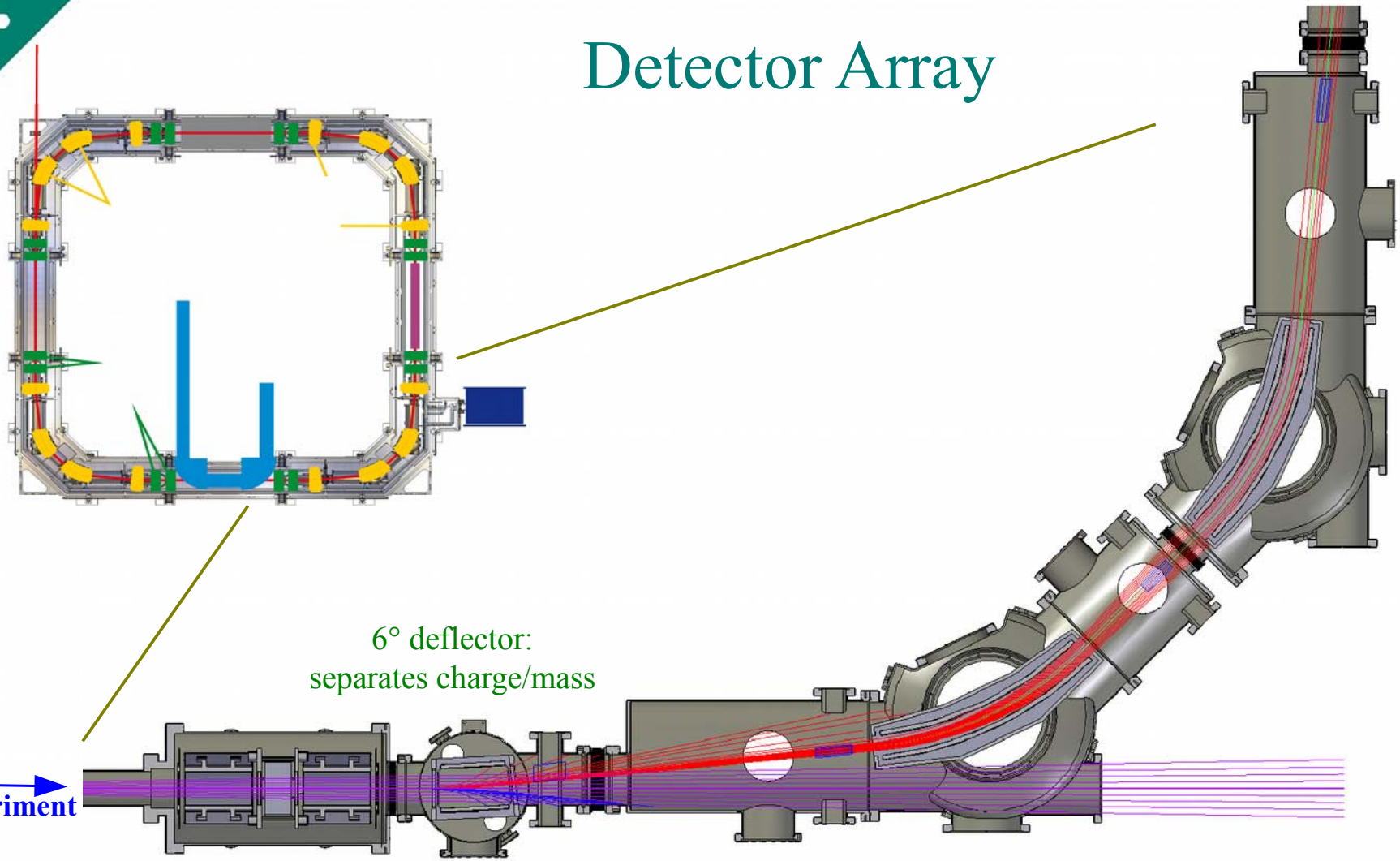
Superconducting coils have been tested

(LNe, approx. 30 K)



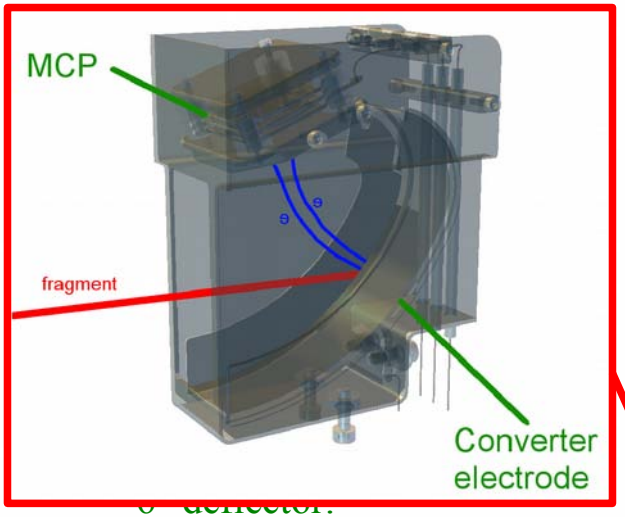
Merging magnets and chambers are being manufactured.

Detector Array



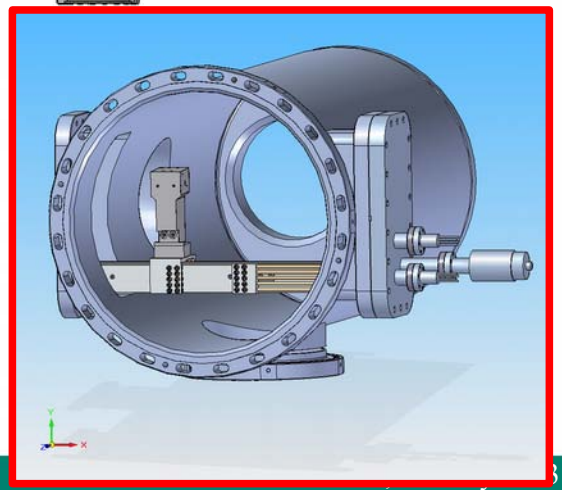
Detector Array

charged product detectors



separates charge/mass

from experiment



Detector Array

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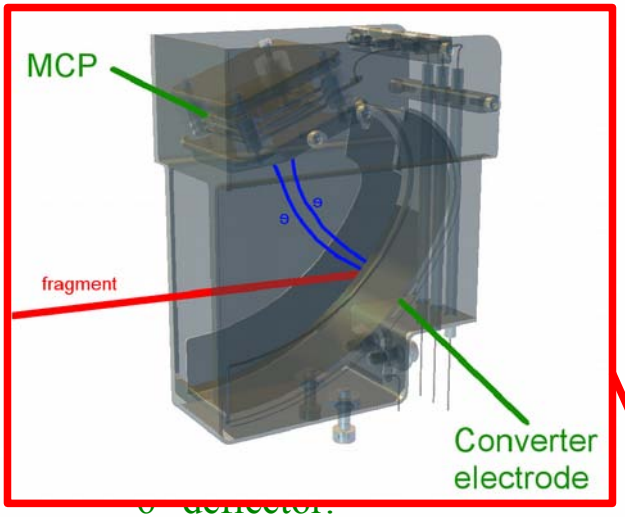

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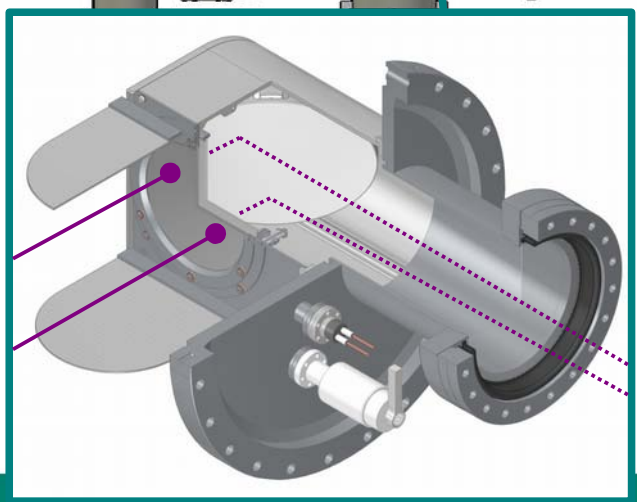
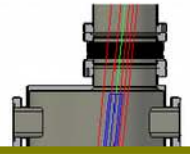
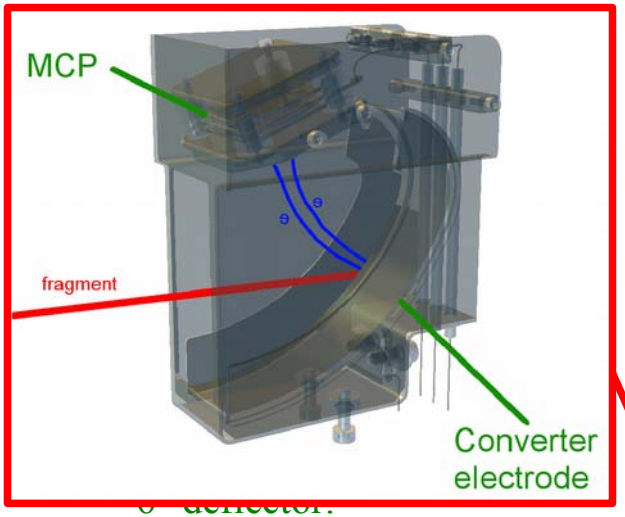


neutral product detector: MCP, phosphor screen + timing

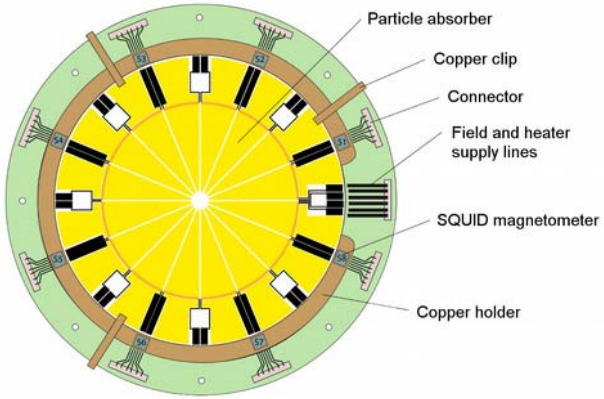
Detector Array



charge-changed product detectors



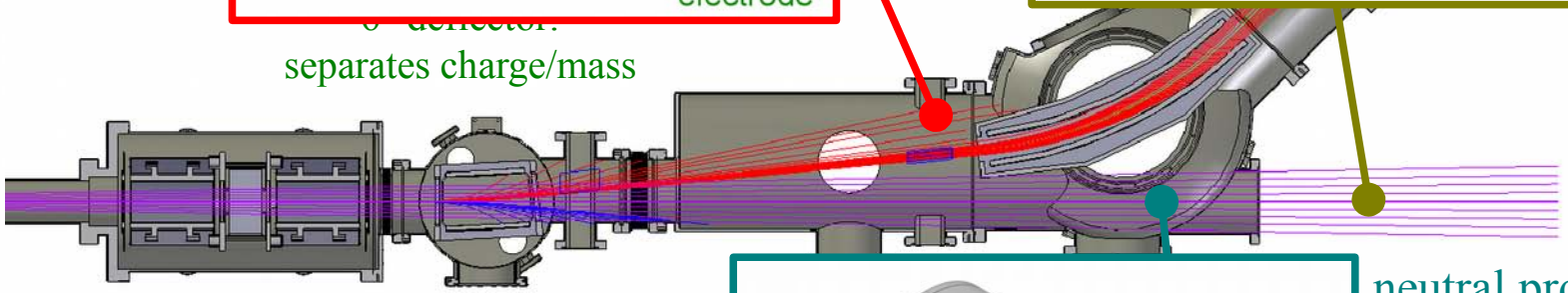
Future upgrade:
Microcalorimeter "PIZZA"

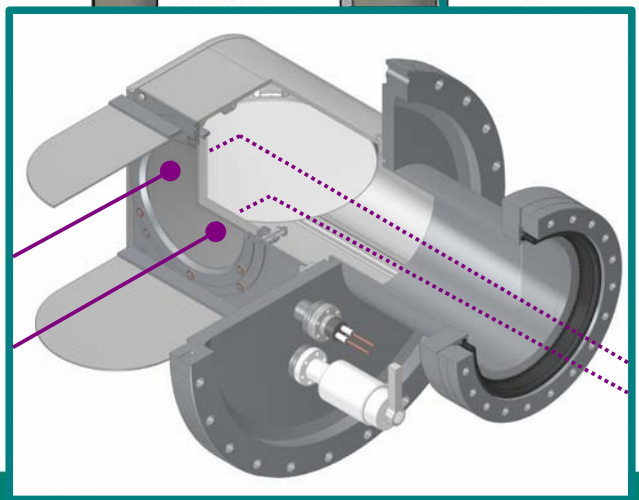


[Enss et al.] see poster!

separates charge/mass

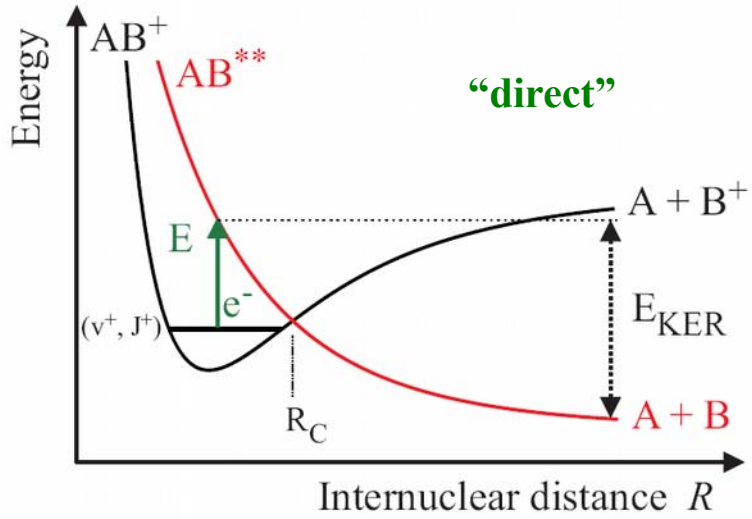
from experiment

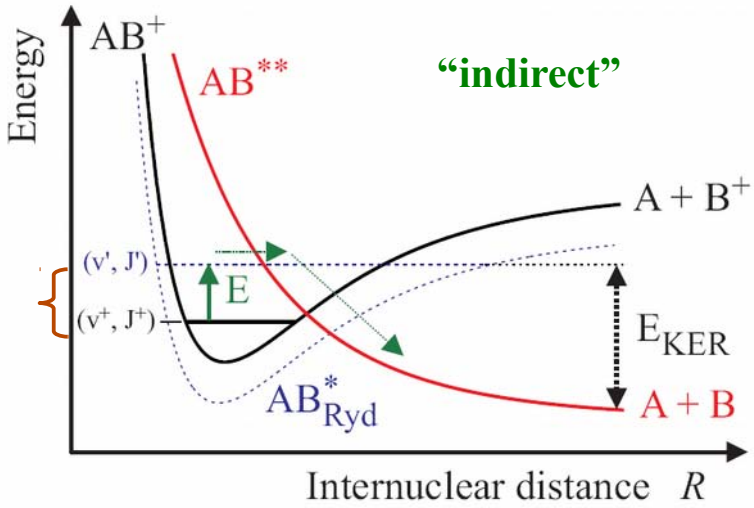




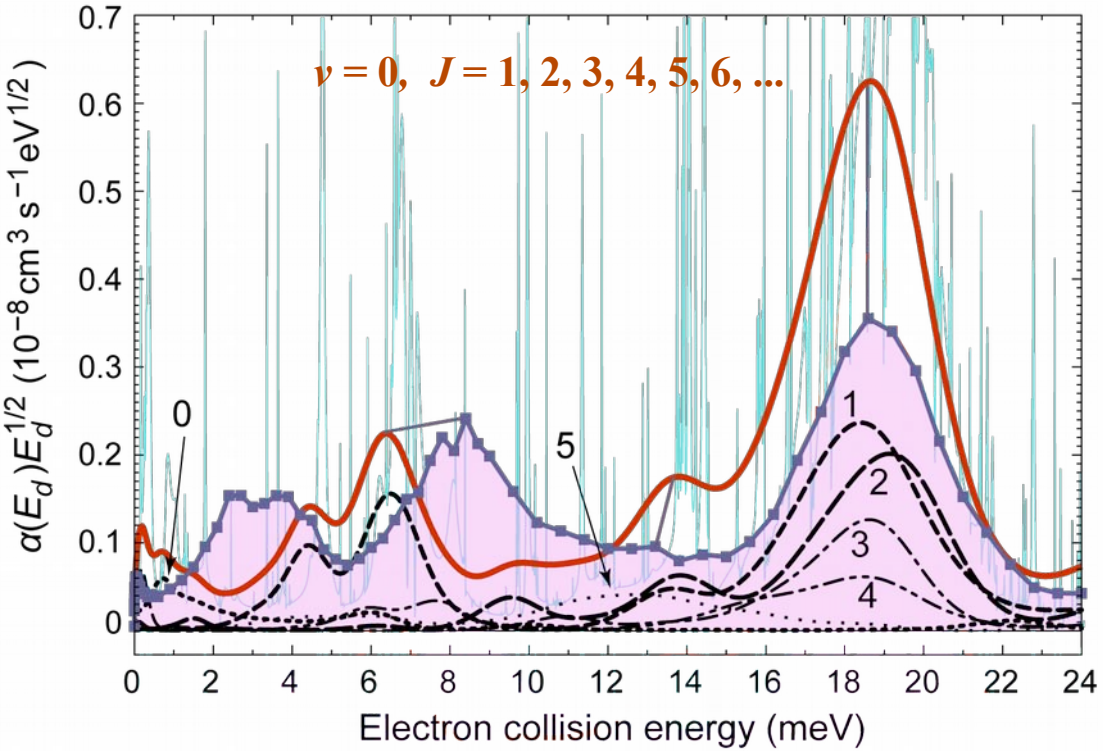
neutral product detector:
MCP, phosphor screen + pulse timing

DR Experiments: "Benchmarks"





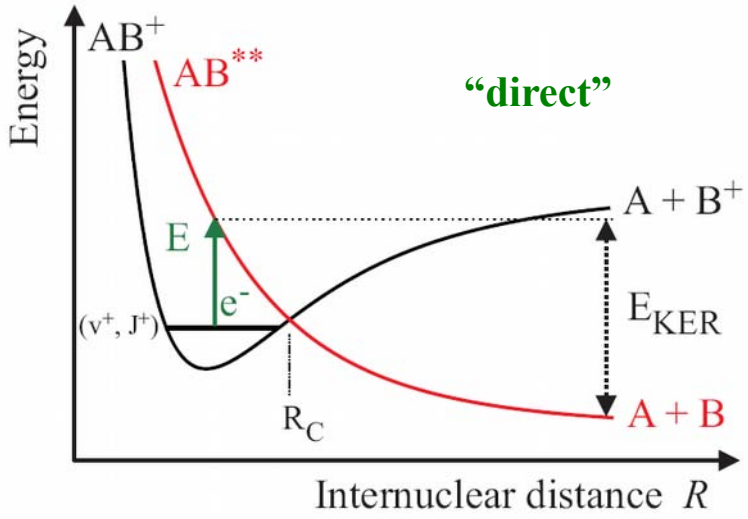
$HD^+ + e \rightarrow H + D$

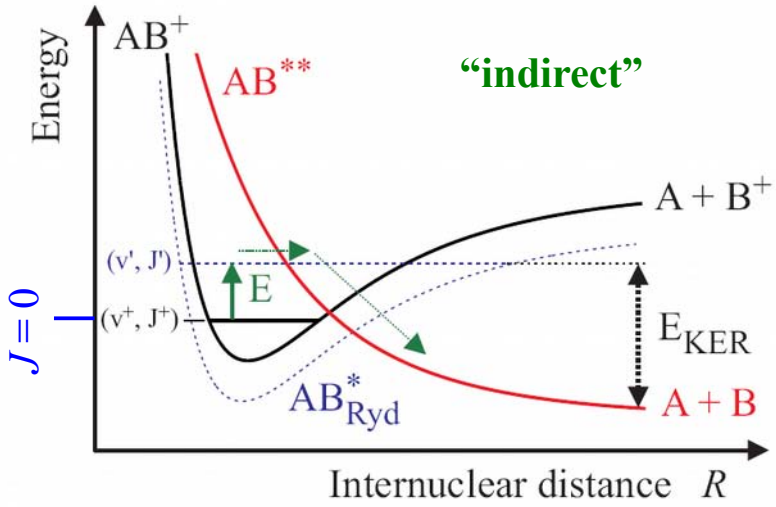


Waffeu-Tamo *et al.*, PRA 84 (2011) (0 K)

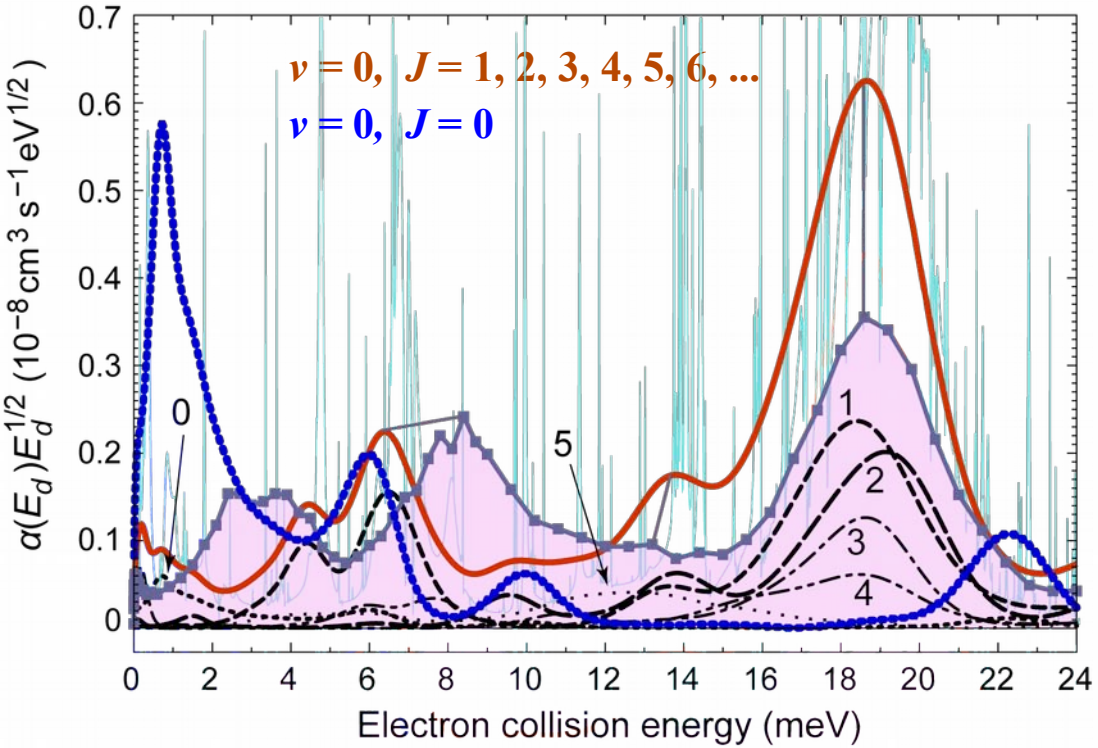
TSR data (kT_e ~ 1 meV, T_{ion} ~ 300 K)

DR Experiments: "Benchmarks"





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



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

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

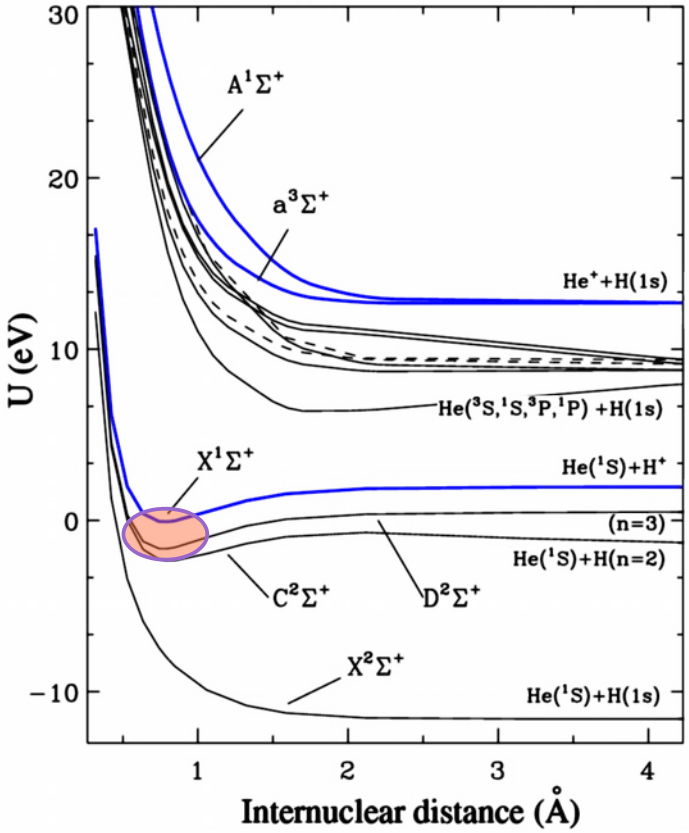
CSR prediction ($T_{ion} = 10$ K)

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

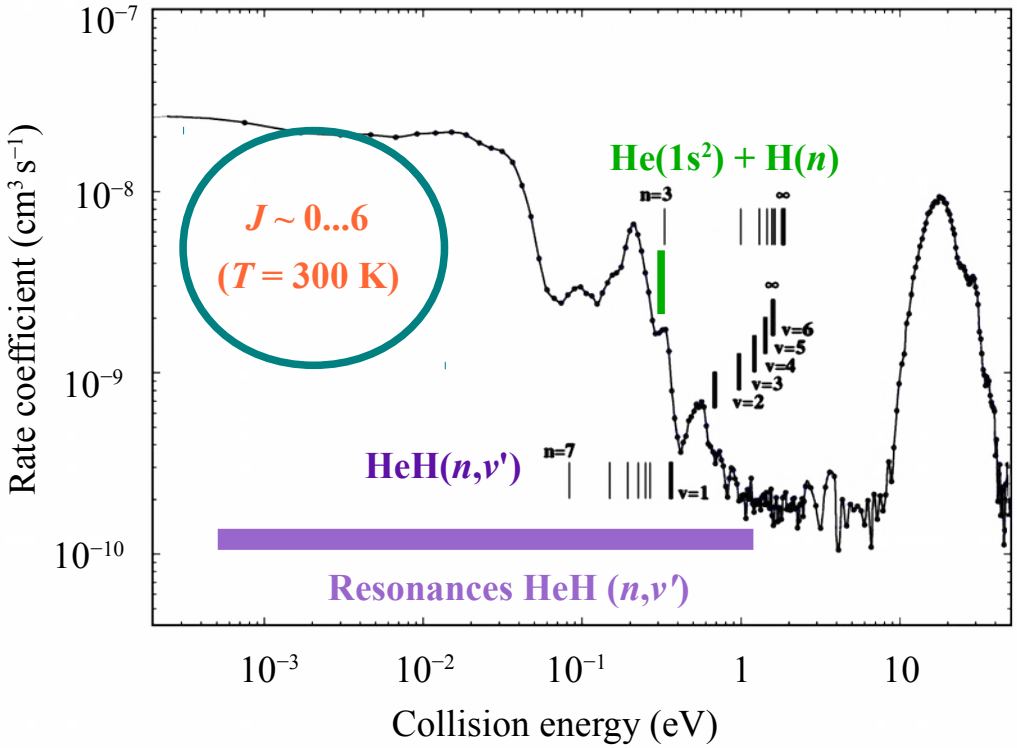
10 K → $J = 0$

DR Experiments: "Benchmarks"

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

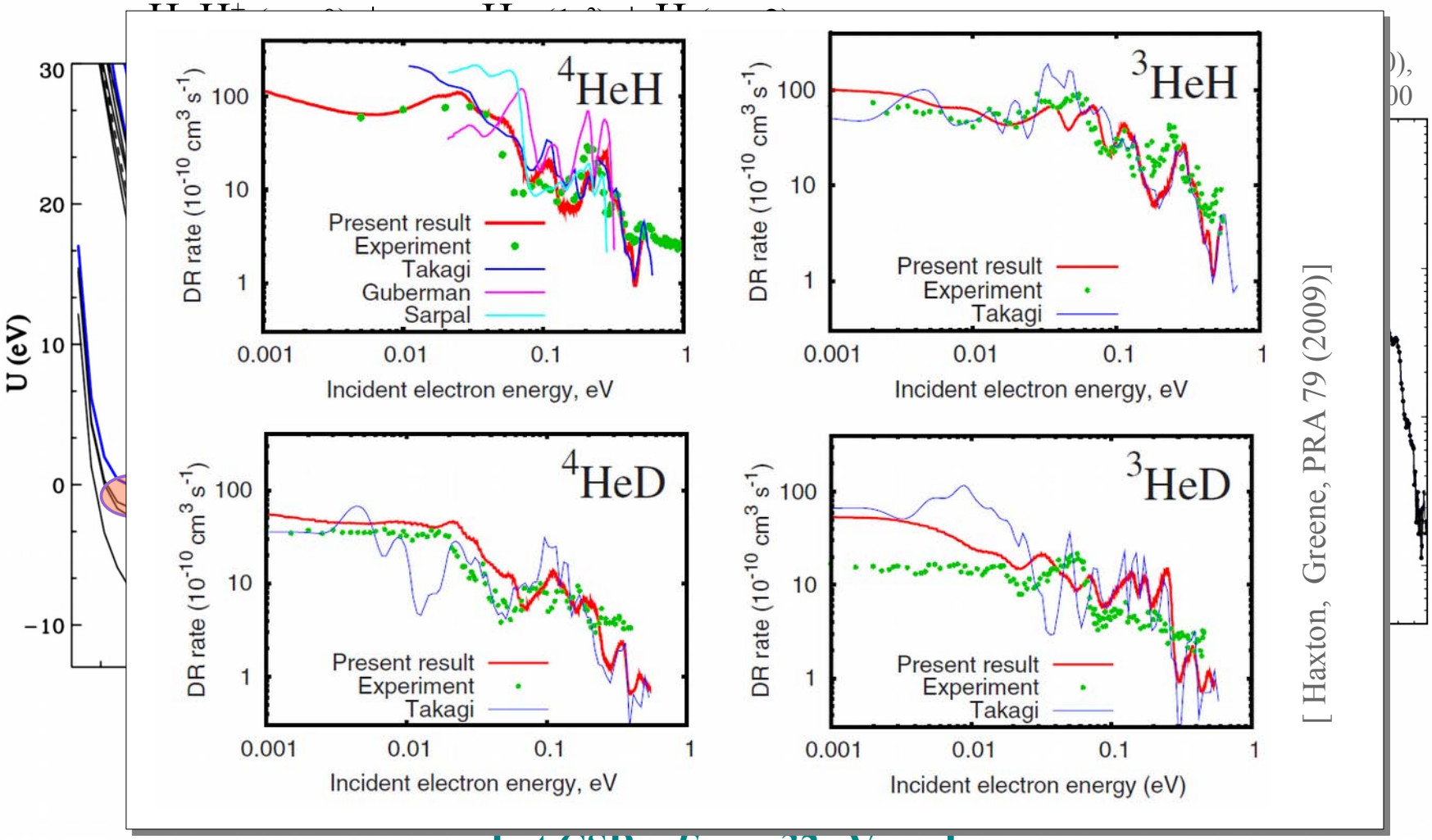


TSR (S. Krohn, 2000),
data scaled to Tanabe *et al.*, 2000



at CSR: E_{cool} = 32 eV
10 K $\rightarrow$ $J = 0$

DR Experiments: "Benchmarks"



at CSR: E_{cool} = 32 eV

10 K → J = 0

DR Experiments: Complex Systems

- Polyatomics: H_3^+, H_3O^+, HNO^+/HON^+, CCN^+/CNC^+ ...
- DR of large organic molecules $C_xH_y^+$, $C_xH_yOH^+$ ...
- Transition to non-dissociative recombination?
- 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 collisions of (negative) Cluster ions …
  Dependence of rate coefficients on internal excitations ?

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 electron collision experiments on molecular and other heavy ions.

Thank You!

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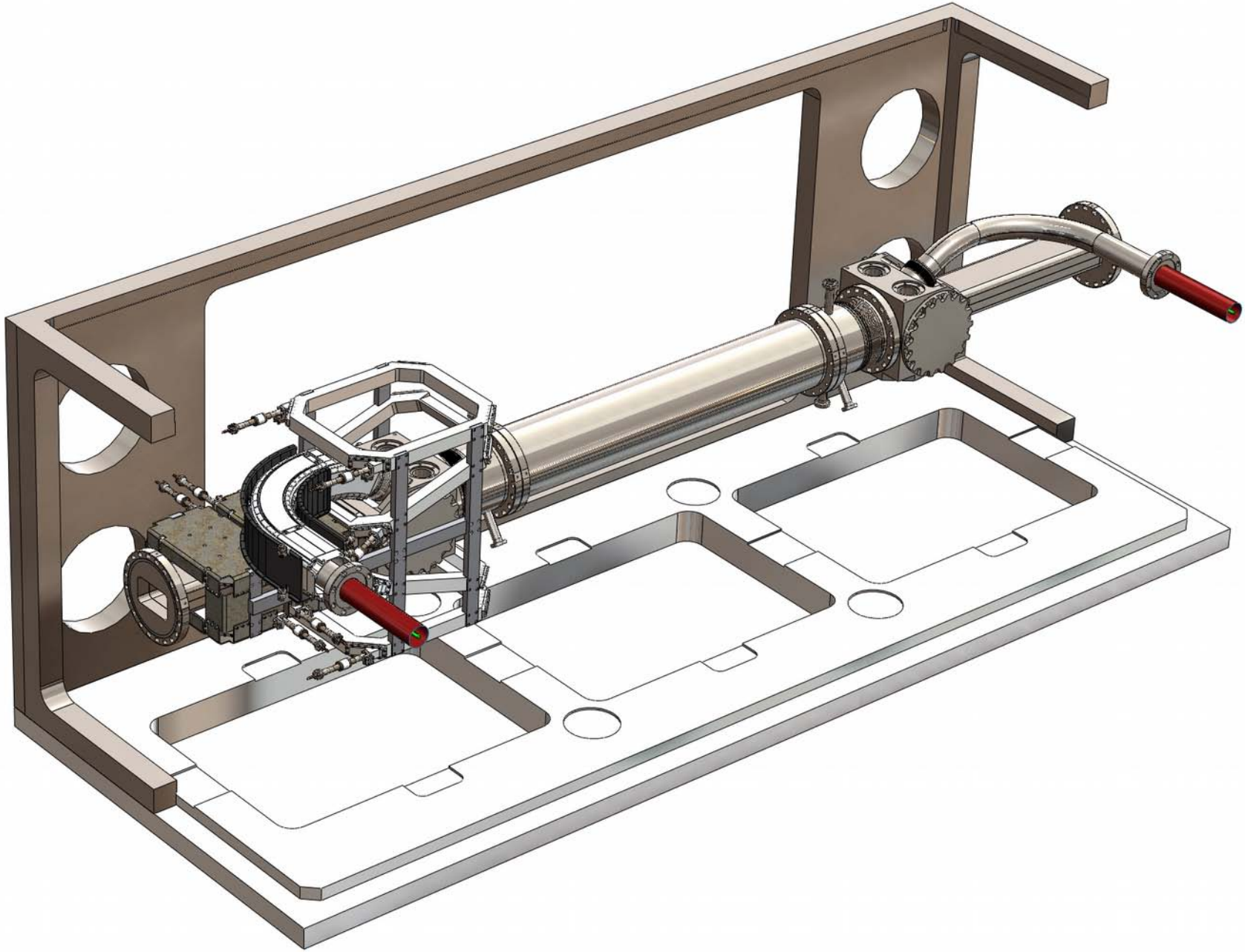
Electron Cooler



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

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

- 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