MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Low-energy particle detection at the Heidelberg Cryogenic Storage Ring

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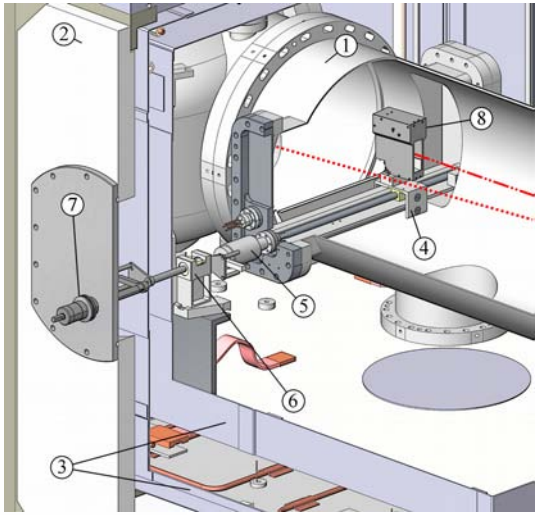
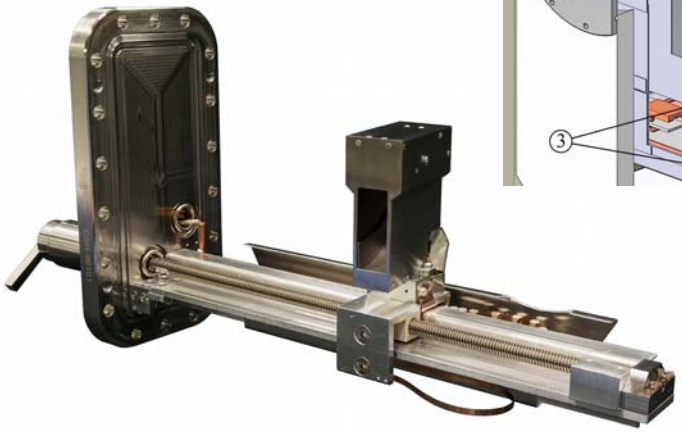
1 – The **Cryogenic Storage Ring**

2 – **Particle detection** in the CSR

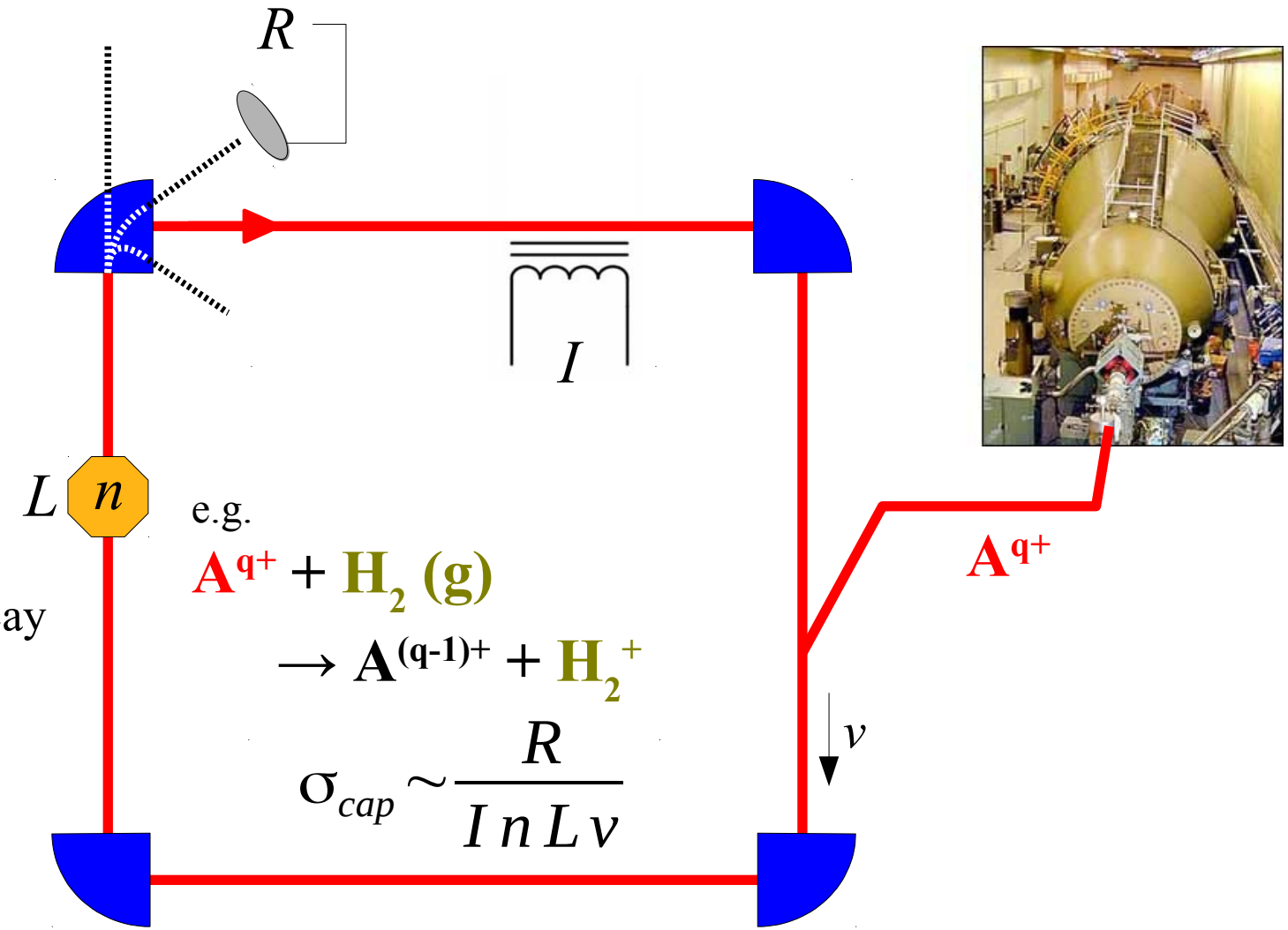




Atomic and Molecular Physics with Storage Rings

Ion Storage Ring

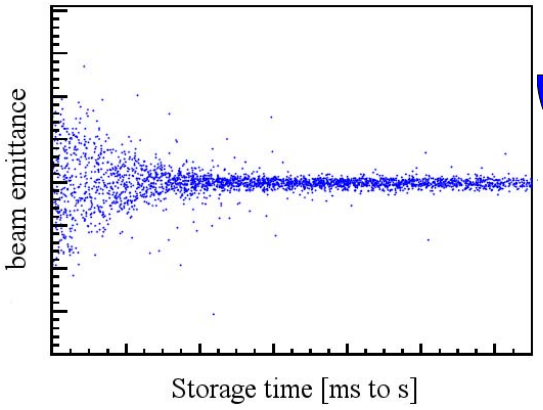
* **Recycle** ions (higher *I*)
* Increase **ToF** (μs to s) e.g. allow **metastables** to decay

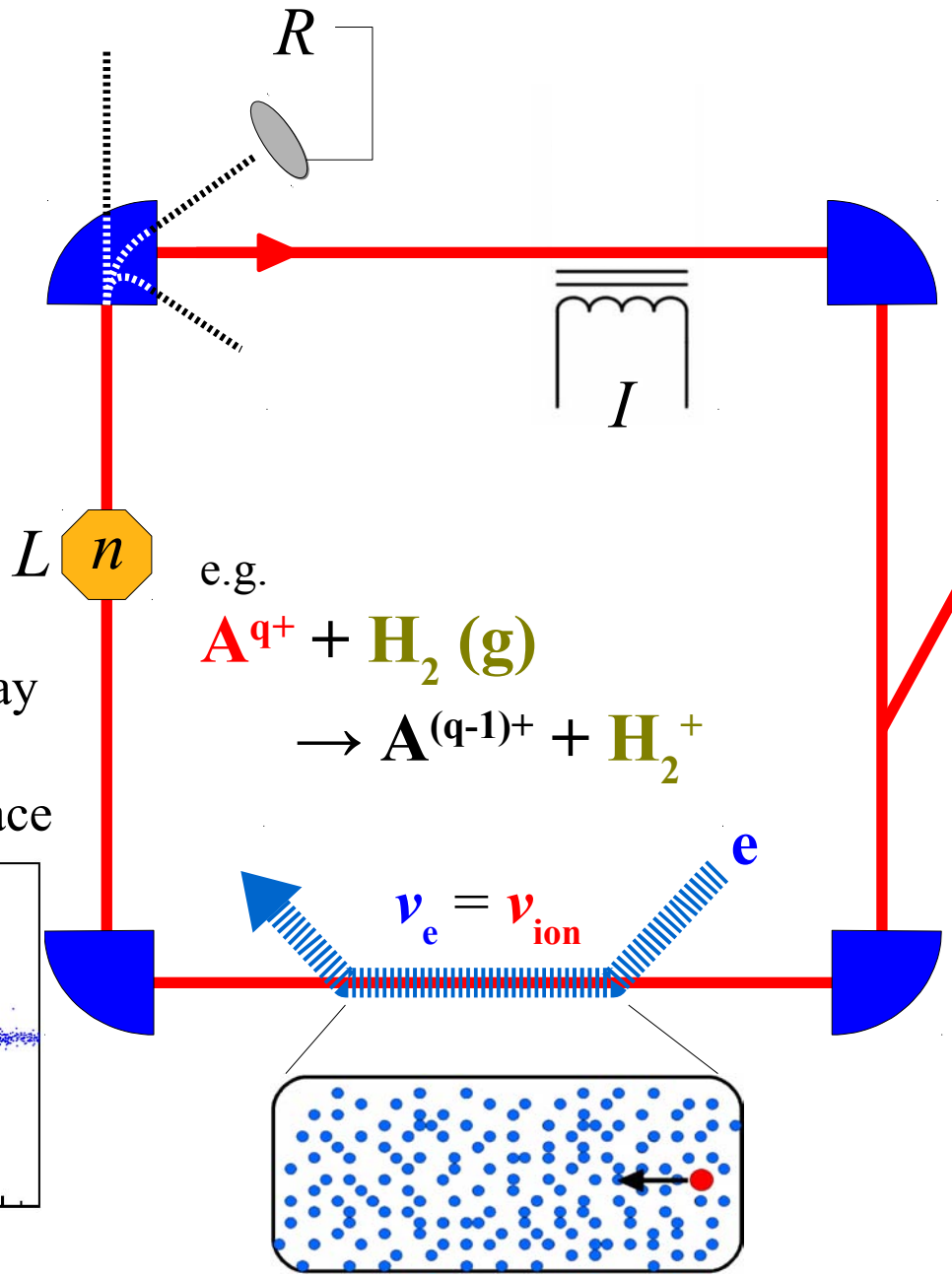


Atomic and Molecular Physics with Storage Rings

Ion Storage Ring
+ Electron Cooler

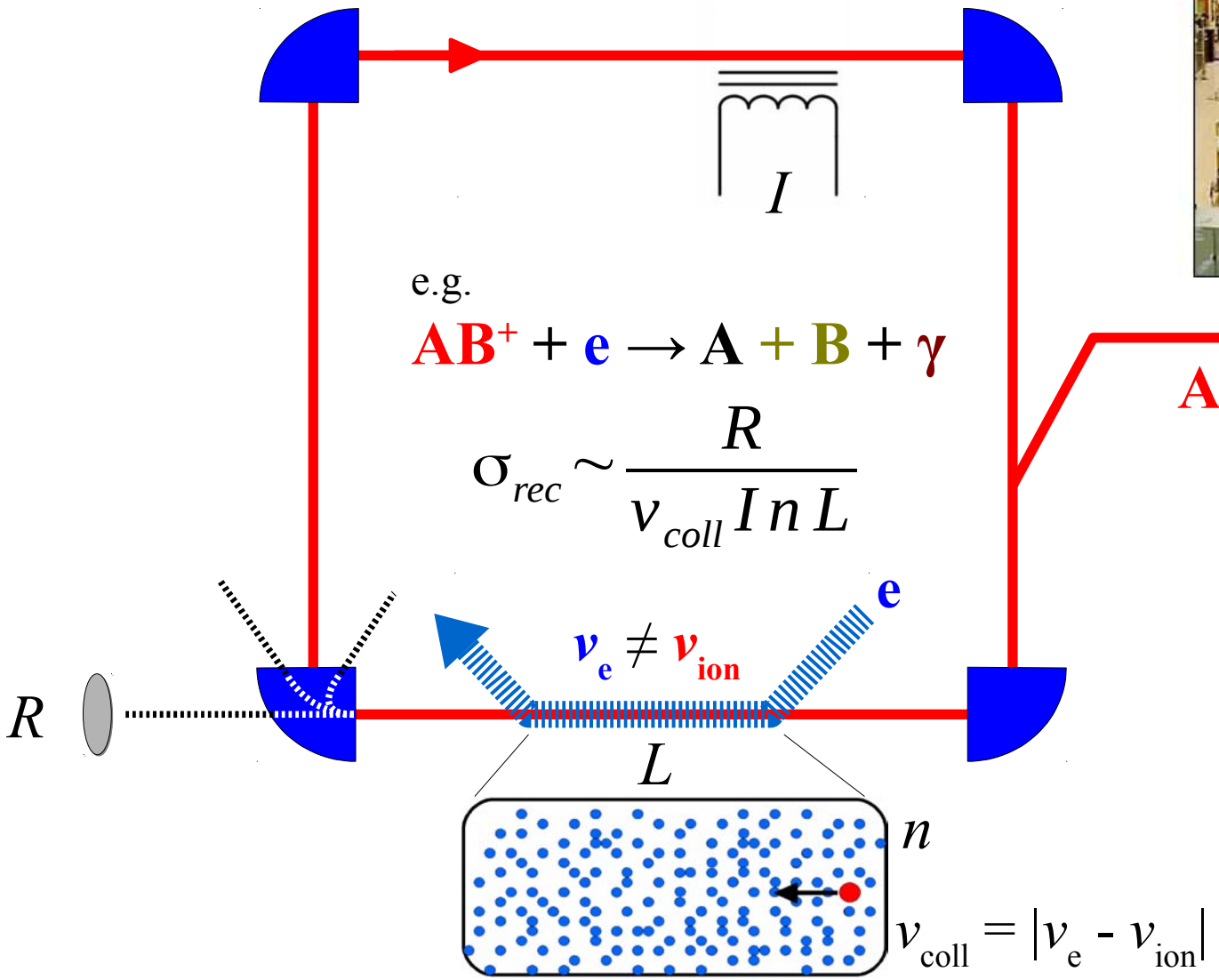
* **Recycle** ions (higher *I*)
* Increase **ToF** (μs to s) e.g. allow **metastables** to decay
* Decrease **ion beam spread** in phase space



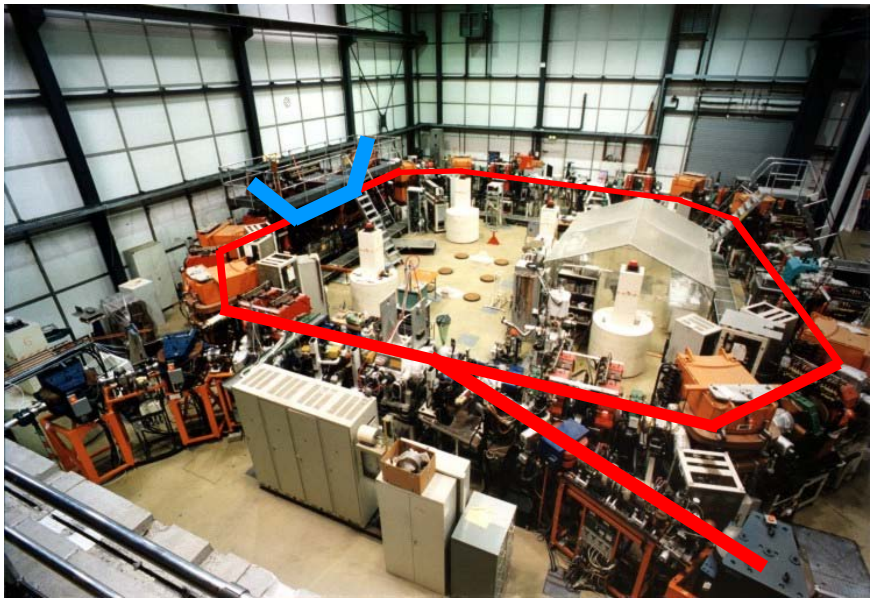


A^{q+}

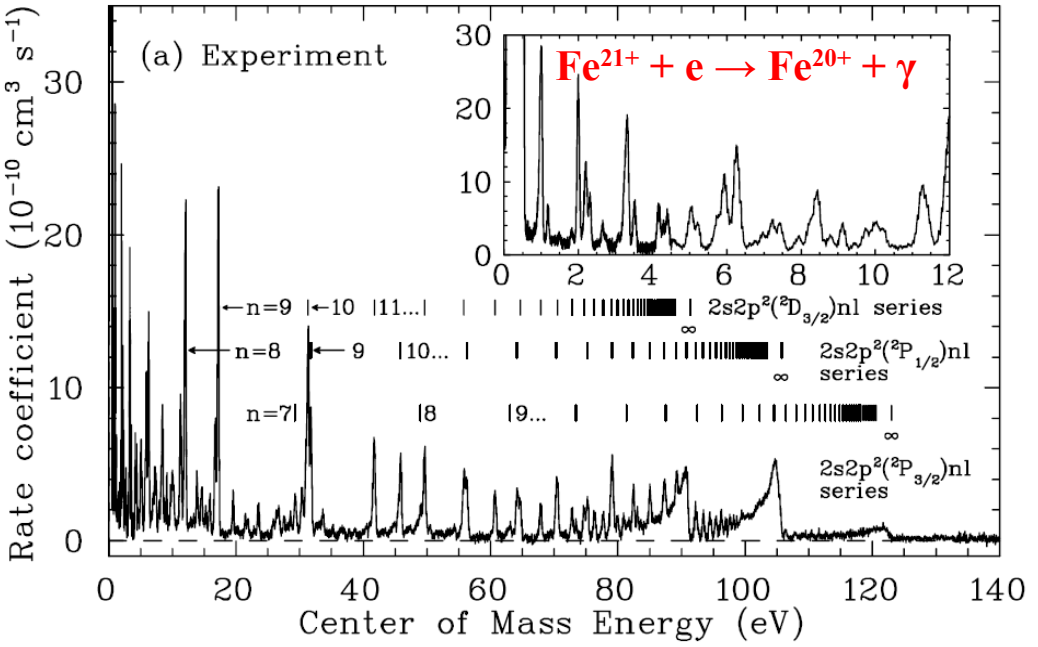
Atomic and Molecular Physics with Storage Rings



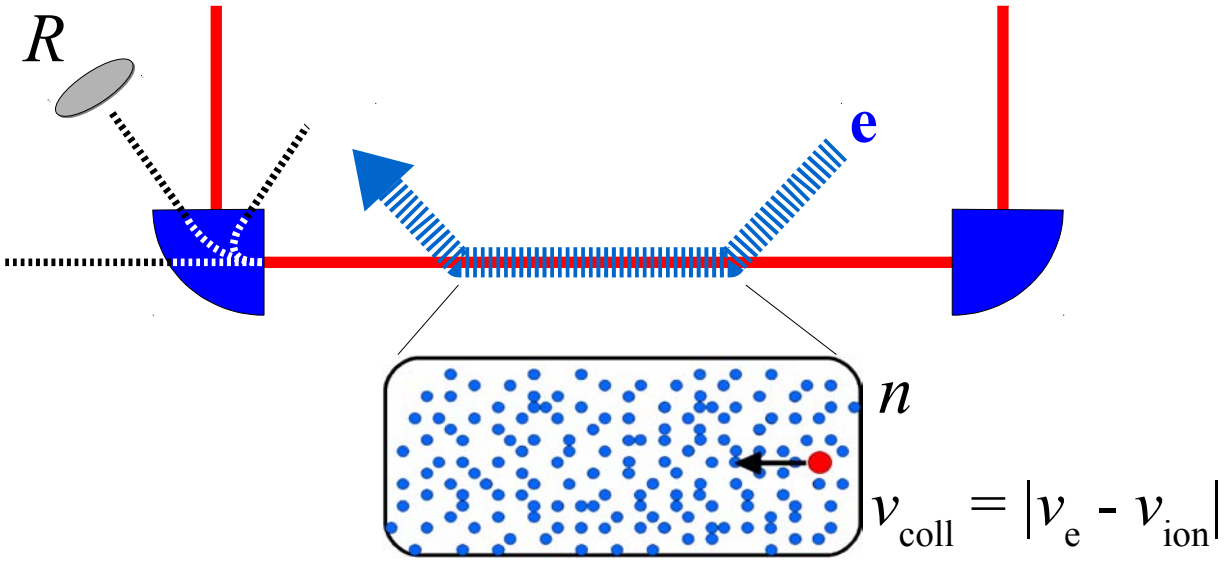
Atomic and Molecular Physics with Storage Rings



Storage Ring TSR (decom. end 2012)



Savin, ApJ Suppl. Ser. 147 (2003)



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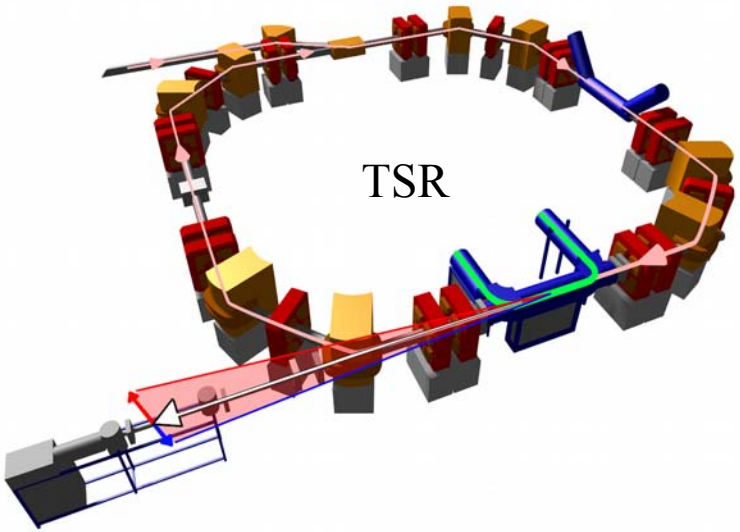
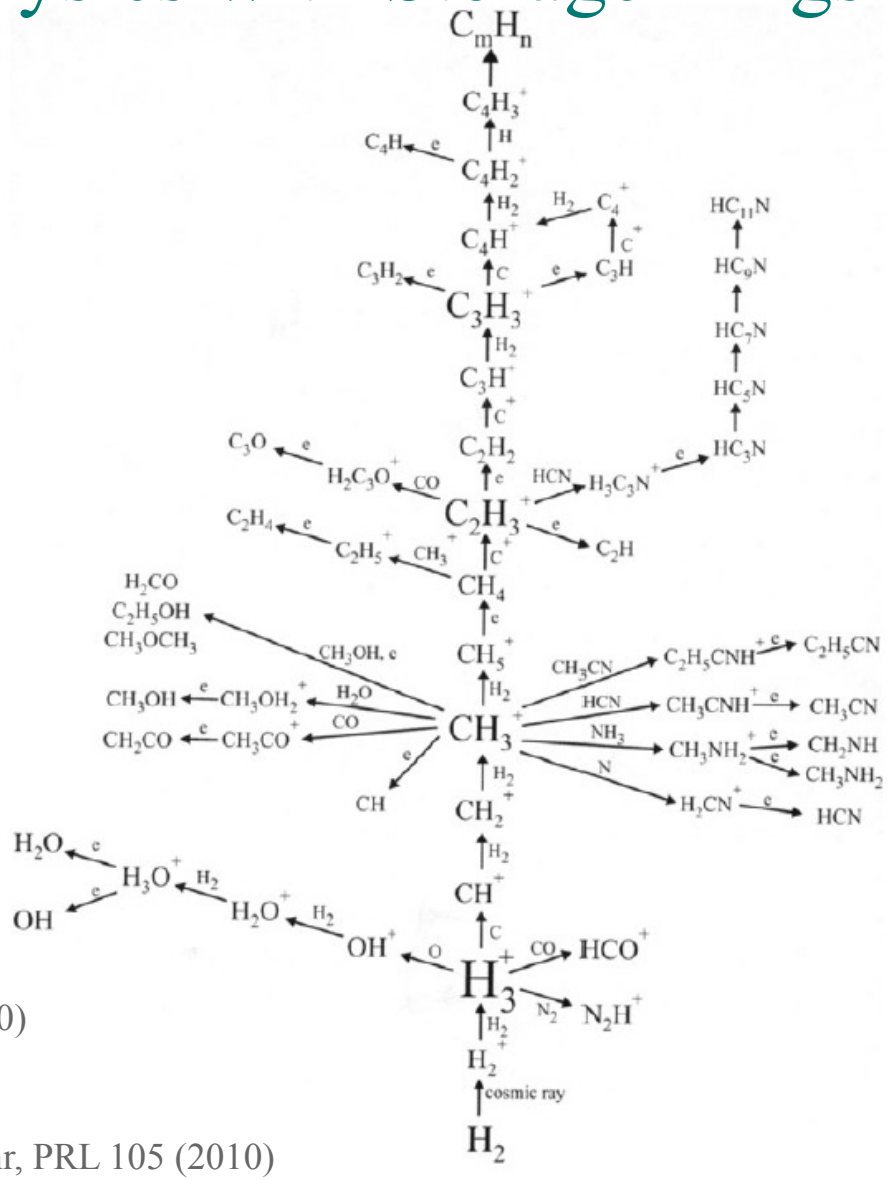




Gas-phase chemistry in ISM driven by H_3^+:

$H_3^+ + e \rightarrow H + H + H$

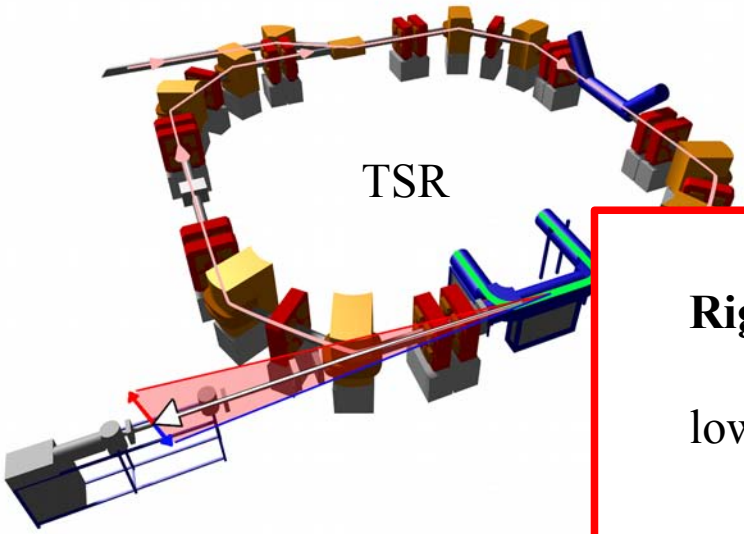
e.g. Petrignani, PRA 83 (2011); Kreckel, PRA 82 (2010)

Formation of neutral molecules

$H_3O^+ + e \rightarrow H_2O^{**} + H$ Buhr, PRL 105 (2010)

$HCNH^+ + e \rightarrow HCN/CNH^{**} + H$ Mendes, ApJ Lett. 746 (2012)

Atomic and Molecular Physics with Storage Rings



Rigidity limit

low q, high m

0.01 c

→ low velocity
→ lots of res. gas scattering (background!)
→ short storage time (no relaxation!)

+ IR radiation background (rot. trans.!)

Gas-phase chemist
ISM driven by H_3^+:

$H_3^+ + e \rightarrow H + H +$

e.g. Petrignani, PRA 83 (2011), Kreckel, PRA 82 (2010)

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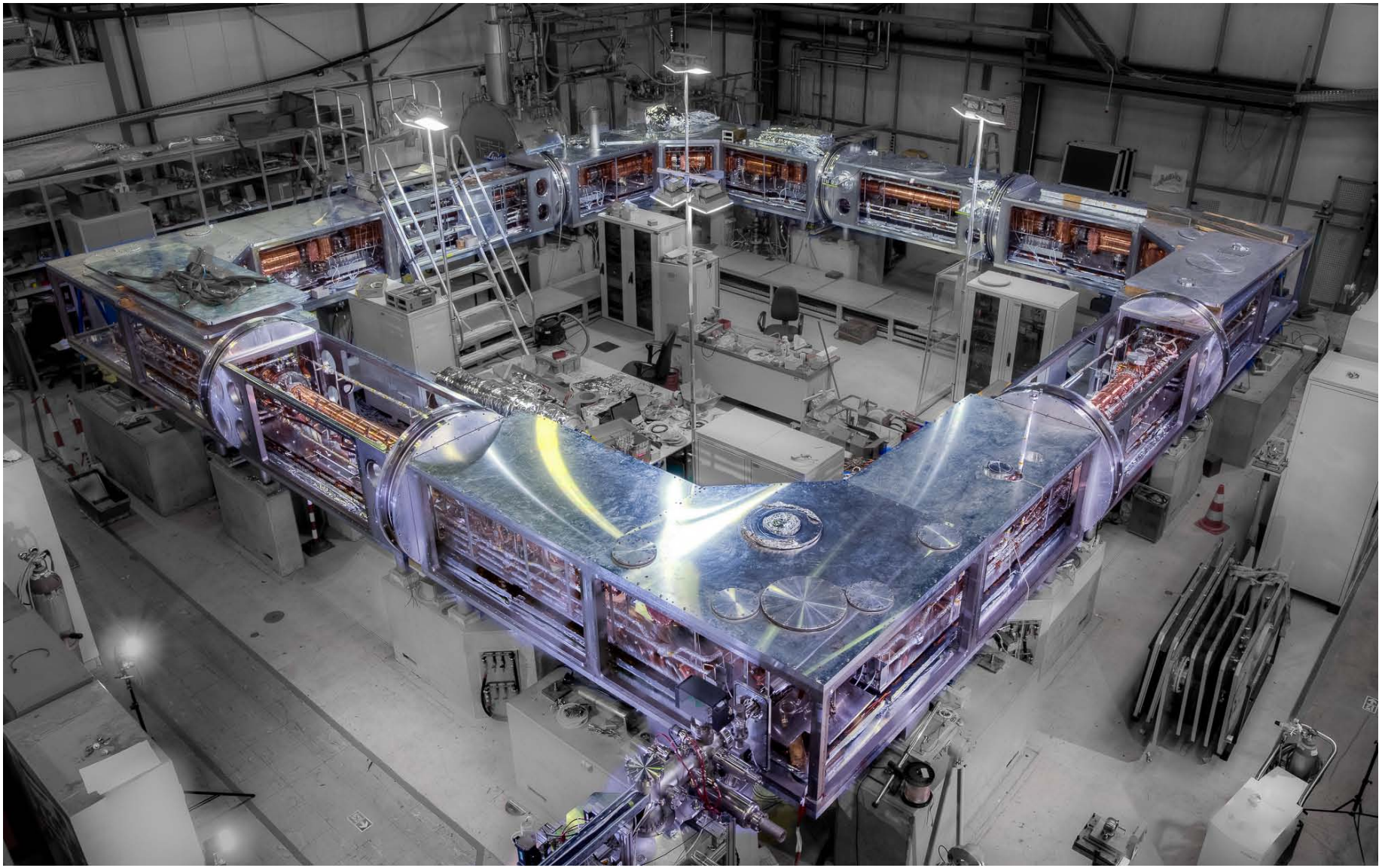
The Cryogenic Storage Ring



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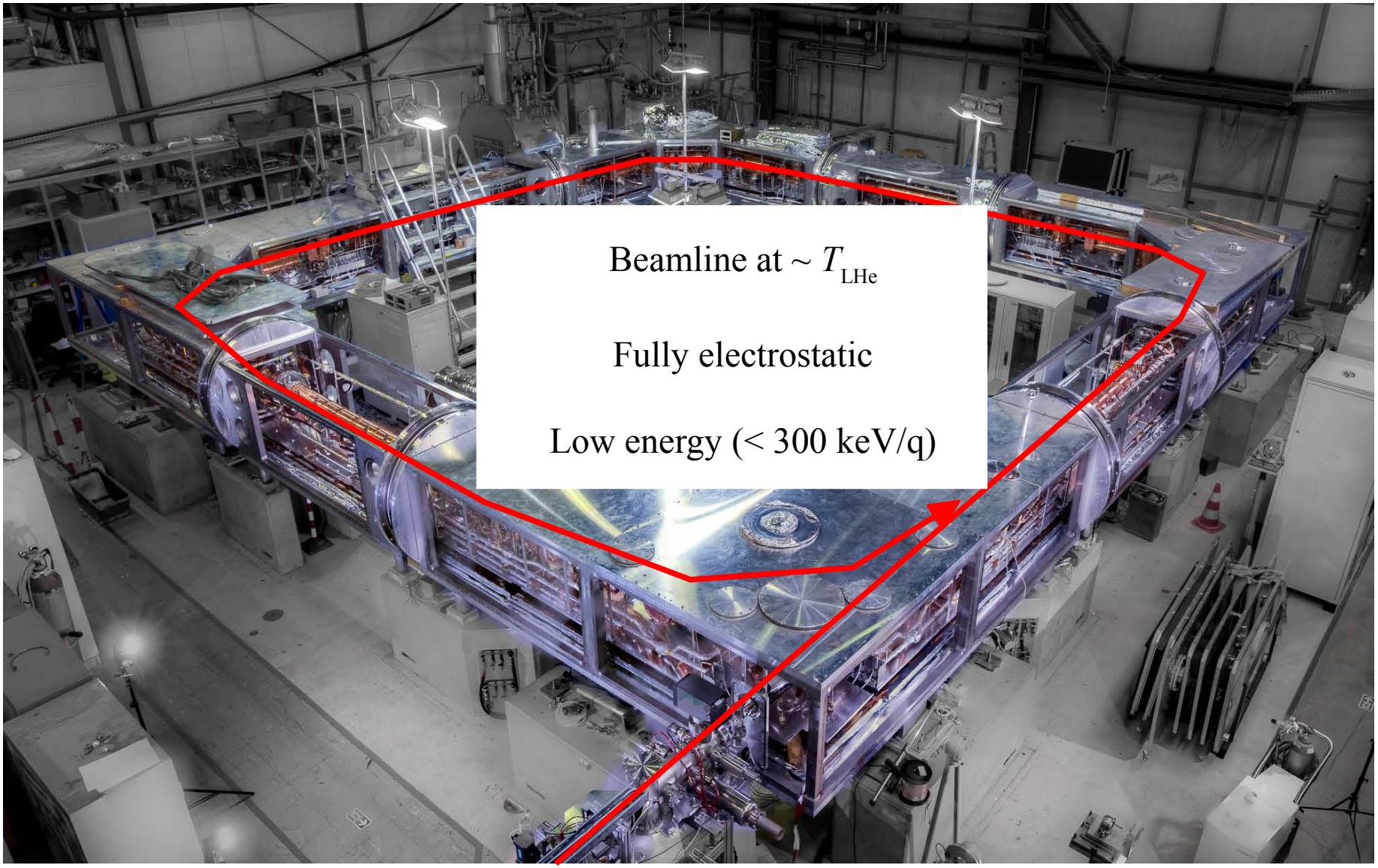

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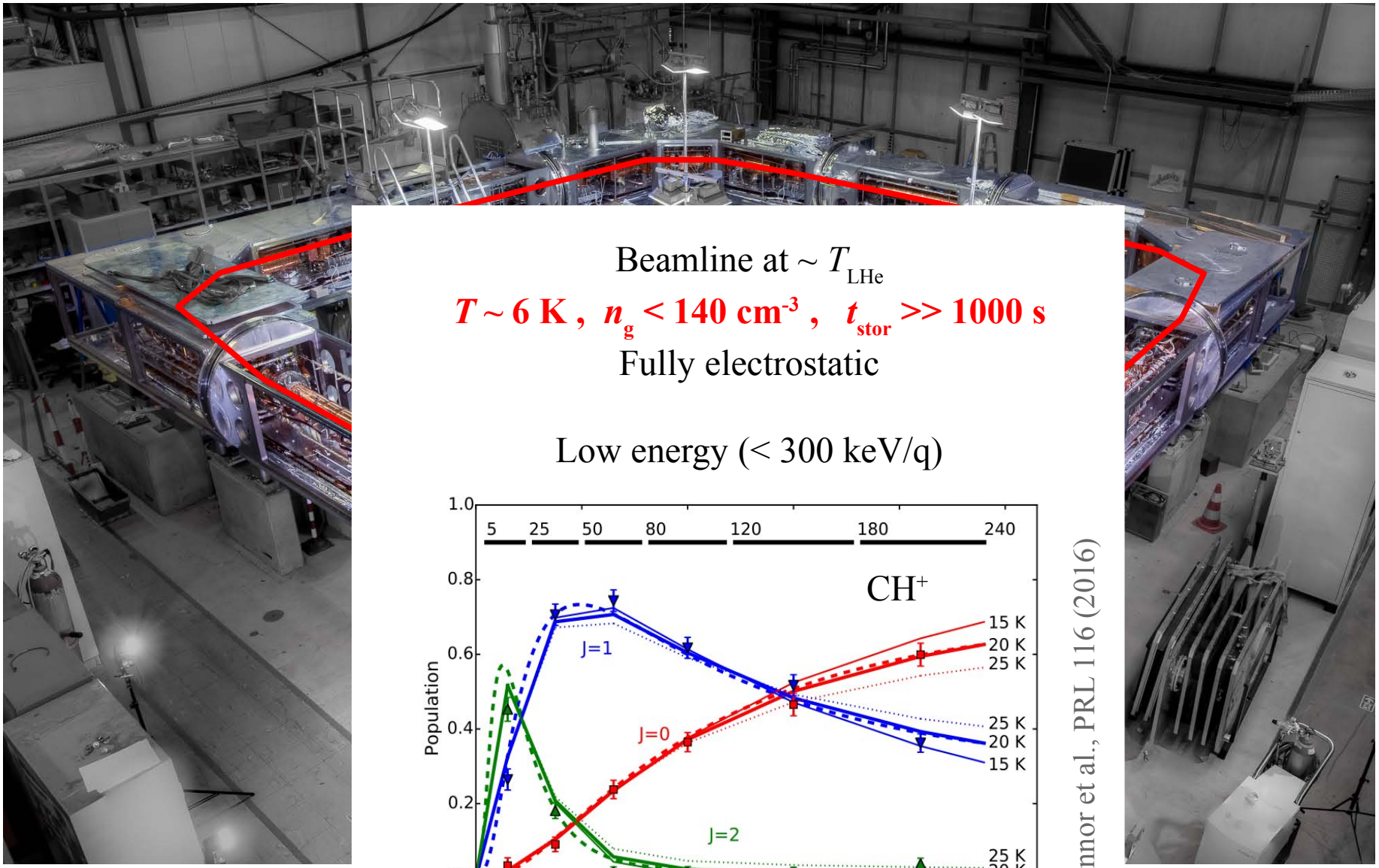


Beamline at ~ T_{LHe}

$T \sim 6$ K , $n_g < 140$ cm^{-3} , $t_{stor} >> 1000$ s

Fully electrostatic

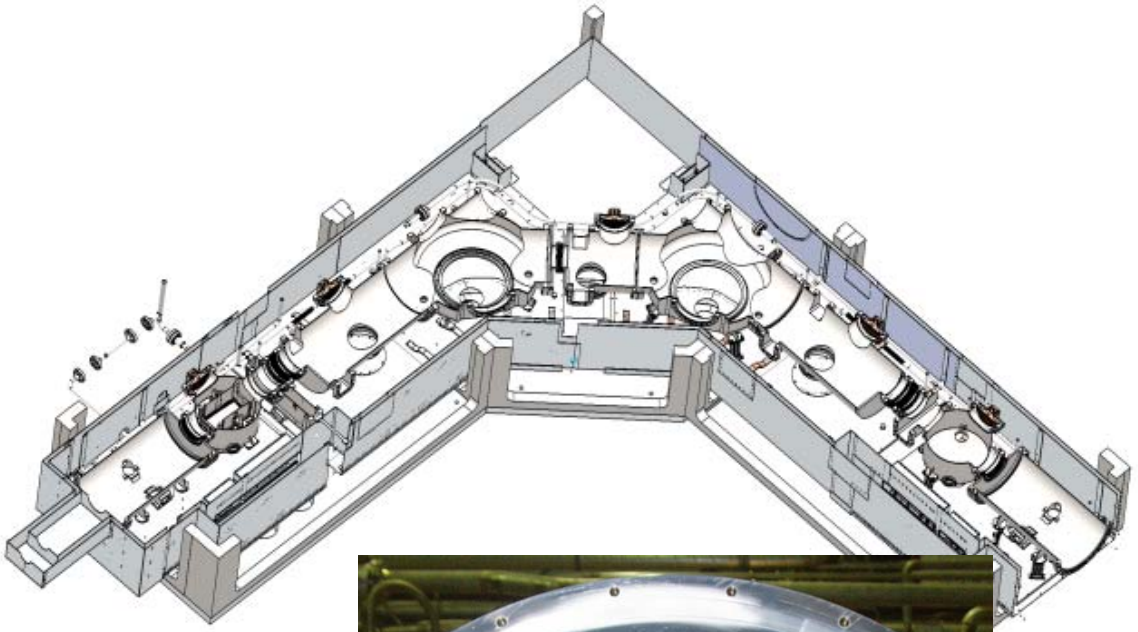
Low energy (< 300 keV/q)

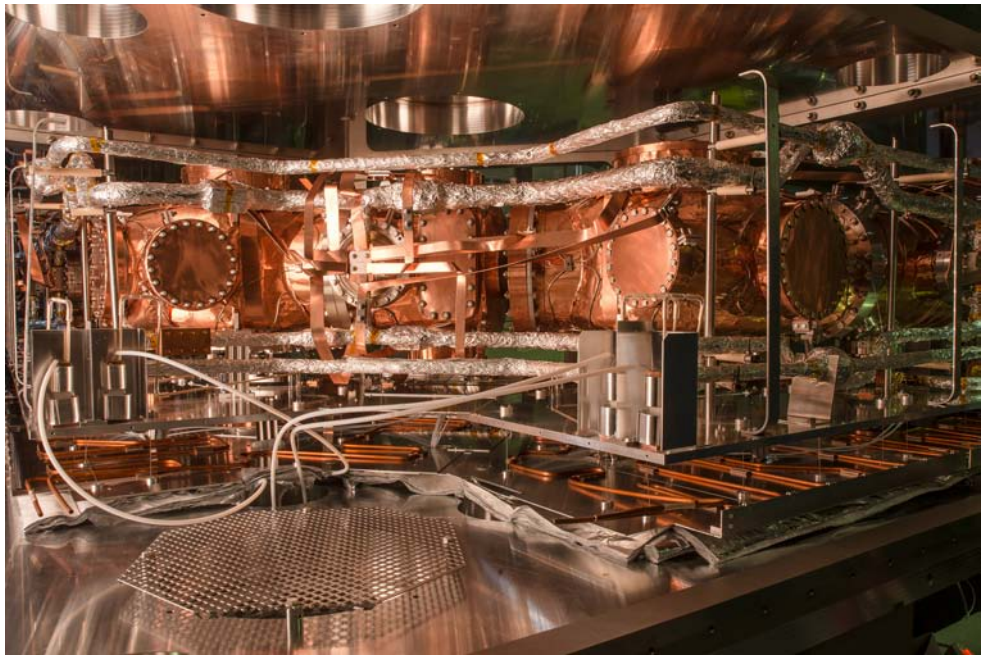
O'Connor et al., PRL 116 (2016)

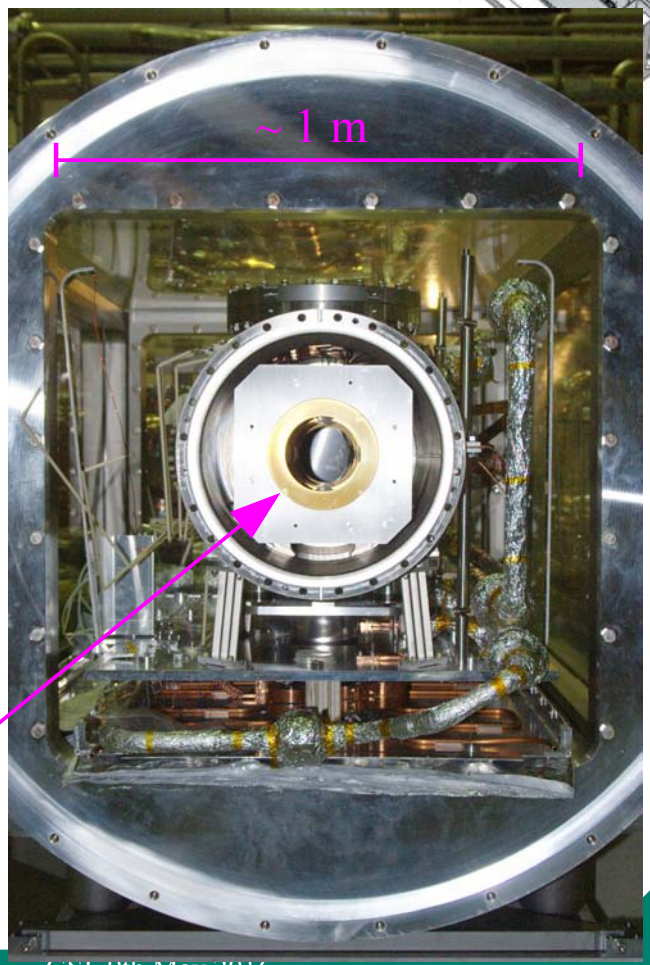
The CSR

Cryogenics

- XHV vacuum chamber
  6 K, ~10^{-14} mbar (rte)
- 2 radiation shields
  ~30 and 50 K
- Multi-Layer Insulation
- Isolation vacuum chamber (10^{-6} mbar)



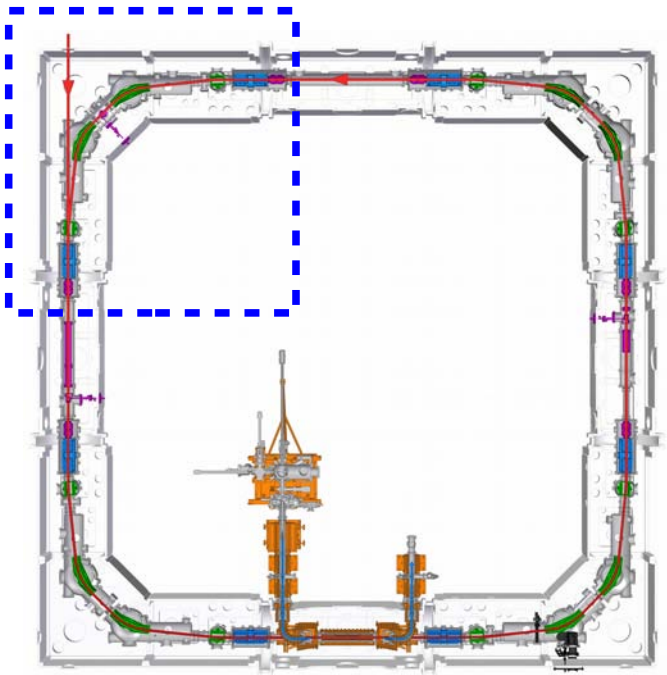


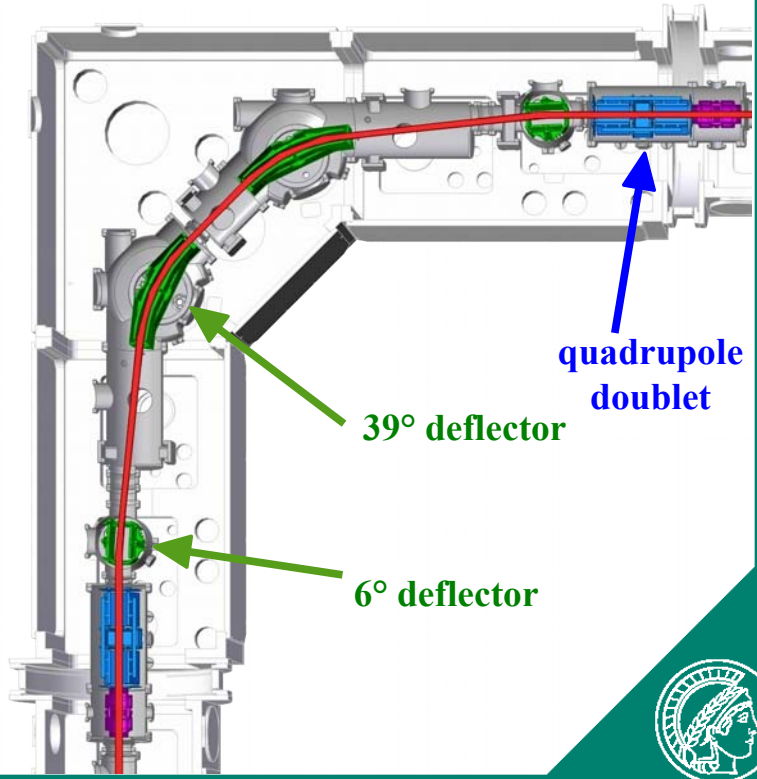


The CSR

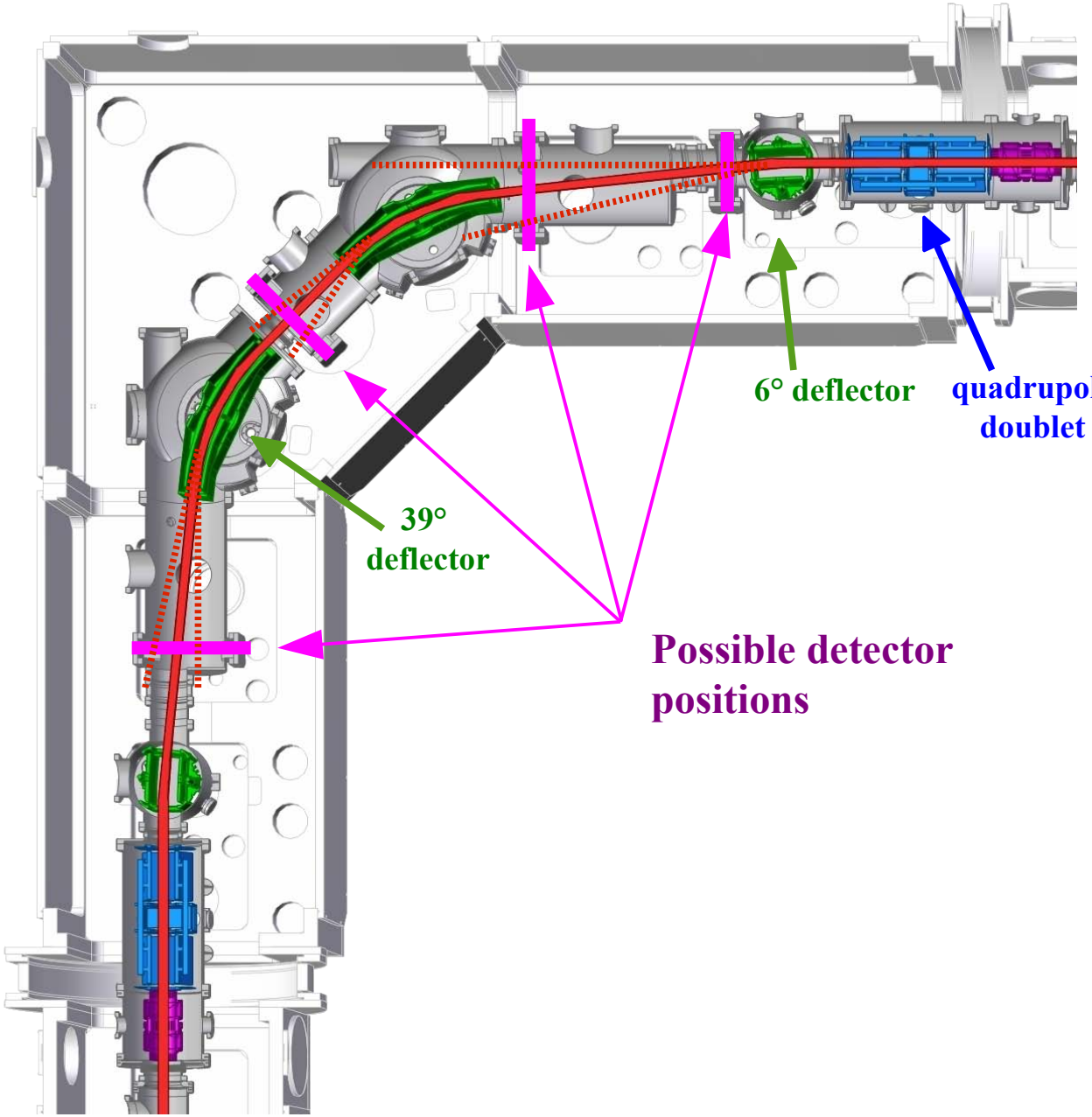
Electrostatic beam optics

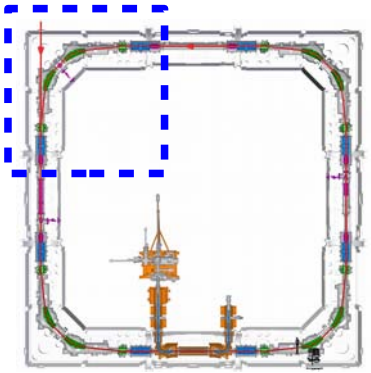
- 4 periods
  - 4 identical “corner” sectors
- 4 x 2 **quadrupole doublets**
- 4 x 2 **6°-deflector** electrodes (±20 kV)
- 4 x 2 **39°-deflector** electrodes (±20 kV)
- 4 free straight sections (2.4 m, experiments)





The CSR


6° deflector
quadrupole doublet
39° deflector
Possible detector positions



Requirements for a CSR detector ...

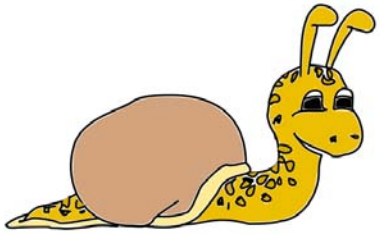
2) Engineering challenges:

CSR **cools to T_{LHe}** …
… and is **baked to 250°C**.

Target vacuum at RT: **~ 10^{-11} mbar**.

Only non-magnetic materials allowed.

Needs to be a robust solution.



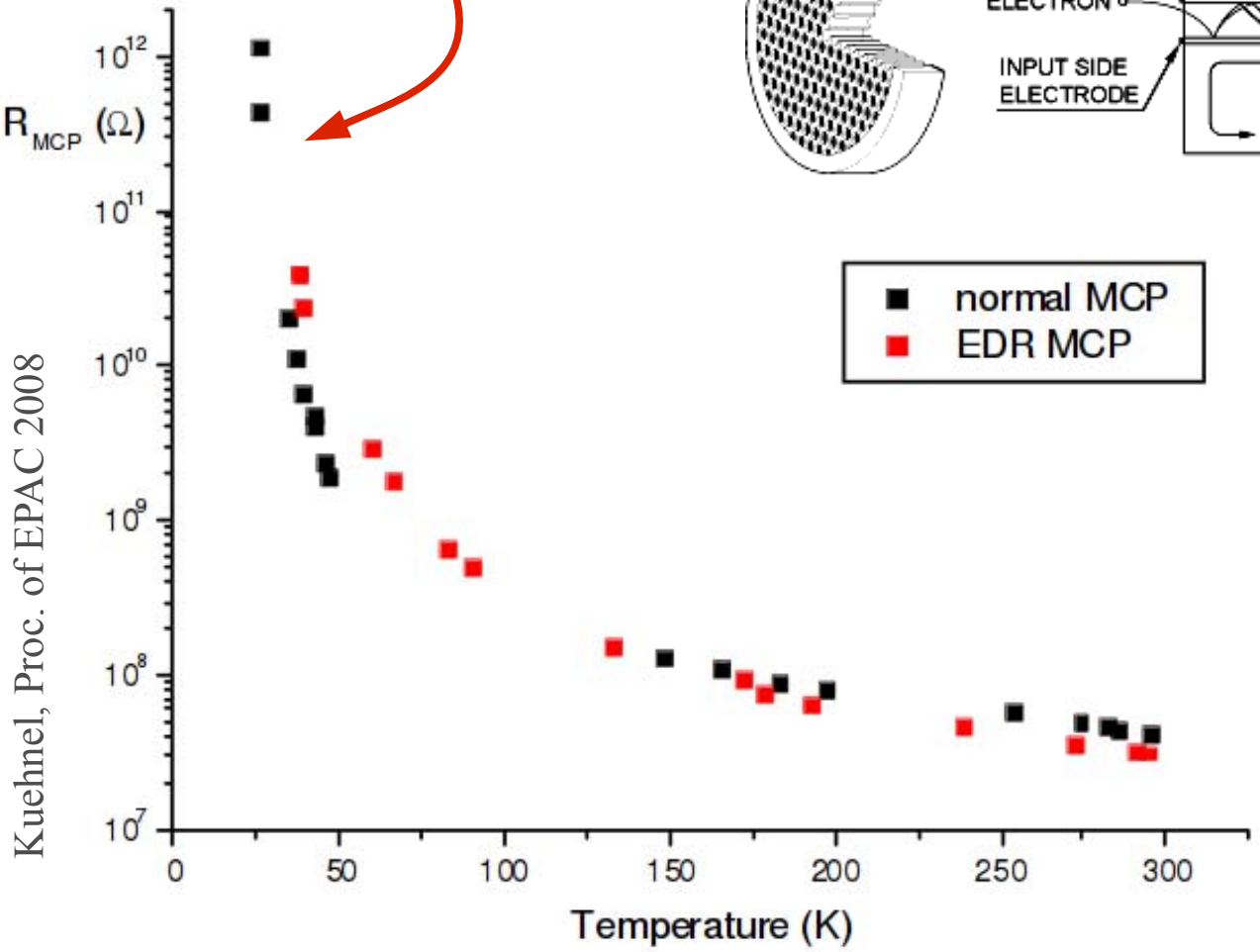
1) Particles are slow!

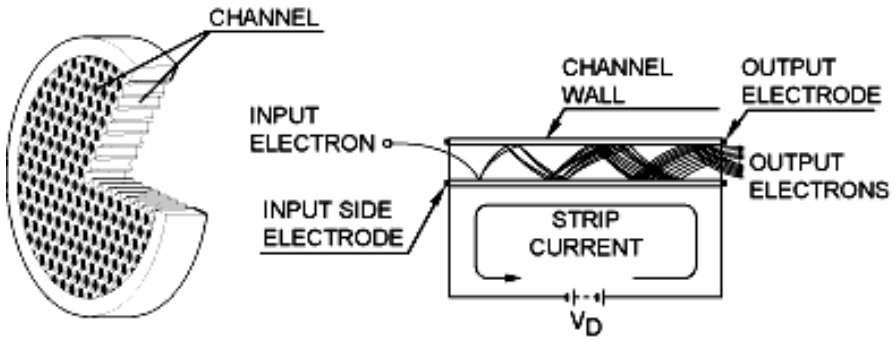
E < 300 keV/q , typically q = 1 , m >> 1
→ 0.1 … 10 keV/u

→ Surface electron emission/detection

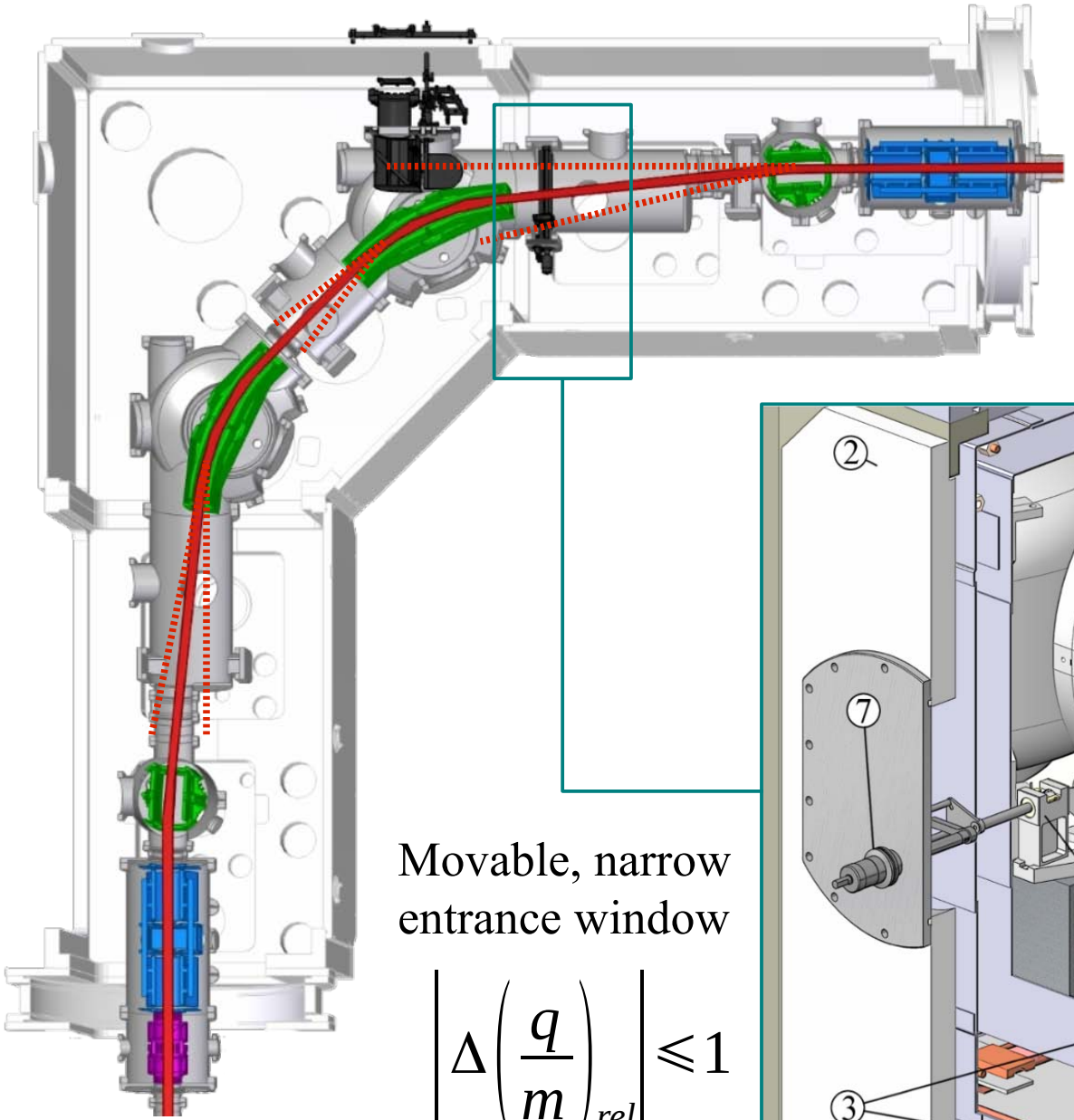
Requirements for a CSR detector ...

Exp. rise at low T
→ Risk of detector saturation

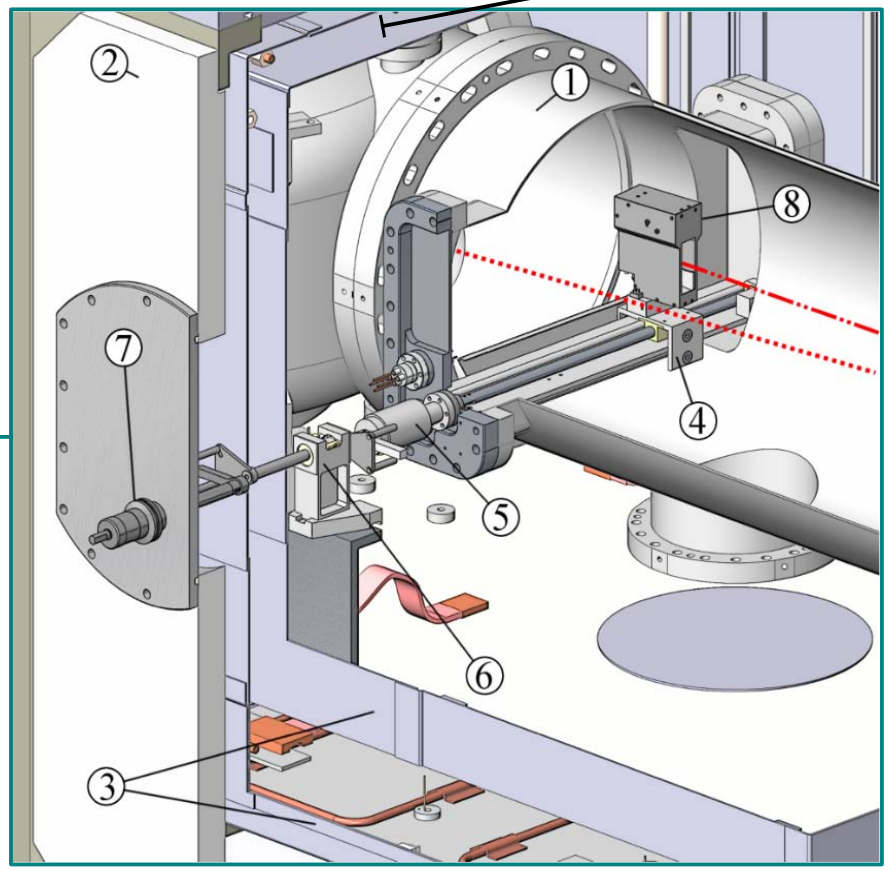




The COld Movable PArticle CounTer (COMPACT)



beams from experiment



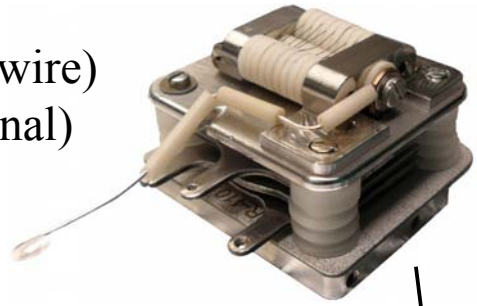
Movable, narrow entrance window

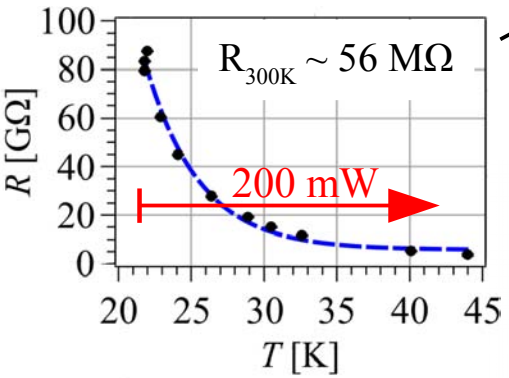
$$\left|\Delta\left(\frac{q}{m}\right)_{rel}\right| \leqslant 1$$

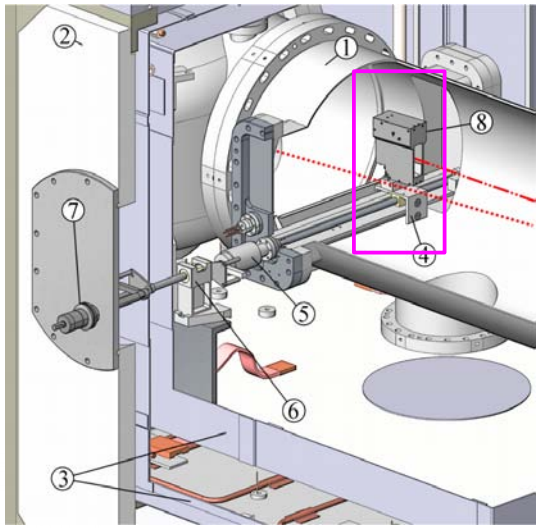
Spruck, Rev. Sci. Instrum. 86, 023303 (2015)

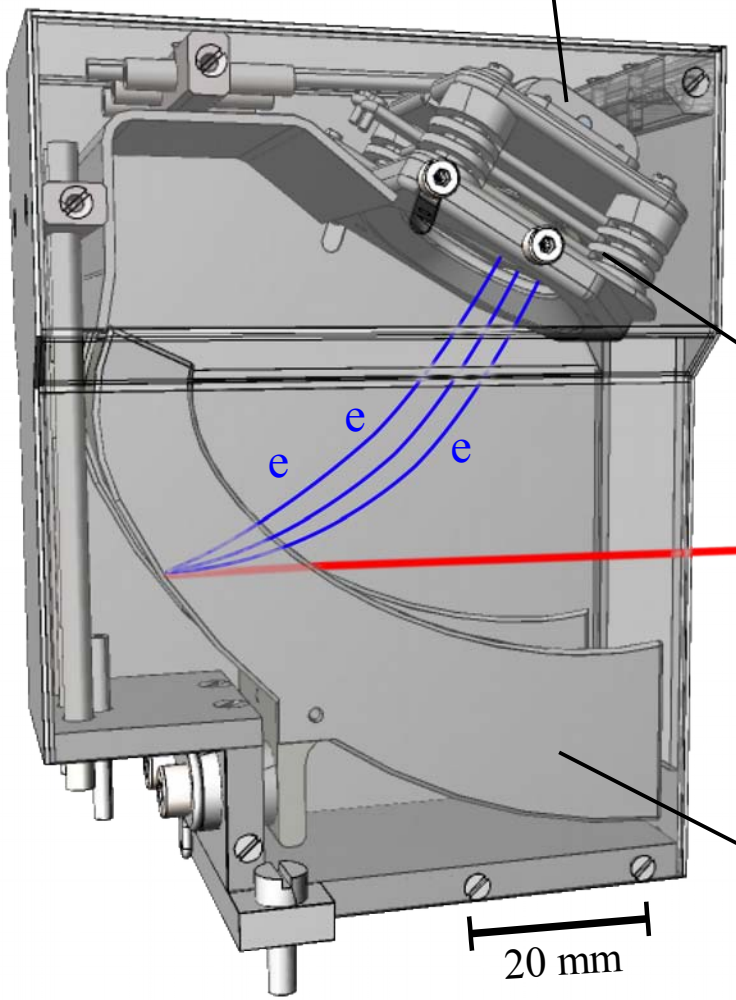
The COMPACT Detector

MCP heating (res. wire)
(~ 200 mW, optional)









Secondary electron emission + multiplication

EDR MCP

heavy particles (~ keV/u)

"Daly" electrode

4 HV electrodes:

- "Daly" (–400 V)
- MCP-in (+800 V)
- MCP-out (+2700 V)
- Anode (+3000 V)

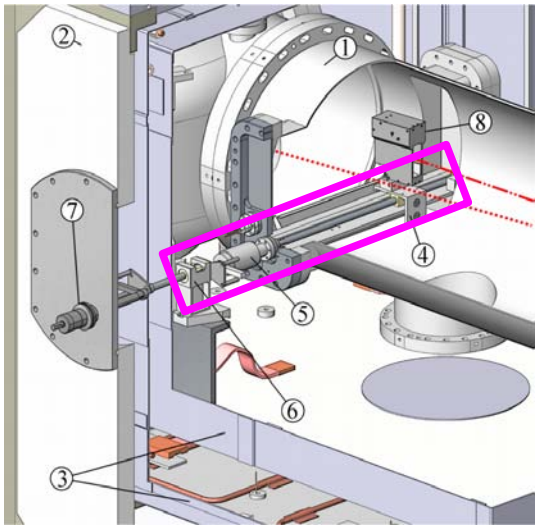
+ MCP Heating (+)

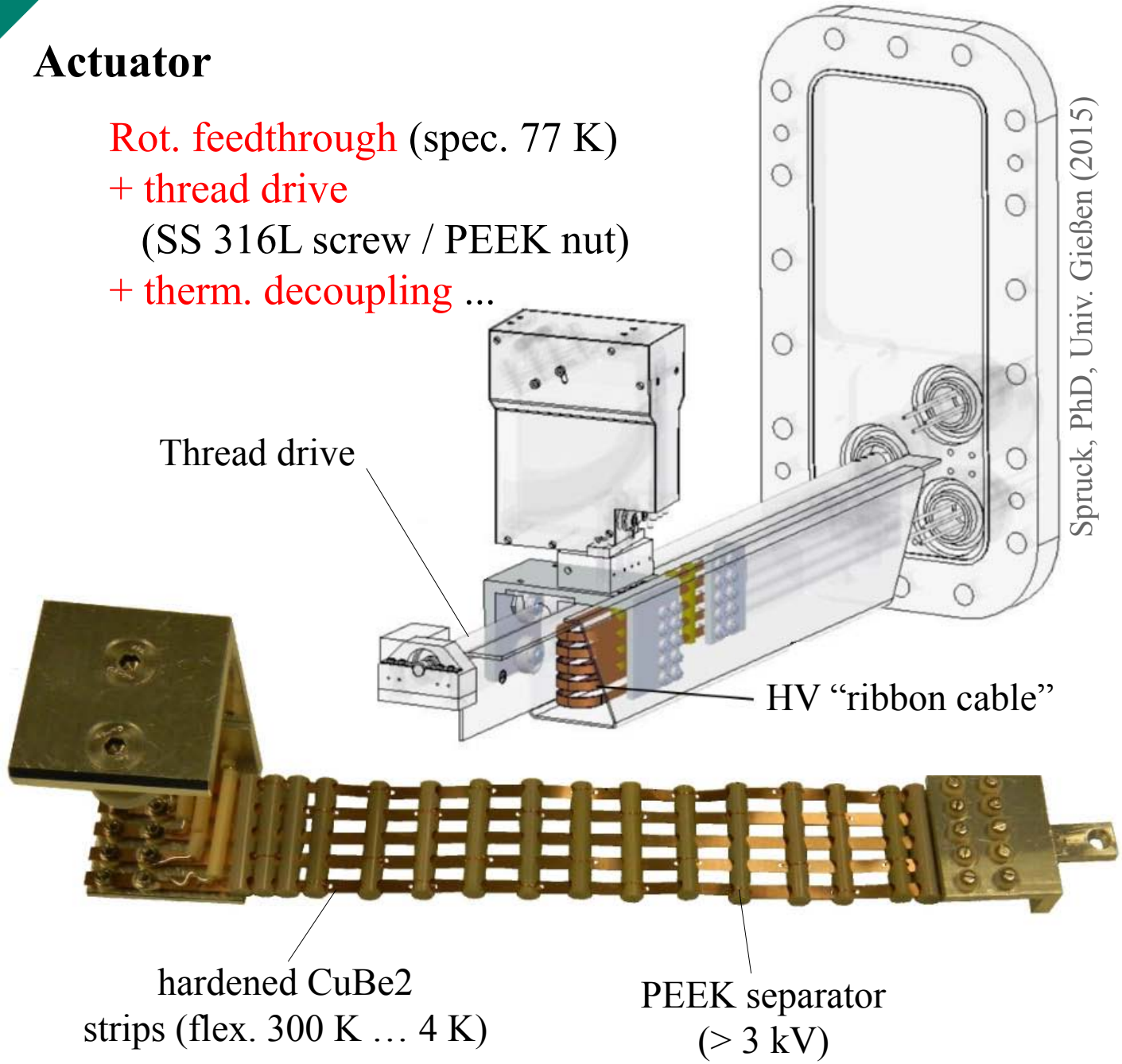
→ **Needs 5 el. potentials (+ gnd)**

The COMPACT Detector

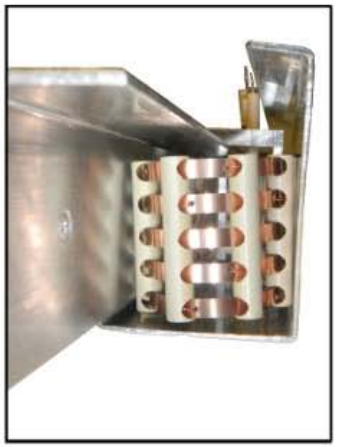
Actuator

Rot. feedthrough (spec. 77 K)
+ thread drive
(SS 316L screw / PEEK nut)
+ therm. decoupling ...





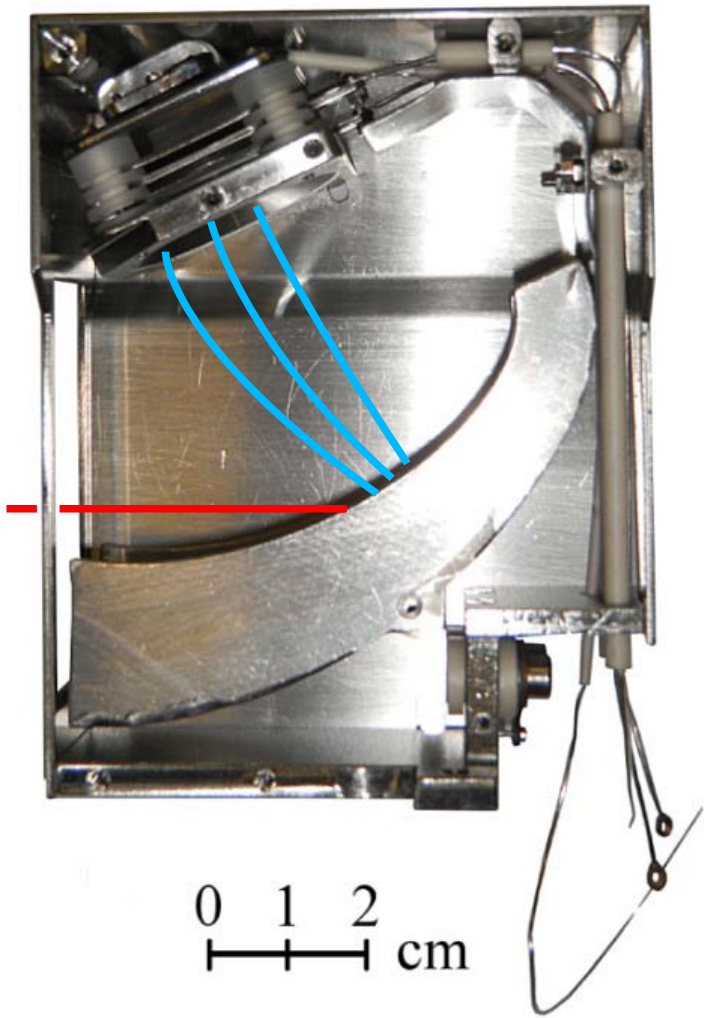
Spruck, PhD, Univ. Gießen (2015)

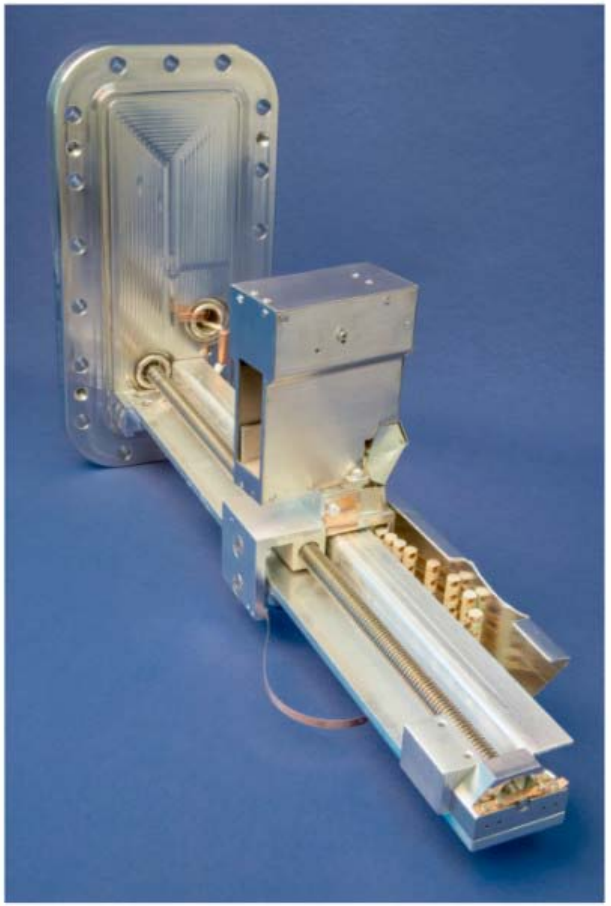


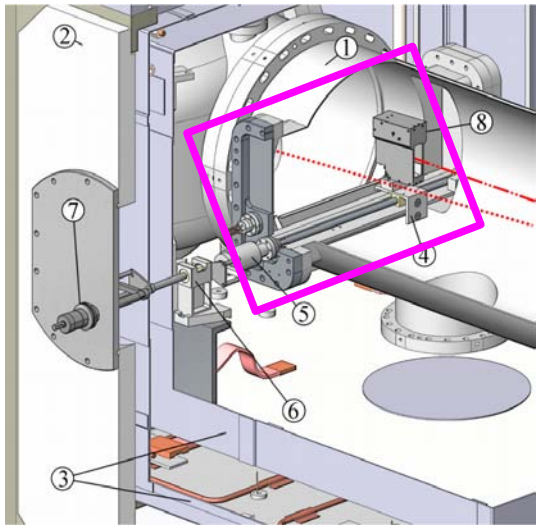
The COMPACT Detector

XHV components: (~ 10^{-11} mbar at RT)

Bakeable to 250°C / non-mag. / movable at 6 K.







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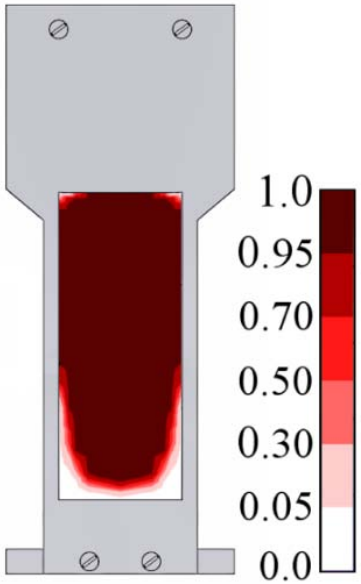

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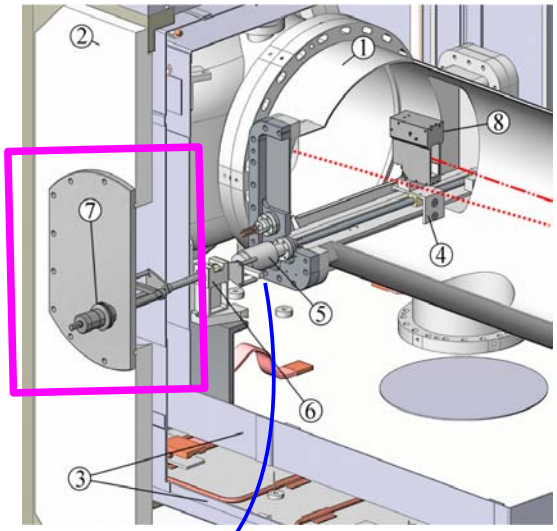
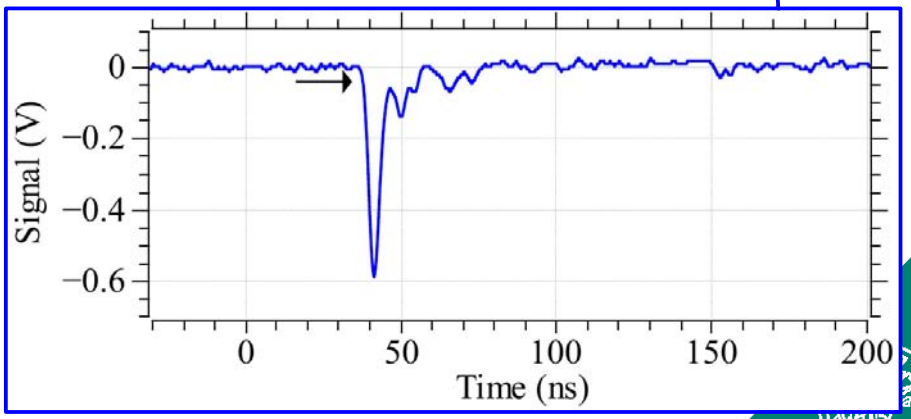
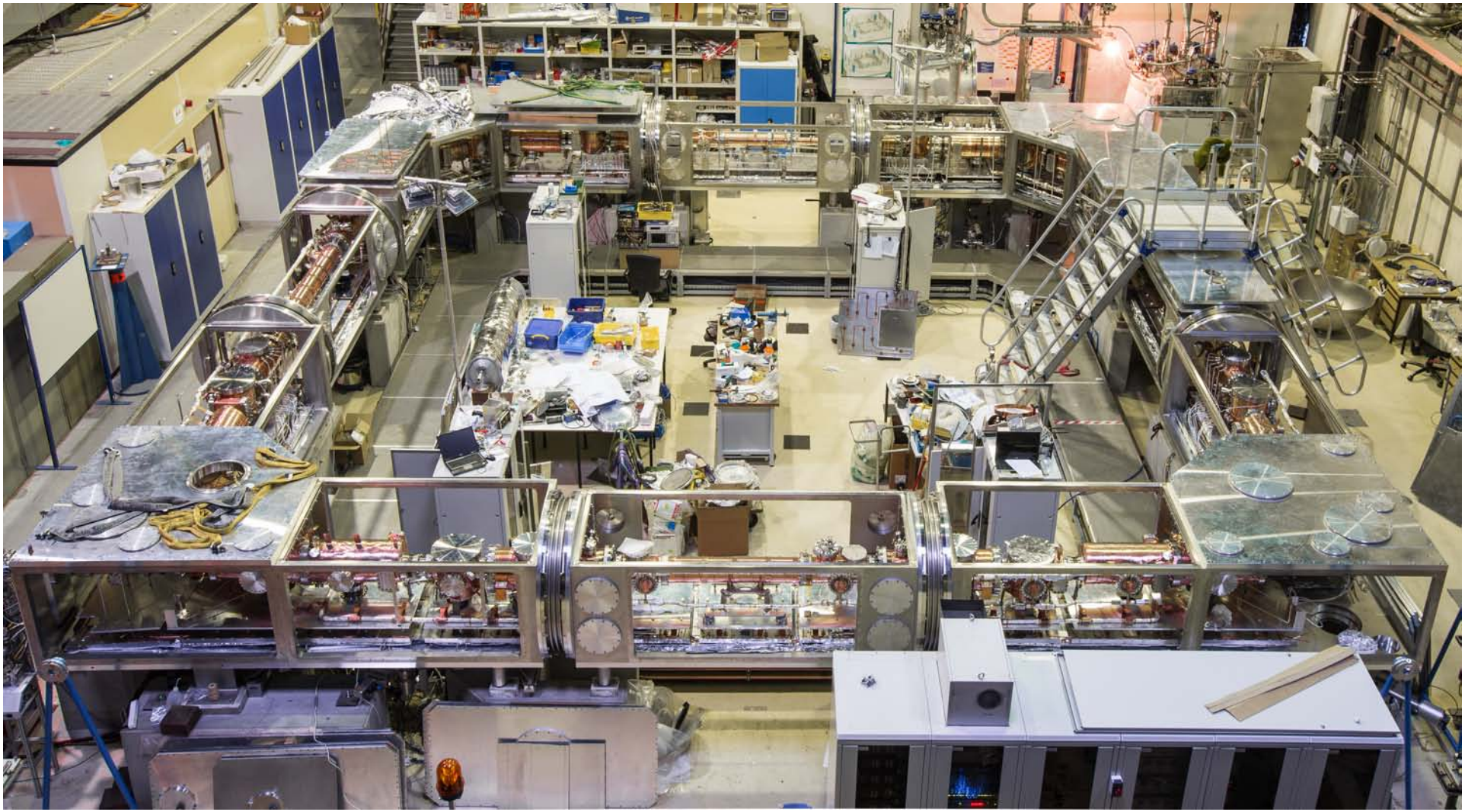




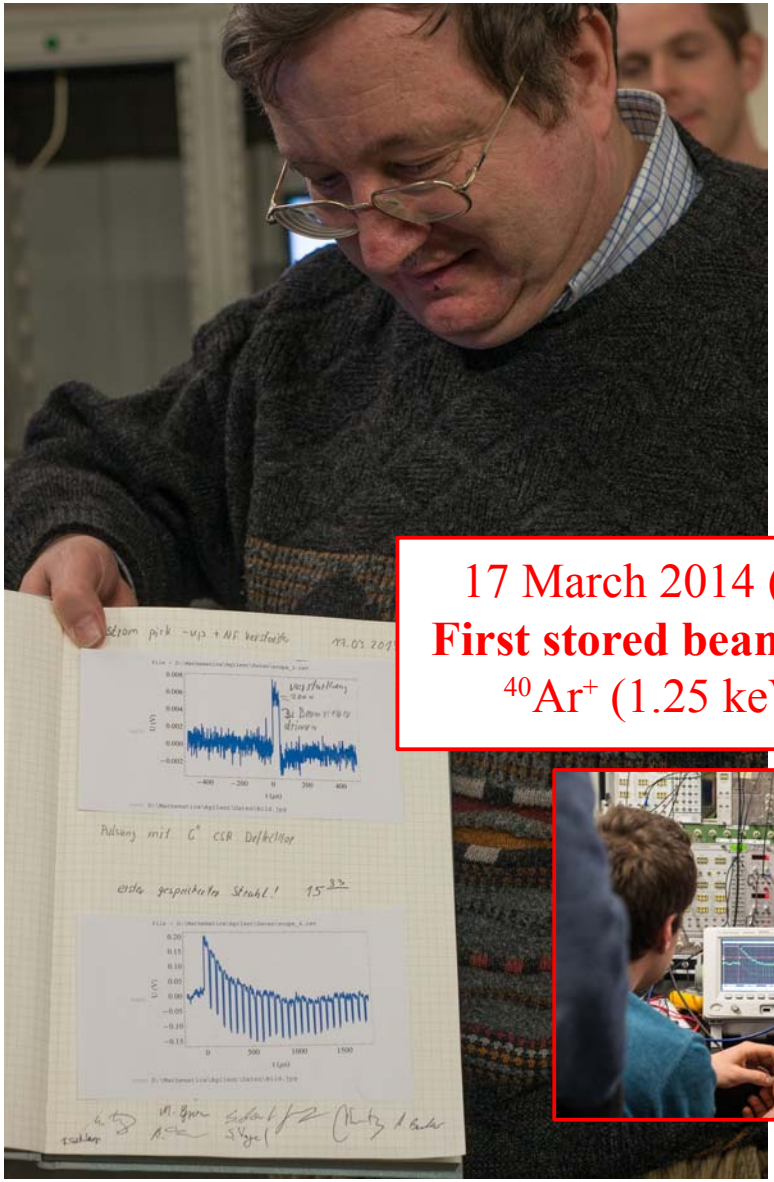
Room-temperature commissioning (2014)



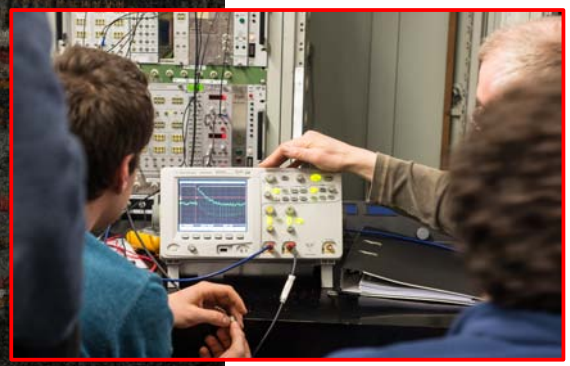
The CSR in March 2014

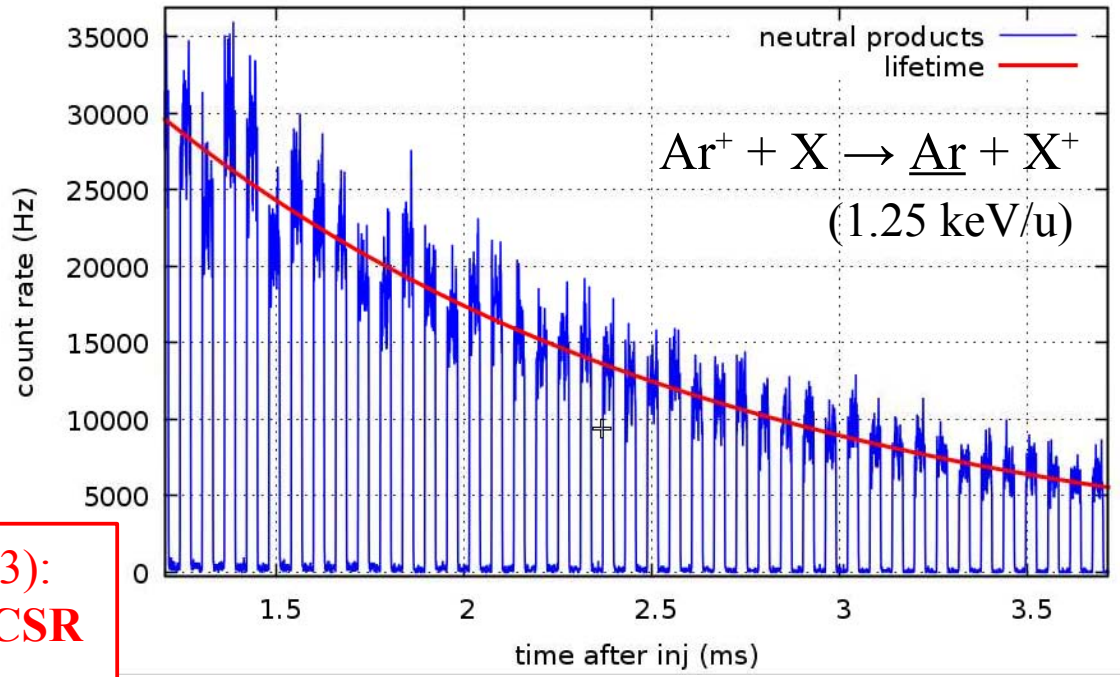
Room-temperature commissioning (2014)

19 March 2014: First beam at COMPACT



17 March 2014 (15:33):
First stored beam in CSR
$^{40}Ar^{+}$ (1.25 keV/u)



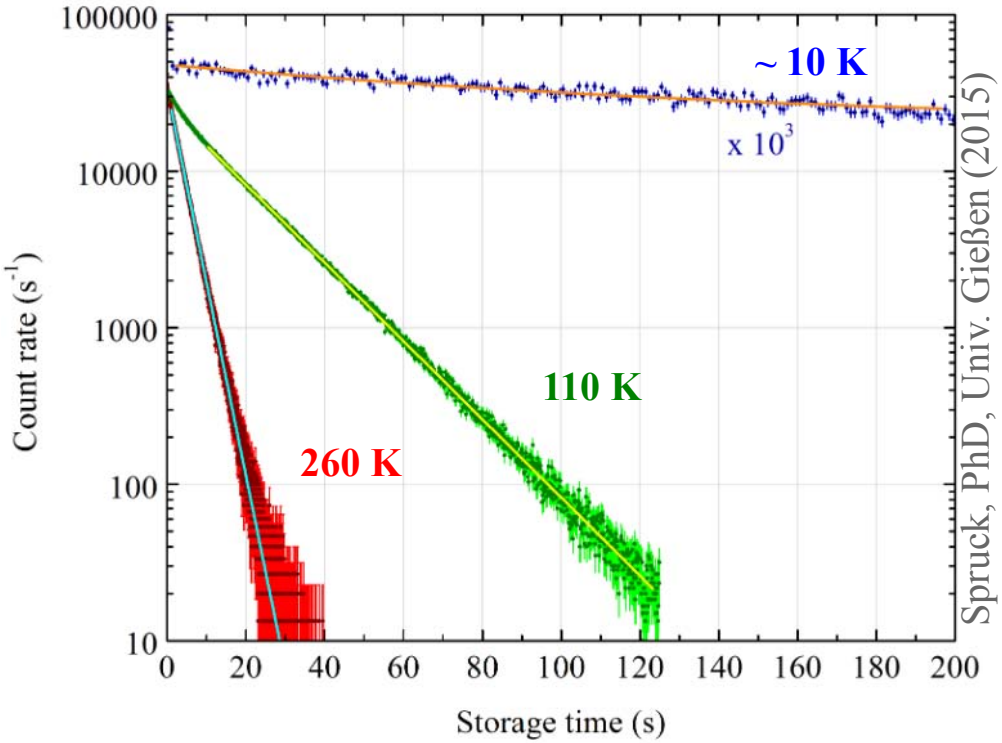


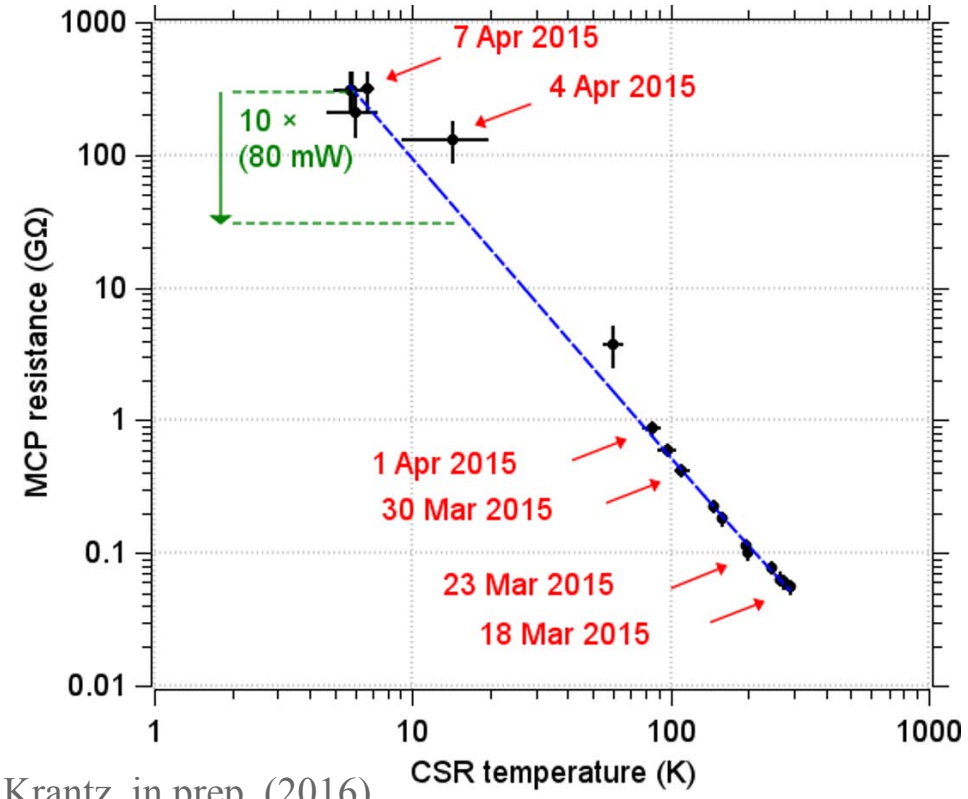
At 300 K:

Count rates up
to 10^{6} s^{-1}
so far, so good ...

Cryogenic commissioning (2015): CSR at ~ 6 K

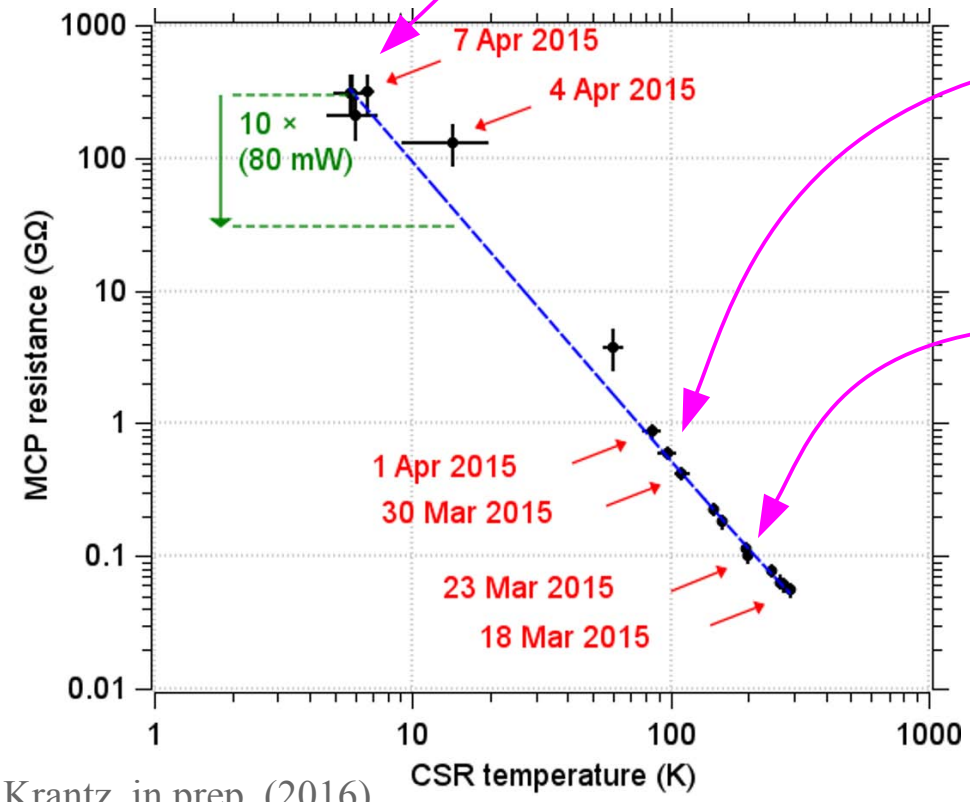
$$Ar^+ + X \rightarrow Ar + X^+$$





Krantz, in prep. (2016)

Cryogenic commissioning (2015): CSR at ~ 6 K



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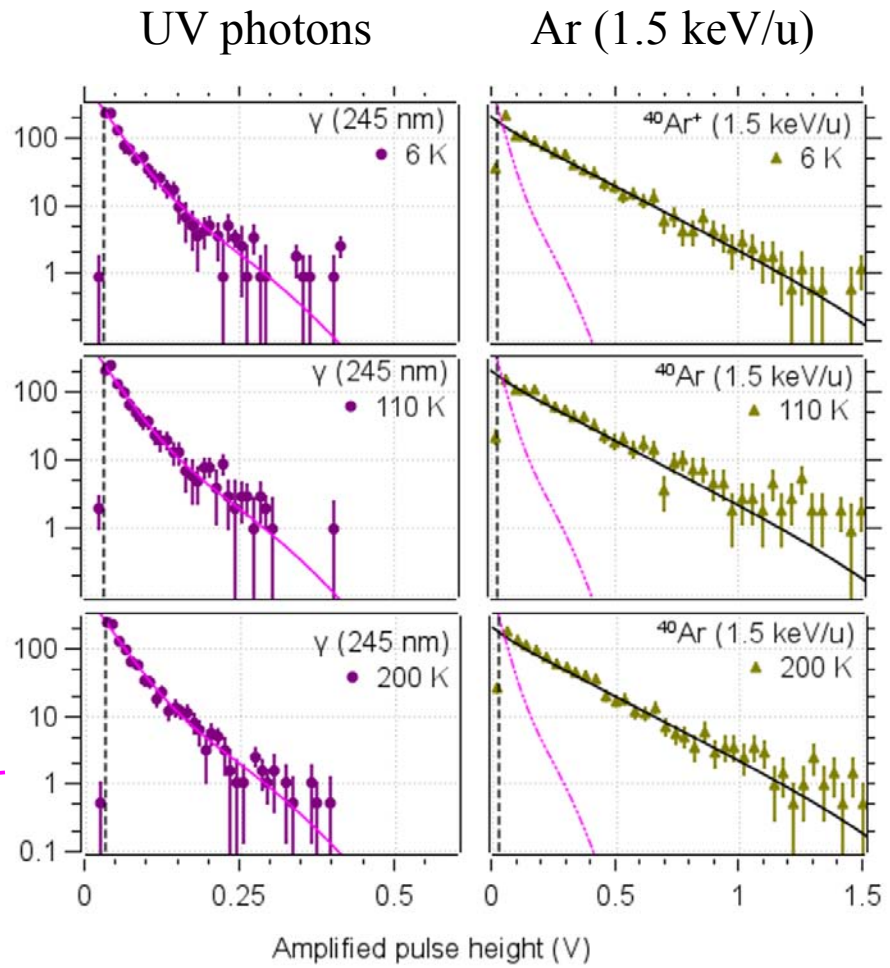


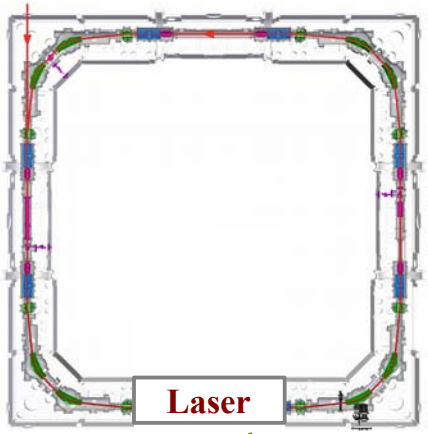
Krantz, in prep. (2016)

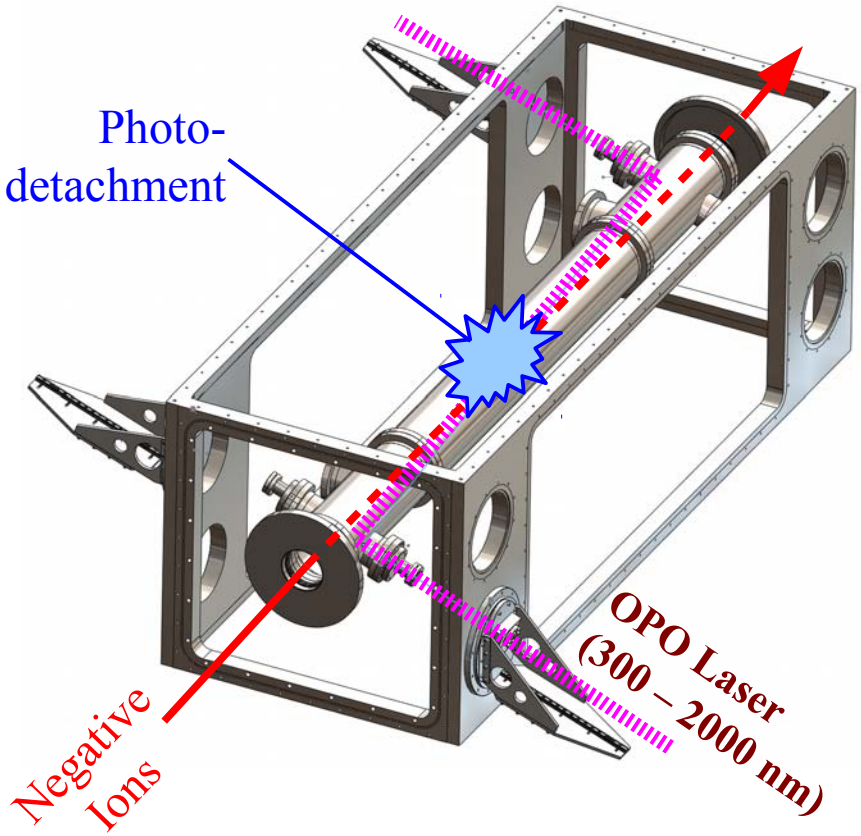
For heavy particles @ 6 K (~ 1 keV/u)

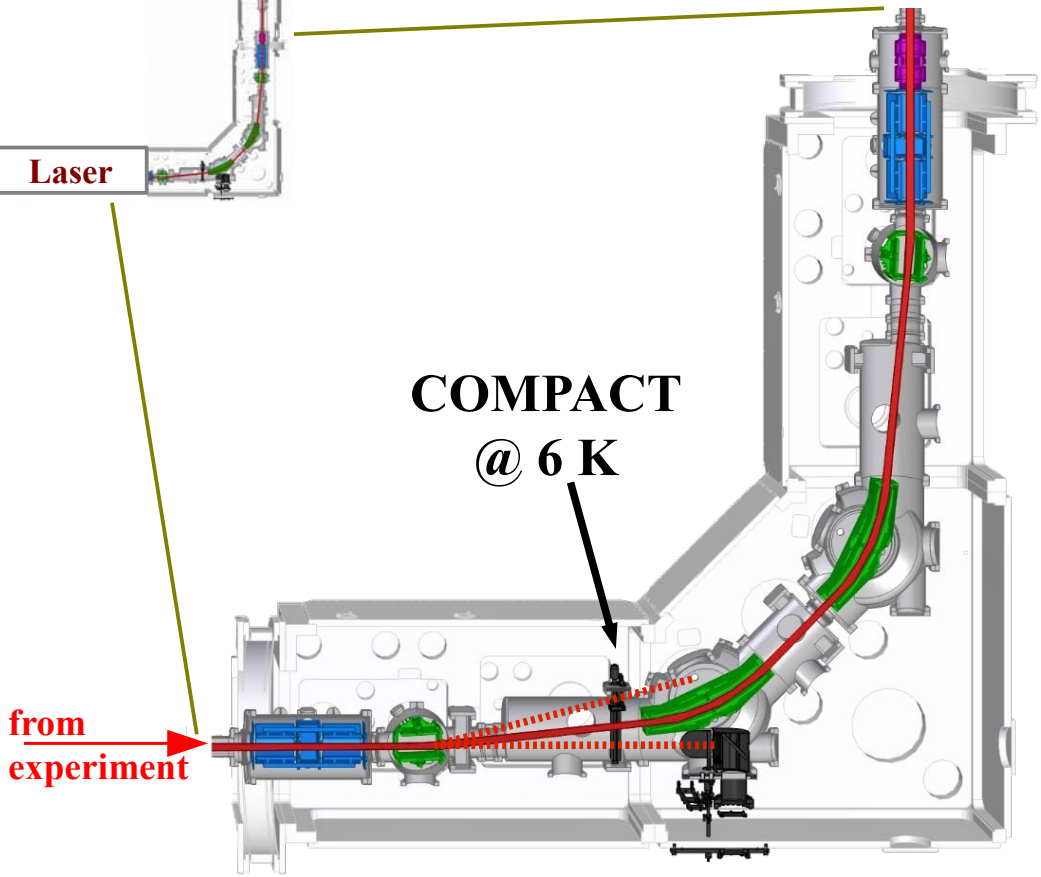
no MCP heating necessary

up to ~ 1000 s^{-1}

CSR at ~ 6 K: First Atomic-Physics



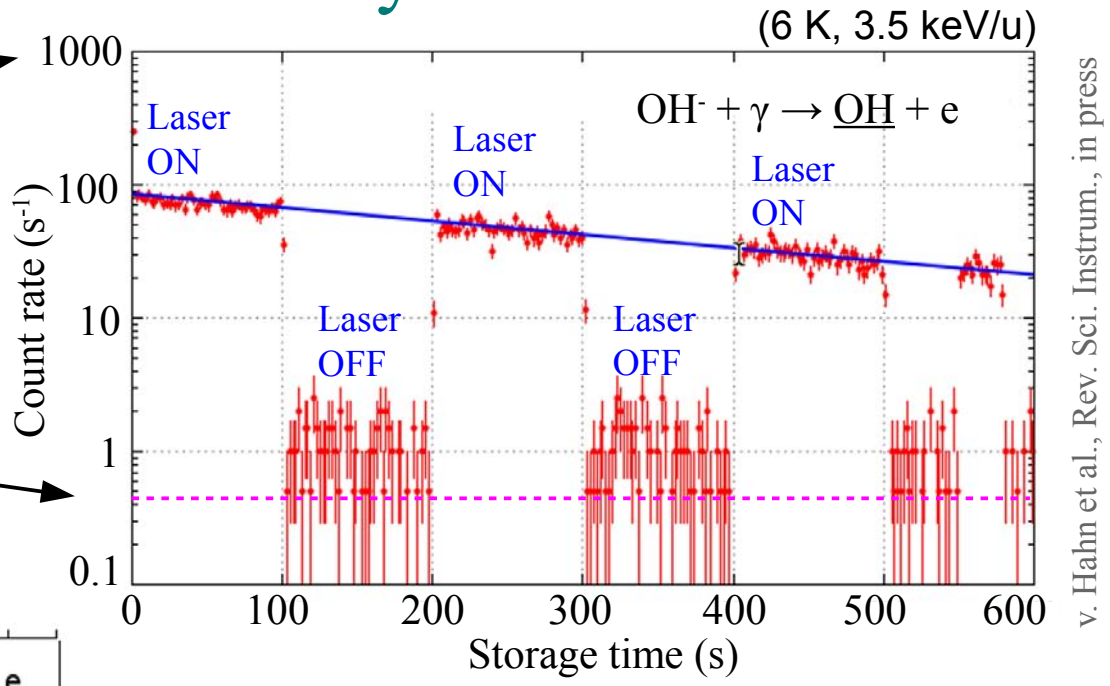




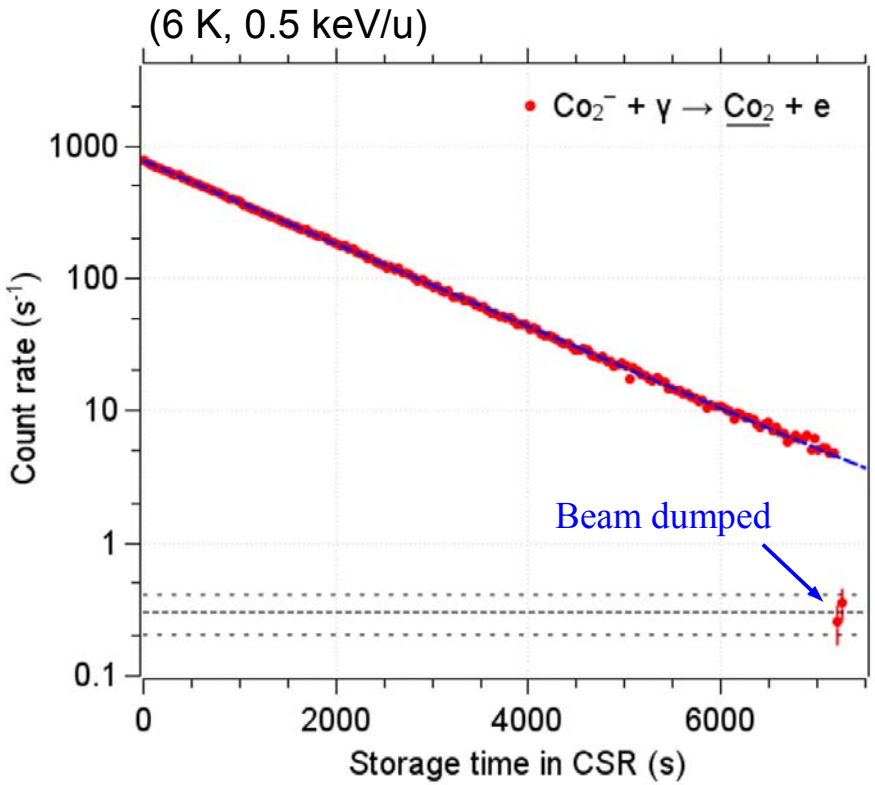
CSR at ~ 6 K: First Atomic-Physics

DC experiments at 6 K
→ stay below 1000 s^{-1}

Low background level
~ 0.3 s^{-1} (at all *T*)



v. Hahn et al., Rev. Sci. Instrum., in press

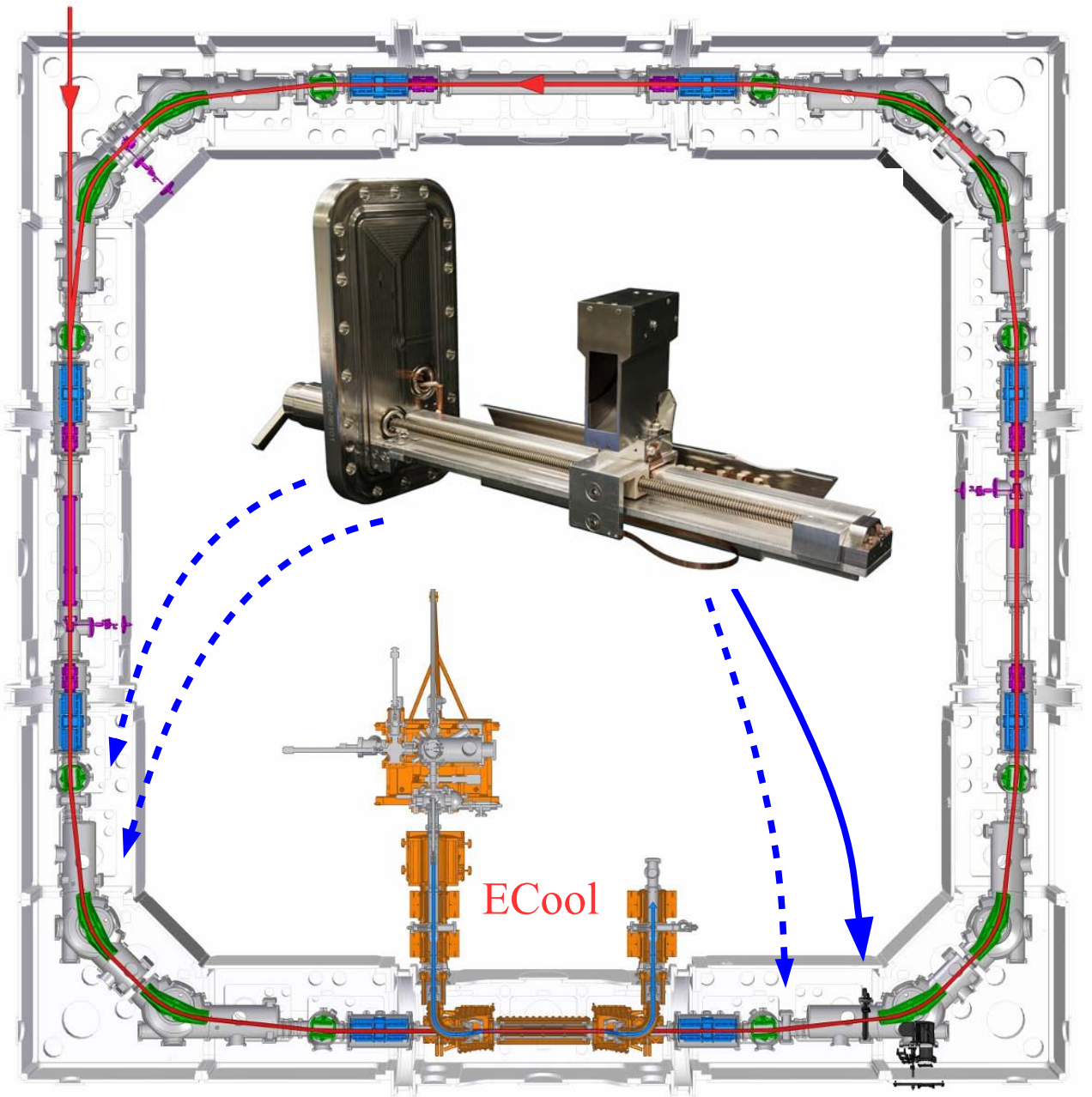


Krantz, in prep. (2016)

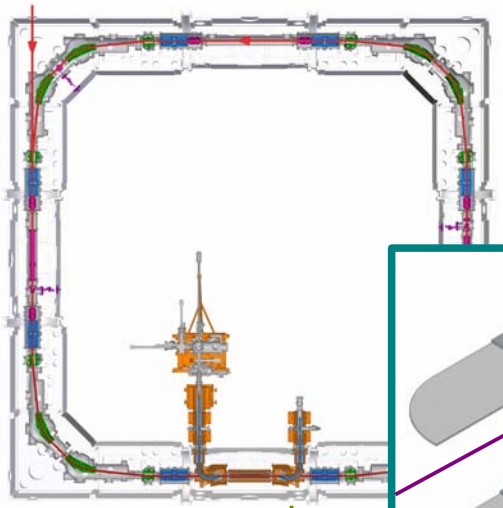
At 6 K (no MCP heating):
Dynamic range ~ 3000 x
= 8 1/*e* lifetimes

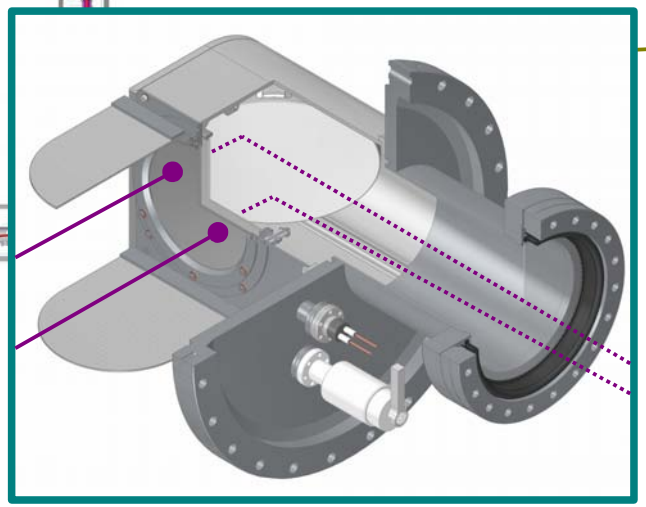
Even more with MCP heating?
(to be tested ...)

Outlook: More COMPACT detectors



... more CSR detectors



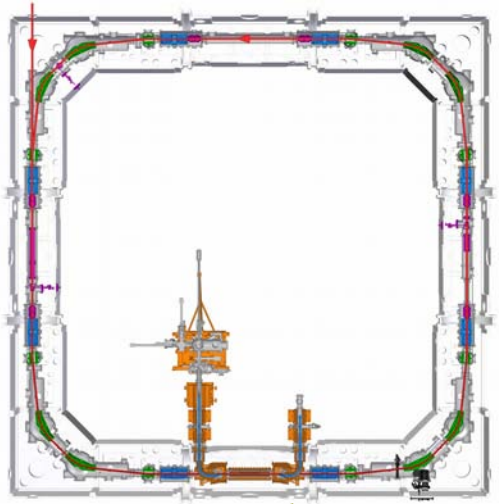


Becker, PhD, Univ. Heidelberg (2016)

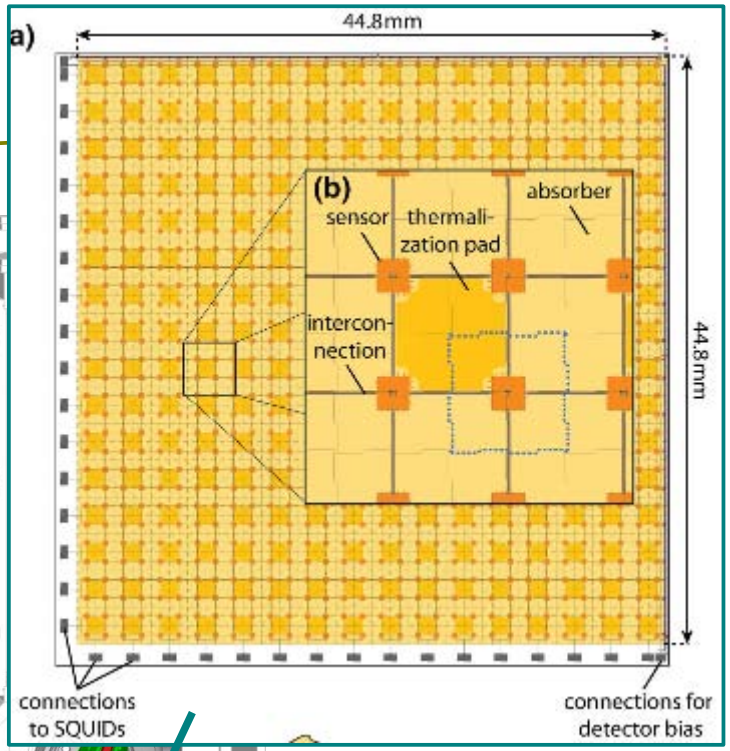
NICE "Neutral Imaging in Cryogenic Environment"

from ECool

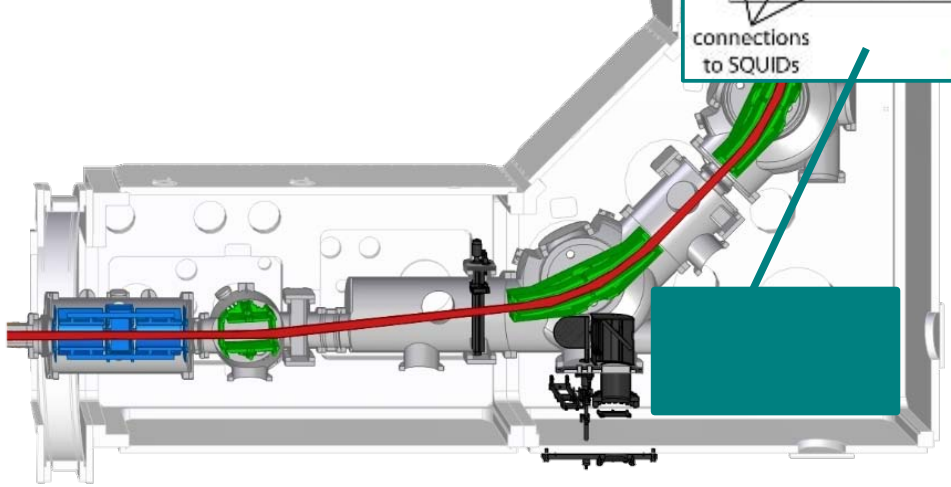
... more CSR detectors



MOCCA: 4000-pixel (microcalorimetric) energy resolving detector (SQUID-based)



Gamer et. al, J. Low. Temp. Phys (2016)



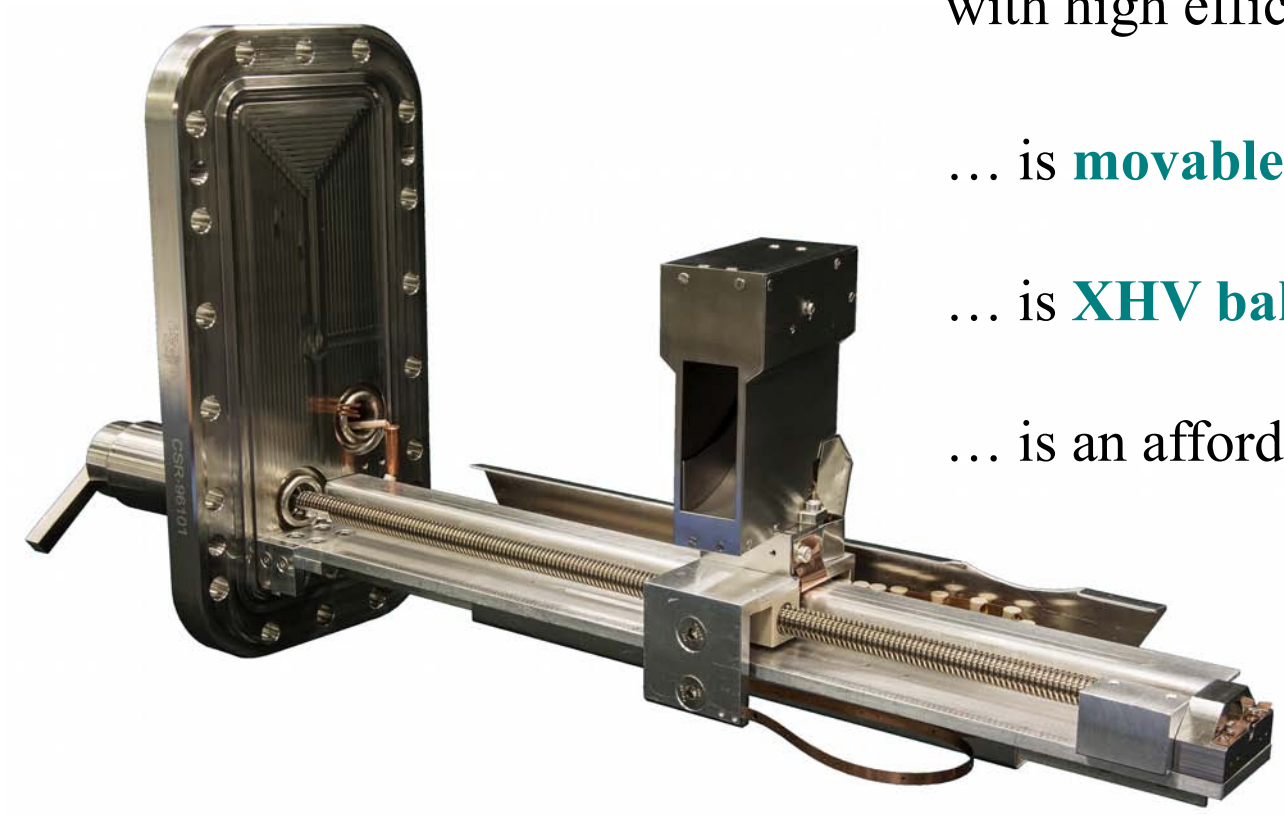
from ECool

Precursor Experiments done
Development ongoing.

Novotný et al.
J. Appl. Phys. 118 (2015)

That's all folks ...

We have a **detector for the CSR** that ...



… detects **low-energy** heavy products with high efficiency at **~T_{LHe}**.

… is **movable** in the beamline at **6 K**.

… is **XHV bakeable** and non-magnetic.

… is an affordable and **robust** solution.

More detector development at CSR is ongoing ...

Thank You!

Max Planck Institute for Nuclear Physics, Heidelberg

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