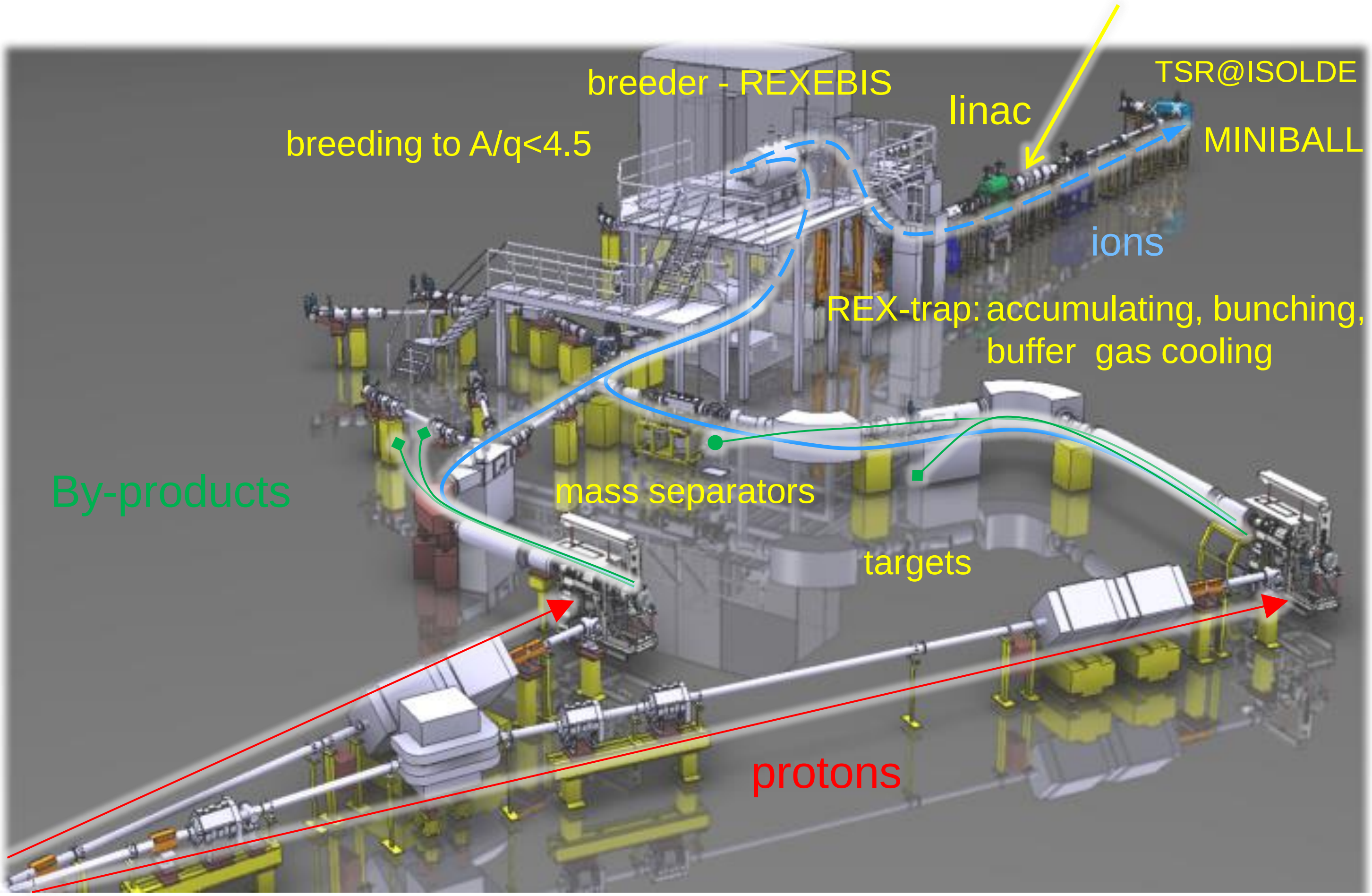
Progress of a charge breeder for HIE-ISOLDE and TSR@ISOLDE

YEARS / ANS CERN

Andrey Shornikov

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Re-acceleration branch – need to breed charges

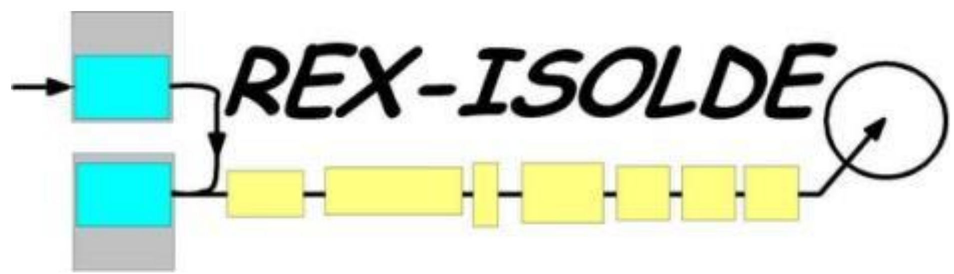


Re-acceleration branch of ISOLDE. CB makes ions suitable for linac
A high performance breeder makes any ion a “light ion” for linac

Upgrade of ISOLDE to HIE-ISOLDE

Which one does not represent technologies of the year 2000?

Best seller 2000

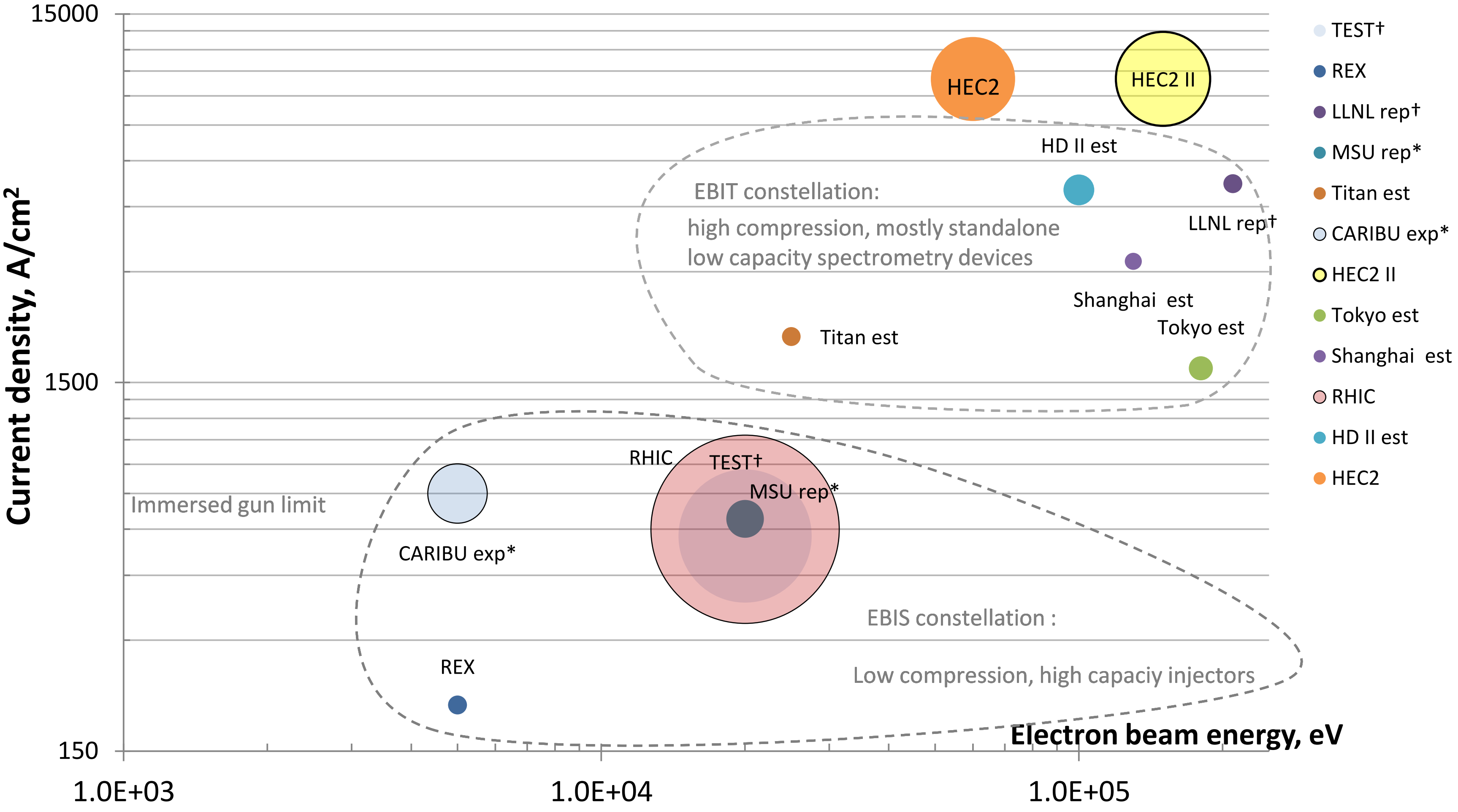


Online 2000

Online 2005

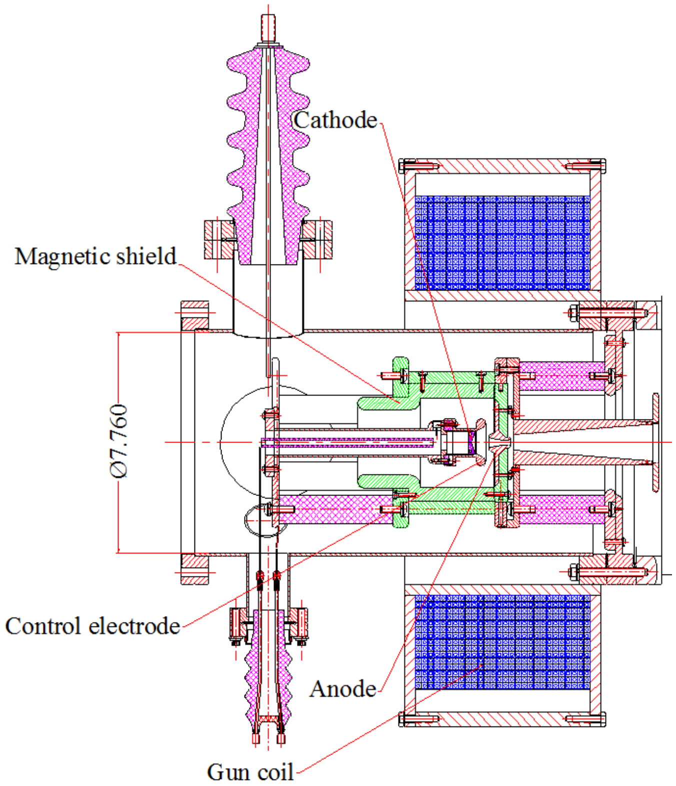
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

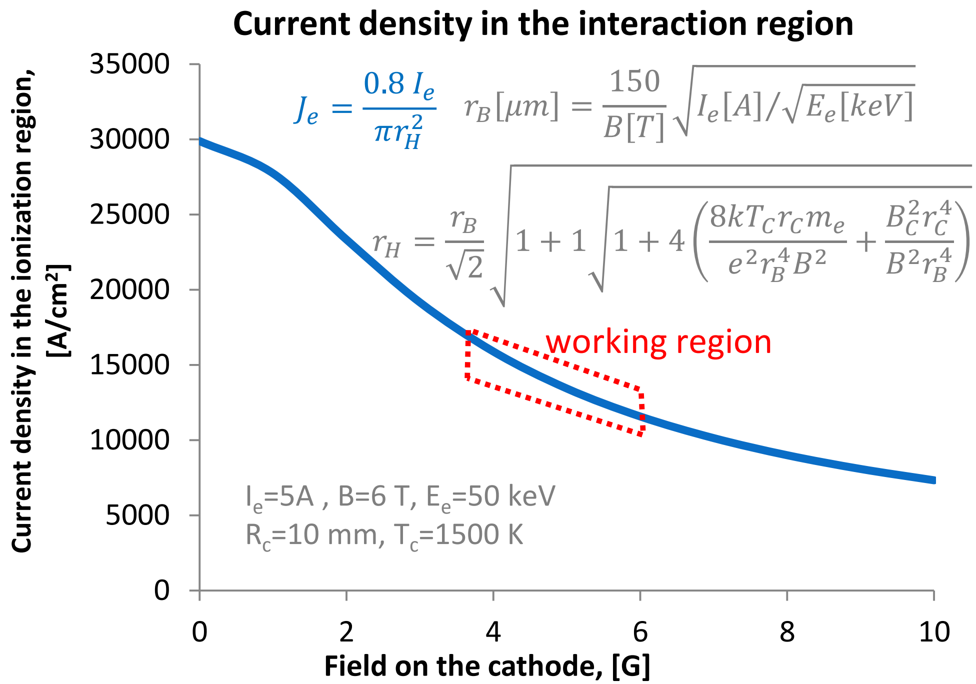
What is out there?



Bubble size represents electron current rep - reported, est - estimated, * - in commissioning phase † - discontinued

Why high compression is hard to achieve?

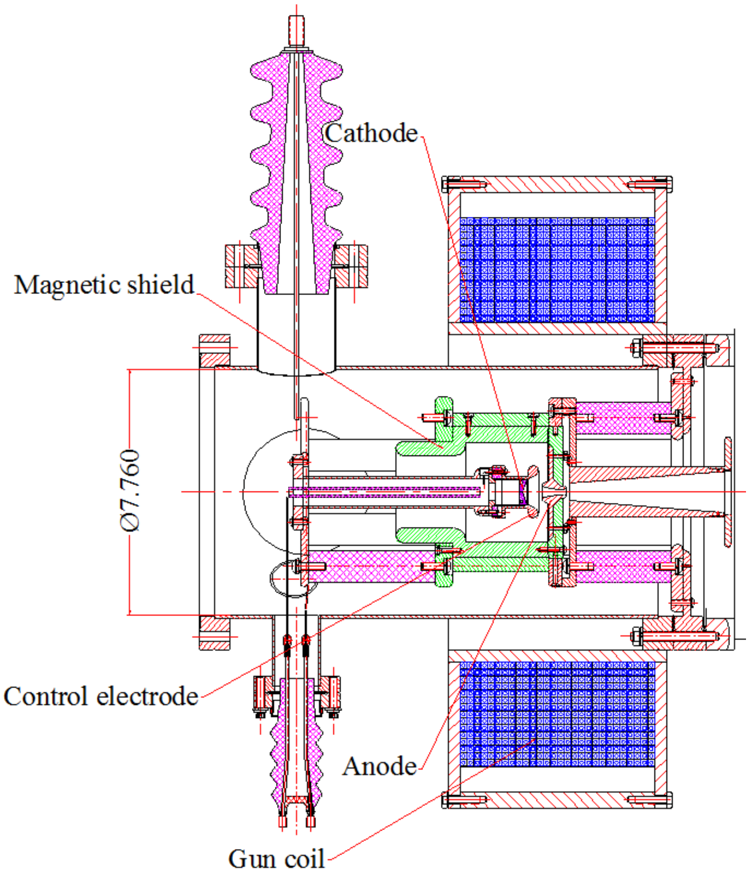


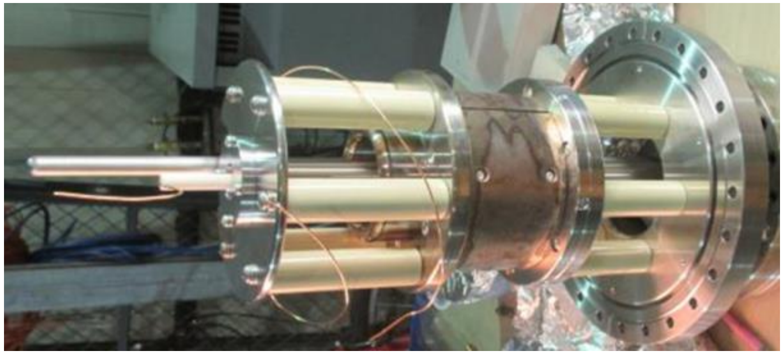


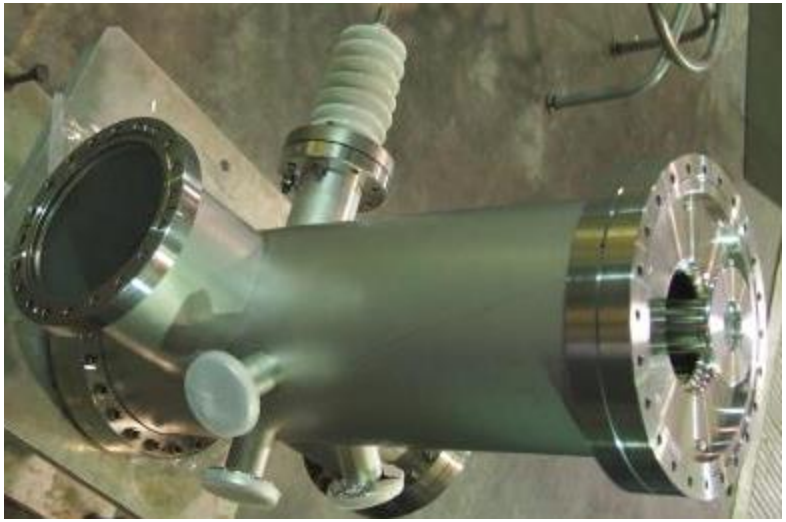
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Challenge accepted – HEC^2 joint project by CERN and BNL

High Energy Current and Compression (HEC^2) electron beam for charge breeding







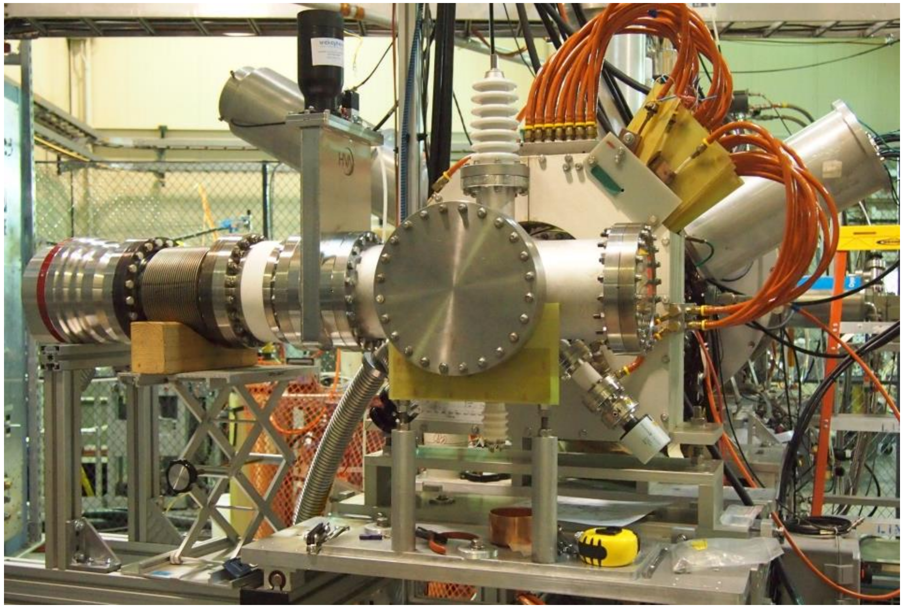
BROOKHAVEN NATIONAL LABORATORY

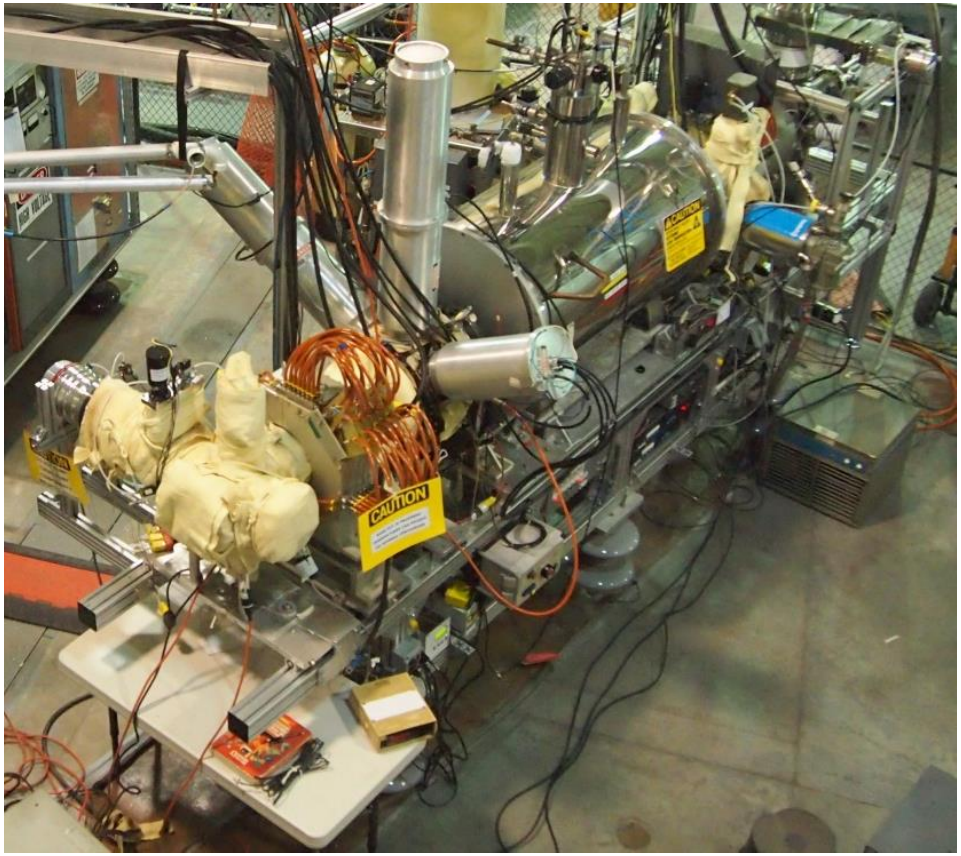
Preliminary development

01-06.2013 manufacturing phase

And test it at BNL

TestEBIS – the cradle of all 4 highest current EBISes ever built





07-08.2013 HEC^2 moved to BNL, assembled, preparations of the Test EBIS started

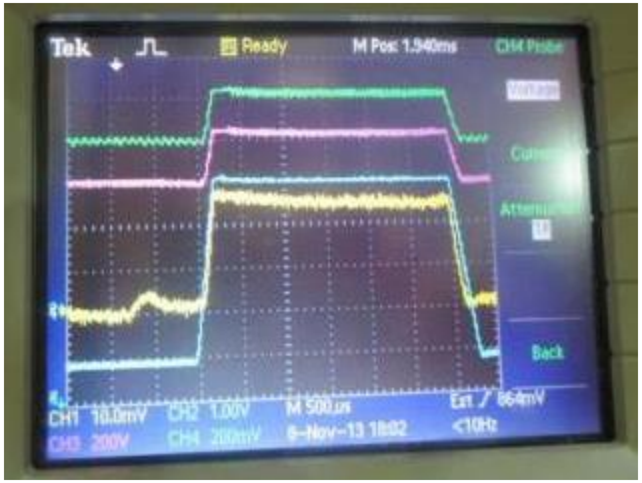
CERN
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

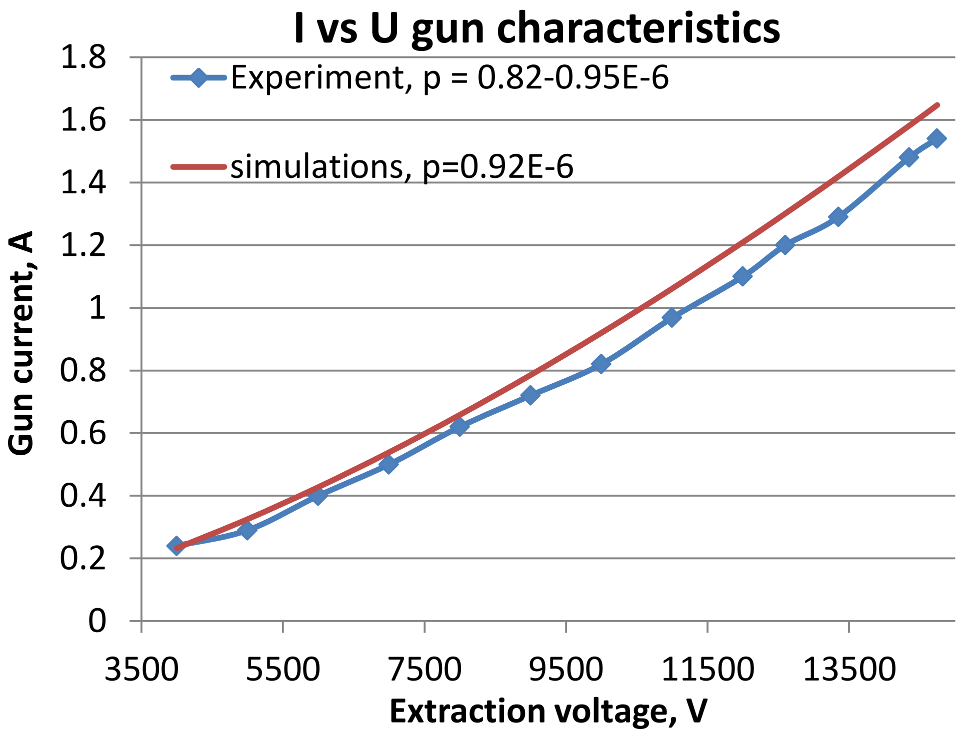
2-nd installation campaign

10.2013 HV safety, cryogenics, interlocks, etc

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

In 6 days of commissioning current ramped From 0.22 to 1.54 A

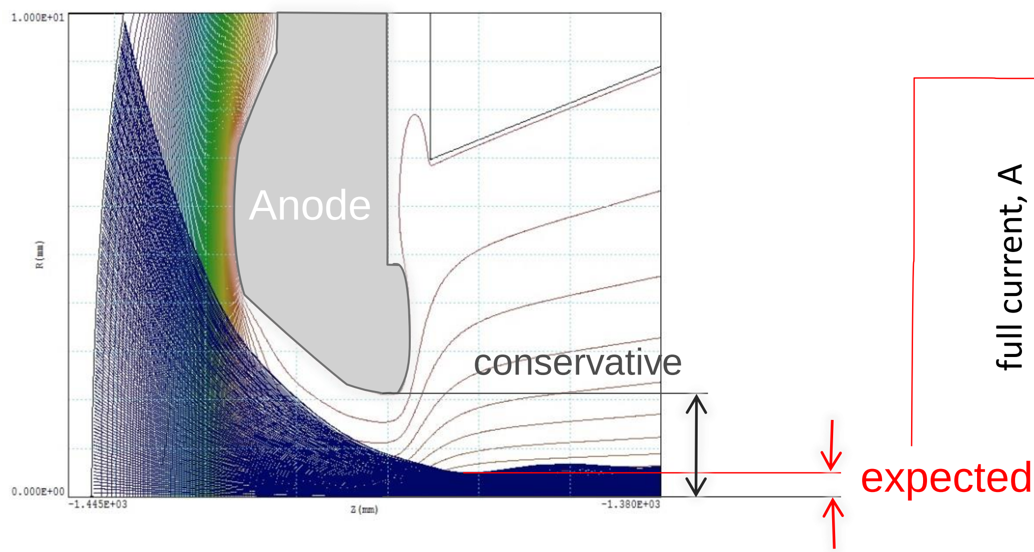




First run summary

Current density?

Conservative – it passes through the anode opening x magnetic compression by the actual field of 3.3 T ~ 170 A/cm^2



Expected (to be verified) ~ Herrmann radius of the beam at given I_e, B, E_e, B_c, T_c

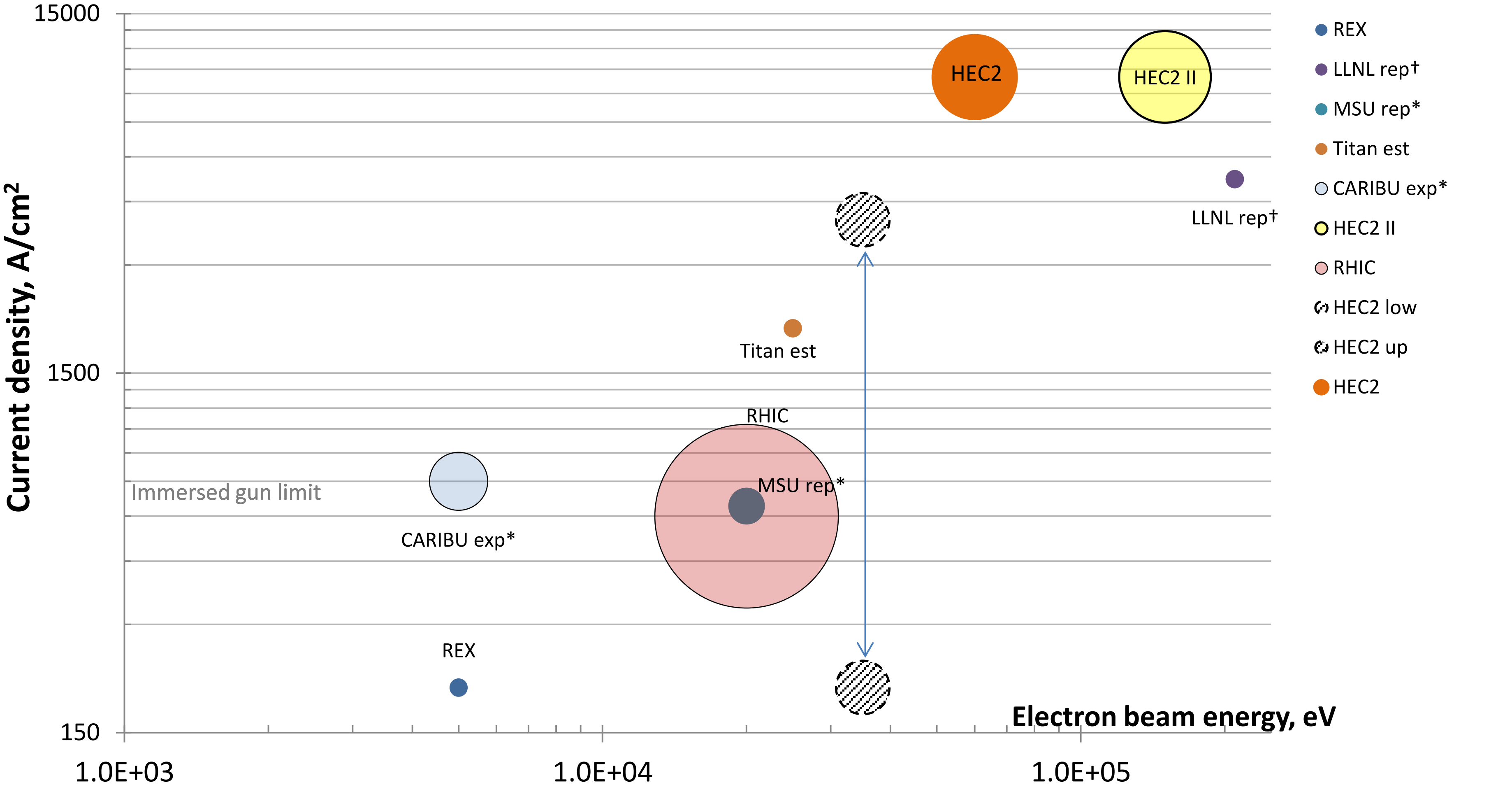
Central magnet field, T

full current, A	3.3	4	4.5	4.8
1.5	**3.4**	**4.1**	**4.6**	**4.9**
2	**4.5**	**5.4**	**6.1**	**6.5**
2.5	**5.6**	**6.8**	**7.6**	**8.1**
3	**6.6**	**8.1**	**9.1**	**9.7**
3.5	**7.6**	**9.3**	**10.5**	**11.3**
4	**8.6**	**10.6**	**11.9**	**12.8**
4.5	**9.6**	**11.8**	**13.3**	**14.2**
5	**10.5**	**12.9**	**14.6**	**15.6**

Current density, kA/cm^2

CERN
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Where we are on the map?



What we outlined on ISOLDE workshop 2013

What is our plan for

Short term (till summer 2014, within CATHI framework, material budget – HIE-ISOLDE)

- ❑ Extract ionized residual gas to estimate the J_e by the CSD measured with ToF MS
- ❑ Install second anode PS and ramp the current to the limit

Mid term (in 2014, relies on HIE-ISOLDE design study budget and BNL cooperation)

- ❑ Replace collector electrodes to a design suitable for HEC^2
- ❑ Install primary ion injection line and test charge breeding
- ❑ Improve magnetic optics in the transition region

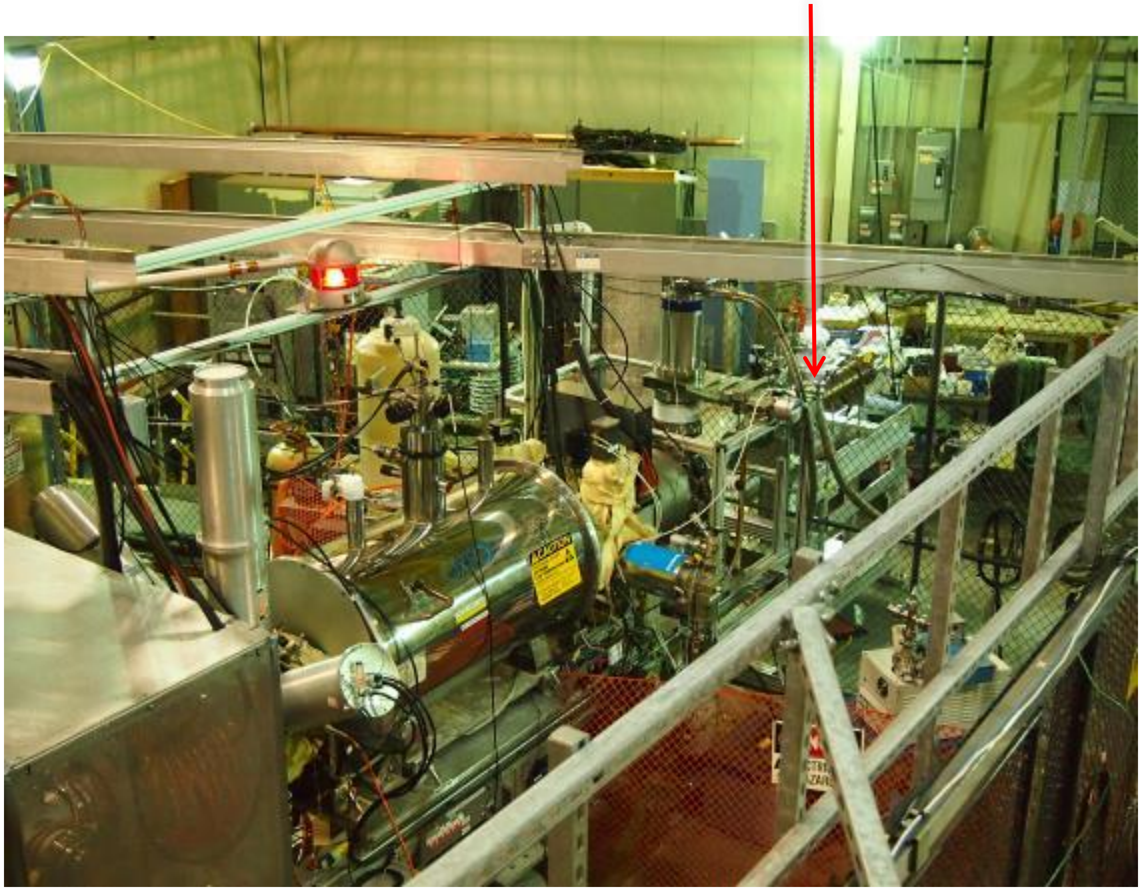
Long term (2015-16, relies on not yet granted support by ENSAR-2, otherwise canceled*)

- ❑ Upgrade PS and HV isolation to enable high energy DC operation
- ❑ Improve discharge stability of the gun for DC operation
- ❑ Adjust the gun design to boost J_e

* These goals are out of scope for BNL and will not be supported by DoE

The second run.

ToF MS to measure CSD of charge bred ions



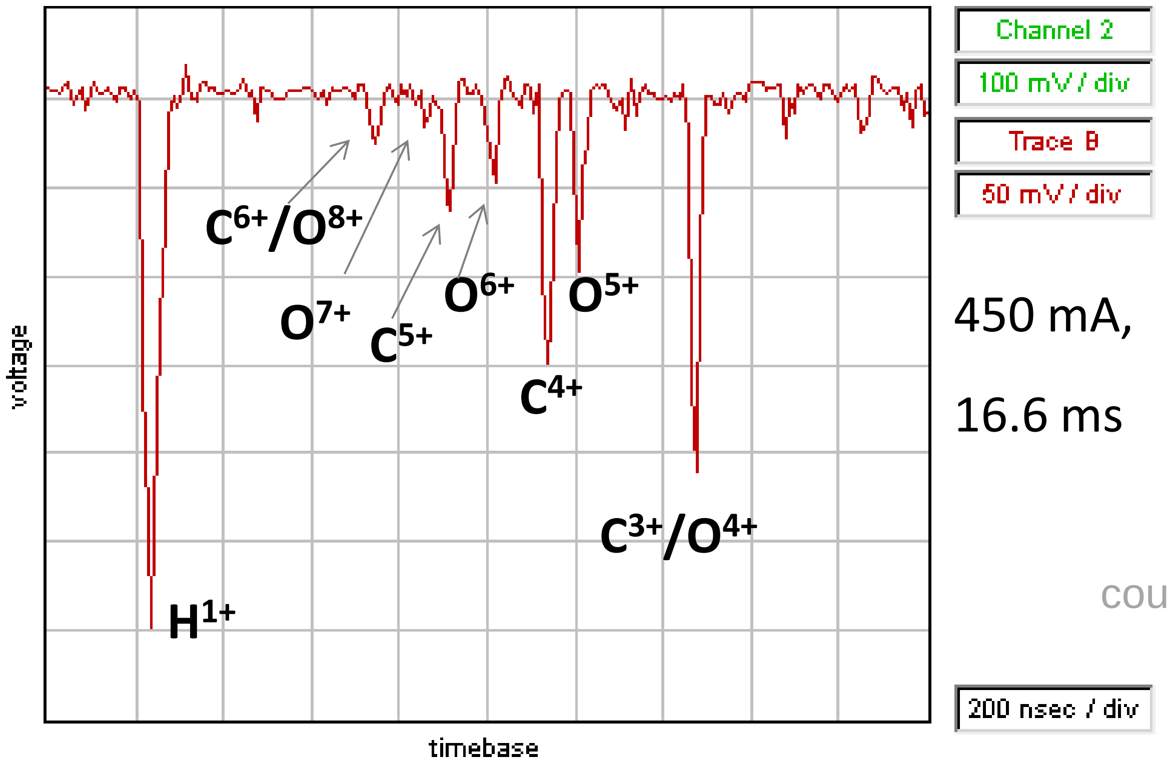
What is missing in the picture?

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

CSD from nowhere

Short term (till summer 2014, within CATHI framework, material budget – HIE-ISOLDE)

- ❑ Extract ionized residual gas to estimate the J_e by the CSD measured with ToF MS
- ❑ Install second anode PS and ramp the current to the limit



450 mA,

16.6 ms

courtesy E. Beebe

Ions extracted, O^{6+}/O^{5+} and C^{5+}/C^{4+} give too big error bars to define J_e

Newest electron current value

Short term (till summer 2014, within CATHI framework, material budget – HIE-ISOLDE)

- ❑ Extract ionized residual gas to estimate the J_e by the CSD measured with ToF MS
- ❑ Install second anode PS and ramp the current to the limit

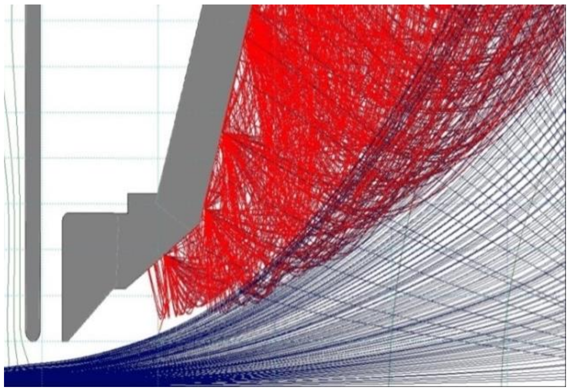
Second PS installed, current ramped to 1.7 A, still limited by loss current, not the PS

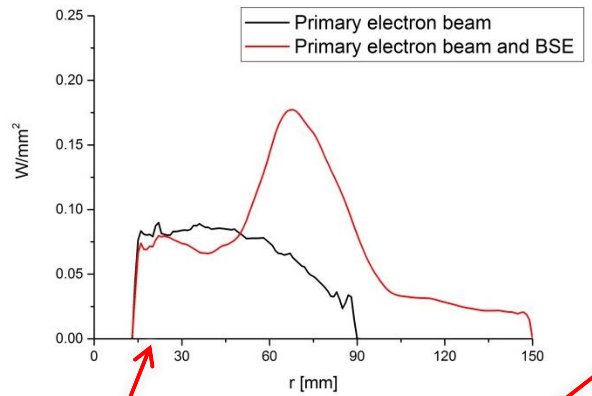
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

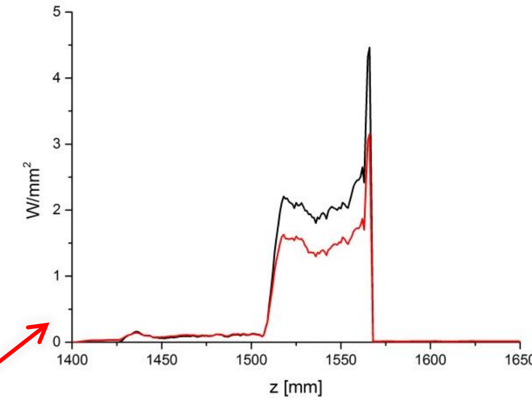
Collector studies

Mid term (in 2014, relies on HIE-ISOLDE design study budget and BNL cooperation)

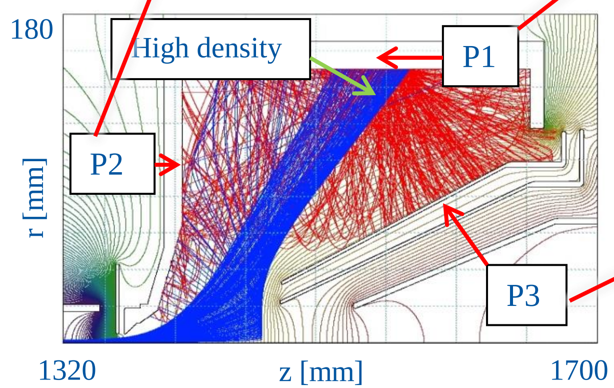
- ❑ Replace collector electrodes to a design suitable for HEC^2 design study in progress

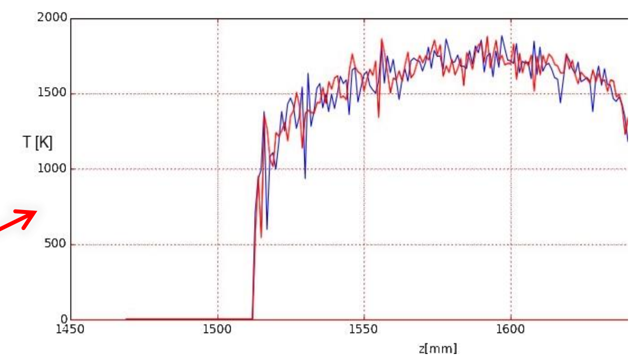






BSE loss analysis





BSE heat transfer analysis

courtesy R. Mertzig

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Primary ion injection

Mid term (in 2014, relies on HIE-ISOLDE design study budget and BNL cooperation)

- ❑ Replace collector electrodes to a design suitable for HEC^2 design study
- ❑ Install primary ion injection line and test charge breeding - 3-d installation campaign
- ❑ Improve magnetic optics in the transition region

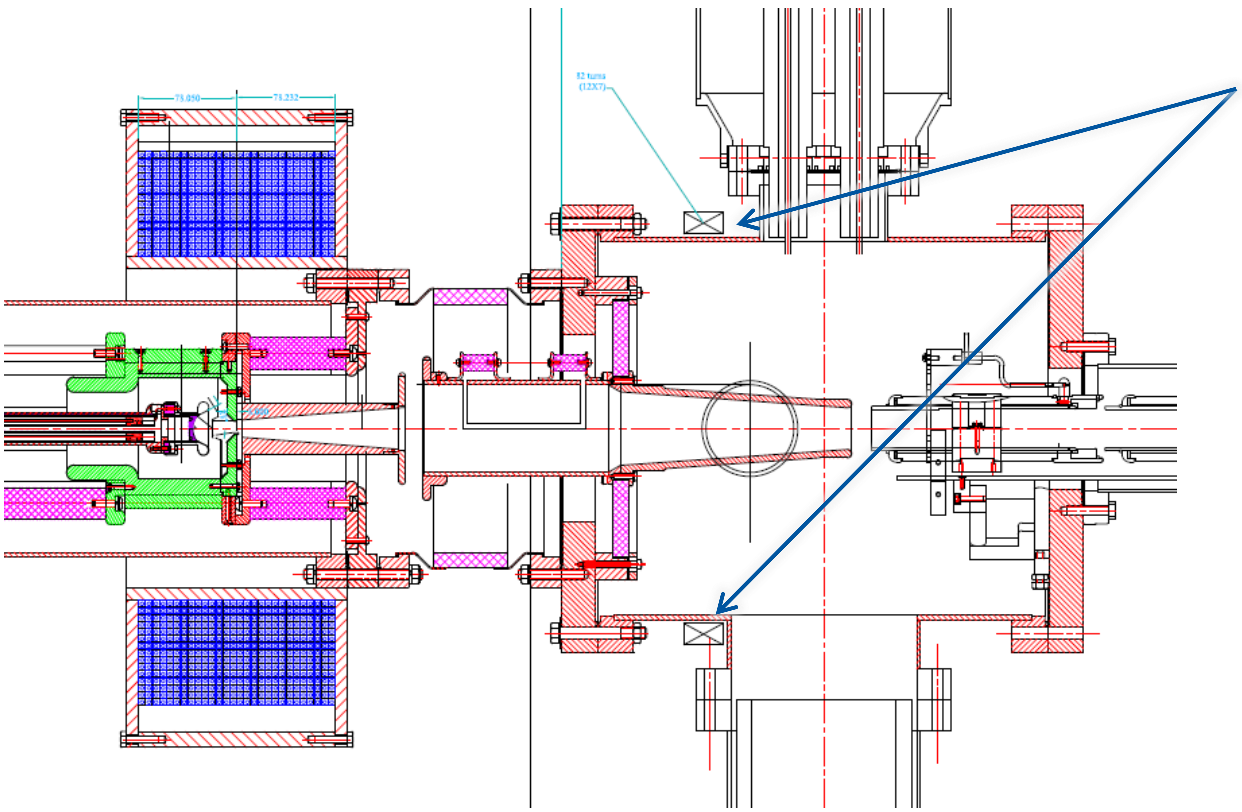
Primary ion source with ExB filter

Primary ion source 3-way switchyard
To connect primary source, ToF,
and emittance meter to the EBIS

HEC^2 gun gen II

Mid term (in 2014, relies on HIE-ISOLDE design study budget and BNL cooperation)

- ❑ Replace collector electrodes to a design suitable for HEC^2 design study
- ❑ Install primary ion injection line and test charge breeding - 3-d installation campaign
- ❑ Improve magnetic optics in the transition region



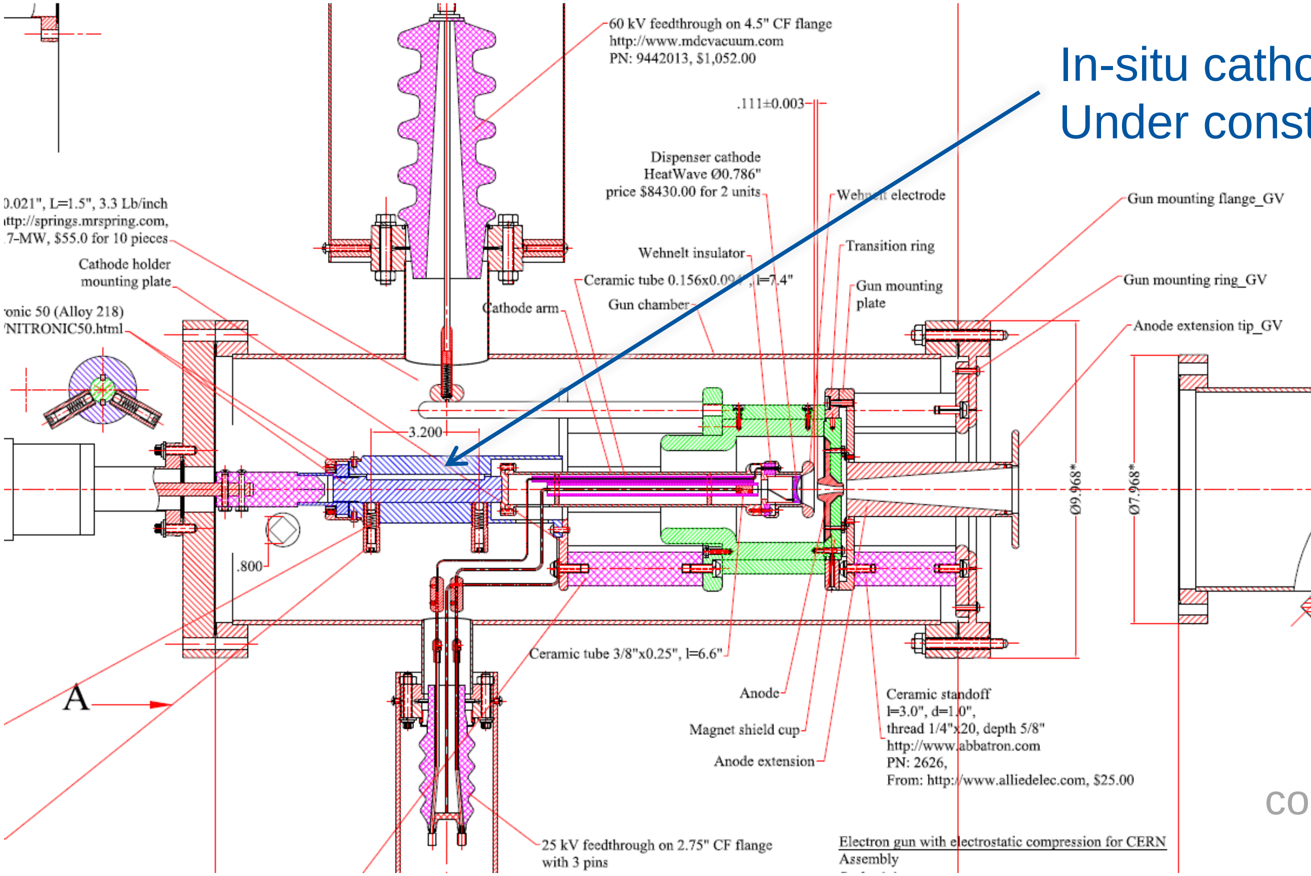
Phase-controlling
Low field region coil

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

HEC^2 gun gen II

Long term (2015-16, relies on not yet granted support by ENSAR-2, otherwise canceled*)

- ❑ Upgrade PS and HV isolation to enable high energy DC operation
- ❑ Improve discharge stability of the gun for DC operation
- ❑ Adjust the gun design to boost J_e



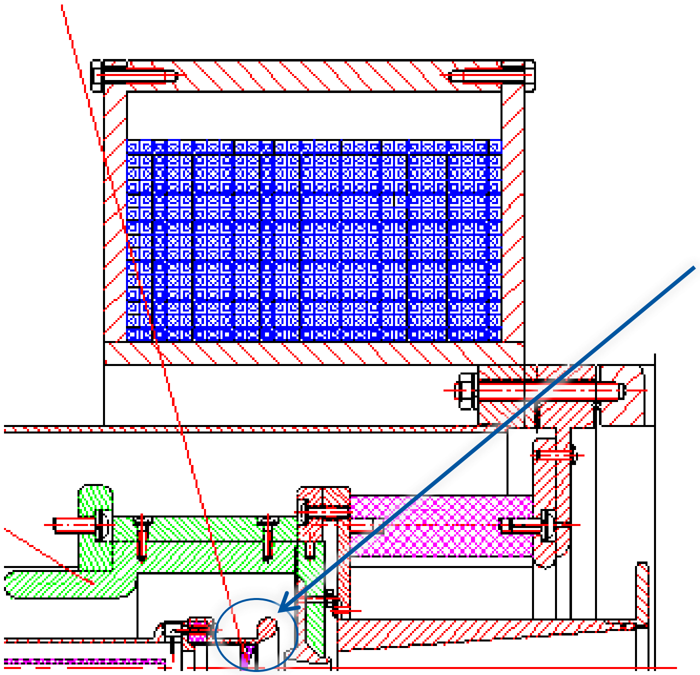
In-situ cathode alignment system
Under construction at BNL

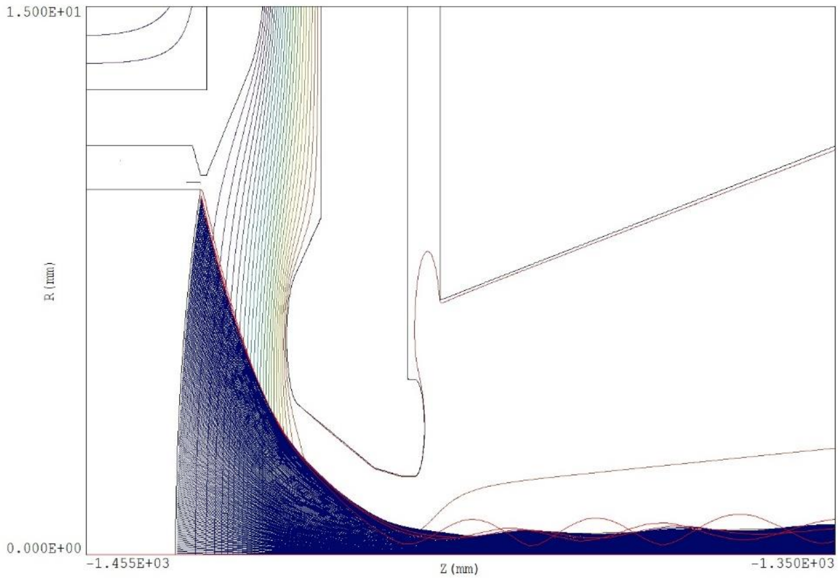
courtesy A. Pikin

HEC^2 gun gen II

Long term (2015-16, relies on not yet granted support by ENSAR-2, otherwise canceled*)

- ❑ Upgrade PS and HV isolation to enable high energy DC operation
- ❑ Improve discharge stability of the gun for DC operation
- ❑ Adjust the gun design to boost J_e





courtesy R. Mertzig

New focusing optics to supress side emission (beam quality, limiting loss)

Beam diagnostics tools in production at CERN

Deploying new diagnostics

←Ion beam emittance meter

Reflection mode Time of Flight mass spectrometer/ → Energy analyzer

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Future objectives

Electron beam physics

- ❑ Suppress loss current with new alignment and focusing
- ❑ Ramp up current and current density
- ❑ Verify current density by charge breeding of injected primary ions

Multicomponent plasma physics

- ❑ Test stability of the electron-ion plasma to TSI*
- ❑ Verify the ion beam emittance

* It's OK to ask what the TSI is

The transatlantic HEC^2 team

A. Shornikov (coordination, QA, on-site commissioning)
R. Mertzig (simulations, on-site commissioning)
F. Wenander (supervision at CERN)
E. Barbero (manufacturing, post-production)

A. Pikin (chief designer, BNL supervision, EBIS)
E. Beebe (operation of EBIS)
R. Schoepfer (operation/commissioning support)
D. McCafferty (operation/commissioning support)

our supporters

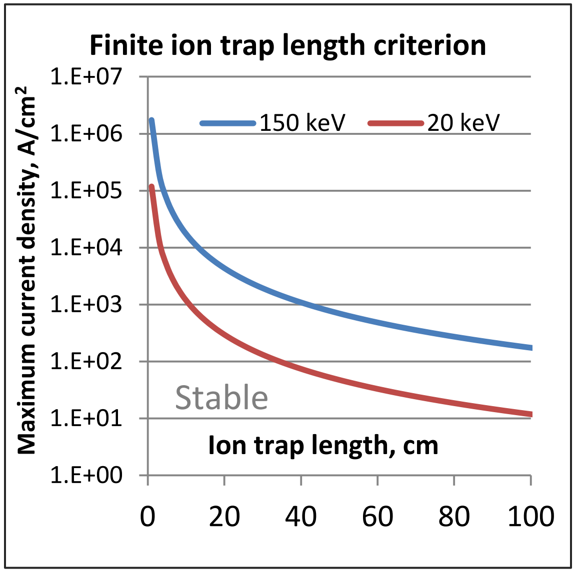
R. Catherall, Y. Kadi, R. Scrivens, J. Alessi,

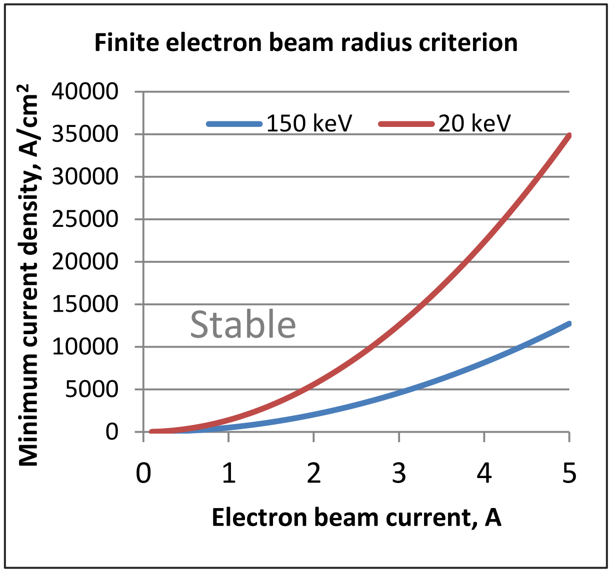
funding bodies

5.3 Two-Stream Instability

Consider the case in which the electron fluid is moving with speed u_e^0 relative to the ion fluid in a uniform plasma K. Nishikawa, M. Wakatani, Plasma Physics, Third edition

Sounds like a definition of EBIS

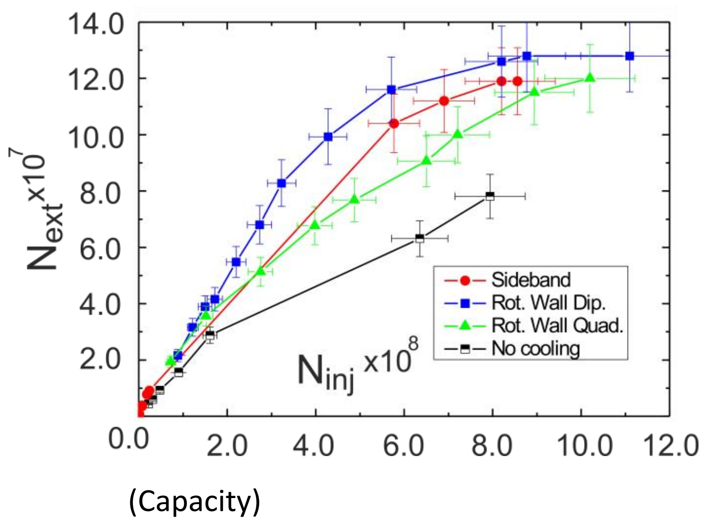


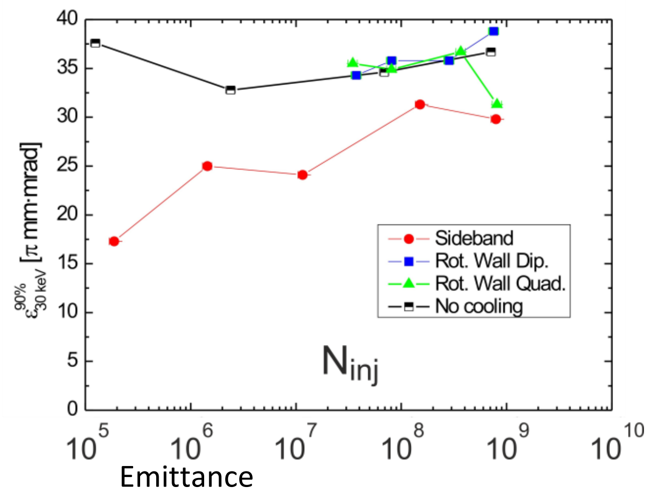


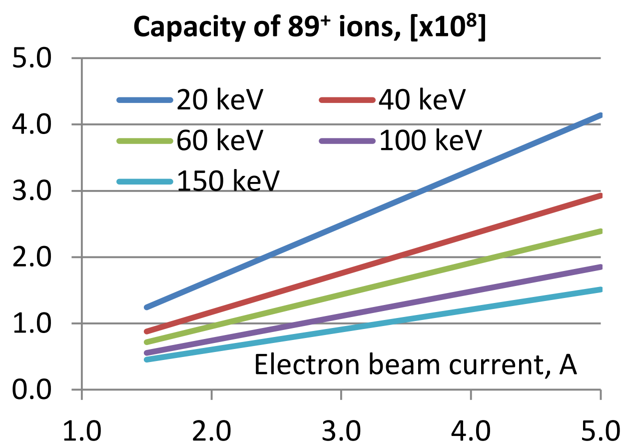
TSI stabilization in an EBIS
Due to finite trap length

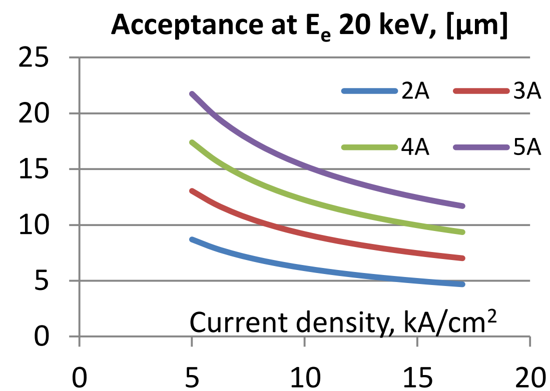
TSI stabilization in an EBIS
Due to finite beam radius

Requirements for ECB –
Accept as many ions as good as REXEBIS



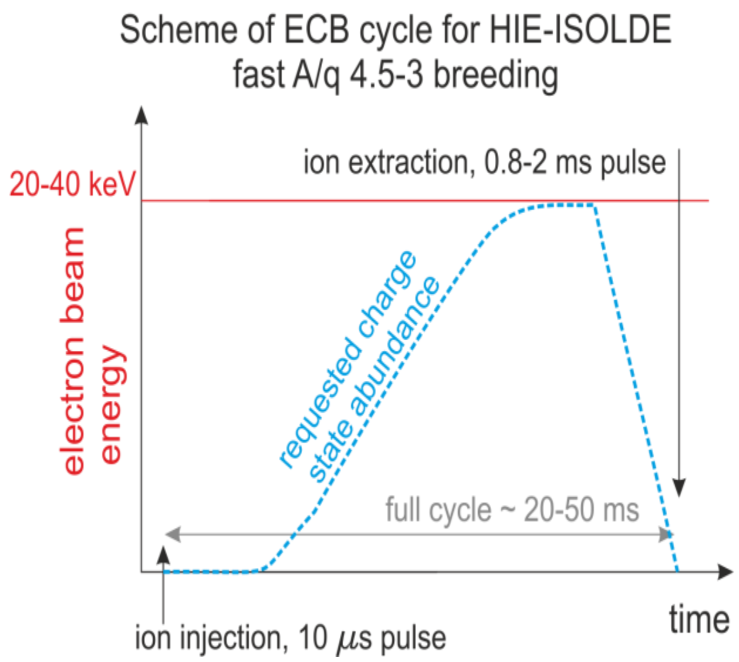


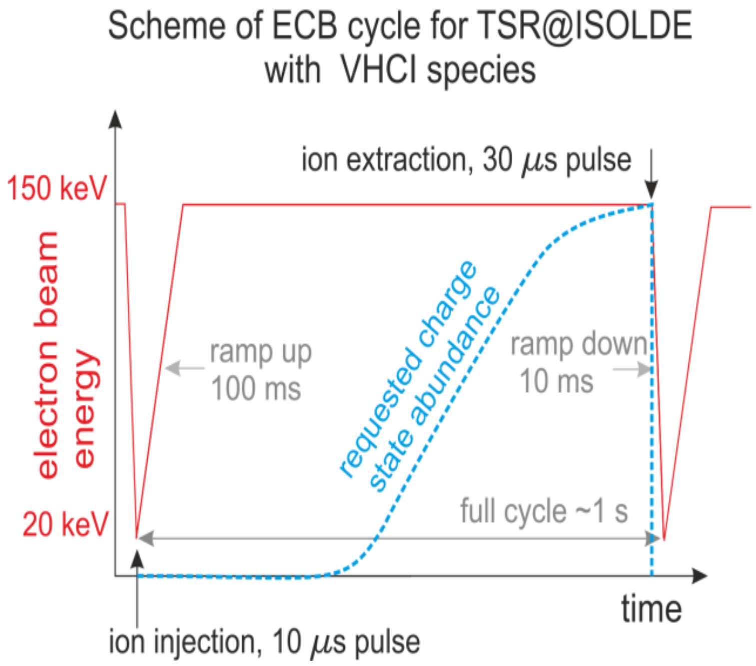




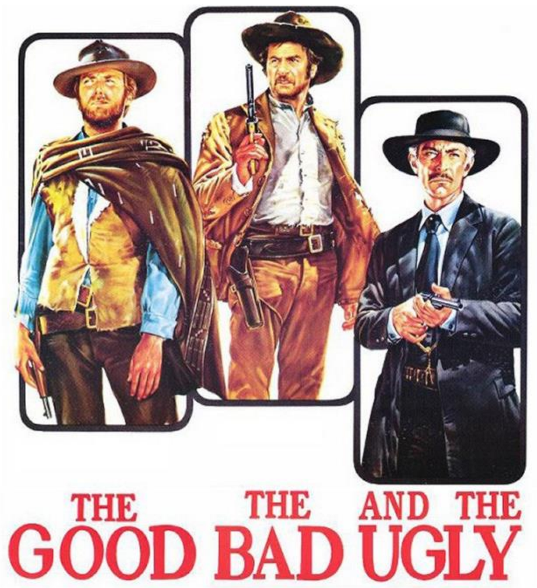
CERN
Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Requirements for ECB: higher charge state and faster

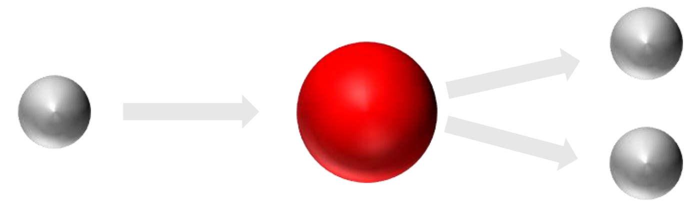




ECB physics: the good, the bad and the ugly



Impact Ionization (II): $e^- + q^{n+} = 2e^- + q^{(n+1)+}$

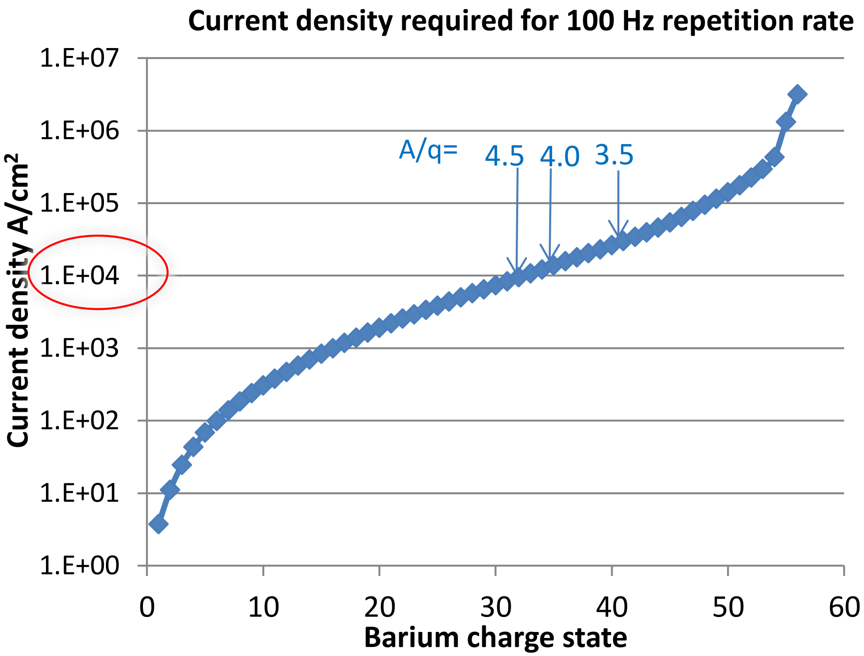


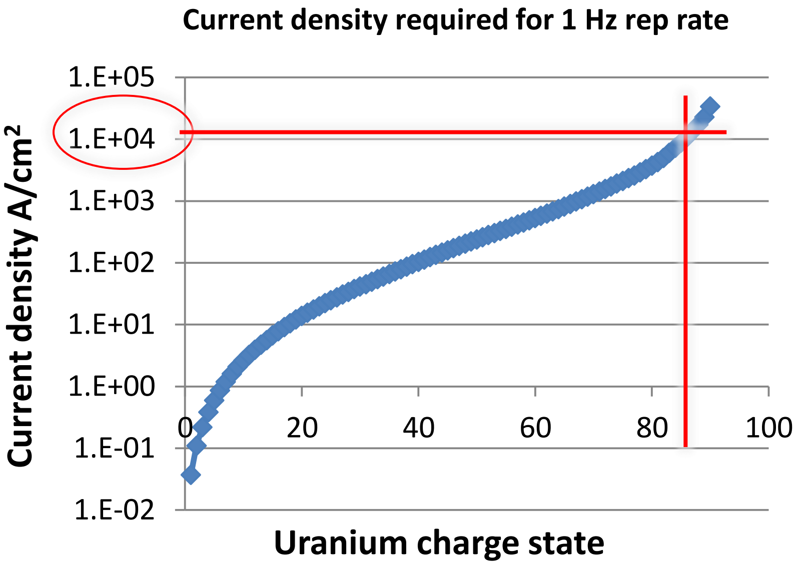
Radiative Recombination (RR) : $e^- + q^{n+} = q^{(n-1)+} + \gamma$

Charge eXchange (CX) : $A + q^{n+} = q^{(n-1)+} + A^+$

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

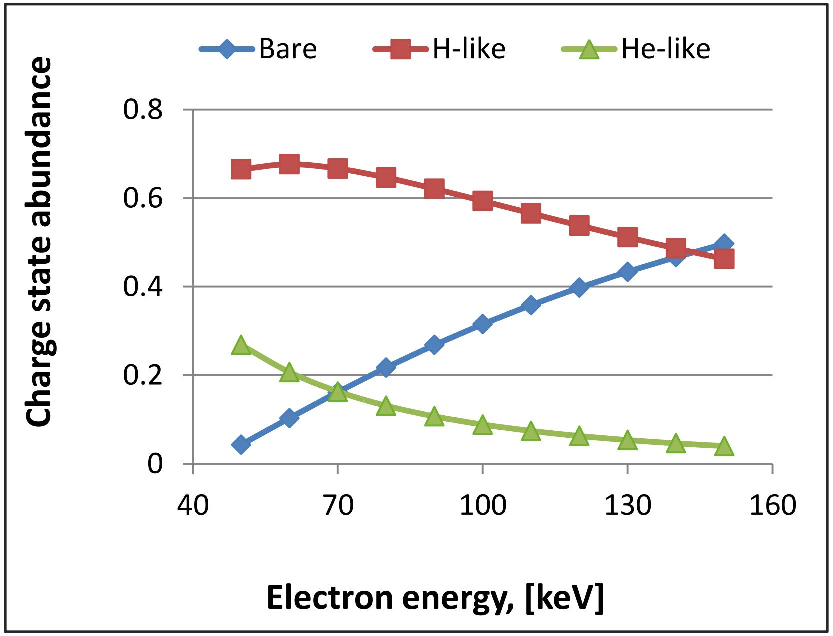
ECB physics: required current density

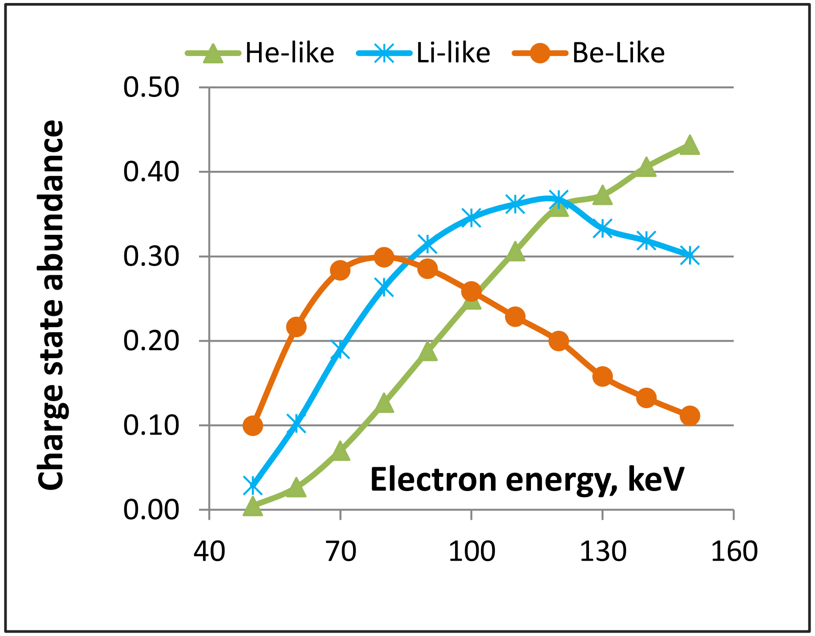




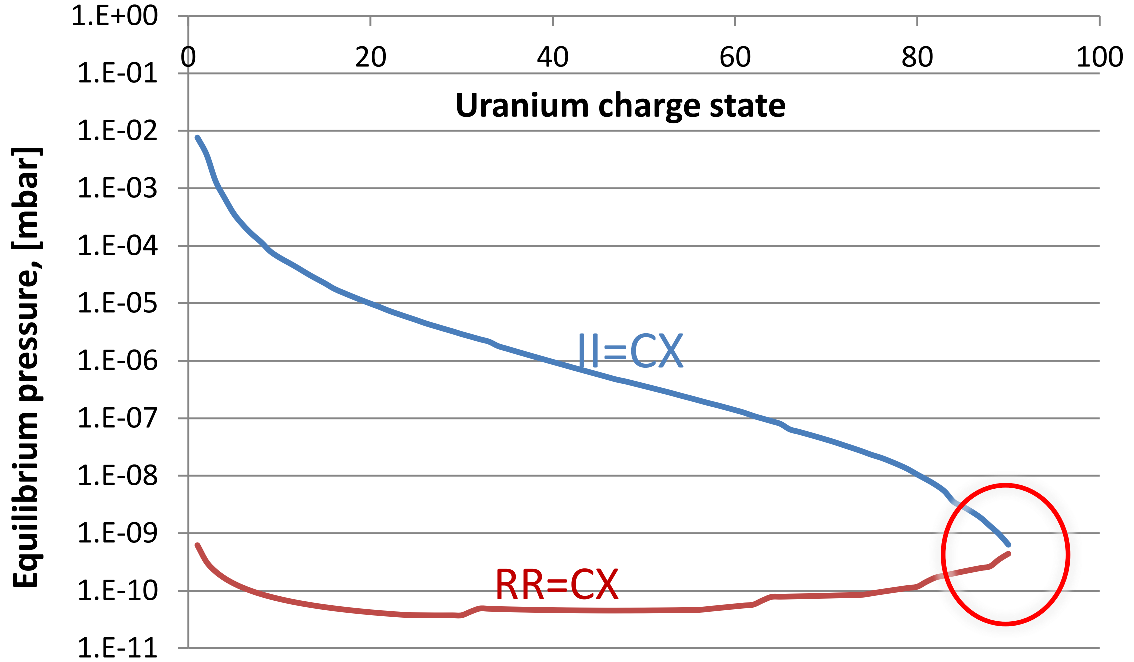
"*My dear, here we must run as fast as we can, just to stay in place. And if you wish to go anywhere you must run twice as fast as that.*"
— Lewis Carroll, *Alice in Wonderland*

ECB physics: required electron energy





ECB physics: required vacuum



Andrey Shornikov
Hadron Sources and Linacs section
Beams department

ECB technical parameters

Figures of merit for a new breeder in a nutshell

Design values for HEC² EBIS TSR@ISOLDE HIE-ISOLDE	
Electron energy [kV] (REXEBIS value)	150 (5)
Electron current [A] (REXEBIS value)	3.5 (0.2)
Electron current density [A/cm^2] (REXEBIS value)	1-2x10^4 (100)
Vacuum base pressure, [mbar]	10^{-11}

Andrey Shornikov
Hadron Sources and Linacs section
Beams department