Charge breeder for HIE-ISOLDE and TSR@ISOLDE

Charge breeder – the gear box of ISOLDE

Andrey Shornikov

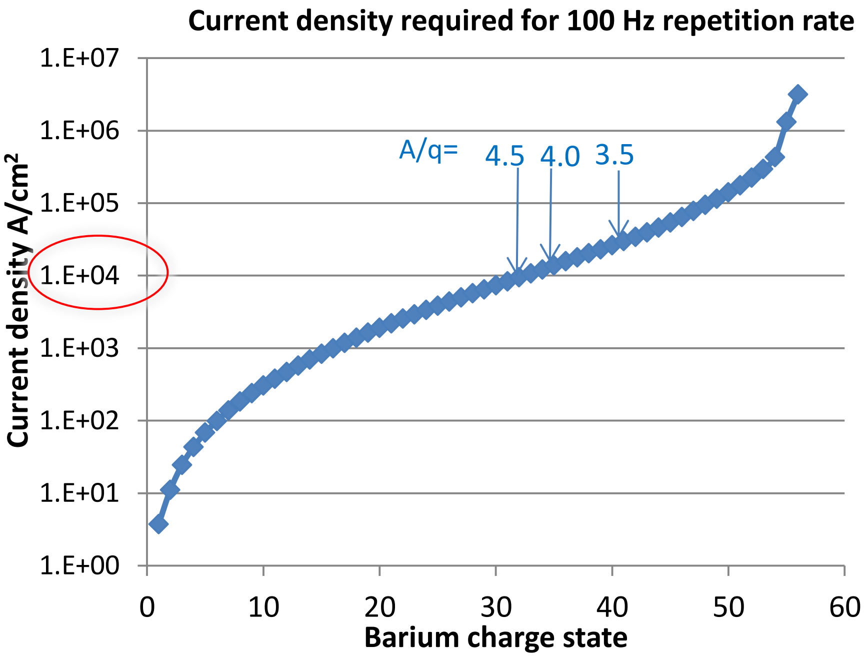
You should care if…

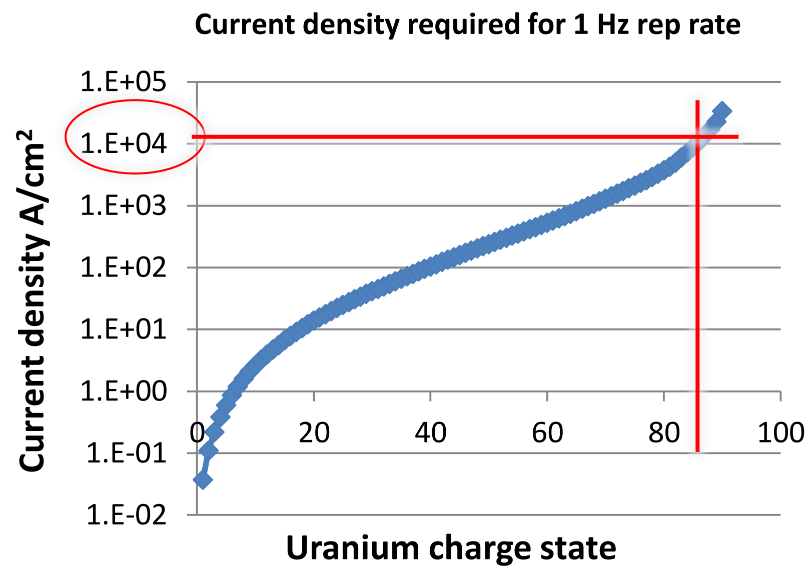
your experiment is down the linac and:

- it will benefit from increased repetition rate
- it will benefit from energy increase from 9.3 to14.5 MeV/u
- it has something to do with TSR@ISOLDE
- it requests Very Highly Charged Ions (VHCI)

Why you need a *new* charge breeder?

Breeding of VHCI and faster breeding





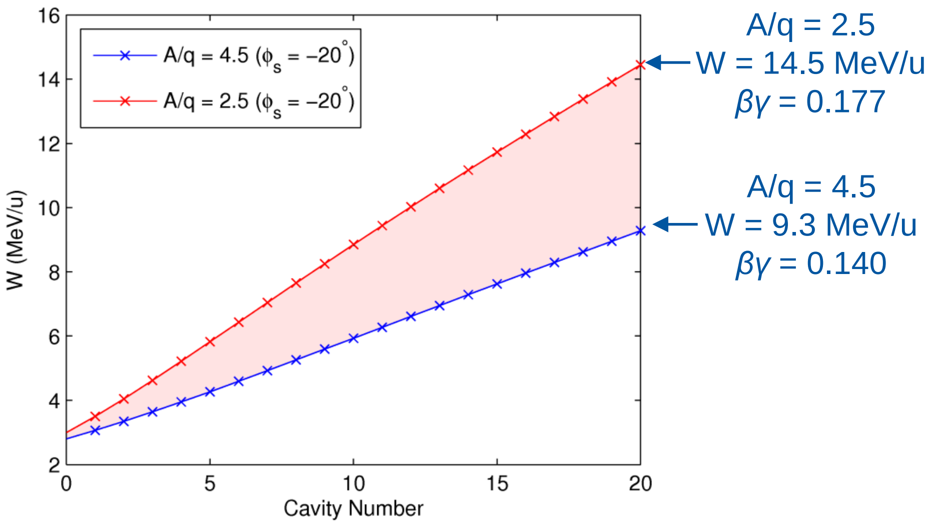
Breeding time (i.e. repetition rate) is defined by J_e (electron current density)

J_e ~ 10 000 A/cm^2 allows to reach max rep rate of linac for HIE-ISOLDE

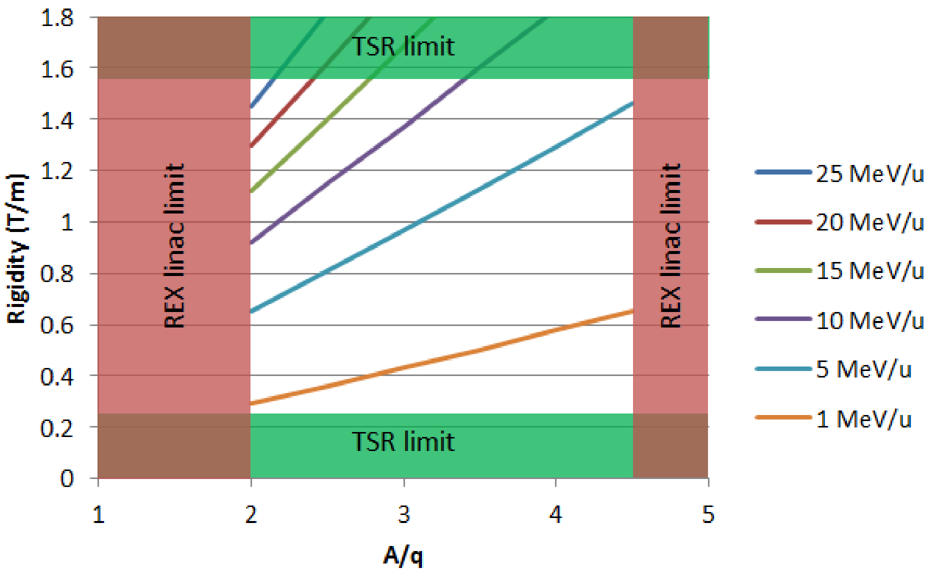
J_e ~ 10 000 A/cm^2 allows to match the pace of injection+cooling cycle at TSR for HCI and VHCI

Why you need a *new* charge breeder?

Increased energy from linac and injection to TSR – lower A/q



HIE-ISOLDE linac, phase 2a
courtesy M. Fraser



See the following talk on TSR@HIE-ISOLDE
by F. Wenander

Lower A/q needs higher electron beam energy
Lower A/q at the same or higher rep rate needs higher electron beam J_e
VHCI, bare medium-Z and few-electron high-Z need extreme electron energy > 100 keV

Why you need a *new* charge breeder?

Acceptance and capacity

With J_e and E_e ↑ acceptance ↓ if I_e=const

EBIS acceptance, microns (electron energy keV vs. Electron current, A)

Electron current, A	20	40	60	80	100
1.5	20.7	17.4	15.8	14.7	13.9
2.0	23.9	20.1	18.2	16.9	16.0
2.5	26.7	22.4	20.3	18.9	17.9
3.0	29.4	24.6	22.2	20.7	19.5
3.5	31.9	26.6	24.0	22.3	21.1
4.0	34.2	28.5	25.7	23.9	22.6
4.5	36.5	30.3	27.3	25.3	23.9
5.0	38.8	32.0	28.8	26.7	25.3

REXEBIS acceptance=34 microns

To have acceptance equal to REXEBIS 4-5 A is required together with E_e ramping down at injection

With E_e ↑ capacity ↓ if I_e=const

Capacity of 50+ ions in 0.7 m trap at 0.1 neutralisation, 1E+8 (electron energy keV vs. Electron current, A)

Electron current, A	20	40	60	80	100
1.5	1.6	1.1	0.9	0.8	0.7
2.0	2.1	1.5	1.2	1.0	0.9
2.5	2.6	1.8	1.5	1.3	1.2
3.0	3.1	2.2	1.8	1.6	1.4
3.5	3.7	2.6	2.1	1.8	1.6
4.0	4.2	3.0	2.4	2.1	1.9
4.5	4.7	3.3	2.7	2.3	2.1
5.0	5.2	3.7	3.0	2.6	2.3

REXTRAP capacity = 1E+8 ions/bunch

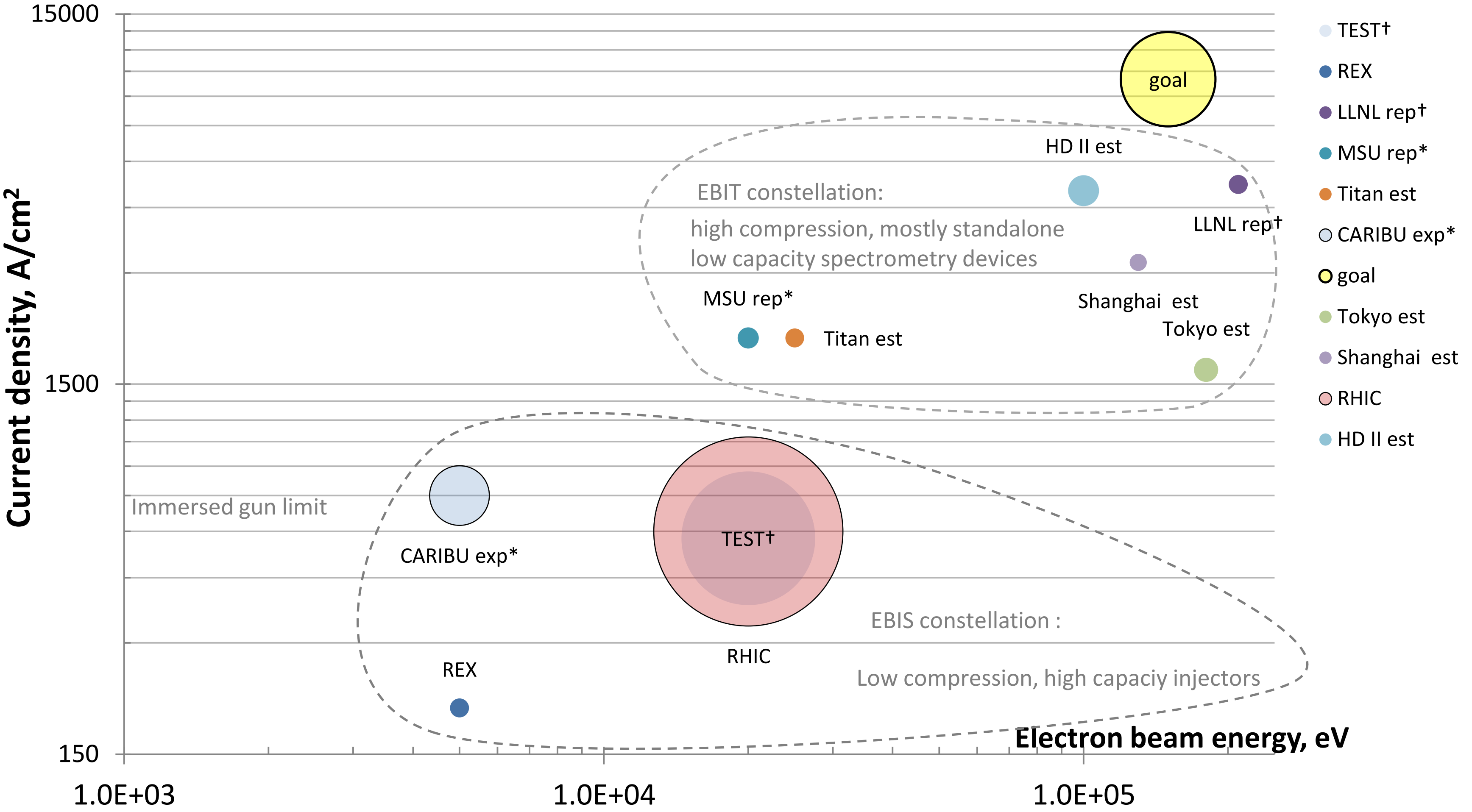
To have >1E+8 50^+ ions capacity in the EBIS at 10% neutralization for any E_e one needs ~ 3 A

Why you need a *new* charge breeder?

Figures of merit for a new breeder in a nutshell

Design values for HEC^2 EBIS TSR@ISOLDE HIE-ISOLDE	
Electron energy [kV] (REXEBIS value)	150 (5)
Electron current [A] (REXEBIS value)	2-5 (0.2)
Electron current density [A/cm^2] (REXEBIS value)	1-2x10^4 (100)

What is out there?



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

If EBIT people tell you it's not a big deal...

Livermore Super EBIT - the best EBIT ever built

Production of U^{92+} with an electron beam ion trap (invited)

R. E. Marrs

Lawrence Livermore National Laboratory, Livermore, California 94550

(Presented on 12 September 1995)

ization and recombination.) The most abundant charge states (U^{88+} and U^{89+}) are produced even more quickly, so a yield of roughly 2×10^4 extracted ions per second can be expected for these charge states from the present LLNL Super EBIT.

TABLE II. The observed equilibrium ionization balance in the LLNL Super EBIT for uranium at 198-keV electron beam energy.

Ionization stage	Charge	Abundance (%)	Number of ions
Bare	92	0.02	10
H-like	91	1.0	500
He-like	90	17	8500
Li-like	89	34	17 000
Be-like	88	31	15 500
B-like	87	15	7500
C-like	86	3	1500
Total		100	5×10^4

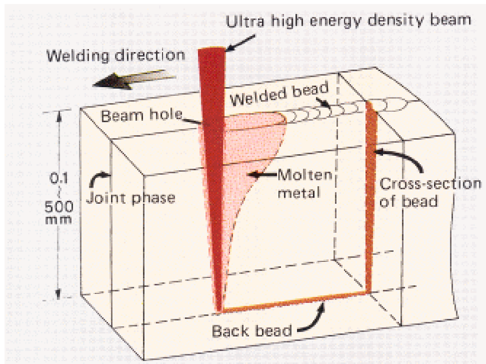
Rev. Sci. Instrum. 67 (3), March 1996

EBIT is not an ion source, it's a dedicated spectroscopic device

Let's get a feeling of what it is

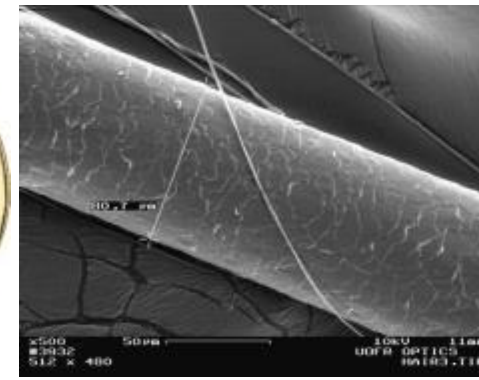
150 kV, 2-5 A, 10^4 A/cm^2

60 kV, 25 kW - an industrial electron beam welder

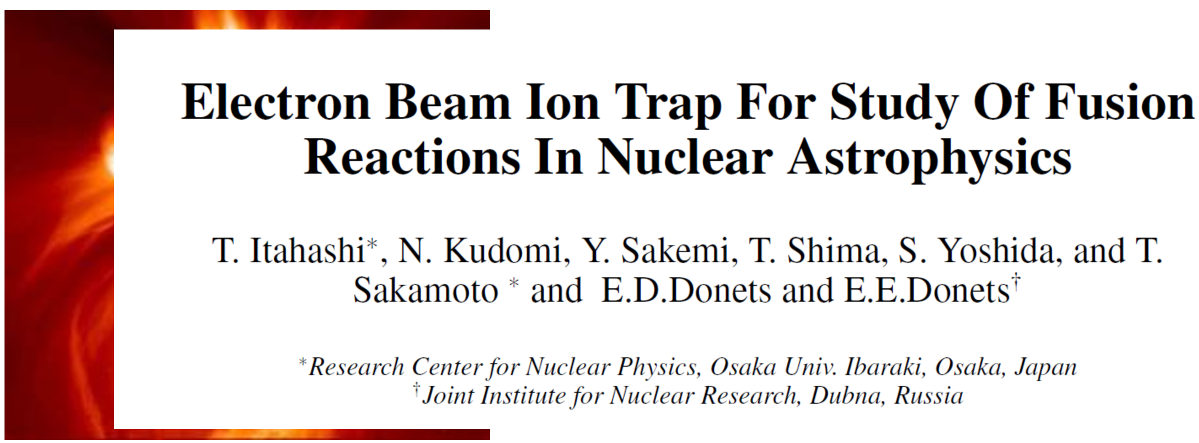


e$^-$ beam heating enough to ignite D-T fusion

10^4 A/cm^2 - beam compression from cathode (1€ size) to trapping region (human hair size)



e$^-$ beam potential enough to confine fusion plasma



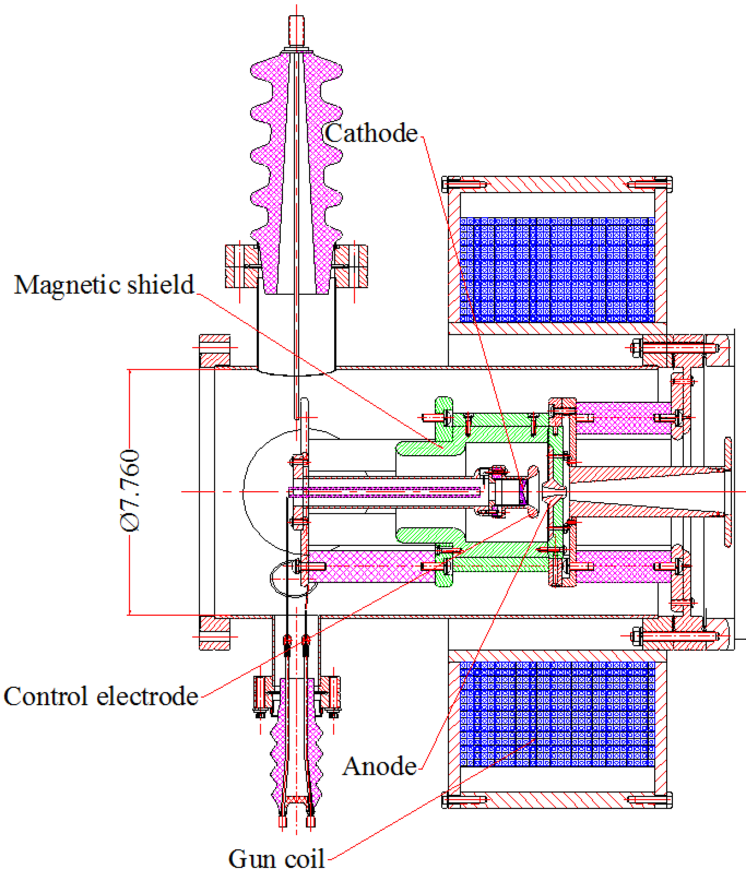
Electron Beam Ion Trap For Study Of Fusion Reactions In Nuclear Astrophysics

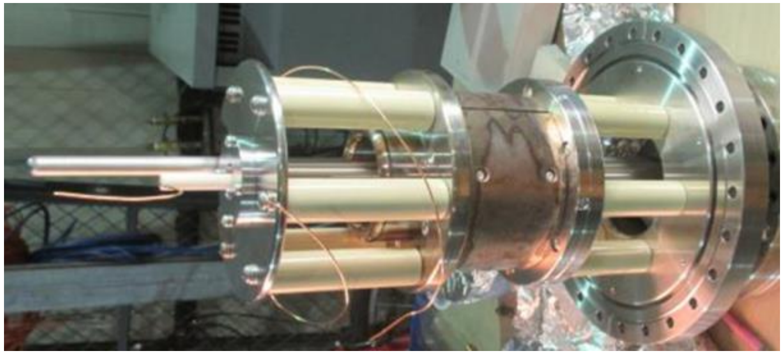
T. Itahashi*, N. Kudomi, Y. Sakemi, T. Shima, S. Yoshida, and T. Sakamoto * and E.D.Donets and E.E.Donets†

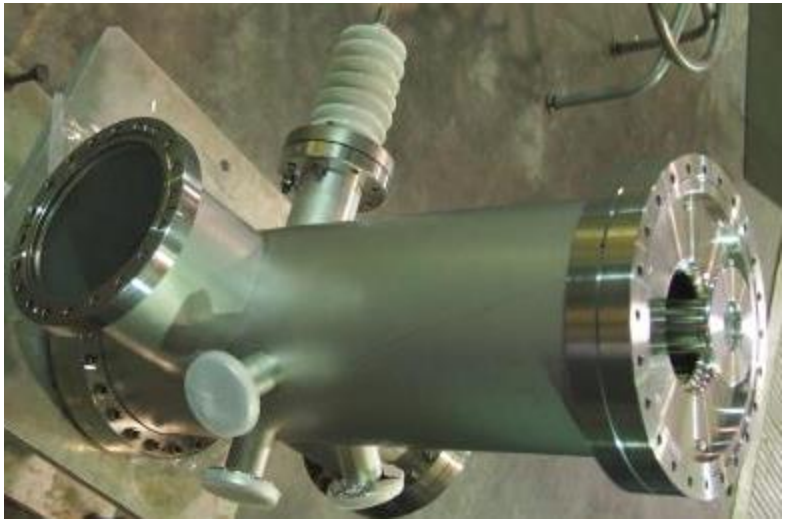
**Research Center for Nuclear Physics, Osaka Univ. Ibaraki, Osaka, Japan*
†Joint Institute for Nuclear Research, Dubna, Russia

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

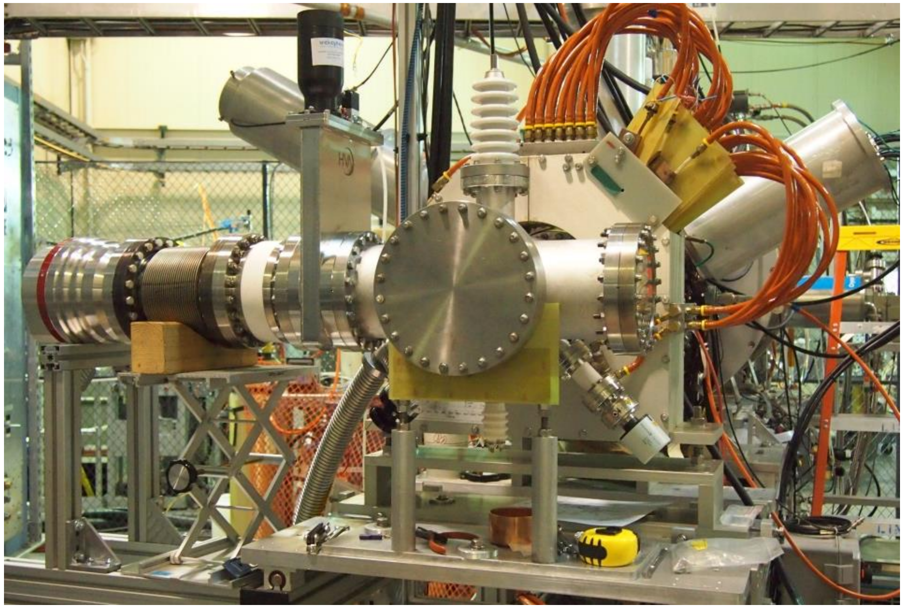
Preliminary development

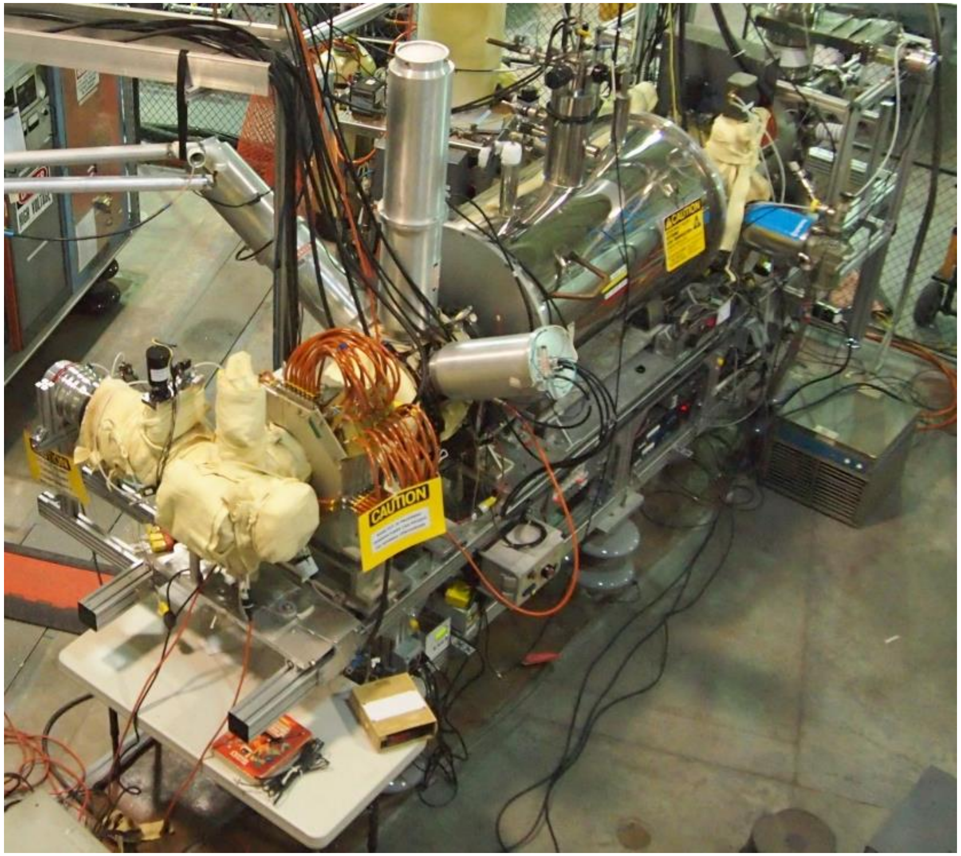
01-06.2013 manufacturing phase

Andrey Shornikov
Hadron Sources and Linacs section
Beams department

Challenge accepted – using TestEBIS at BNL

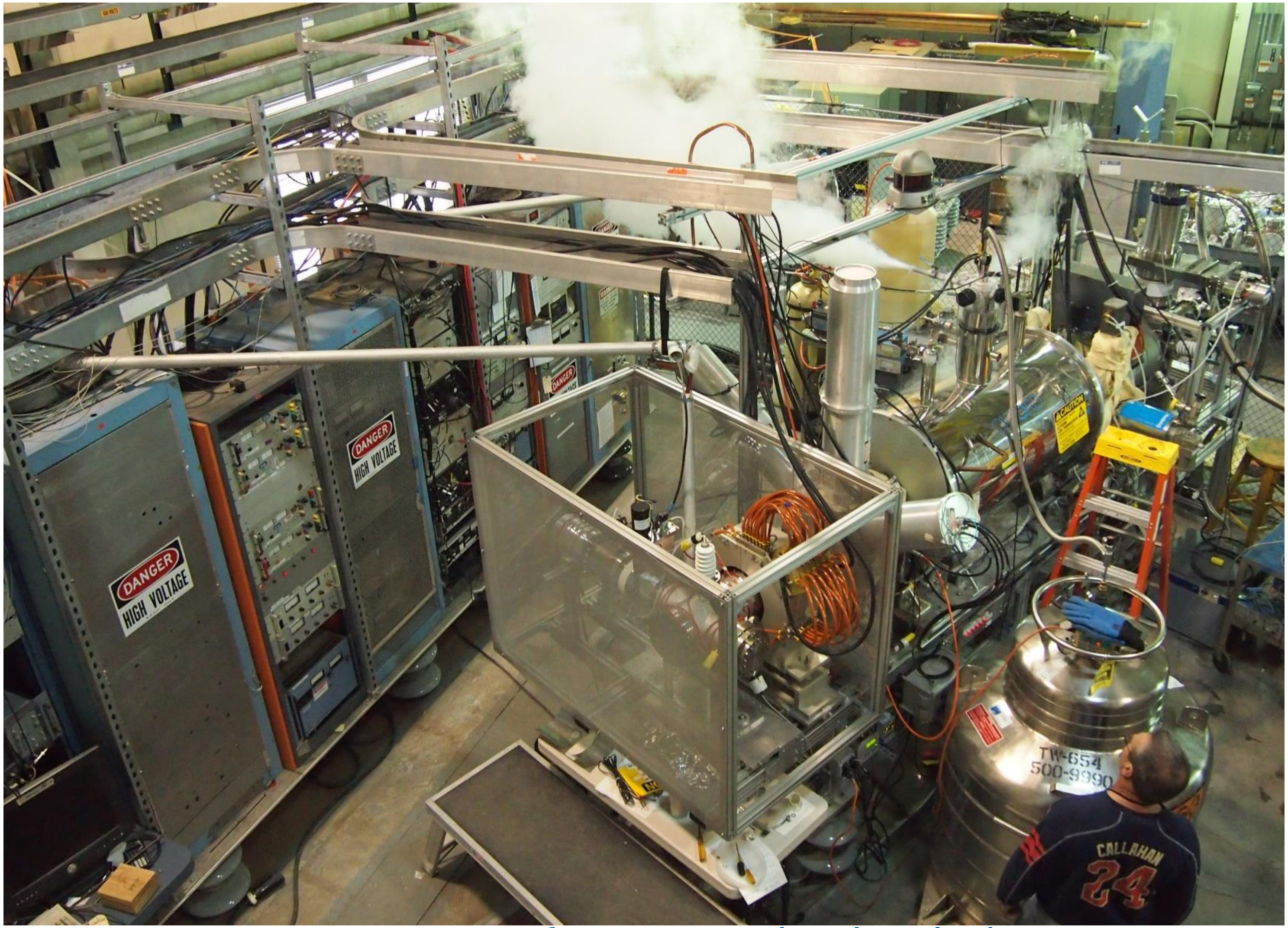
TestEBIS – the cradle of all 4 highest current EBISes ever built





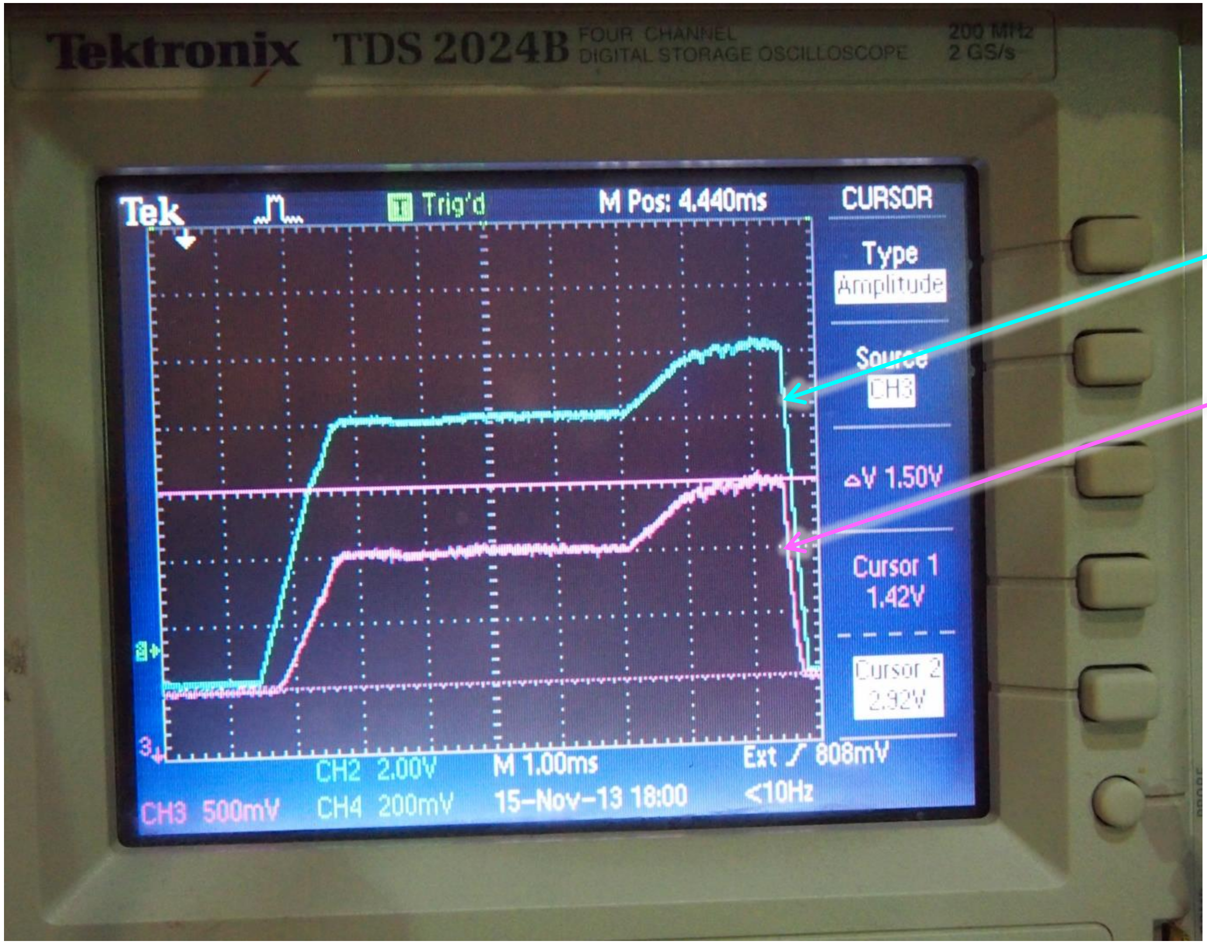
07-08.2013 HEC^2 moved to BNL, assembled, preparations of the Test EBIS started

Challenge accepted – using existing TestEBIS at BNL



10.2013 HV safety, cryogenics, interlocks, etc

First e⁻ beam – 08.11.2013



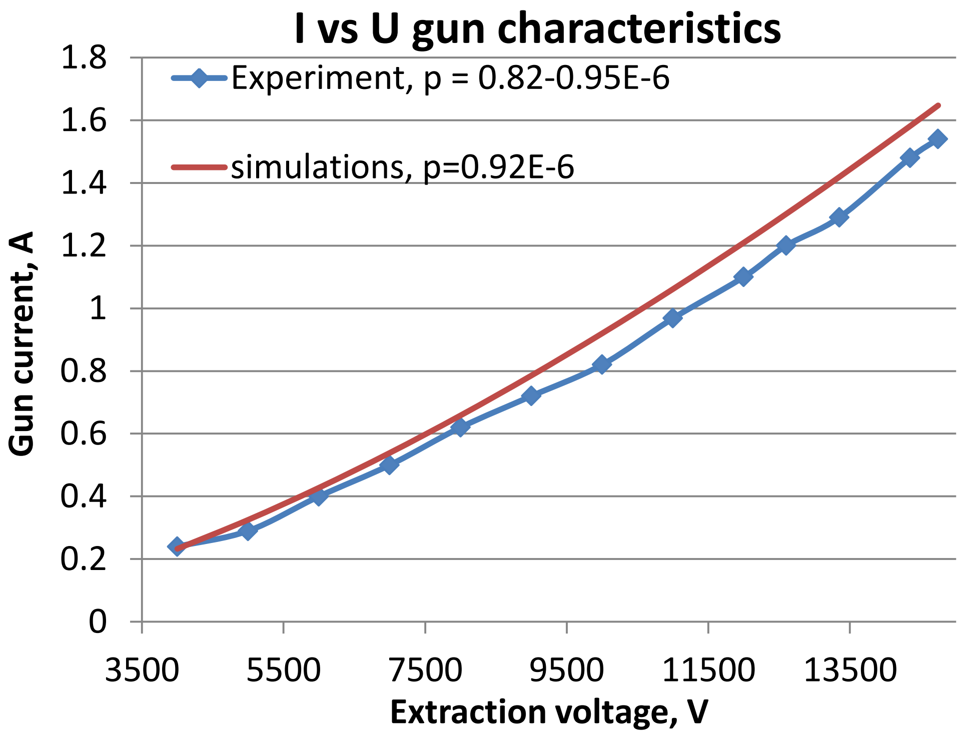
Anode voltage

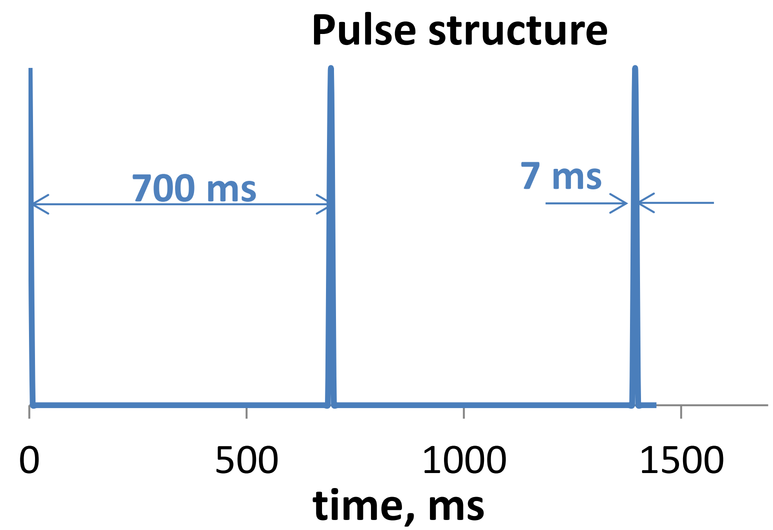
Extracted current (1V=1A)

After 6 days of HV training and tuning – the current ramped to 1.5 A

Training is essential due to numerous regions with ExB prone to magnetron discharge

First run summary





Beam properties:

Main magnet field – 3.3 T (out of 4.8)

Current – up to 1.54 A

Electron energy 25-30 keV (max 40 keV)

Pulse structure:

Operation – pulsed (PS+collector limited)

Pulse length – 3-7 ms (PS limited)

Duty cycle - 0.5-3 % (collector limited)

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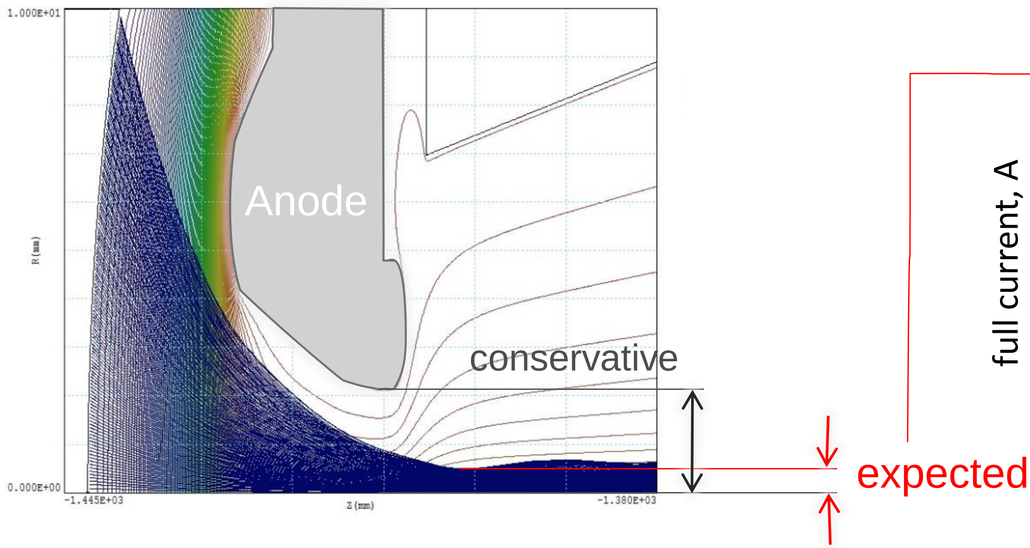
Hadron Sources and Linacs section
Beams department

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/cm²

Potential (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/cm²

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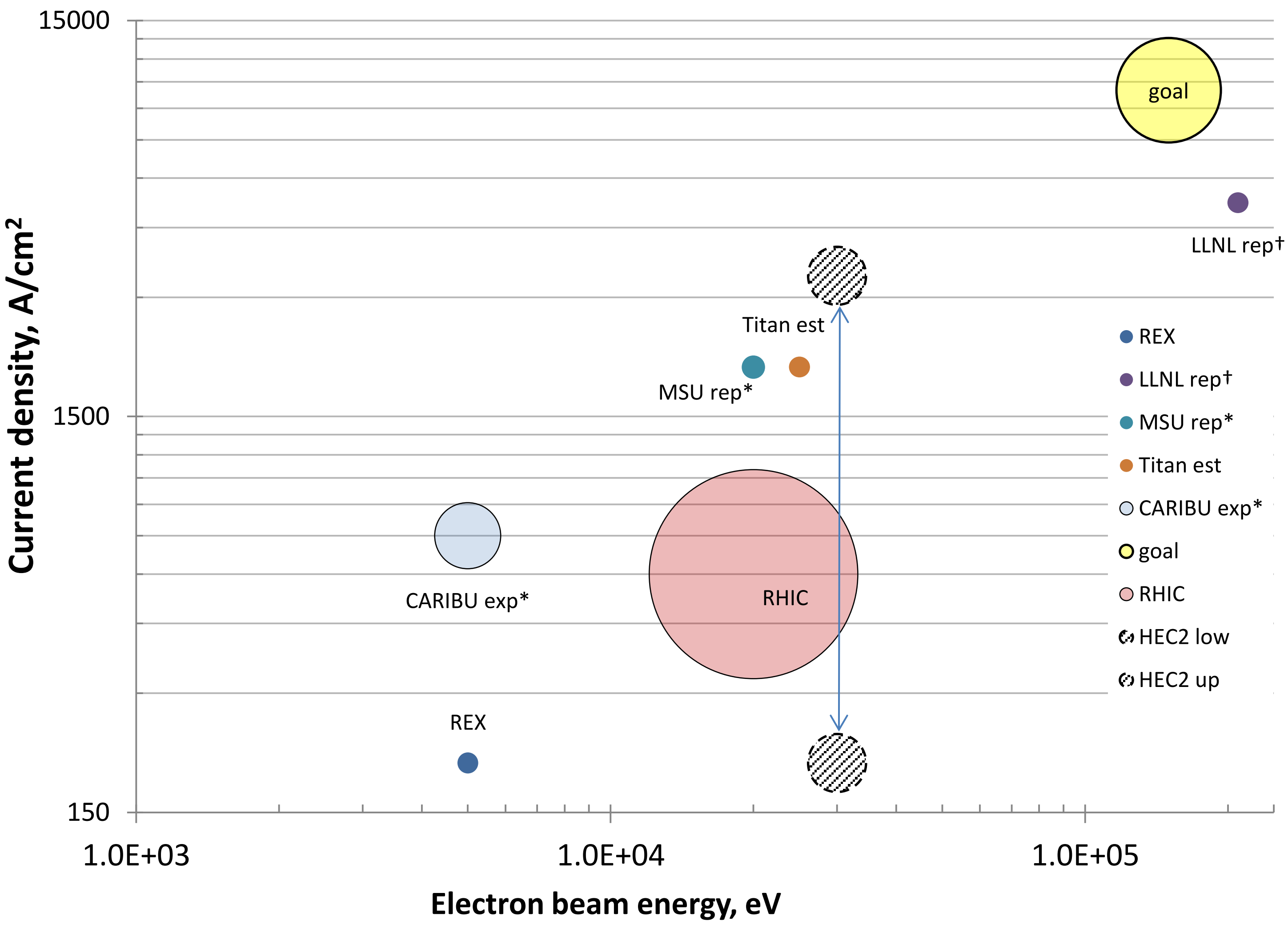
Where we are on the map



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

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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

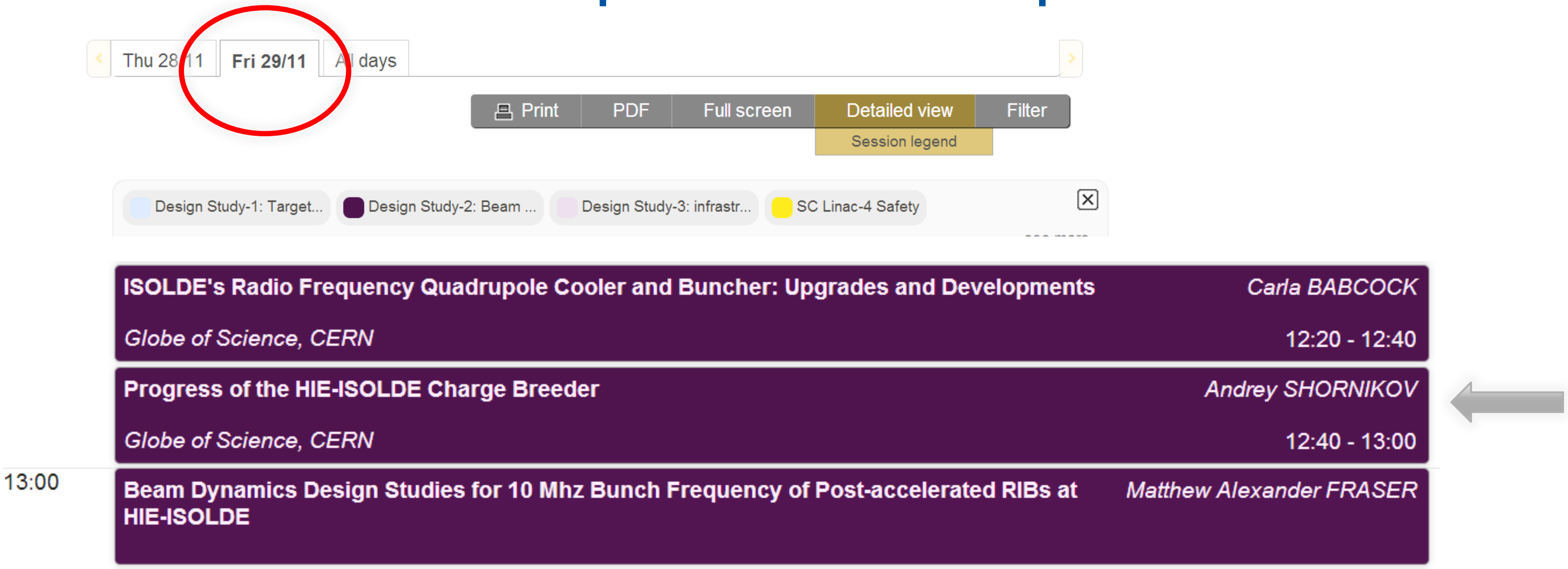
Long term (2015-16, relies on not yet granted support by ENSAR-2, otherwise canceled*)

- ❑ 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

Find out more on the HEC^2 project

HIE-ISOLDE Workshop: The Technical Aspects



Further materials:

- ❑ Charge breeder for HIE-ISOLDE – Shornikov et al DOI:10.1016/j.nimb.2013.06.030
- ❑ High compression gun – Pikin et al DOI: 10.1063/1.4793773
- ❑ Next expected update – IPAC 2014

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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

and many others…