# Negative Ion Beam Acceleration and Transport in HV injector prototype

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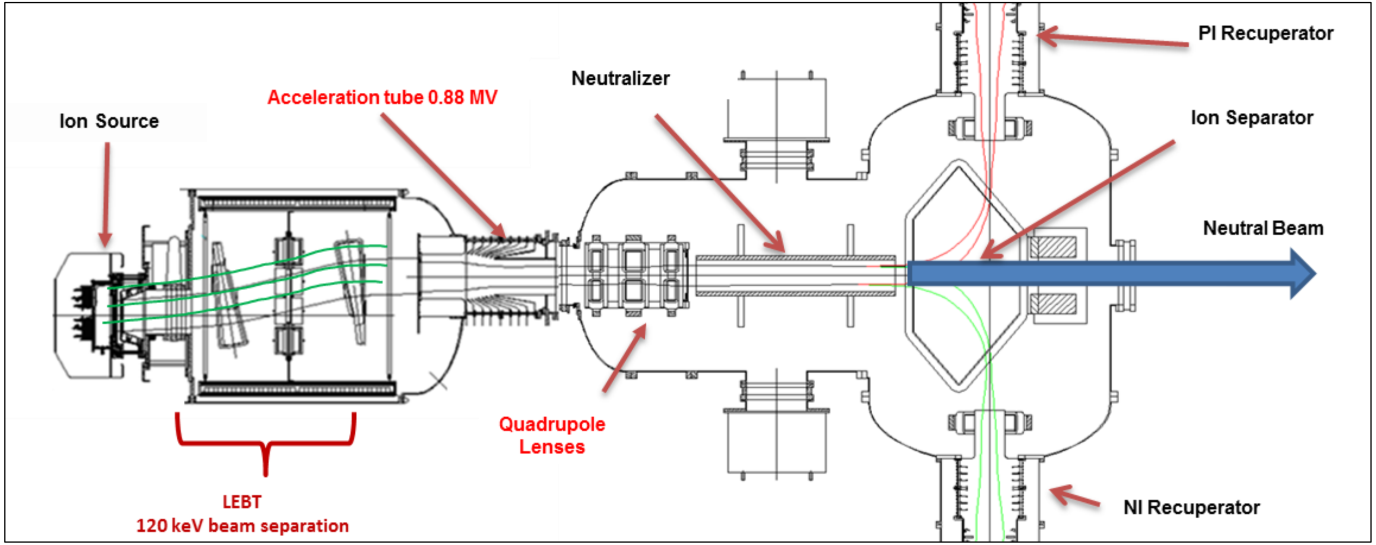
*Budker Institute of Nuclear Physics*

- BINP N-NBI design
- HV injector prototype
- Beam transport through LEBT and HEBT with AV off
- First results of beam transport and acceleration

# BINP project of HV negative ion based Injector*

*A. Ivanov, G. Abdrashitov, V. Anashin, Yu. Belchenko, A. V. Burdakov et al. AIP Conf. Proc. **1515**, 197 (2013)*



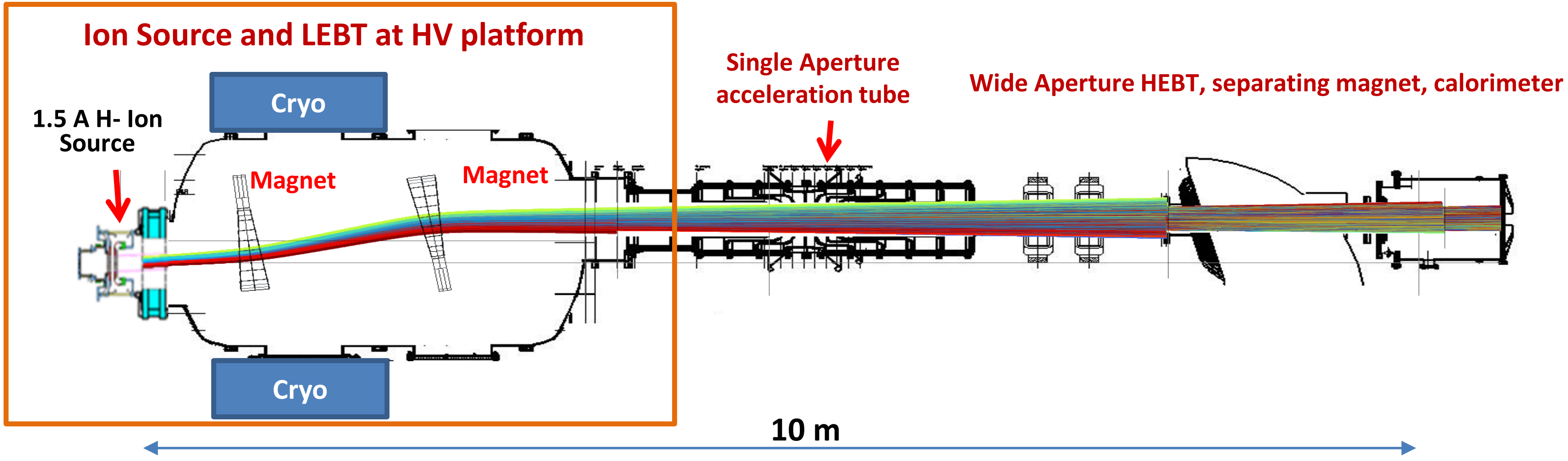

## Principal :

- Beam acceleration after purifying from the co-streaming fluxes of primary and secondary particles (gas, fast neutrals, electrons, cesium, light)
- Single-aperture accelerator with intense pumping. Secondary particles production and stresses of the accelerator could be considerably reduced

## Under development:

- RF SPS with 1.5 A and 9 A, 120 kV H- beam production
- HV injector prototype
- Plasma target for HV beam neutralization
- Photon target with nonresonant photon accumulation

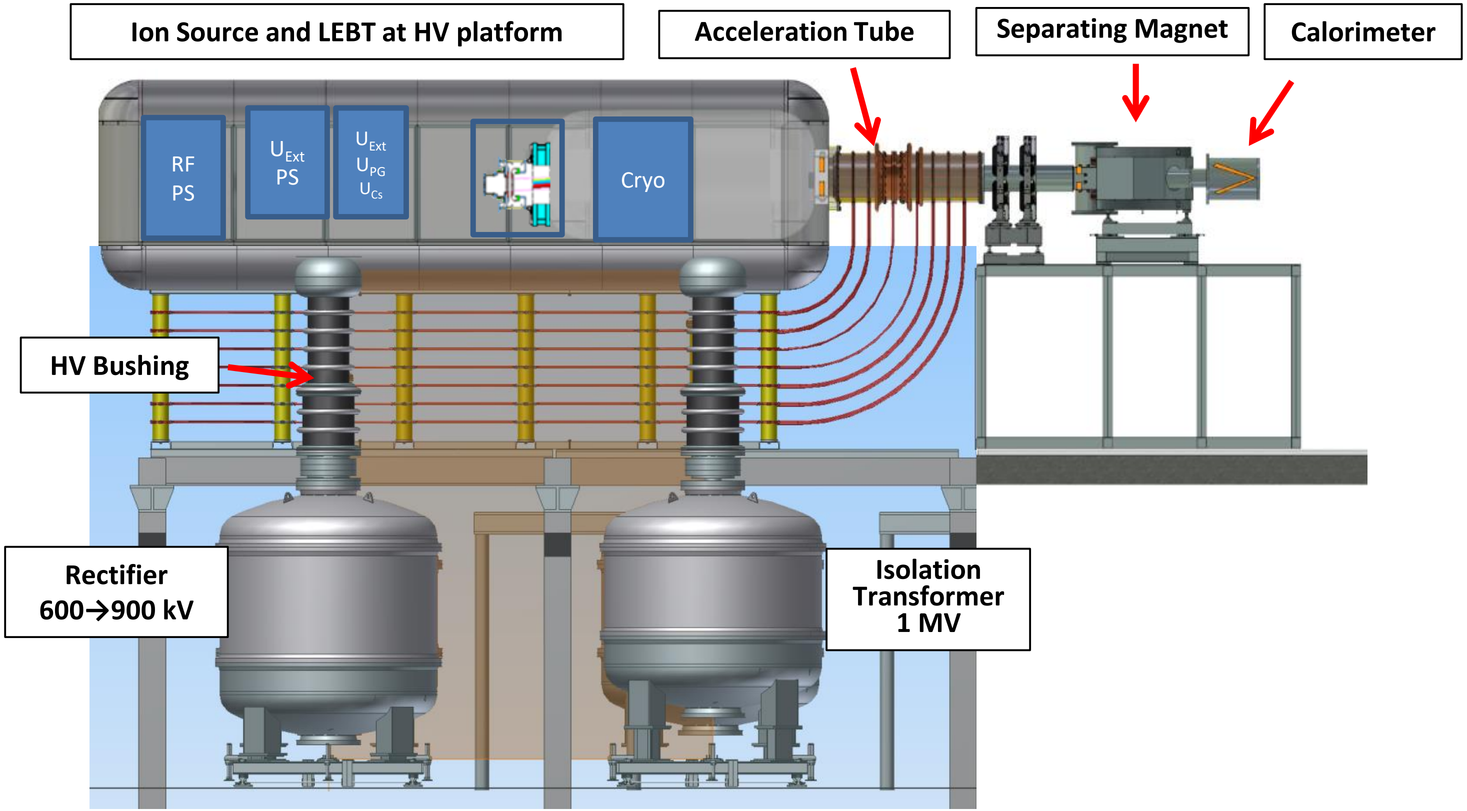
# HV Injector Prototype Test Stand



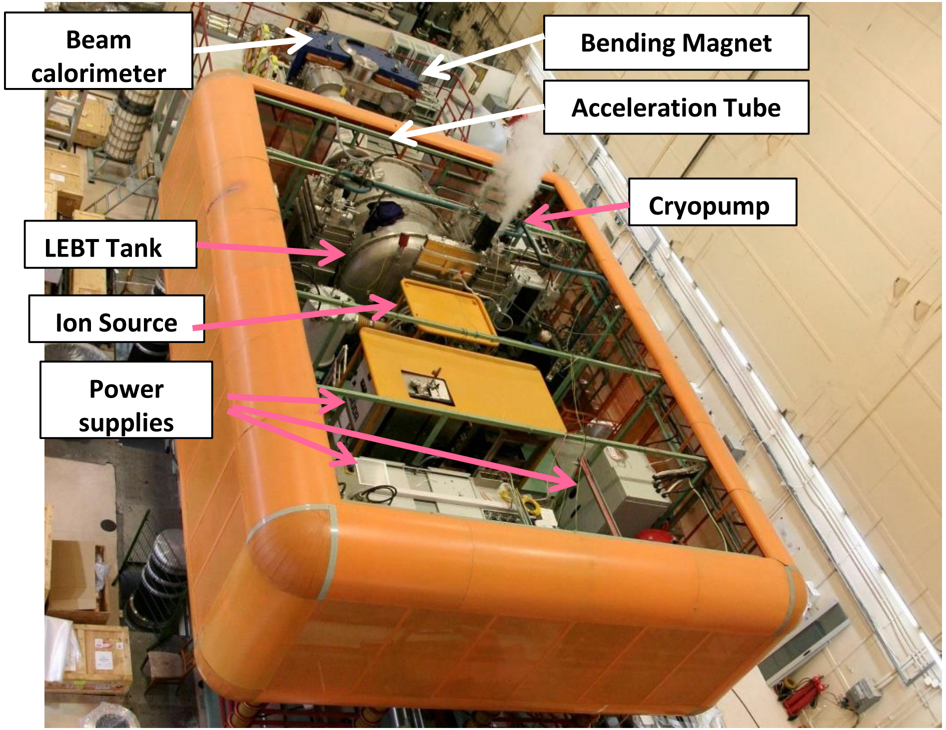

**First studies (2020):**

- **Beam transport to acceleration tube entrance**
- **Beam transport through HEBT with acceleration voltage off**
- **Beam acceleration and transport through HEBT**

# 3D drawing of Injector Prototype



# HV Injector Prototype in the Hall

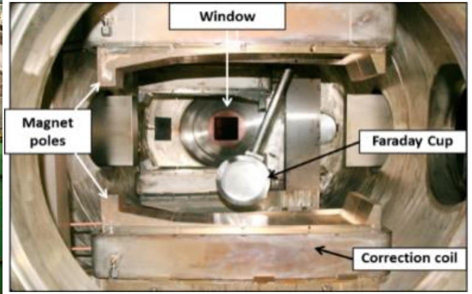



HV platform top view

HV platform side view

# Components of Injector Prototype

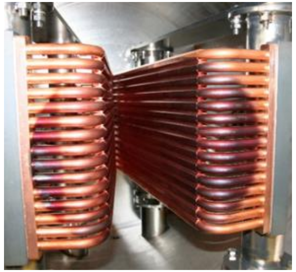
Ion Source




Magnets in the LEBT tank

Acceleration Tube

Quadrupoles



Beam calorimeter

Primary line rectifier
3kV, 3 MW

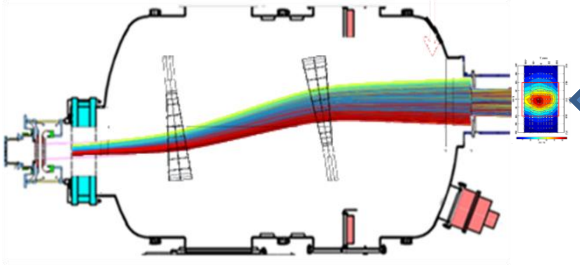
Invertors Boxes for HV
rectifiers feed 2kHz

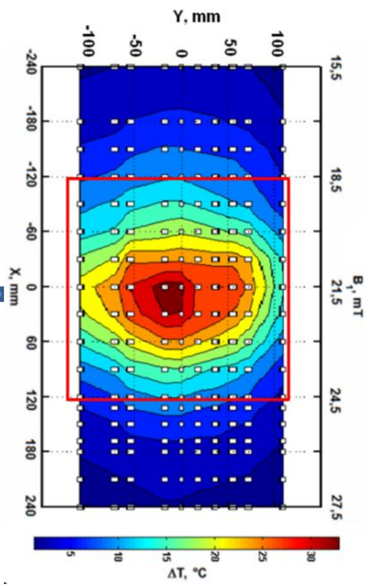
Rectifier 0-330 kV

Rectifier 330-660 kV

# Beam Transport through LEBT *

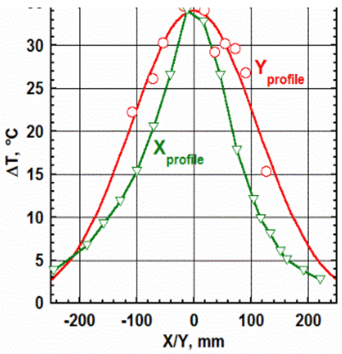
**O. Sotnikov, Yu. Belchenko, P. Deichuli, A. Ivanov, and A. Sanin. AIP Conf. Proc.* ***2052***, 070003 *(2018)*





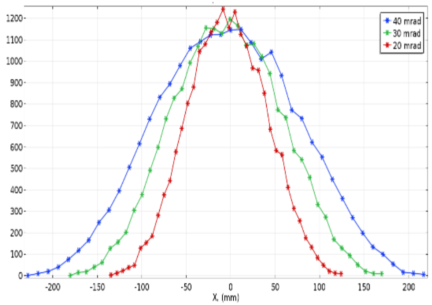

Beam distribution obtained at 3.5 m from the source by magnetic beam scan across calorimeter

Calculated trajectories (COMSOL) show ~60% beam transmission through 24x24 cm LEBT exit aperture for beam with initial divergence ± 40 mRad




Experimental beam profile at distance 3.5 m

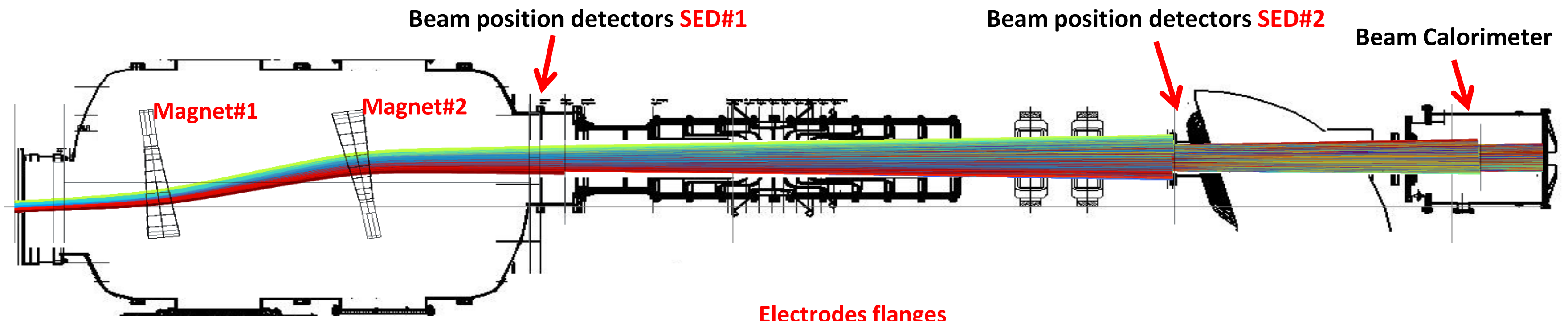
$U_B$=9+84 = 93 kV

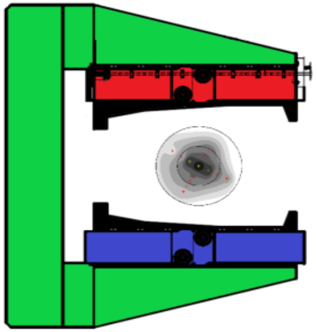



Calculated profiles for beam with divergence ± 20, 40 и 60 mrad. COMSOL

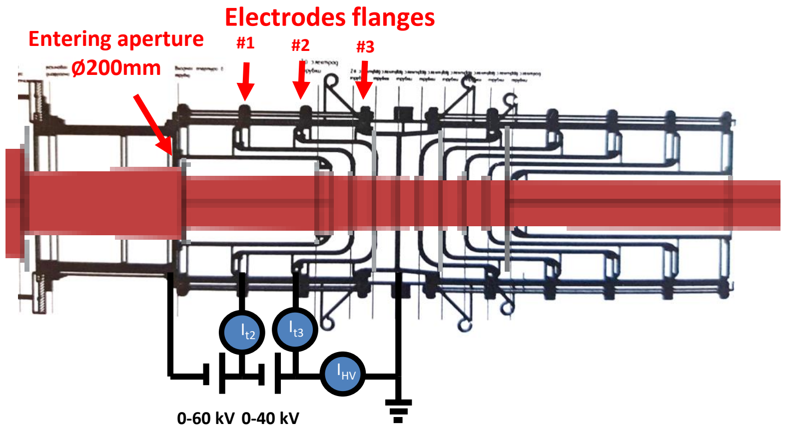
**It confirms the obtained beam divergence ΔX'~30 mrad, ΔY'~45 mrad**

# Beam Transport through HEBT

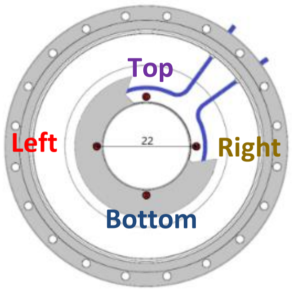


Beam position in the LEBT magnet aperture

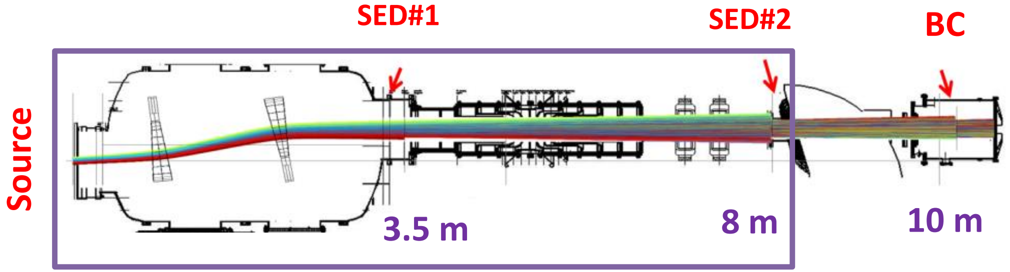



Connection of acceleration tube electrodes and Scheme of intercepted current measurements in the 100 kV acceleration test

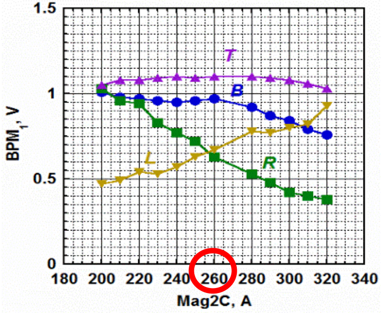



Beam position detector 4 SEDs at periphery

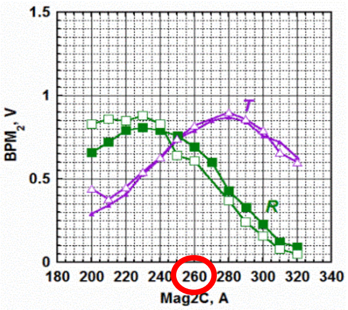
# Beam Transport through HEBT
## (with no HV at acceleration tube)




Calculated trajectories for beam with divergence ± 20 mRad are shown (COMSOL)

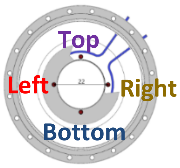



SED#1 probes L,R,T,B
at distance 3.5 m




SED#2 probes R,T
at distance 8 m

Beam magnetic scan by magnet #2 current change
Beam optimal position at current $I_{Mag2}$ =260 A



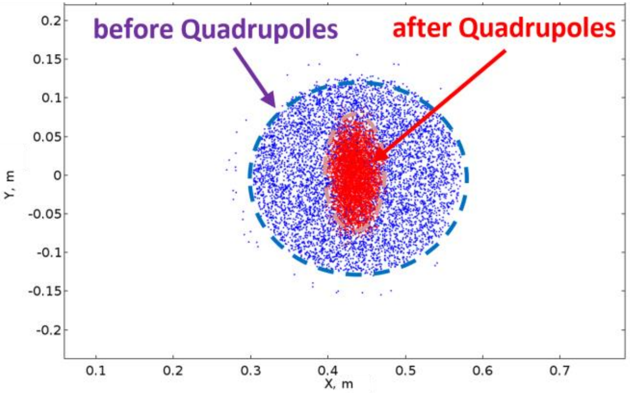

| | SED#1 (3.5 m) | | | | SED#2 (8 m) | | | |
|---|---|---|---|---|---|---|---|---|
| $U_{ex}$ | Bottom | Right | Top | Left | Bottom | Right | Top | Left |
| 7kV | 1 | 0.7 | 1.1 | 0.7 | 0.6 | 0.6 | 0.8 | – |
| 10kV | 1.1 | 0.5 | 1.3 | 0.5 | 0.6 | 0.4 | 0.9 | – |

SED data for two values of the source Extraction voltage 7 and 10 kV.

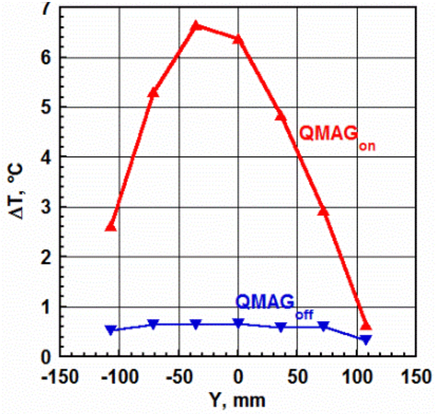
**Beam sizes are lower at $U_{ex}$ = 7 kV**

# Beam Transport through HEBT
## (with no HV at acceleration tube)

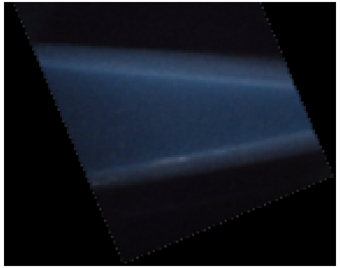
### *Beam Focusing by Quadrupoles*



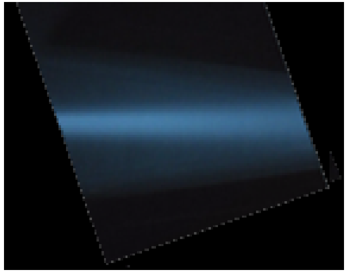

**Beam compression by Quadrupoles**
**Calculated beam profile (Comsol)**
**Ub= 85 kv, $U_{HV}$ =0**




**Beam profile at 10m**
**with Quadrupoles ON & OFF**



**Quadrupoles OFF**

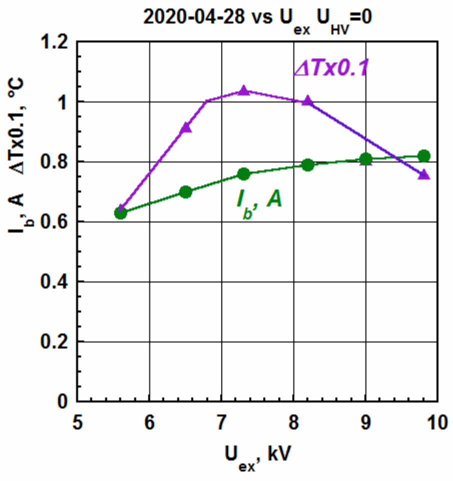


**Quadrupoles ON**

**Beam compression is seen by glow, caused by beam in the area between the calorimeter plates**
Photo taken by bottom CCD

**Quadrupoles decrease beam size at calorimeter. Beam power, incident to BC increases ~10 times**

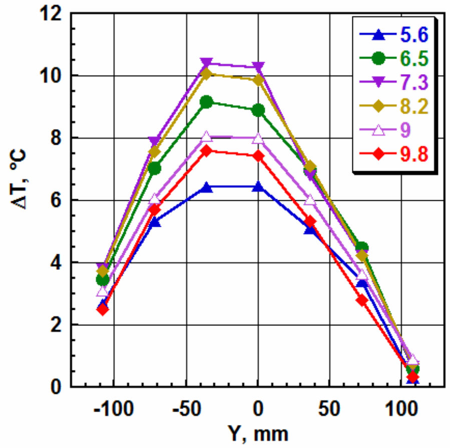
# Beam Transport through HEBT
## (with no HV at acceleration tube)




BC temperature ΔT and Beam current $I_b$ dependencies vs Extraction voltage $U_{ex}$

$U_{tot}$=84 kV, $Q_{mag}$ **on**

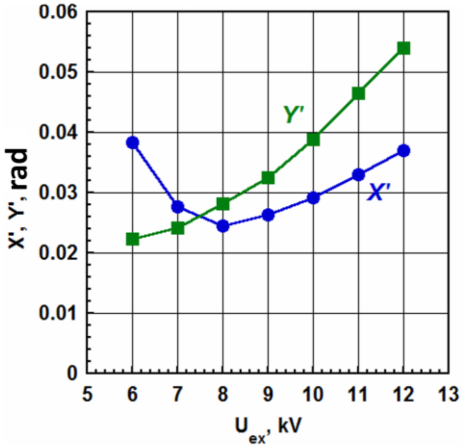
**Beam transport is maximal at $U_{ex}$ =7-8 kV**




Temperature growth ΔT of BC lamellas vs Extraction voltage $U_{ex}$

$U_{tot}$=84 kV, $Q_{mag}$ **on**

**ΔT is larger at $U_{ex}$ =7-8 kV**




**Beamlet divergence vs $U_{ex}$ (IBSIMU)**

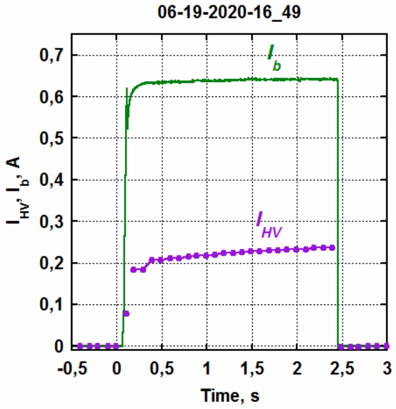
for $I_b$ =30 mA, $U_B$=85 kV

**X' = 25 mrad, Y'= 28 mrad at $U_{ex}$ =8 kV**

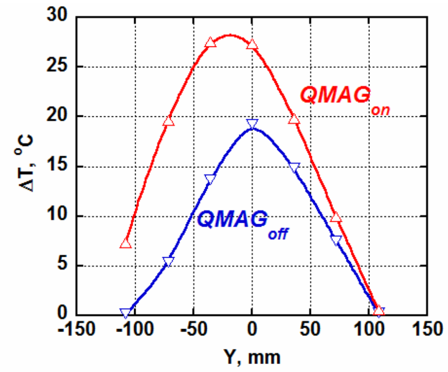
**The maximal beam transport was recorded at the optimal $U_{ex}$ ~7-8 kV for 85 kV, 0.6 A beam**

**It is consistent with the simulations by IBSIMU**

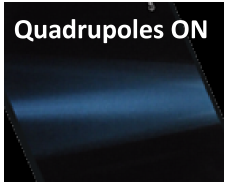
# Beam acceleration study



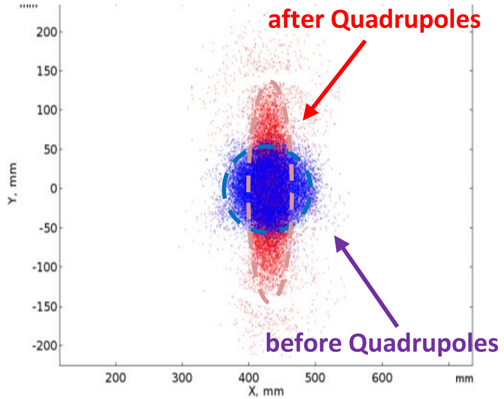

Oscillogramme of beam current from the source $I_b$ and of accelerated current $I_{HV}$




Beam profile at 10 m with Quadrupoles ON & OFF


Beam compression is seen by glow in the area between the calorimeter plates taken by bottom CCD

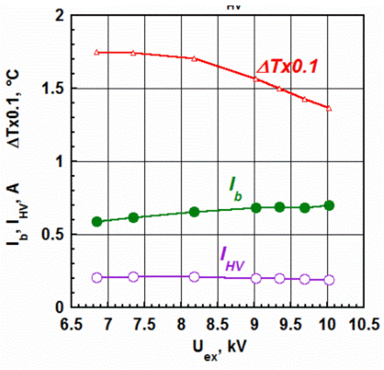



Beam compression by Quadrupoles
Calculated beam profile (Comsol)
Ub= 85 kv, $U_{HV}$ =100 kV

- **~ 37 % of beam were accelerated to energy 83+100 = 183 kV**
- ~ 3 mA current (1.3%) was measured in the 1st acceleration electrode circuit
- Accelerated Beam current $I_{HV}$ increases to the pulse end (due to Cs redistribution on PG ?)
- Quadrupoles switching on diminishes the beam size at BC plane

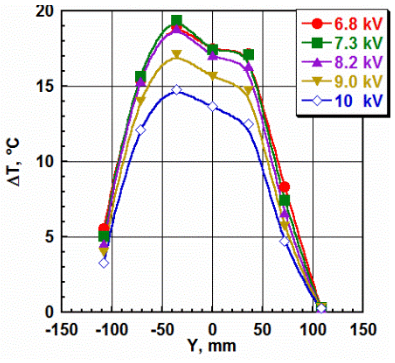
# Beam transport vs source parameters

## Acceleration with HV voltage $U_{HV}$ 36 kV
## Extraction voltage change




BC temperature growth ΔT, beam current $I_b$ and accelerated current $I_{HV}$ vs Extraction voltage

$U_B$=84 kV, $U_{HV}$=36 kV

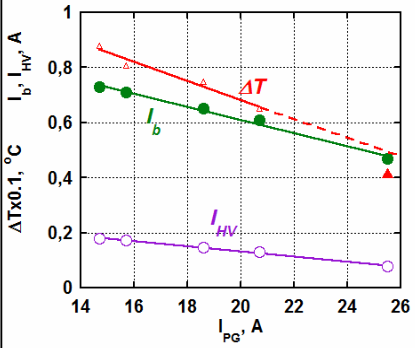



BC lamellas temperature growth ΔT for various Extraction voltage

$U_B$=84 kV, $U_{HV}$=36 kV

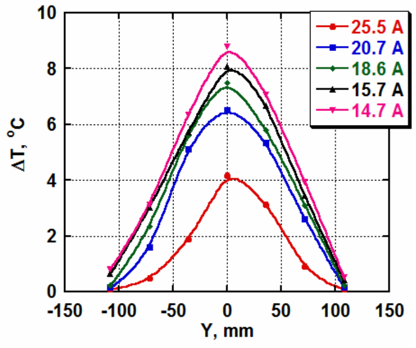
ΔT is larger at $U_{ex}$ =7-8 kV

## Acceleration with HV voltage $U_{HV}$ 79 kV
## PG bias change




BC temperature growth ΔT, beam current $I_b$ and accelerated current $I_{HV}$ vs PG current

$U_B$=78 kV, $U_{HV}$=79 kV




BC lamellas temperature growth ΔT for various PG current $I_{PG}$

$U_B$=78 kV, $U_{HV}$=79 kV

Beam at BC is larger at $I_{PG}$ =15 A

Beam transport is optimal for $U_{ex}$ = 7 kV-8 kV (at $U_{HV}$ 36 kV)

Optimal beam size FWHM at calorimeter is 170 mm

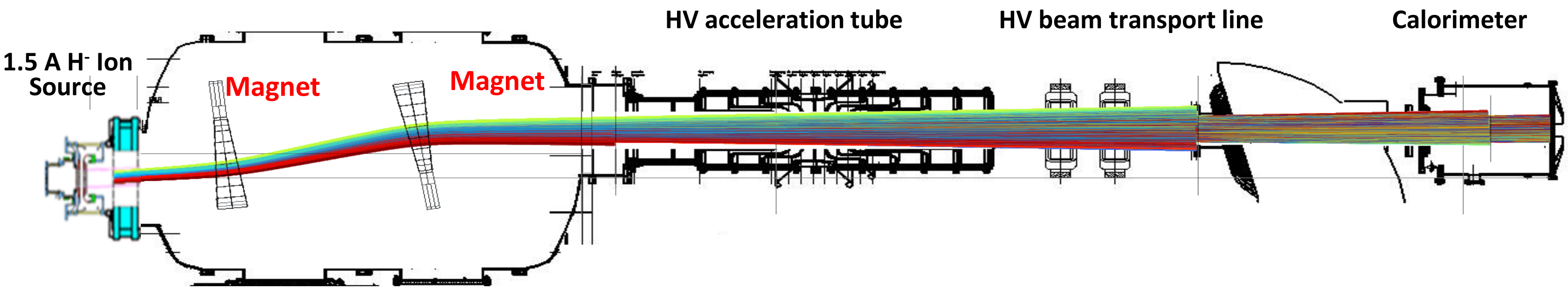
$I_{PG}$ influences beam current $I_b$ and correspondingly the transported beam.

Optimal beam size FWHM at calorimeter is 140 mm

**Transported beam size and value is mainly determined by entrance aperture of HV tube.**

**Beam focusing by Electrostatic lens of the accelerator first gap is more effective for the higher $U_{HV}$ applied**

# Beam transport efficiency $I_{HV} / I_b$




| | Ion Source | | HV acceleration tube | | | At Calorimeter | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $I_b$, A | $U_B$, kV | $I_{HV}$, A | $U_{HV}$, kV | $I_{HV}/I_b$, % | $\bar{I}_{BC} = P_{BC}/U_{tot}$ | $\bar{I}_{BC} / I_b$, % | $P_{BC}$, kW | FWHMy, cm |
| Comsol 40 mRad | – | 85 | – | **100** | **39** | – | 39 | – | 9 |
| Active Cs | 0.64 | 83 | 0.24 | **100** | **37** | not measured | | | 11 |
| Passivated Cs | 0.46 | 75.7 | 0.12 | 76 | **26** | 0.1 A | 21 | 13.8 | 10 |

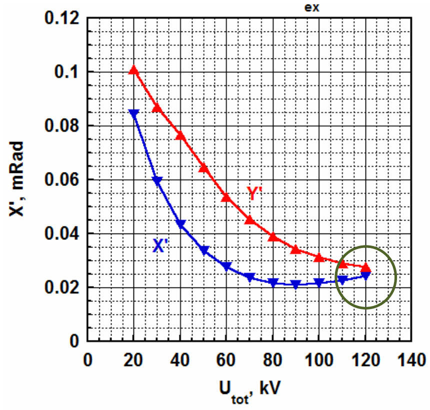
**Beam Transport through LEBT and HEBT is consistent with the simulations by Comsol**

**Beam transport is worser for the source with passivated Cs**

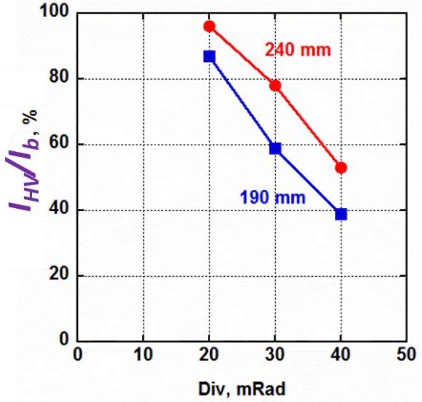
# Beam transport growth with optimization of source and accelerator parameters

**First experiments** on beam acceleration were produced with decreased beam current 0.6 A and energy 85 keV
The acceleration voltage of 100 keV was limited by HV PS (covid). It resulted in the reduced value of **beam transport 37%**

**The transport value up 90% could be obtained with beam energy increase to the designed 120 keV and by entrance diaphragm enlargement to Ø 240 mm**




Beam divergence decrease down to 26 mrad with beam energy growth ($U_{ex}$=10 kV, $I_{beamlet}$=50 mA, IBSIMU)




Beam transport through HEBT $I_{HV}/I_b$ for entrance diaphragm Ø 190 and 240 mm and various beam divergence (Comsol)

## Summary of first experimental and goal values

| | First experiments | Goal |
|---|---|---|
| $I_b$, A | 0.65 | 1.5 |
| $U_B$, kV | 85 | 120 |
| Divergence , mrad | 40 | 26 |
| Diaphragm Ø, cm | 20 | 24 |
| Beam transport, % | 37.5 | 90 |

**100% transmission of $H^-$ beam, entering the accelerated tube could be provided (COMSOL)**

# Summary

- **First measurements of Negative ion beam transport through the HEBT were produced.**
- **Up to 37% of 0.65 A, energy 85 kV H- beam were accelerated to energy 182 keV and transported trough HEBT to distance 10 m from the source**
- **The data obtained are in good agreement with calculation by COMSOL and IBSIMU**
- **The transport efficiency of about 90 % could be provided for H- beam with energy 120 keV to acceleration tube entrance Ø24 cm.**
- **100% transport of $H^-$ beam could be provided for beam entering the accelerator**

**Thank you for attention!**