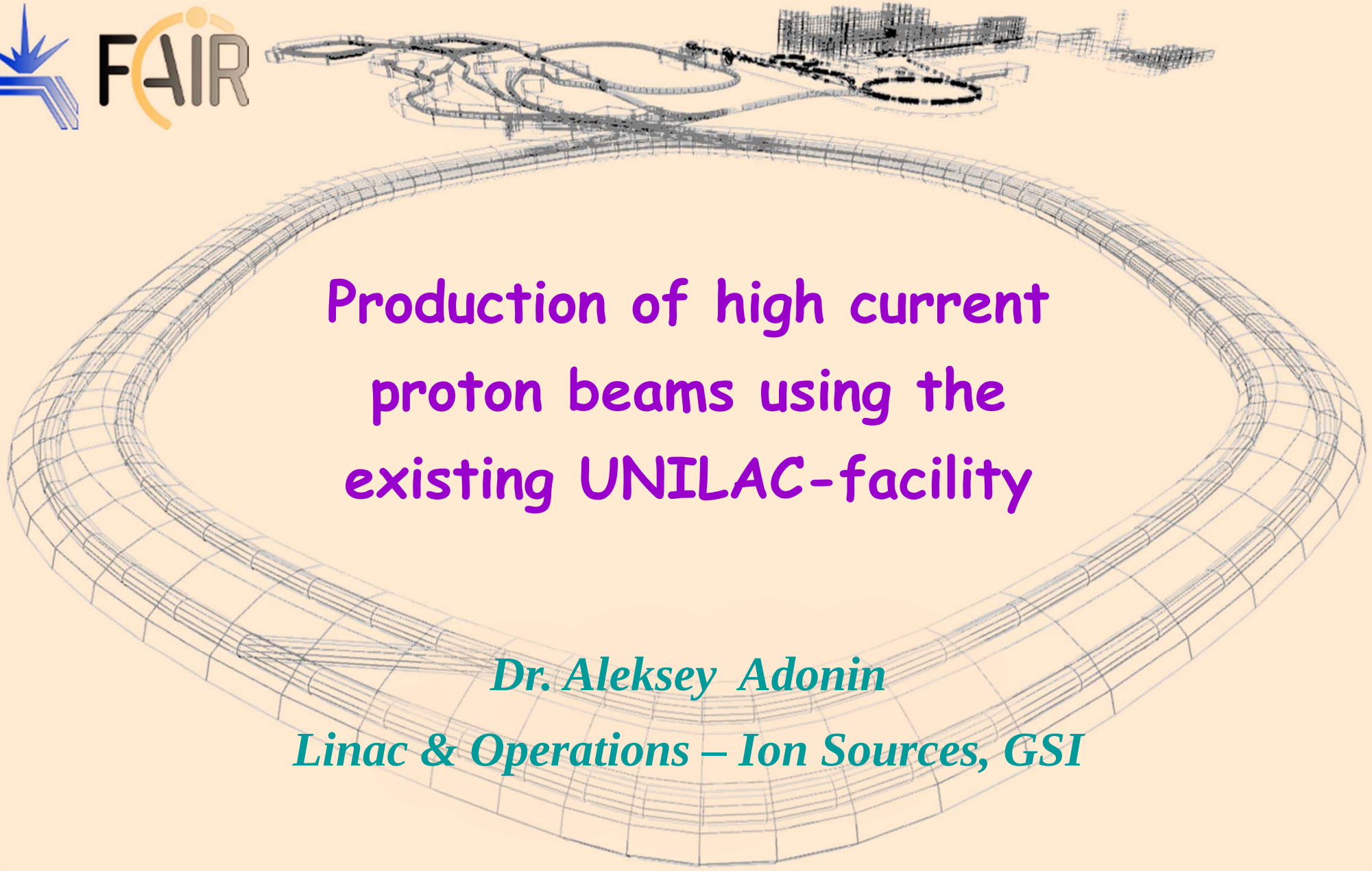


Production of high current proton beams using the existing UNILAC-facility

Dr. Aleksey Adonin

Linac & Operations – Ion Sources, GSI

GSI facility

High Current Injector NORTH

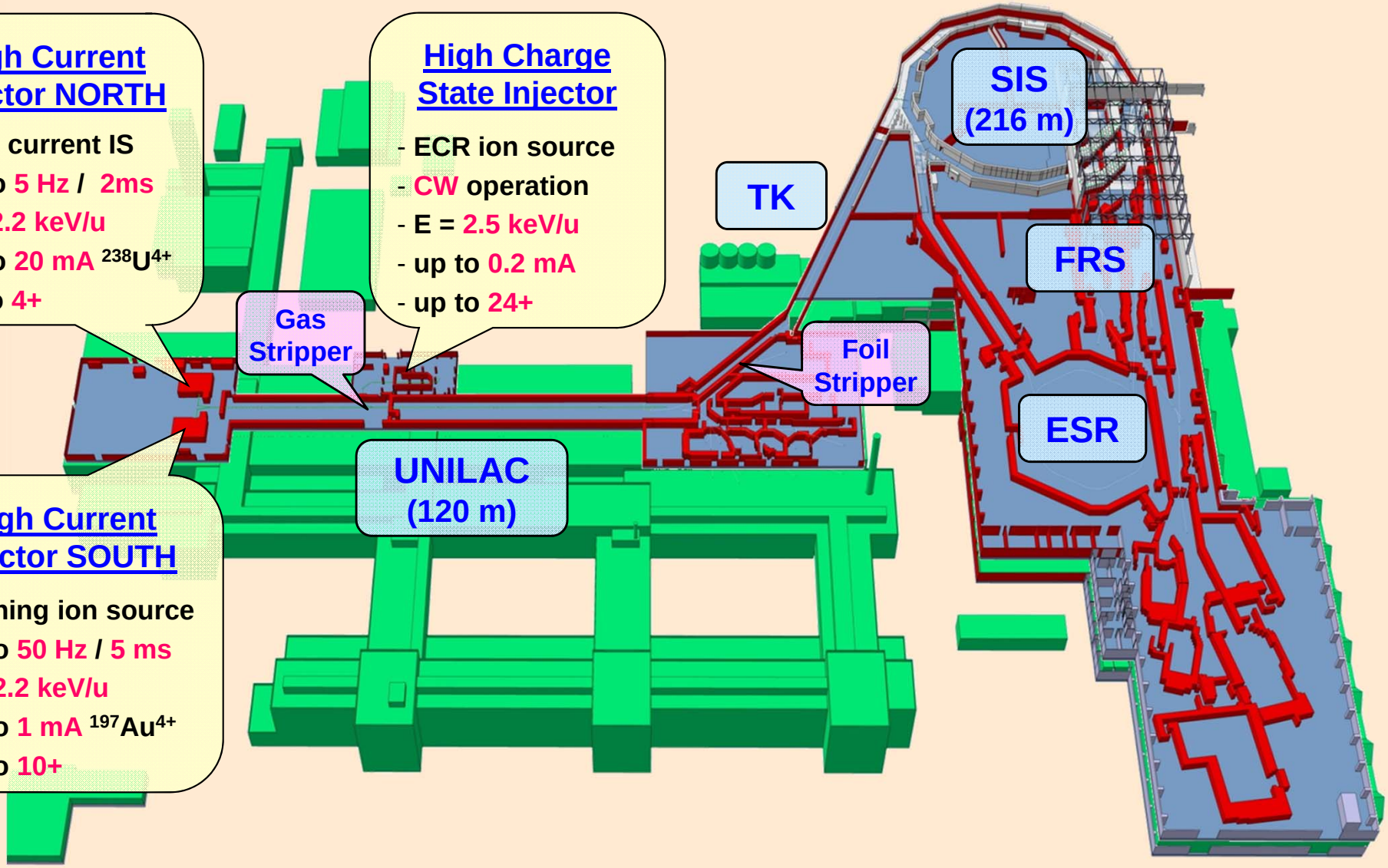
- High current IS
- up to 5 Hz / 2ms
- E = 2.2 keV/u
- up to 20 mA $^{238}U^{4+}$
- up to 4+

High Charge State Injector

- ECR ion source
- CW operation
- E = 2.5 keV/u
- up to 0.2 mA
- up to 24+

High Current Injector SOUTH

- Penning ion source
- up to 50 Hz / 5 ms
- E = 2.2 keV/u
- up to 1 mA $^{197}Au^{4+}$
- up to 10+



GSI facility

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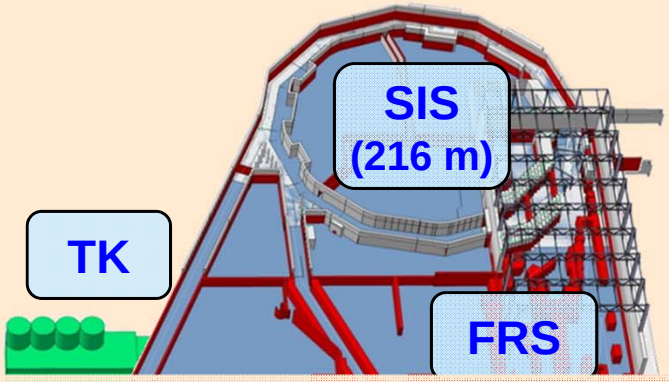
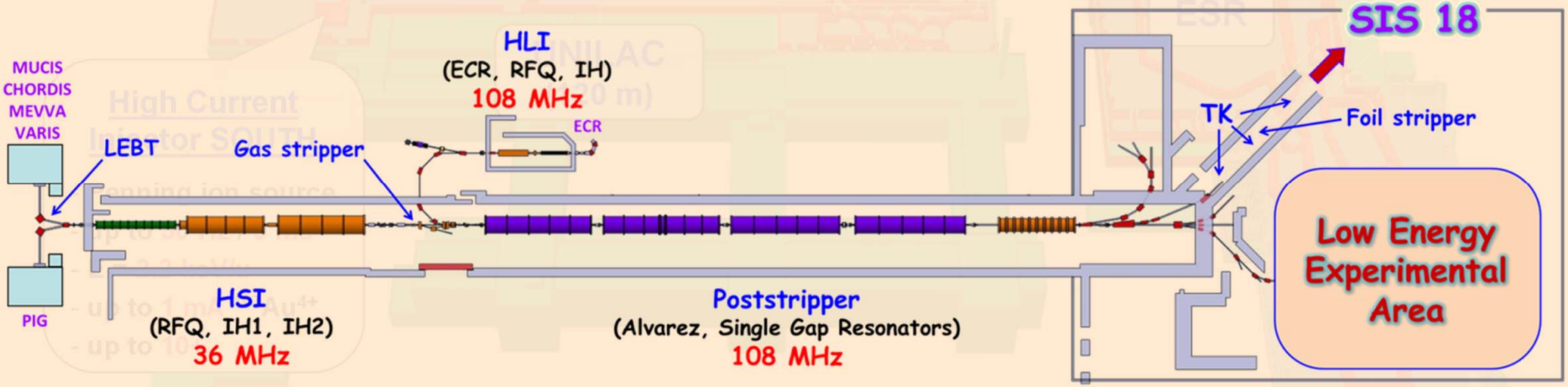
- up to 0.2 mA

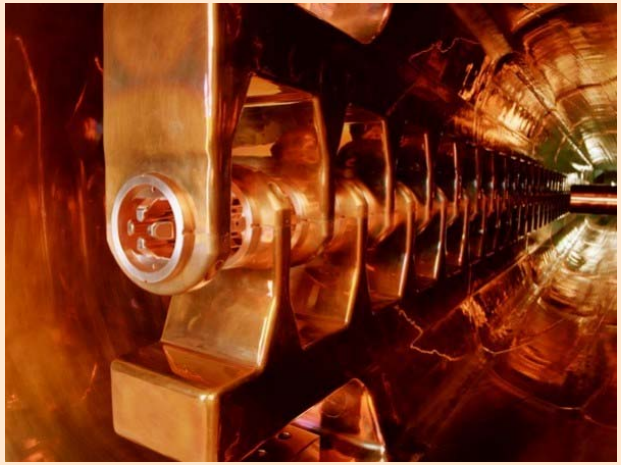


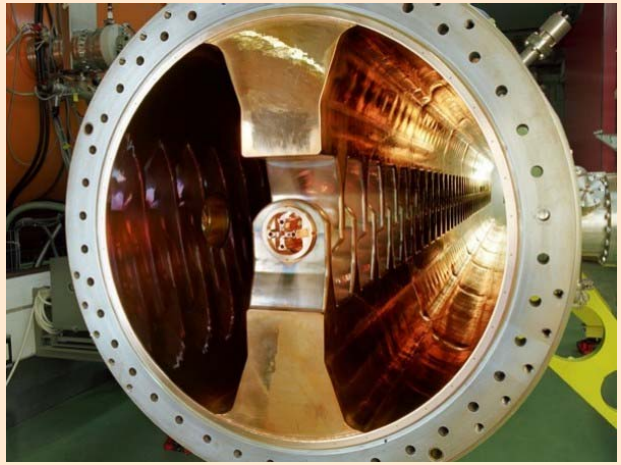


High Current Injector

Injection requirements into RFQ (UNILAC):

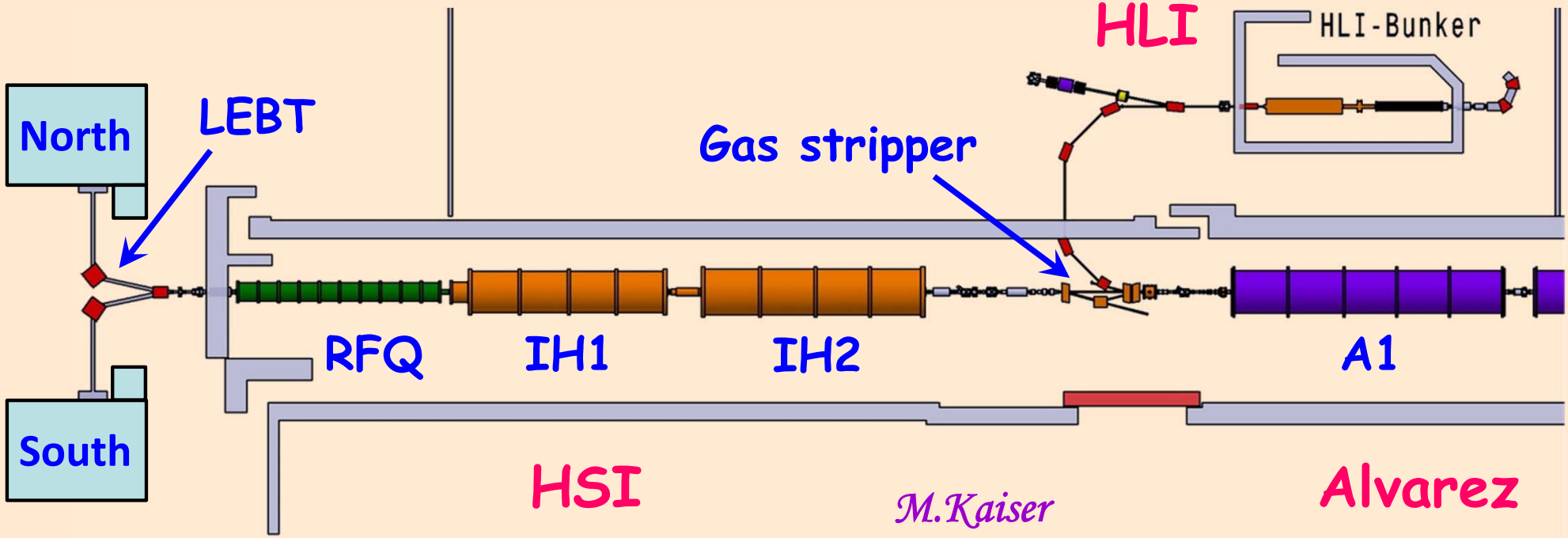
Specific Energy:	2.2 keV/u
MAX Mass to Charge (A/ζ):	65
Space-charge limit RFQ:	$0.25 \times A/\zeta$ [mA]
Acceptance RFQ:	$\varepsilon_{x,y}=138\pi$ mm·mrad





Motivation

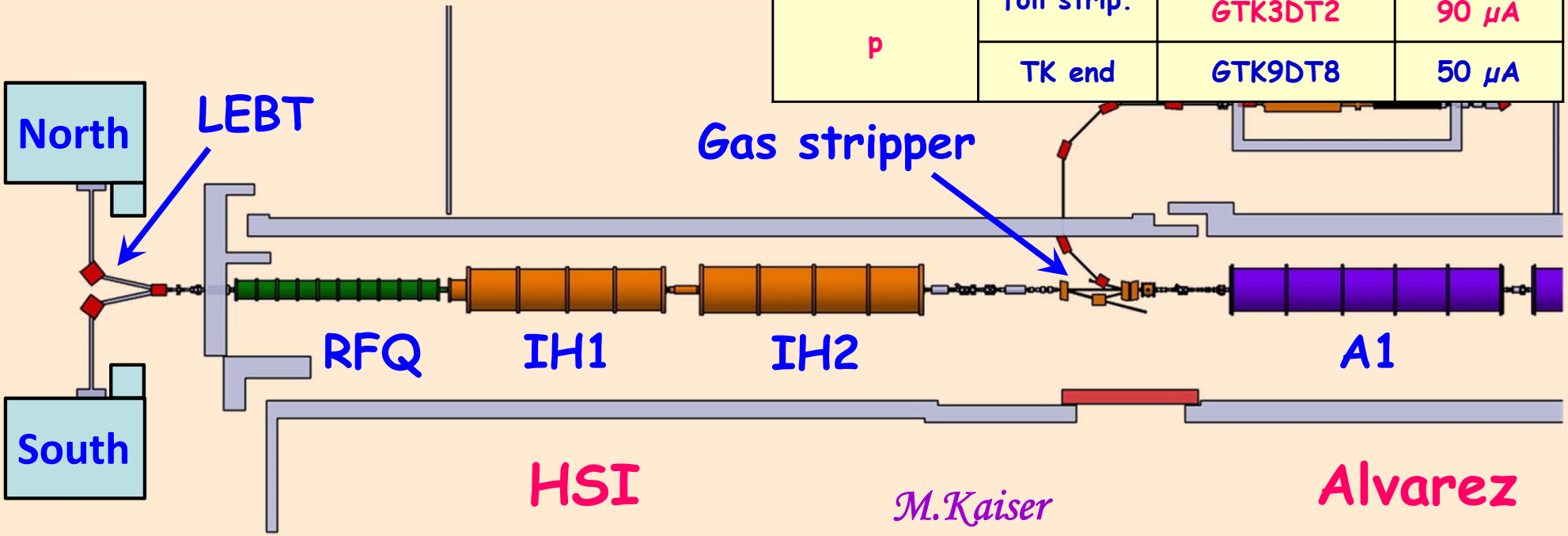
- **Problems of HSI operation with light ion beams**
  - Low applied $U_{ext.}$ (E = 2.2 keV/u) => limited $I_{ext.}$ from ion source
  - No focusing in post-acceleration system (U_{PA} = 0)
  - Big transversal emittance => very low transmission through HSI
  - Critical for proton beams



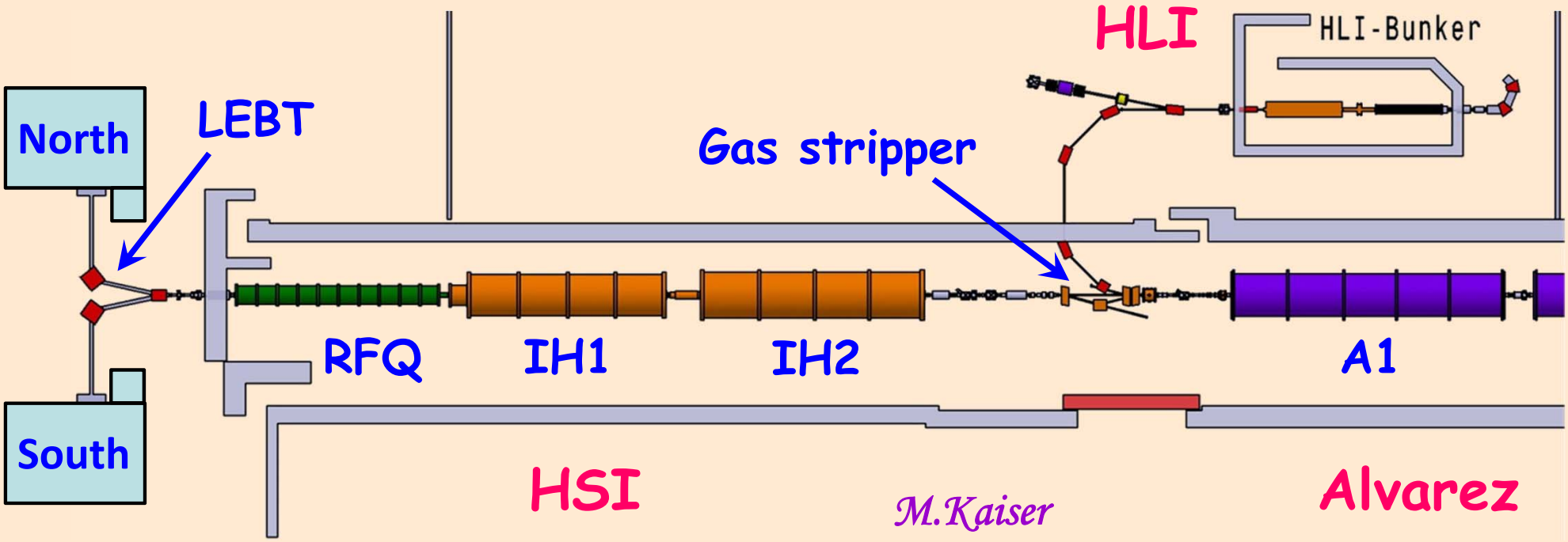
Motivation

- **Problems of HSI operation**
  - Low applied $U_{ext.}$ (E = 2.2 keV/u
  - No focusing in post-acceleration
  - Big transversal emittance => v
  - Critical for proton beams

Ion beam	Position	Current transformer	Beam current
Unanalyzed 37% - H^+ 8% - H_2^+ 55% - H_3^+	Ion source	Extraction	90 mA
H_3^+	LEBT	GUL4DT4	15 mA
		GUL5DT5	7 mA
		GUL5DT8	0.87 mA
	HSI	GUH1DT1	0.54 mA
		GUS2DT5	61 μA
	TK foil strip.	GTK2DT4	30 μA
p		GTK3DT2	90 μA
	TK end	GTK9DT8	50 μA



Motivation

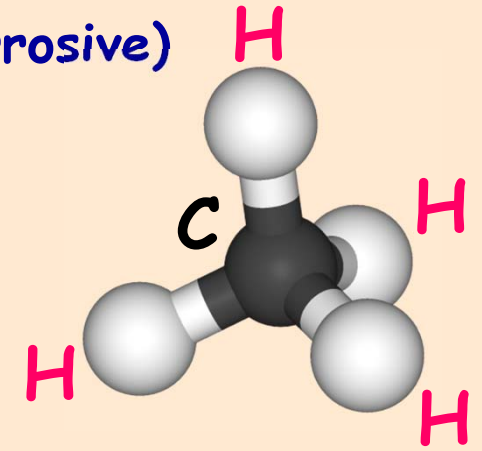


- **Possible solution**
  - H-rich molecular heavy ion beam (M/Q up to 60)
  - Accelerated up to 1.4 MeV/u
  - Cracked on the gas stripper => high intensity proton beam

Selection of candidates

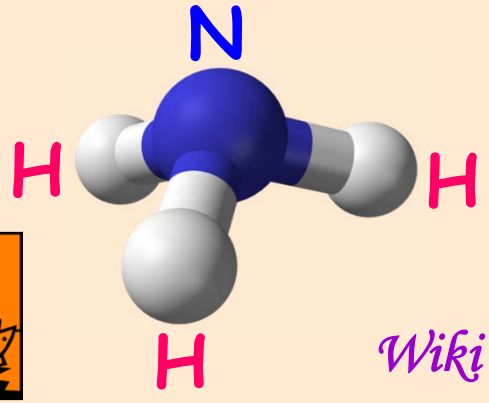
Desired requirements:

- Operation with volume type ion source (MUCIS, CHORDIS)
- Heavy molecule: Q = 1 => 10 a.u. < M < 60 a.u.
- High content of H-atoms
- Comply with safety requirements (non-toxic, non-corrosive)

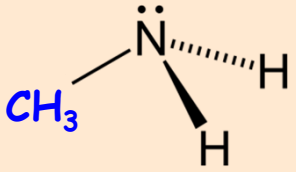


Alkane: C_nH_{2n+2} => **Methane – CH_4**

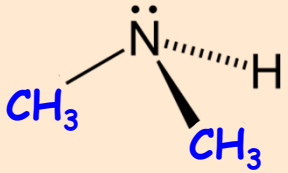
Amine: $NR^1R^2R^3$ => **Ammonia – NH_3**



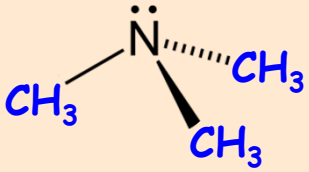
Wiki



Methylamine



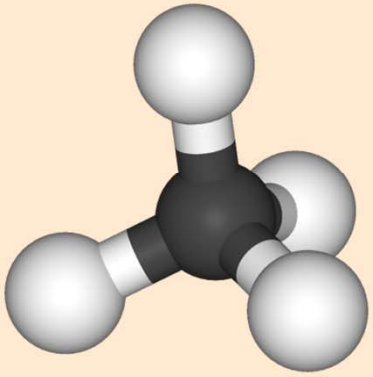
Dimethylamine

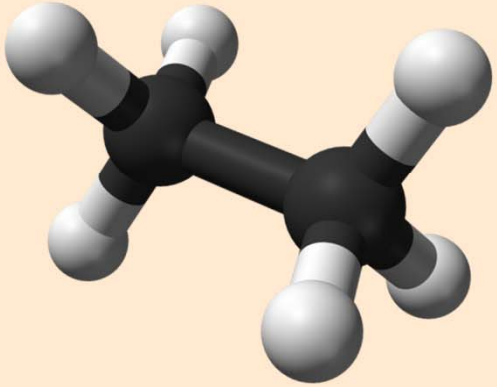


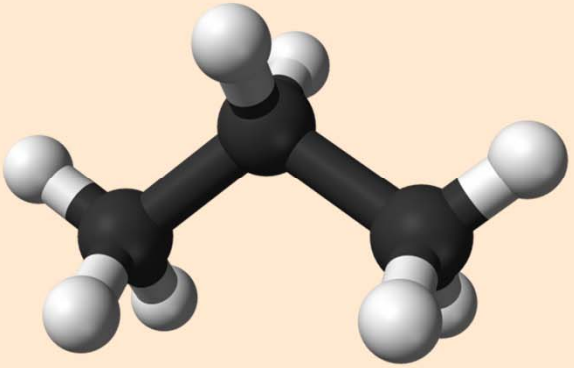
Trimethylamine

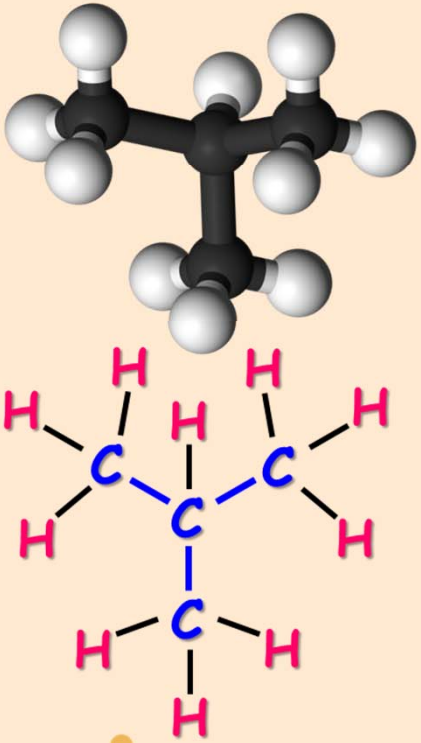
Alkane

Methane	Ethane	Propane	Butane
CH_4	C_2H_6	C_3H_8	C_4H_{10}
M=16	M=30	M=44	M=58





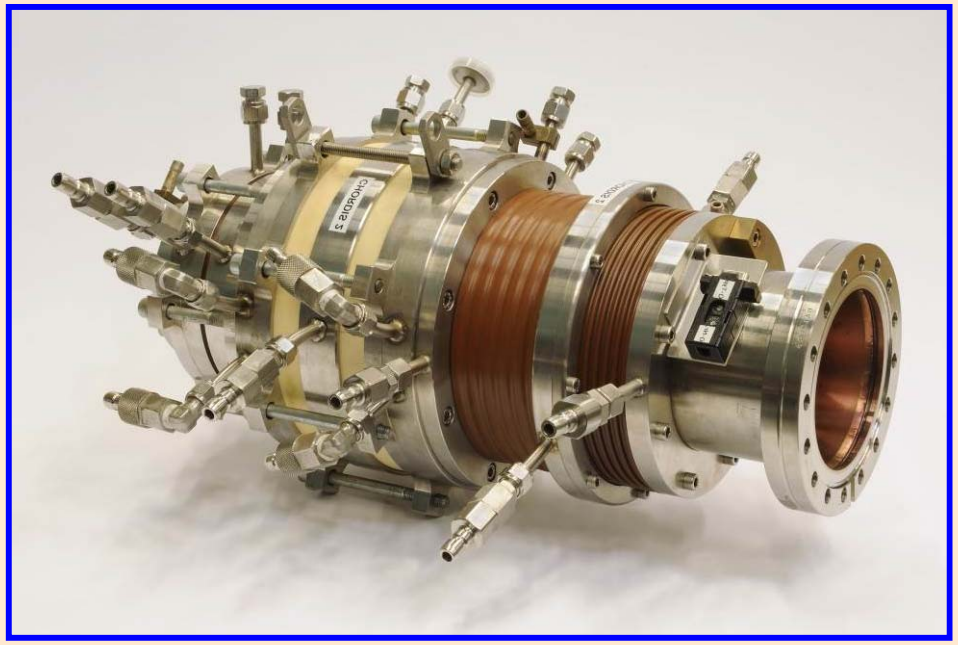




First experiments

CHORDIS

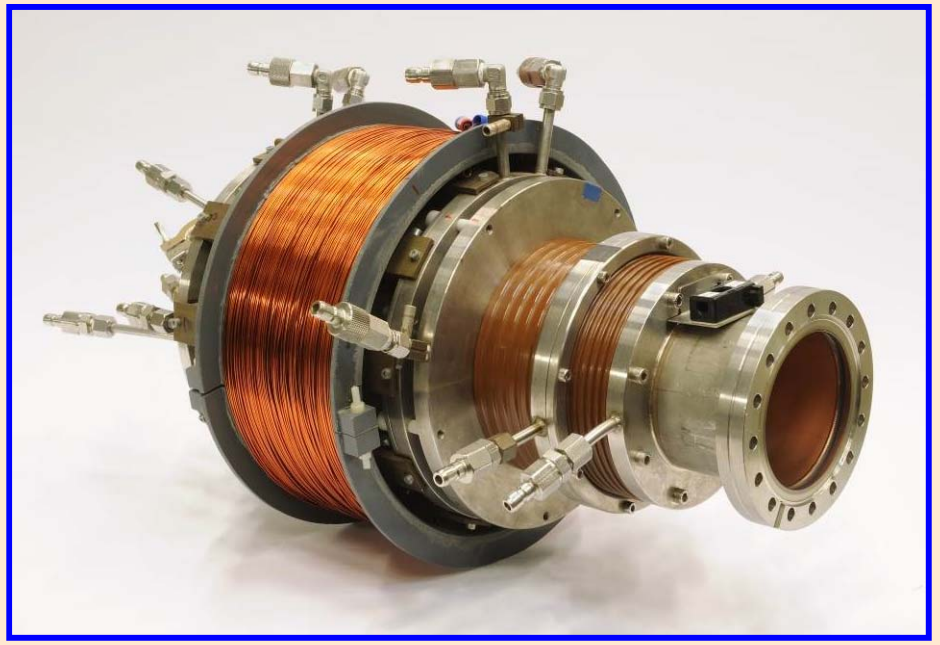
Cold or Hot Reflex Discharge Ion Source



- Optimized for singly-charged ions
- 20 SmCo-Magnets (1.8 Tesla)
- 1x6 Filaments: W (up to 220 A)
- Longer lifetime
- Emission Current Density: 130 mA/cm^2

MUCIS

Multi Cusp Ion Source

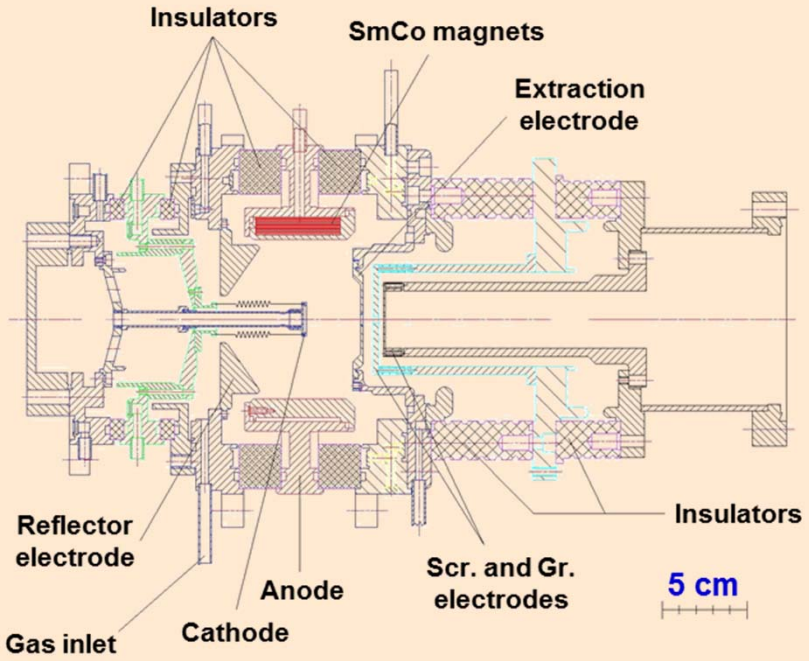


- Universal
- 60 SmCo-Magnets (1.8 Tesla)
- 2x3 Filaments: Ta (up to 190 A)
- Duty Cycle: 5 Hz / 1 ms
- Emission Current Density: 150 mA/cm^2
- Solenoid: 0.1 T

First experiments

CHORDIS

Cold or Hot Reflex Discharge Ion Source



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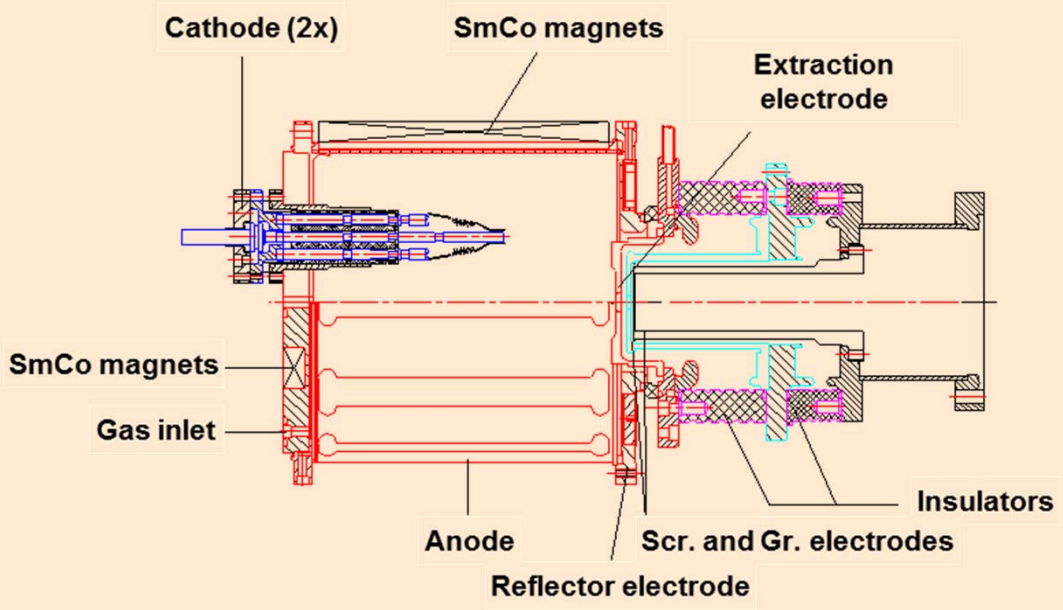

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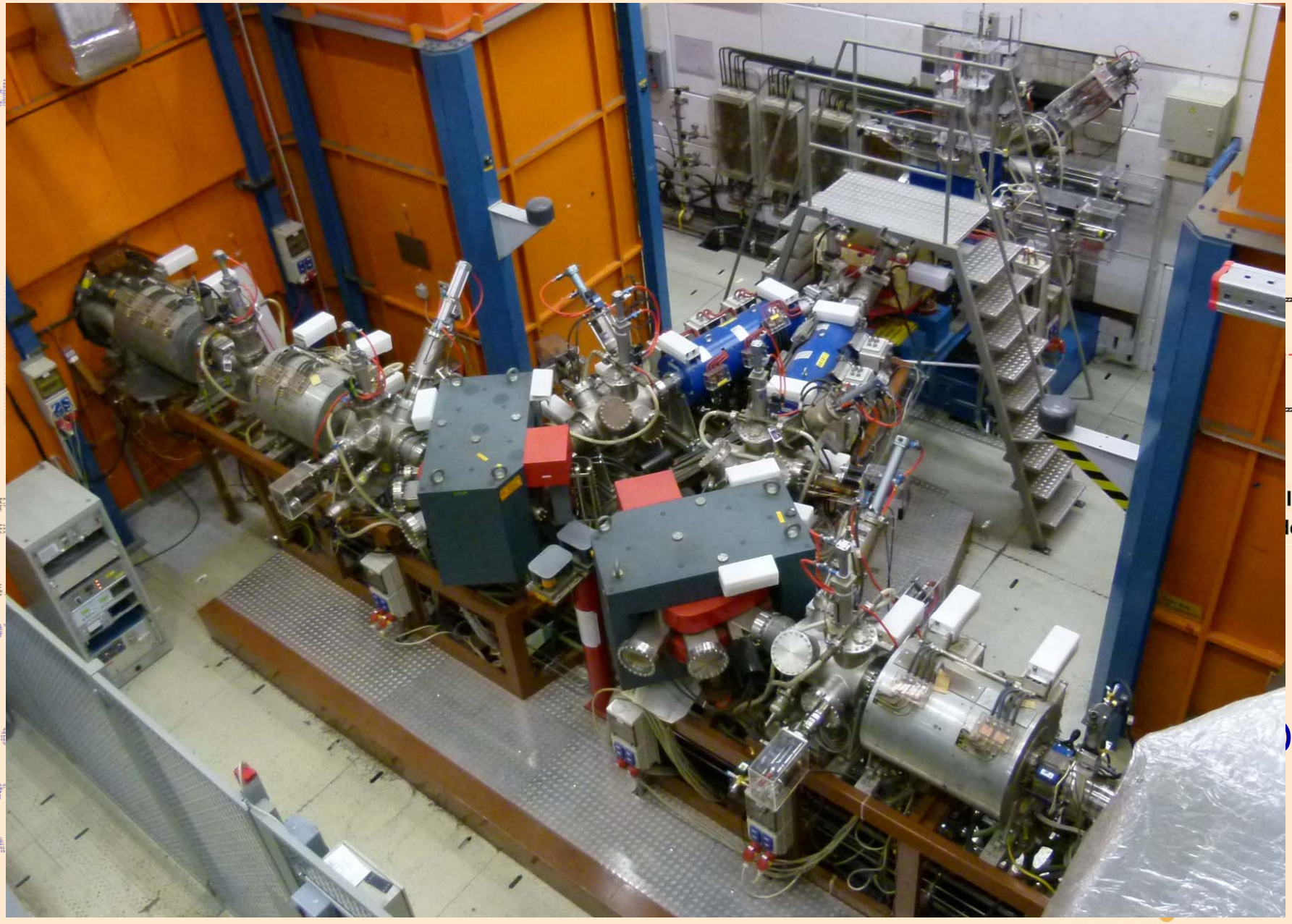
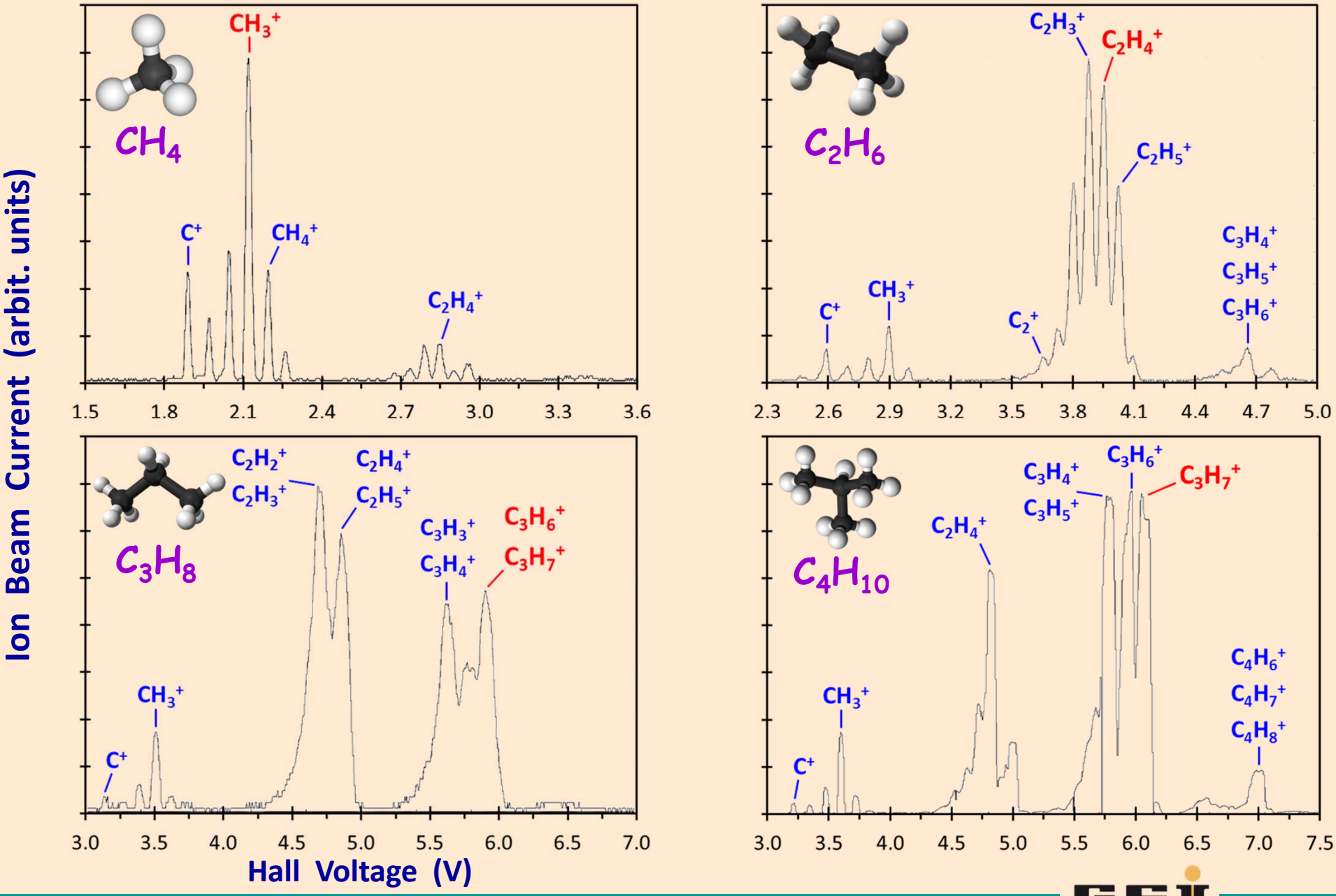


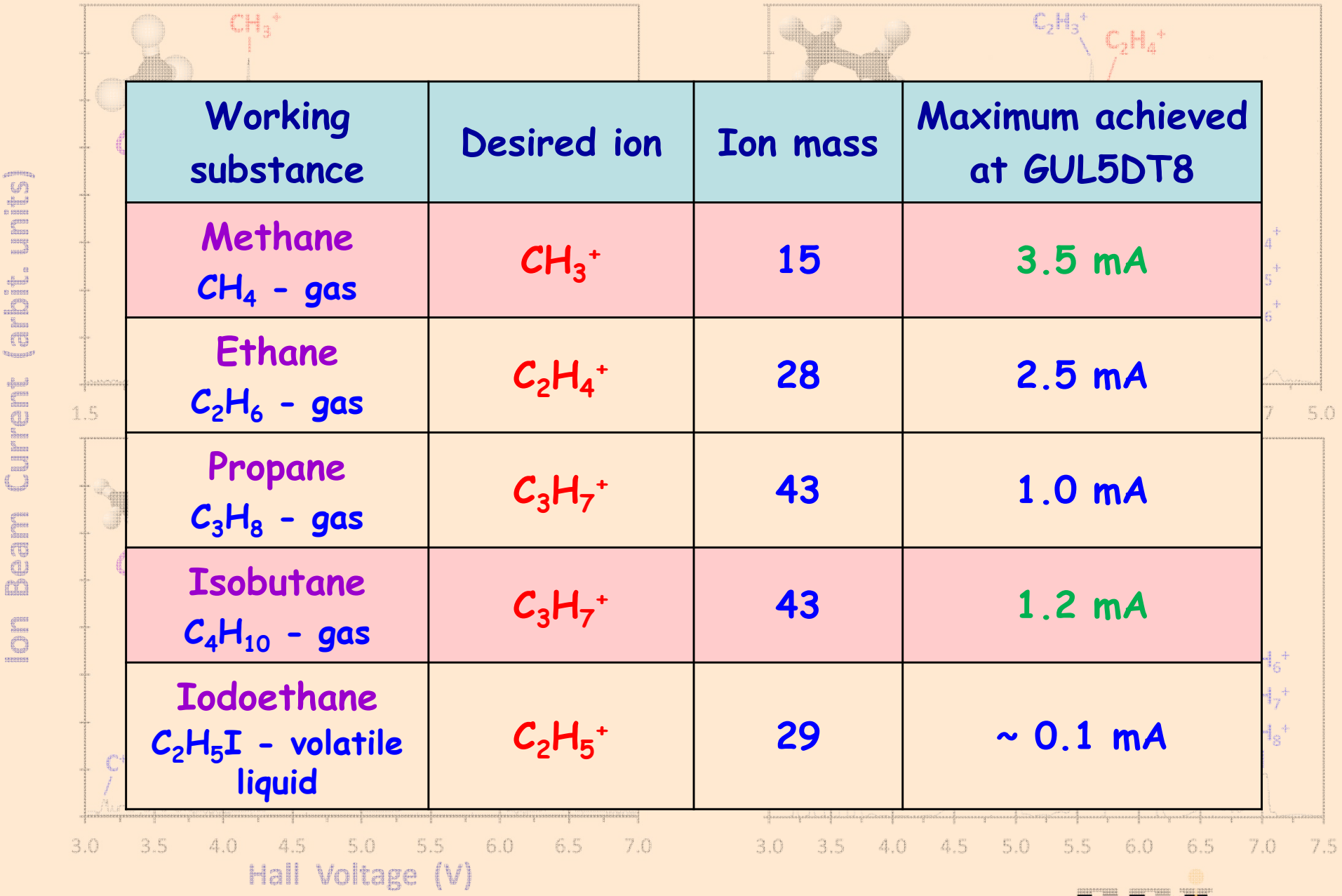
Insulators
les

Results


Ion Beam Current (arbit. units)
CH4
CH3+
C+
CH4+
C2H4+
1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6
C2H6
C2H3+
C2H4+
C2H5+
C+
CH3+
C2+
C3H4+
C3H5+
C3H6+
2.3 2.6 2.9 3.2 3.5 3.8 4.1 4.4 4.7 5.0
C3H8
C2H2+
C2H3+
C2H4+
C2H5+
C3H3+
C3H4+
C3H6+
C3H7+
CH3+
C+
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0
Hall Voltage (V)
C4H10
C2H4+
C3H4+
C3H5+
C3H6+
C3H7+
CH3+
C+
C4H6+
C4H7+
C4H8+
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5

Results

Working substance	Desired ion	Ion mass	Maximum achieved at GUL5DT8
Methane CH_4 - gas	CH_3^+	15	3.5 mA
Ethane C_2H_6 - gas	$C_2H_4^+$	28	2.5 mA
Propane C_3H_8 - gas	$C_3H_7^+$	43	1.0 mA
Isobutane C_4H_{10} - gas	$C_3H_7^+$	43	1.2 mA
Iodoethane C_2H_5I - volatile liquid	$C_2H_5^+$	29	~ 0.1 mA



Contamination of IS with carbon

Plasma chamber

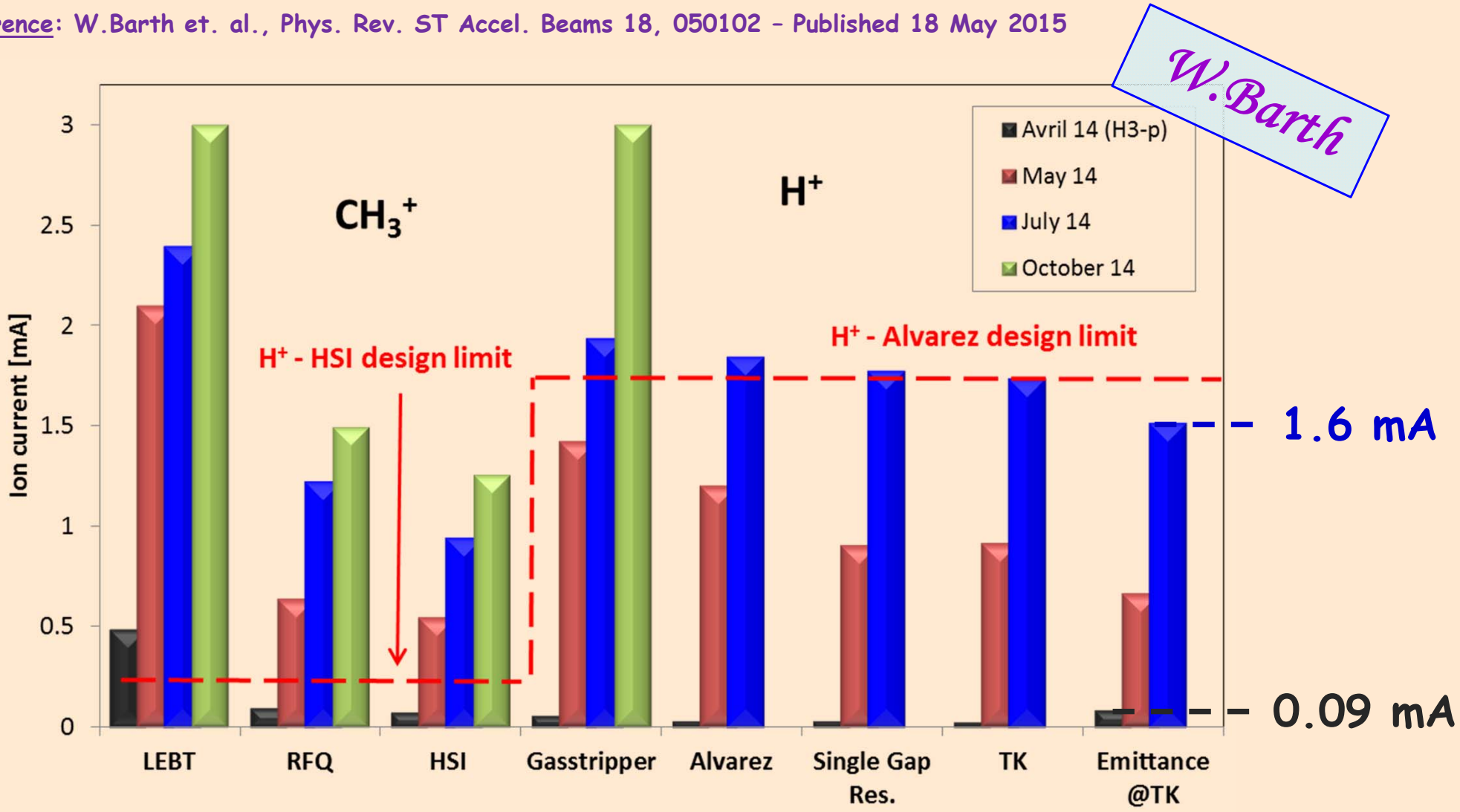
Extraction system

- Sparking in the extraction system
- Reduced durability and lifetime of the heating filaments
- A full service of the ion source with cleaning of the plasma chamber is required after 1 week operation

Filaments

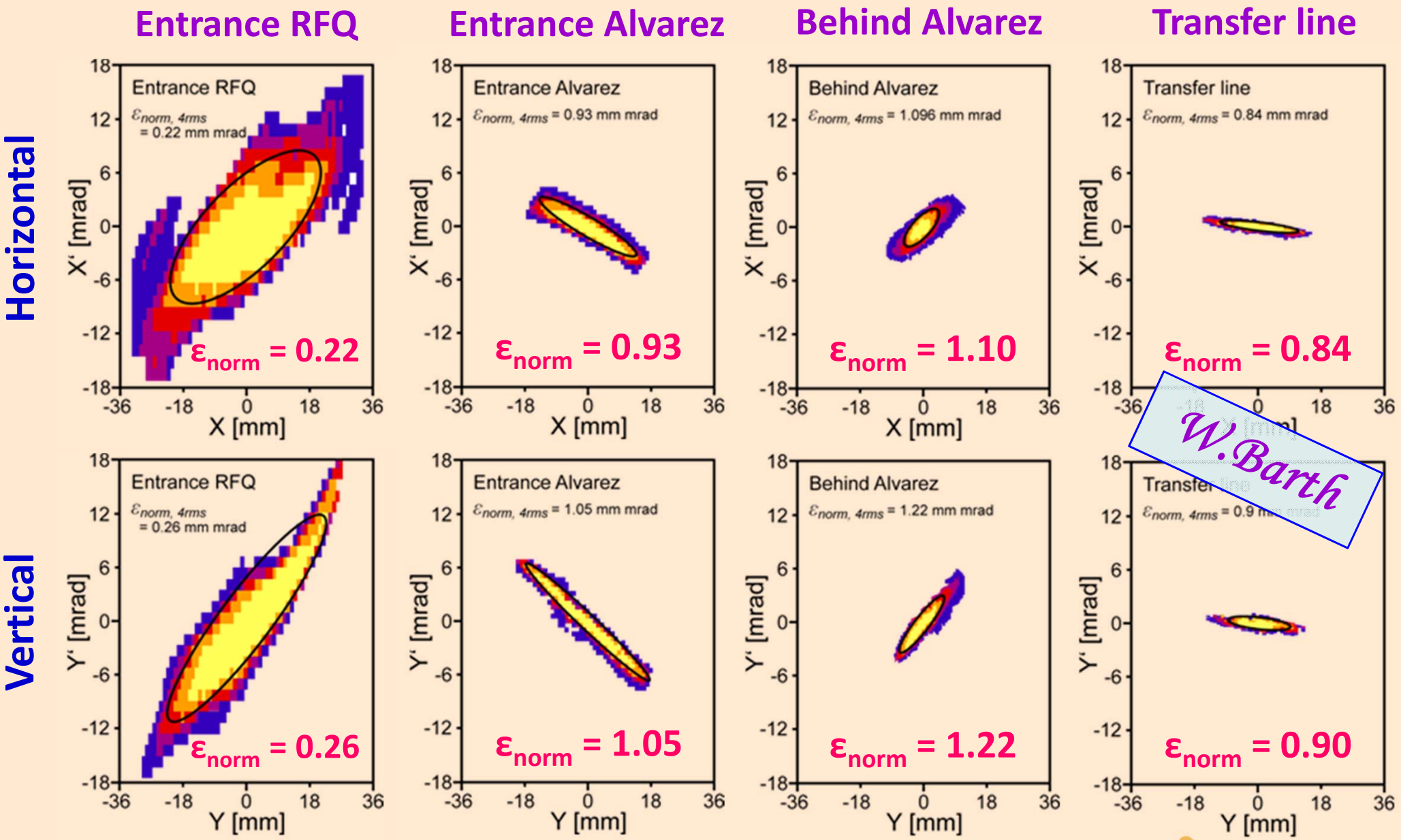
UNILAC proton performance (2014)

Reference: W.Barth et. al., Phys. Rev. ST Accel. Beams 18, 050102 – Published 18 May 2015



Recent Results: 4 mA proton beam behind Alvarez 1 out of $C_3H_7^+$ molecular beam (Sep. 2015)

Emittance measurements

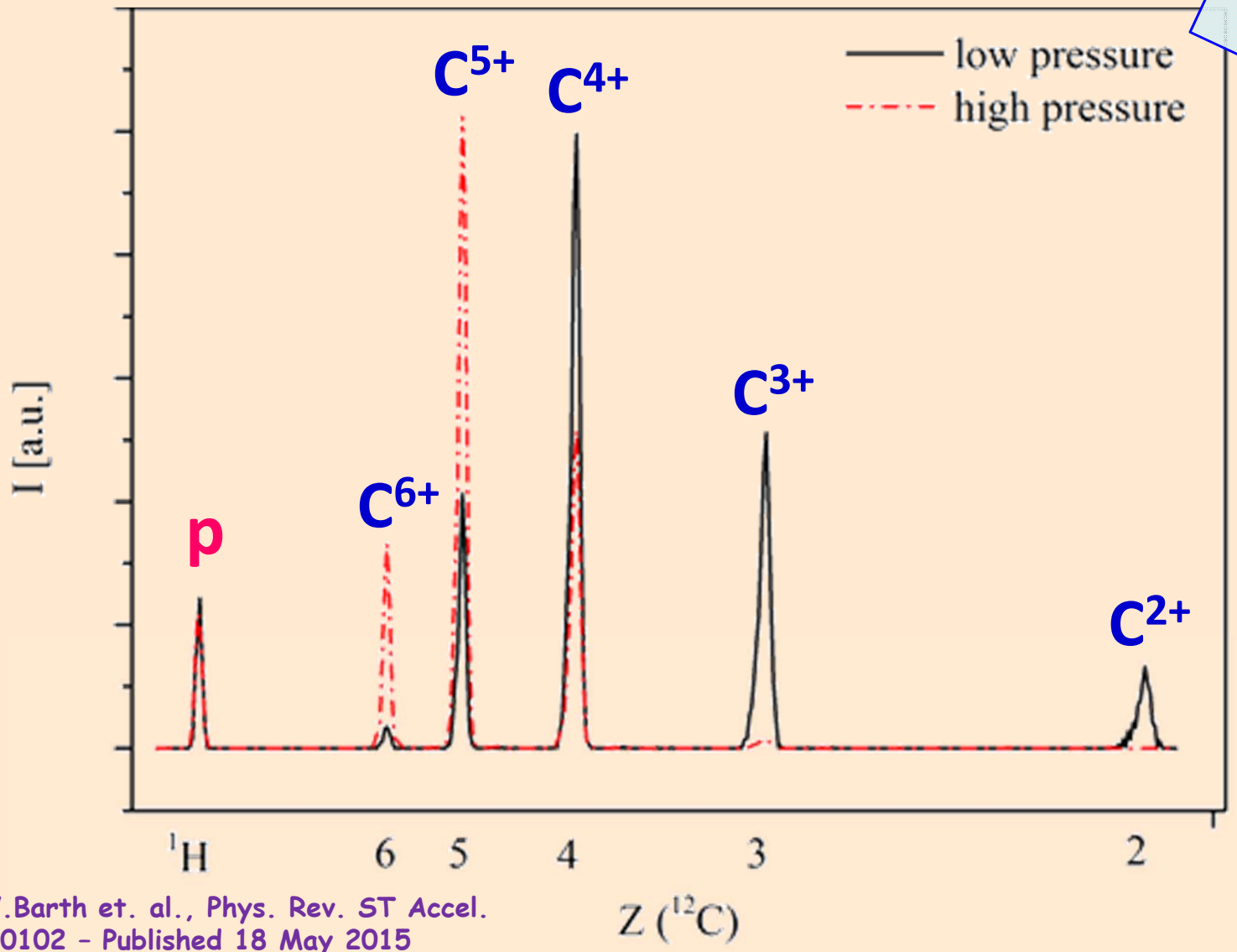


Reference: W.Barth et. al., Phys. Rev. ST Accel. Beams 18, 050102 – Published 18 May 2015

Production of C-beam

Spectrum behind the Gas stripper

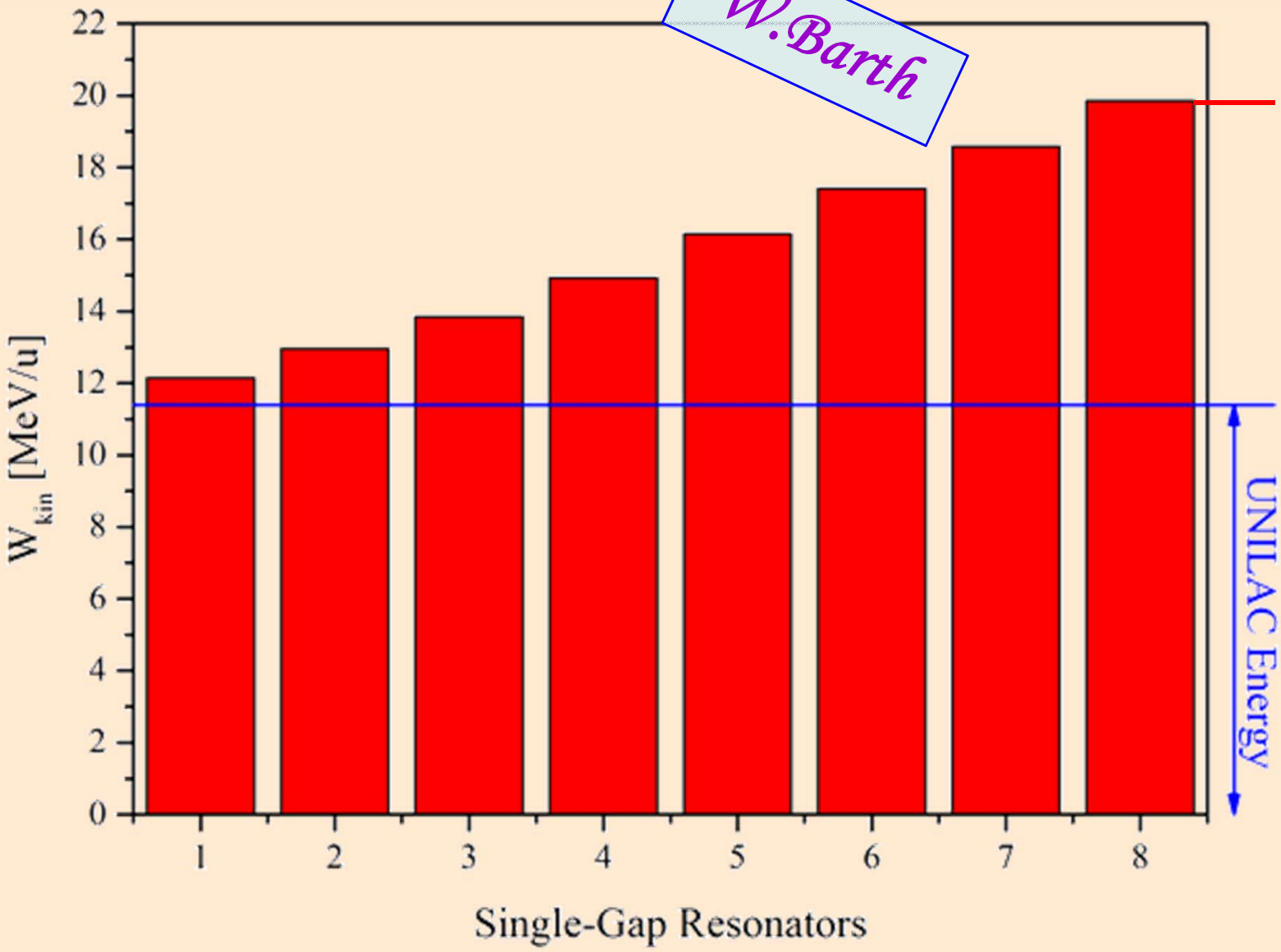
W.Barth



Reference: W.Barth et. al., Phys. Rev. ST Accel. Beams 18, 050102 – Published 18 May 2015

High energy operation

Reference: W.Barth et. al., Phys. Rev. ST Accel. Beams 18, 050102 – Published 18 May 2015



Comparison of estimated intensities for different FAIR proton injector options

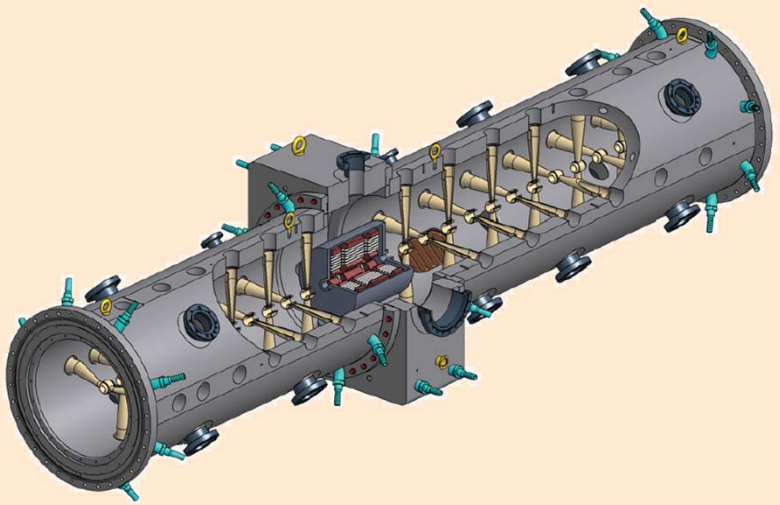
S.Appel

	p-LINAC	UNILAC	
	Design	Measurement	Extrapolation
E [MeV]	70	11.4 / 20	20
I [mA]	35	2 / 2	3
$E_{x,y\ phys.}$ 4·rms [mm·mrad]	7/8	7/8 / 3/3	3/3
$E_{x,y\ norm.}$ 4·rms [mm·mrad]	2.9/3.4	1.1/1.3 / 0.6/0.6	0.6/0.6
SIS18 MTI output (N)	5.8e12	8.2e11 / 9.7e11	1.5e12
Space charge limit (N)	5.8e12	8.7e11 / 1.5e12	1.5e12
SIS100 output (particles/cycle)	1.8e13	2.4e12 / 2.9e12	4.5e12
SIS100 output (relative)	100%	13.0% / 16.0%	25.0%

Reference: W.Barth et. al., Phys. Rev. ST Accel. Beams 18, 050102 – Published 18 May 2015

Post acceleration of UNILAC p-beam

W. Barth, Injector Upgrade for FAIR, ICST, Worms/Germany (2014)

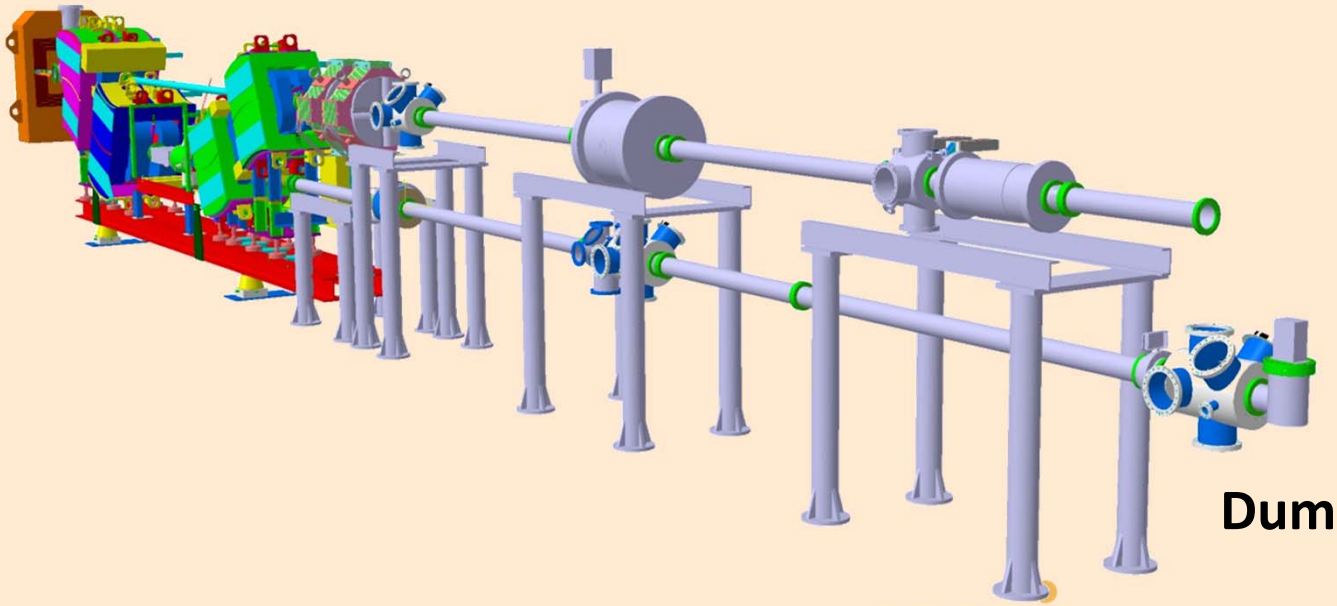


CH-cavity prototype for p-LINAC (to be tested 2015)

W.Barth

Beam Diagnostic Test Bench (since 2008)

no. of gaps	13 + 14 = 27
frequency [MHz]	325.2
energy range [MeV]	11.7 - 24.3
beam loading [kW]	882.6
heat loss [MW]	1.35
total power [MW]	2.2
Q_0-value	15300
effective shunt impedance [MΩ/m]	60
average E_0T [MV/m]	6.4 - 5.8
Kilpatrick factor	2.0
coupling constant [%]	0.3
aperture [mm]	20
total inner length [mm]	2800

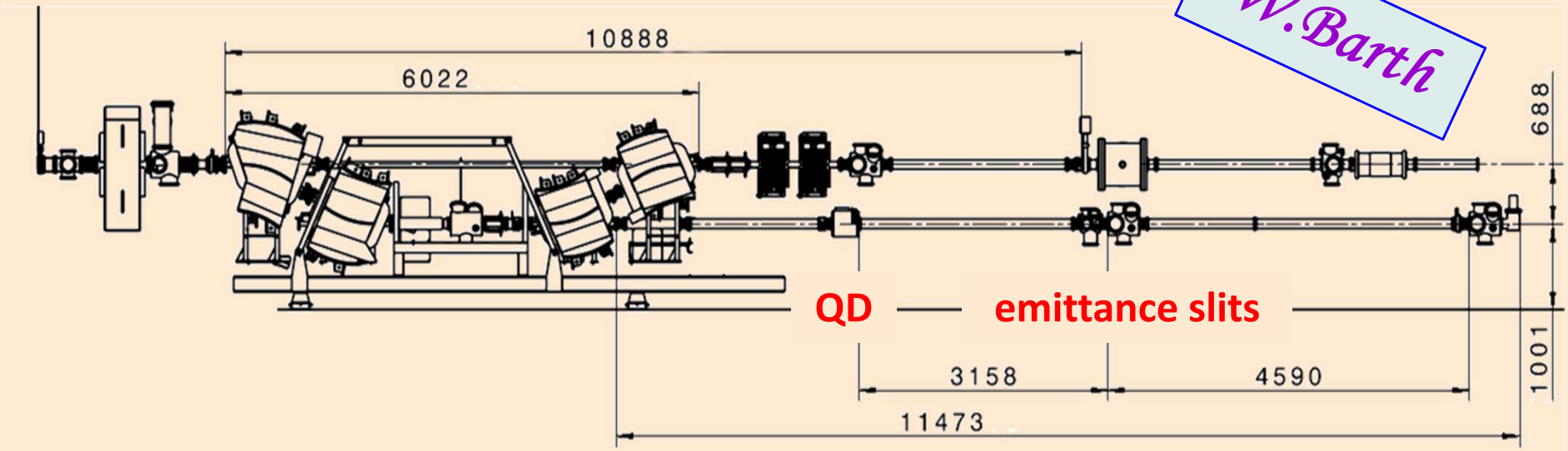


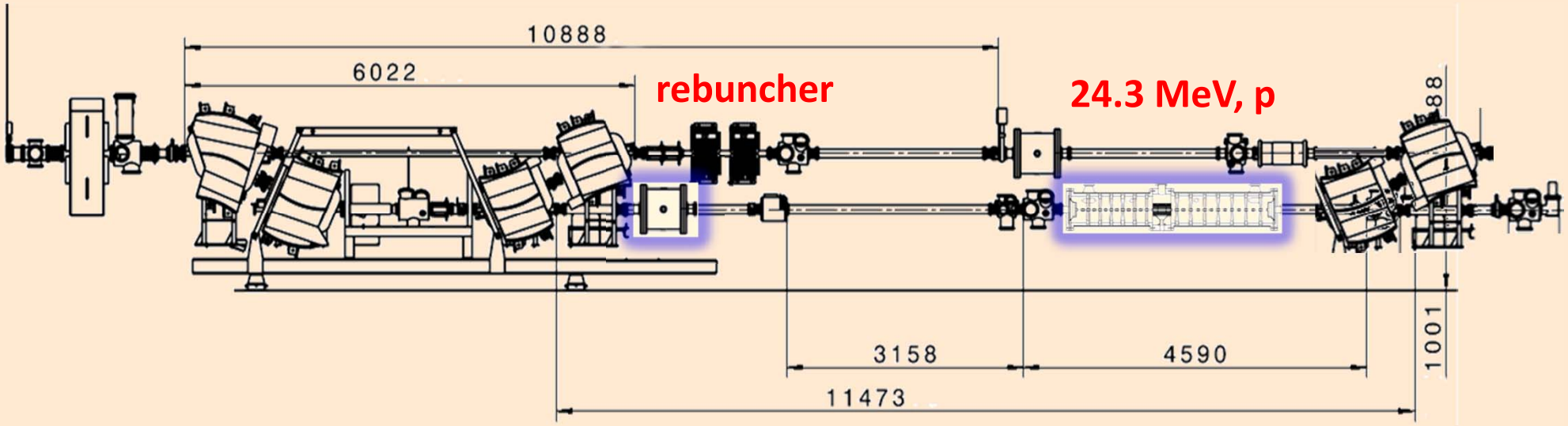
Dump

Post acceleration of UNILAC p-beam

W. Barth, Injector Upgrade for FAIR, ICST, Worms/Germany (2014)

W.Barth





Conclusions & Outlook

Highlights:

- Production of brilliant p-beam avoiding HSI problems with light ions
- World intensity record for proton beams from heavy ion accelerator $8.2 \cdot 10^{11}$ protons per pulse (almost 20 times higher than prev. record)
- Reached up to 25% of the FAIR design proton intensity with existing UNILAC facility (up to $1.5 \cdot 10^{12}$ protons per pulse extrapolated)
- Production of high current C-beam for parallel operation

Outlook:

- Further ion source development to improve performance
- Post acceleration of recently achieved 4 mA UNILAC p-beam in TK

Conclusions & Outlook

Highlights:

- Production of brilliant p-beam avoiding HSI problems with light ions
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  $8.2 \cdot 10^{11}$ protons per pulse (almost 20 times higher than prev. record)
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  UNILAC [illegible] ed)
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Спасибо за Внимание !!!

Outlook:

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- Post acceleration of recently achieved 4 mA UNILAC p-beam in TK