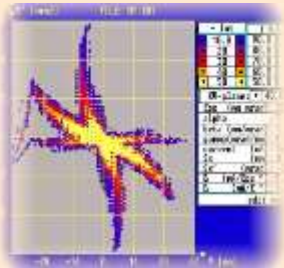
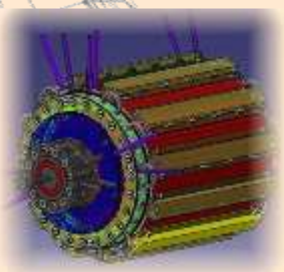
Status and Persectives of Ion Source Developments for FAIR

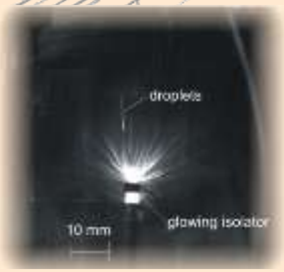




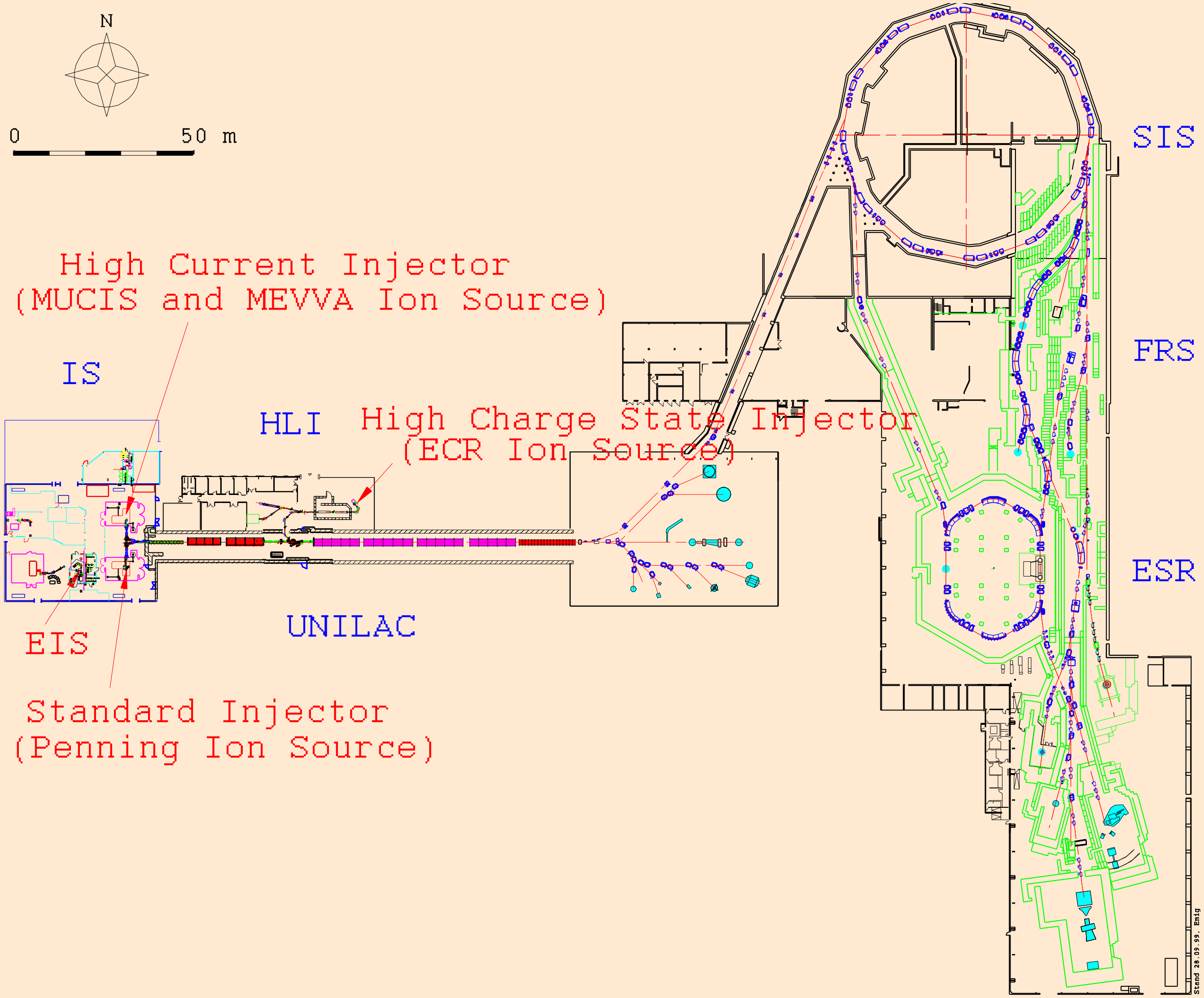
Dr. Ralph Hollinger

Ion Sources, GSI

15. October 2014



Overview of the GSI accelerator facility



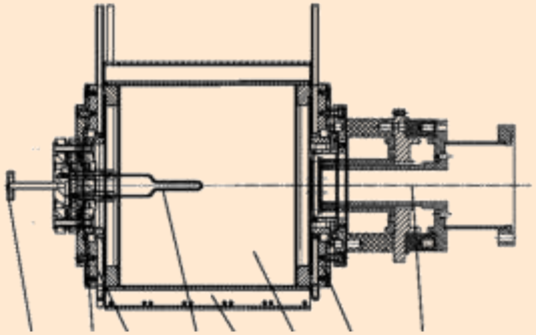
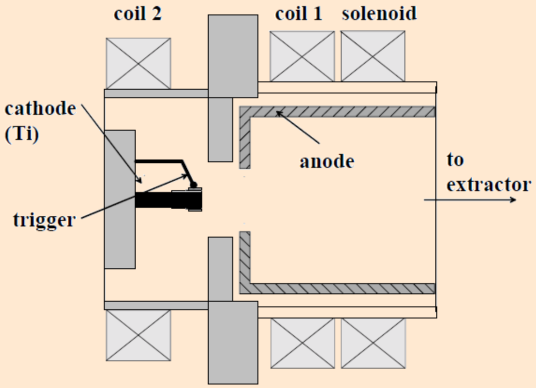
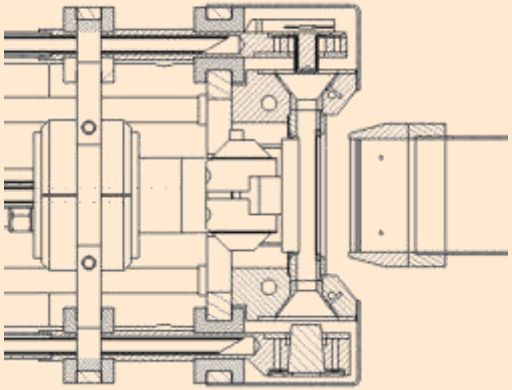
Terminal Nord and LEBT

Part 1:

Ion sources

Types of High Current Ion Sources

High Current Ion Sources

Filament driven	Vacuum Arc driven	High Duty factor
		
MUCIS, MUCIS New, CHORDIS	MEVVA, VARIS	PIG & ECR
Working material: Gases	Metalls and Gases	Metalls and Gases

Filament driven Ion Sources

MUCIS

MUCIS New

CHORDIS

Filament driven Sources

Generated Ions

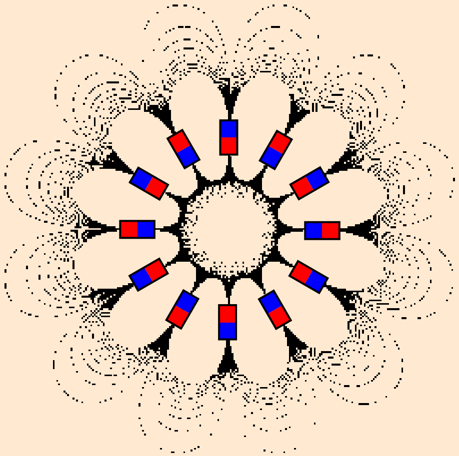
Element / Working Gas	Ion	Extracted current I_{FC} (mA)	Post-accelerated I_{ACC} (mA)	In front of the RFQ I_{RFQ} (mA)	SCL (mA)	Ion spectrum (%) $1^+/2^+/3^+/4^+$…	Life Time (days)
H_2	$^{1}H_3^+$	40 / 6.6	15	1	0.75	H_1^+ - 37; H_2^+ - 8; H_3^+ - 55	7
D_2	$^{2}H_3^+$	90 / 13.2	50	2	1.5	D_1^+ - 30; D_2^+ - 5; D_3^+ - 65	7
CH_4	$^{12}C^+$	15 / 6	9	0.5	3	(C, H, CH,…)	2
	$^{12}CH_3^+$	30 / 8	12	1.2	3.75	(C, H, CH,…)	2
N_2	$^{14}N^+$	20 / 10	12	2.5	3.5	N_2^+ - 31; N^+ - 69	7
	$^{14}N_2^+$	40 / 14	35	4	7	N_2^+ - 31; N^+ - 69	7
Ar	$^{40}Ar^+$	65 / 20	42	20	10	80 / 20	5
	$^{40}Ar^{2+}$	50 / 16	16	1.5	5	65 / 35	5
Kr	$^{80}Kr^{2+}$	60 / 22	28	0.15	10	17 / 53 / 29	3
	$^{86}Kr^{2+}$	80 / 23	34	9	10.75	48 / 45 / 7	3
Xe	$^{132}Xe^{3+}$	25 / 18	17	0.02	11	79 / 18 / 3	1
	$^{136}Xe^{3+}$	40 / 21	18	0.8	11.3	78 / 21 / 1	6

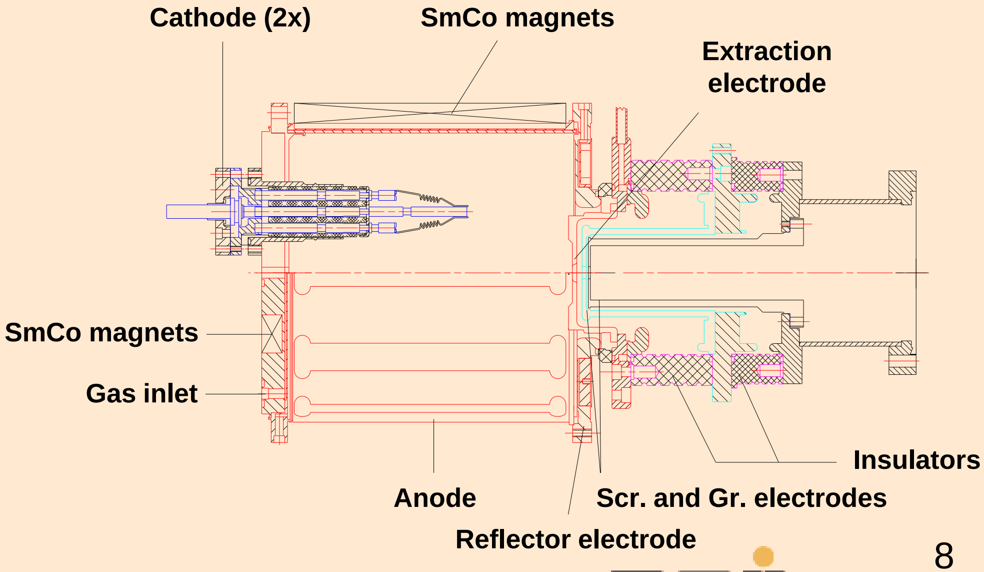
Filament driven Sources

MUCIS (Multi Cusp Ion Source)

60 SmCo-Magnets (2 Tesla)

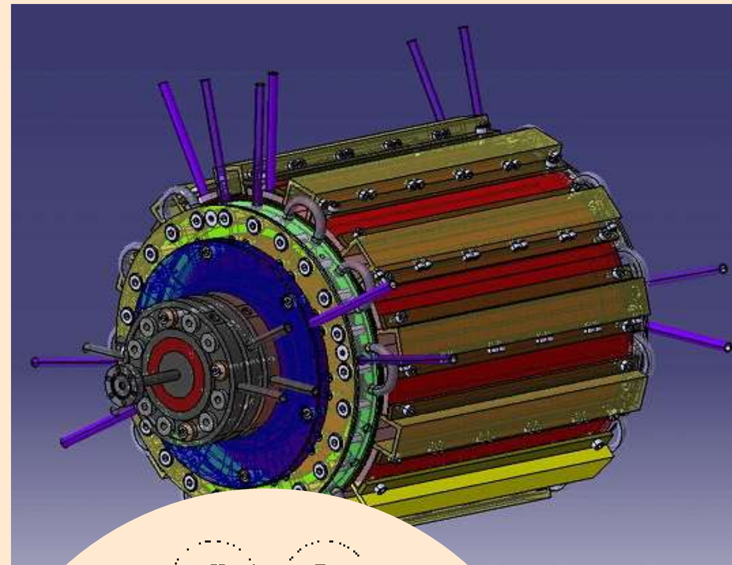
Solenoid:	0.1 T
6 Filaments:	W / Ta
Duty Cycle:	5 Hz
Pulse Length:	1 ms
Arc Power:	3 kW (I_{arc}=100A)
Emission Current Density:	150 mA/cm² (Argon)

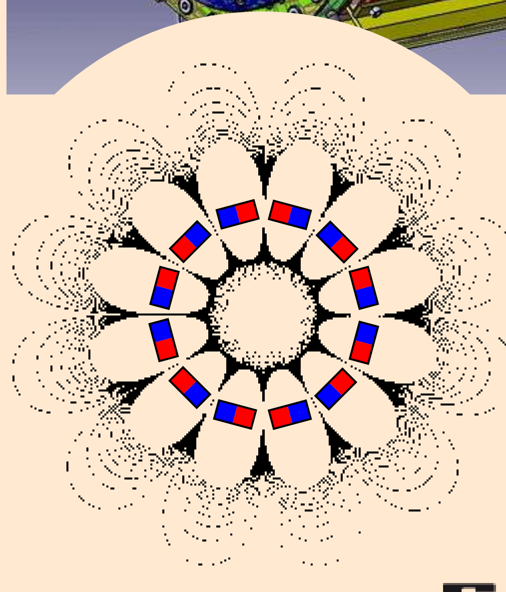




Filament driven Sources

MUCIS New



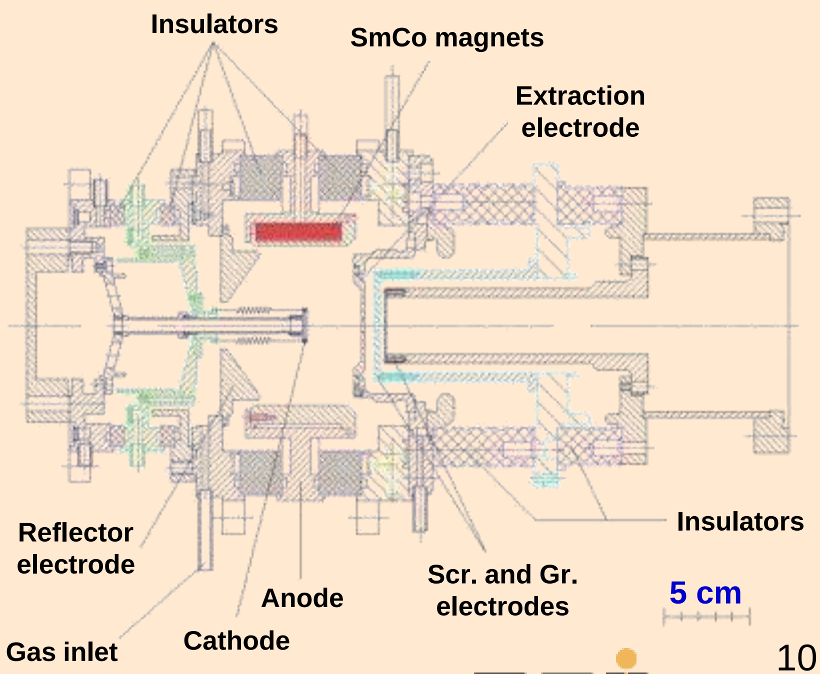


- Bigger Plasma chamber
- Improved Cooling (I_{arc} = 200A)
- Symmetrical Magnet alignment at the ends
- Halbach-alignment of the Magnets
- Optimized for highly-charged ions (Kr^{2+}, Xe^{3+})

1 - Gas inlet
2 - Cooling system
3 - Cathode flange
4 - Filament
5 - Magnets
6 - Anode
7 - PE flange
8 - Triode system

Filament driven Sources

CHORDIS (Cold or Hot Reflex Discharge Ion Source)



- Smaller Plasma chamber
- 20 SmCo-Magnets (2 Tesla)
- Plasma-Electrode at the Cathode potential
- Optimized for singly-charged ions

R. Keller

Vacuum Arc driven Ion Sources

VARIS

MEVVA

Vacuum Arc driven Sources

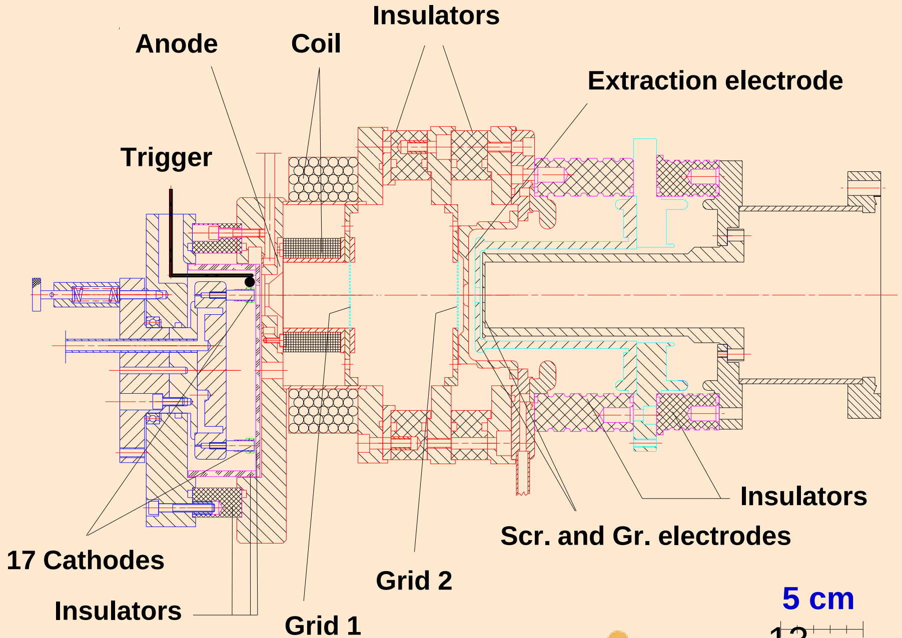
Generated Ions

Element / Working Gas	Ion	Extracted current I_{FC} (mA)	Post-accelerated I_{ACC} (mA)	In front of the RFQ I_{RFQ} (mA)	SCL (mA)	Ion spectrum (%) $1^+/2^+/3^+/4^+$…	Life Time (days)
O_2	$^{16}O_2^+$	30 / 13	15	3.5	8	O^+ - 21; O^{2+} - 35	7
	$^{18}O_2^+$	30 / 13	15	3.5	9	O^+ - 21; O^{2+} - 35	7
Mg (+O_2)	$^{24}Mg^+$	80 / 18	28	2	6	24 / 62	7
Ca	$^{40}Ca^{2+}$	40 / 15	15	5	5	6 / 94	2
Ni (+N_2)	$^{58}Ni^+$	60 / 22	40	8	14.5	72 / 22 / 5	4
	$^{58}Ni^{2+}$	60 / 18	17	5	7.25	8 / 76 / 16	4
Mo (+N_2)	$^{94}Mo^{2+}$	50 / 18	19	0.5	11.75	6 / 56 / 28	10
	$^{100}Mo^{2+}$	50 / 18	19	0.5	12.5	6 / 56 / 28	10
Ag (+N_2)	$^{107}Ag^{2+}$	40 / 18	23	3	13.4	13 / 81 / 6	4
Nd	$^{142}Nd^{3+}$	80 / 28	32	1.5	11.8	0 / 4 / 87 / 9	10
	$^{150}Nd^{3+}$	80 / 28	32	0.4	12.5	0 / 4 / 87 / 9	10
Ta (+Ar)	$^{181}Ta^{3+}$	75 / 24	31	7	15.1	0 / 0 / 56 / 35 / 8	5
	$^{181}Ta^{4+}$	80 / 24	34	8	11.3	0 / 0 / 35 / 51 / 13	5
U	$^{238}U^{4+}$	100 / 30	40	12	15	0 / 0 / 22 / 65 / 13	5

MEVVA (Metal Vapor Vacuum Arc Ion Source)

Revolver with 17 Cathodes

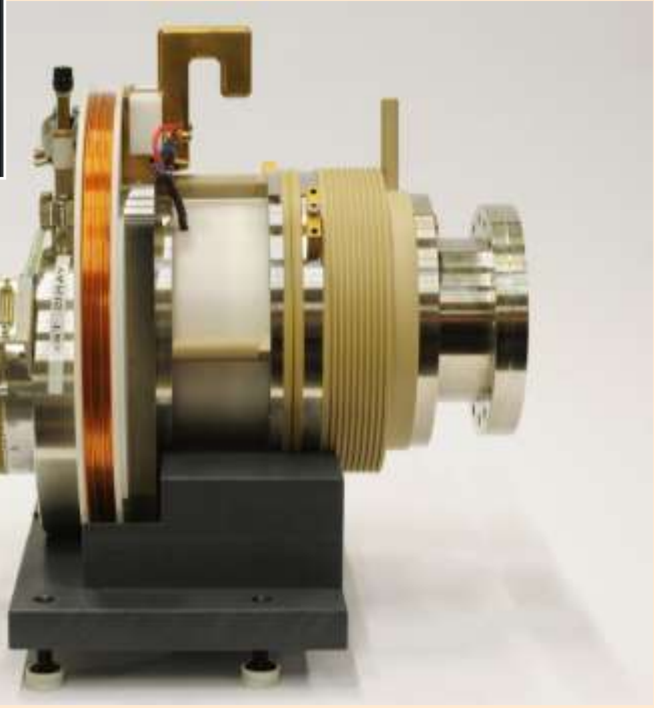
2 Solenoids:	0.1 and 0.2 Tesla
Arc Power:	50 kW (13.3 MW/cm^2)
Arc Current:	~1 kA
Duty Cycle:	typical 1 Hz, 1 ms
Working Material:	ductile Metalls
Life time:	~1 Week (Uranium)

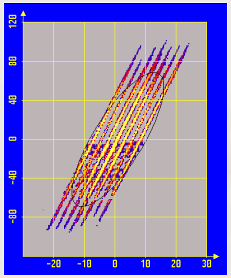


I. Brown

Vacuum Arc driven Sources

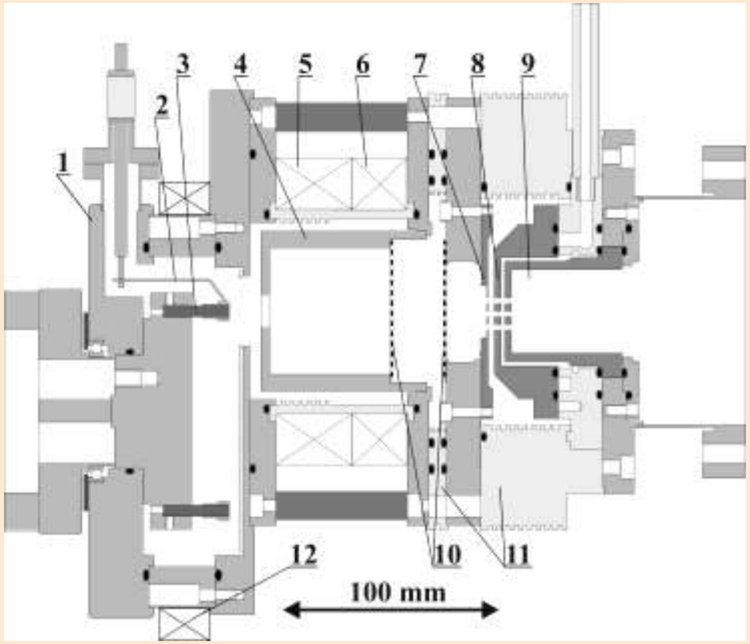
VARIS (Vacuum Arc Ion Source)



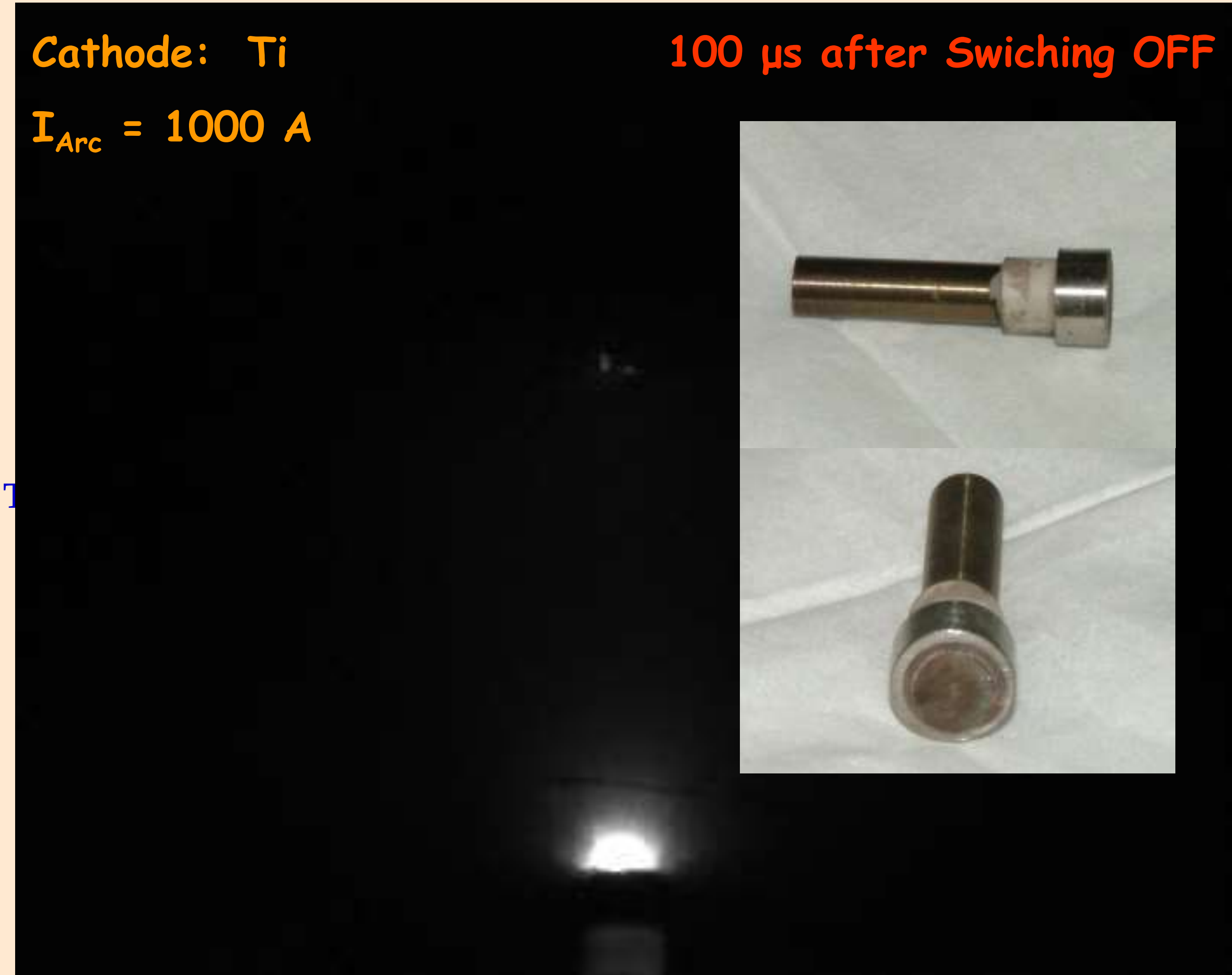


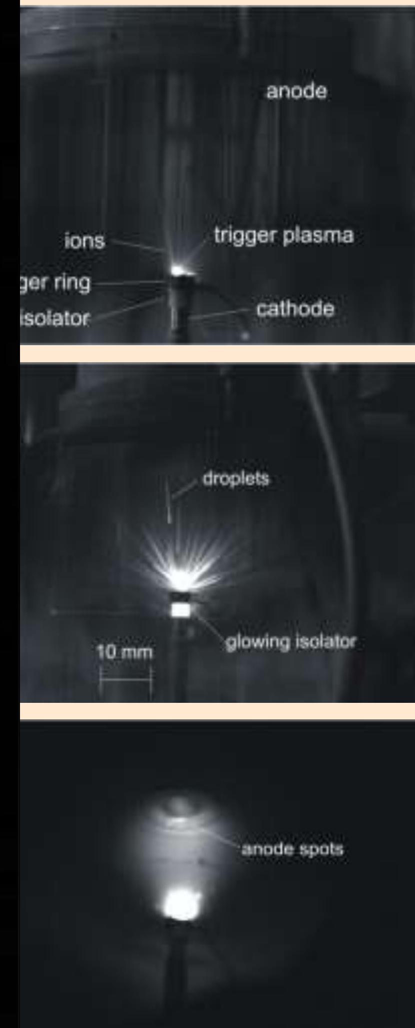
- Optimized for Uranium (67% of $^{238}U^{4+}$)
- NO water cooling necessary
- 170 mA/cm^2; 156 mA @ 32 kV
  55 mA @ 131 kV

16 mA in front of the RFQ
8 mA behind the RFQ



Vacuum Arc driven Sources





Extraction System

Triode Extraction Systems:

1 hole	7 holes	13 holes	19 holes
ø 4÷8 mm	ø 4÷6 mm	ø 3 mm	ø 2÷3 mm

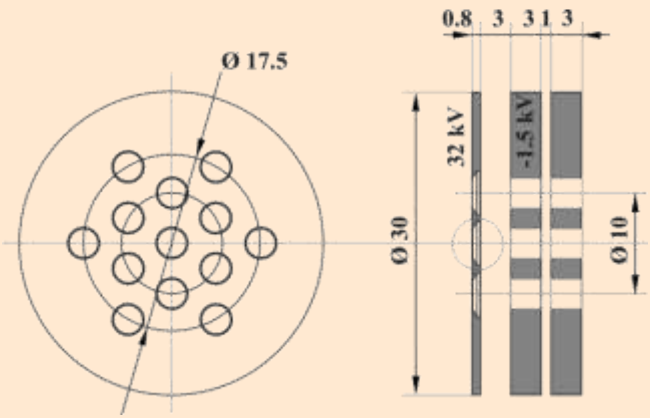


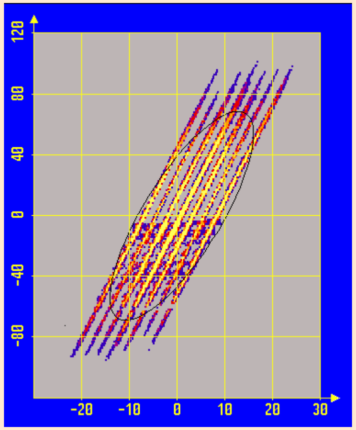

Plasma - Screening distance: r = 3 mm

Aspect Ratio: S = 0.5

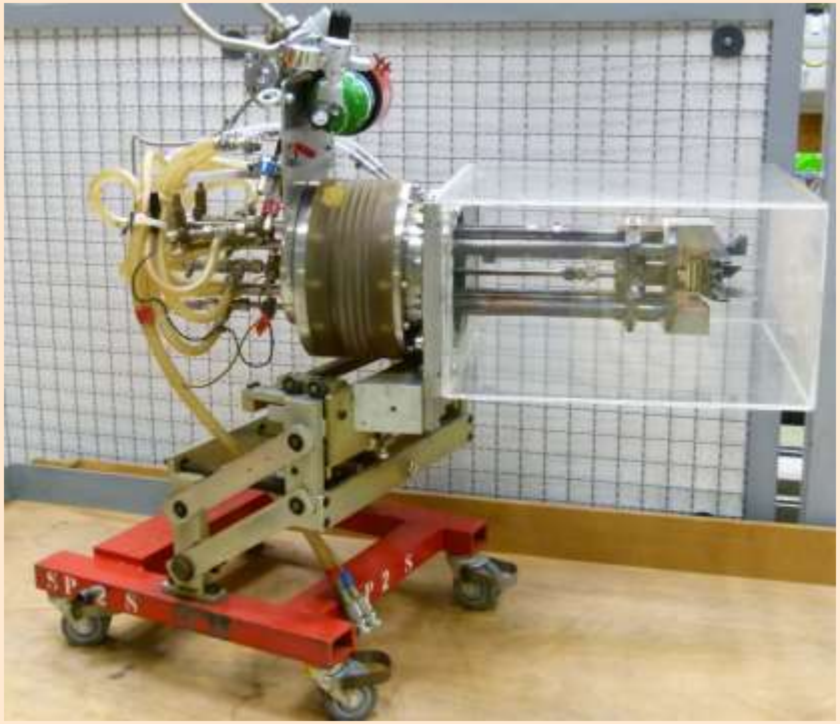
MAX Ext. Voltage: 35 kV

Emission Area: 92 mm²

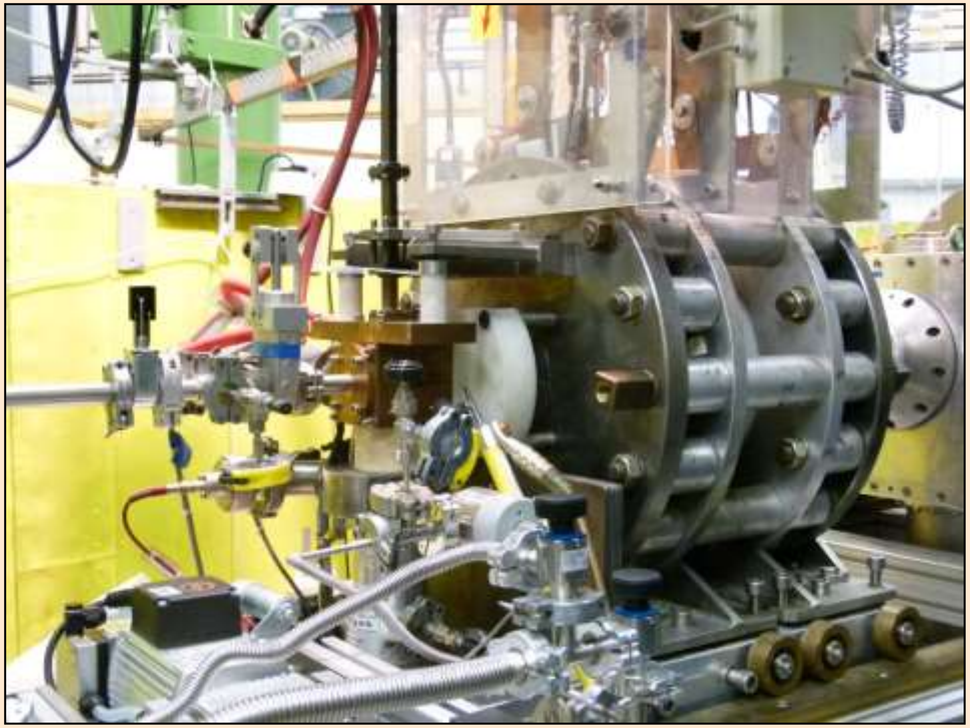




High Duty Factor Ion Sources



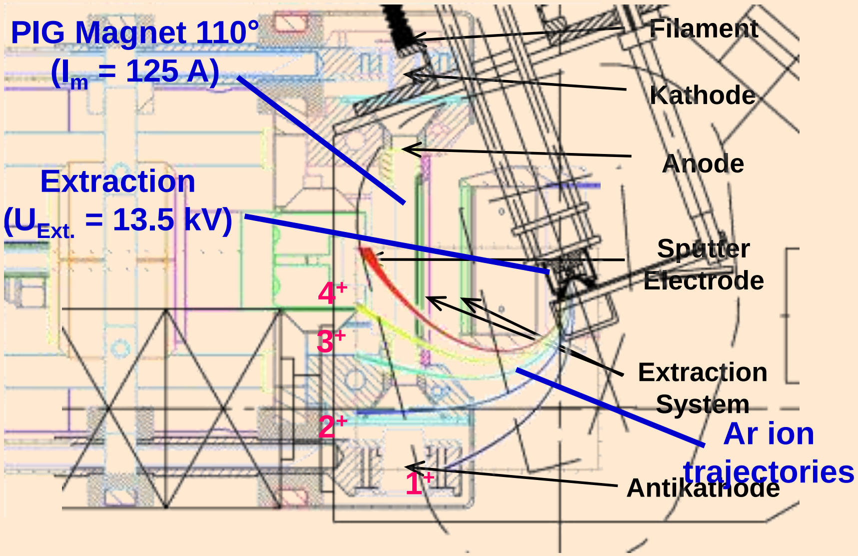
PIG

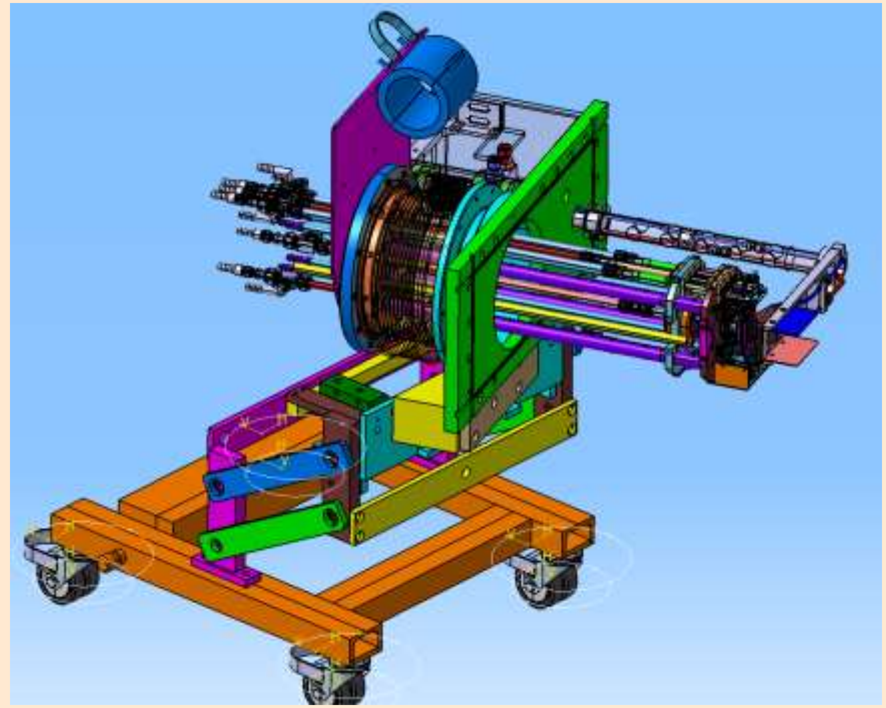


14.5 GHz ECR

Penning Ion Source

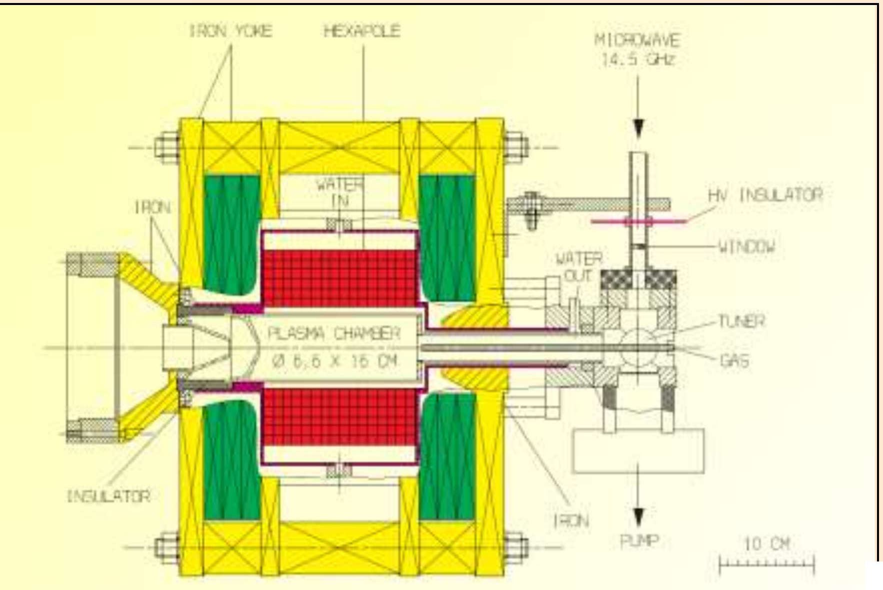
PIG (Penning Ionization Gauge)





- Slit Extraction System
- Working Material:
  Gases and conductive Metals
- Duty Cycle: up to 50Hz / 5ms
- Emission Current Density:
  up to 100 mA/cm²
- Charge State: 1+...10+

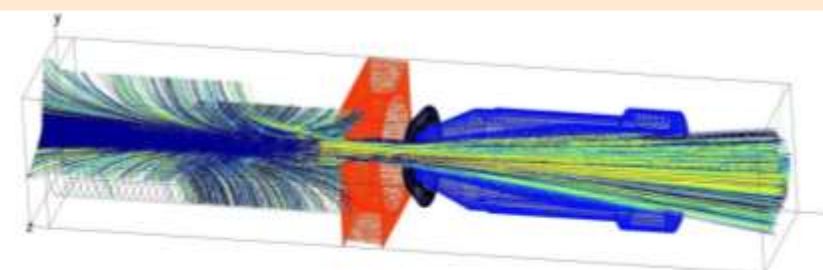
ECR Ion Source

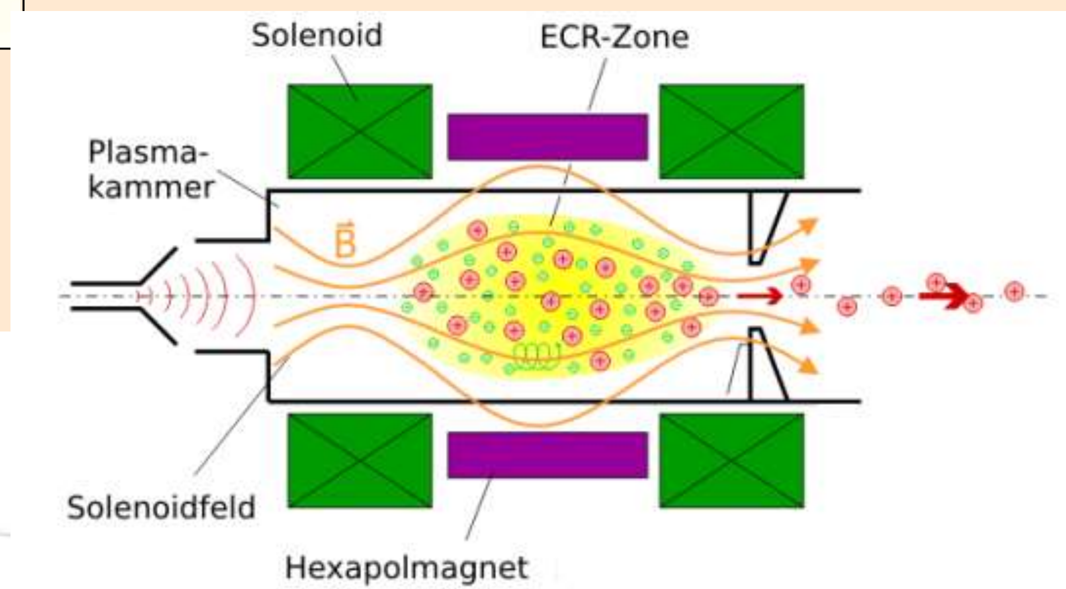


<u>Caprice ECRIS :</u>

Hexapol:	**ca. 1 T**
Solenoid:	**0,8..1,4 T**
µW-Power:	**50..700 W cw**
µW-Frequency:	**14,5 GHz**
Gas Pres.:	**10^{-6}..10^{-4} mbar**

- Solenoids
- Multipolmagnet (Hexapol)
- Plasma Chamber
- Gas Inlet für Working Gas and Auxiliary Gas
- Ofen
- Triode Extraction System

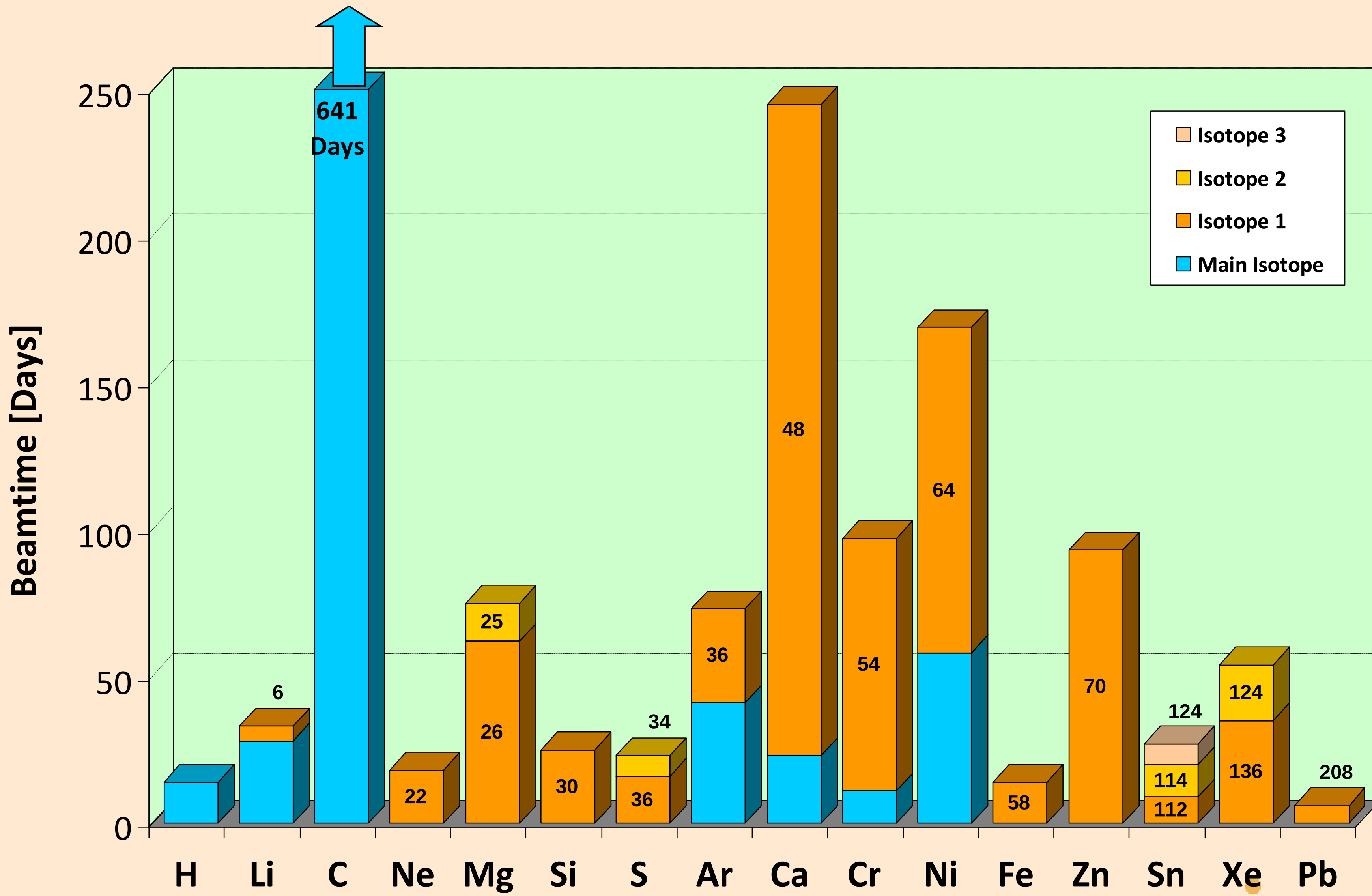




Kobra-INP (INP Wiesbaden) Simulation, P. Spädtke

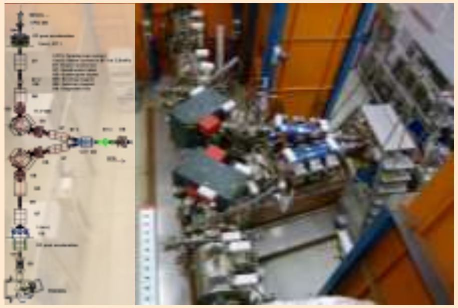
CAPRICE = Compacte A Plusieurs Résonances Ionisantes Cyclotron Electroniques

Ion Beams ECR 2002-2008

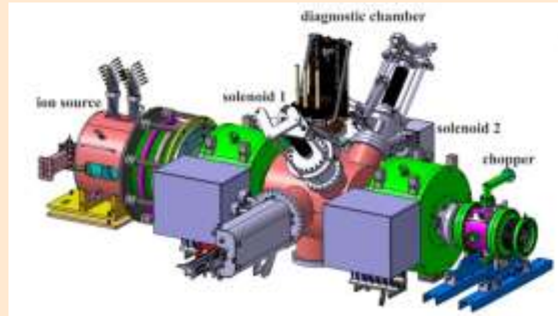


Part 2:

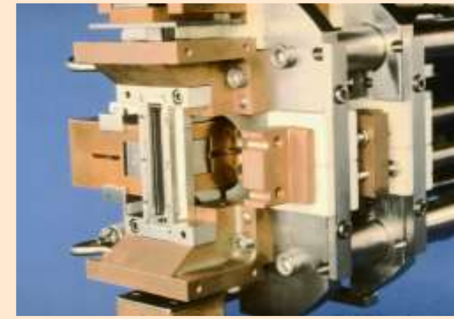
Projects and Development



Terminal West



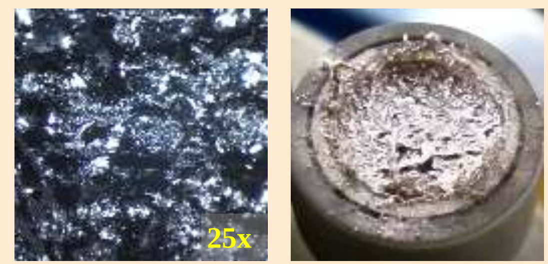
p-LINAC Injector



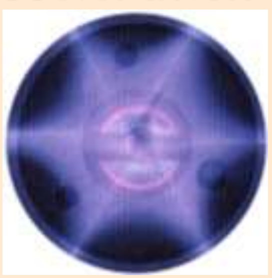
Compact PIG/
PIG upgrade

New Elements
for acceleration

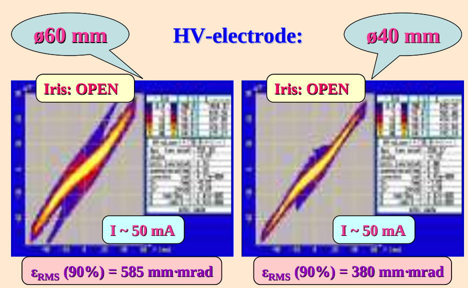
Projects



Higher
Duty cycle



28 GHz ECR



Improved Beam Brilliance for Uranuim

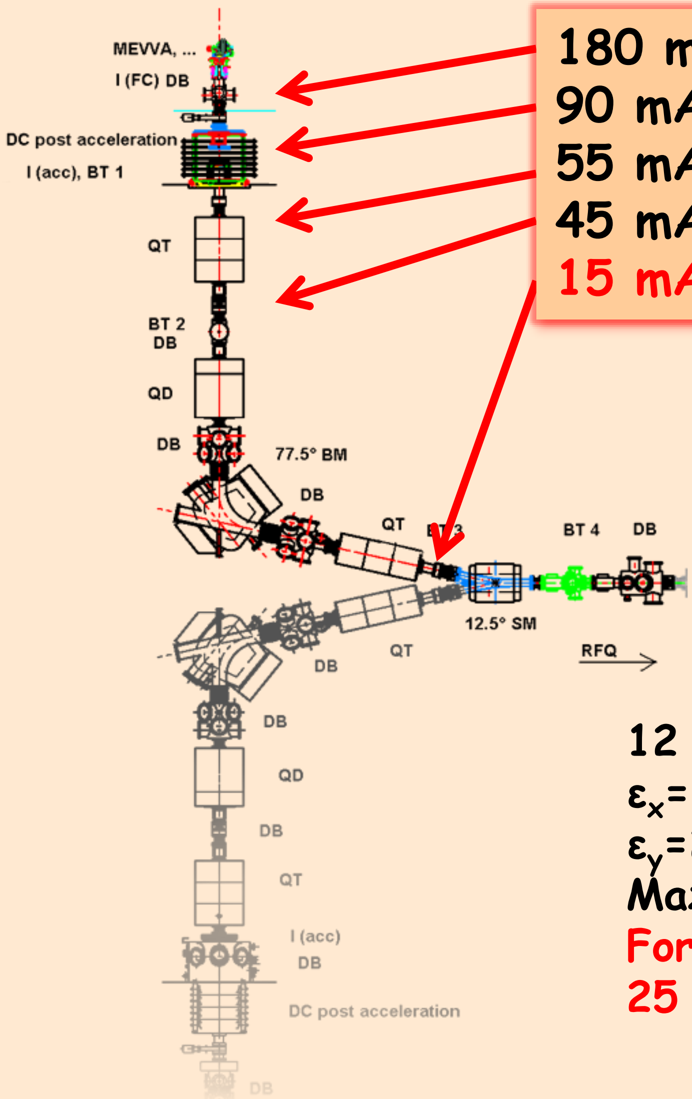
Motivation

FAIR requirements for uranium beam:

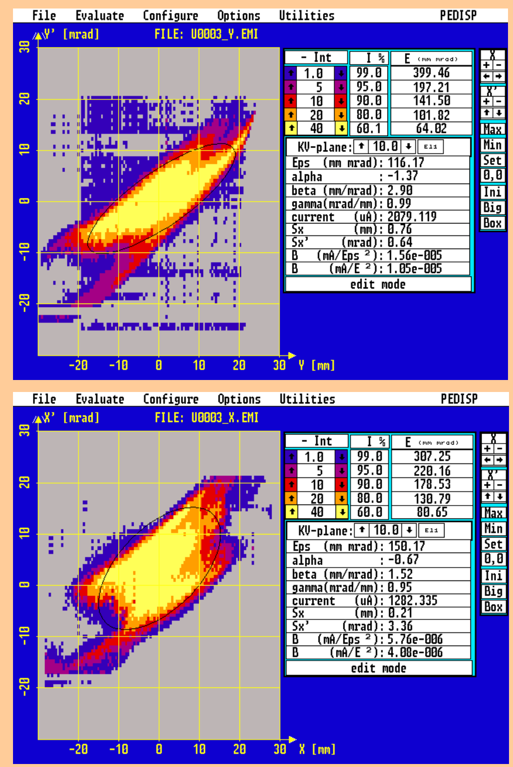
		Present Status
Ion charge state:	$^{238}U^{4+}$	
Specific Energy:	2.2 keV/u	
Pulse Length:	0.5 ms	
Repetition Rate:	2.7 Hz	(1 Hz)
Beam Current (RFQ):	25 mA	(16 mA)
Beam Emittance (RFQ):	$\varepsilon_{x,y}$ = 250π mm·mrad	($\varepsilon_{90\%}$ ~ 300π mm·mrad)

Present Status for Beam Time Operation

180 mA, 120 mA U^{4+}
90 mA, 60 mA U^{4+}
55 mA, 37 mA U^{4+}
45 mA, 30 mA U^{4+}
15 mA U^{4+}, Max.: 25 mA

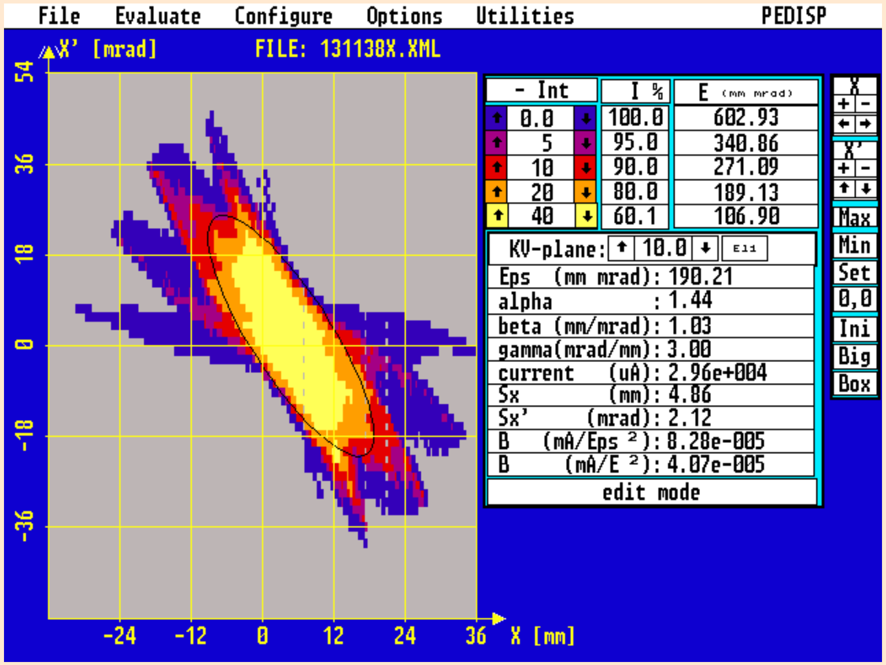


12 mA U^{4+} (in front of RFQ)
$\varepsilon_x = 220\pi$ mm mrad
$\varepsilon_y = 200\pi$ mm mrad
Max.: 16 mA
For FAIR:
25 mA, $\varepsilon_x = 250\pi$ mm mrad

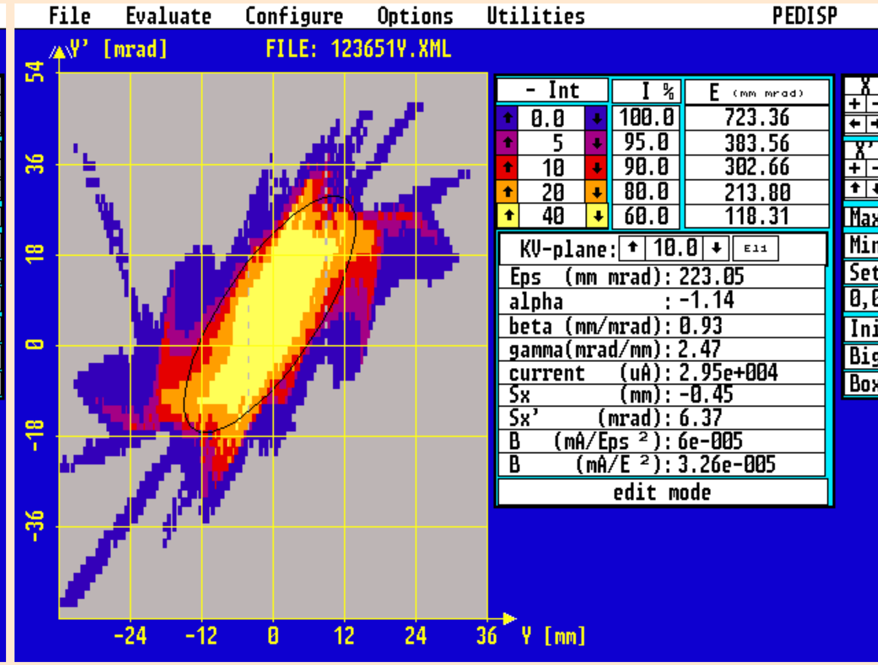


Measurements behind Triplet (Terminal North)

x plane



y plane



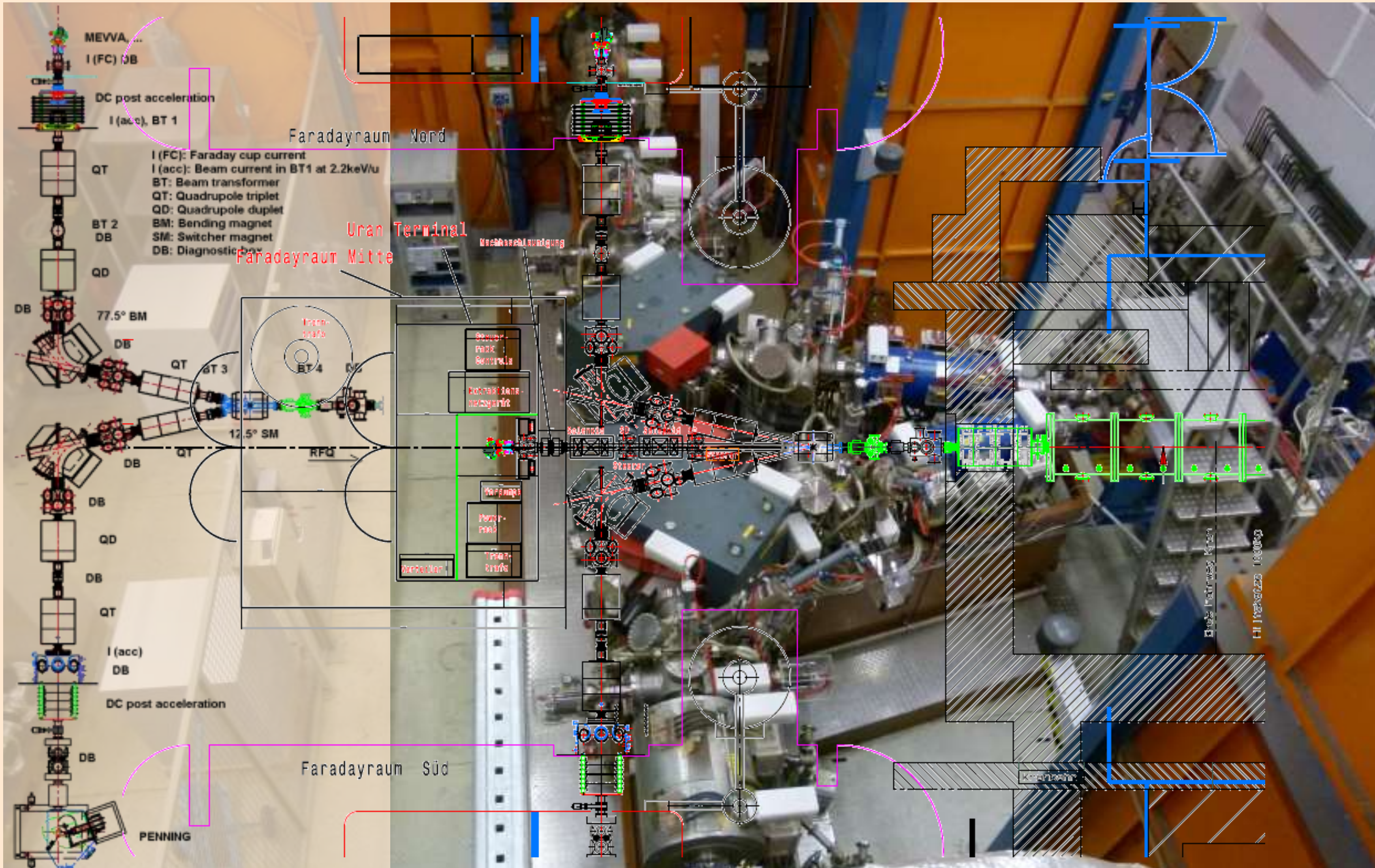
best of

Uranium ion beam (all charge states)
Transmission through triplet nearly 100%
34 mA full beam ⇨ 21 mA $^{238}U^{4+}$ behind triplet
FAIR requirements: 25 mA inside 250π mm mrad
But: 8 m distance to RFQ

Goals

- Upgrade the high current ion sources
  - Increase of Beam brilliance by factor of **2**
  - Increase of Duty cycle by factor of **2.7**
- Build up a new Injector (Terminal West)
  - Specified only for uranium operation
  - Includes uranium service area (safety and rad. protec. reasons)
- Design the Compact LEBT
  - Short, consists of 2 focusing elements
  - Optimized for $^{238}U^{4+}$ beam

Goals

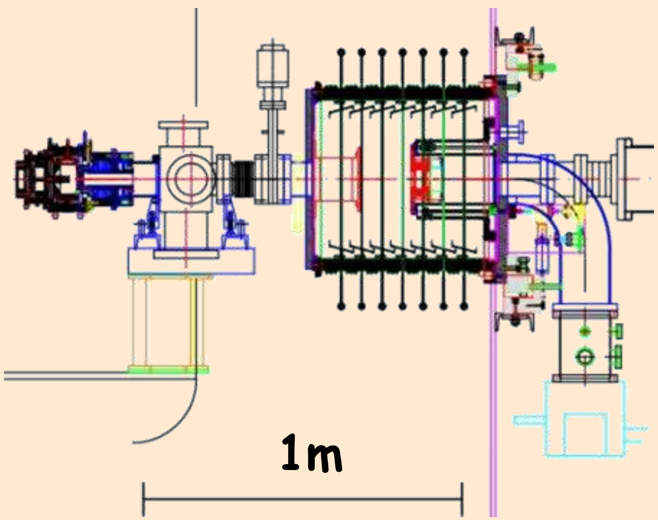


MEVVA, ...
I (FC) DB
DC post acceleration
I (acc), BT 1
QT
BT 2
DB
QD
DB
77.5° BM
QT
BT 3
BT 4
12.5° SM
RFQ
I (acc)
DB
DC post acceleration
PENNING
I (FC): Faraday cup current
I (acc): Beam current in BT1 at 2.2keV/u
BT: Beam transformer
QT: Quadrupole triplet
QD: Quadrupole duplet
BM: Bending magnet
SM: Switcher magnet
DB: Diagnostic box
Faradayraum Nord
Uran Terminal
Faradayraum Mitte
Faradayraum Süd

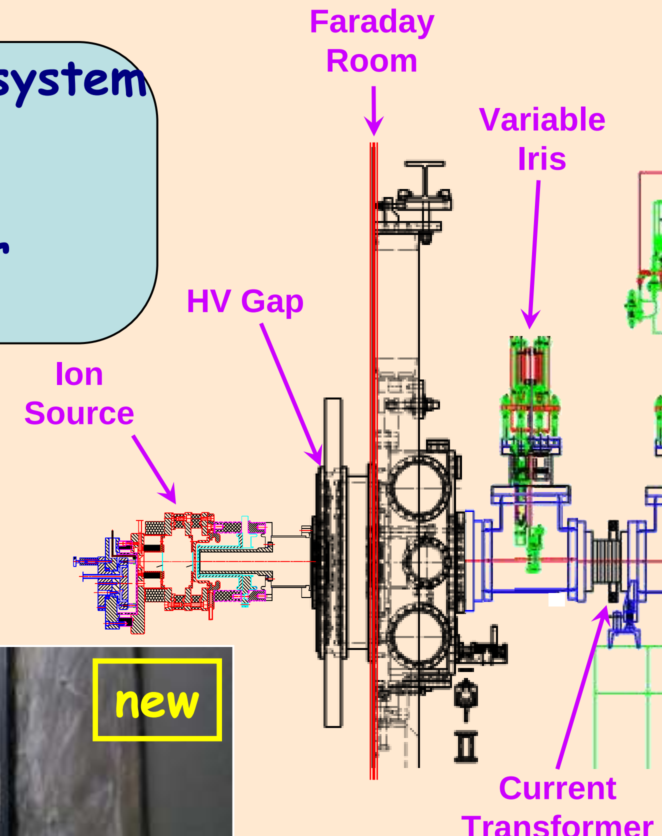
New DC Post Acceleration System

old, designed for 300 kV

new, designed for 100 kV



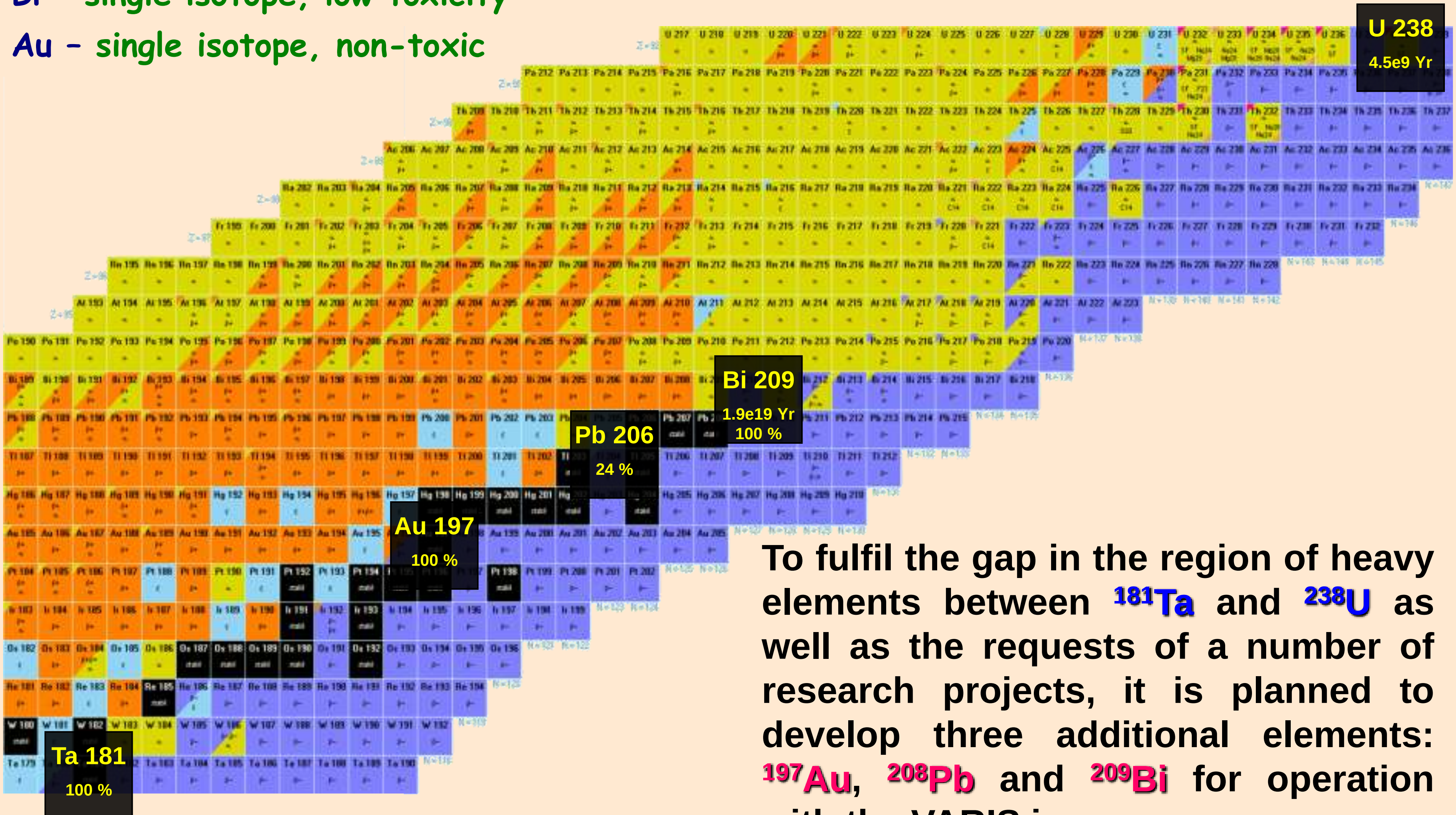
Movable 4 electrode system
Aperture 40-60mm
Aspect ratio: 0.3-1
Repeller electrode for
SCC beam transport



Heavy elements for acceleration

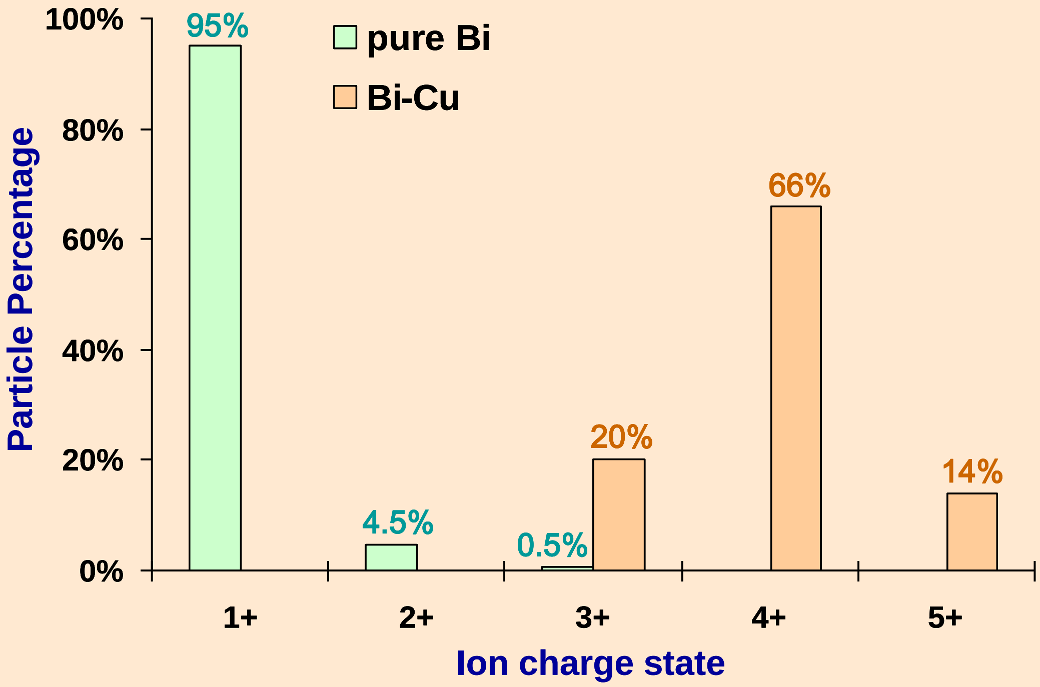
Bi – single isotope, low toxicity

Au – single isotope, non-toxic

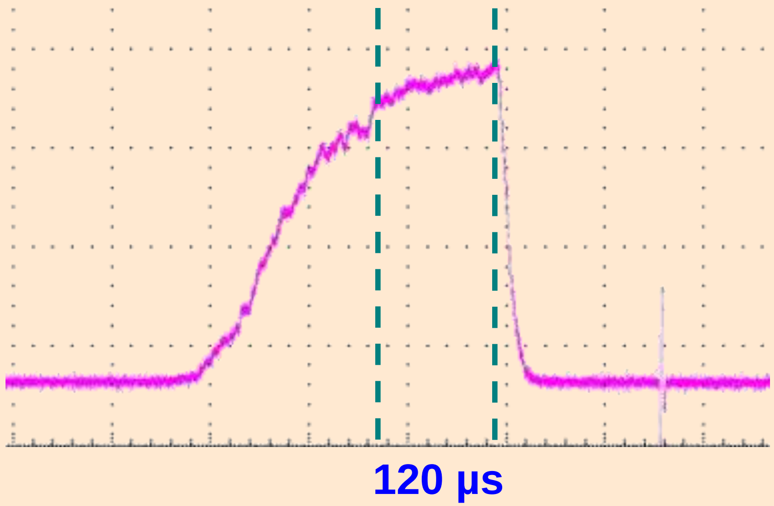


To fulfil the gap in the region of heavy elements between ^{181}Ta and ^{238}U as well as the requests of a number of research projects, it is planned to develop three additional elements: ^{197}Au, ^{208}Pb and ^{209}Bi for operation with the VARIS ion source.

Experiments with Bi



Temporal profile of Bi^{4+} beam:



Pure Bi cathodes:

- Operation with low discharge currents (below 500 A)
- Melting of the material at higher currents
- NO Bi^{4+} ions observed in the Spectrum

Bi-Cu cathodes:

- Cu admixture between 8% and 15%
- Discharge currents up to 900 A
- Stable operation
- Good pulse-to-pulse repetition
- 15 mA of Bi^{4+} in front of the RFQ

Bi - SEM investigation

Cathode 4

"GOOD"

Bi – Cu (15%)

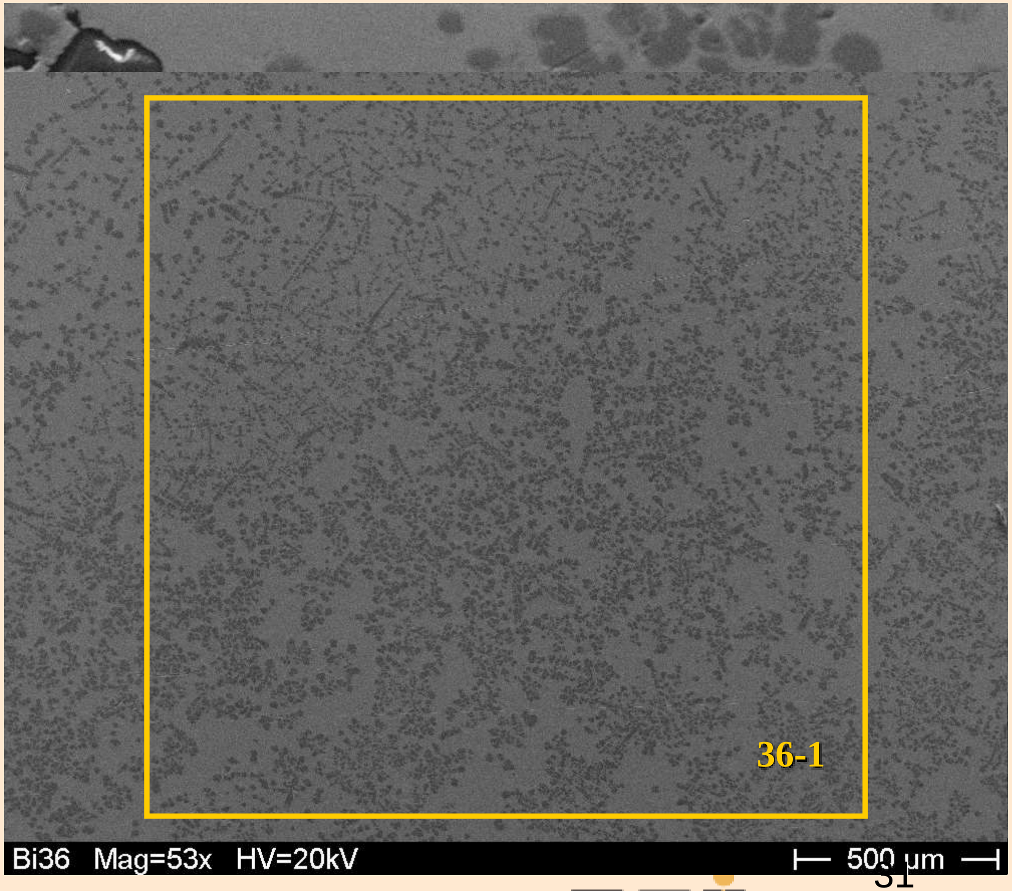
41 hours in operation

2.27 MJ

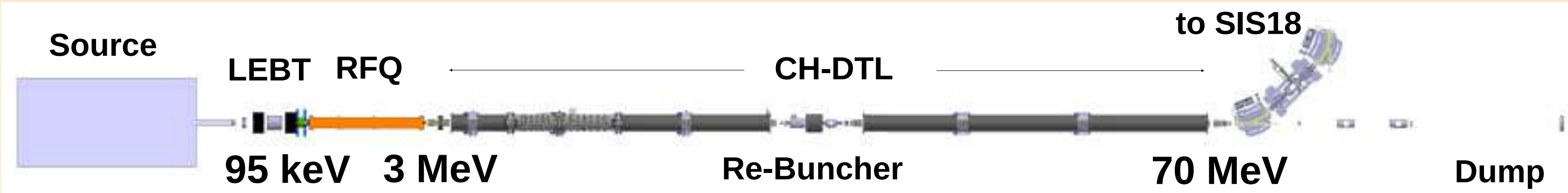
ROI	Element	Composition	
		Wt (%)	At (%)
35-1	Bi	50.3	23.5
	Cu	49.7	76.5
35-2	Bi	56.9	28.6
	Cu	43.1	71.4
35-3	Bi	63.8	34.9
	Cu	36.2	65.1
36-1	Bi	83	59.7
	Cu	17	40.3

- Higher Cu-concentration on the surface =>

  => "GOOD" behaviour



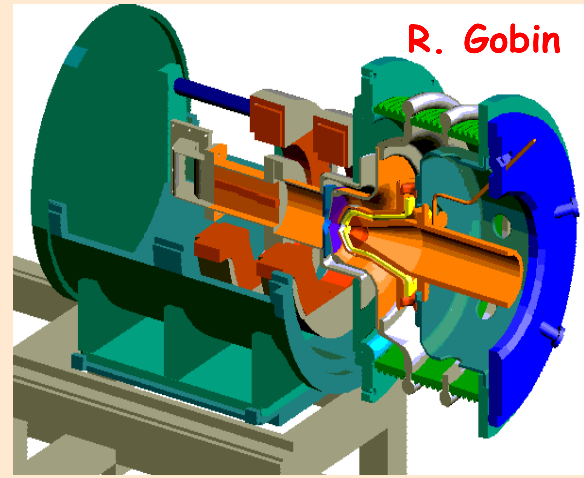
Plinac

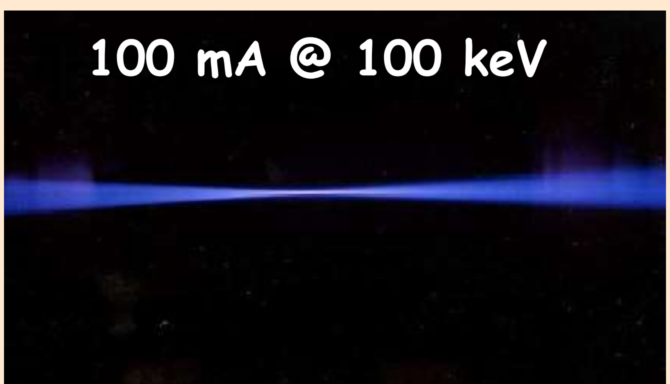


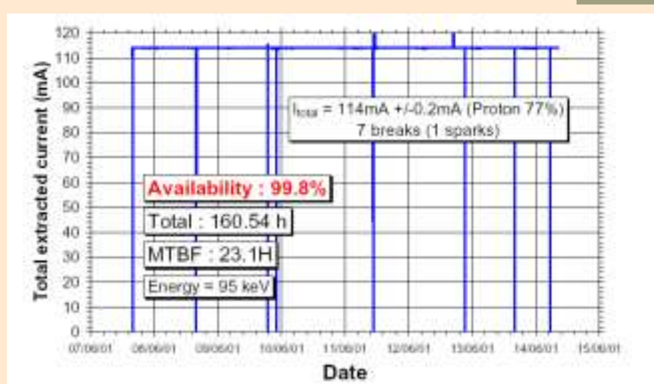
44 m

Beam energy	70 MeV
Beam current (op.)	35 mA
Beam current (des.)	*70 mA*
Beam pulse length	36 μs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Tot. hor. emit. (norm.)	2.1 / *4.2* μm
Tot. mom. spread	≤ ± 10^{-3}
Linac length	≈ 33 m

SILHI from CEA:
130 mA @ 95 keV
~95 % protons
>99 % availibility
cw (pulsed operation poss.)
ε (rms) = 0.2 mm mrad
life time of months
low noise
small beam fluctuations



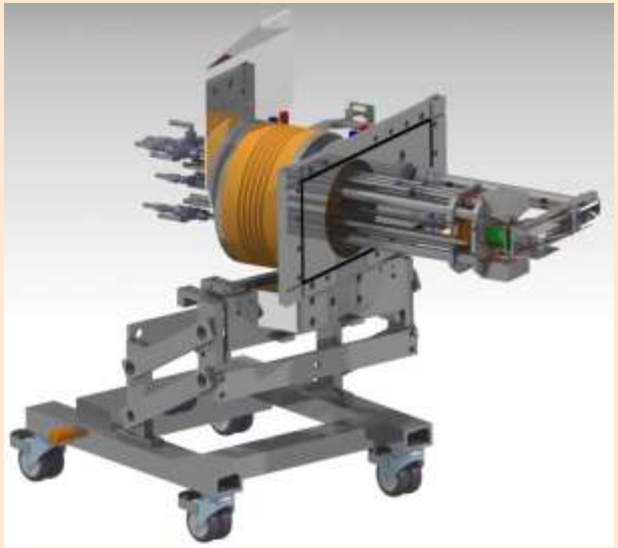




ECR @
2.45 GHz

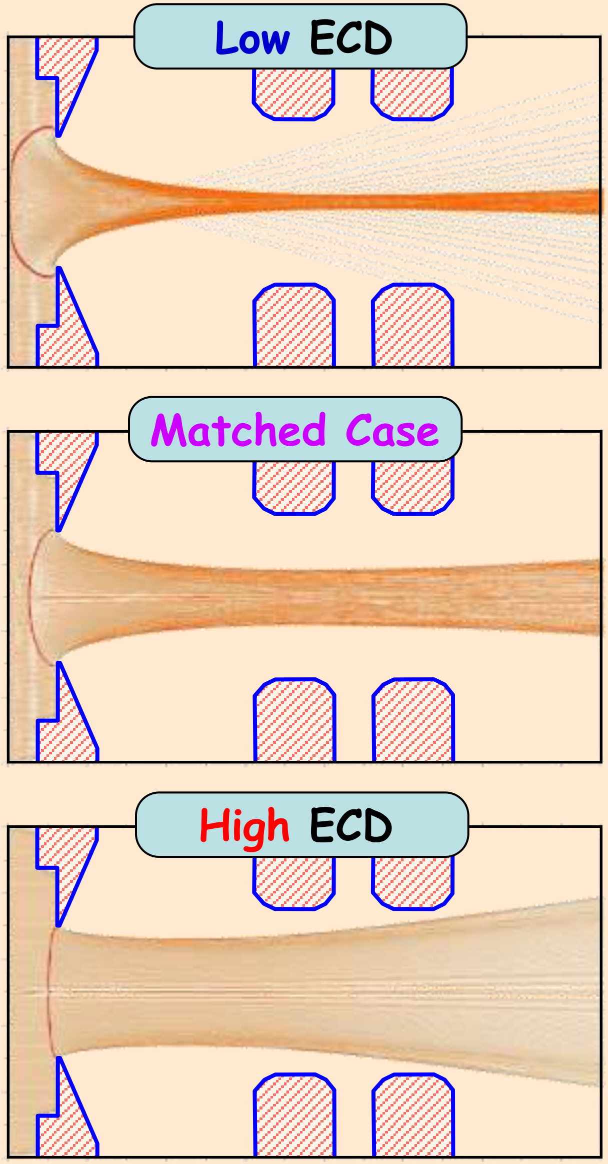
Renew of the PIG

- PIG Ion Sources are modeled in CATIA 3D
- „old“ sources are on their way of being „renewed“
- Very dificile structure at source head (more than 70 pieces for „the head“)
- Task for the future: simplify mechanics and boost intensity



Thank you for your attention!

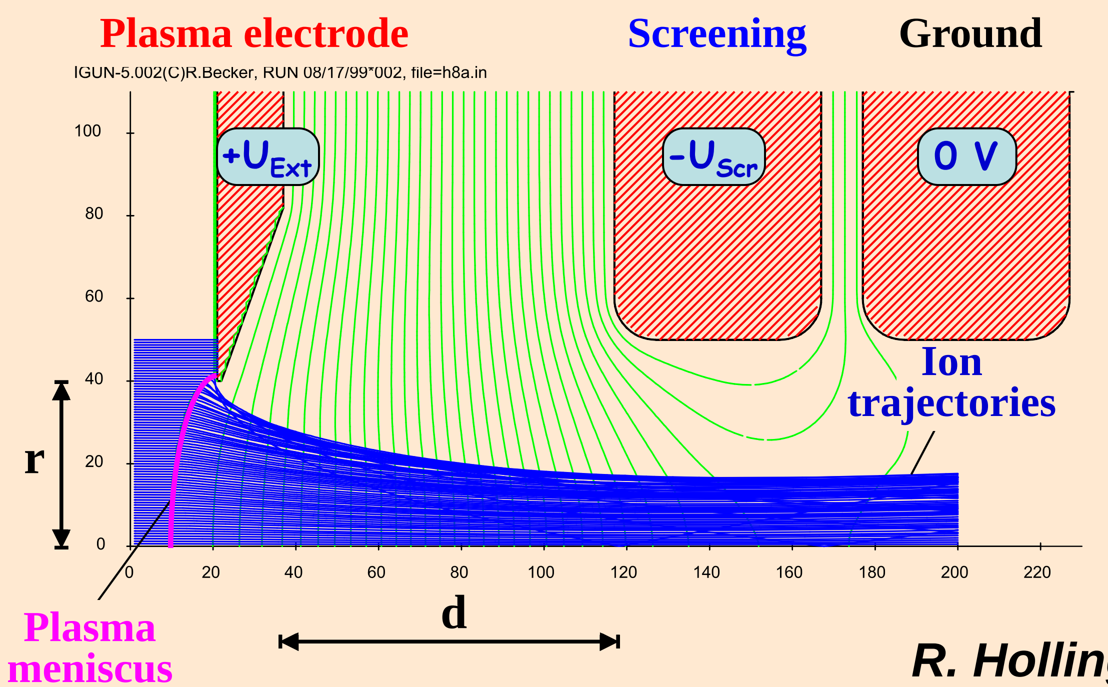
Ion Extraction



Child-Langmuir Law:

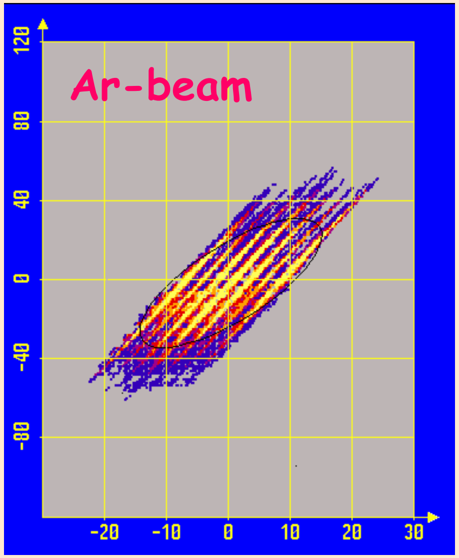
$$j_{CL} = \frac{4}{9}\varepsilon_0 \cdot \sqrt{\frac{2e\zeta}{m}} \cdot \frac{1}{\sqrt{d}} \cdot E^{3/2} \qquad S = \frac{r}{d} \qquad E = \frac{U_{Ext}}{d}$$

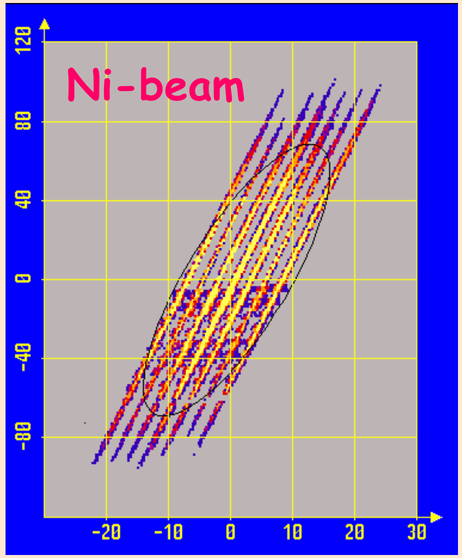
$$I_{CL} = \frac{4}{9}\pi \cdot \varepsilon_0 \cdot \sqrt{\frac{2e\zeta}{m}} \cdot S^2 \cdot U_{Ext}^{3/2}$$



R. Hollinger

Beam Quality

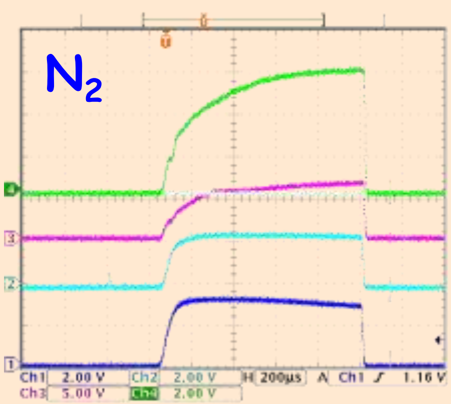




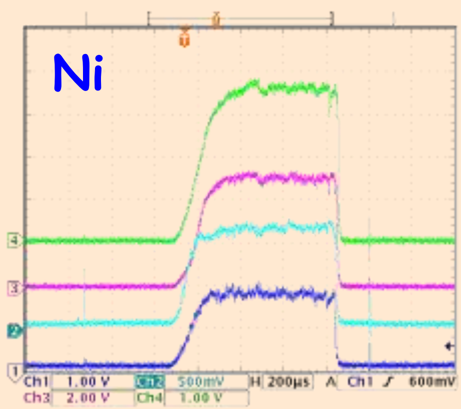
Beam Characteristics

	Ar-beam (CHORDIS)	Ni-beam (VARIS)
U_{Exr}:	18 kV	18 kV
I_{Ext}:	60 mA	60 mA
Div. Angle:	50 mrad	95 mrad

CHORDIS



VARIS

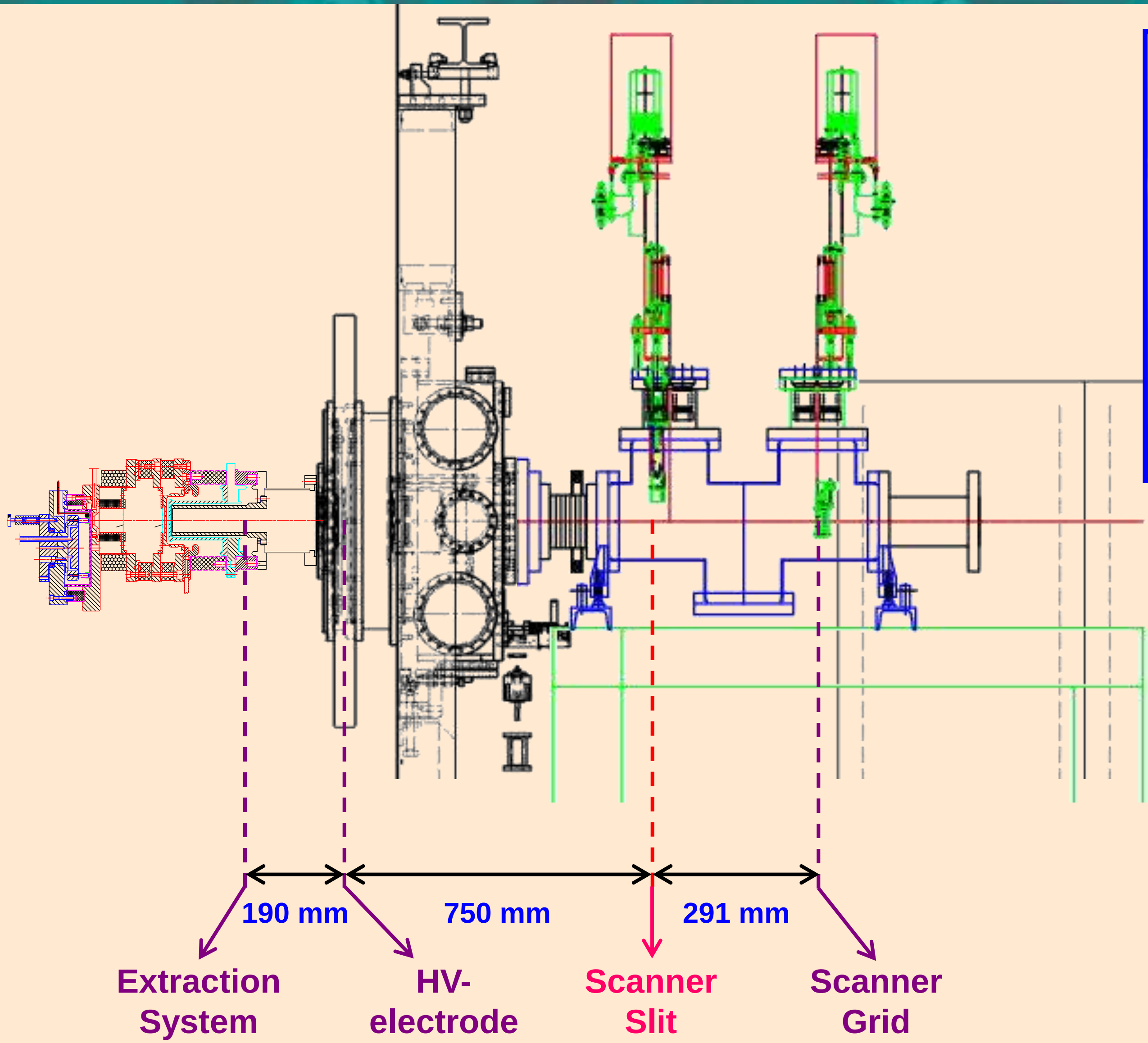


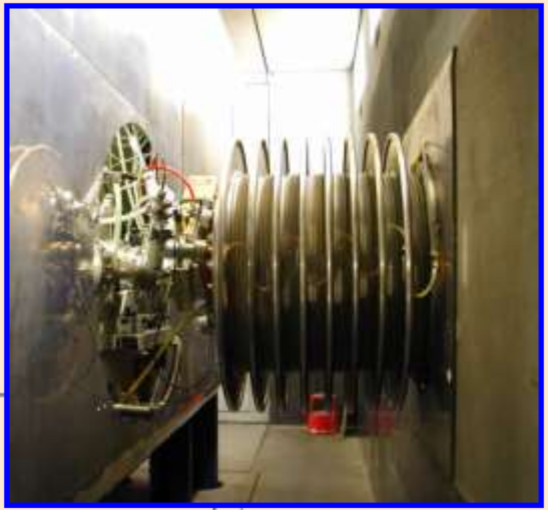
Ion beam pulses along the LEBT

	N_2-beam (CHORDIS)	Ni-beam (VARIS)
CT 1:	20 mA/div	10 mA/div
CT 2:	20 mA/div	5 mA/div
CT 3:	5 mA/div	2 mA/div
CT 4:	2 mA/div	1 mA/div

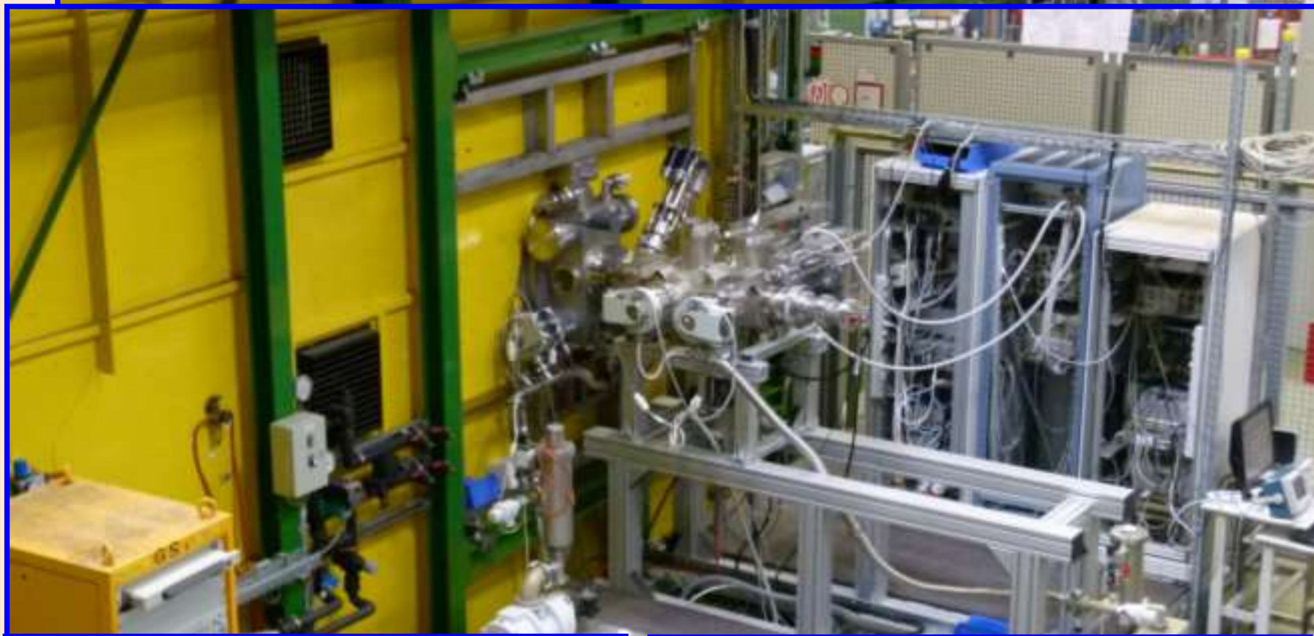
R. Hollinger

HOSTI – New setup

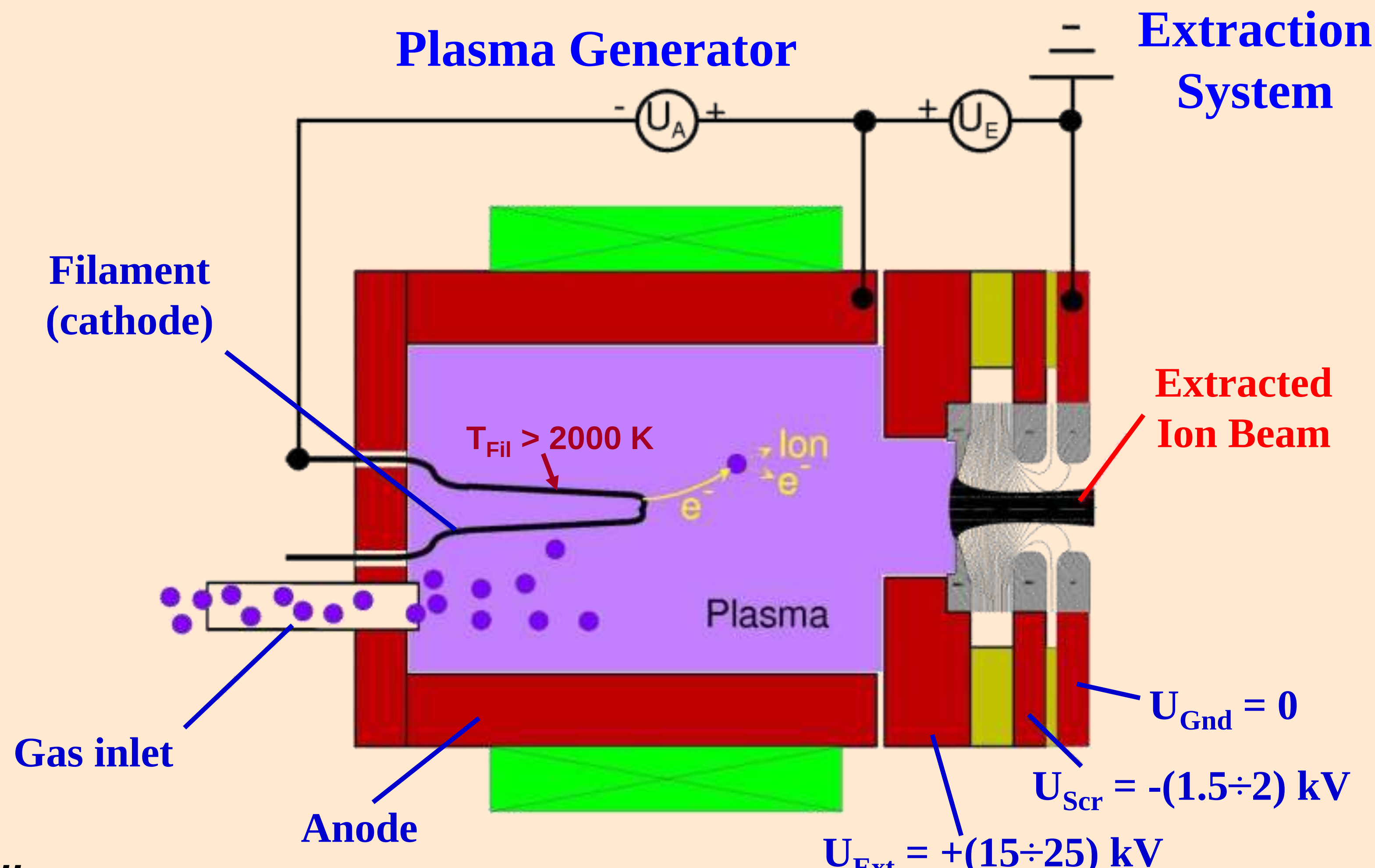




HOSTI – New setup



Operation principle (ion production)



K. Volk