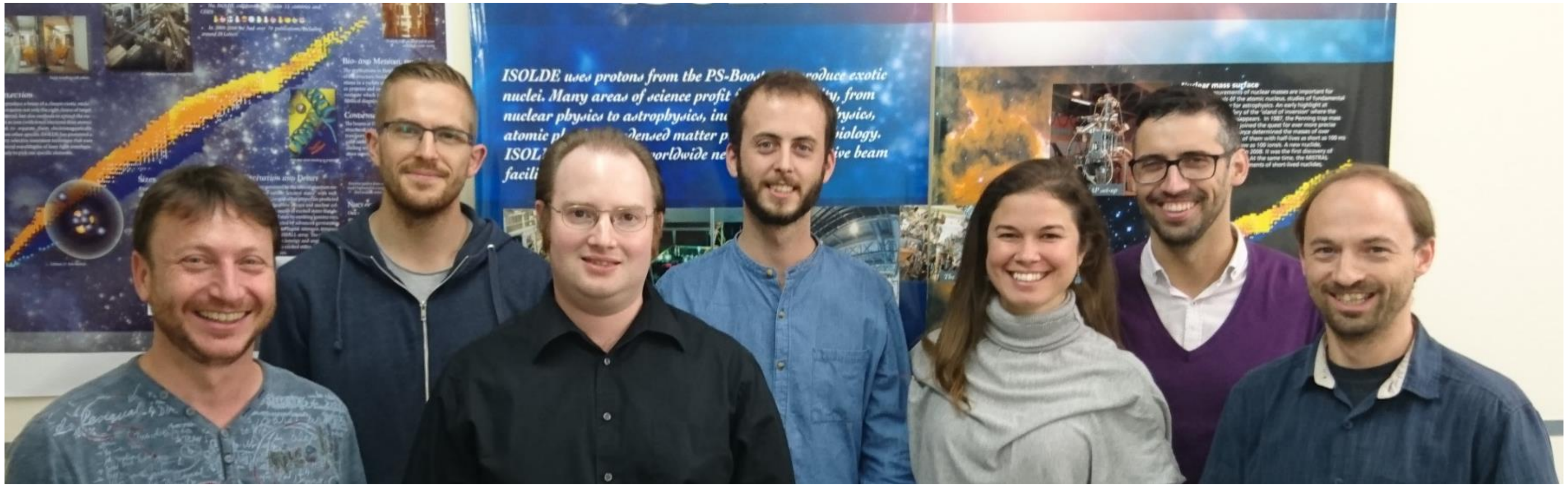
Target and ion source developments at CERN-ISOLDE

Sebastian ROTHE
for EN-STI-RBS/LP

ENGINEERING
DEPARTMENT

ISOLDE Target and Ion Source Development teams

The target team



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RILIS

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EN-STI-LP

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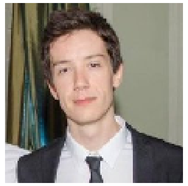
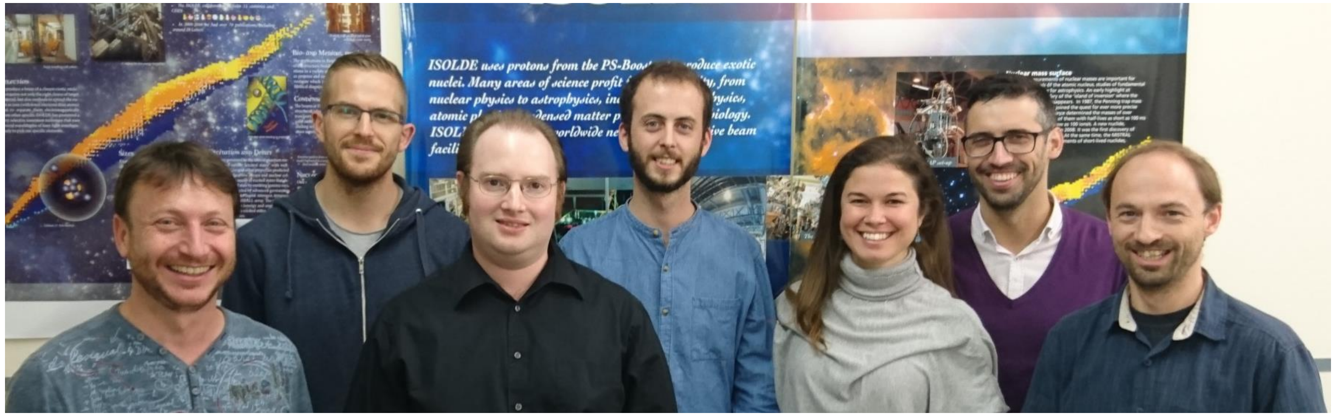
Doctoral student
Univ. Mainz



Fellow #2
CERN Fellow
Shane Wilkins

Target and ion Source Development (TISD) mandate



RILIS

Providing a large choice of **intense** and **pure** radioactive beams

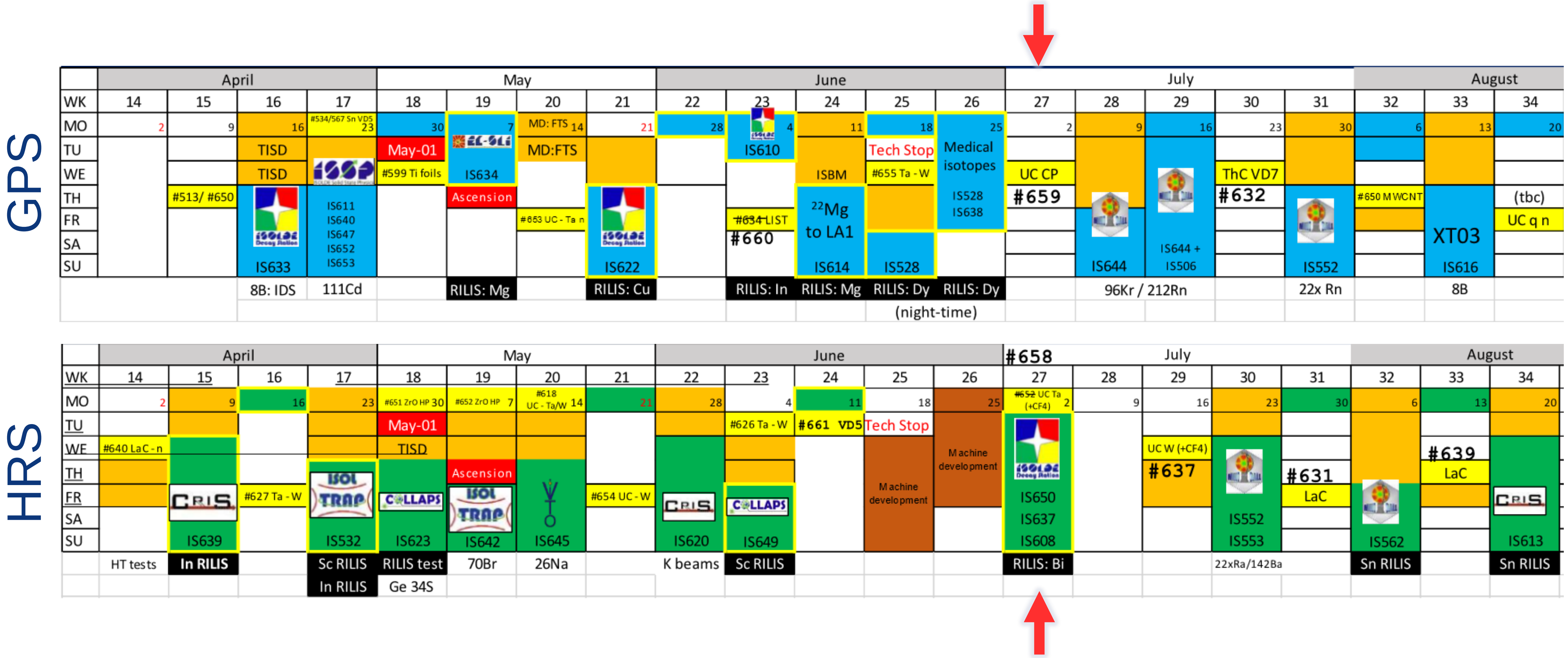
Constant development is required to keep ISOLDE at the forefront of RIB facilities

- target and ion source units
- target materials
- beam interactions (p2n converter)
- ion source design / mode of operation shared with ISBM group

- yield & release study
- ion source efficiency measurements
- prototype tests

Sharing same resources as the ISOLDE physics program
- WORKSHOP: target unit production
- OFFLINE: target quality control
- ISOLDE: beamtime

ISOLDE Schedule 2018



Target production APR-JUN 2018

21 targets used / tested at offline

6 Units for development

11 Units irradiated at ISOLDE

#614	empty	VD5	Mn tests PSI , Se tests ILL
#633	Nb foil	MK4 negative LaB6	Development, GANDALPH
#640	LaC	RILIS	In -> CRIS
#650	MWCNT	VD7	8B -> IDS
#627	Ta	RILIS	Sc
#567	Sn molten	VD7	backup for #534
#657	No target	VD7	LIEBE test
#651	ZrO	VD5	GeS /Ge -> COLLAPS
#652	ZrO	VD5	70Br
#653	UC (UC-2018-01)	MK1-Ta	Cu
#654	UC (UC-2018-02)	MK1-W	K
#626	Ta	RILIS	Sc
#660	SiC	LIST - 90mm	22Mg
#661	Empty	VD5	MD ISCOOL
#655	Ta	RILIS	Tb /Dy
#570	n.a.	GANDIS	Gandalph offline source
#656	empty	VD5	Mn tests PSI
#658	UC (UC-2018-04)	RILIS	Bi
#502	empty	n.a.	n-Converter dev
#628	empty	n.a.	nConverter / MEDICIS dev
#634	empty	LIST - 34 mm	LIST development

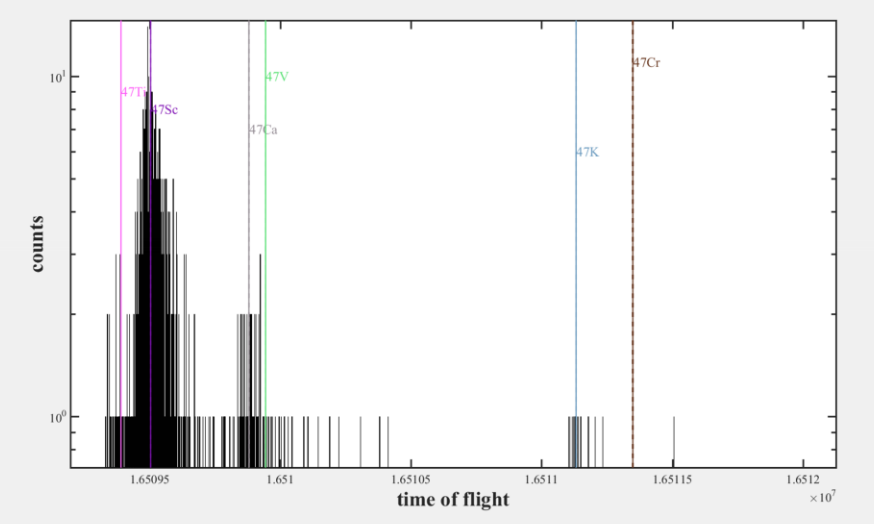
Scandium beams

Target: **#565** Ta foils

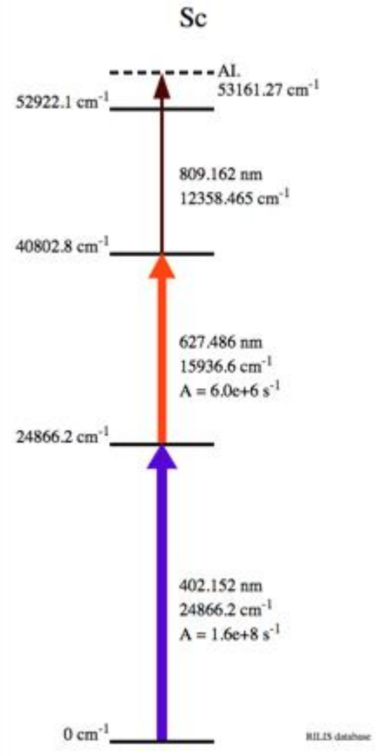
	^{43}Sc $\beta^+=100\%$	^{44}Sc $\beta^+=100\%$	^{45}Sc Abundance=100 %	^{46}Sc $\beta^-=100\%$	^{47}Sc $\beta^-=100\%$	^{48}Sc $\beta^-=100\%$	^{49}Sc $\beta^-=100\%$	^{50}Sc $\beta^-=100\%$	^{51}Sc $\beta^-=100\%$
FC				1.5E+07	1.2E+07	8.1E+06	7.3E+05		
betas							7.6E+05	1.8E+04	
MR-TOF				2.3E+06	1.6E+06	1.2E+06	7.4E+05	1.3E+04	
Extrap.	3.6E+05	1.2E+06							1E+02

RILIS

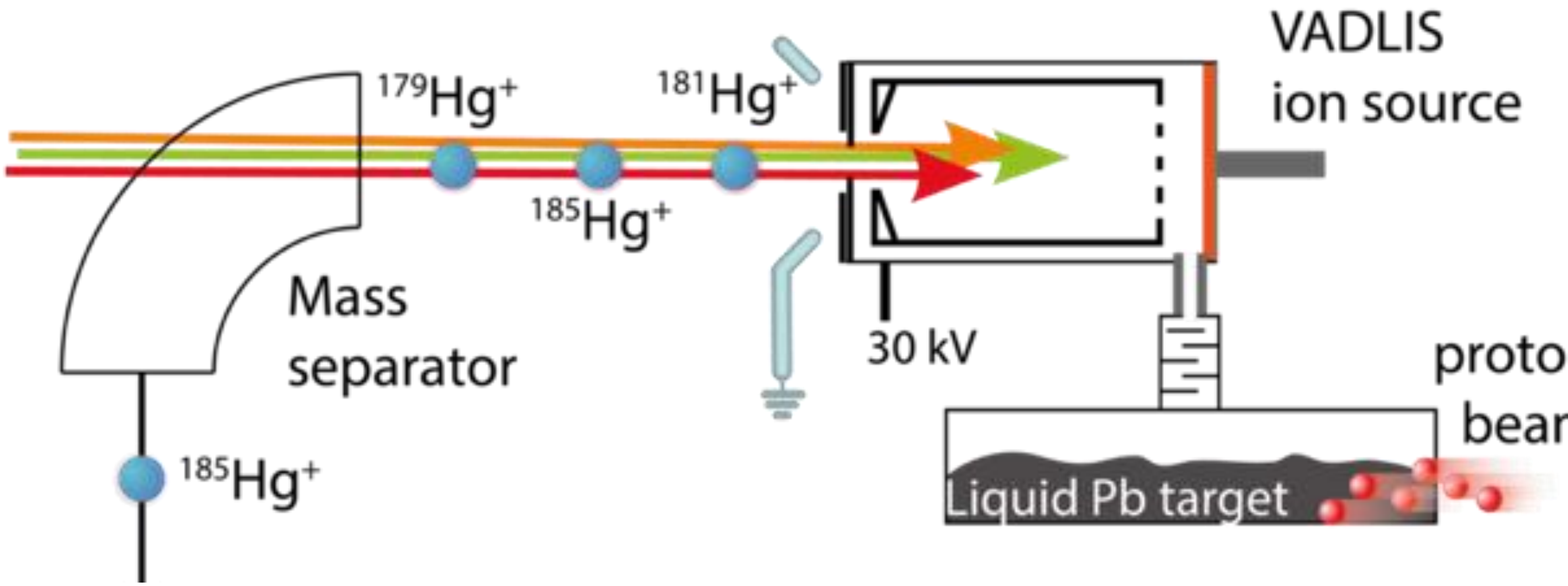
ISOLTRAP
MR-ToF spectrum



Mass scan (FC.558)



Clean ^{206}Hg beams with VADLIS



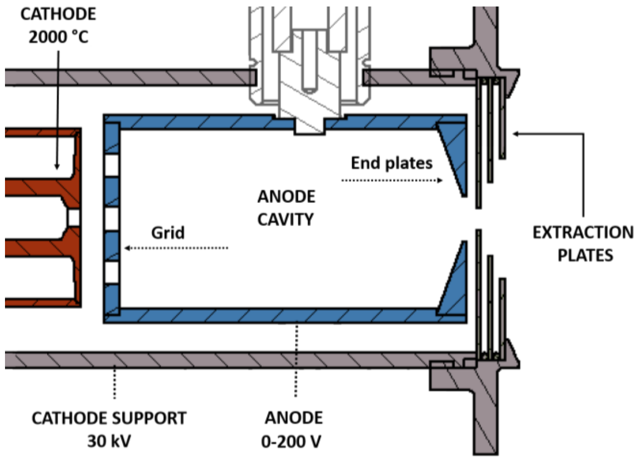
- 3rd on-line application of VADLIS ion source for an experiment
  - (full Hg chain for in source laser spectroscopy; Mg + Ne for ISOLTRAP, 206Hg for Miniball)
- RILIS–mode achieves similar efficiency to VADIS-mode

- Note: RILIS-mode efficiency is expected to improve by at least **2 X** if the adjustable-extractor VADIS is used.

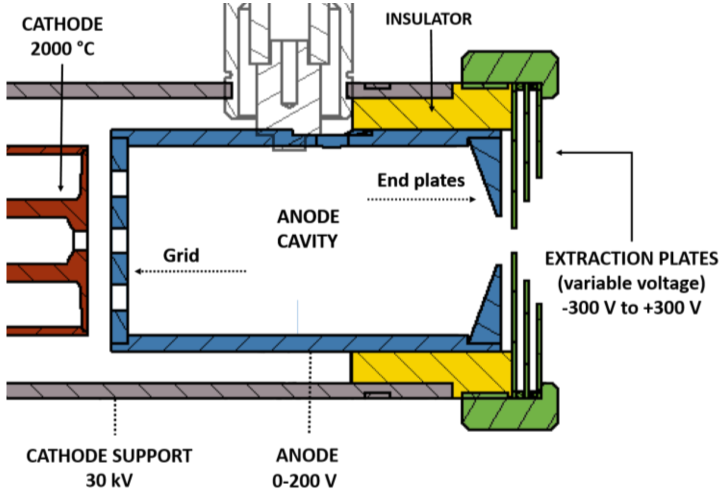
B.Marsh

VADIS / VADLIS developments

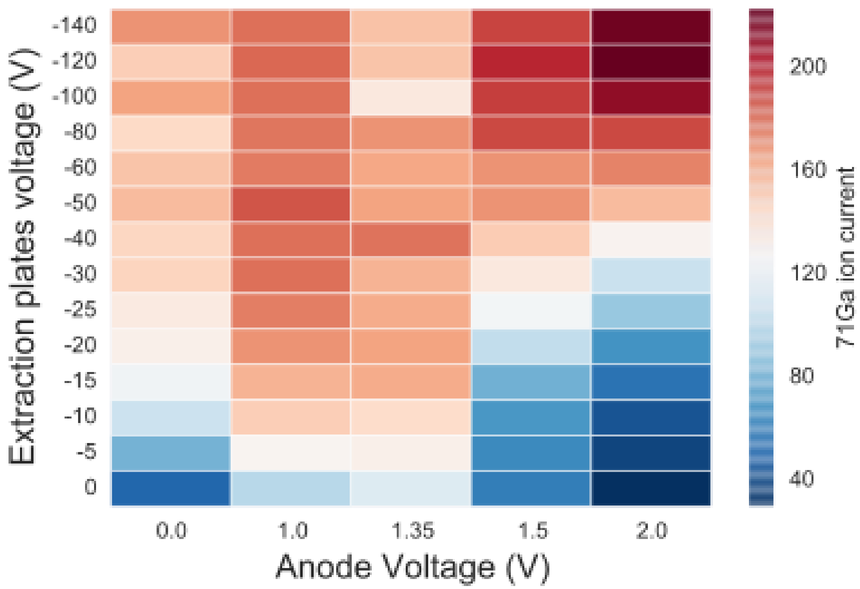
Standard VADIS



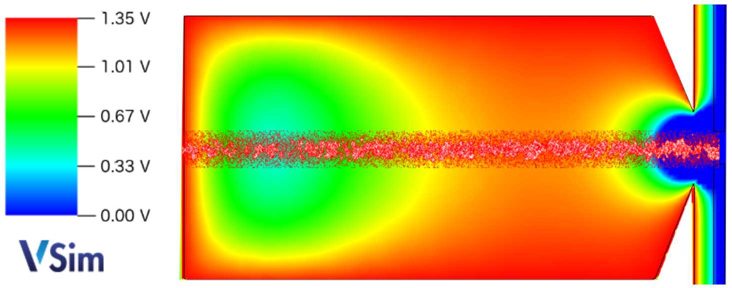
VADIS Dev. [2]



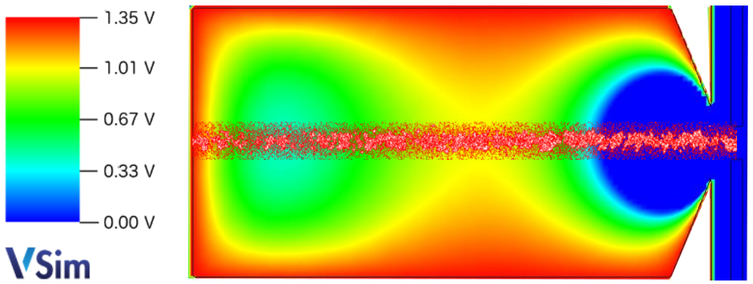
2D voltage scan (RILIS mode)



Extraction plates 0 V



Extraction plates -100 V



Successfully operated new VADLIS #630-MD

Y.Martinez

[2] *Y. Martinez et al. In preparation*

Boron fluoride beams

Principle: $B + 3\,F \rightarrow BF_3$ *Volatilization of refractory boron by injection of SF_6 gas*

First prototype #499

- Small gas leak (3.7e-5 mbar L / s)
- Absence of TaF_x and SF_x in mass spectra

→ Unit did not produce BFx beams
no fluorine saturation

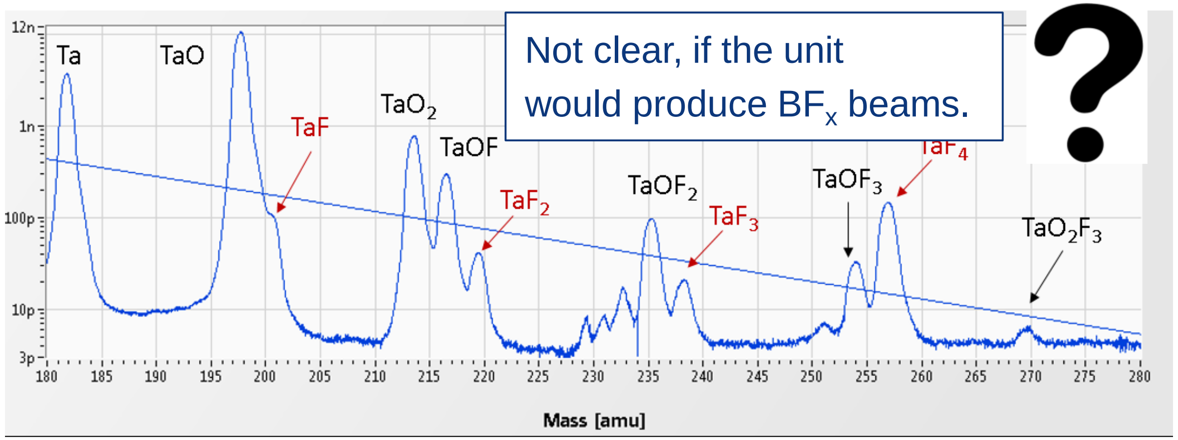
Second prototype #513

- Increased leak (1.84e-4 mbar L/s)
- Strong TaF_x and SF_x peaks
- No TaO peaks

→ Stable and intense 8BFx beams

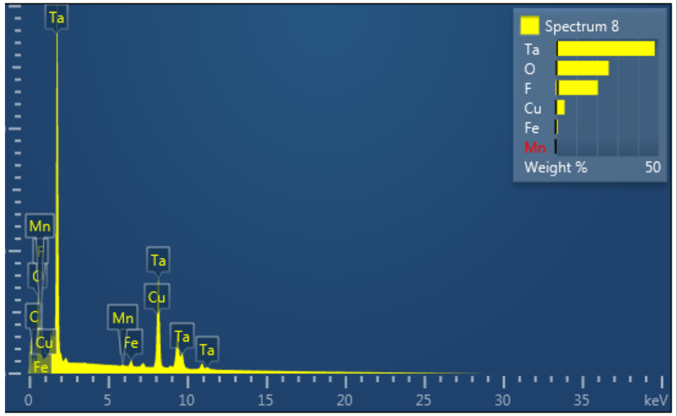
First production unit #606

Despite high injection,
low fluorination, and presence of oxygen. H_2O or air leak?



Not clear, if the unit would produce BF_x beams.

?



TaO_xF_y deposits in target

Gas line rupture

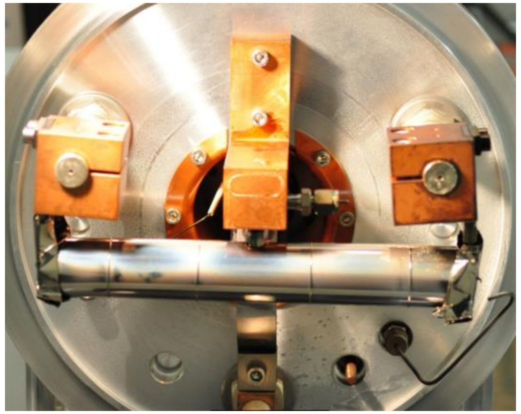
Target #606 -> #650

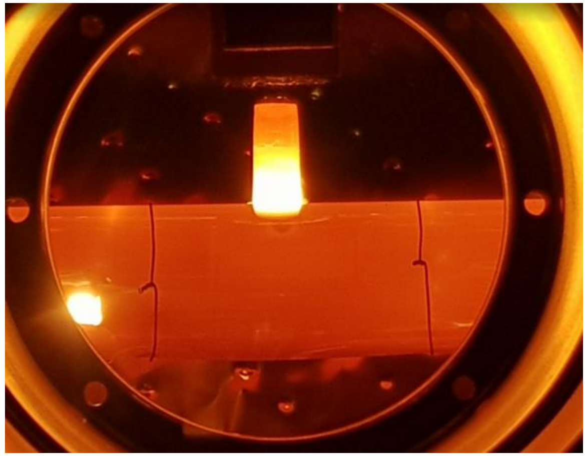
MWCNT for 8BF2 beams at IDS

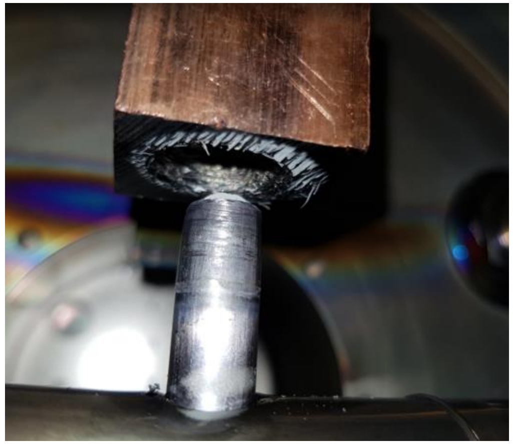
- 2017: #606 Target could not be delivered, #513 was used
- No infrastructure available to handle C nano tubes
- Decided to recuperate charge from #606 for #650
- Disassembly: transferline found clogged with AlF
- Target outgassed to remove contaminants
- Found macroscopic amount of Aluminum in transfer line

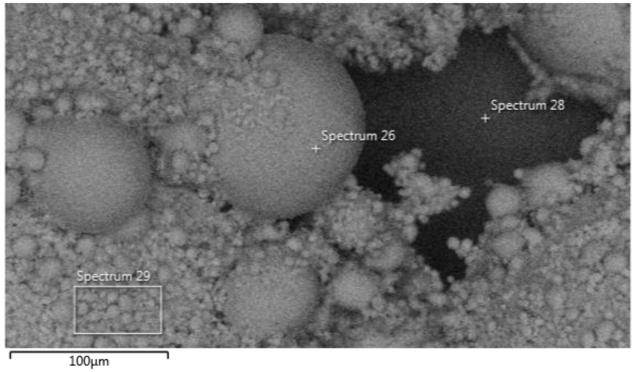
- Successfully used #650 for IDS run
- Factor 10 yield increase compared to #513

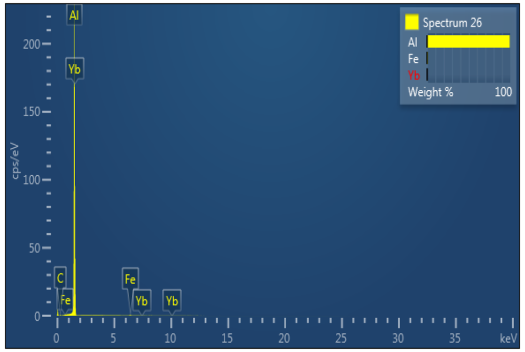
- > #650 rescheduled for HIE ISOLDE







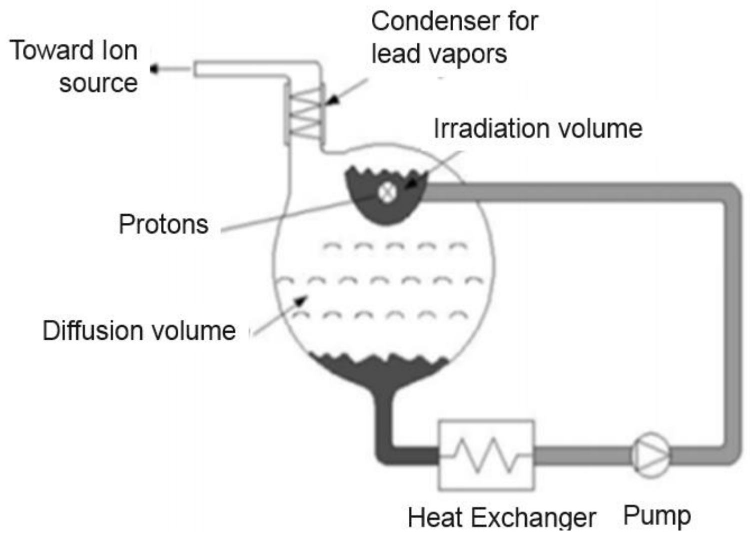




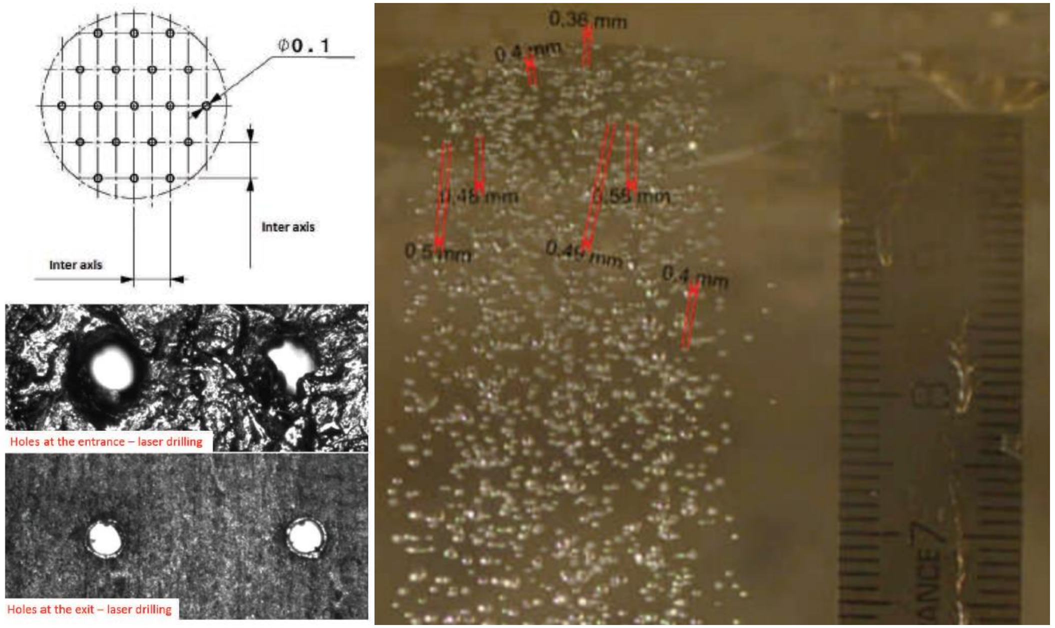
LIEBE: Liquid Eutectic lead Bismuth for Eurisol

- Target material: LBE
- Operational temperature: [200-600]°C
- Targeted isotope: ^{177}Hg (130ms half-life)

- LBE Velocity preferred: **2 m/s** ⟶ **Q=0.13 l/s**
- **Ø0.4 mm** droplets ⟶ factor **5** more release



Concept scheme, E. Noah et all, EURISOL-DS

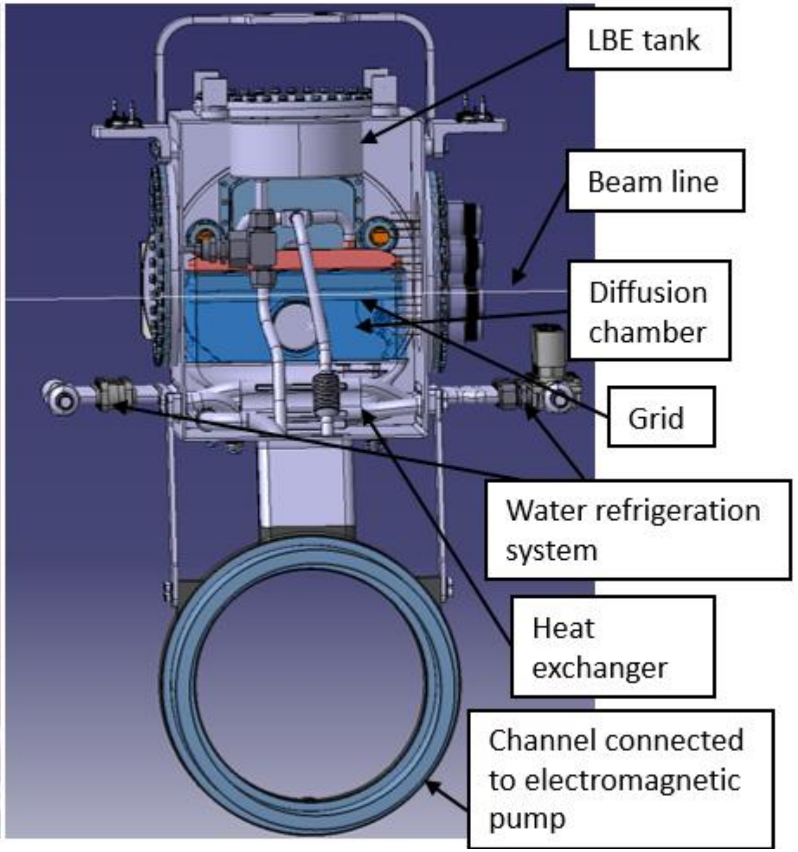


Images from Melanie Delonca CERN Ph.D thesis

Concept ⟶ Prototype ⟶ Offline commissioning ⟶ Online tests

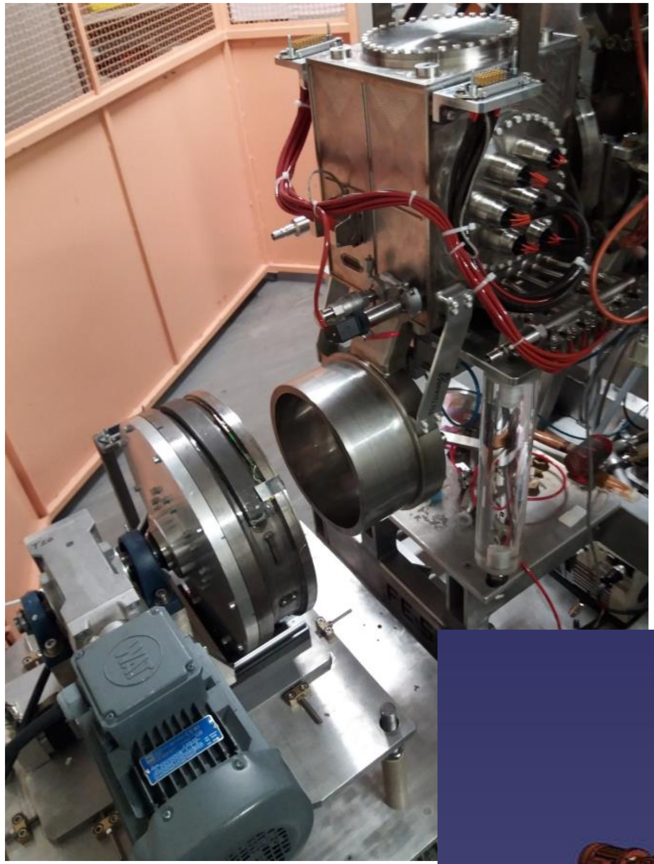
F. Boix Pamies

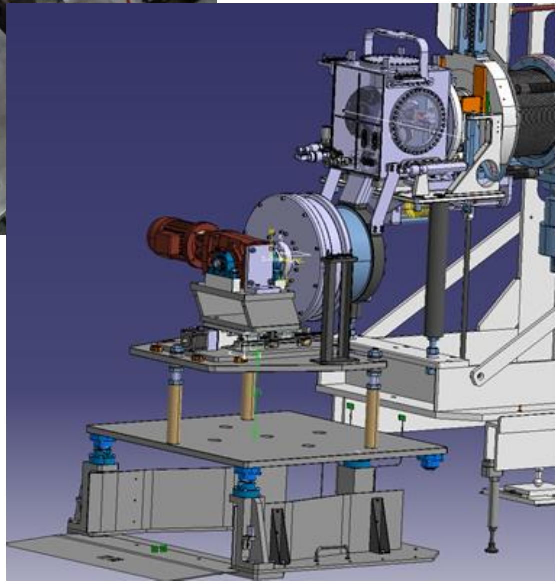
The LIEBE target: Assembled



LIEBE loop before enclosement.

LIEBE fully assembled and coupled to offline 1

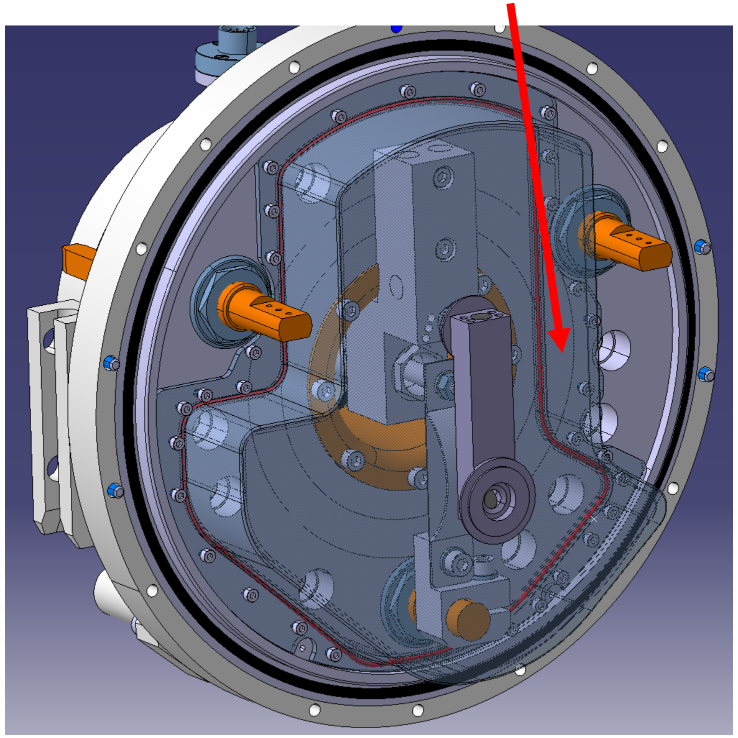


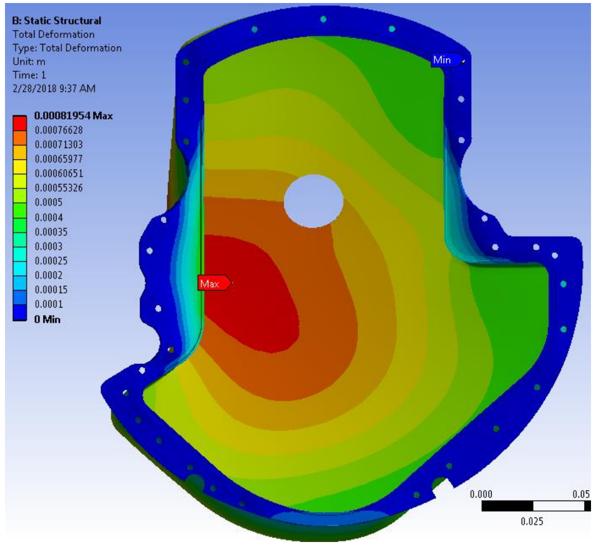


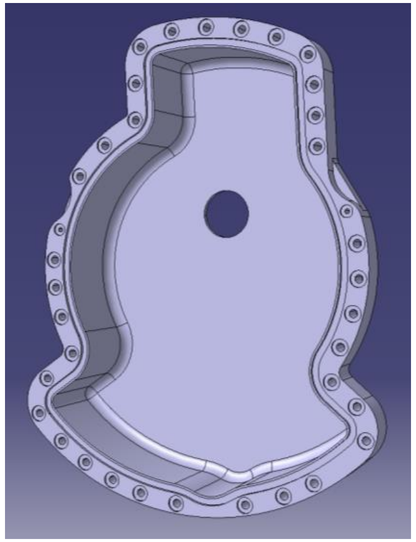
F. Boix Pamies

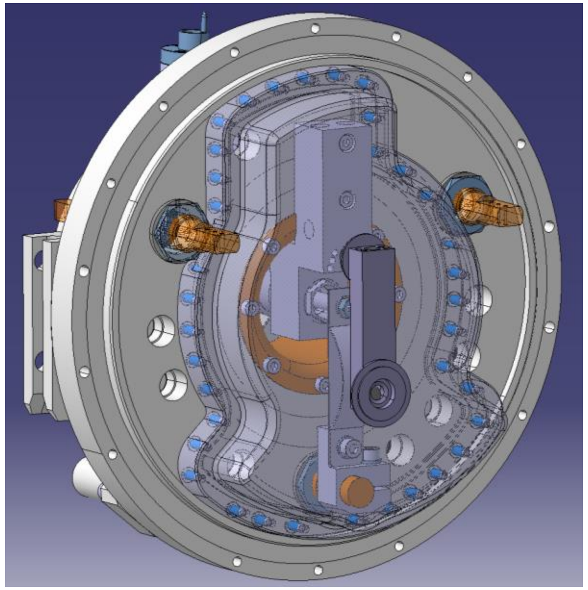
LIEBE Offline commissioning: Leak issue

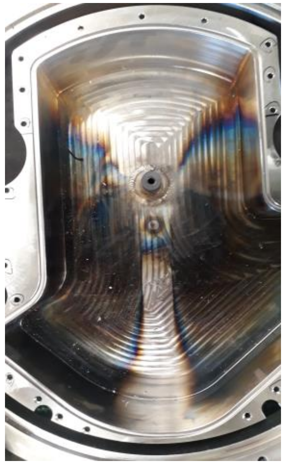
- Leak emergence:
  - Appropriate vacuum level reached with cold target
  - Leak appearing when heating ion source to 1700 ºC

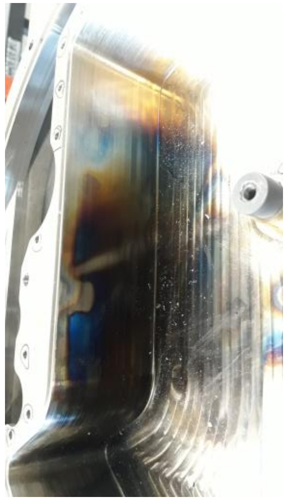












- New vacuum vessel designed and under construction
- Offline tests foreseen in JUL 2018
- Full offline Operation to be demonstrated for operational review

F. Boix Pamies

UCx production: Previous process

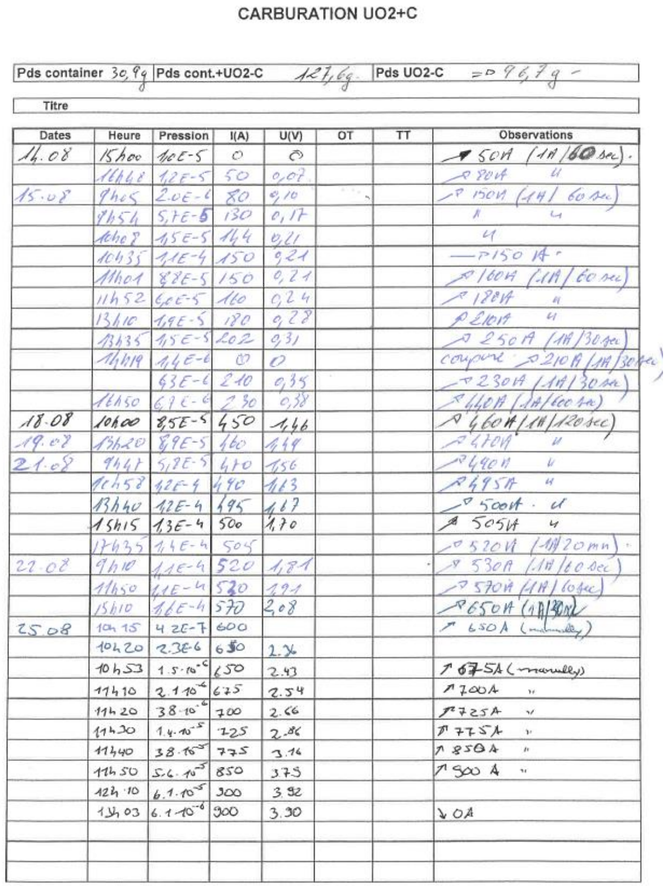
$2UO (s) + 3 C (s) \rightarrow 2 UC (s) + CO_2 (g)$

Increase heating current

Monitor pressure via webcam

Write down values manually

Detect end of carburization
by pressure drop



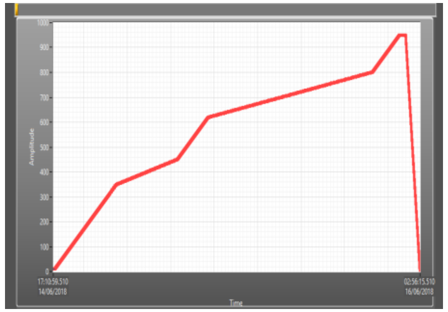
CARBURATION UO2+C

Pds container 30,9g	Pds cont.+UO2-C 127,6g.	Pds UO2-C => 96,7g -
Titre		

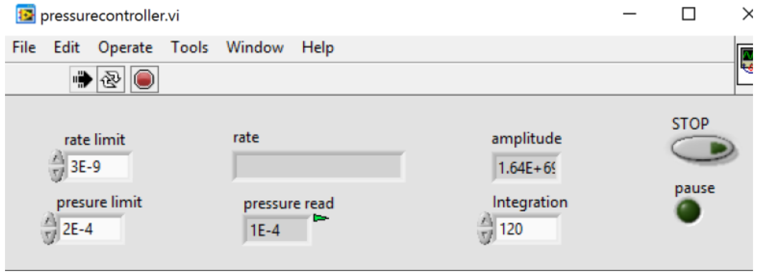
Dates	Heure	Pression	I(A)	U(V)	OT	TT	Observations
14.08	15h00	1,0E-5	0	0			↗ 50A (1A/60 sec).
	16h48	1,2E-5	50	0,07			↗ 80A "
15.08	9h05	2,0E-6	80	0,10			↗ 150A (1A/60 sec)
	9h54	5,7E-5	130	0,17			" "
	10h08	1,5E-5	144	0,21			"
	10h35	1,1E-4	150	0,21			→ 150A.
	11h01	8,8E-5	150	0,21			↗ 160A (1A/60 sec)
	11h52	6,0E-5	160	0,24			↗ 180A "
	13h10	1,9E-5	180	0,28			↗ 210A "
	13h35	1,5E-5	202	0,31			↗ 250A (1A/30 sec)
	14h19	1,4E-6	0	0			coupure ↗ 210A (1A/30 sec)
		6,3E-6	210	0,35			↗ 230A (1A/30 sec)
	16h50	6,7E-6	230	0,38			↗ 440A (1A/600 sec)
18.08	10h00	8,5E-5	450	1,46			↗ 460A (1A/120 sec)
19.08	13h20	8,9E-5	460	1,49			↗ 470A "
21.08	9h47	5,8E-5	470	1,56			↗ 490A "
	10h58	1,2E-4	490	1,63			↗ 495A "
	13h40	1,2E-4	495	1,67			↗ 500A "
	15h15	1,3E-4	500	1,70			↗ 505A "
	17h35	1,4E-4	505				↗ 520A (1A/20mn)
22.08	9h10	1,1E-4	520	1,81			↗ 530A (1A/60 sec)
	11h50	1,1E-4	530	1,91			↗ 570A (1A/60 sec)
	15h10	1,6E-4	570	2,08			↗ 650A (1A/30s)
25.08	10h15	4.2E-7	600				↗ 650A (manually)
	10h20	2.3E-6	650	2.36			
	10h53	$1.5\cdot10^{-6}$	650	2.43			↗ 675A (manually)
	11h10	$2.1\cdot10^{-6}$	675	2.54			↗ 700A "
	11h20	$3.8\cdot10^{-6}$	700	2.66			↗ 725A "
	11h30	$1.4\cdot10^{-5}$	725	2.86			↗ 775A "
	11h40	$3.8\cdot10^{-5}$	775	3.16			↗ 850A "
	11h50	$5.6\cdot10^{-5}$	850	3.75			↗ 900A "
	12h10	$6.1\cdot10^{-5}$	900	3.92			
	13h03	$6.1\cdot10^{-6}$	900	3.90			↘ 0A

May result in inconsistent carburization.
Time consuming (~10 days).

Automatic UCx Production



- Setting a ramp
- Set thresholds
- Start carburization

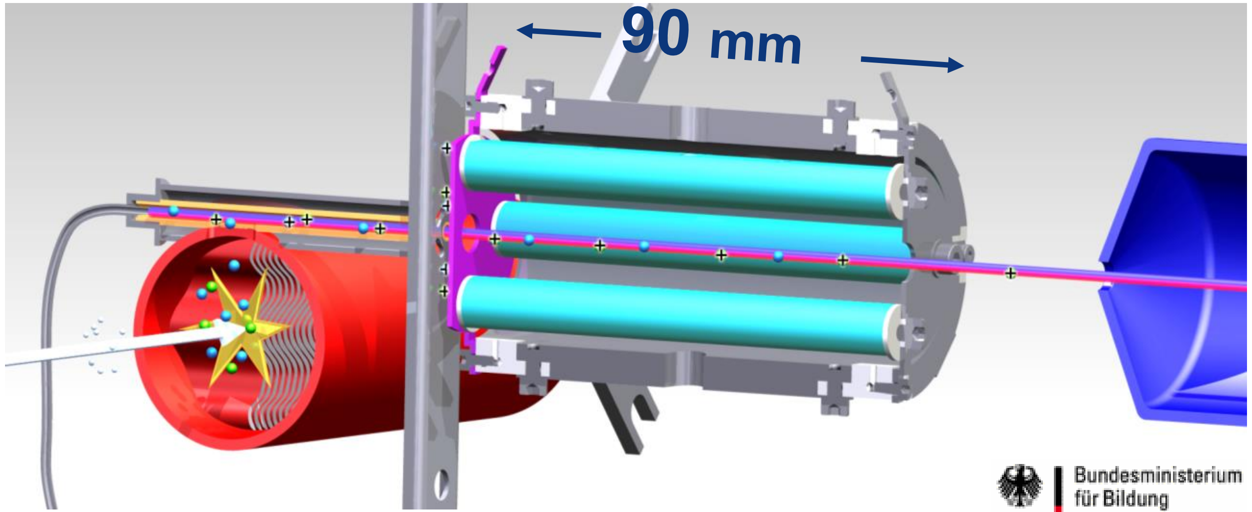


- Heating is regulated automatically

Successfully used for **UC611** and **UC618**
Finished in **4 days** without human intervention
Used for UC and ThC production throughout 2018

LIST v 1.0

HFS studies of polonium / supression of francium (IS456, September 2012)



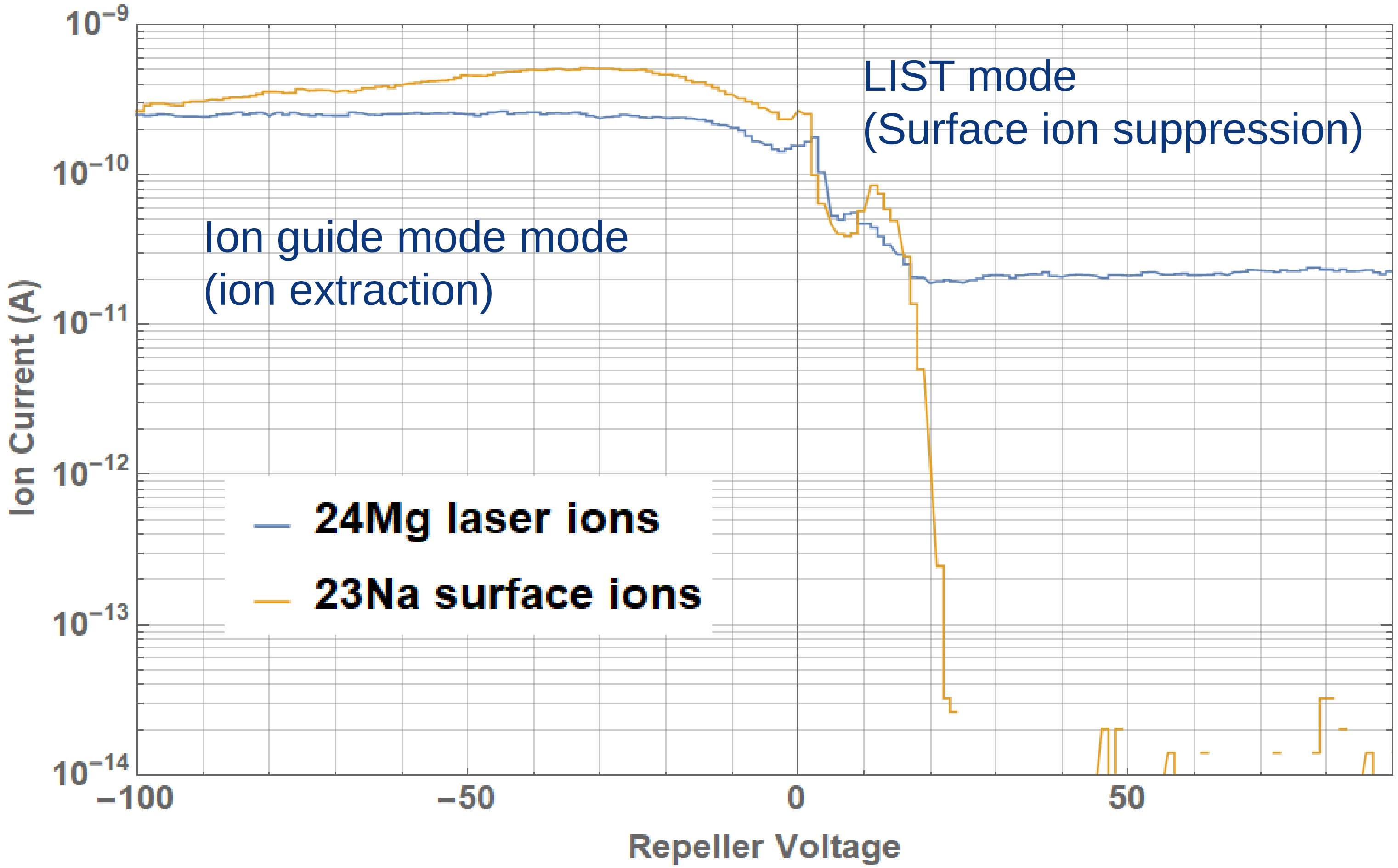
Bundesministerium
für Bildung
und Forschung

Isobaric suppression > 1000, efficiency loss ≈ 50

On-line implementation and first operation of the Laser Ion Source and Trap at ISOLDE/CERN, D. Fink et al**.,** **NIMB 344**, 83-95 (2015)

In-Source Laser Spectroscopy with the Laser Ion Source and Trap: First Direct Study of the Ground-State Properties ^{217,219}*Po*, D. Fink et al., **PRX 5**, 011018 (2015)

Results: 90mm „standard“ LIST /w 2 repeller electrodes @ ISOLDE



- ^{24}Mg laser ion loss factor ~ 20-30 (as seen off-line)
- Required repeller voltage slighlty reduced
  Suppression factor > 50.000

Final on-line characteristics with SiC target:

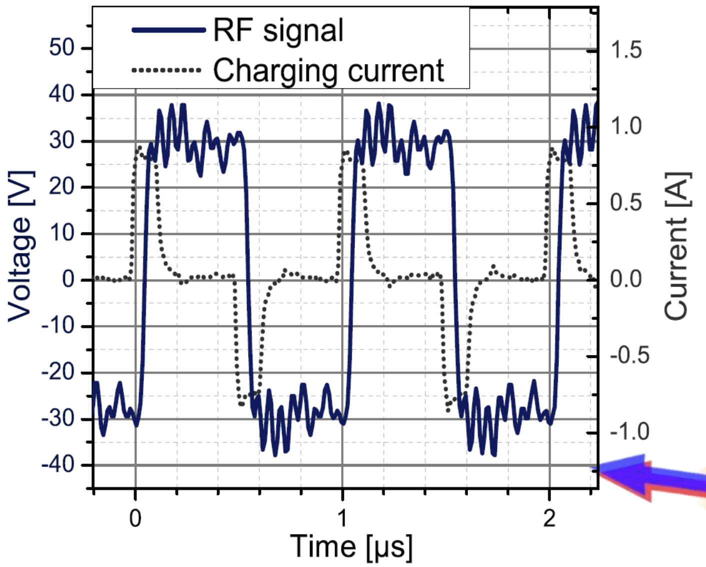
- Suppression factor: **1E6** (^{21}Na)
- Laser ion loss factor: **27** (on ^{22}Mg)
- No ^{22}Na seen in IS614 detectors

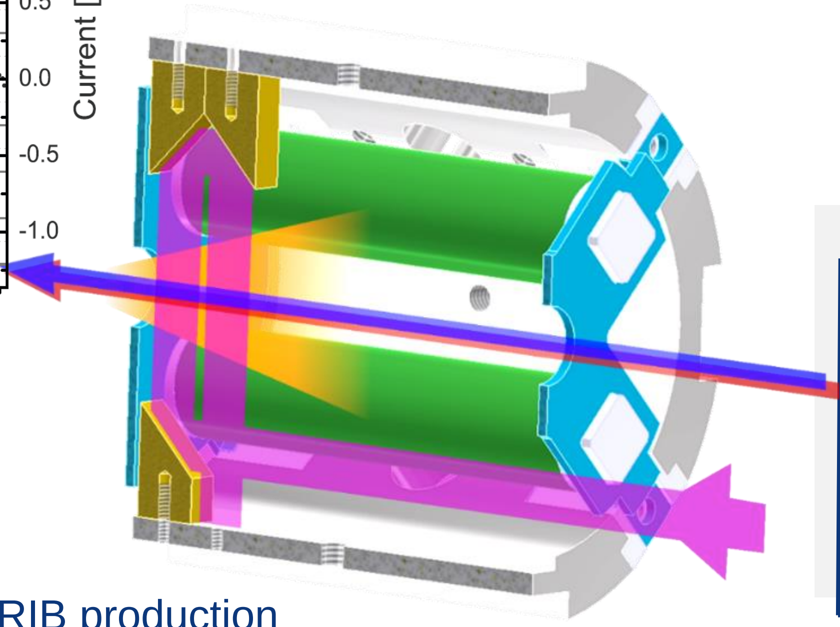
Ongoing developments

Square wave RF confinement by MHz switching:

- suppression of RF box attached to target unit
- simplified control of symmetricity, amplitude, offset
- Supply to source via multipin connector

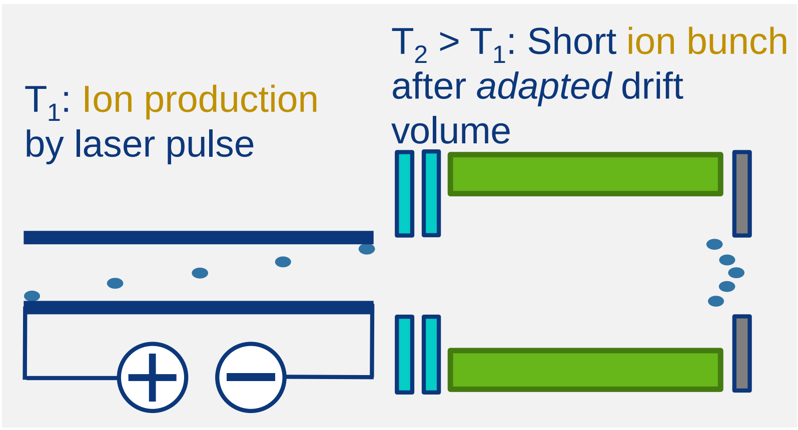
S. Raeder *et al.*, Rev. Of Sc. Instr. 85, 033309 (2014)



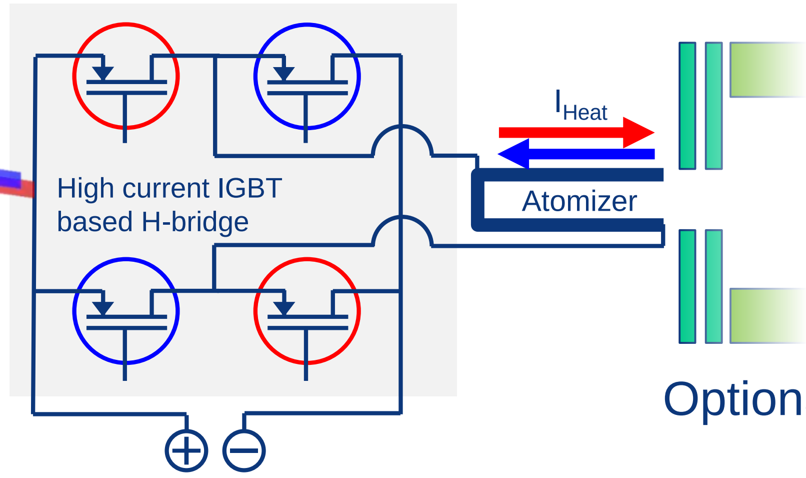


Perpendicular laser irradiation:
Doppler-free spectroscopy and RIB production

ToF-LIS: Field-free drift volume (= LIST)

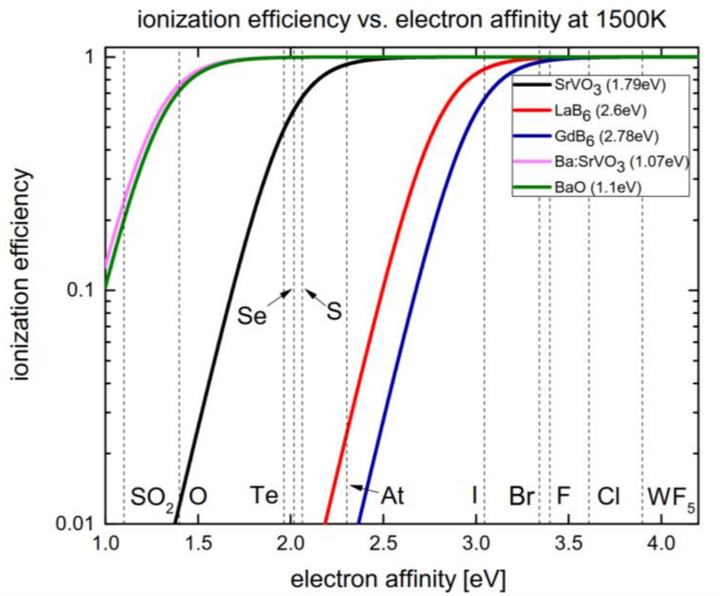


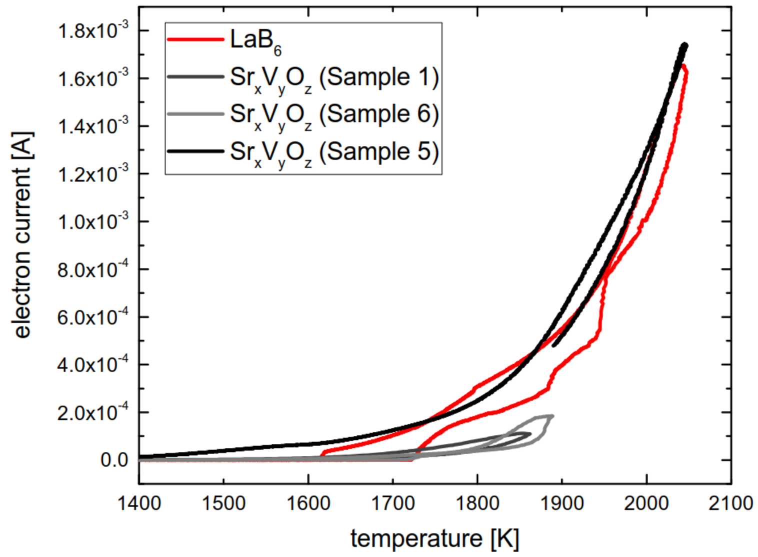
In-situ heating current switching:
Fast polarity swapping and pulsing



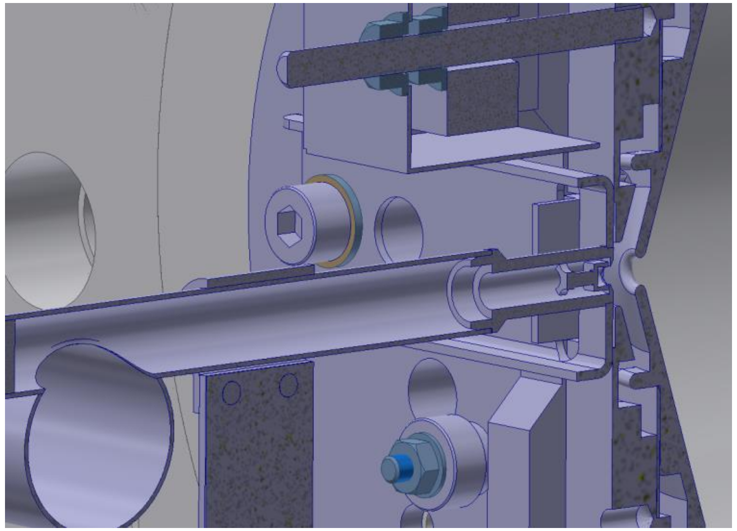
Optional LIST

Low work function materials for negative ion production

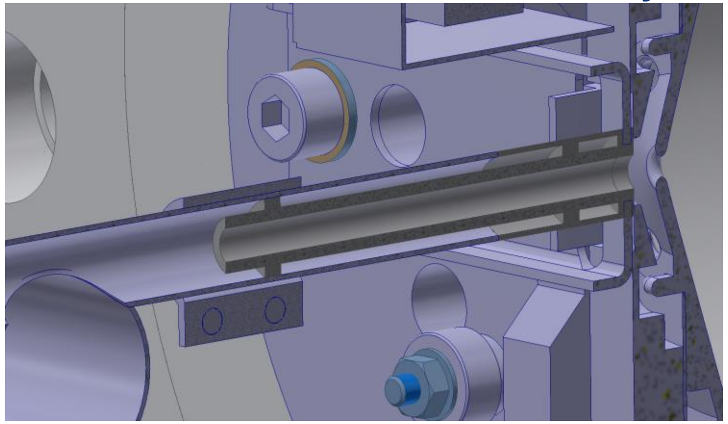




MK4 – Pellet source



Tubular low workfunction cavity



Improvement of ionization efficiency:

- Elements with low affinities are not efficiently ionized by LaB_6
- New compounds needed:
  - $SrVO_3$ with expected work function <2eV

First steps:

- Production of suitable candidates
- Electron emission tests with LaB_6 as benchmark
- Performance studies

Next steps:

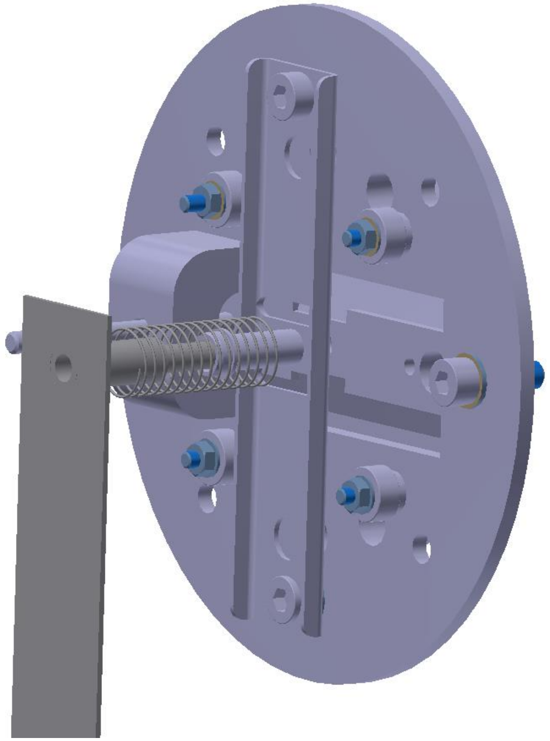
- Compare geometries offline

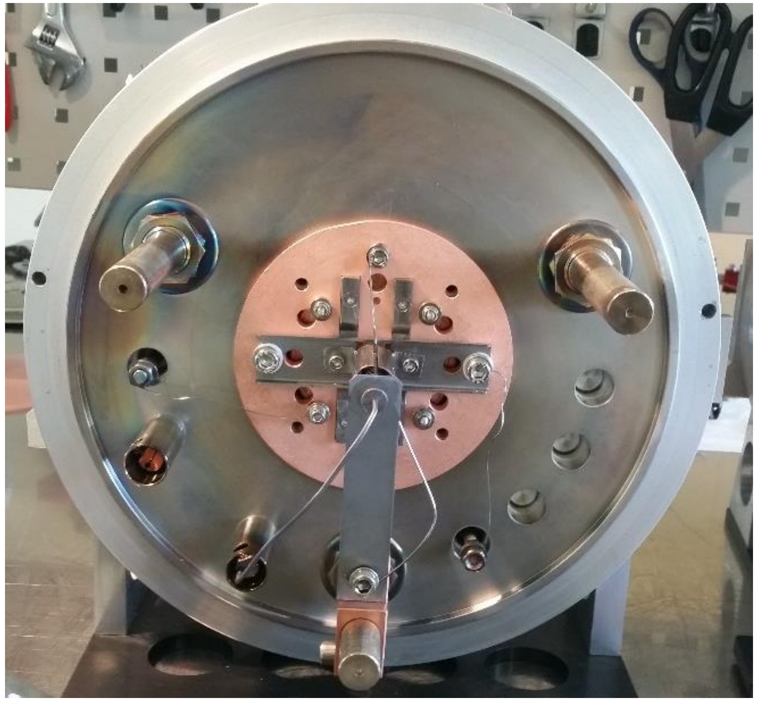
D.Leimbach

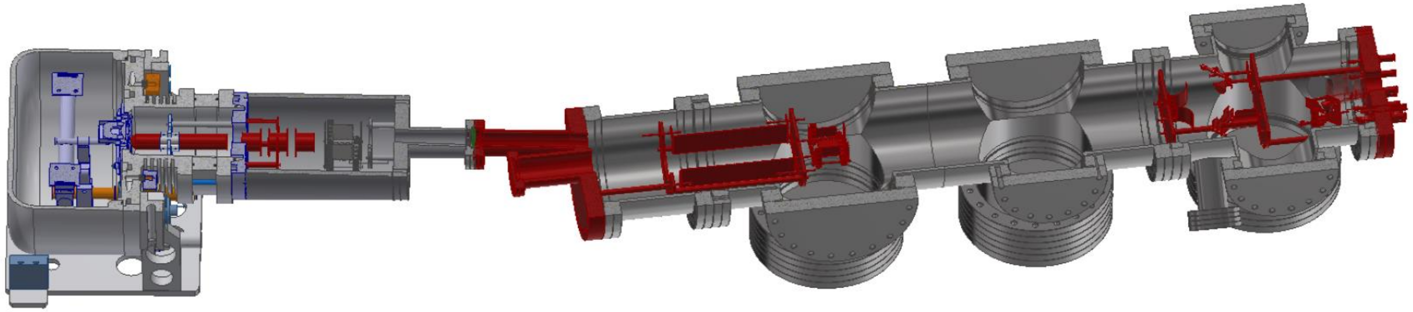
#570 GANDALPH negative Ion source (GANDIS)

- Goal: off-line testing of photodetachment setup

- Ion extraction via negative source potential
  - ➢ Electrical Isolation of the source from the base avoids faraday cage
  - ➢ external heating required

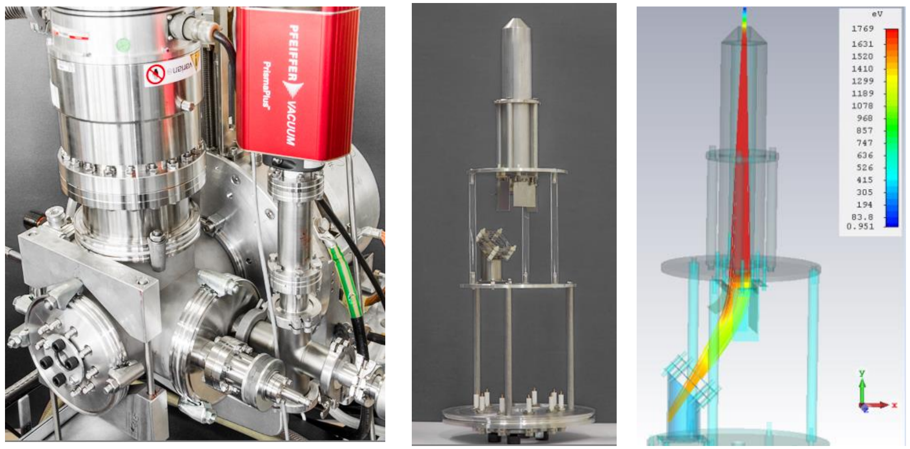




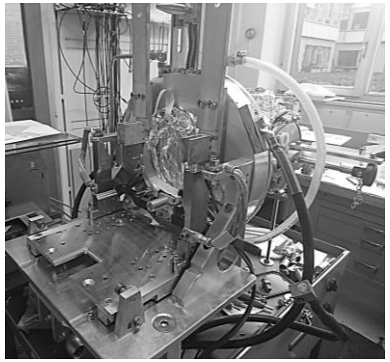


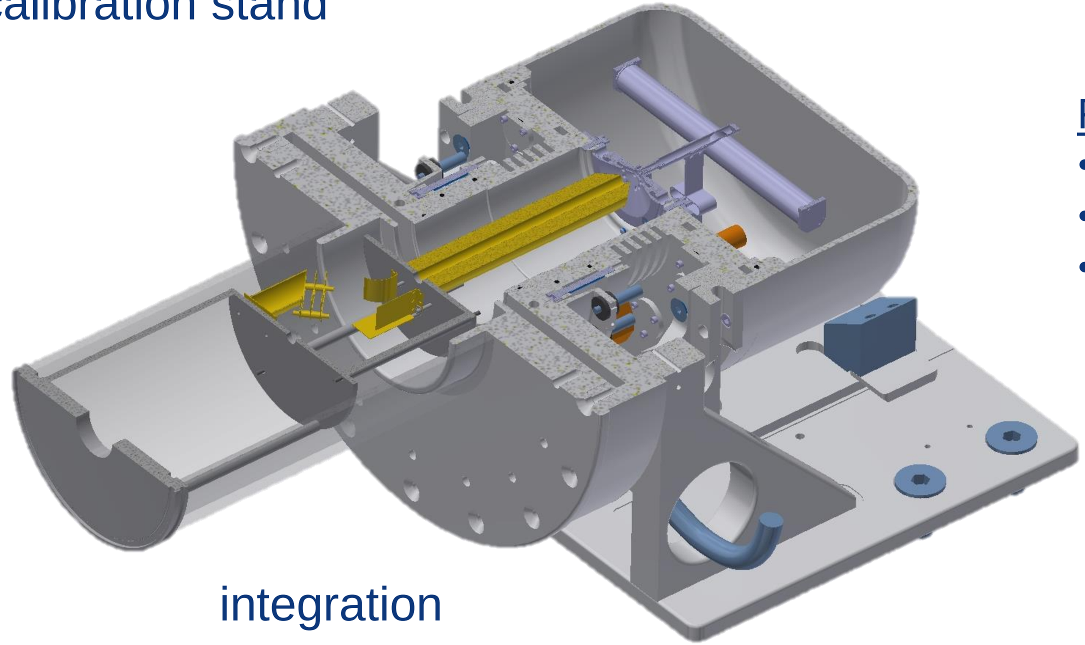
D. Leimbach

Dedicated test stand for ion source development



ISOLDE calibration stand





integration

Main features:

- ion **beam extraction** and detection
- residual gas analyzer (RGA)
- **automated control and data recording (LabVIEW)**

First application:

- **negative ion source** development
- investigation of source poisoning and regeneration

Future plans:

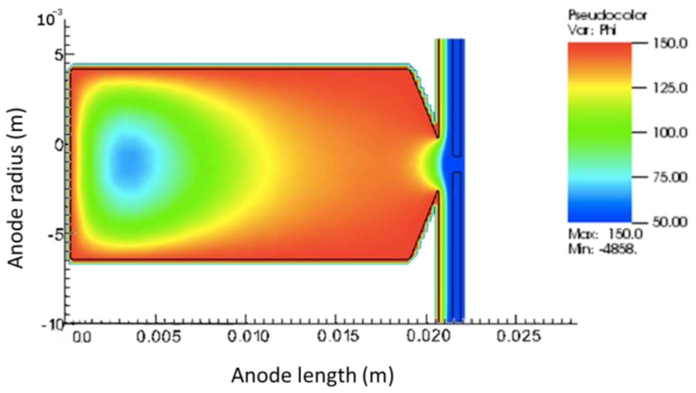
- long-term performance studies
- thermal stress tests
- destructive tests
  - **operational limits**
  - **failure mode analysis**

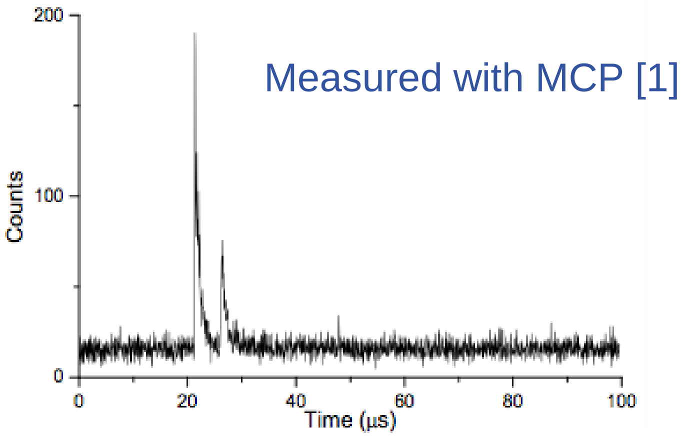
D.Leimbach

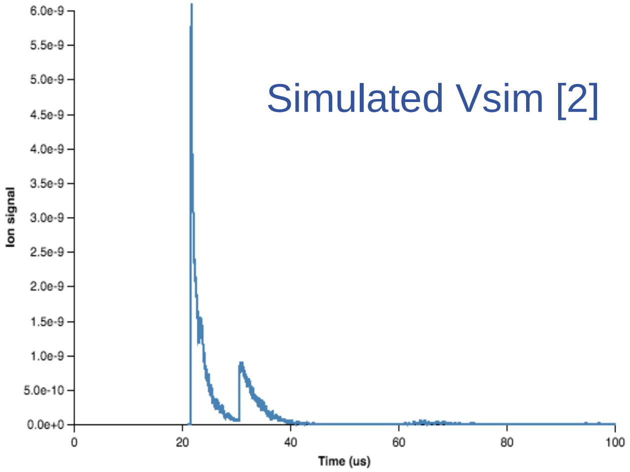
Ion source simulations: VSim

Is a flexible, multiplatform, multiphysics software tool for running computationally intensive electromagnetic, electrostatic, magnetostatic, and plasma simulations in the presence of complex dielectric, magnetic, and metallic shapes.
(https://www.txcorp.com/vsim)

Goal: Full Simulation **VADIS ion source**







- 1st reproduction of electrostatic field distribution inside the VADIS using PIC code

[1] T. Day Goodacre et al., NIM B 376, 39 (2016). [2] *Y. Martinez et al. Accepted.*

Y.Martinez

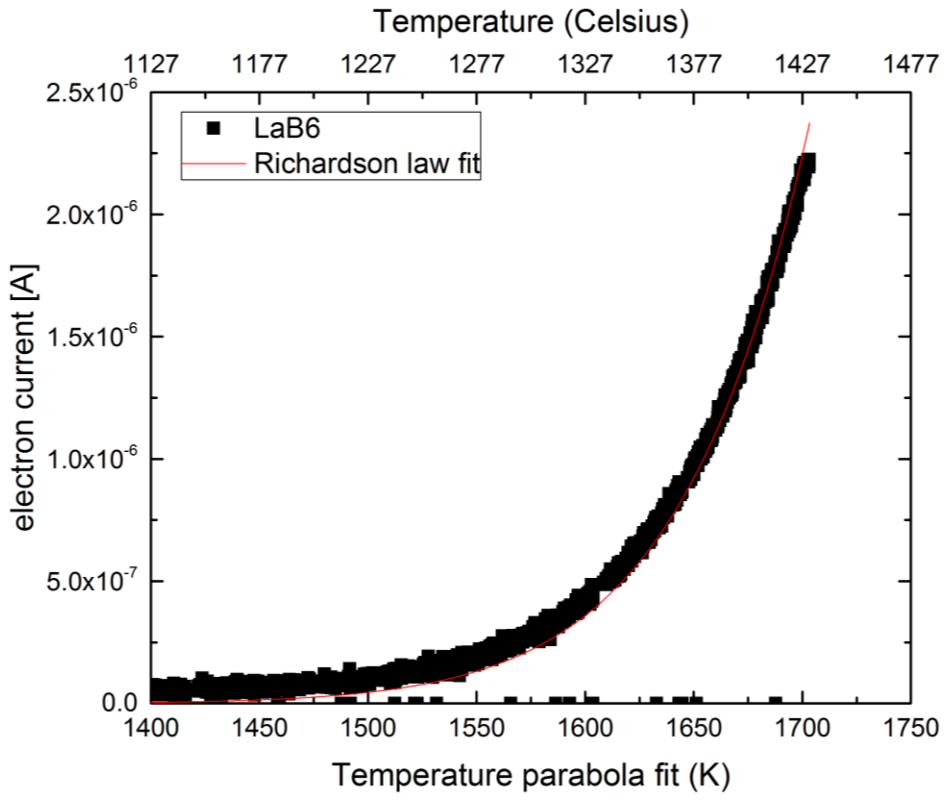
Ion source simulations: VSim software

TECH-X
SIMULATIONS EMPOWERING YOUR INNOVATIONS

- Validation of hot cavity ion source model :

  electron emission measurements performed at CERN-ISOLDE (ongoing)

Collaboration with SCK•CEN



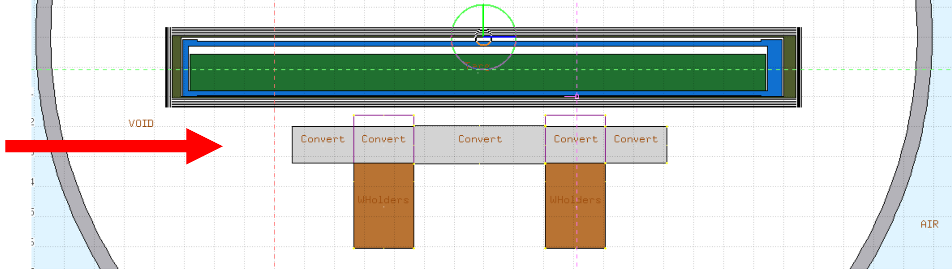
Vsim workshop @ EMIS2018

Registration is open. Link via EMIS2018 website

D. Leimbach

P2n Converter

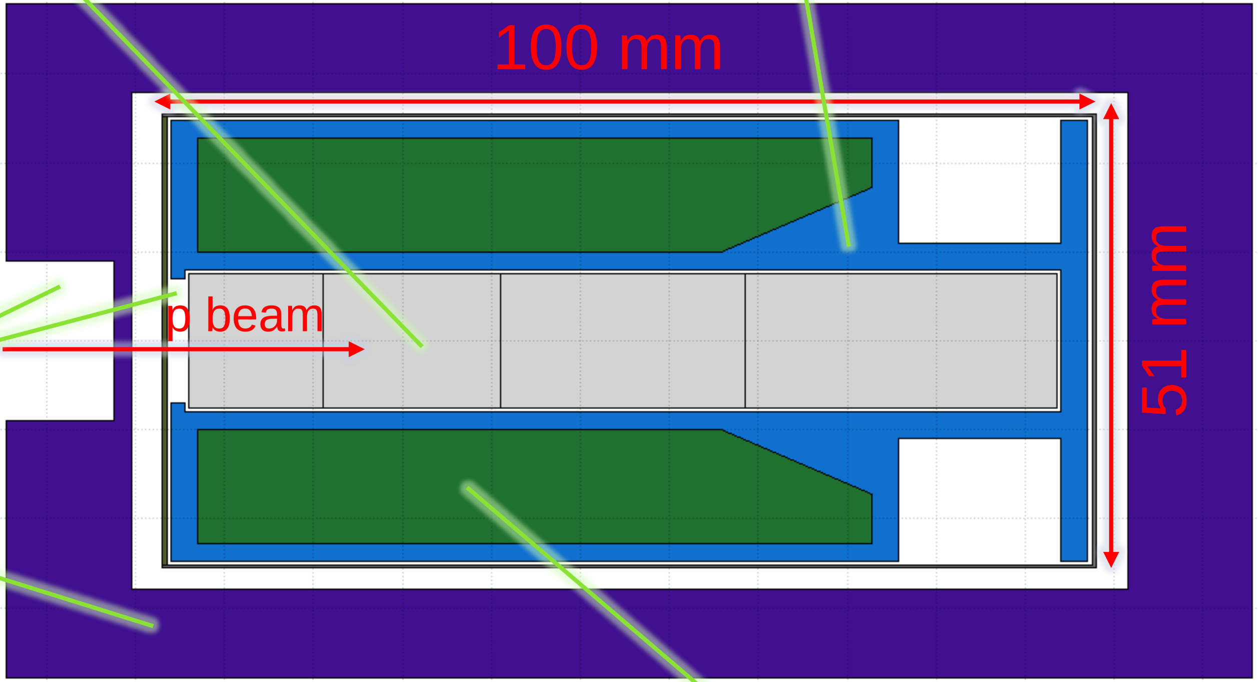
Converter very close to uranium carbide – high neutron flux!

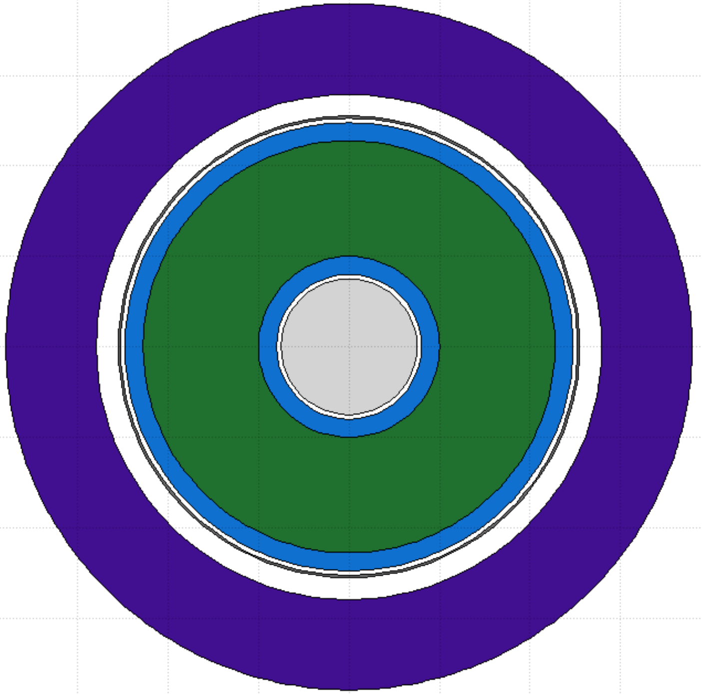


W converter

- Ø15 mm (12 mm - standard)
  - Sliced to mitigate thermal shocks
- Operated at 2000 °C

Graphite container



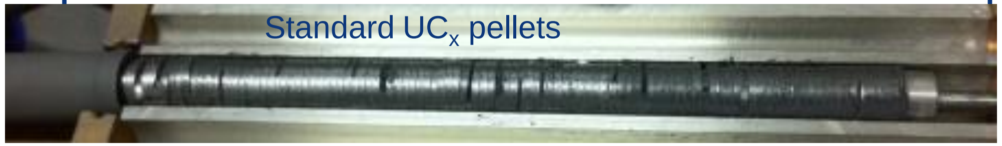


Avoid proton scattering

Thermal Shielding

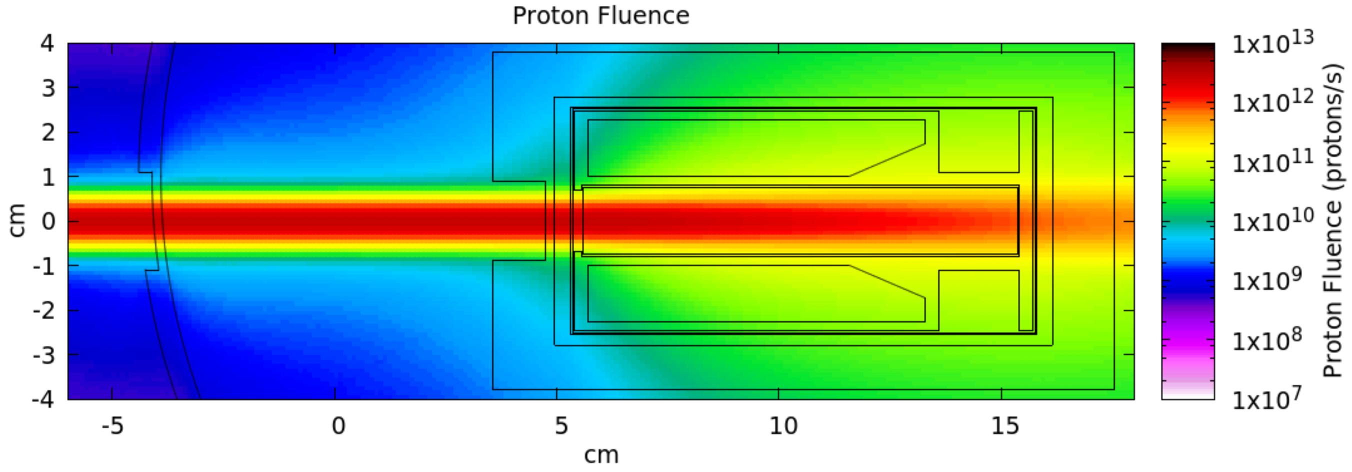
- Sigratherm® - “graphite foam”
- 0.2 g/cm^3
- Low thermal conductivity

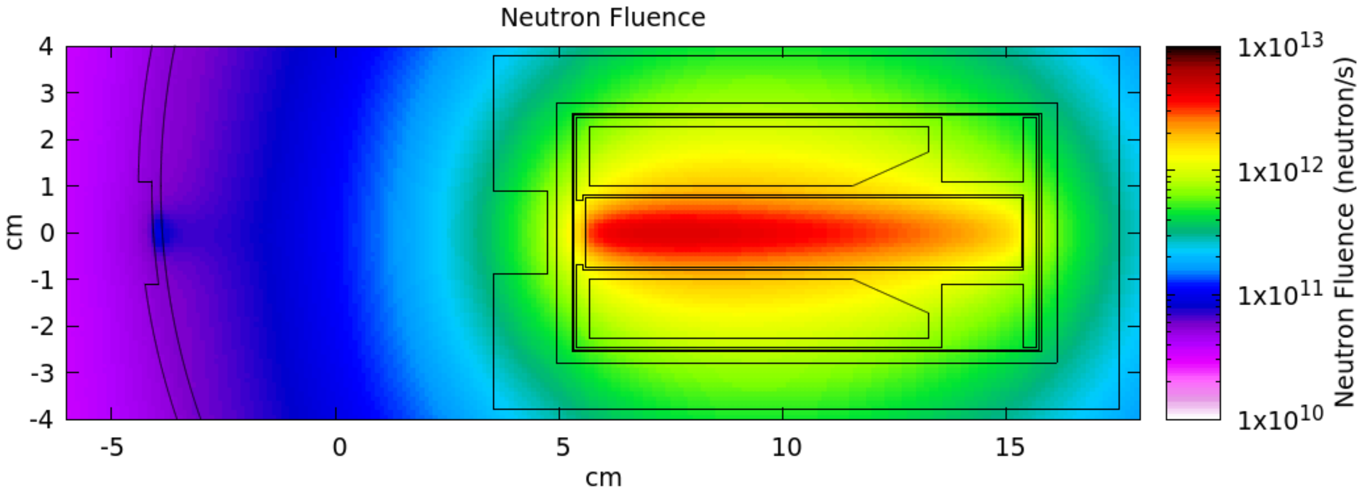
UC_x: new procedure has to be made for annular shape

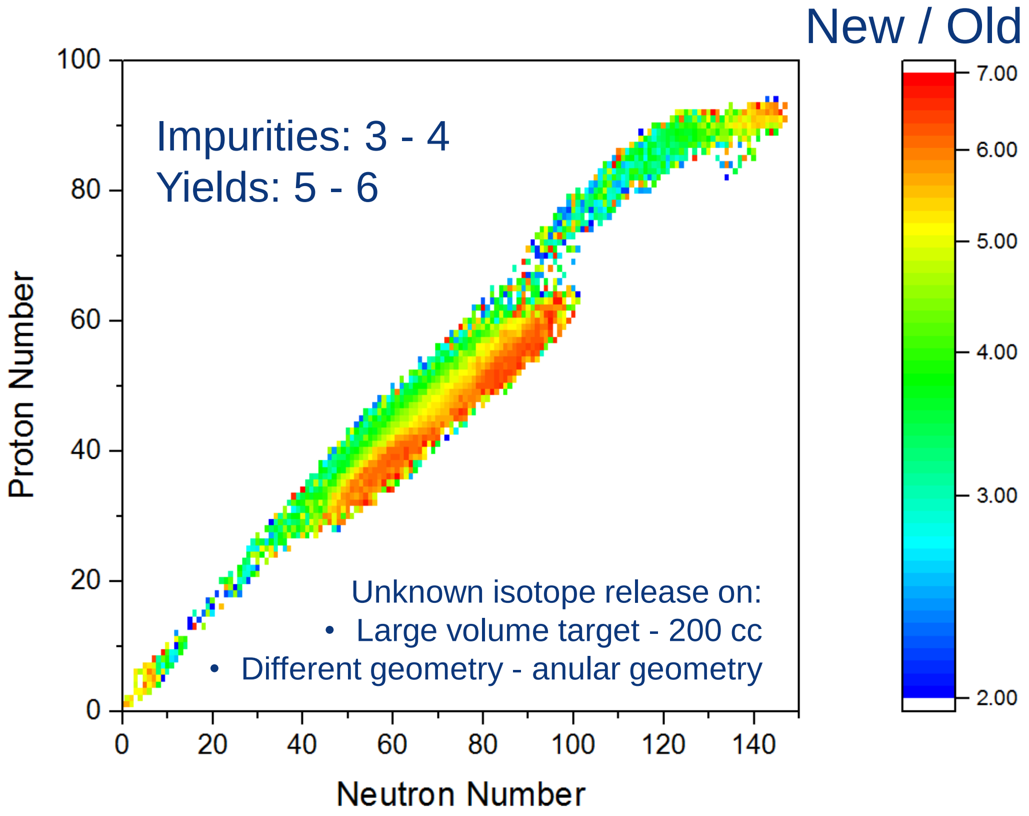


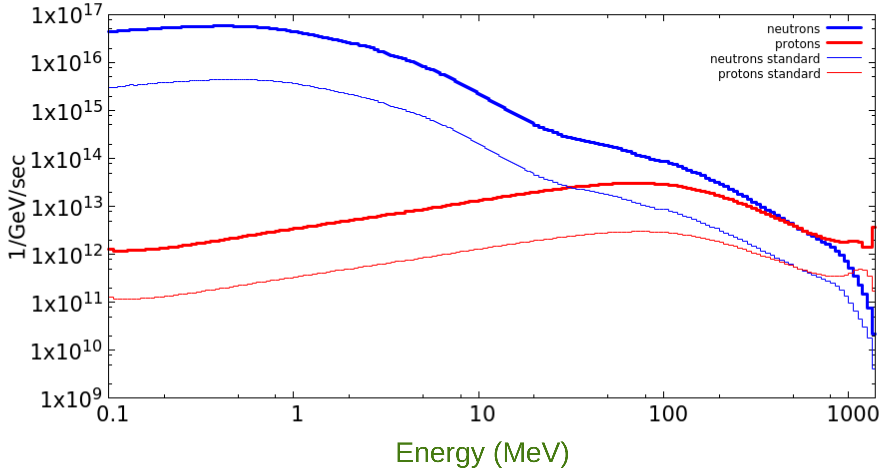
Standard UC_x pellets

P2n Converter

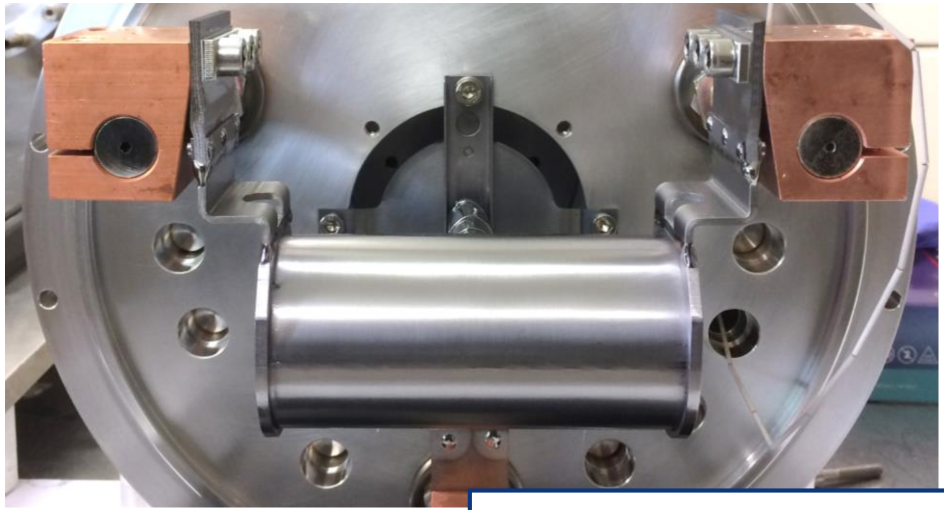




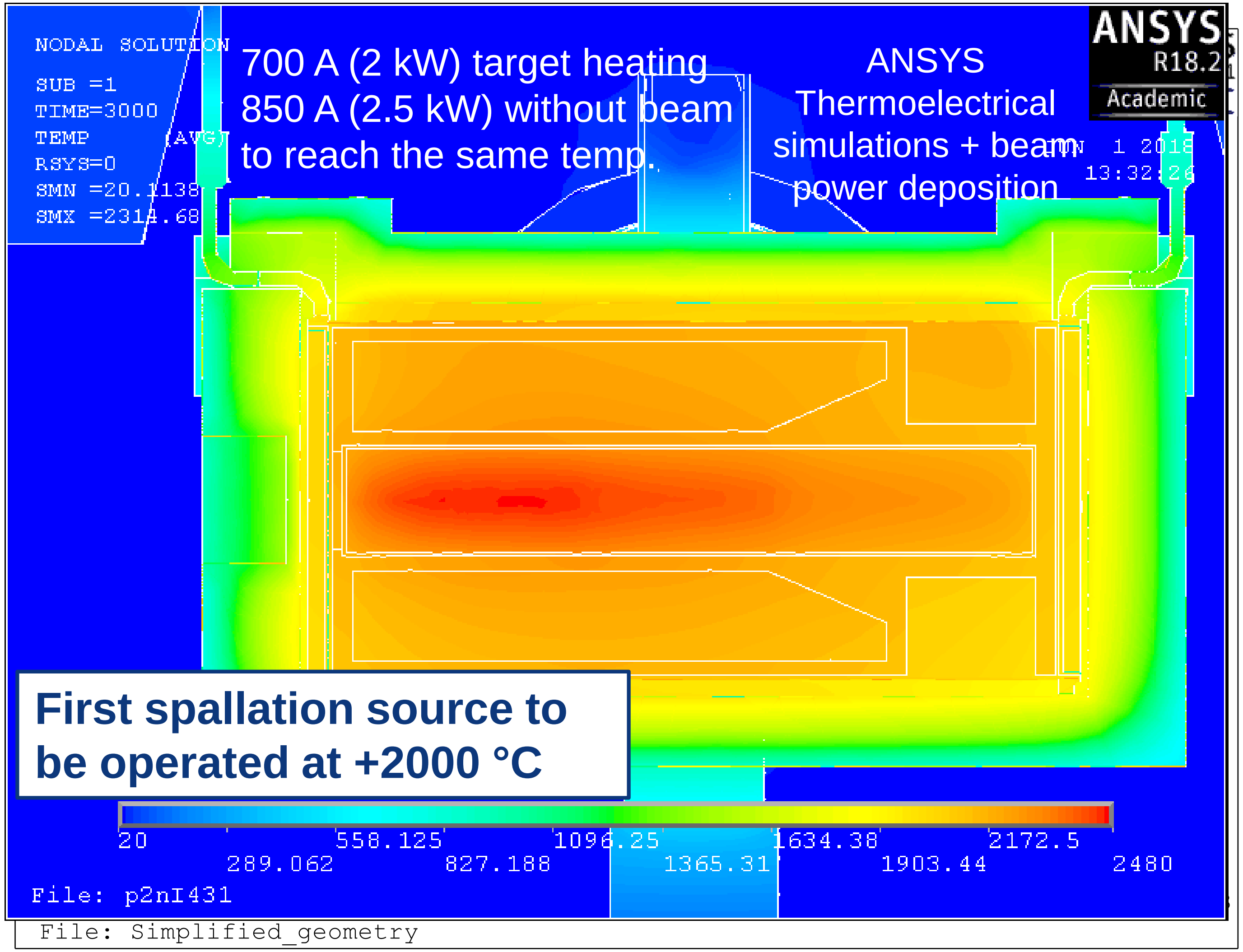




p2n Challenges: beam heating



2150 °C have been reached in the target

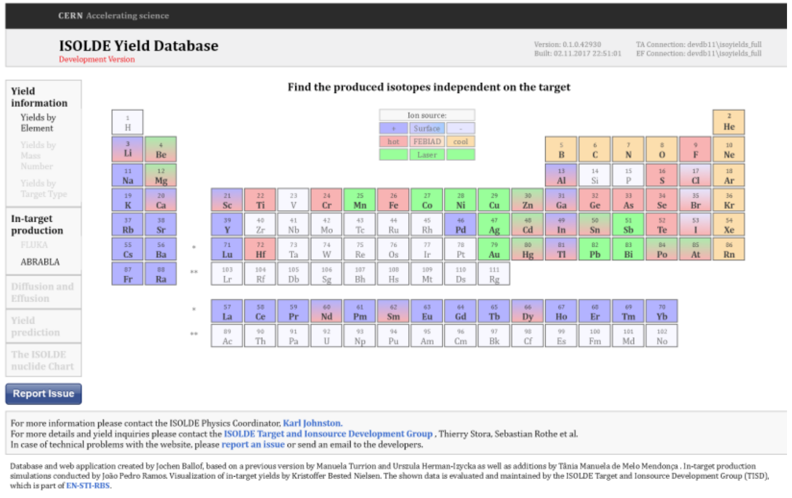


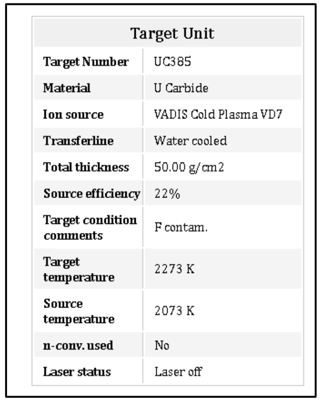
700 A (2 kW) target heating
850 A (2.5 kW) without beam to reach the same temp.

ANSYS Thermoelectrical simulations + beam power deposition

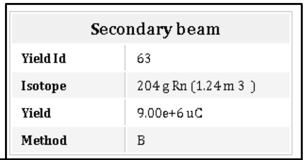
First spallation source to be operated at +2000 °C

ISOLDE Yield Database YYDB(https://isoyields2.web.cern.ch)

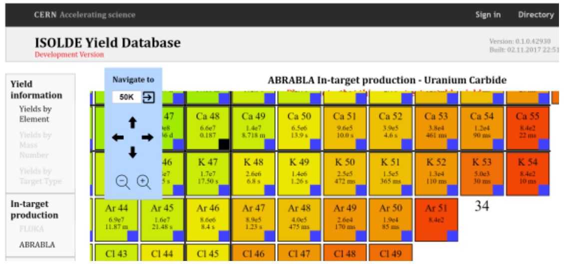


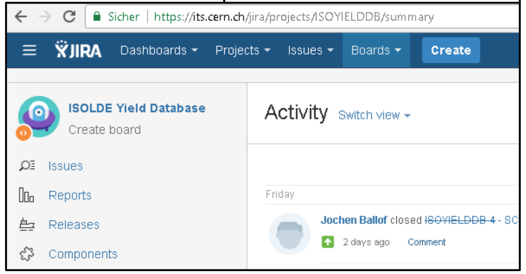


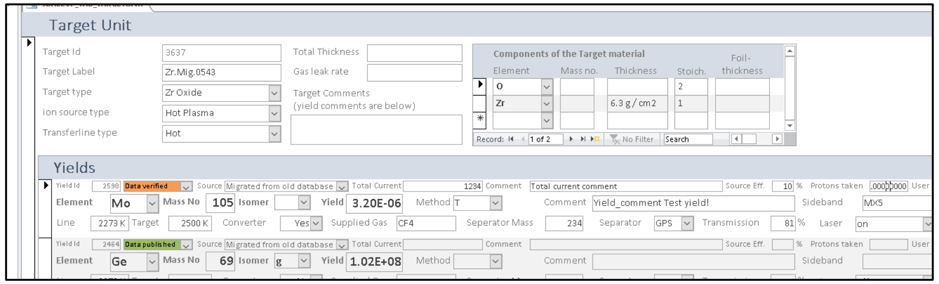
Target Unit	
Target Number	UC365
Material	U Carbide
Ion source	VADIS Cold Plasma VD7
Transferline	Water cooled
Total thickness	50.00 g/cm2
Source efficiency	22%
Target condition comments	F contam.
Target temperature	2273 K
Source temperature	2073 K
n-conv. used	No
Laser status	Laser off

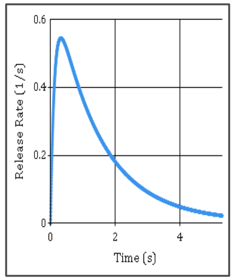


Secondary beam	
Yield Id	63
Isotope	204 g Rn (1.24 m 3)
Yield	9.00e+6 uC
Method	B









Features

- CERN SSO
- New Database design
- In target production (ABRABLA, FLUKA)
- Release curves available
- More target details visible
- Issue tracking

Philosophy

- All measurements (TISD, USERS) get entered into YYDB
- Manually change attribute (measured -> validated -> published)
- Attribute determines visibility

Future

- Web based interface allows entering of yields to registered users
- Add yield prediction
- Establish link to CRIBE database

J.Ballof

CERN EN ENGINEERING DEPARTMENT

TISD @ ISOLDE, 2018
(in order of appearance)

Dedicated TISD

- RILIS offline work Q1-Q2
- LIST 2.0 Q2
- M(CO)x formation @ MEDICIS irradiation point Q2-Q3 — ongoing
- p2n converter prototype test Q3-Q4 — ongoing
- LIEBE online Q4 — ongoing

Opportunistic TISD

- Si yields Q2-Q4 — Planned for #658
- RILIS 2photon online Q1-Q4
- VADLIS 1.5 online use Q2-Q4

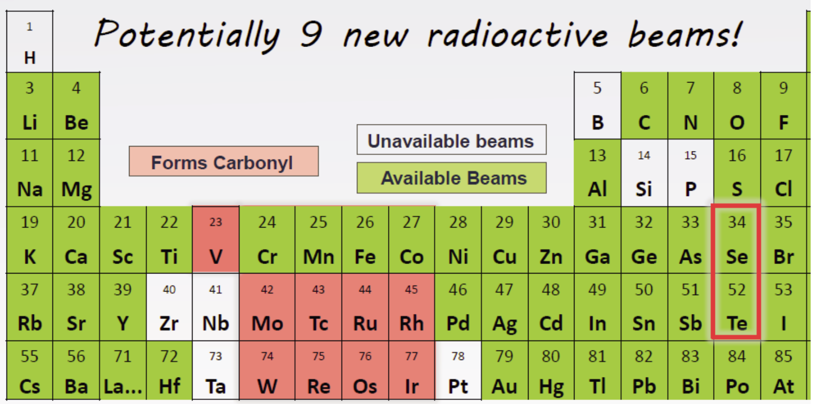
Offline tests required, ongoing

Thanks to the TISD and RILIS teams

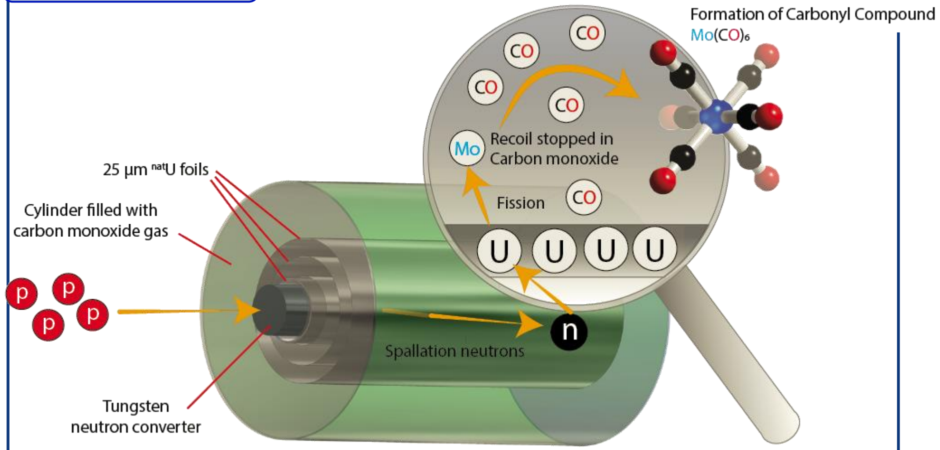
Volatile Carbonyl Compounds for New Refractory Beams at ISOLDE

J. Ballof[1,2], C. Seiffert[1], Ch. E. Düllmann[2,3,4], J. P. Ramos[1], S. Rothe[1], T. Stora[1], A. Yakushev[3,4]

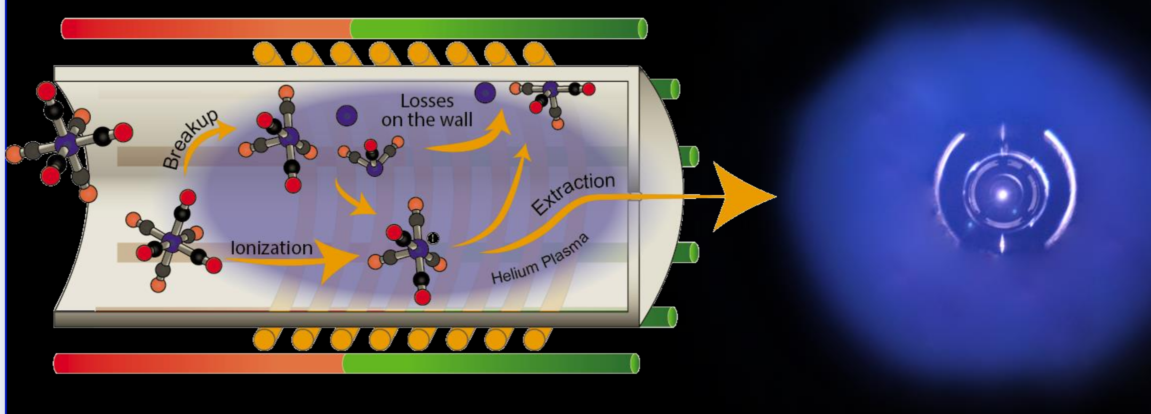
Motivation

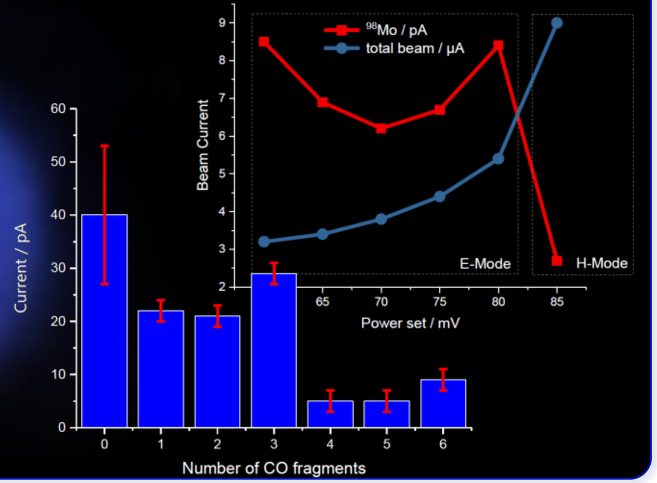


Production



Ionization



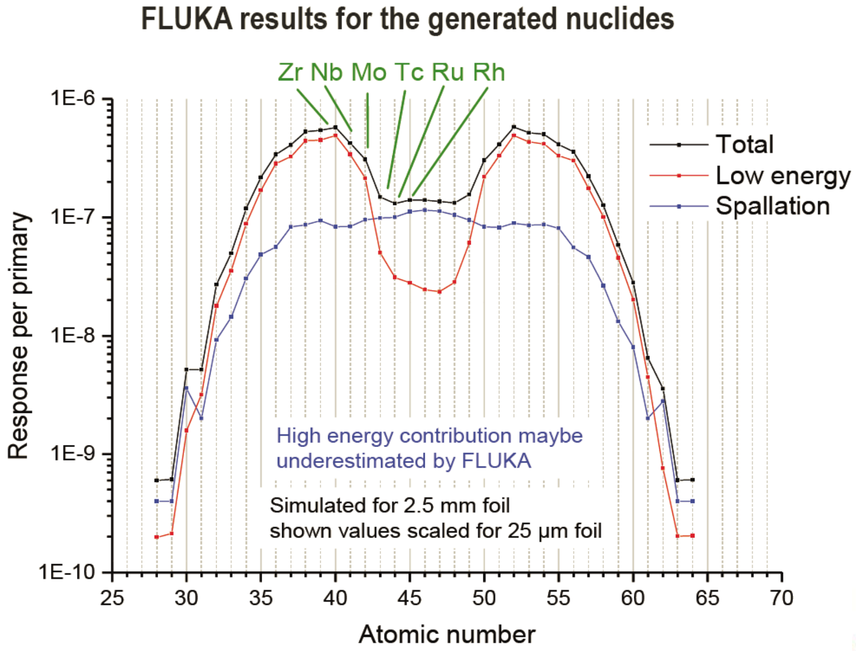


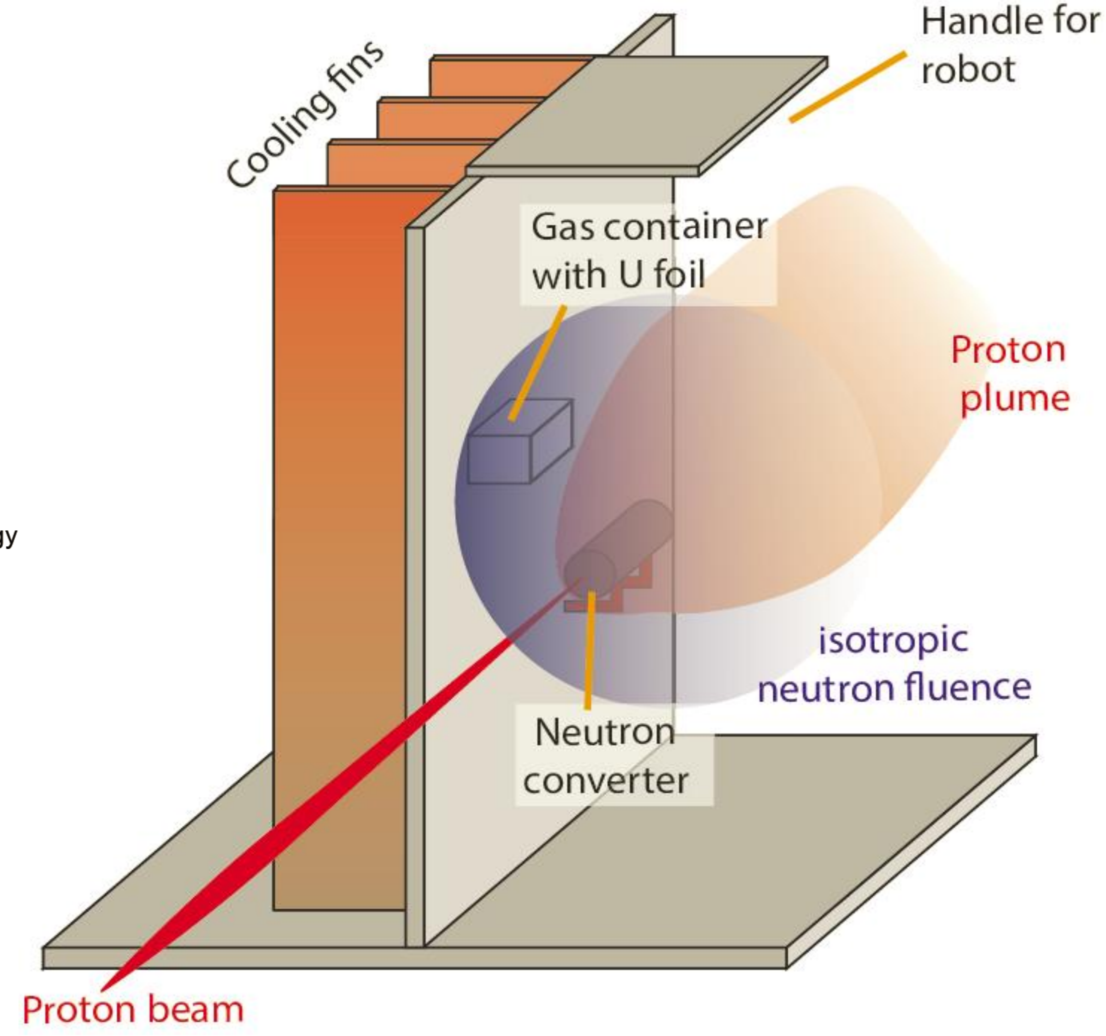
J.Ballof

Up next

Irradiations at MEDICIS

carbonyl formation and Stability at ISOLDE



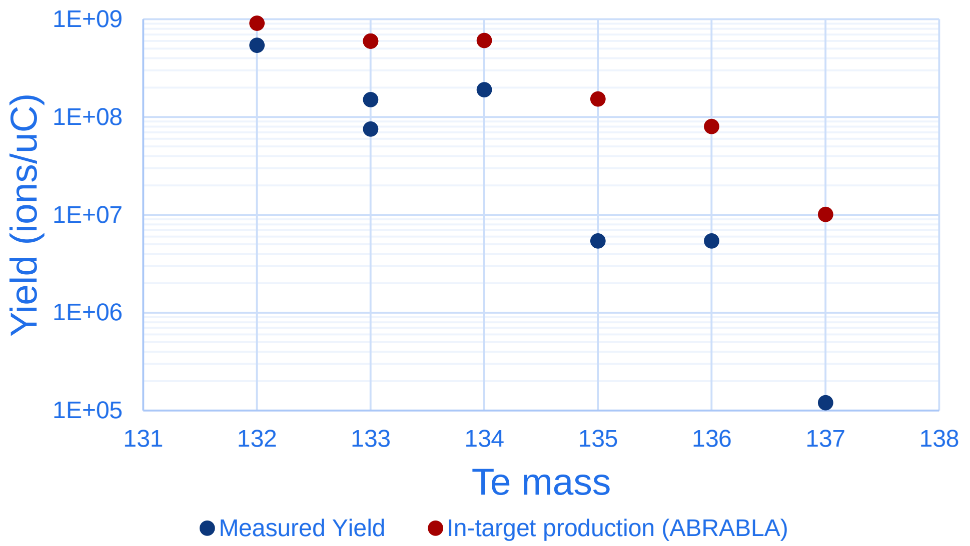


J.Ballof

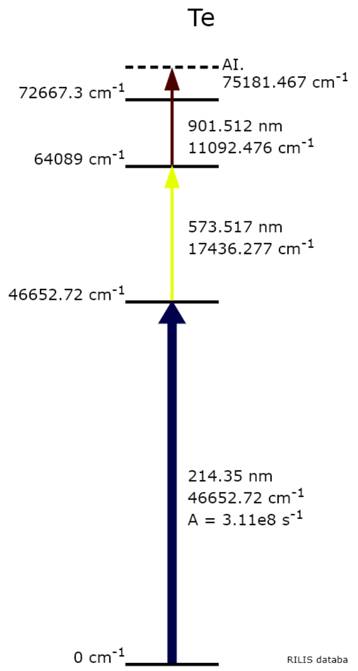
Tellurium beams

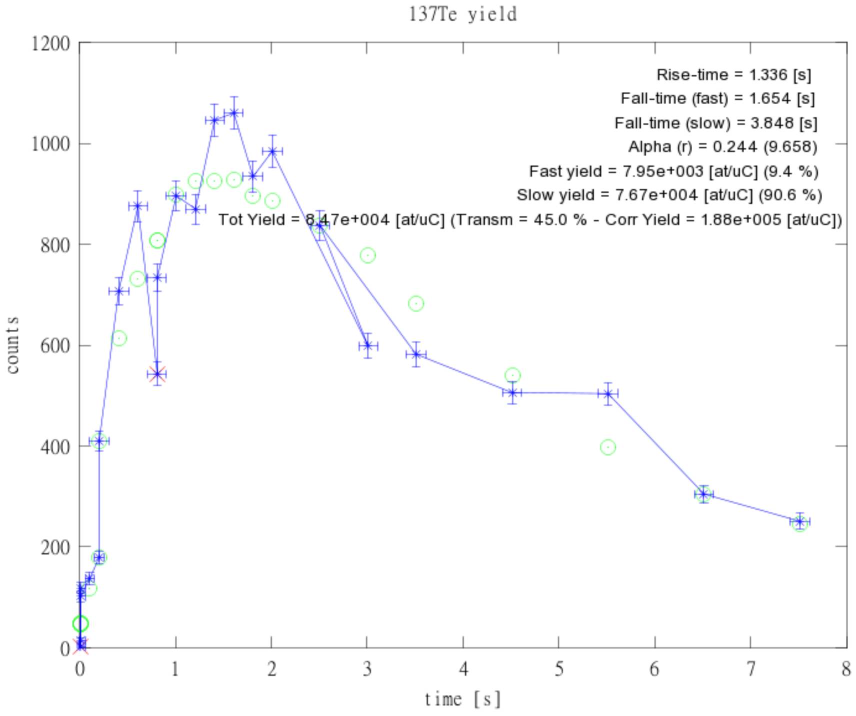
Target #601 UC n

A (Te)	t1/2	Te Yield	Cs yield	t1/2	A (Cs)
132	76.3	5.40E+08		6.47 d	132
133	12.5 m	7.50E+07		stable	133
133m	55.4 m	1.50E+08		stable	133
134	41.8 m	1.90E+08	1.10E+09	2.90 h	134m
135	18.6 s	5.40E+06	5.50E+08	53 m	135m
136	17.5 s	5.40E+06	5.30E+08	19 s	136m
137	2.5 s	1.20E+05		30.17 y	137

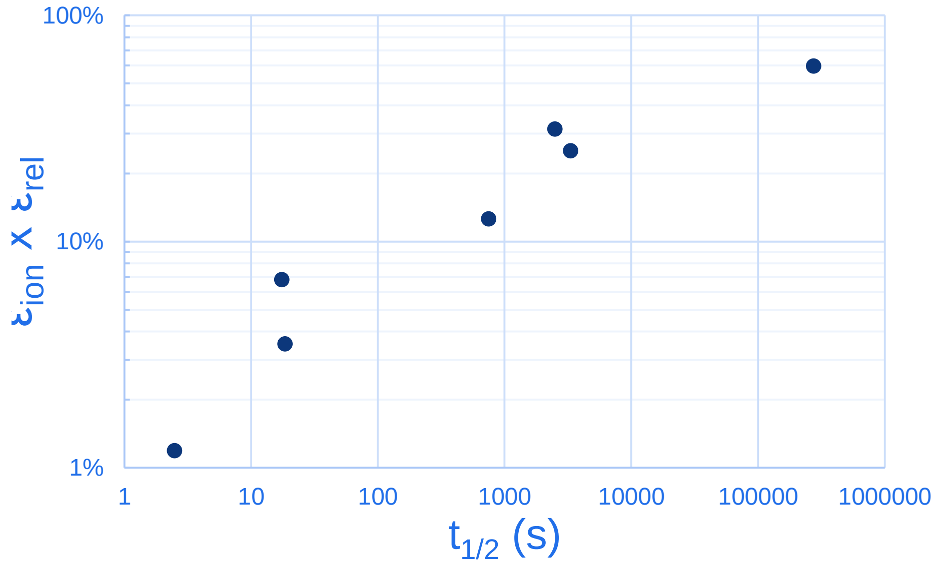


RILIS





Total efficiency = Ionization efficiency x release efficiency



J.P. Ramos, S. Rothe, et al.

MWCNT Target production for #606

CERN safety has forbidden any handling of nanomaterial

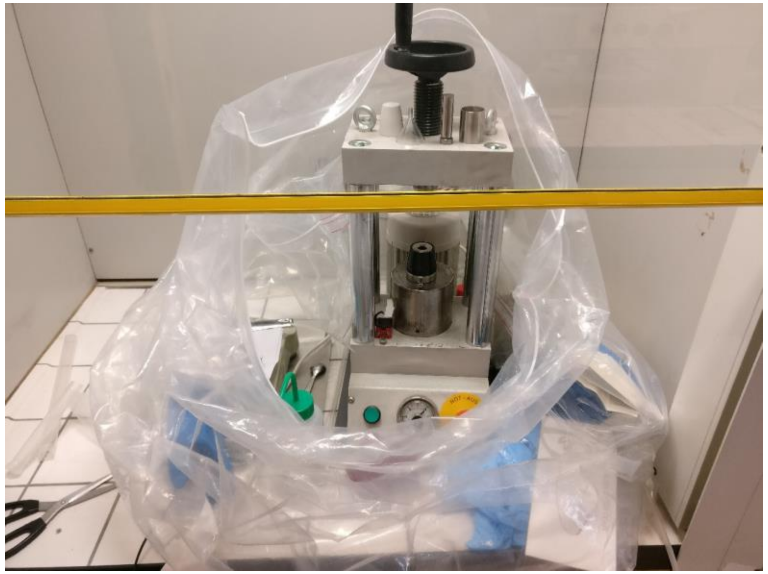
- Nanomaterials are requested at ISOLDE for physics (in this case MWCNT)

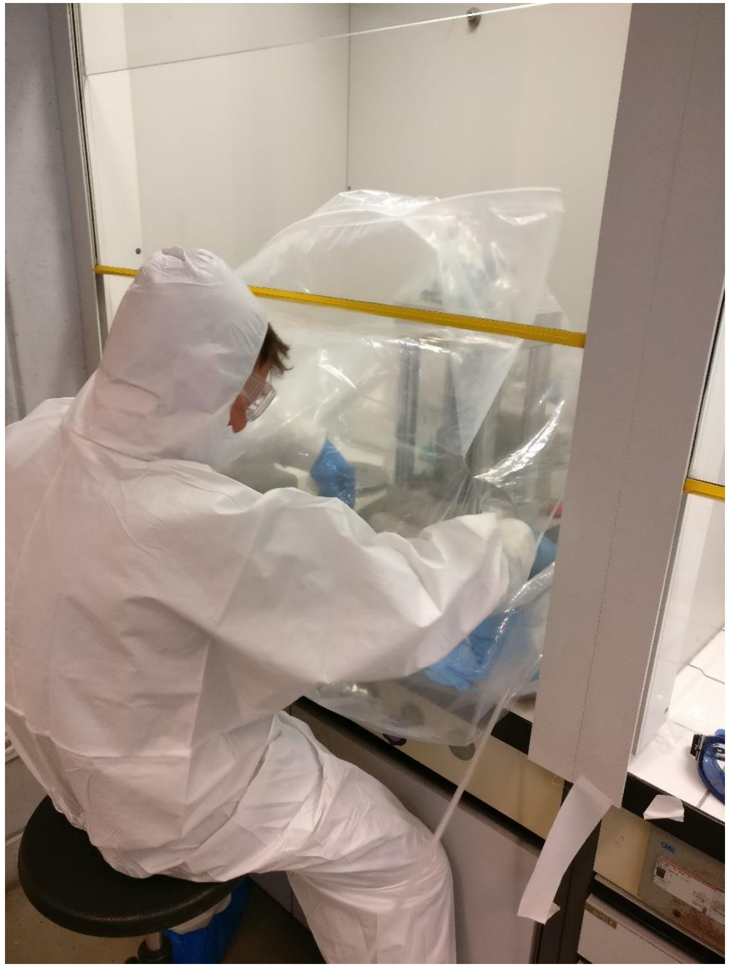
Powder technology laboratory in **EPFL**, has a class “nano 2”

- Accordingly to EPFL specifications “nano 3” is needed to handle MWCNT (need to have the nanomaterial sealed in glovebox)

Glove bag was bought from Sigma Aldrich and used instead of Glove box.

- Possible solution to lift the prohibition of handling nanomaterials





Successful press of full batch of MWCNT for ISOLDE target #606

J.P. Ramos, B. Crepieux, T. Stora, et al.

Target Materials

What	Why	How	Where	Who
Ensure non-actinide nano material production	faster release/higher yields	Derogation / Collaboration / Initiate non-actinide nano lab at CERN	Offline chemical lab /?/?	JPR
Optimize target heating	Reproducibility Uniformity of temperature	Collaboration w. SPES	Offline Pump stand	DOCT1 / FELL1
Investigate UCx sintering	Optimize Release	Sequential thermal treatment + characterization / on-line sintering at synchrotron beam line	Class A + MME labs / tbd	JPR,srr
Investigate Material Pre-treatment	Avoid contamination	Chemical reactions (etching etc)	Chemical lab Offline	Srr, Collaborations ?
Study Molecular beam chemistry	Volatilization and/or Purification	Develop dedicated setup	Offline /ext.	JB Collaborations
Optimize UCx production	Reproducibility	More observables during production	Class A	srr
Investigate ThCx	Higher yields in specific regions	FLUKA, reactivating procedures	Class A	BC,JPR

Target Materials

What	Why	How	Where	Who
Neutron converter (s)	High Purity High Production	Design iteration	ISOLDE	JPR, coll. With TRIUMF
Mass marker development	More control, Avoid cold spots	Simulation, Iterative testing	Pump stand + RGA	DL, FELL Collaboration
Autopsy of used targets	Learn from failure, improve future designs	List of priorities, Open targets in hot cell	ISOLDE Hot cell	PGH

Ion sources

What	Why	How	Where	Who
VADLIS 2.0	Improve RILIS mode Validate reliability	Simulations Design iterations Testing	Offline	DL, ISBM
COLD VD7	CO beams, fragile molecules	review design (from PS), construct, test	Offline	DOCT2, FELL2
Ion source simulation	Starting point for optimization	VSIM Collaboration	in silico	DL, FELL SCK
TOFLIS	Beam purity	High ohmic cavity Drift region Fast beam gating Integrate LIST	Offline ISOLDE	SW, Fell1, ISBM
2 Photon laser ionization	Resolution for in source spectroscopy isomer selectivity Accessibility to other elements	Mirror in ion source PI-LIST	offline	KC, RH
Negative ion source	Yield, purity Rectify design	Simulation, testing. Develop new low work-function materials	offline	DL, FELL

Ion sources

What	Why	How	Where	Who
Integrated yields + stress test	Optimize lifetime + efficiency	Long-time performance tests, destructive tests	New ion source test stand	DL, FBP, FELL
RILIS General R&D	Increased range of accessible elements, isomer selectivity, reliability	Spectral range Laser and lab infrastructure, Bandwidth optimization, ion source developments	RILIS, Offline	RILIS & ISBM

Dedicated session in next GUI

Infrastructure

What	Why	How	Where	Who
Improve VADIS gas distribution system	Measure pressure Ensure purity	Add gas loop, recirculation pump & filters	OFFLINE, then ISOLDE	JB, FELL
Upgrade beam gate switches	No spares. No high frequency possible	Test fast BG during 2018 at GPS Specify product with manufacturer	OFFLINE, ISOLDE	SW, srr ISBM
Build second pump stand	Dedicated ion source test stand Lifetime tests + integrated yield measurements	Copy of existing Pump stand	LARIS, then OFFLINE	DL, BC
Intensify use of RGA	Monitor Target and ion source behavior already during heating process	Survey, then purchase .	Offline, Pumpstands, Class A	Srr, LV support
Improving YIELD database	Link to target documentation Add yield prediction Add user interface Add interface to CRIBE	Test during 2018, collect feature requests	CERN	JB, FELL2, srr, Users

Infrastructure

What	Why	How	Where	Who
Improve target documentation	Spread of information -> Single entry document required. Track target location, link to control system	EDMS, infor, Link databases	ISOLDE	srr, BE-OP, Target production, RP, Users, LV support
Upgrade Isolde Timing System	Not very user friendly	Review specification	ISOLDE	TG
Lasers at OFFLINE 2 and MEDICIS	RILIS is most efficient and selective ion source.	Install full laser systems	Offline 2 Medicis	RILIS, KU LEUVEN/PROMED, Umz,
RILIS control system upgrade	Current system not easy to maintain by LV support	Employ (shared) PJAS Refactoring of RILIS control software	RILIS	BM, PJAS @ LV support
Development of unified controls system for Offline machines	Synergies, Still features missing Improve stability More automation	Employ (shared) PJAS Dedicated development time at offline machines.	OFFLINE	srr, PJAS@LV Support
Improve target health monitoring	Enable preventive actions	Link production rates from experiments permanent yield checks set up display for target health	OFFLINE, ISOLDE	srr, Users, BE-OP, LV support