83rd ISCC meeting

CERN, 7th November 2018

RILIS status and development plans for LS2

Bruce Marsh, *CERN EN-STI-LP*

EN Engineering Department

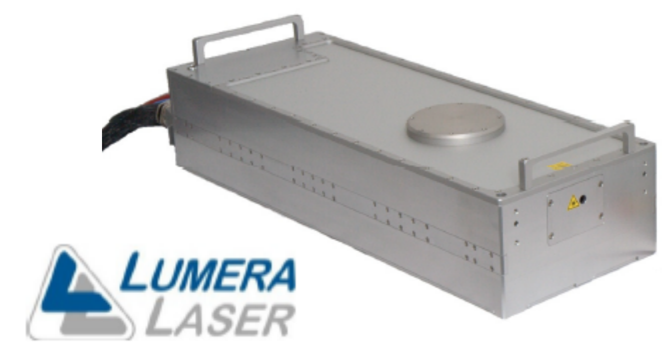
Outline

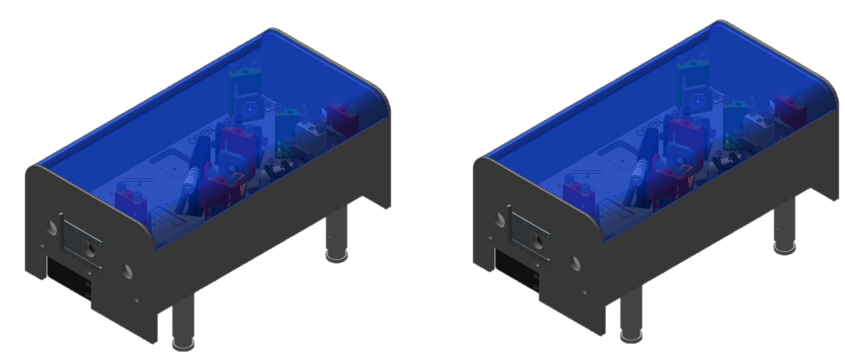
- RILIS Laboratory Infrastructure
    - CV upgrade (postponed)
    - Laser equipment and controls
- MEDICIS RILIS system
- Off-line lab infrastructure
- Off-line laser and ion source R&D
    - Molecular breakup, LIST, ToFLIS, 2-photon ionisation, VADLIS, Raman lasers.

RILIS hardware consolidation and upgrades

ONLINE

Consolidation budget from EN-Dept:
280 kCHF being used



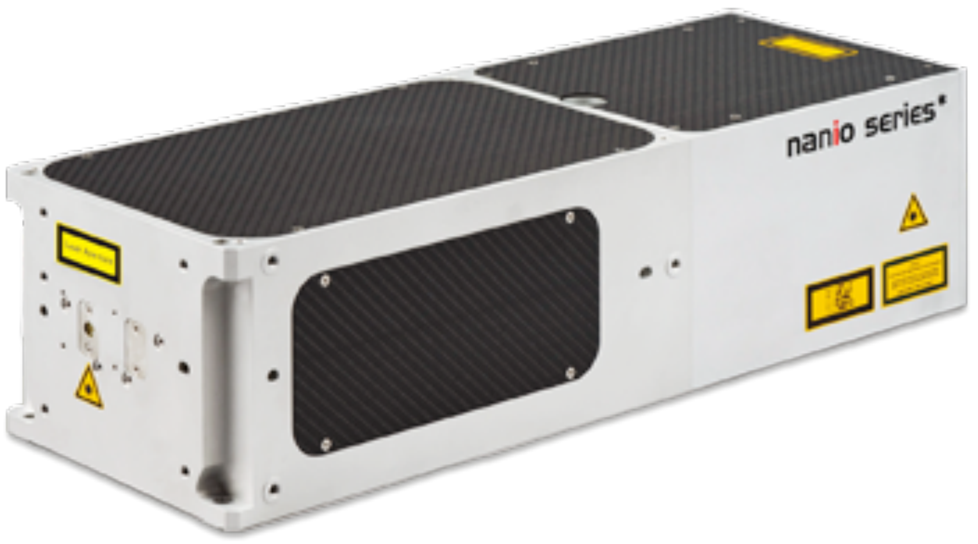


- RILIS dye pump laser replacement in 2017
- ~~Spare BLAZE laser in 2017~~
- New TiSa cavities
- Alternative TiSa pump laser
- Pulse amplified CW lasers for PI-LIST
- Test picosecond laser for molecular breakup
- Replace dye lasers
- Test and purchase a replacement Blaze laser

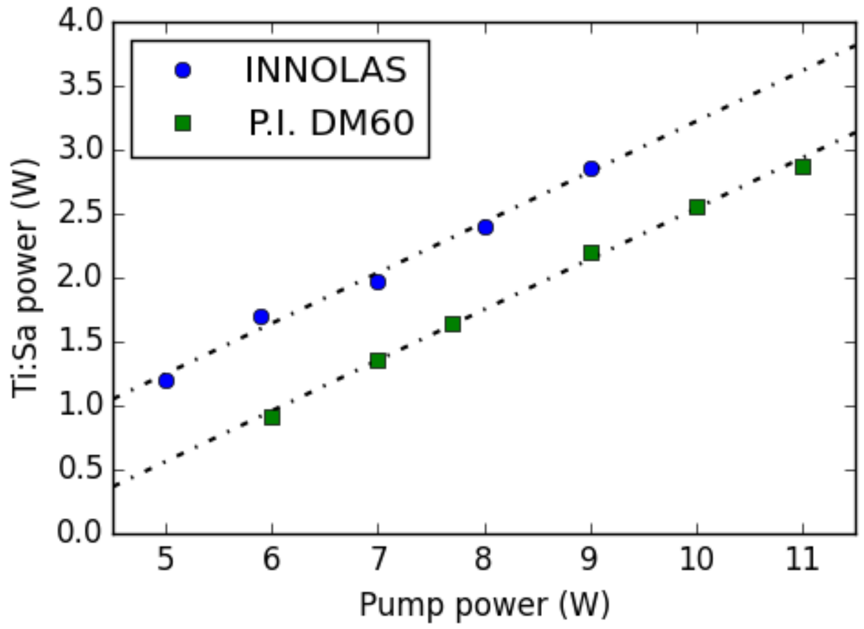
Multi-purpose pump laser

- New DPSS laser **Innolas Nanio** for Ti:Sa pumping and other applications
  - TEM00 – mode
  - 18W outpout @ 10kHz pulse rate, 30ns pulse length
- Simpler cooling mechanism → decreased risk for chiller failures
- Proposed laser for CERN-MEDICIS

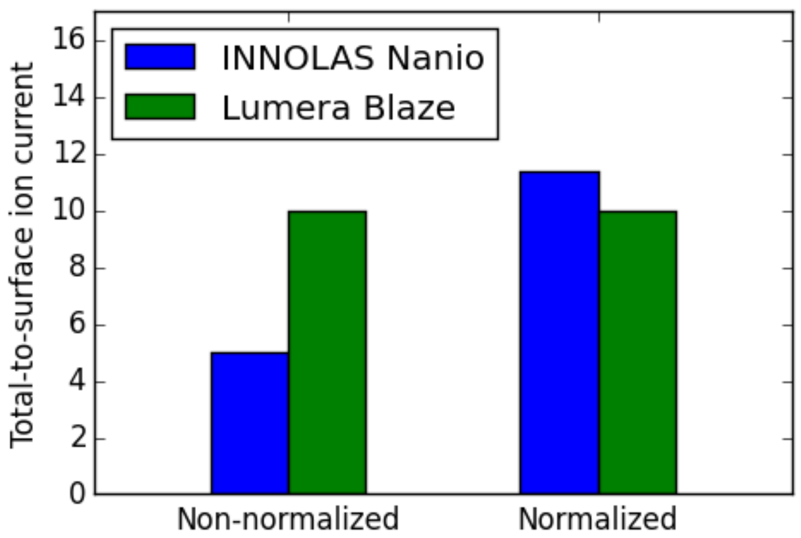
2 will be delivered this week



Ti:Sapphire pumping test:
Increased efficiency:
lasing at <5W pump power



Non-resonant ionization test:



Demonstrated to be effective for non-resonant ionization

New Dye Lasers

LiopStar-HQ - high repetition rate

Investigate the addition of 2 LIOPTEC dye lasers at RILIS

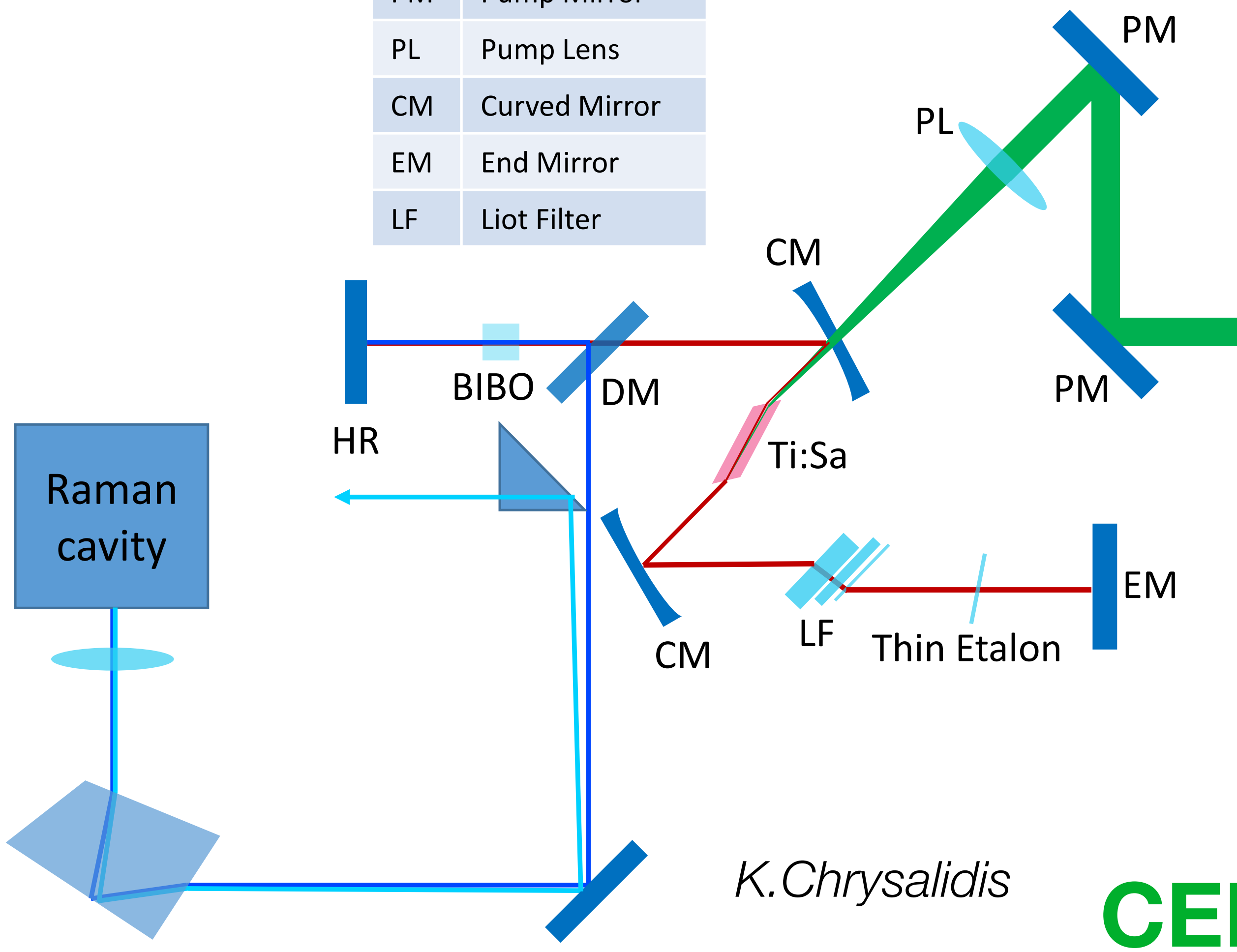
Compact and more ergonomic alternative to Sirah Credo laser

Quieter operation and easier to manipulate dye circulators

Move one Sirah laser to Offline 2 ?

Solid-State Raman lasers for RILIS

PM	Pump Mirror
PL	Pump Lens
CM	Curved Mirror
EM	End Mirror
LF	Liot Filter



K.Chrysalidis

Use blue TiSa to pump a diamond Raman laser

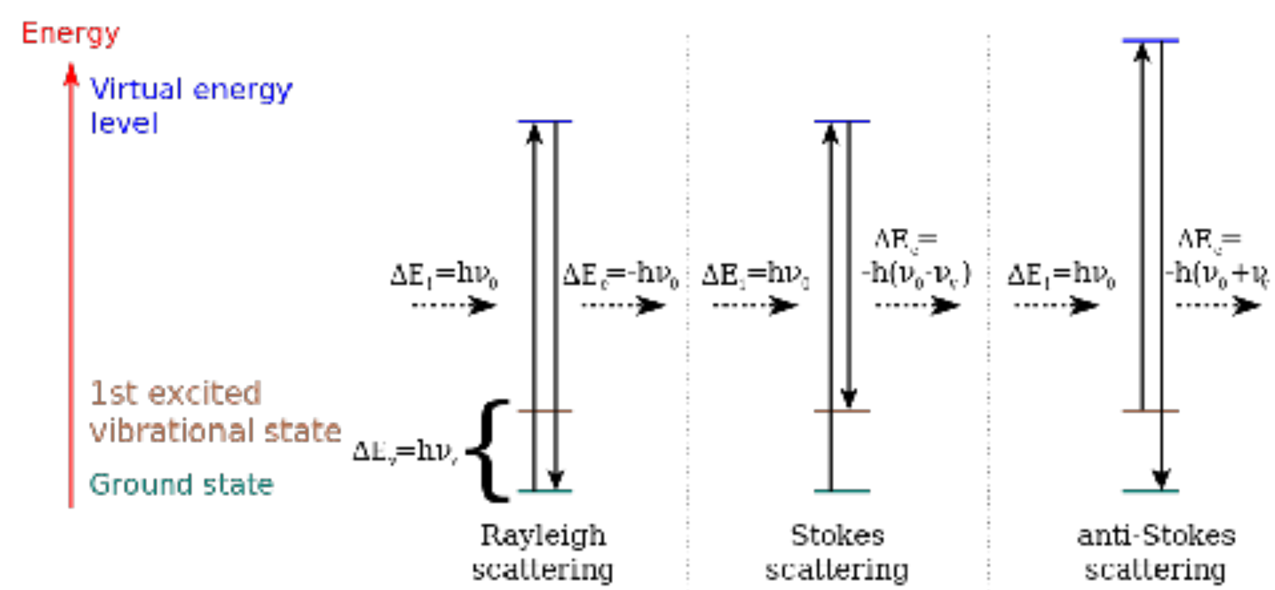
Bridge the Ti:Sa/dye spectral gap

Promising tests already conducted

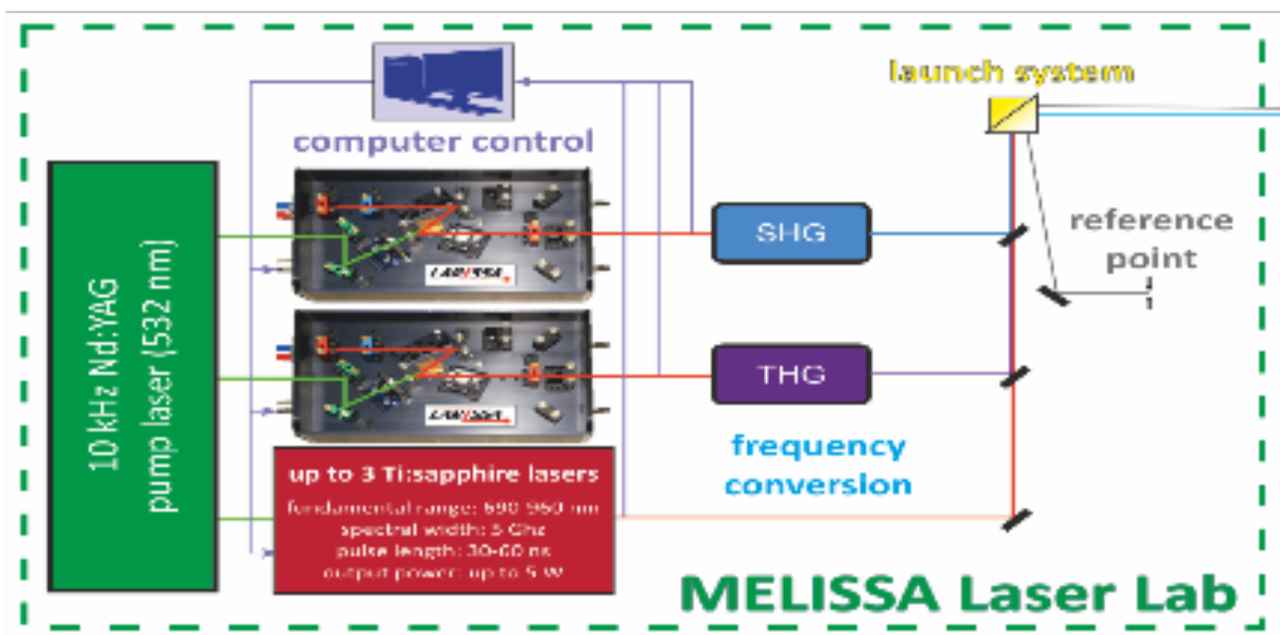
To be presented in CLEO19

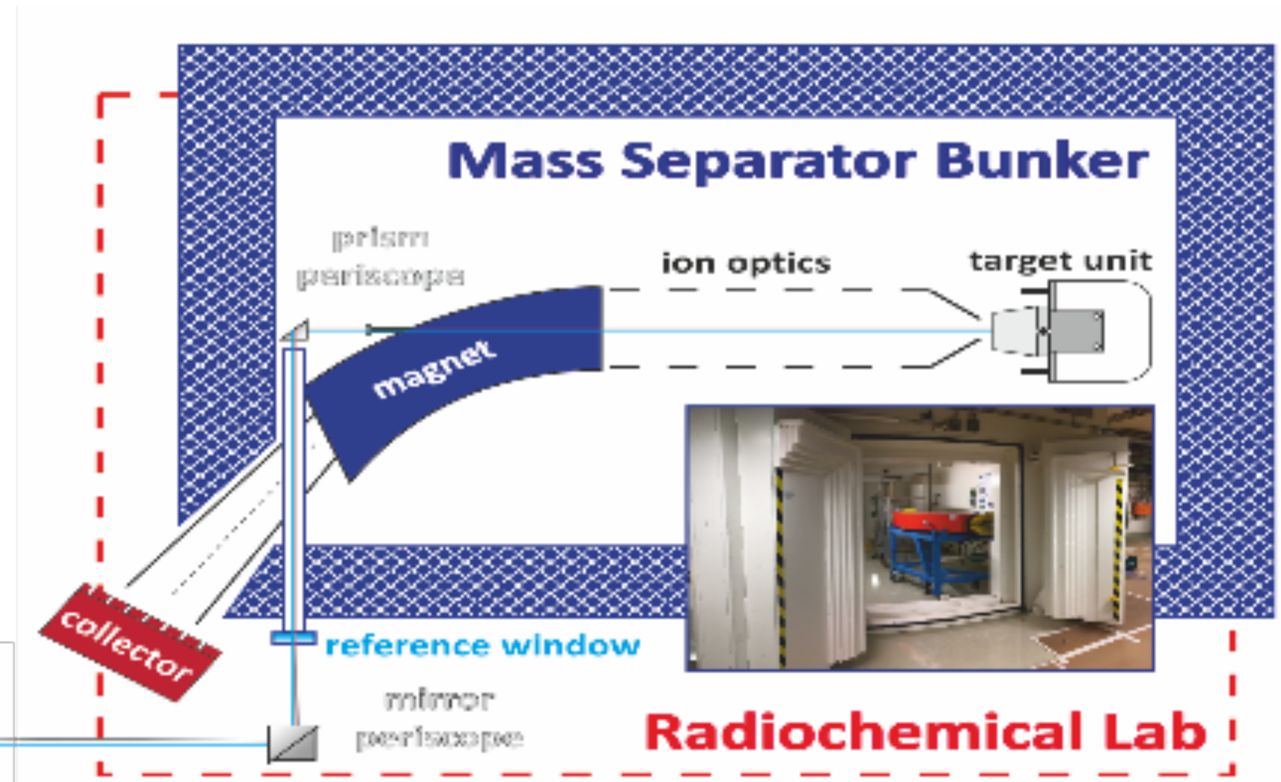
Under discussion with KT

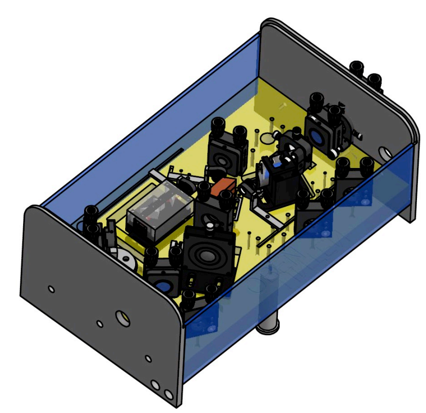
CERN DOCT student during LS2



MEDICIS laser lab (MELISSA)







V. Gadelshin, K. Dockx for MEDICIS-PROMED

First MELISSA beams in winter 2018/2019

Simultaneous HRS and GPS RILIS

- Upgraded laser beam observation system and stabilisation system
- Re-arrange optical layout with compact telescope systems and additional optics/optomechanics

Reduced setup time, faster switching between elements and mass separators

Consolidate RILIS controls and monitoring systems

- 50% of EN/SMM PJAS working on this task jointly with development of control system for the off-line mass separator.

Improve long-term maintenance and expandability of RILIS DAQ and controls, and make use of CERN specialist support

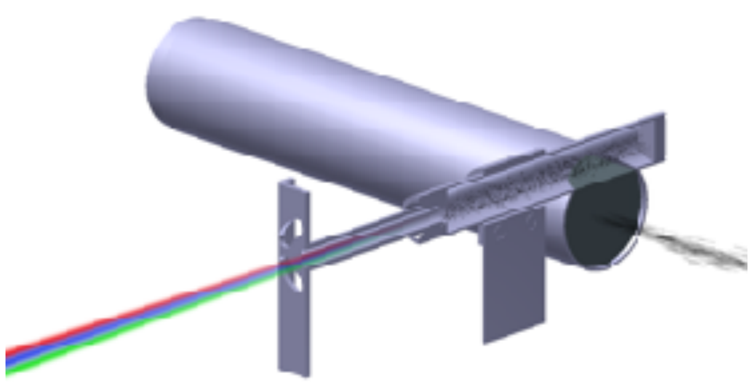
Offline 2

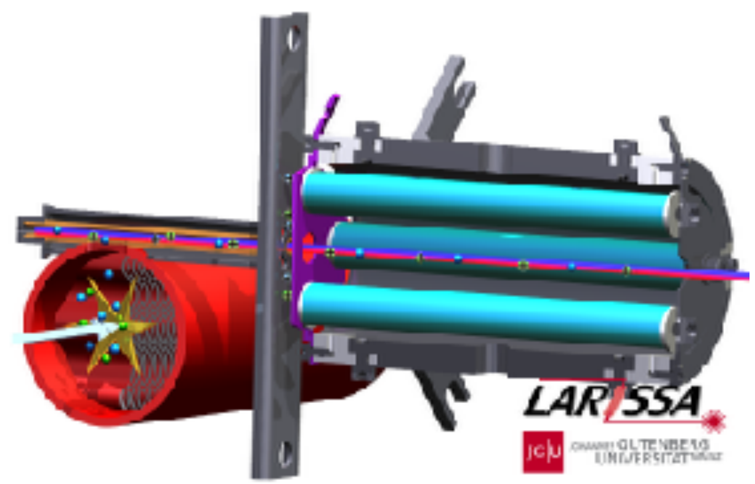
OFFLINE (+ MEDICIS)

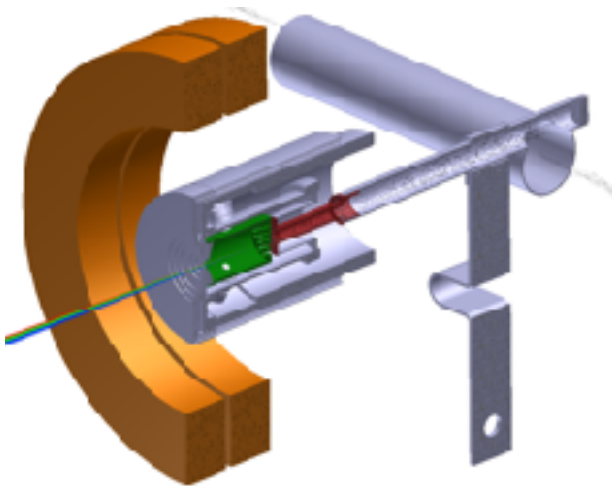
- ~300 kCHF required *(not allocated)* to properly equip RILIS @ offline-2
- Offline-2 can also be also considered a RILIS@MEDICIS test bench, and we should try to have similar hardware at all installations (redundancy)
- All RILIS development will move to offline 2 (remove laser system from offline 1)
- Offline 2 will be running with spare RILIS hardware in early 2019

RILIS cavity development directions

HC-RILIS | **HC-LIST** | **VADLIS**







HIGH SELECTIVITY

- High resistance cavity
- Pulsed line heating
- 'DC-offset'
- Short LIST
- Inverted-LINE
- LWF-VADLIS

HIGH RESOLUTION

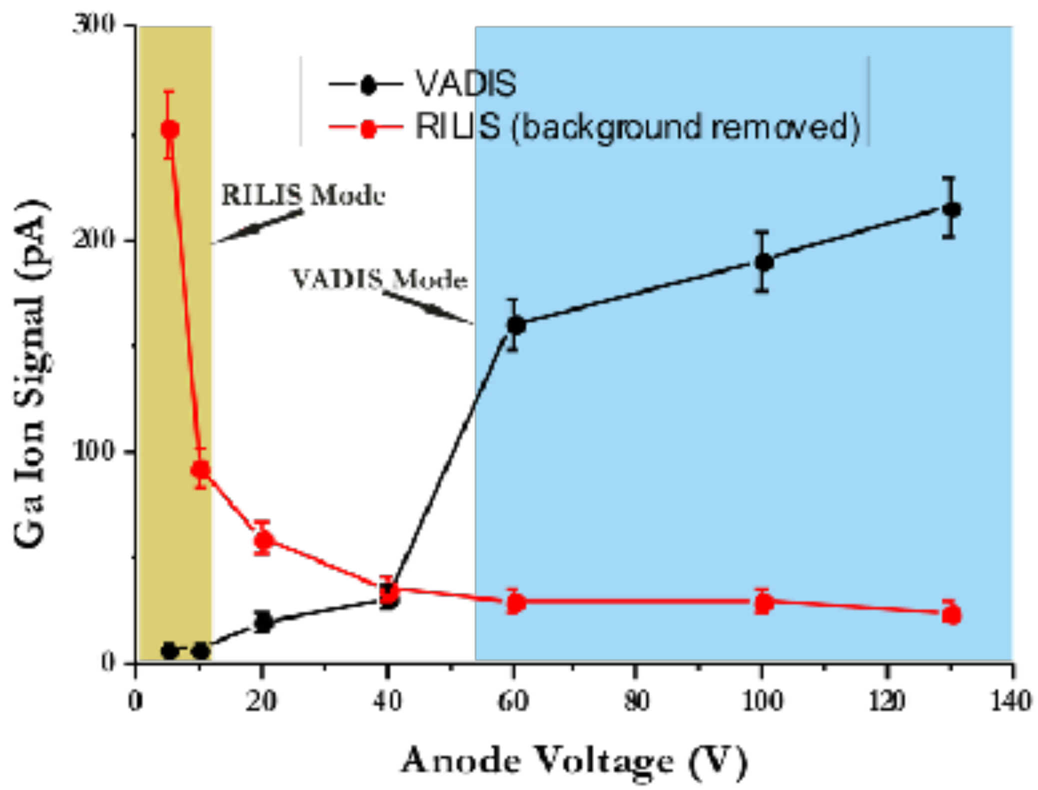
- 2-photon HC-RILIS
- PI-LIST

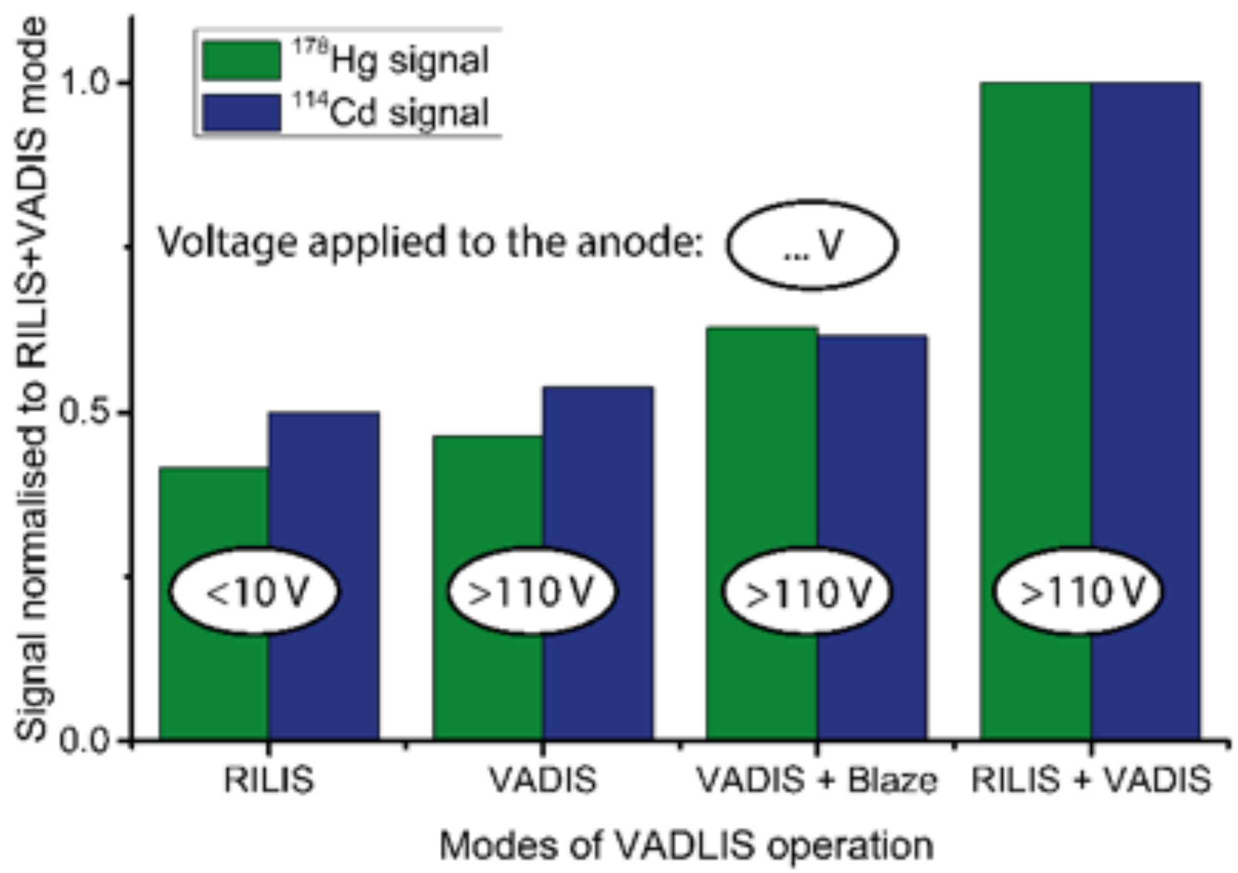
HIGH EFFICIENCY

- New materials
- ToF-LIS
- Adjustable EXTRACTOR VOLTAGE

\+ RILIS for M(CO)x breakup + Ion load issues for next-gen facilities

VADLIS – explanation





Selectivity

Increased efficiency

Beam diagnostics (laser ON/OFF)

RILIS coupled with liquid targets

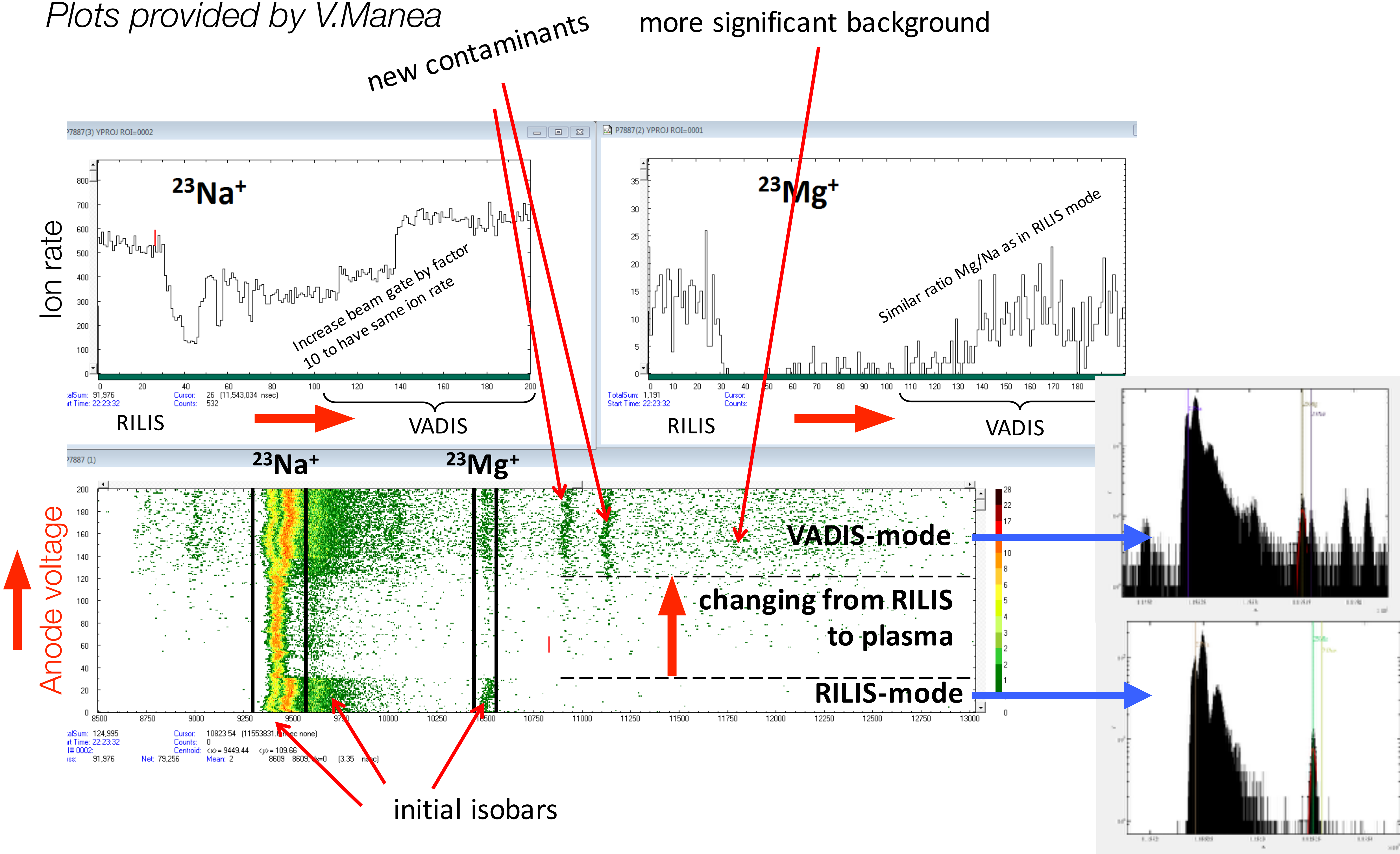
Still not optimised for RILIS

So far demonstrated for:

Ga, **Cd**, **Hg (2016, 2017, 2018)**, **Ba**, **Ba+, Sn,** **Mg (for 2016 ISOLTRAP run)**

Demonstrating VADLIS modes for Mg beams

Plots provided by V.Manea



VADLIS development

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
Volume 376, 1 June 2016, Pages 39-45

Blurring the boundaries between ion sources: The application of the RILIS inside a FEBIAD type ion source at ISOLDE

T. Day Goodacre [a,b], J. Billowes [b], R. Catherall [a], T.E. Cocolios [b], B. Crepieux [a], D.V. Fedorov [c], V.N. Fedosseev [a], L.P. Gaffney [a,f], T. Giles [a], A. Gottberg [a], K.M. Lynch [a], B.A. Marsh [a], T.M. Mendonça [a], J.P. Ramos [a,d], R.E. Rossel [a,f,g], S. Rothe [a], S. Sels [e], C. Sotty [e] ... M. Veinhard [a]
Show more

https://doi.org/10.1016/j.nimb.2016.03.005
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Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
Volume 431, 15 September 2018, Pages 59-66

Enhancing the extraction of laser-ionized beams from an arc discharge ion source volume

Y. Martinez Palenzuela [a,c], B.A. Marsh [a], J. Ballof [a,b], R. Catherall [a], K. Chrysalidis [a,d], T.E. Cocolios [c], B. Crepieux [a], T. Day Goodacre [a,e,f], V.N. Fedosseev [a], M.H. Huyse [c], P.B. Larmonier [a,g], J.P. Ramos [a], S. Rothe [a], J.D.A. Smith [h], T. Stora [a], P. Van Duppen [c], S. Wilkins [a]
Show more

https://doi.org/10.1016/j.nimb.2018.06.006
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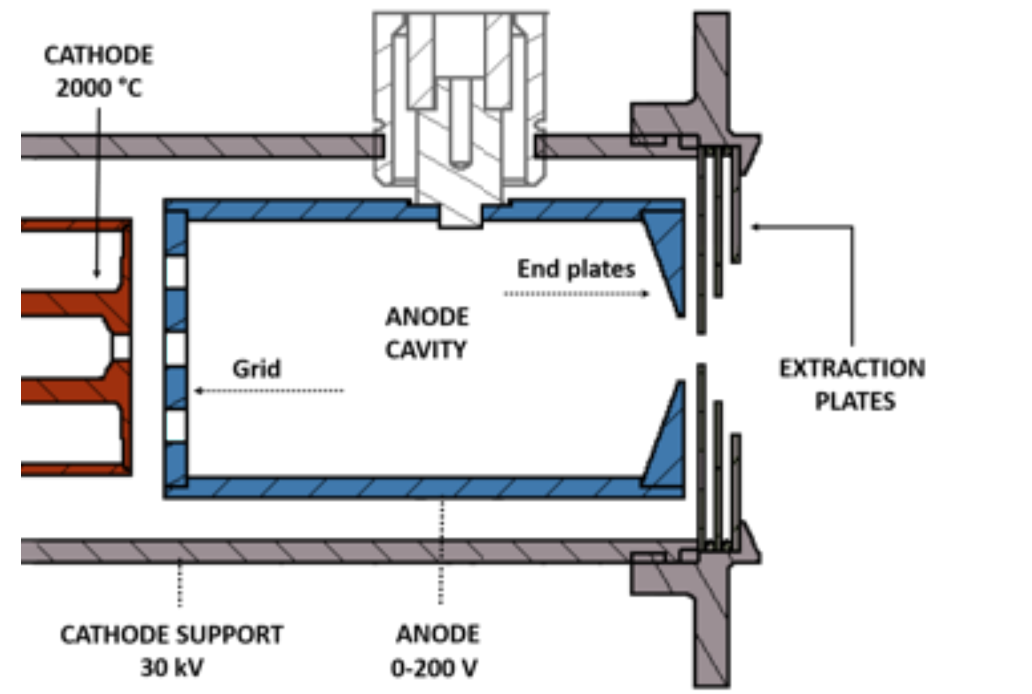
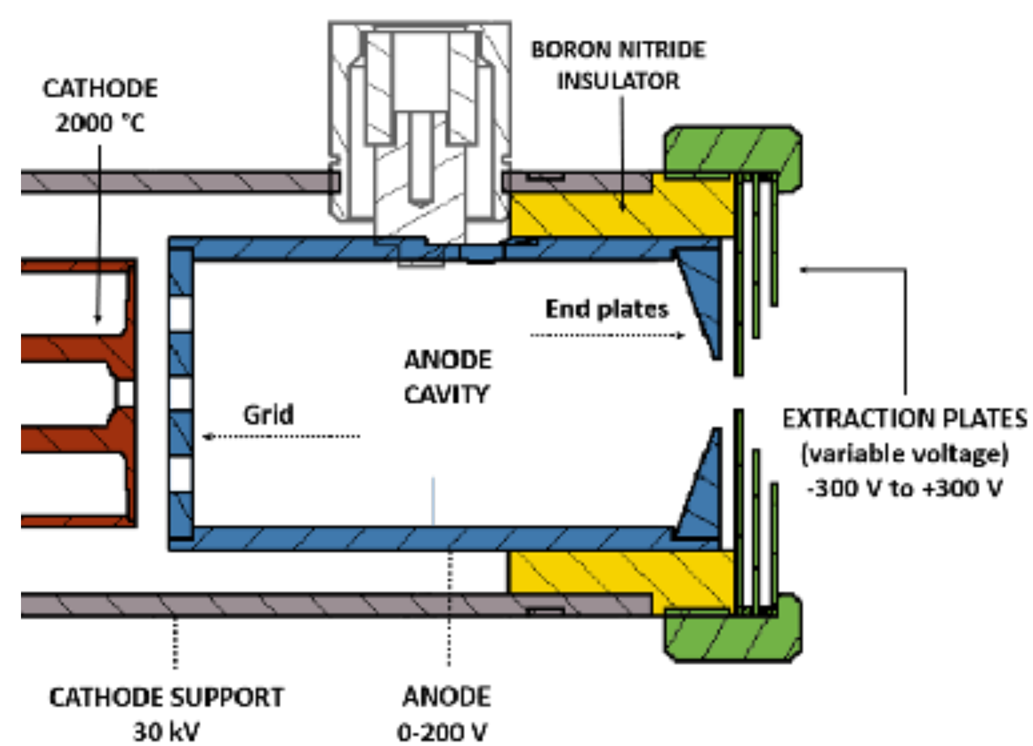
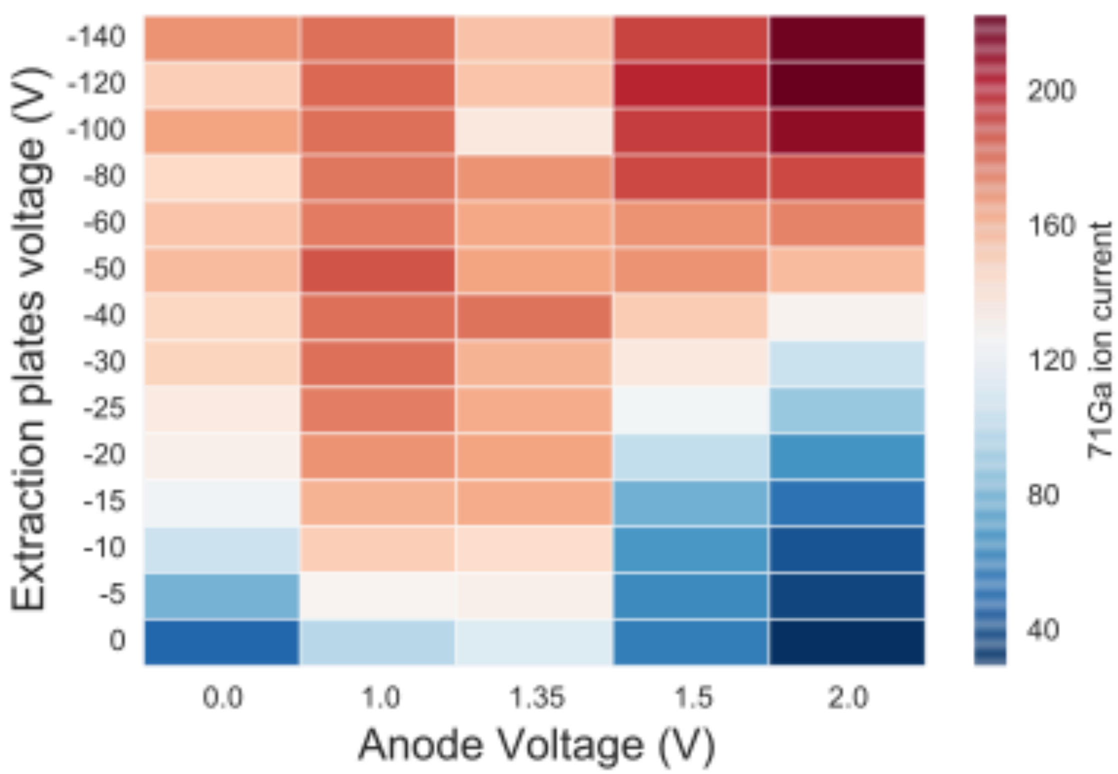
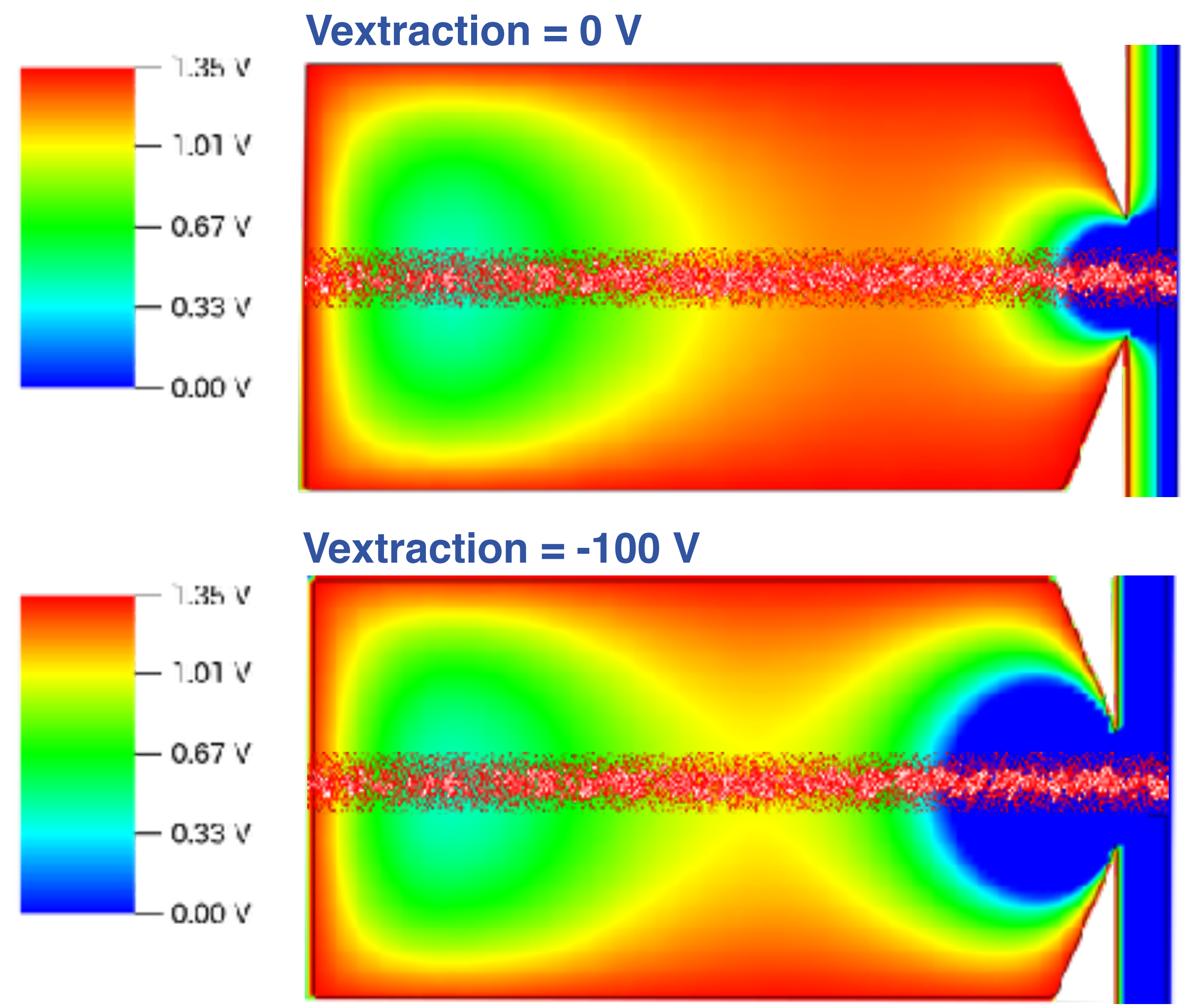




VADLIS modes of operation



Credit: Y. Martinez Palenzuela



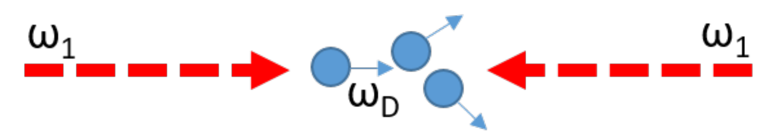
- New design with variable extaction voltage improves laser ion extraction
- Demonstrated off-line with Ga
- Demonstrated on-line with Mg: factor 3 extraction efficiency improvement when voltage was adjusted!

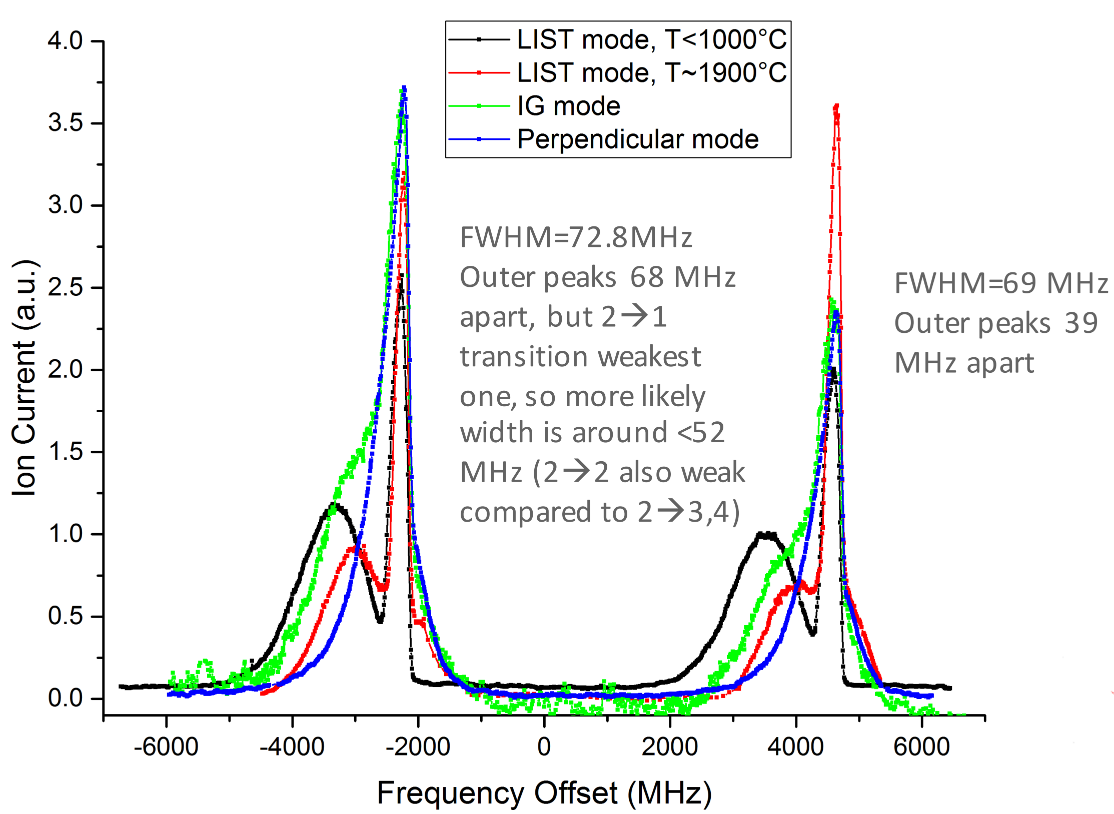
Possible reliability advantage also, even for normal VADIS operation

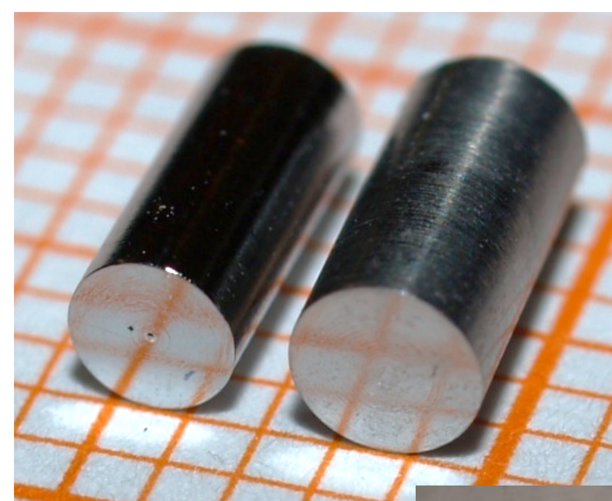
Development of 2-photon ionisation at RILIS

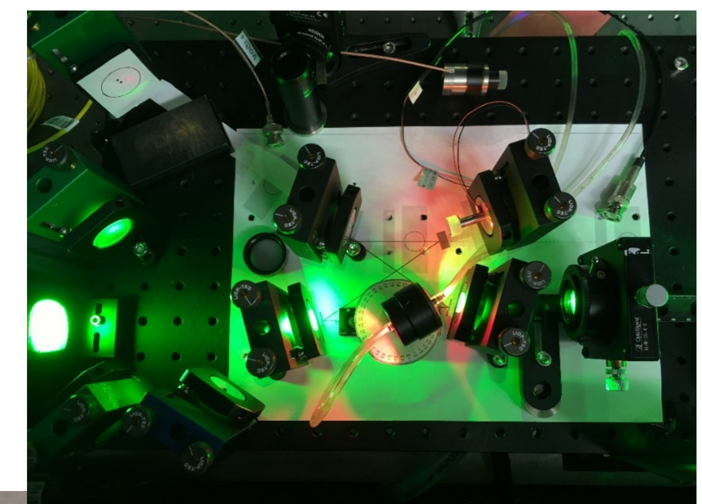
- Efforts towards high resolution spectroscopy
- Aim: Doppler-free two-photon excitation in-source
- Demonstrated succesfully at RISIKO Mainz off-line separator for Rb

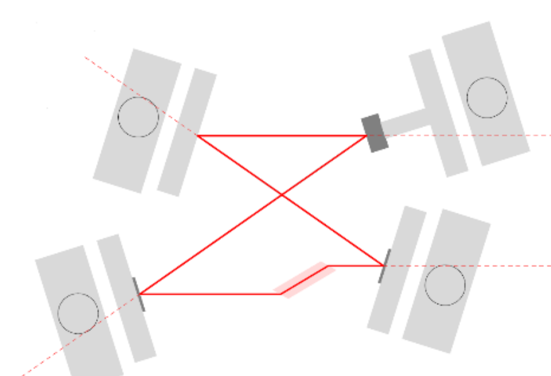
$(\omega_1+\omega_D)+(\omega_1-\omega_D)=2\omega_1$





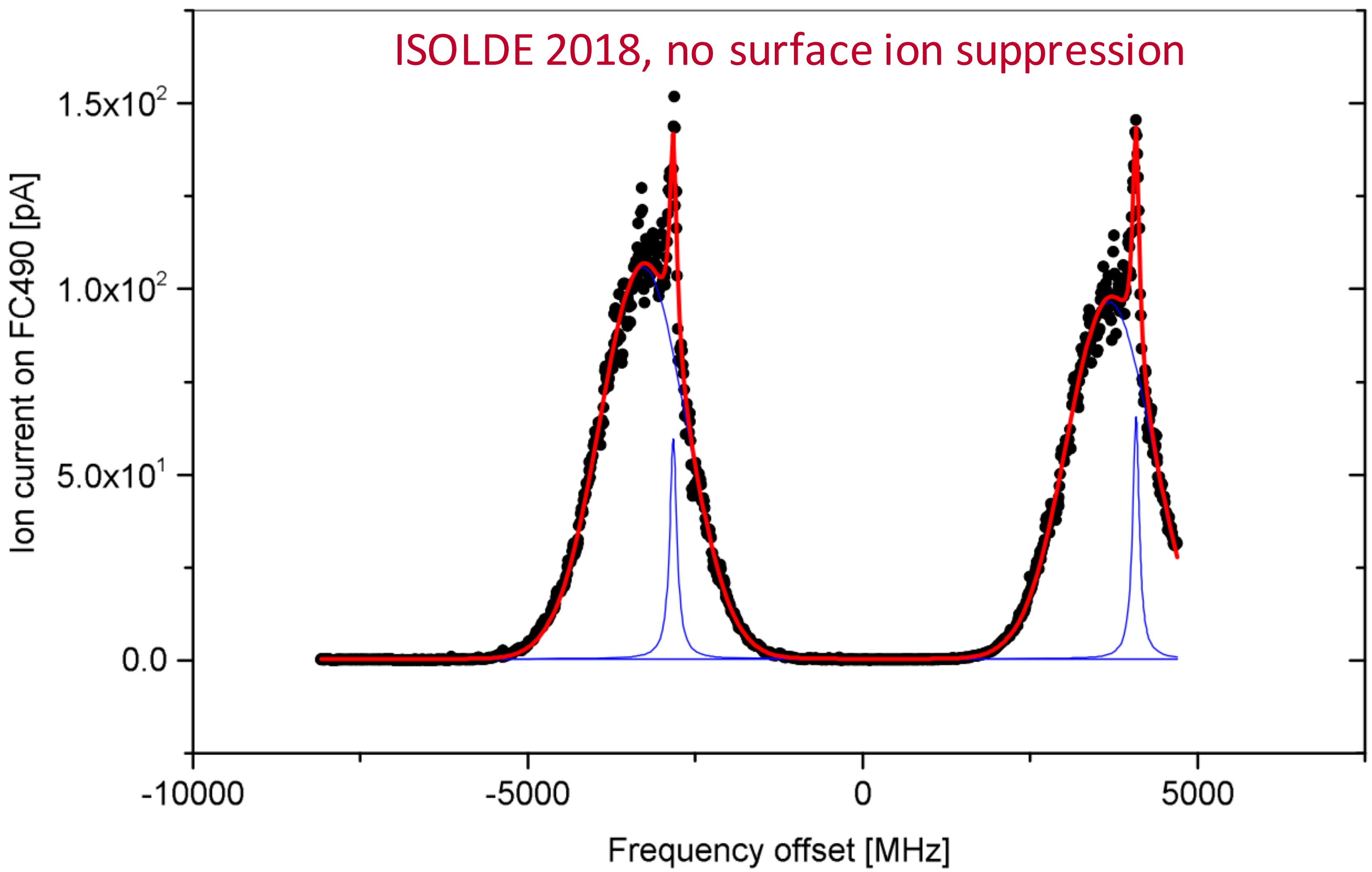






First demonstration at ISOLDE

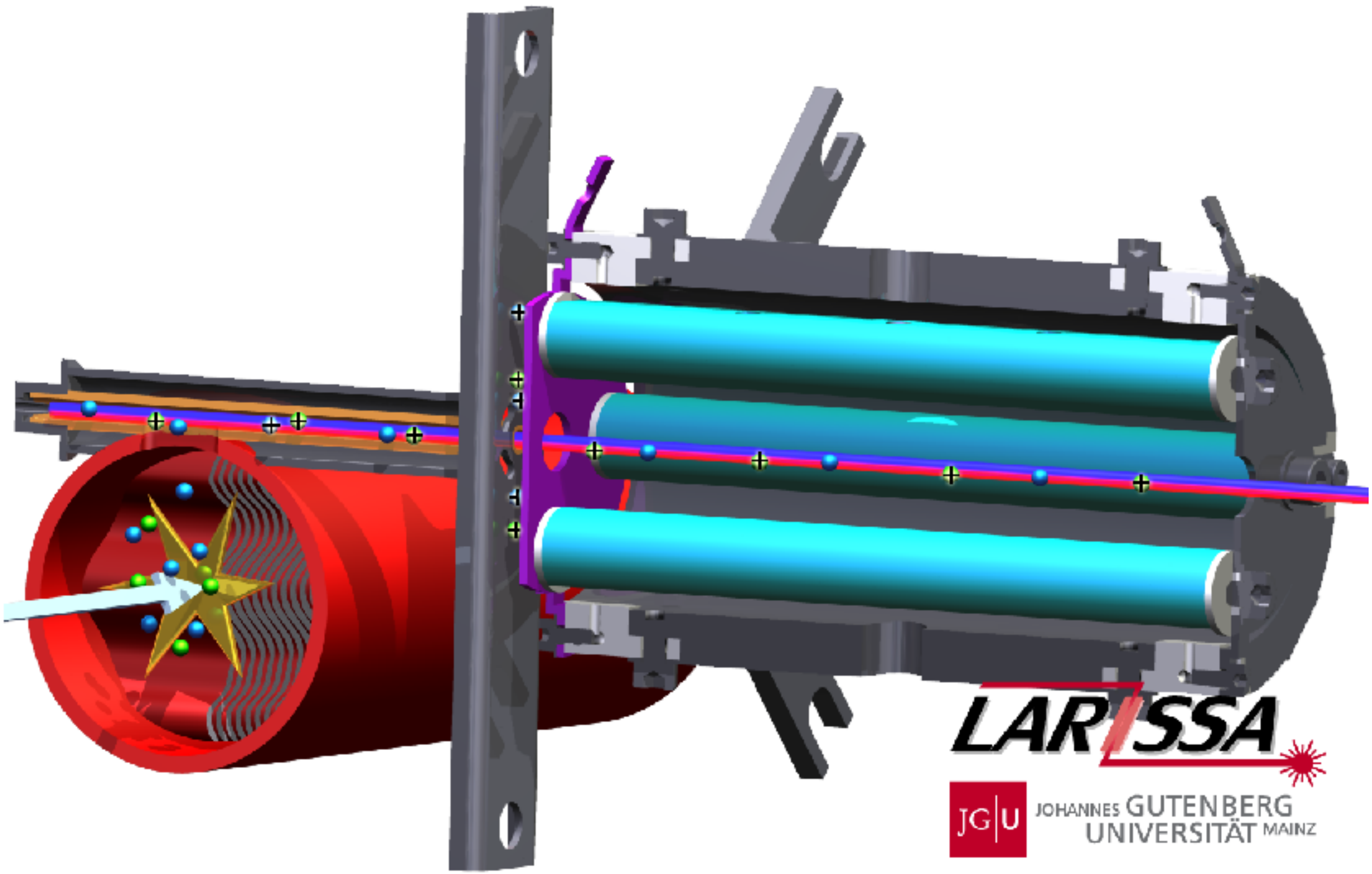
- First measurements at ISOLDE with Mo foil
- Clearly visible two-photon peaks – less dominant than in Mainz
- Continue efforts towards more suited mirror solution



FWHM:
126.7 MHz for ‚left‘ peak
116.5 MHz for ‚right‘ peak
→ Broadening mechanism needs to be investigated with better reflectivity of mirror

Katerina Chrysalidis (EMIS talk)

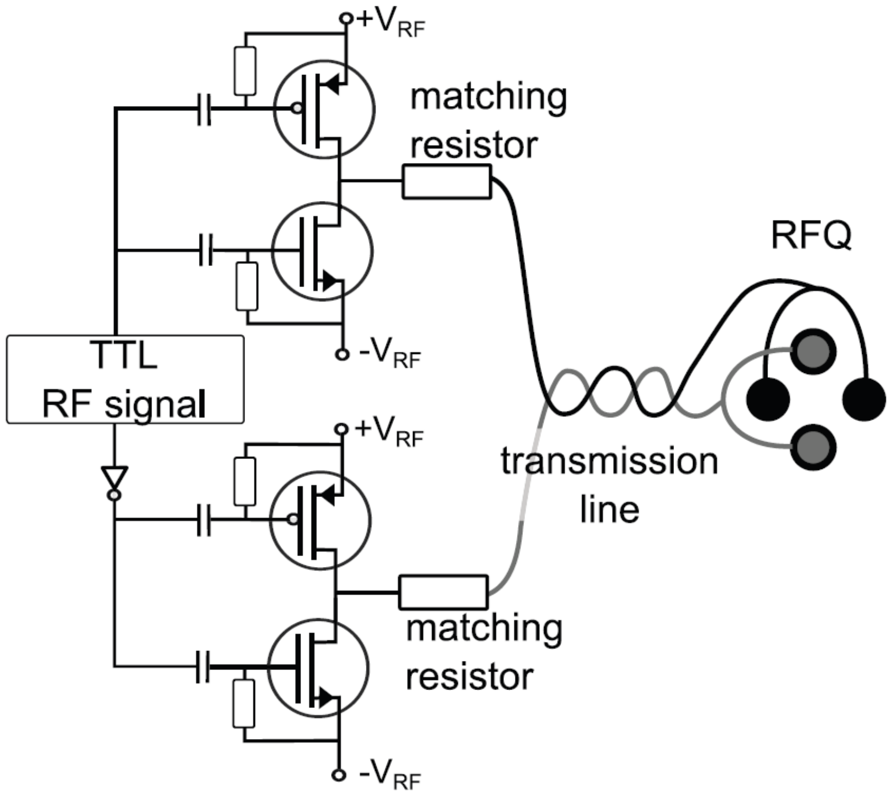
LIST development



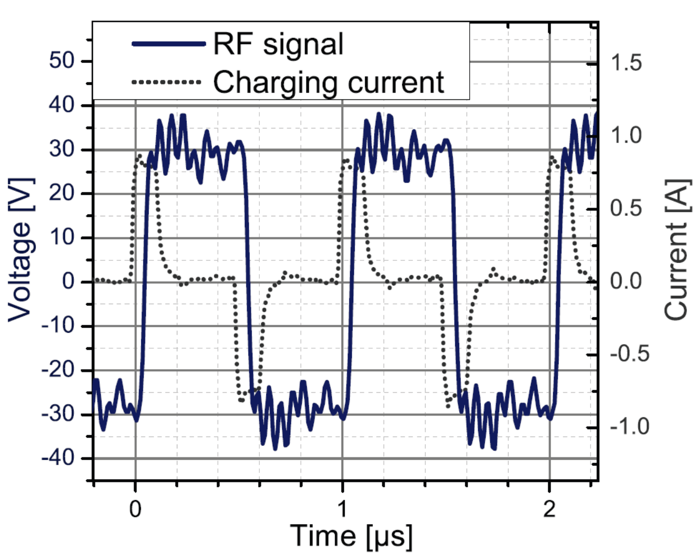
LARISSA

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

LIST with GPS and HRS compatibility?



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

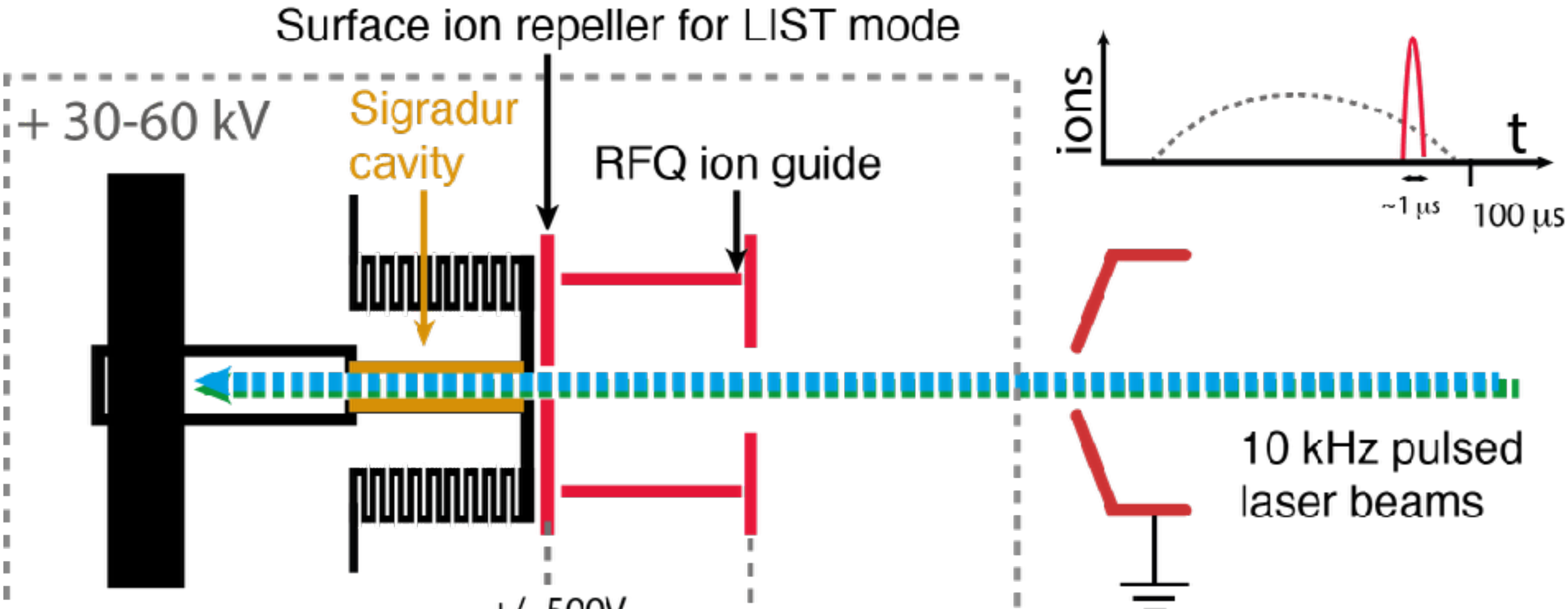


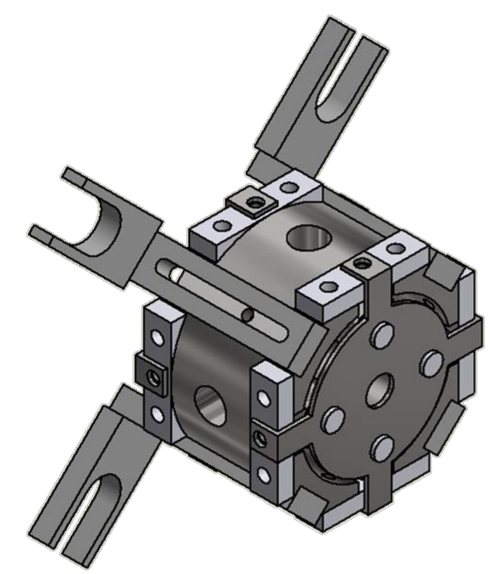
MHz-switched DC voltages (instead of sine wave) on quadrupole rods

- Transducer box obsolete
- Easy implementation of DC offset on rods
  - ➢ DC Offset LIST
- Method succesfully used at TRIUMF

- High switching currents
- Low capacity transmission cables to target
- Impedance matching to reduce power dissipation
- Cooling of switching units on HV platform
- TRIUMF implementation currently refined by electronics workshop @ JGU
- Easy commercial solution with Behlke switches?

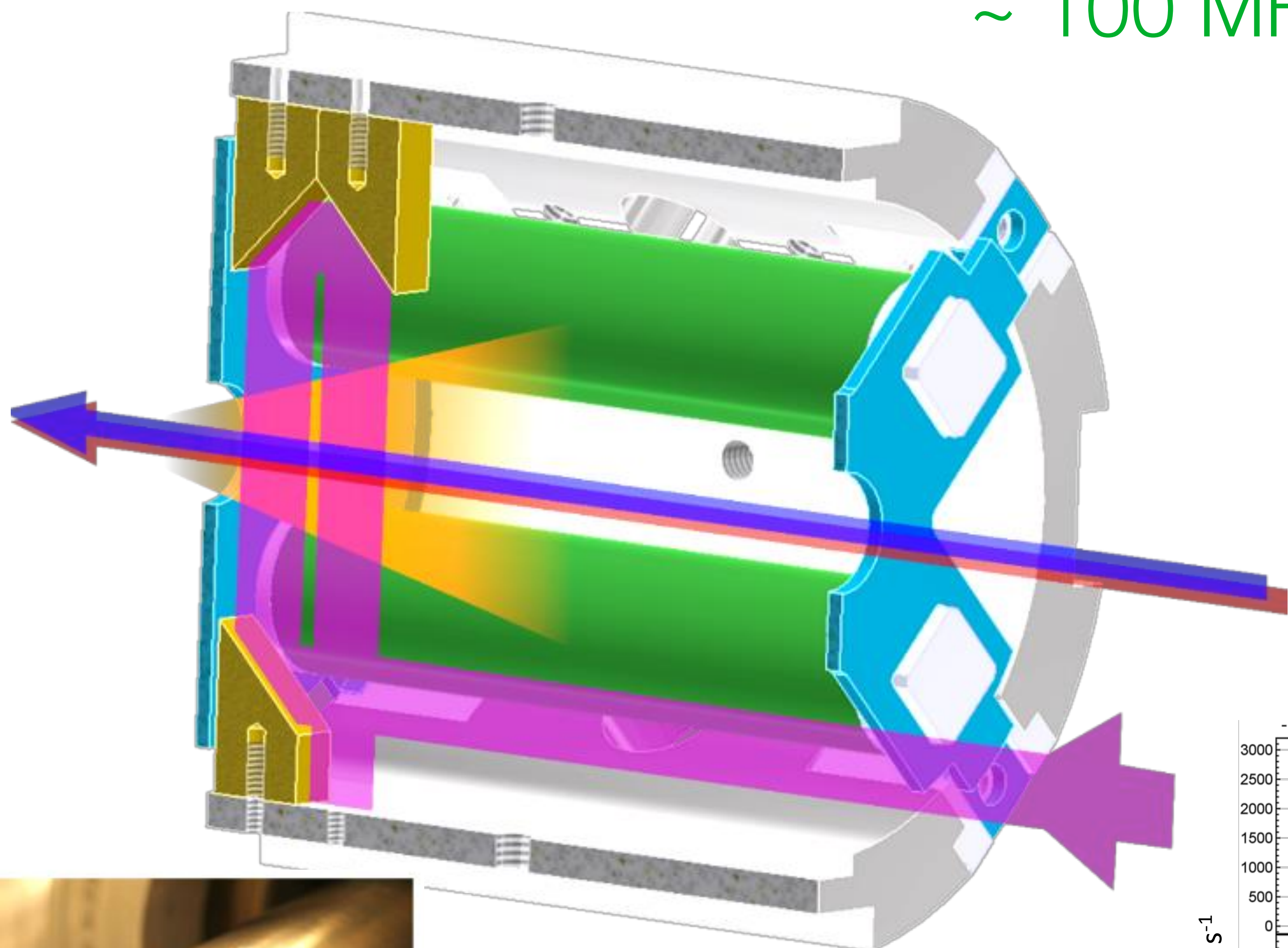
LIST as a field-free region for ToFLIS





- LIST provides transverse confinement along ‘drift’ region
- Hot-cavity (ion-guide) and standard LIST mode still available

Perpendicular illuminated LIST

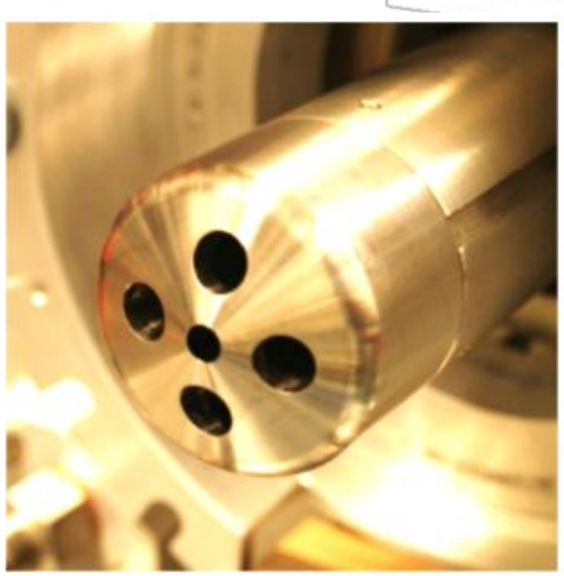


~ 100 MHz resolution (> 10x better)

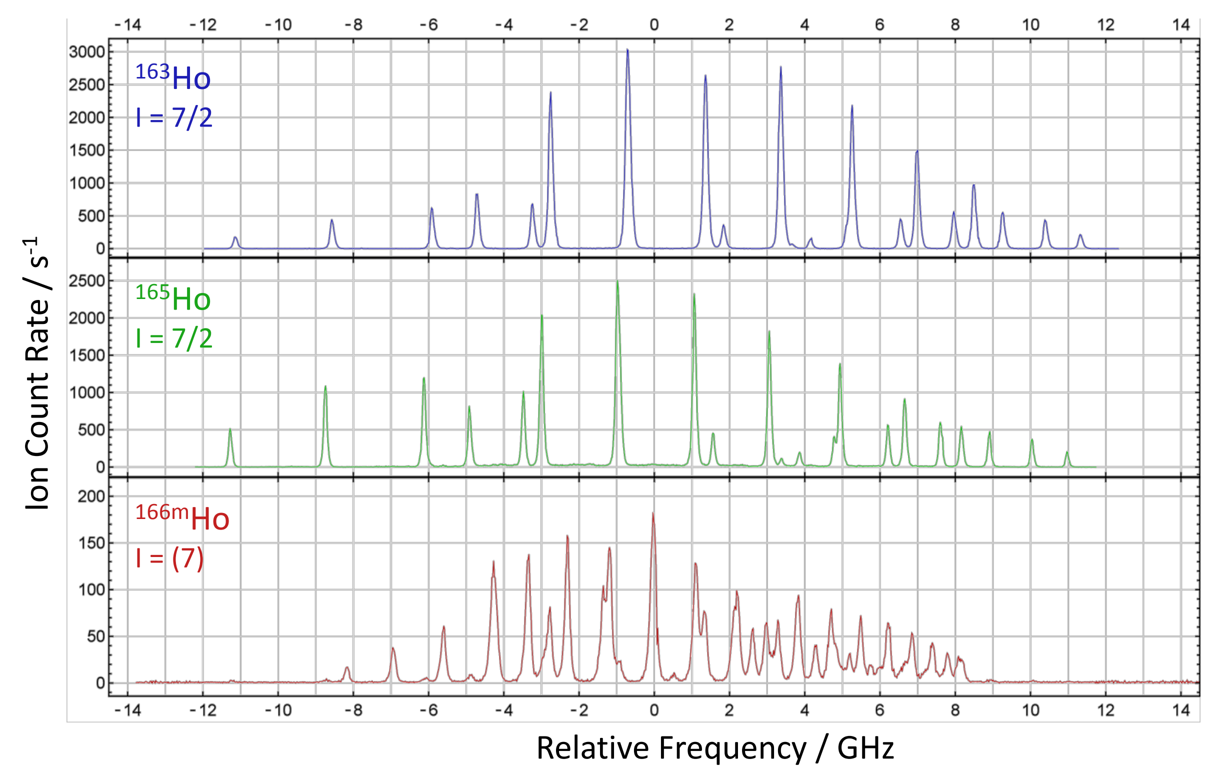
Isomer selective ionization
for many elements

Extend In-Source RIS
to light elements

> 100 x efficiency loss wrt RILIS



Reinhard Heinke (Mainz)

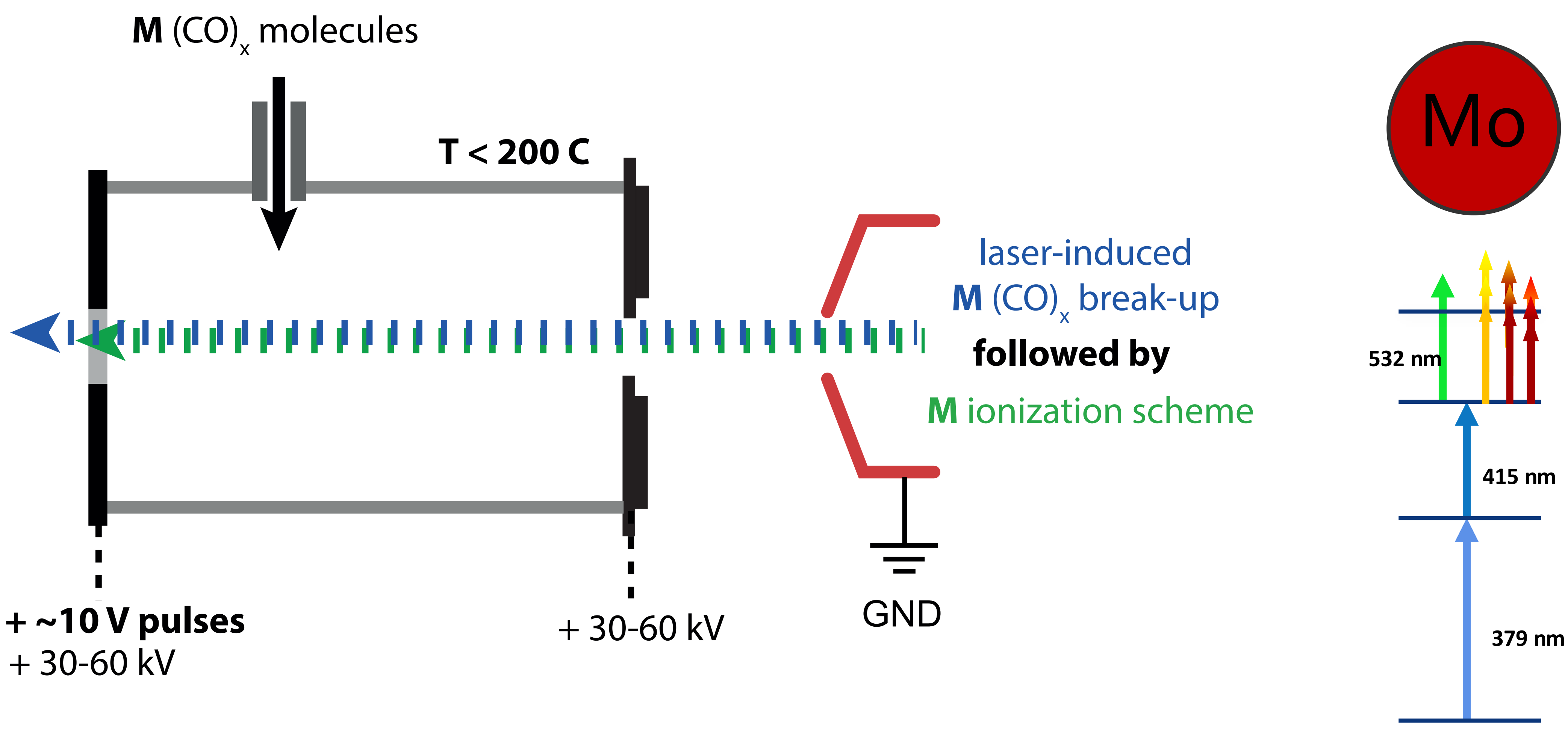


Mo(CO)6 - Molecular breakup + ionisation

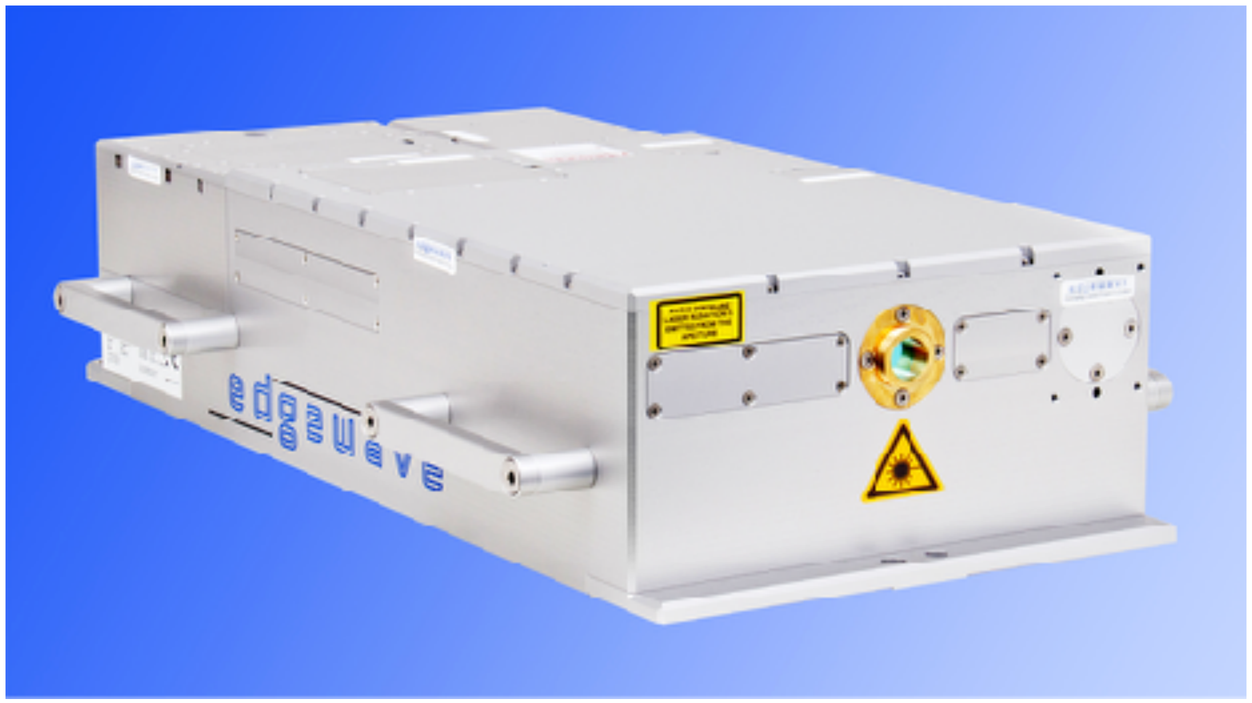
1) Creation and transport of volatile molecules of refractory metals

2) Dissociation by laser pulse

3) Resonance ionisation before atom/wall collision

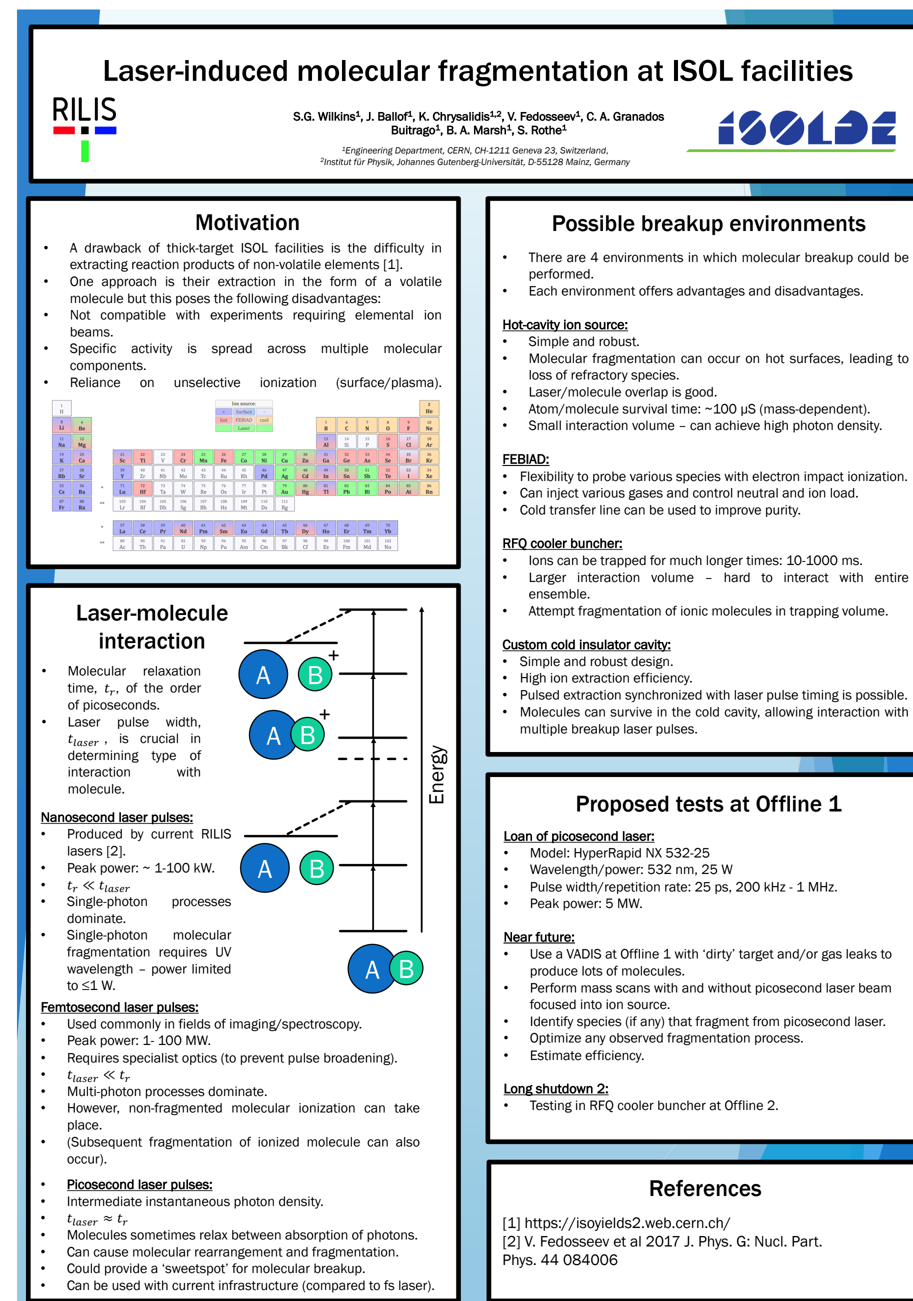


~picosecond laser for molecular breakup



0-200 kHz (600 fs), 100W @ 515 nm

FX series INNOSLAB laser



Laser-induced molecular fragmentation at ISOL facilities

S.G. Wilkins[1], J. Ballof[1], K. Chrysalidis[1,2], V. Fedosseev[1], C. A. Granados Buitrago[1], B. A. Marsh[1], S. Rothe[1]

[1]Engineering Department, CERN, CH-1211 Geneva 23, Switzerland,
[2]Institut für Physik, Johannes Gutenberg-Universität, D-55128 Mainz, Germany

Motivation

- A drawback of thick-target ISOL facilities is the difficulty in extracting reaction products of non-volatile elements [1].
- One approach is their extraction in the form of a volatile molecule but this poses the following disadvantages:
- Not compatible with experiments requiring elemental ion beams.
- Specific activity is spread across multiple molecular components.
- Reliance on unselective ionization (surface/plasma).

Possible breakup environments

- There are 4 environments in which molecular breakup could be performed.
- Each environment offers advantages and disadvantages.

Hot-cavity ion source:
- Simple and robust.
- Molecular fragmentation can occur on hot surfaces, leading to loss of refractory species.
- Laser/molecule overlap is good.
- Atom/molecule survival time: ~100 μS (mass-dependent).
- Small interaction volume – can achieve high photon density.

FEBIAD:
- Flexibility to probe various species with electron impact ionization.
- Can inject various gases and control neutral and ion load.
- Cold transfer line can be used to improve purity.

RFQ cooler buncher:
- Ions can be trapped for much longer times: 10-1000 ms.
- Larger interaction volume – hard to interact with entire ensemble.
- Attempt fragmentation of ionic molecules in trapping volume.

Custom cold insulator cavity:
- Simple and robust design.
- High ion extraction efficiency.
- Pulsed extraction synchronized with laser pulse timing is possible.
- Molecules can survive in the cold cavity, allowing interaction with multiple breakup laser pulses.

Laser-molecule interaction

- Molecular relaxation time, t_r, of the order of picoseconds.
- Laser pulse width, t_{laser}, is crucial in determining type of interaction with molecule.

Nanosecond laser pulses:
- Produced by current RILIS lasers [2].
- Peak power: ~ 1-100 kW.
- $t_r \ll t_{laser}$
- Single-photon processes dominate.
- Single-photon molecular fragmentation requires UV wavelength – power limited to ≤1 W.

Femtosecond laser pulses:
- Used commonly in fields of imaging/spectroscopy.
- Peak power: 1- 100 MW.
- Requires specialist optics (to prevent pulse broadening).
- $t_{laser} \ll t_r$
- Multi-photon processes dominate.
- However, non-fragmented molecular ionization can take place.
- (Subsequent fragmentation of ionized molecule can also occur).

- **Picosecond laser pulses:**
- Intermediate instantaneous photon density.
- $t_{laser} \approx t_r$
- Molecules sometimes relax between absorption of photons.
- Can cause molecular rearrangement and fragmentation.
- Could provide a 'sweetspot' for molecular breakup.
- Can be used with current infrastructure (compared to fs laser).

Proposed tests at Offline 1

Loan of picosecond laser:
- Model: HyperRapid NX 532-25
- Wavelength/power: 532 nm, 25 W
- Pulse width/repetition rate: 25 ps, 200 kHz - 1 MHz.
- Peak power: 5 MW.

Near future:
- Use a VADIS at Offline 1 with 'dirty' target and/or gas leaks to produce lots of molecules.
- Perform mass scans with and without picosecond laser beam focused into ion source.
- Identify species (if any) that fragment from picosecond laser.
- Optimize any observed fragmentation process.
- Estimate efficiency.

Long shutdown 2:
- Testing in RFQ cooler buncher at Offline 2.

References

[1] https://isoyields2.web.cern.ch/
[2] V. Fedosseev et al 2017 J. Phys. G: Nucl. Part. Phys. 44 084006

75 x peak power increase w.r.t our 100 W IS-series laser

> 20 laser-molecule interactions per molecule (in hot cavity)

Test planned for Winter 2018/19

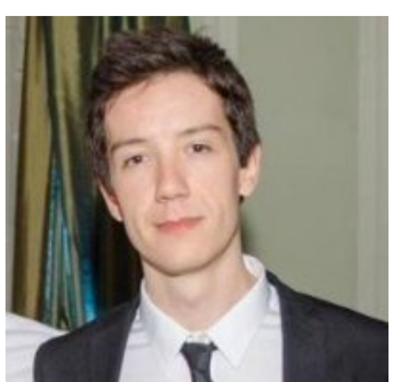
RILIS support

Valentin Fedosseev
Section leader EN-STI-LP

Bruce Marsh
Staff member EN-STI-LP

Camilo Granados
CERN fellow since
Apr. 2017

Katerina Chrysalidis,
PhD student since Oct. 2016



Shane Gary Wilkins
CERN fellow since
Oct. 2017

& Support from PNPI: Dima Fedorov,
Pavel Molkanov, Maxim Seliverstov

Eduardo Granados (new Staff member STI-LP)

Conclusion - aims for after LS2

ISBM activities

RILIS activities

MEDICIS

Fully operational RILIS @ OFFLINE 2

Fully operational RILIS @ MEDICIS

New dye lasers @ RILIS

Spare Blaze equivalent laser @ RILIS

Dual beam observation system (GPS and HRS) @ RILIS

Fourier limited linewidth Dye and Ti:Sapphire systems @ RILIS

RAMAN laser at RILIS?

CERN-supported RILIS control/DAQ

LIST operational at HRS and GPS

Modified VADLIS as standard

High-resistance (Sigradur) RILIS cavity

Offline demonstration of ToFLIS

LIST with PI option ?

Feasibility study of laser-induced molecular breakup spare slides

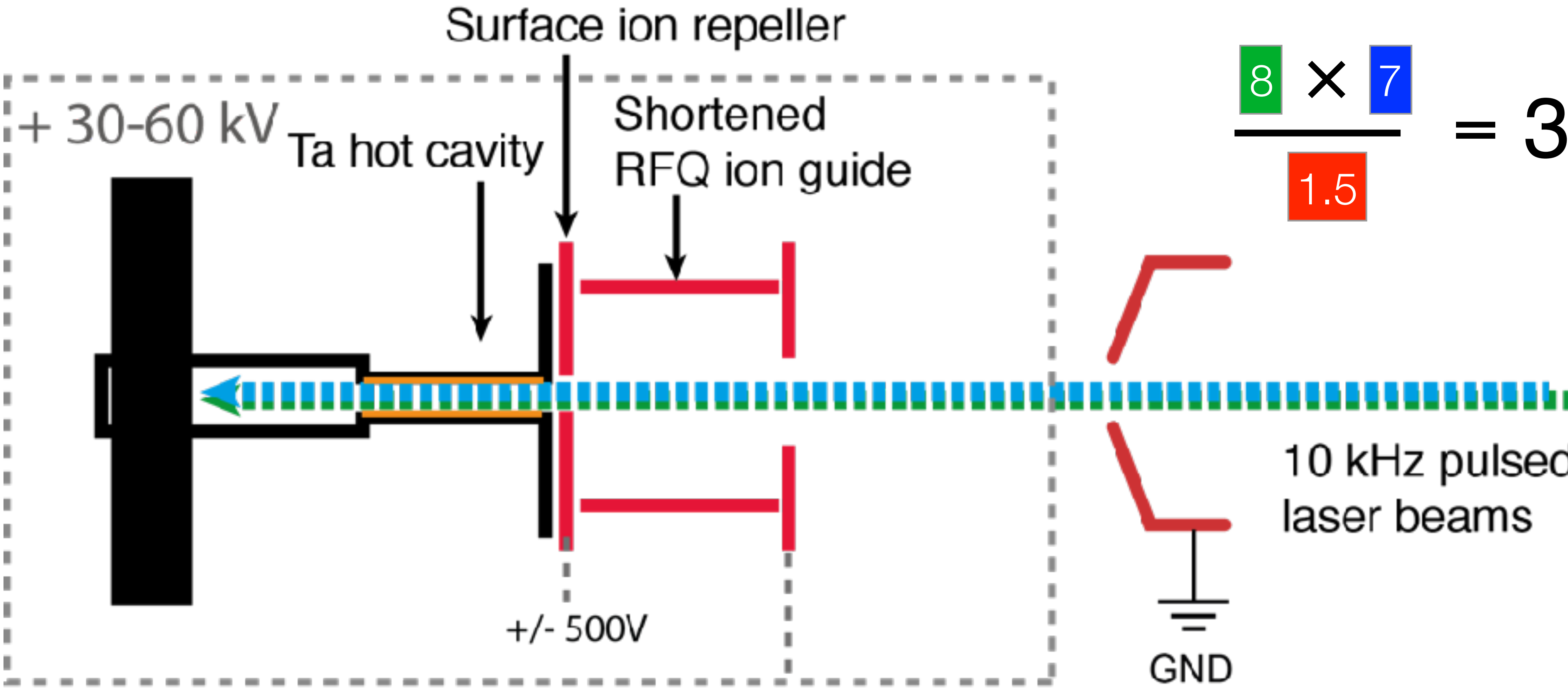
Setting development priorities

$$\frac{\text{Feasibility} \times \text{Usefulness}}{\text{Resources} \times 0.5} = ?$$

Suggestion: apply a 1-10 rating to each of these:

- **Feasibility** How likely it is to work as intended and withstand ISOLDE conditions?
- **Usefulness** How much benefit does it bring compared to existing options?
- **Resources** What are the financial, time, manpower and equipment costs?

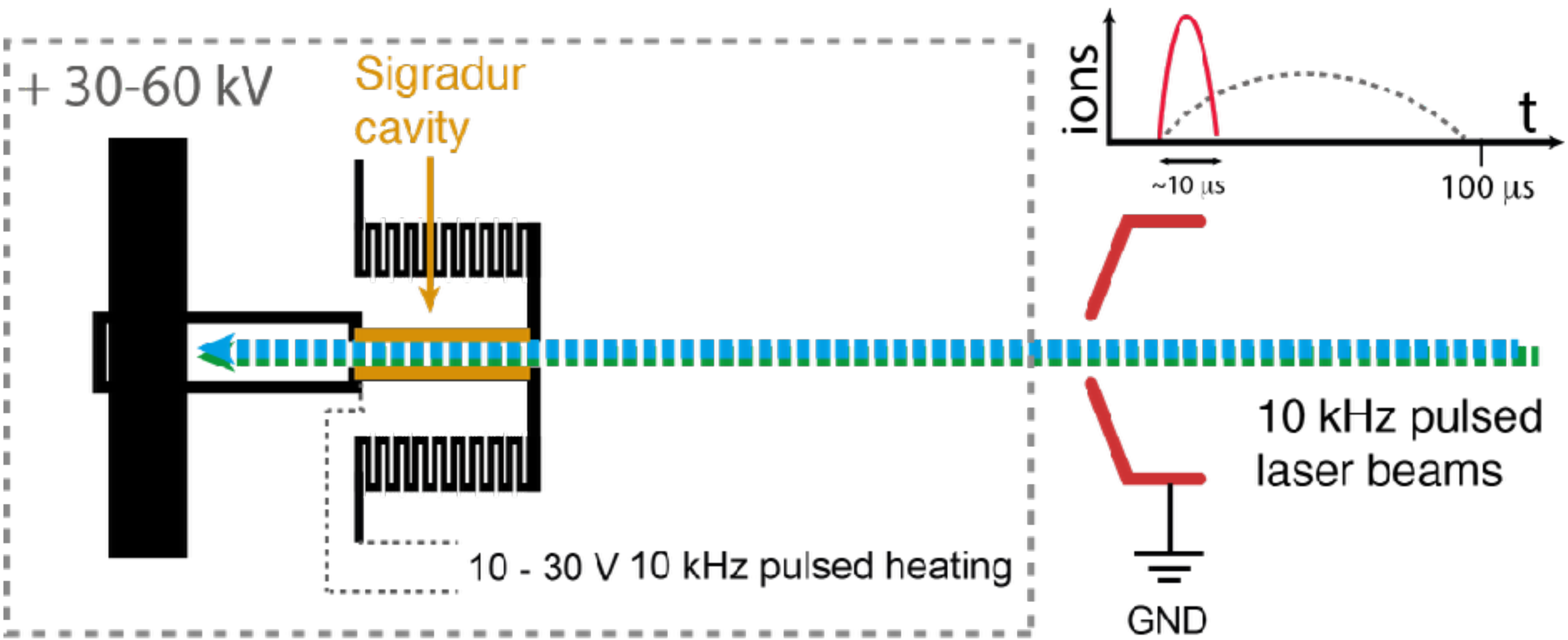
High Selectivity RILIS #1 — Short LIST



$$\frac{8 \times 7}{1.5} = 37$$

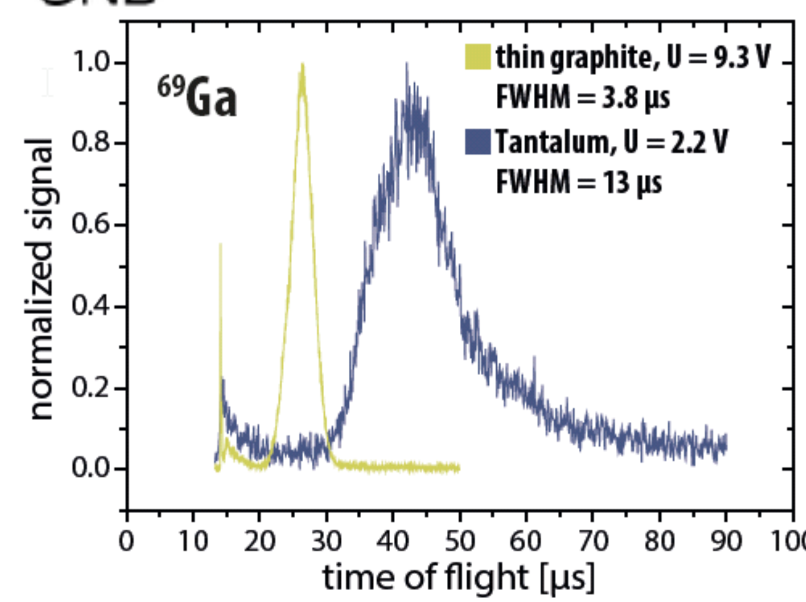
- New size enables compatibility with quartz line for extra selectivity
- No additional efficiency loss factor
- Accepted proposal for Tl, Po
- Quartz line suppression of Fr, Ra and transmission of Tl, Po unknown

High Selectivity RILIS #2 — HR Cavity

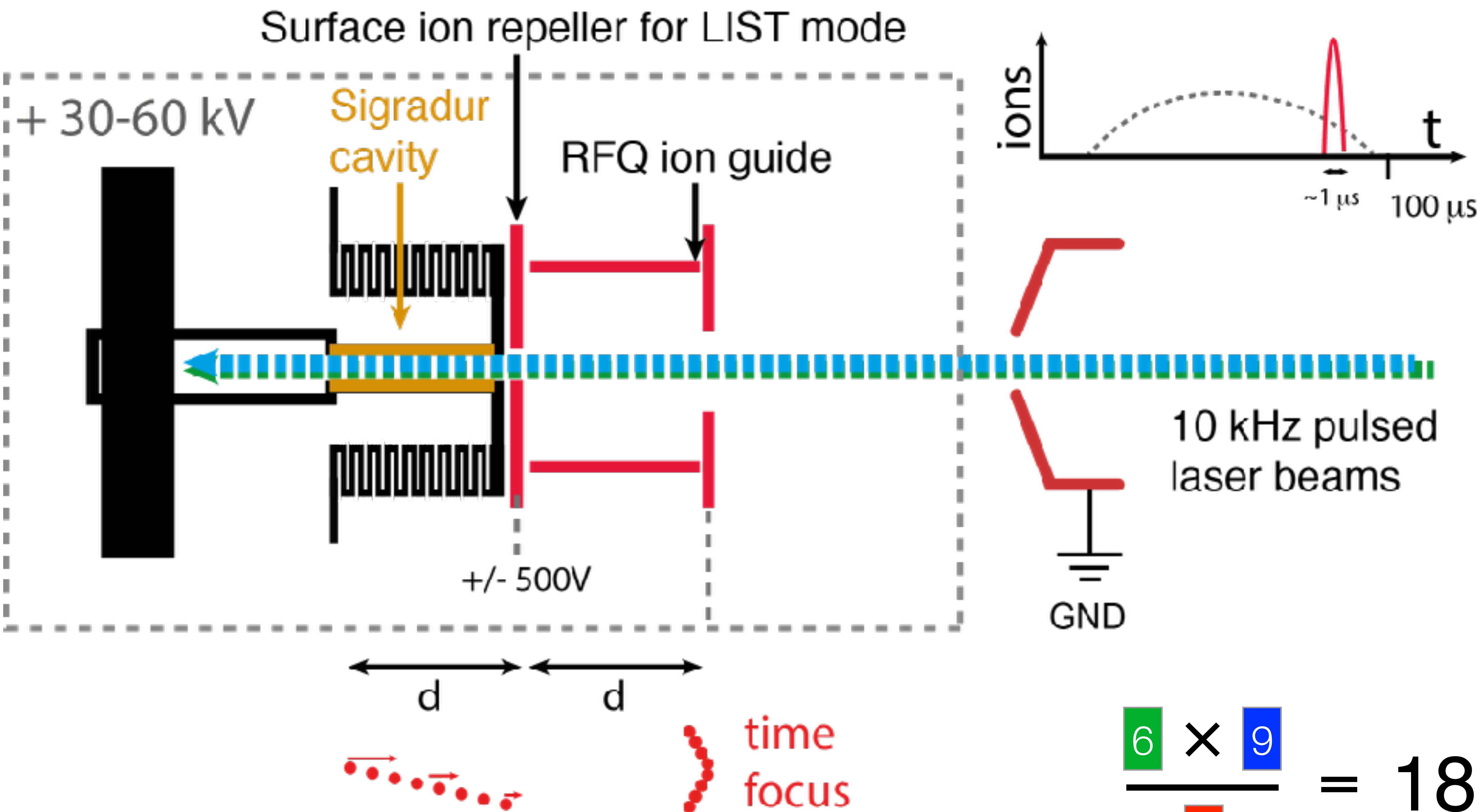


- Factor of ~10 surface ion suppression by beam gating
- Negligible efficiency loss?
- Possible improvement in hot cavity ion capacity??

$$\frac{7 \times 9}{2.5} = 25$$



High Selectivity RILIS #3 — ToF-LIS



$$\frac{6 \times 9}{3} = 18$$

- LIST provides transverse confinement along ‘drift’ region
- Hot-cavity (ion-guide) and standard LIST mode still available