中国科学院近代物理研究所
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Design, Optimization and Construction of MRTOF mass analyzer at IMP/CAS

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- Setup (SHANS)
- Design, optimization of mass analyzer
- Construction of MRTOF mass analyzer at IMP/CAS
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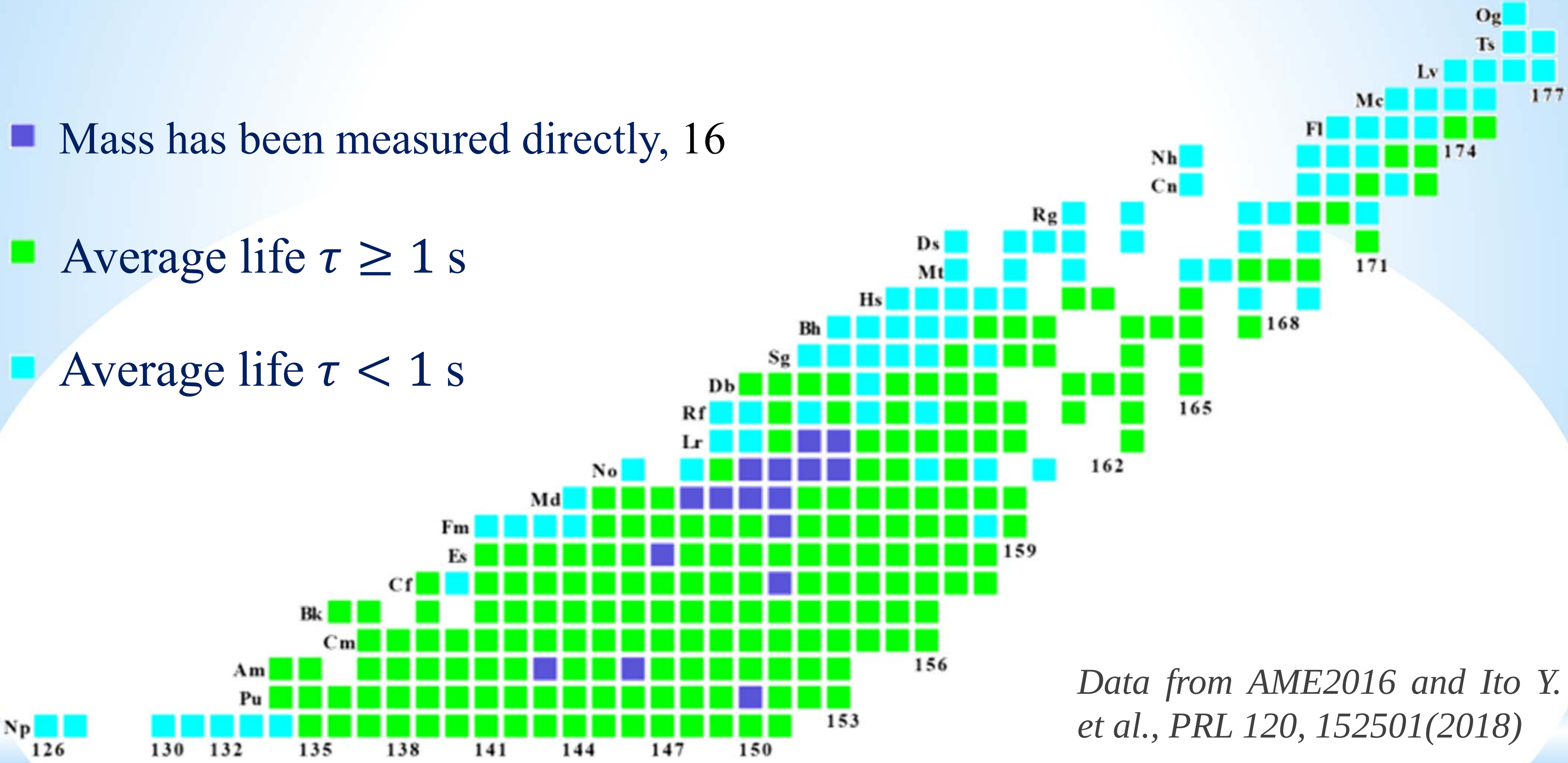
Motivation

- Mass has been measured directly, 16
- Average life $\tau \geq 1$ s
- Average life $\tau < 1$ s

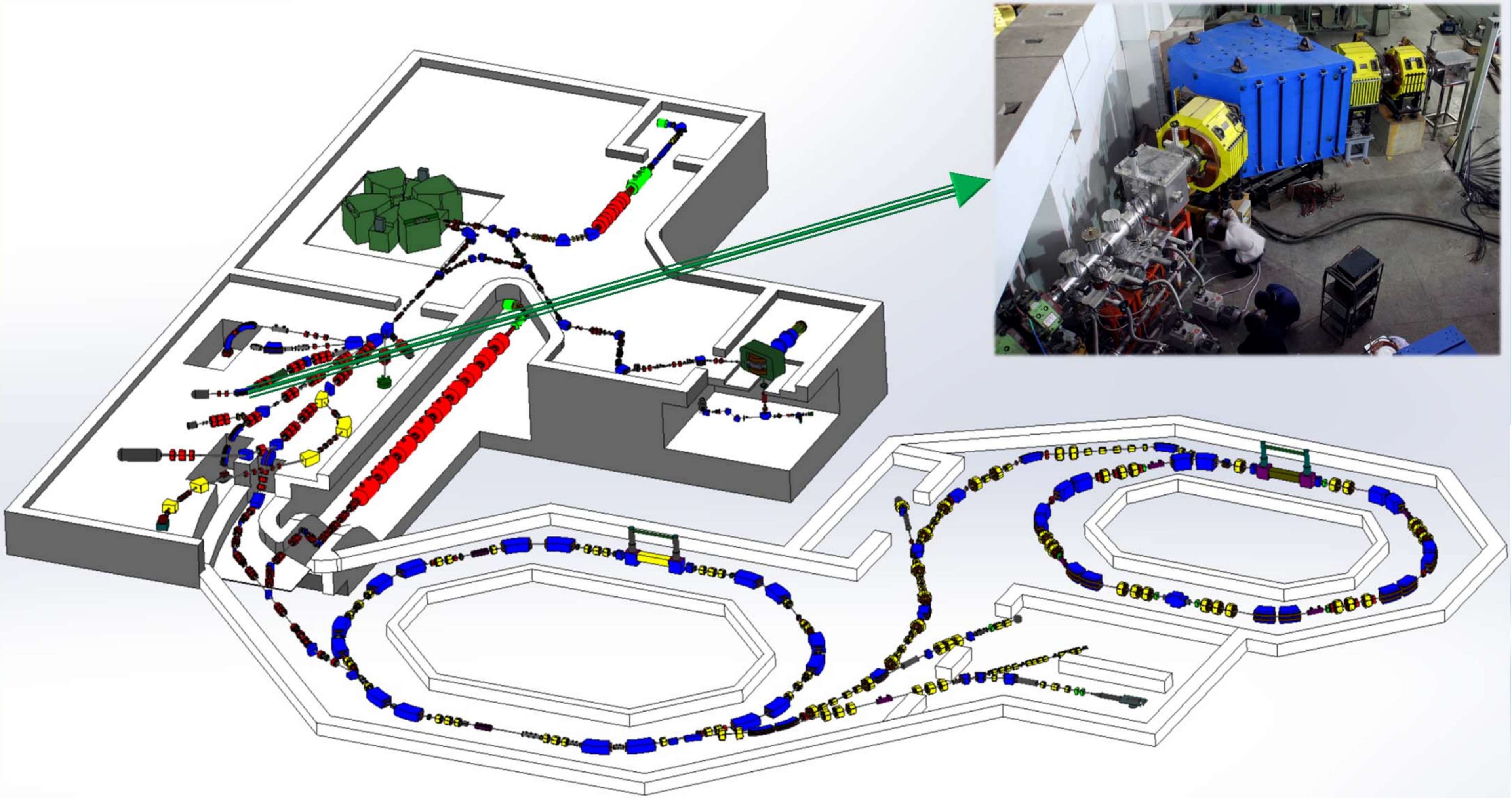


Data from AME2016 and Ito Y. et al., PRL 120, 152501(2018)

To measure the mass value of fusion-evaporation products, especially for the transuranium nuclei, directly.

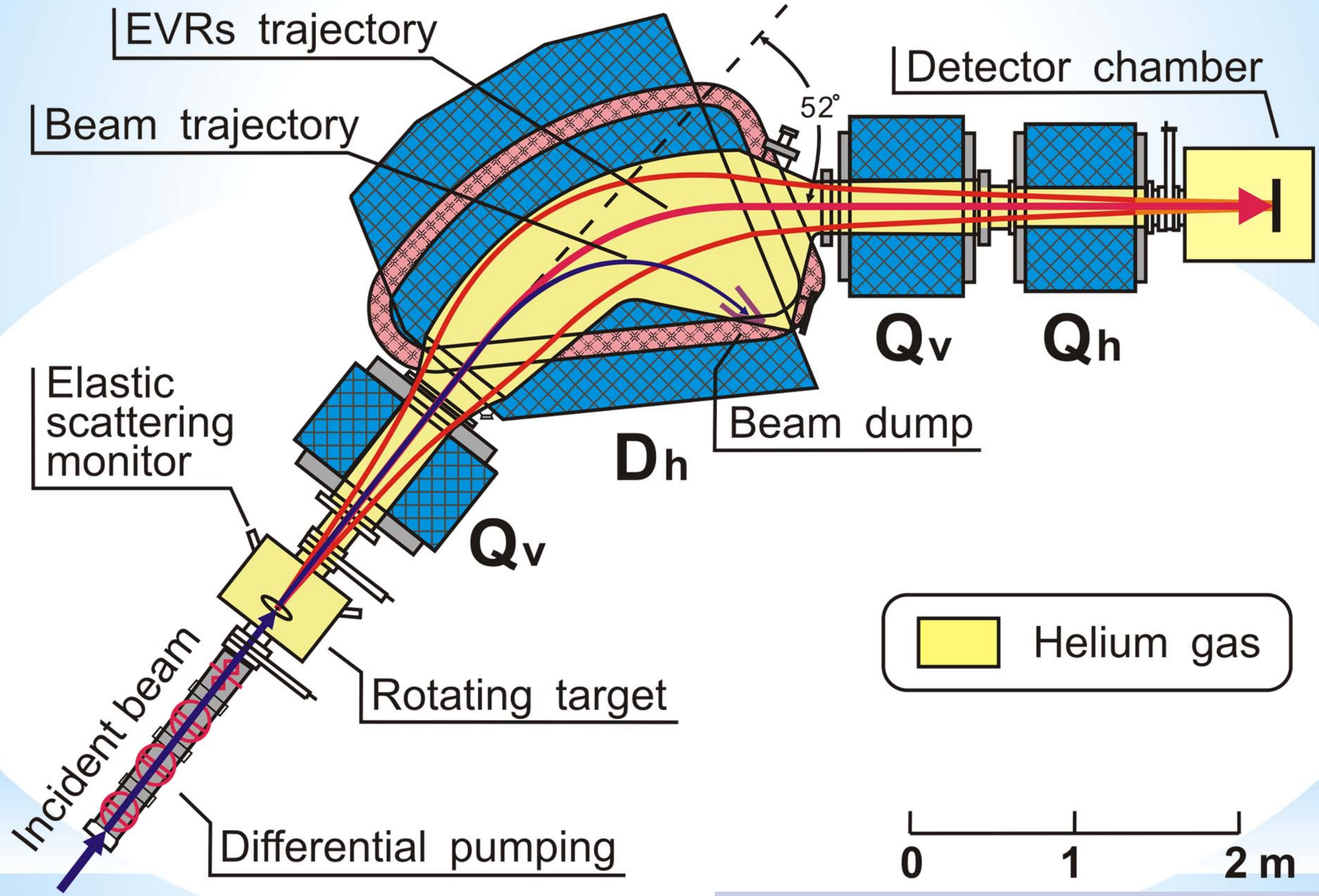
SHANS at HIRFL

Spectrometer for Heavy Atoms and Nuclear Structure



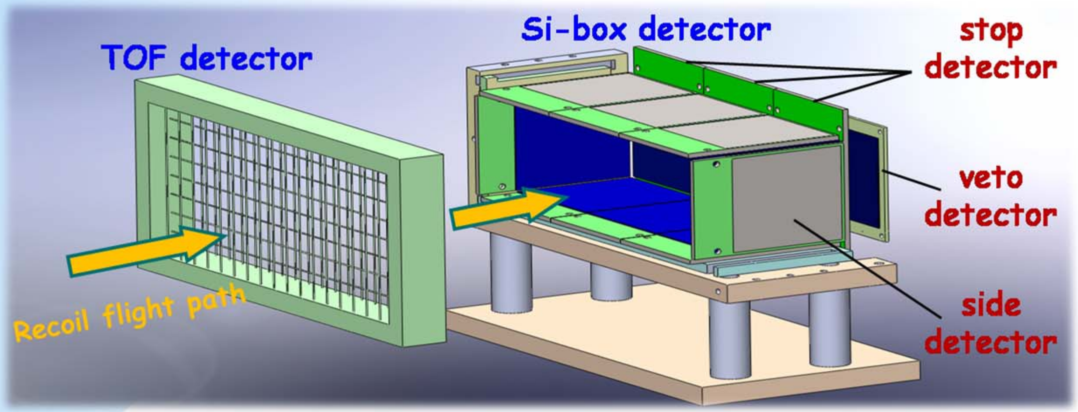
Heavy Ion Research Facility at Lanzhou

SHANS setup



Z. Y. Zhang, et al., Nucl. Instrum. Meth. B. **317**(2013): 315-318.

Nuclei from SHANS



[1] Z.Y. Zhang et al., Phys. Rev. C 89 (2014) 014308.

[2] L. Ma et al., Phys. Rev. C 91 (2015) 051302.

[3] H.B. Yang et al., EPJ A 51 (2015) 1-4.

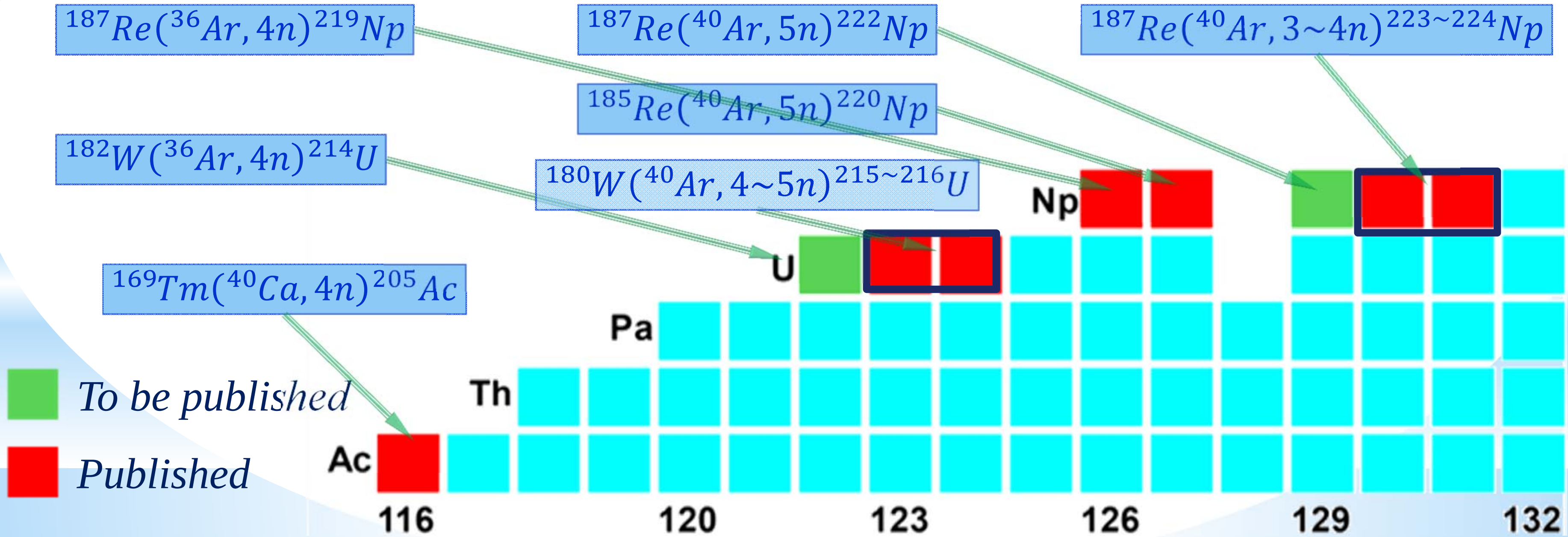
[4] M.D. Sun et al., Phys. Lett. B 771 (2017) 303-308.

[5] H.B. Yang et al., Phys. Lett. B 777 (2018) 212-216.

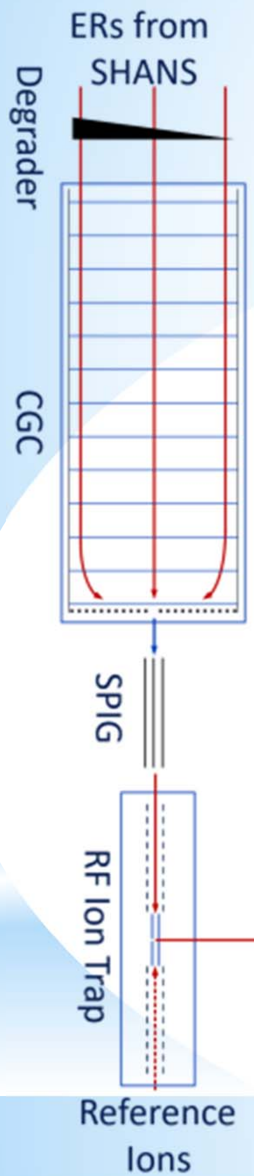
[6] T. Huang et al., Phys. Rev. C 98 (2018) 044302.

[7] Z.Y. Zhang et al., Phys. Rev. Lett. 122(2019) 192503.

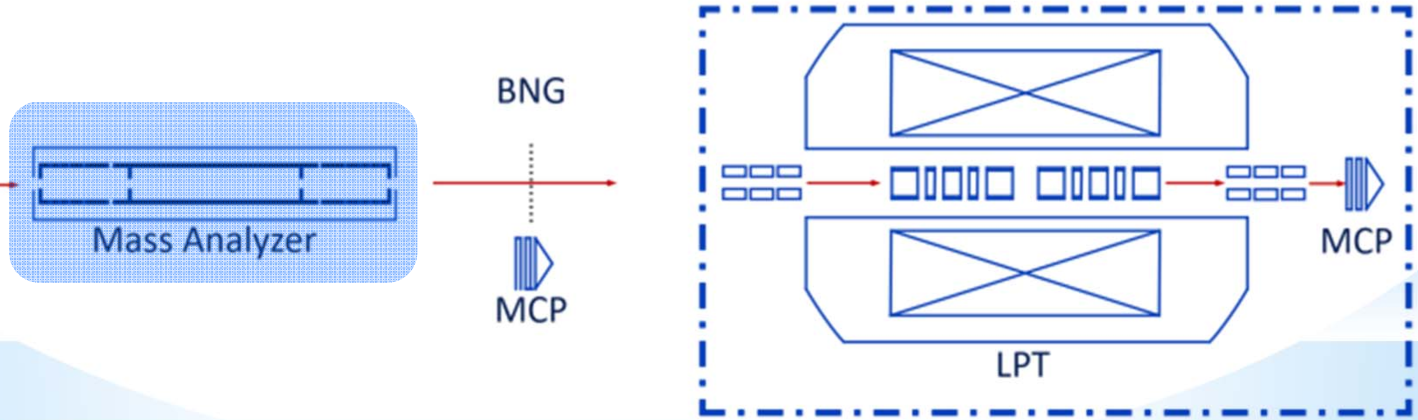
The reaction products are identified by using energy, spatial and time correlations between the implants and subsequent α decays.



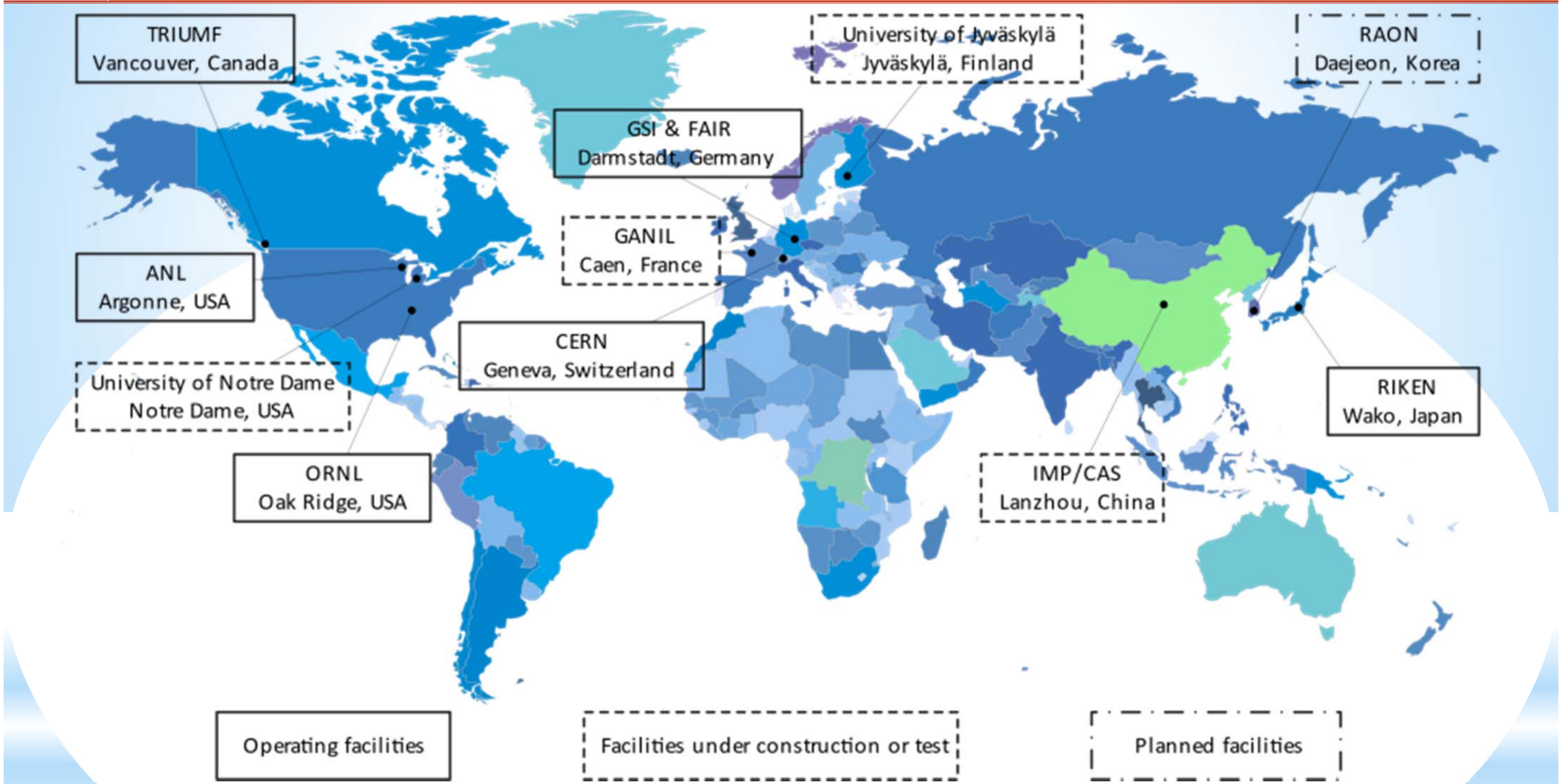
Layout of MRTOF-MS at SHANS



- Gas catcher collects evaporation-residues separated by SHANS and thermalizes them
- SPIG extracts the thermalized ions from gas catcher
- Ion trap provides high quality pulsed beam for mass analyzer
- Mass analyzer separates the ions with different $^{m}/_{q}$
- BN Gate deflects the unwanted ions
- MCP is a time-of-flight detector
- LPT is a Penning trap system



MRTOF-MSs nowadays



High sensitivity

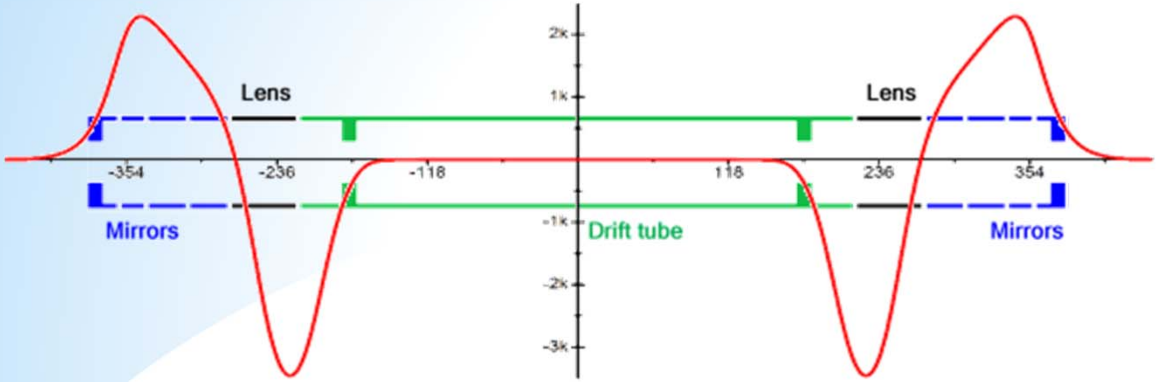
Non-scanning

Large mass range

Short measurement time

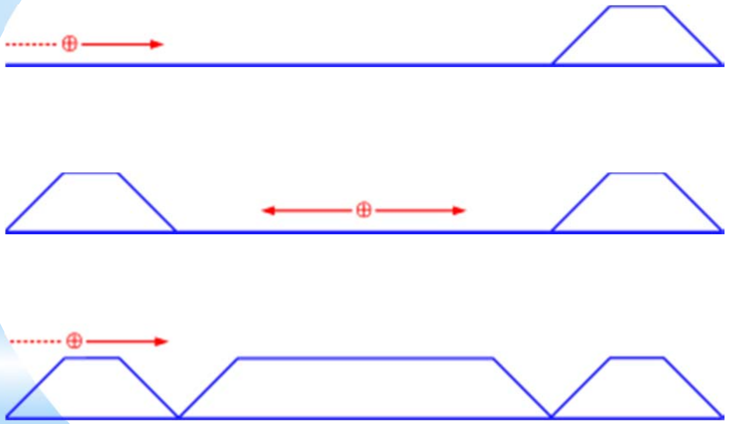
Low construction cost……

Basic theory of MRTOF-MS



$$ToF = \alpha\left(\frac{m}{q}\right)^{1/2} + \beta$$

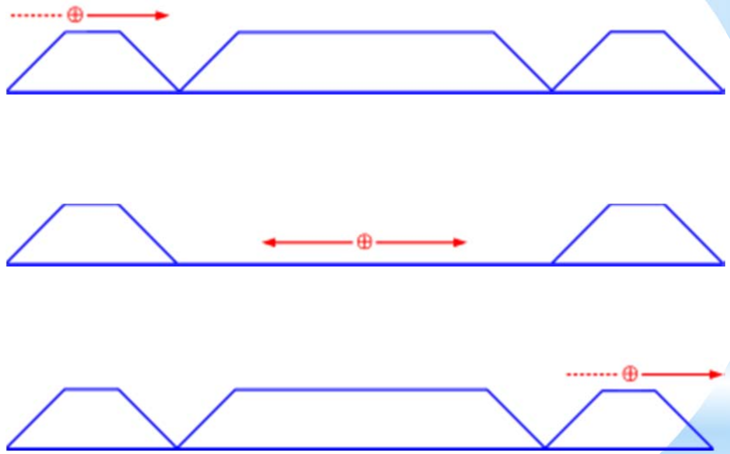
Switching-mirror mode **In-trap-lift mode**



Injection

Confinement

Ejection



- 1 or 2 reference nuclei with well-known masses are needed
- Mass resolving power： $R = \frac{m}{\Delta m} = \frac{ToF}{2\Delta ToF}$

Optimization of MRTOF-MS

- Why?

  The initial conditions of a cluster are complex.

  The phase space is large, but the usable parameters are limited.

- Goal?

  To find out the optimal parameters.

- How?

  SIMION code for ion trajectory calculation.

  Local code developed using C++ with Nelder–Mead simplex algorithm for parameter search.

Optimization procedure

A model is created in the SIMION according to the configuration of the MRTOF-MS

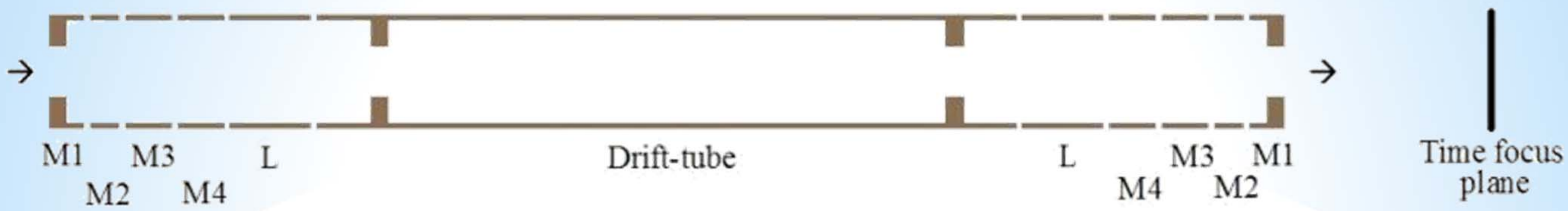
Global search: the initial parameters are elements from a potential matrix estimated roughly according to the knowledge of the beam optics

Local refine: inputting a few sets of relatively high resolving power from global search, a large number of local minima can be obtained and the best are chosen to be the optimal parameter sets

Advantages: the best parameter sets can be found; easy to change or expand the configuration

Disadvantage: very time consuming

Optimization conditions



	$M1$	$M2$	$M3$	$M4$	L	$Drift$
Length (mm)	20	16	26	26	46	400
Diameter (mm)				60		

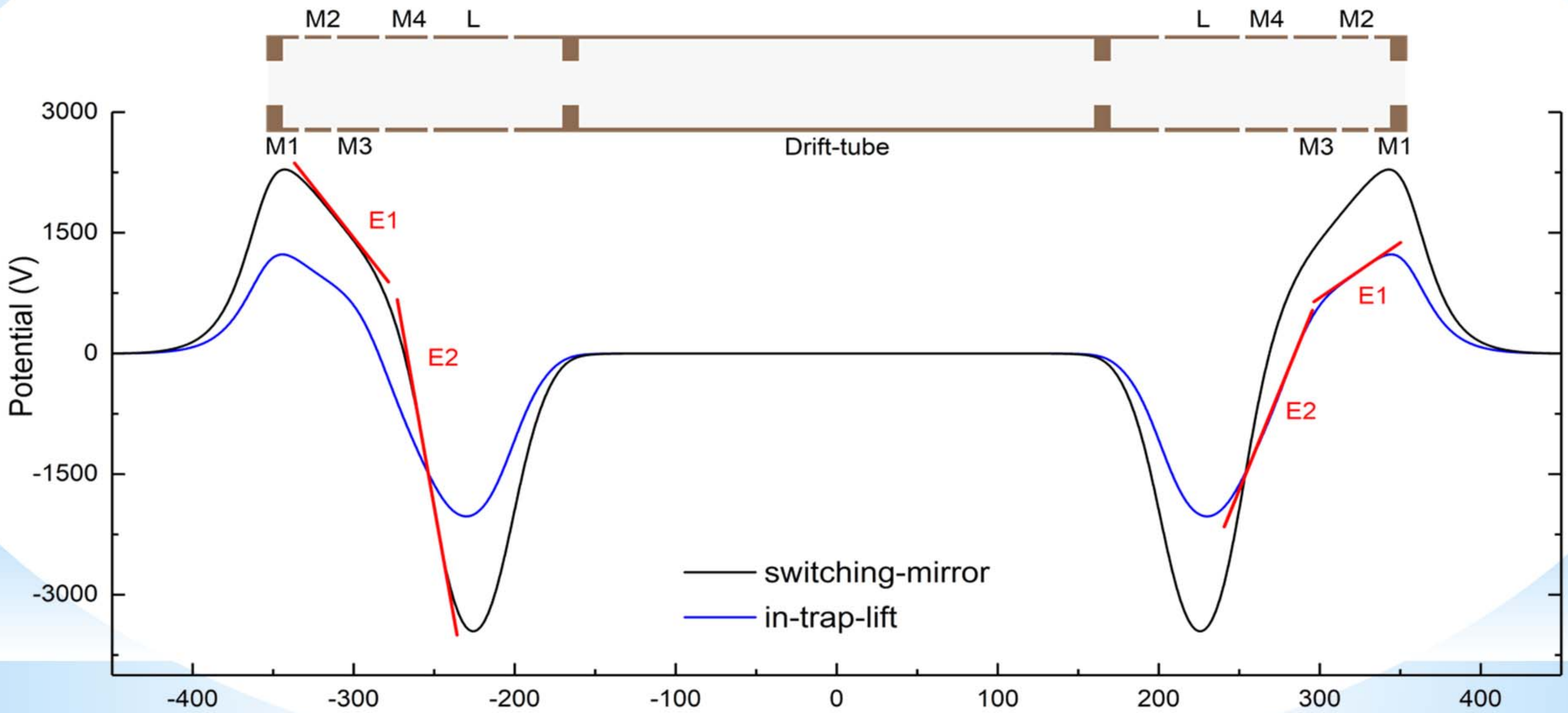
Initial conditions

	Kinetic energy		Position				Angle			
Ion	K (eV)	δK (eV)	x (mm)	δx (mm)	y (mm)	δy (mm)	a $(mrad)$	δa $(mrad)$	β $(mrad)$	$\delta\beta$ $(mrad)$
$^{40}Ar^{1+}$	1500	8.5	0	1	0	1	0	1.5	0	1.5

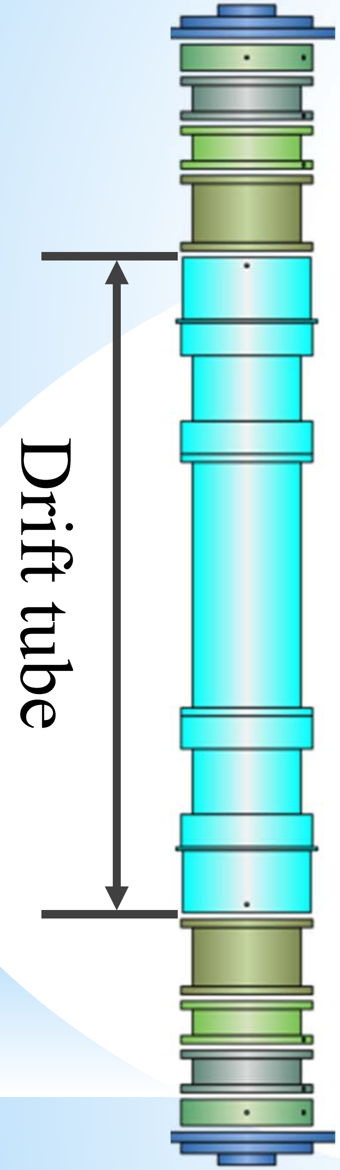
Potential optimization

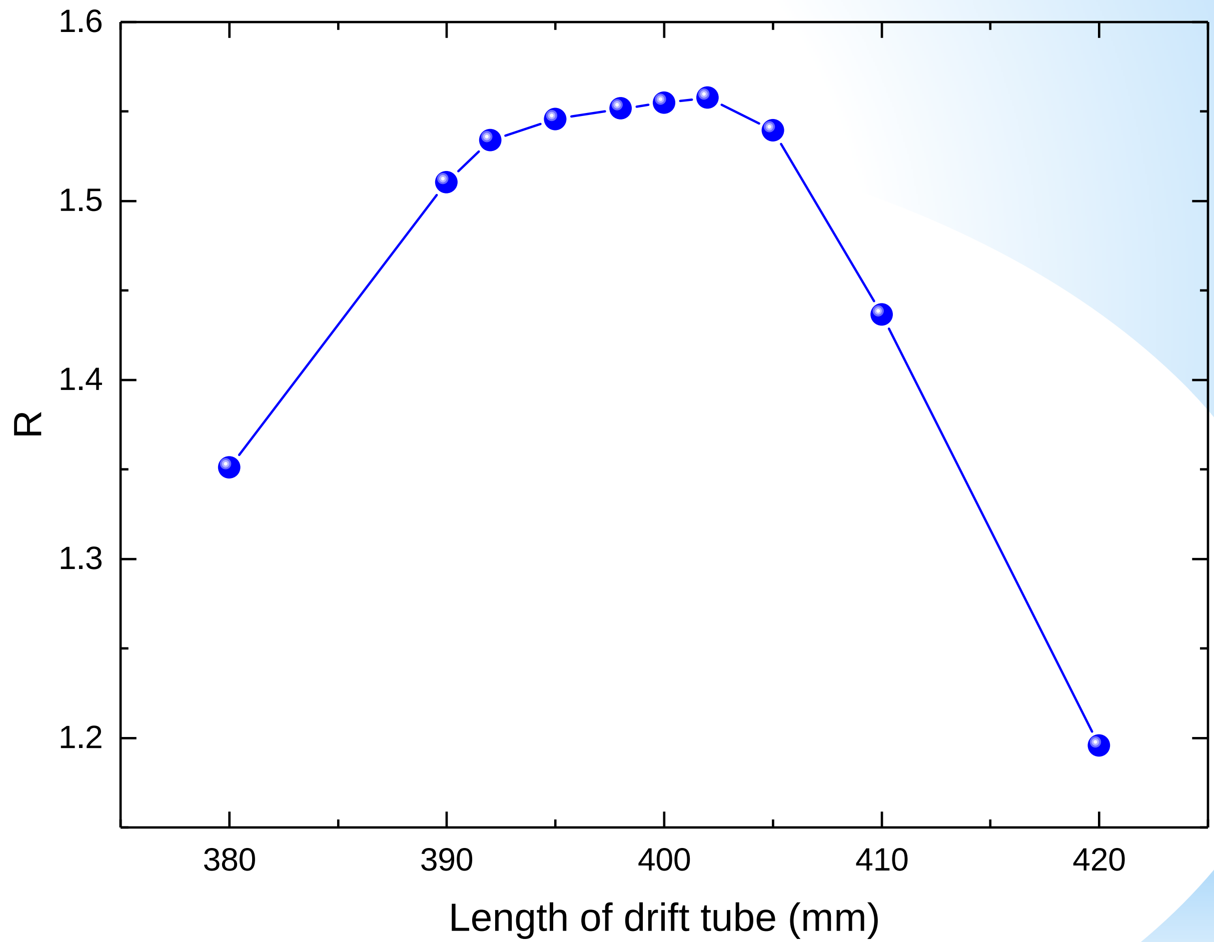
The optimal voltages can be found in different conditions (6.5ms as example)

Elec. No.		M_1	M_2	M_3	M_4	L	Drift
Potential(V)	switching-mirror	2502.5	2002.2	1420.9	817.1	-4473.1	0
	in-trap-lift	1159.5	756.5	743.9	-1262.9	-2234.2	703.5



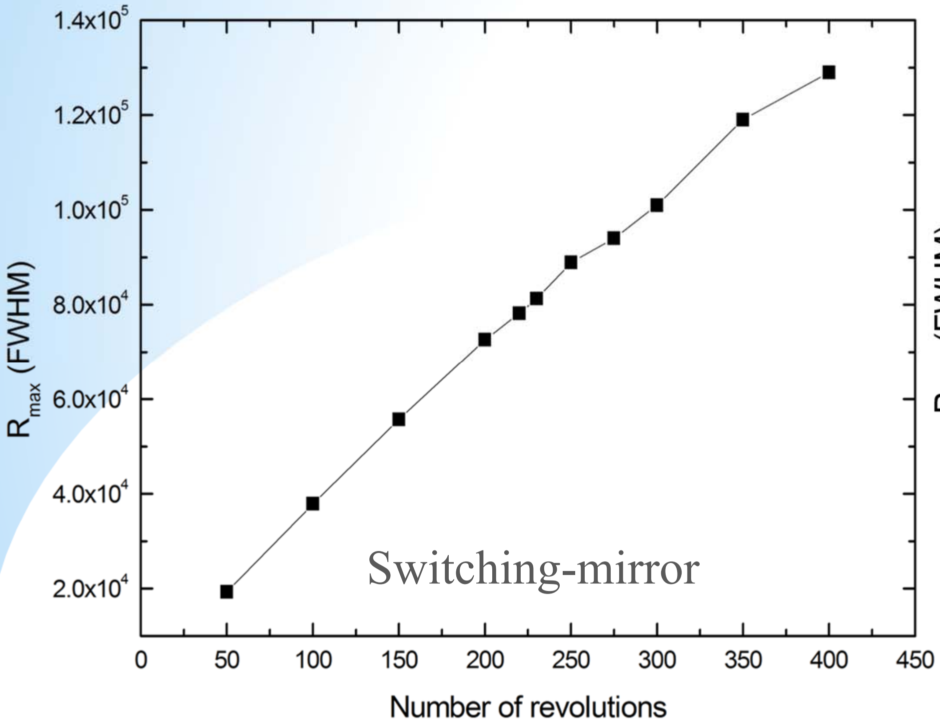
Length of the drift tube

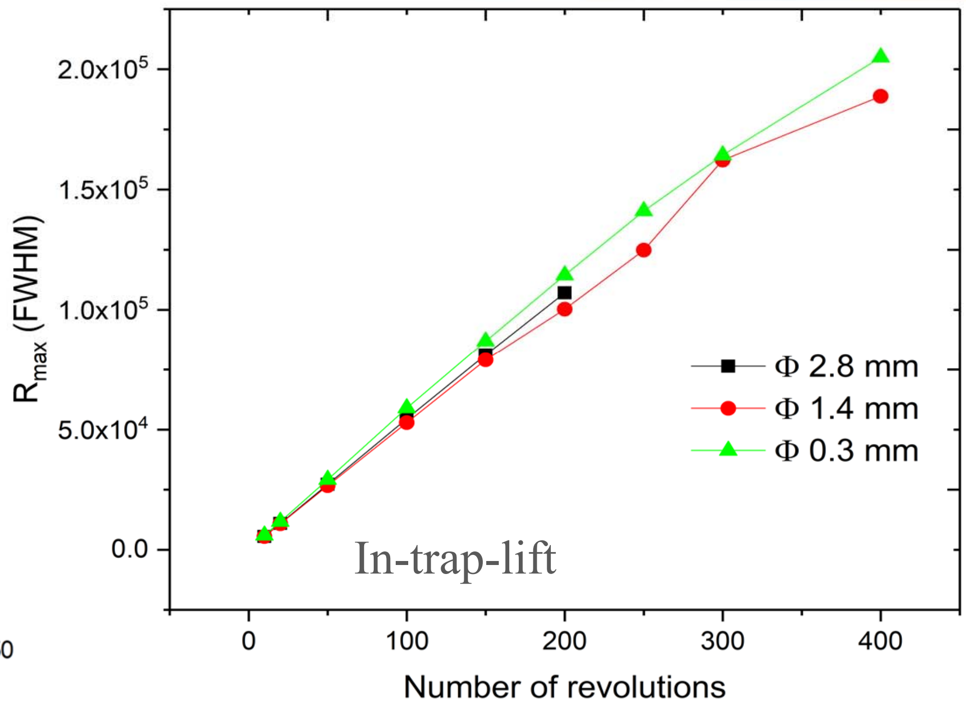




Optimal length： 398-402 mm

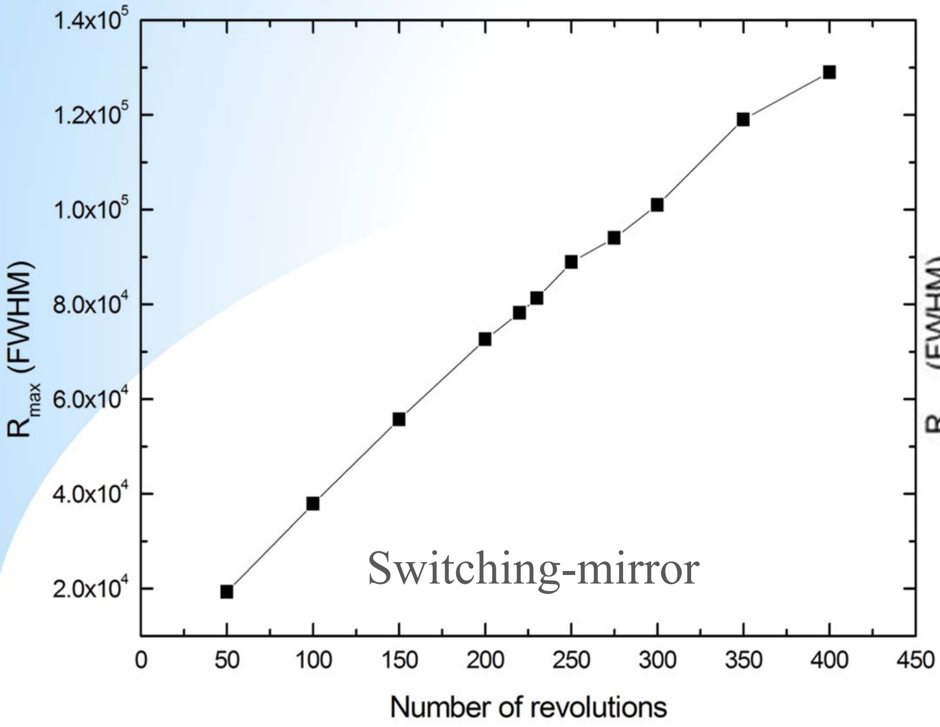
R_{max} at different revolutions

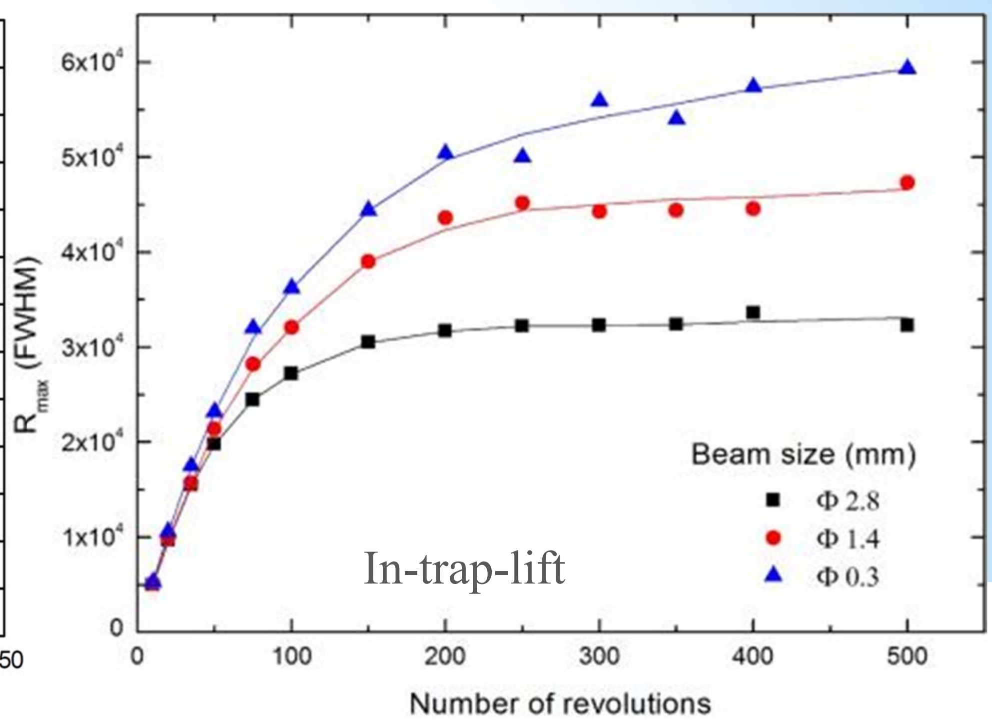




- The mass resolving power increases with the increasing of revolution numbers
- Beam size affects R_{max} little at optimal parameter sets, but shows more significant influence at other set points

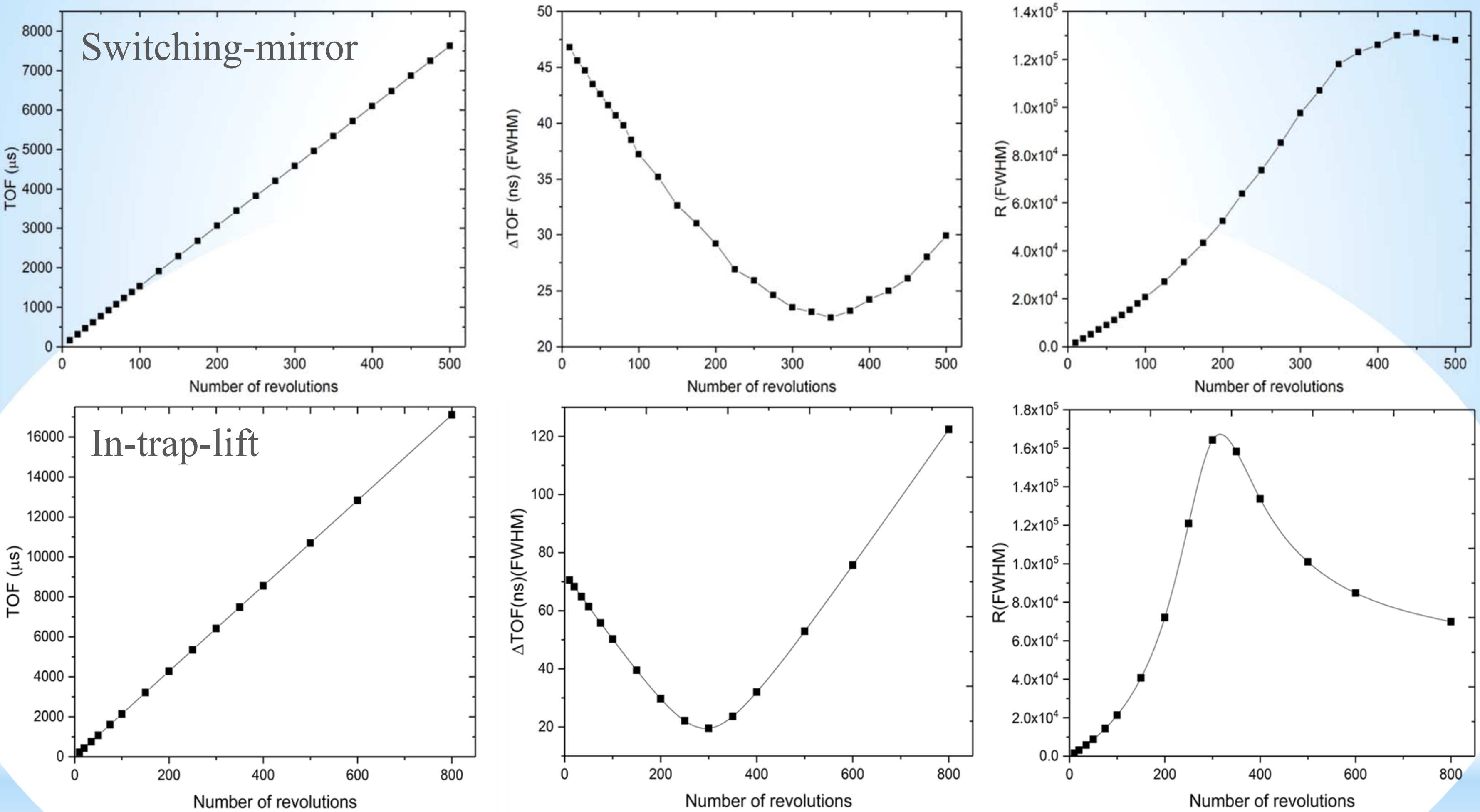
R_{max} at different revolutions





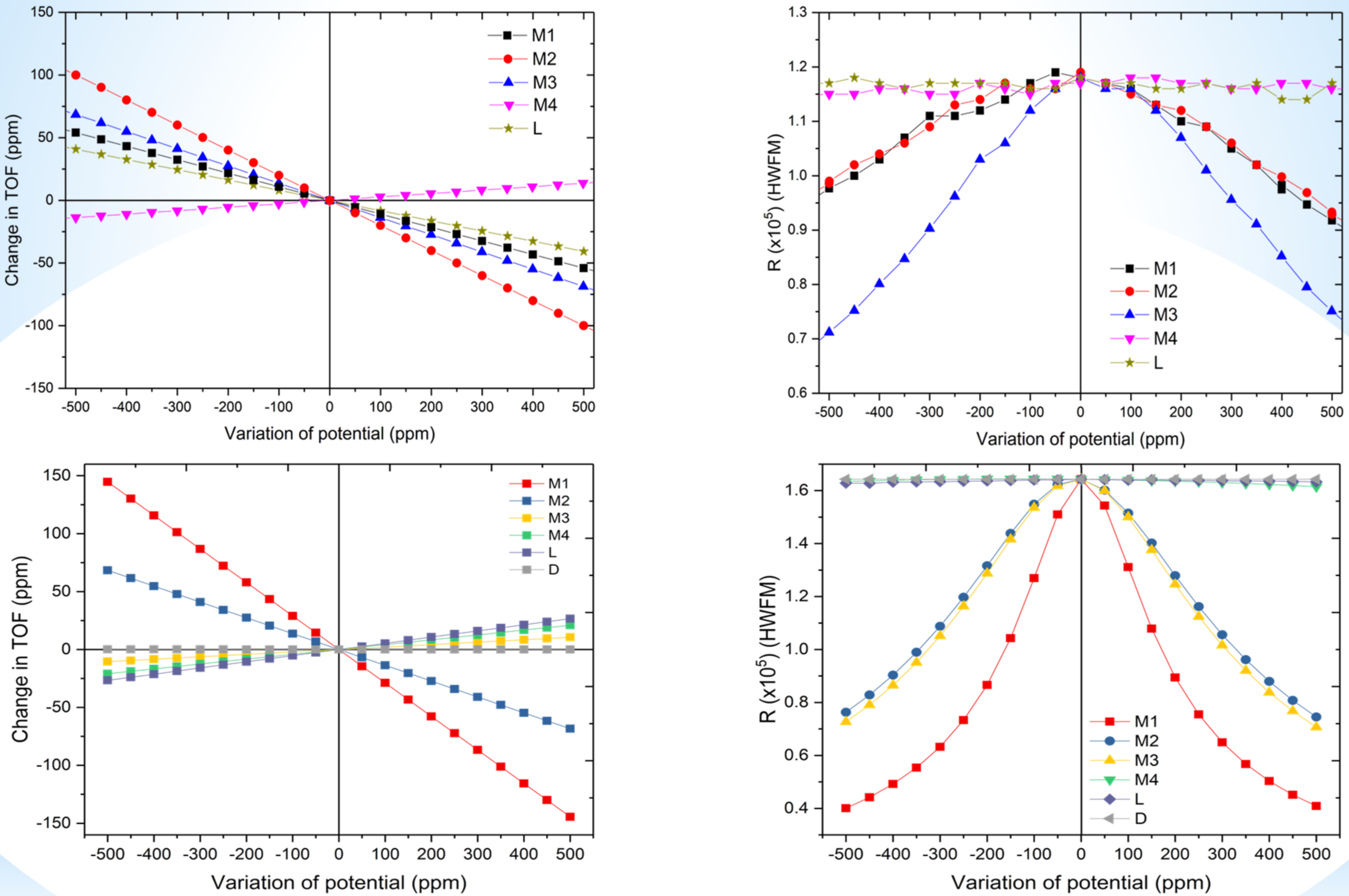
- The mass resolving power increases with the increasing of revolution numbers
- Beam size affects R_{max} little at optimal parameter sets, but shows more significant influence at other set points

TOF, ΔTOF, R with fixed potentials



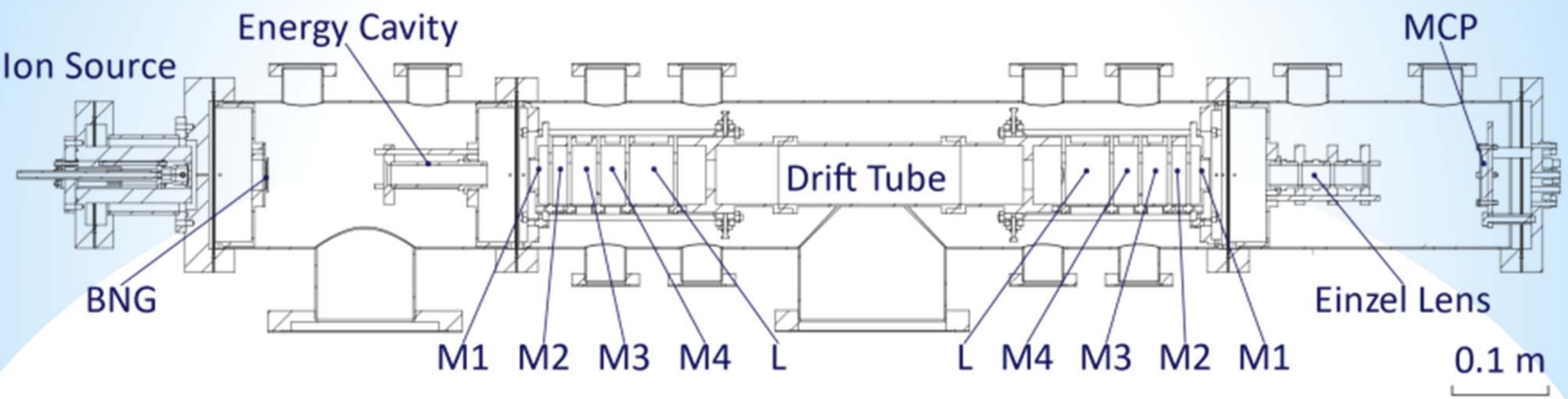
- TOF almost increases linearly with the increase of number of revolutions
- The temporal spread decreases until a minimum, $\approx 20\ ns$
- Resolving power $\mathrm{R} > 10^5$

Potential inaccuracy influence



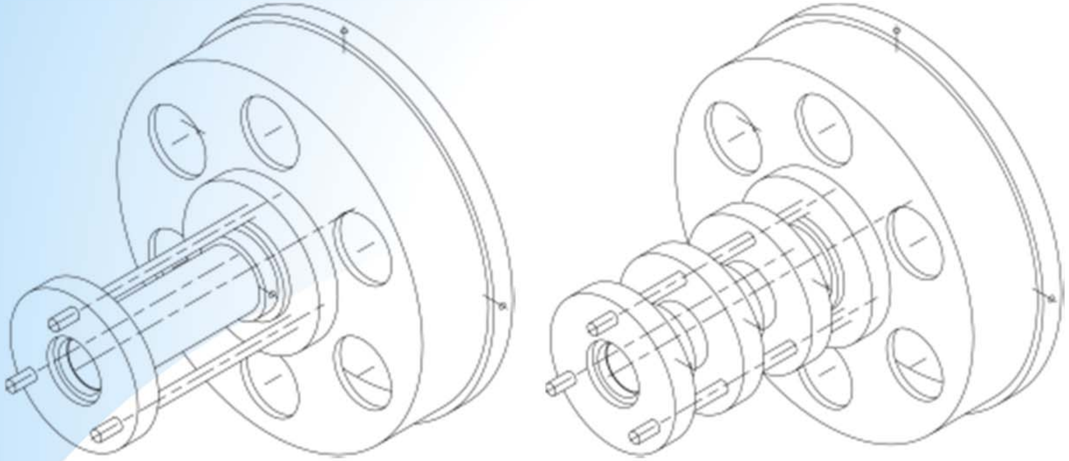
Potential inaccuracy on electrodes where the ions turn around shows more significant influence to mass resolving power.

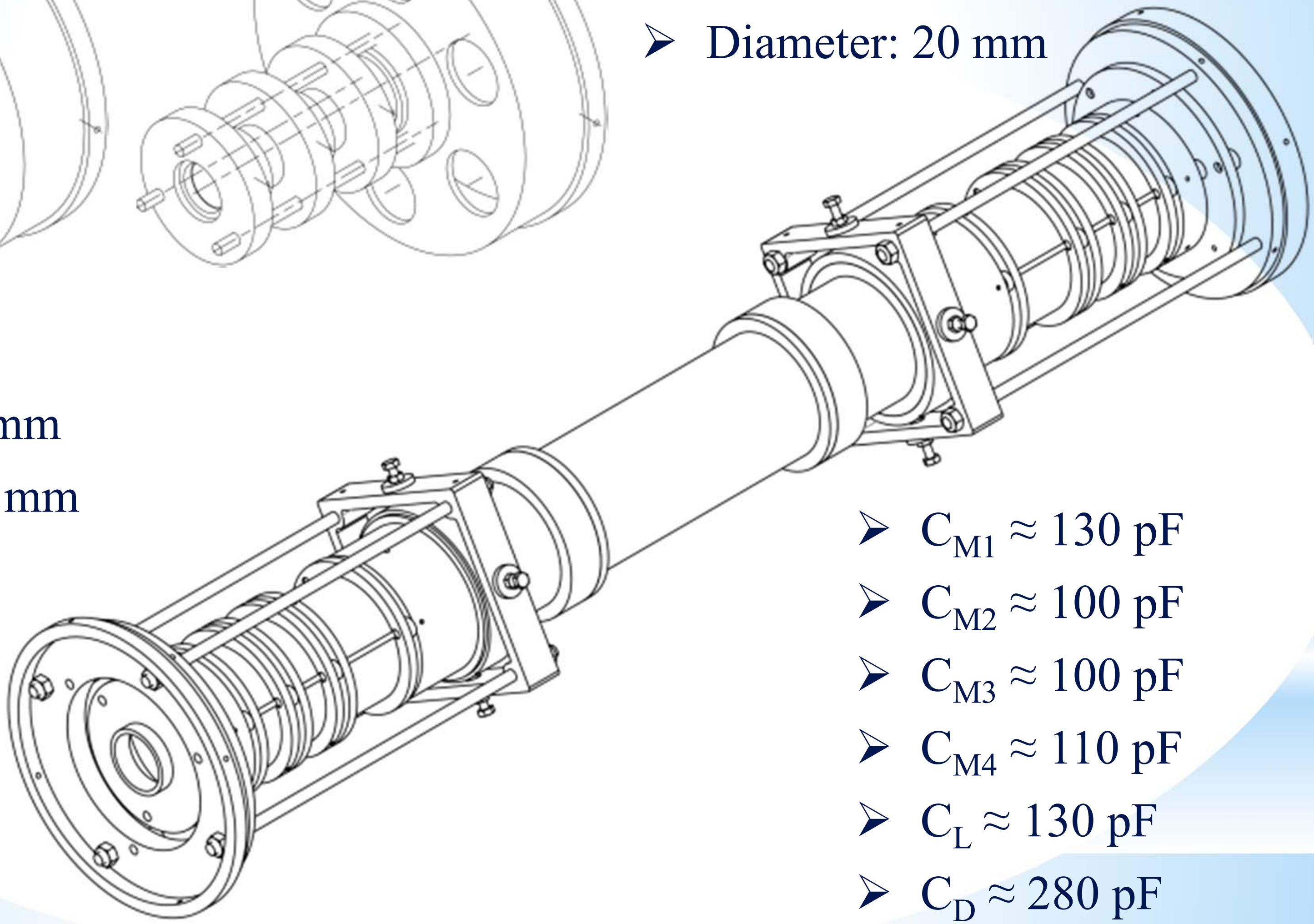
Construction of MRTOF mass analyzer at IMP/CAS



- Total length ≈ 1.5 m, total weight ≈ 70 kg, total number of parts ≈ 160
- Electrode material: 304 stainless steel
- Insulation material: Ceramic (low outgassing rate), Poly-Ether-Ether-Ketone/ PEEK (excellent mechanical properties)
- Wires：Kapton cable (good conductive, voltage-resistant and insulating properties, and low outgassing rate)

Geometry parameters of components





Einzel Lens

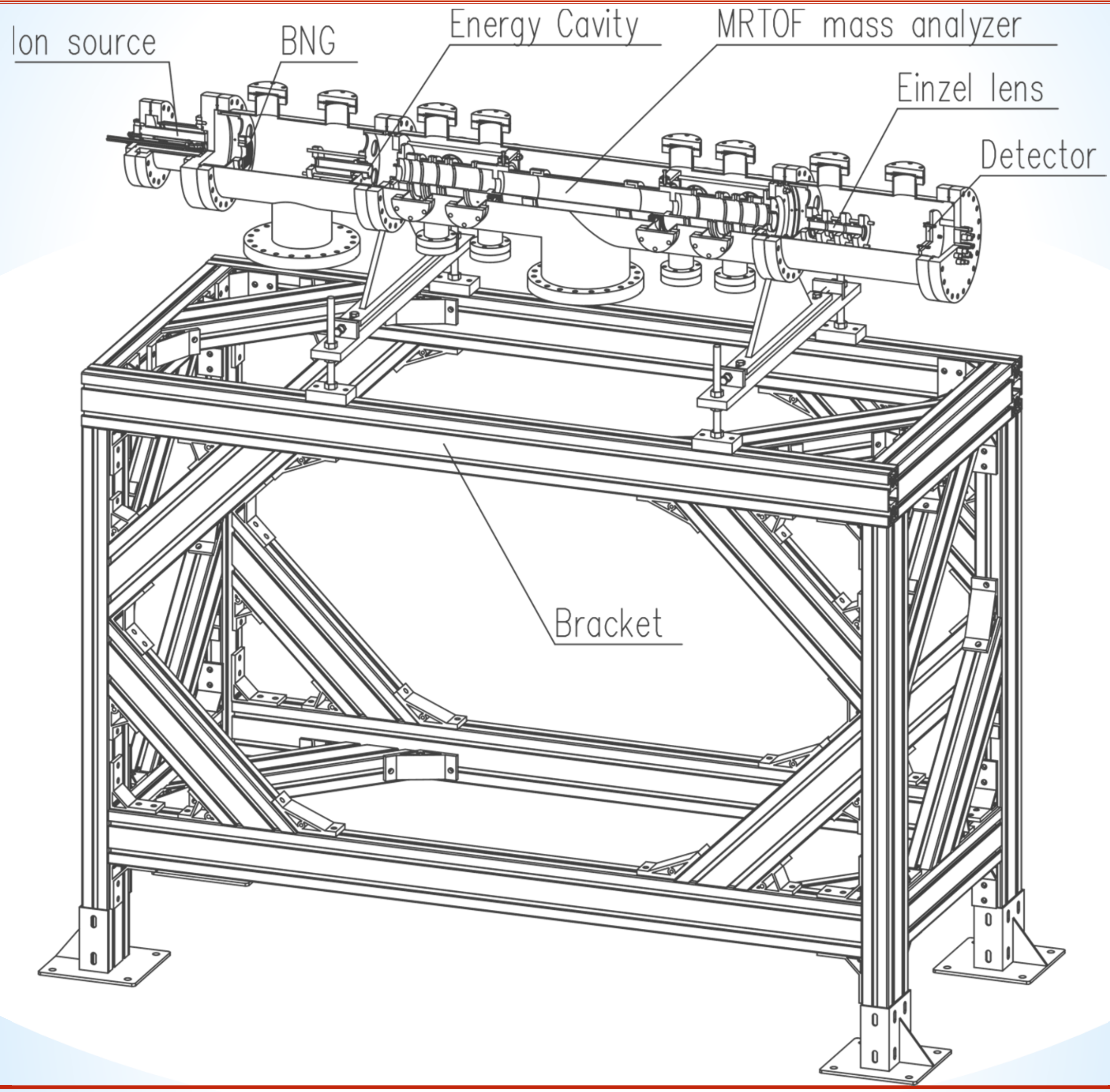
- Length: 30 mm
- Diameter: 20 mm

Energy Cavity

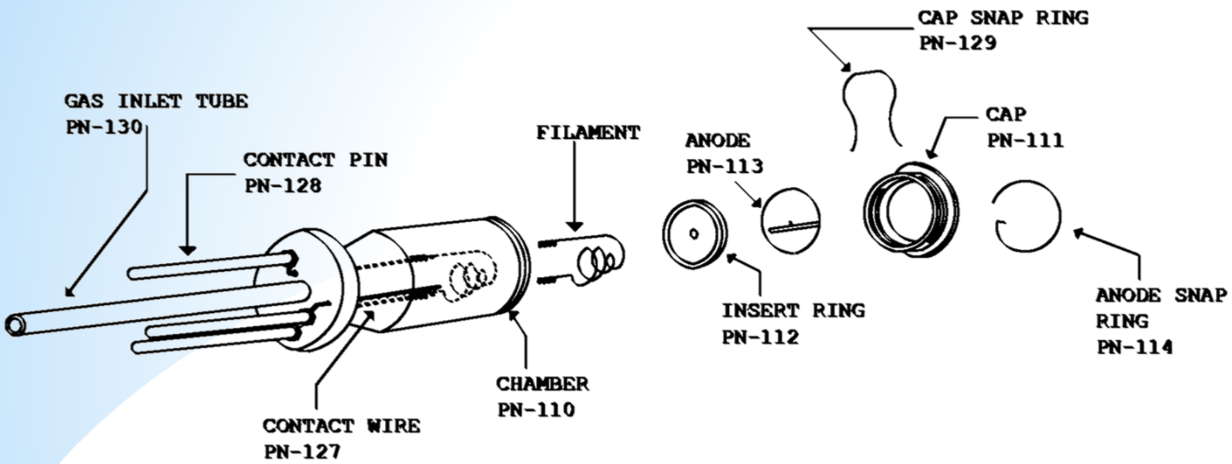
- Length: 100 mm
- Diameter: 20 mm
- $C_{EC} \approx 90$ pF

- $C_{M1} \approx 130$ pF
- $C_{M2} \approx 100$ pF
- $C_{M3} \approx 100$ pF
- $C_{M4} \approx 110$ pF
- $C_{L} \approx 130$ pF
- $C_{D} \approx 280$ pF

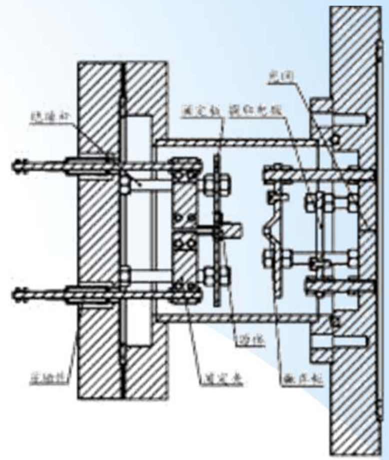
Overall assembly diagram



Ion source



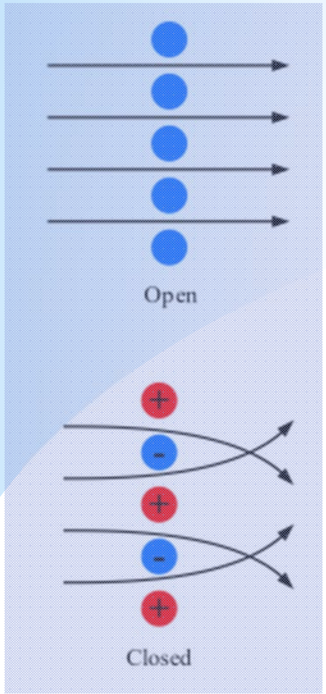
Gas ion ($^{40}Ar^{1+}$、$^{22}Ne^{1+}$) or alkali metal ion …

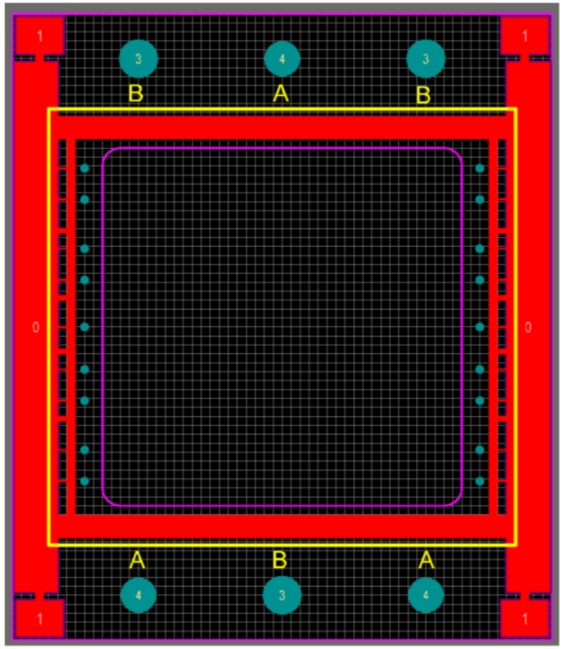


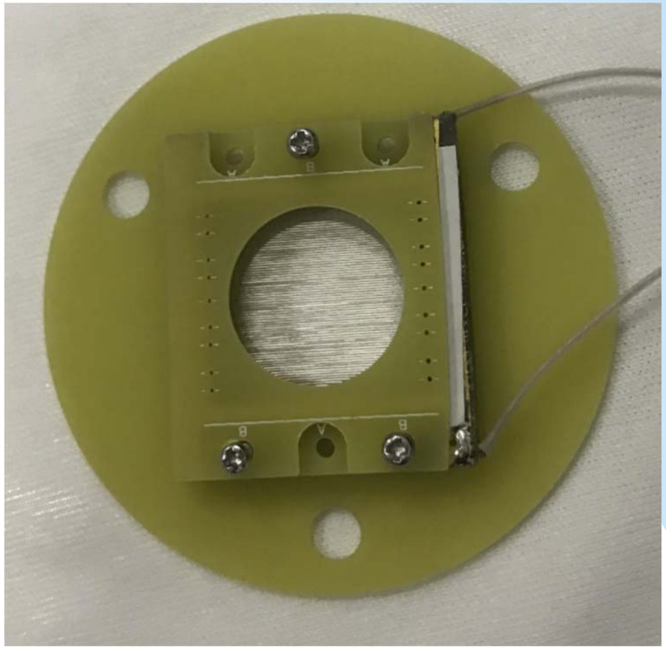
alkali metal or alkaline-earth metal ion …

- **Function**: provide stable beam for off-line test and reference ion for online operation
- Hot cathode discharge ion source
  - advantage: large beam intensity, many kinds of ions, no limits on the life of ions
  - disadvantage: poor vacuum, regular maintenance
- Surface ionization source
  - advantage: stable, little impact on vacuum, no need for maintenance
  - disadvantage: limited types of ions, short service life at strong current

Pulsed Bradbury-Nielsen Gate (BNG)

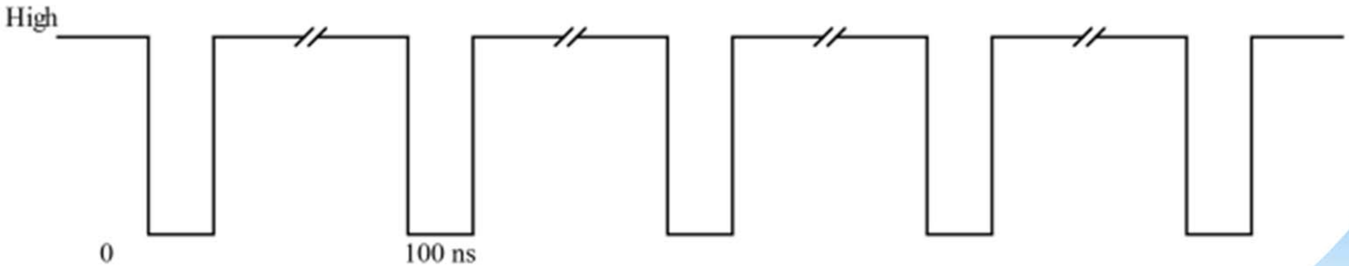






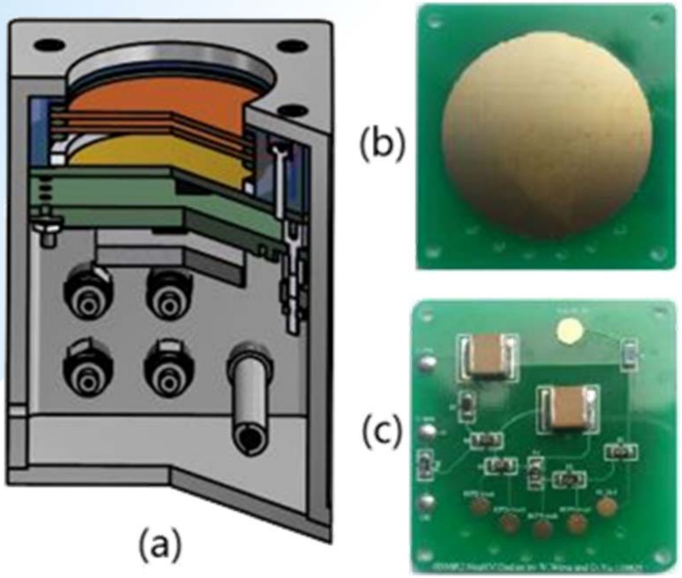
Provided by Dr. Herun Yang from IMP

Timing control



- Convert a continuous beam into a pulse beam with a time-width of about 100 ns.
- Material: stainless-steel; diameter of wires: 50 µm; wire spacing: 250 µm

Detector – MCP



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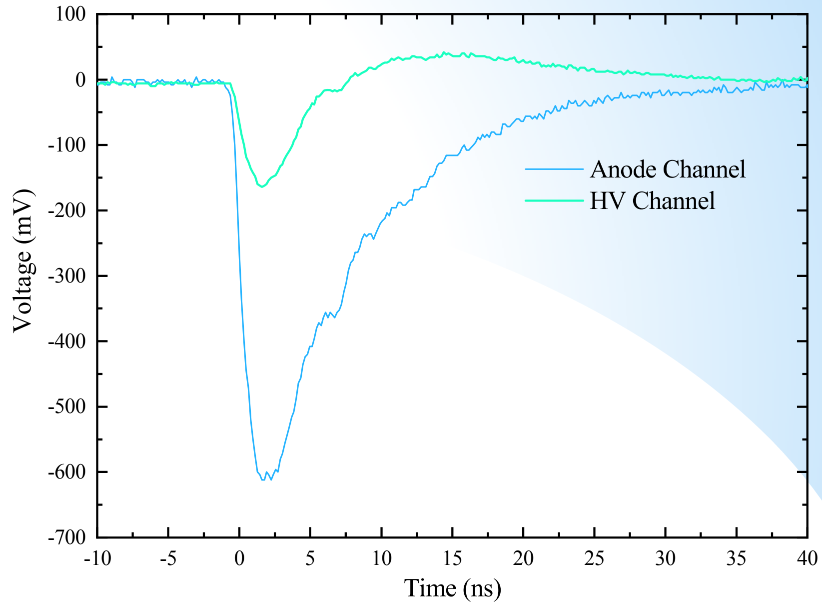
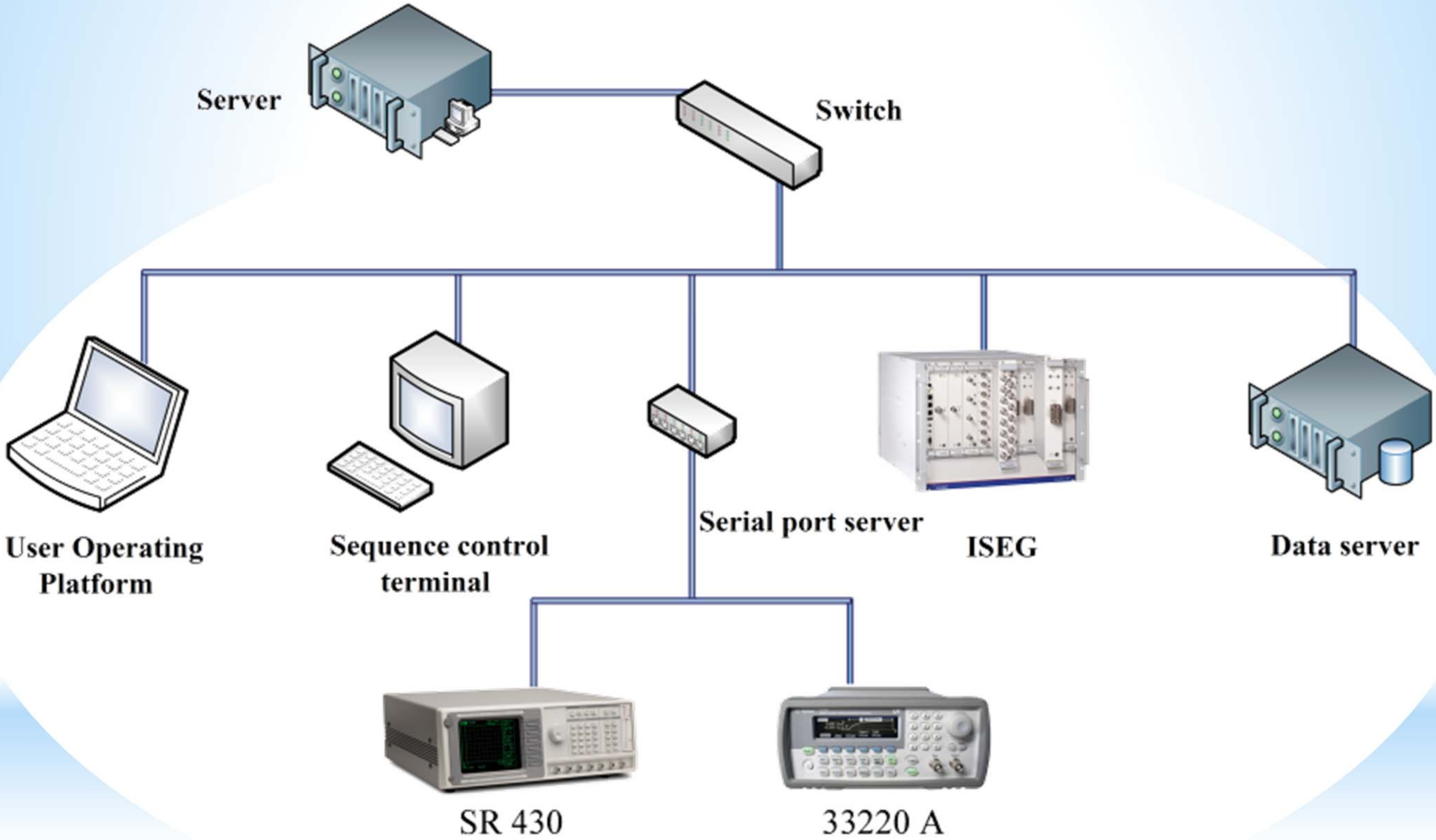
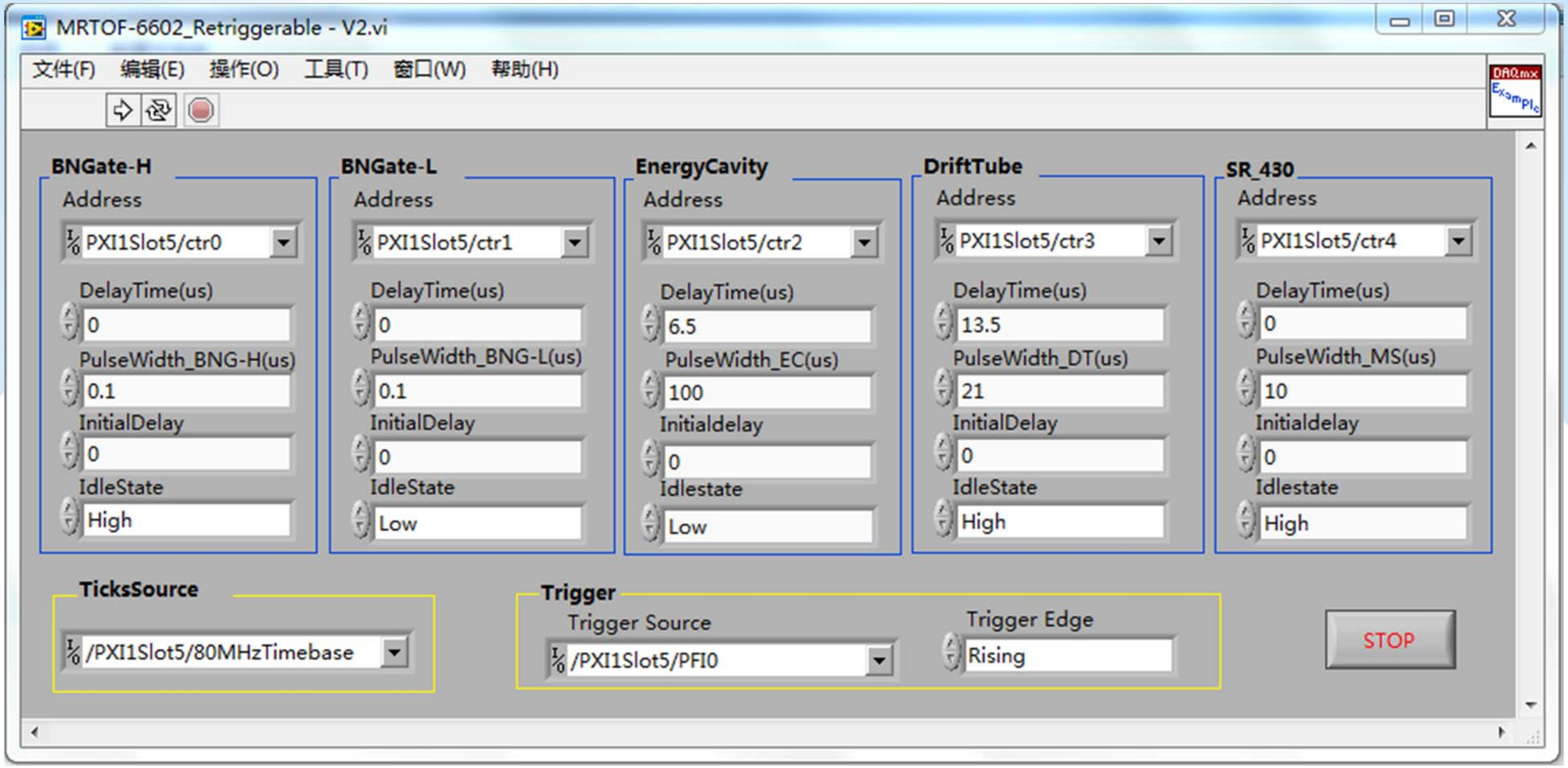


- Integrated and compact electronics
- Strong anti-interference ability
- high signal-to-noise ratio
- Two outputs: Anode channel and HV channel
- Signal of anode channel: 600 mV
- Rise time: ≈ 2 ns

Distributed control and data acquisition system

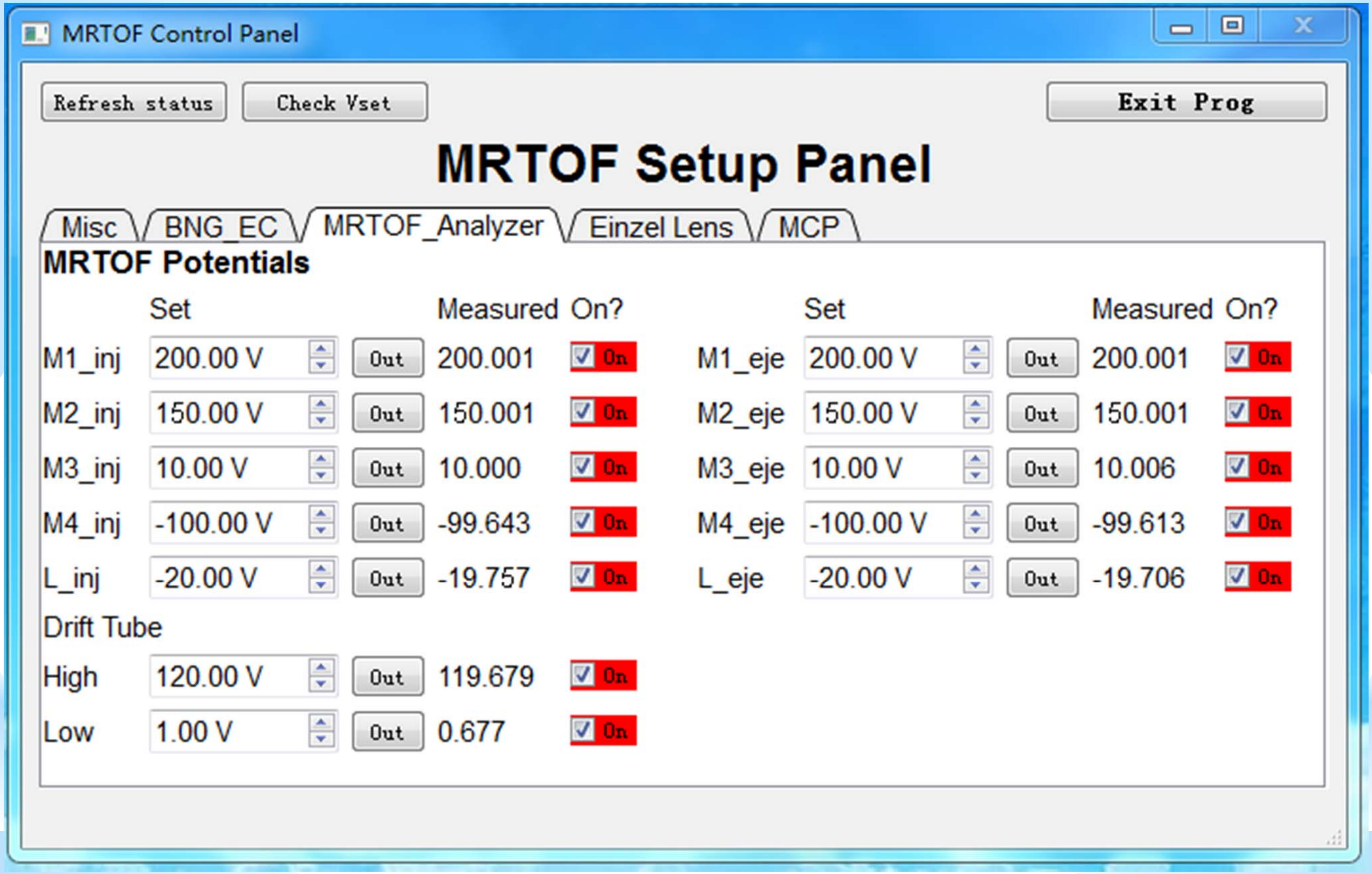


Sequential control system

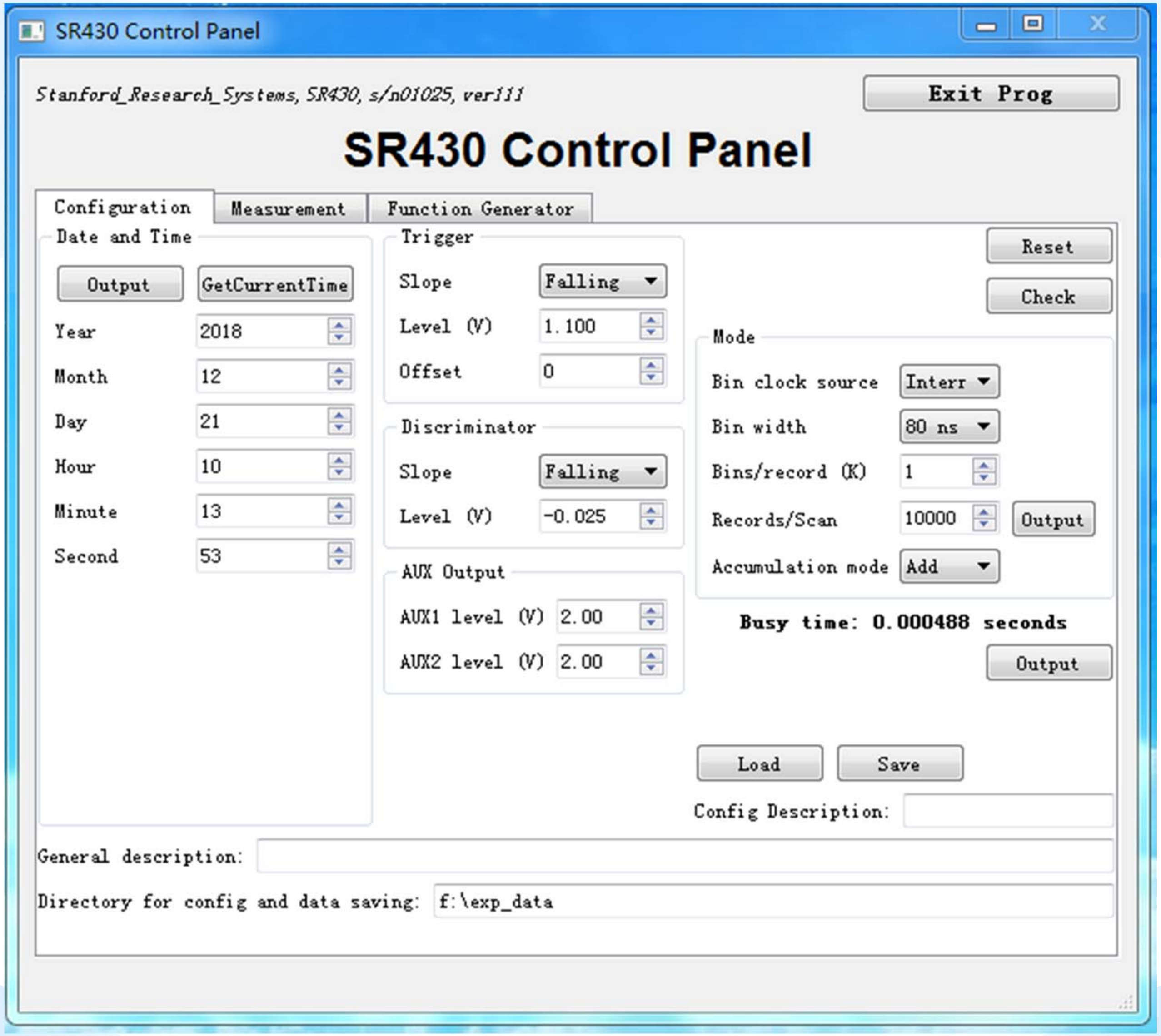


- NI PXI-6602, a timing and digital input and output module
- 80 MHz internal clock source
- Set the delay time and pulse width of the controlled objects as needed

EPICS control interface



EPICS control interface



EPICS control interface

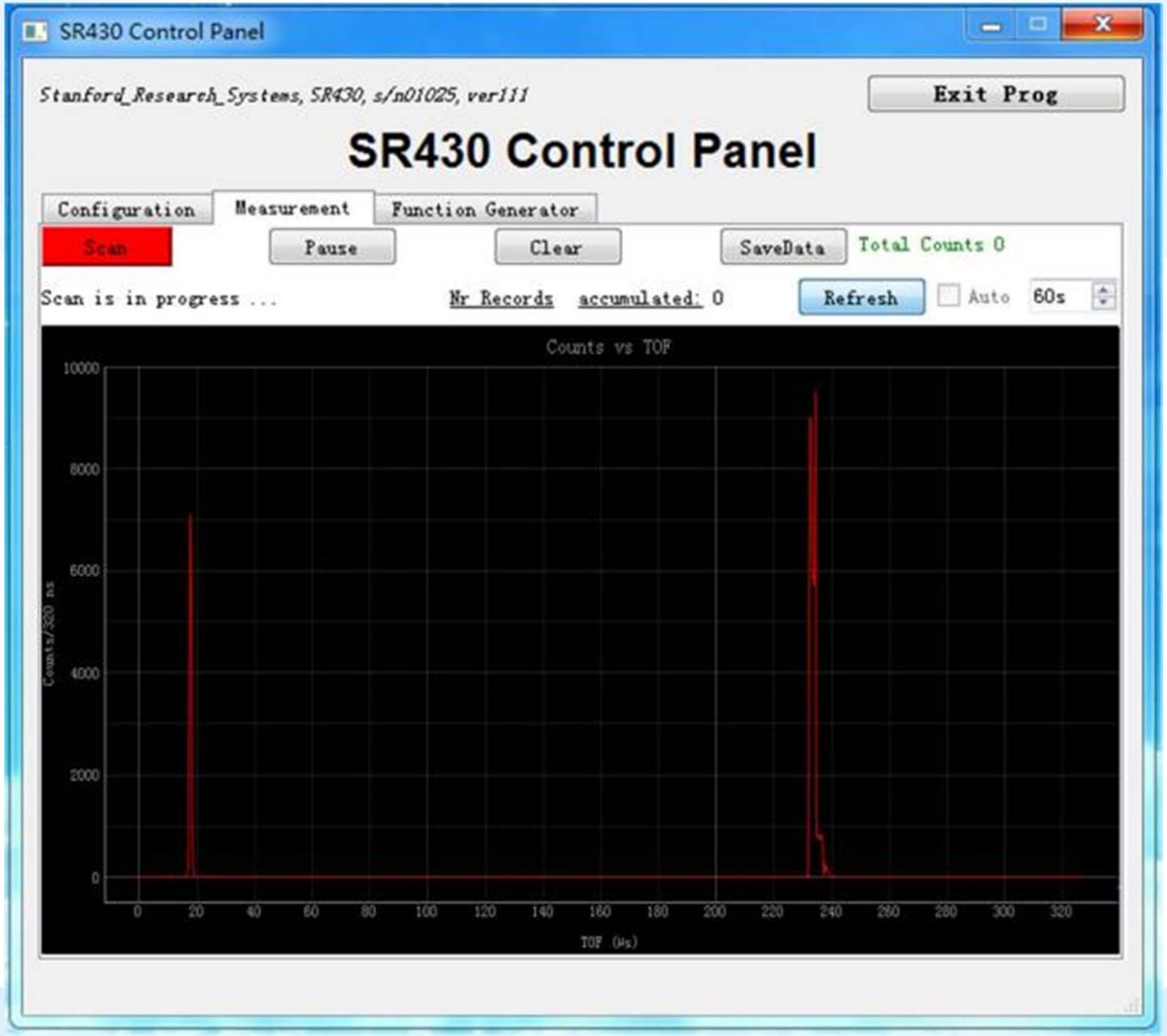
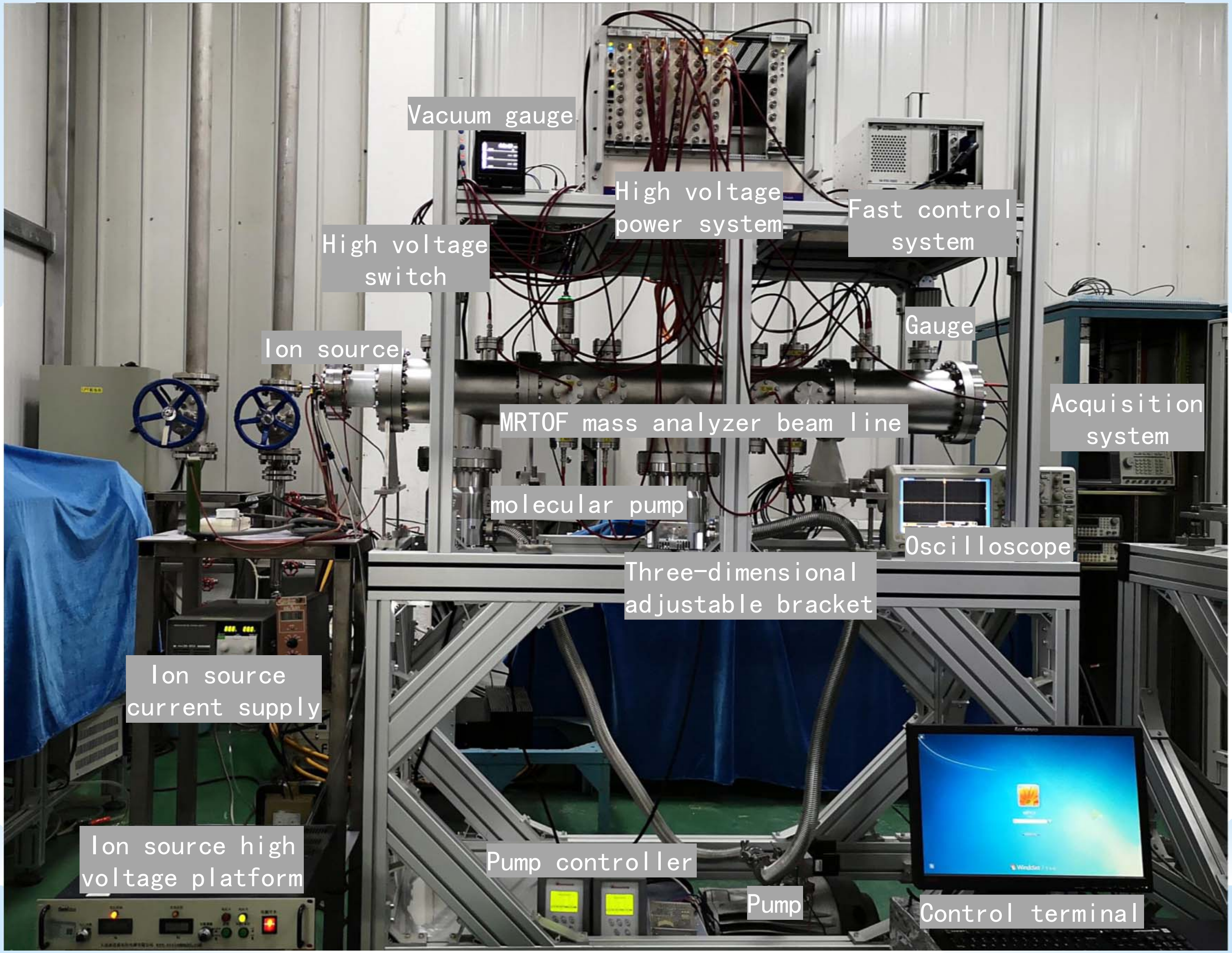
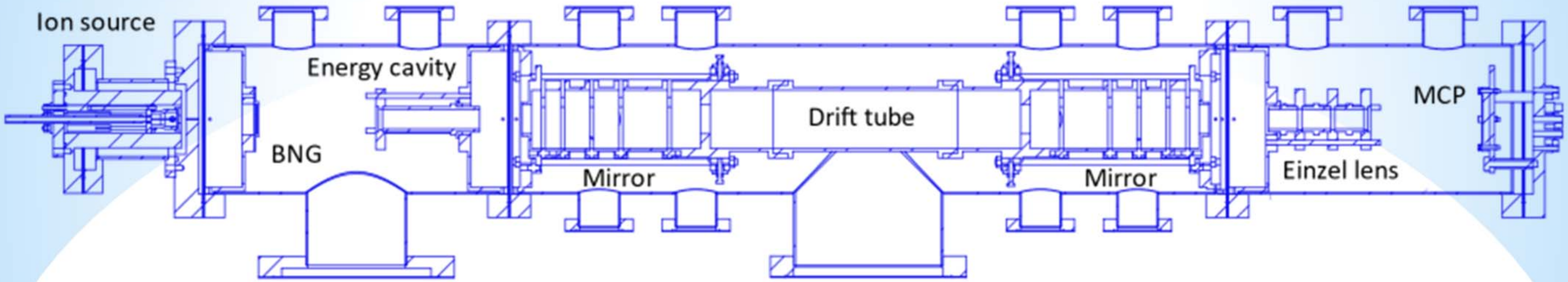


Photo of MRTOF mass analyzer



Process of ions in the test

Produce ions → Pulse → Accelerate → Trap & Flight → Detection



1. Ion source produces ion beam with energy of 200 eV.
2. The beam is pulsed under the action of the BNG.
3. The pulse beam is accelerated to 1500 eV.
4. The number of cycles specified by ions constrained and flown in the MRTOF mass analyzer.
5. The ions are detected by MCP detector to obtain the arrival time of ions recorded by the acquisition system.

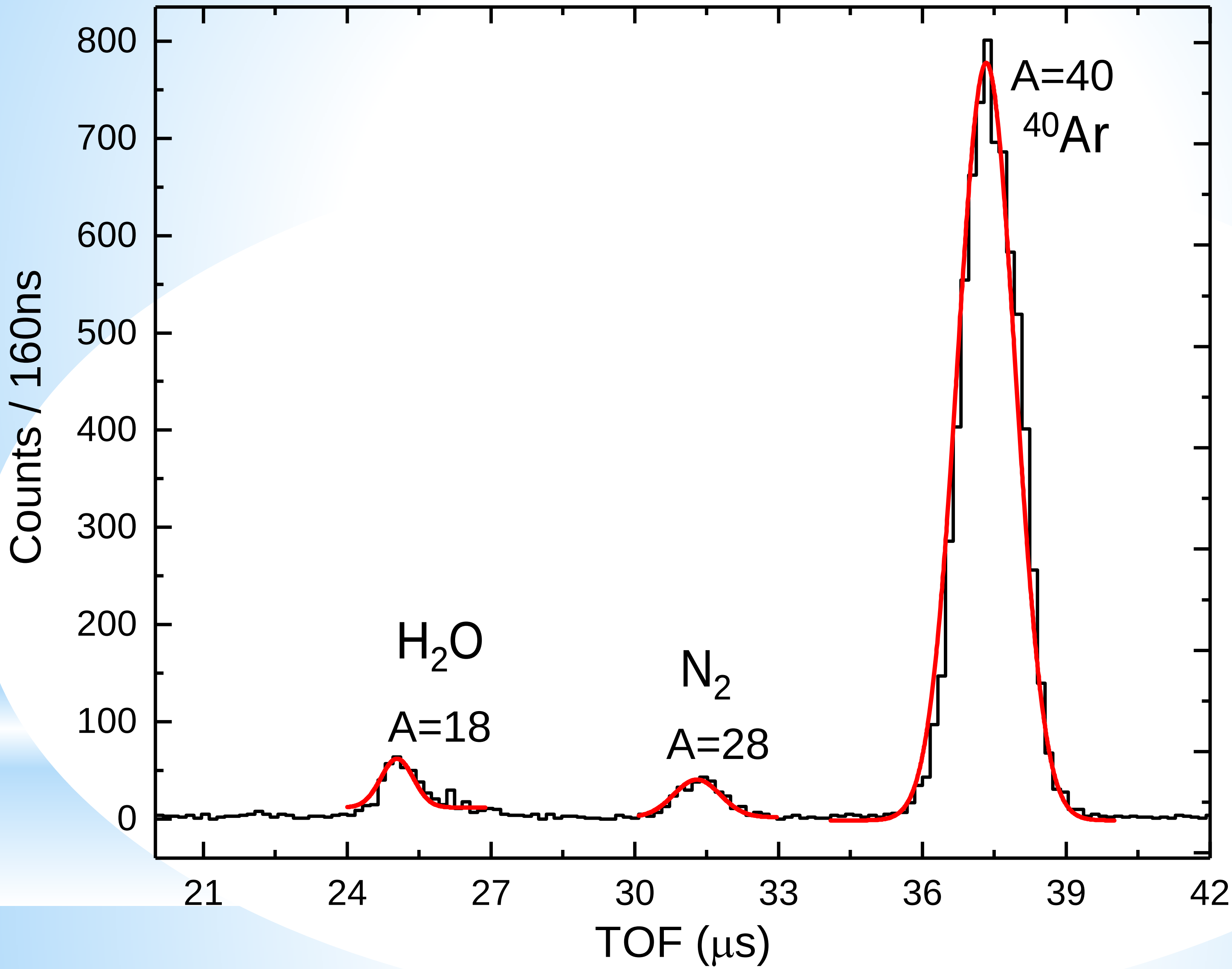
How to test

- Test mode: Switching-mirror & In-trap-lift

- Test steps: Preliminary & Fine

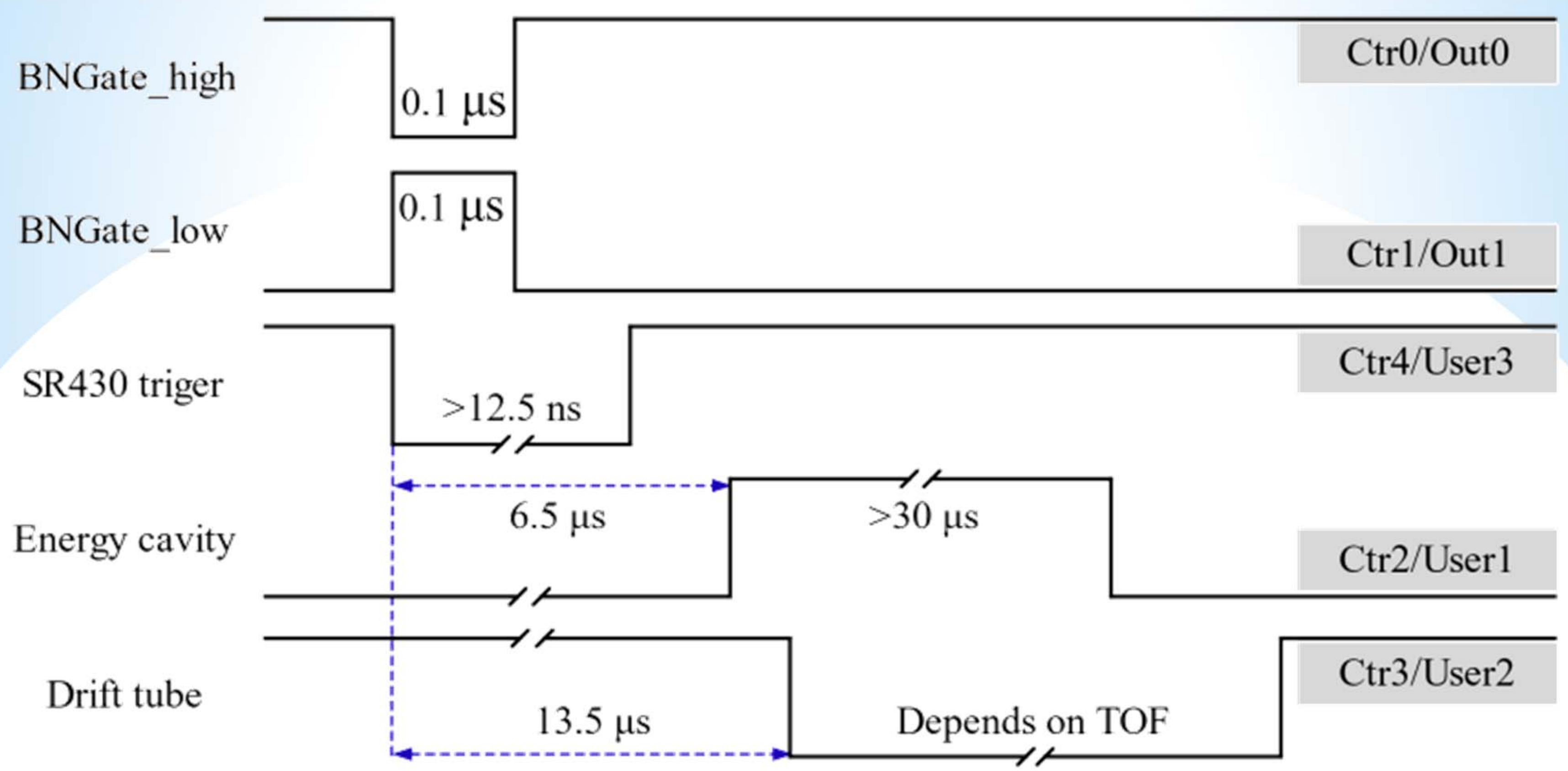
- Test object: Time sequence & Voltage

Shoot-through TOF Spectrum ($^{40}Ar^{+}$)



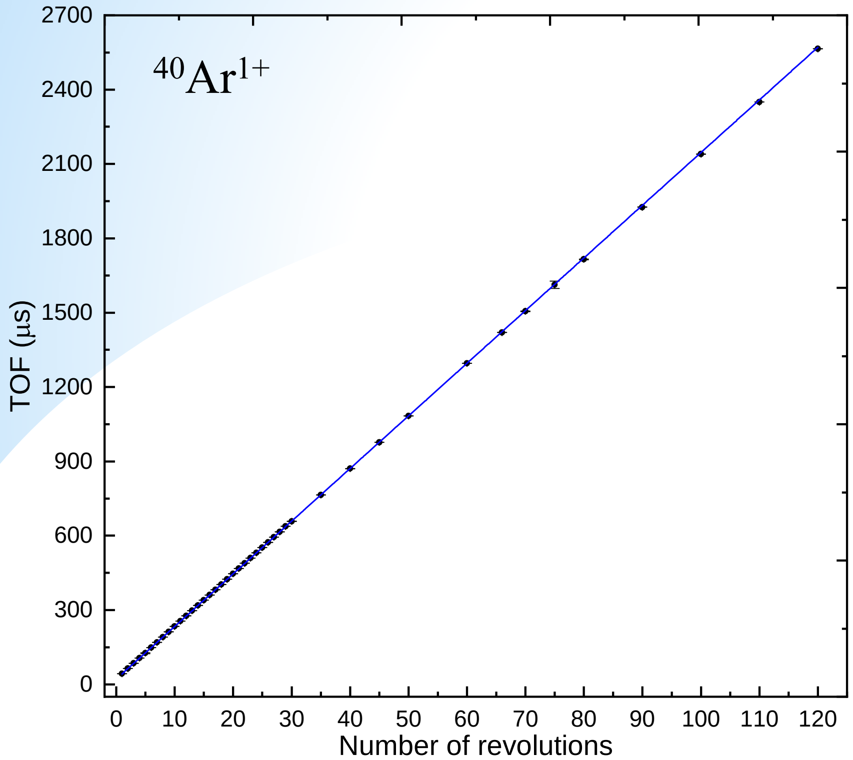
The assignments confirmed by SIMION

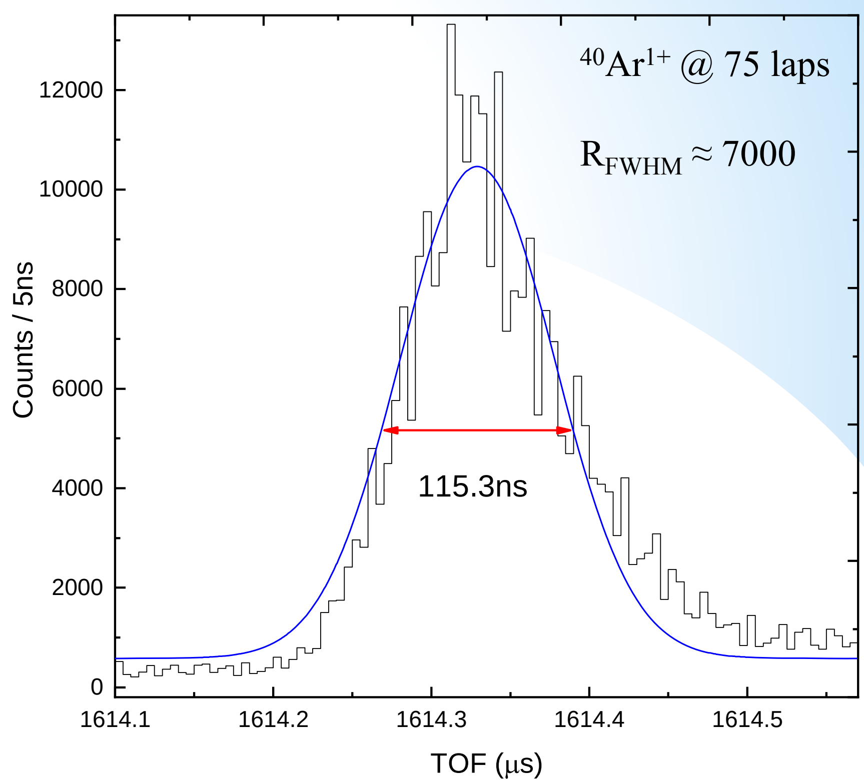
Time sequence ($^{40}Ar^{+}$)



- According to the sequence diagram of $^{40}Ar^{1+}$, the low level pulse width of drift tube should be adjusted according to the actual situation

Preliminary test results ($^{40}Ar^{+}$)



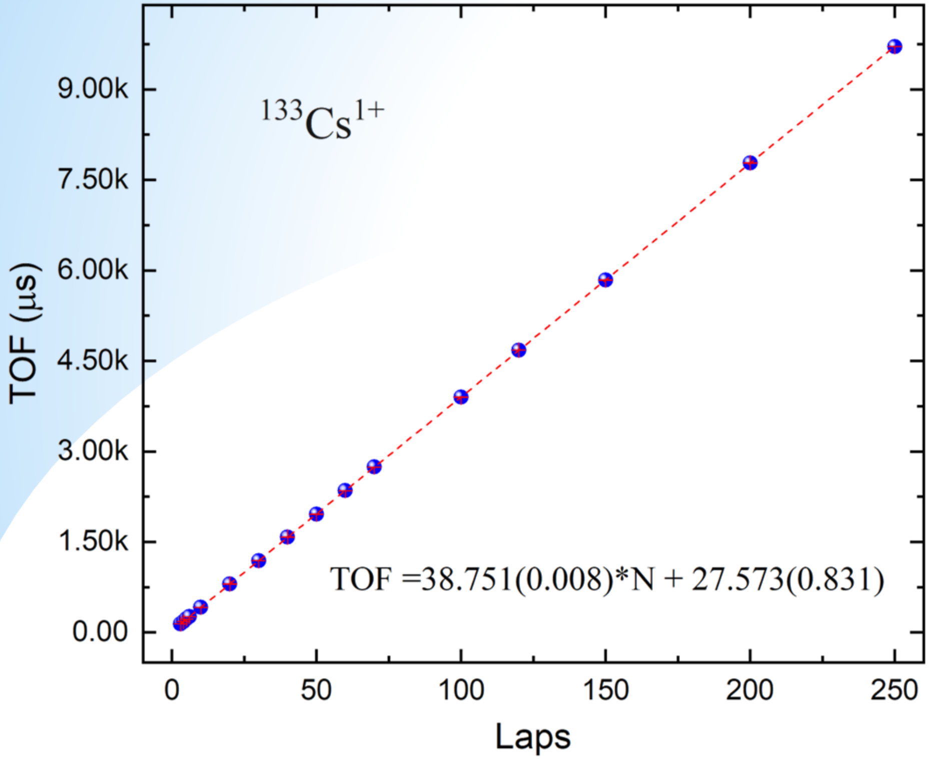


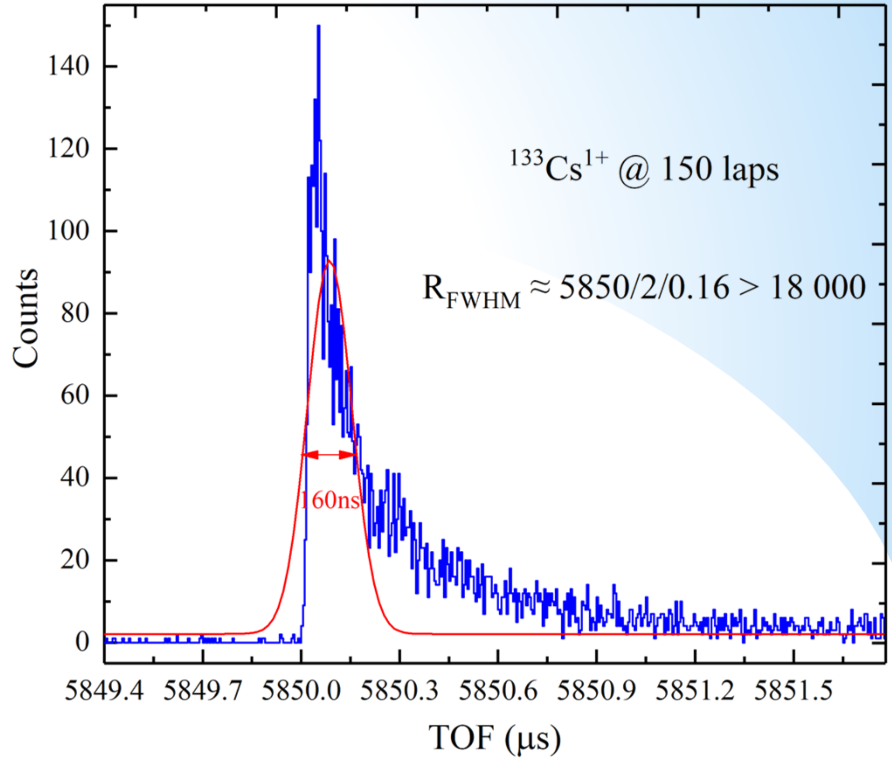
- $^{40}Ar^{1+}$ can be constrained up to 120 revolutions, and there is a good linear relationship between TOF and the number of revolutions.
- When the number of revolutions is 75, mass resolving power $R \approx \frac{TOF}{2\Delta TOF(FWHM)} \approx 7,000$

Upgrade

	Previous		**Now**
Ion source:	Discharge ion source	→	Surface ion source
	^{40}Ar		^{133}Cs
	Vacuum is very bad ($\sim 10^{-5}$ mbar)		Vacuum is good ($\sim 1.7 \times 10^{-7}$ mbar)
	• Ions could not fly beyond 120 laps • MCP detector died very quickly • Ion current was high		• Ions can not fly beyond 250 laps • MCP detector works fine • Ion current is low
HV switches:	BELKE PS	→	CGC PS

Preliminary test results ($^{133}Cs^{+}$)





- $^{133}Cs^{1+}$ can be constrained up to 250 revolutions, and there is a good linear relationship between TOF and the number of revolutions.
- When the number of revolutions is 150, mass resolving power $R \approx \dfrac{TOF}{2\Delta TOF(FWHM)} \approx 18,000$.

Summary

- An MRTOF-MS at IMP/CAS is under construction.
- A new method for MRTOF-MS design is presented. Geometry, potential parameters can be optimized
- By simulation, R_{max} for 1.5 keV $^{40}Ar^{1+}$ in a 4-electrodes mirror MRTOF-MS is >10,0000 both in switching-mirror and in-trap-lift modes
- Preliminary experimental test is completed. For $^{133}Cs^{1+}$, the mass resolving power R has been achieved to be 18,000.

Collaborators

Wenxue HUANG, Yulin TIAN, Junying WANG, Zaiguo GAN, Xiaohong ZHOU

Acknowledgements

Peter SCHURY, Tommi ERONEN, Michiharu WADA, Yuta ITO, Ryan RINGLE, ……

Thanks for your attention!