飛行時間質譜儀
Time-of-Flight Mass Spectrometer

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Outline

- TOF MS的基礎
  - 原理&一些常見的質譜儀設備
  - 基本原件
  - 質量校正
- TOF MS利用到的技術
  - Vacuum system
  - Differential pumping technique.
  - Commercial Time of Flight Mass Spectrometer (反射式飛行時間質譜儀) with many ion guides
- TOF MS目前的應用
  - Coincidence measurement for ions and electrons. (TOF MS & hemispherical energy analyzer)
  - Aerosol (PM 2.5) TOF MS.
  - MALDI (matrix assisted laser desorption/ionization), ESI, LIAD, velocity map ion imaging…

TOF MS的基礎

Mass Spectrometer 質譜儀 原理

- 質譜儀基本需求
  - 先把待測物離子化、氣化
  - 分離不同質荷比，即質量/電荷 (m/z)
  - 偵測訊號

- 質譜儀分類
  - 傳統—磁扇形分析器場 質譜儀
  - 四極質譜儀
  - 飛行時間質譜儀
  - ....

離子化

- 電子撞擊法(electron ionization, EI)
  - 70eV electron beam.
- 快速原子撞擊法 (fast atom bombardment, FAB)

Hard Ionization

- 化學離子化法 (chemical ionization, CI)
  - $CH_5^+ + M \rightarrow CH_4 + MH^+$
- 光子游離法 (photon ionization, PI)

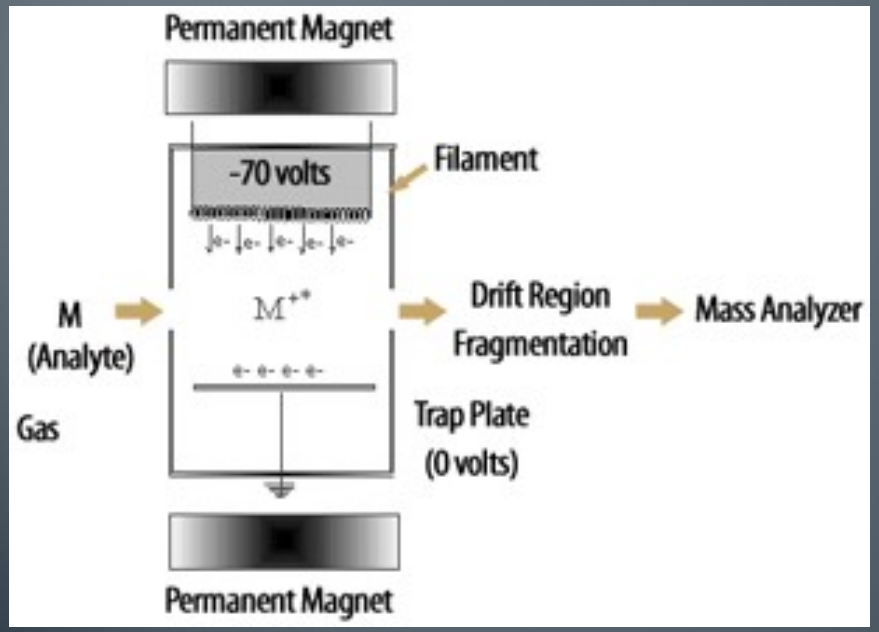
Soft Ionization

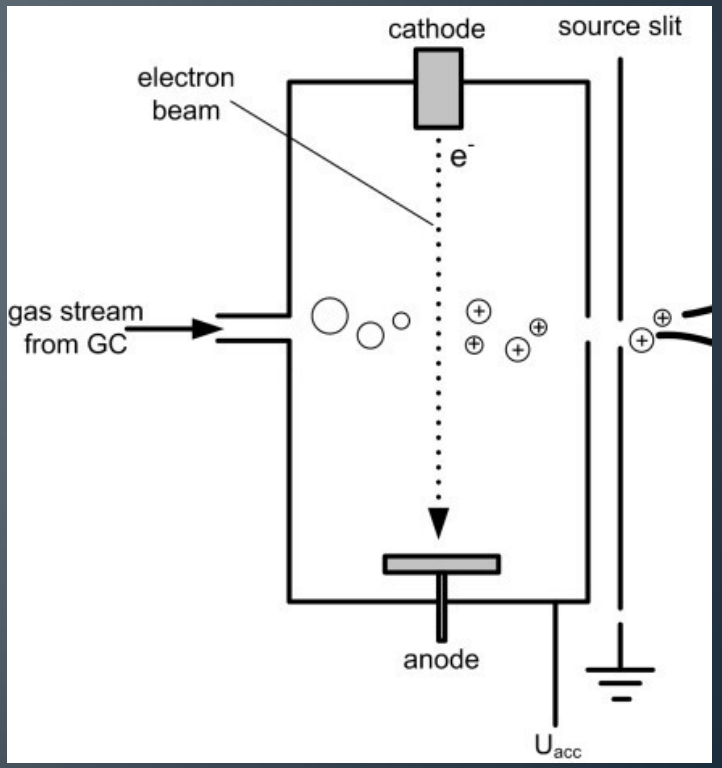
- MALDI
- ESI

離子化

- 電子撞擊法(electron ionization, EI)
  - 70eV electron beam.

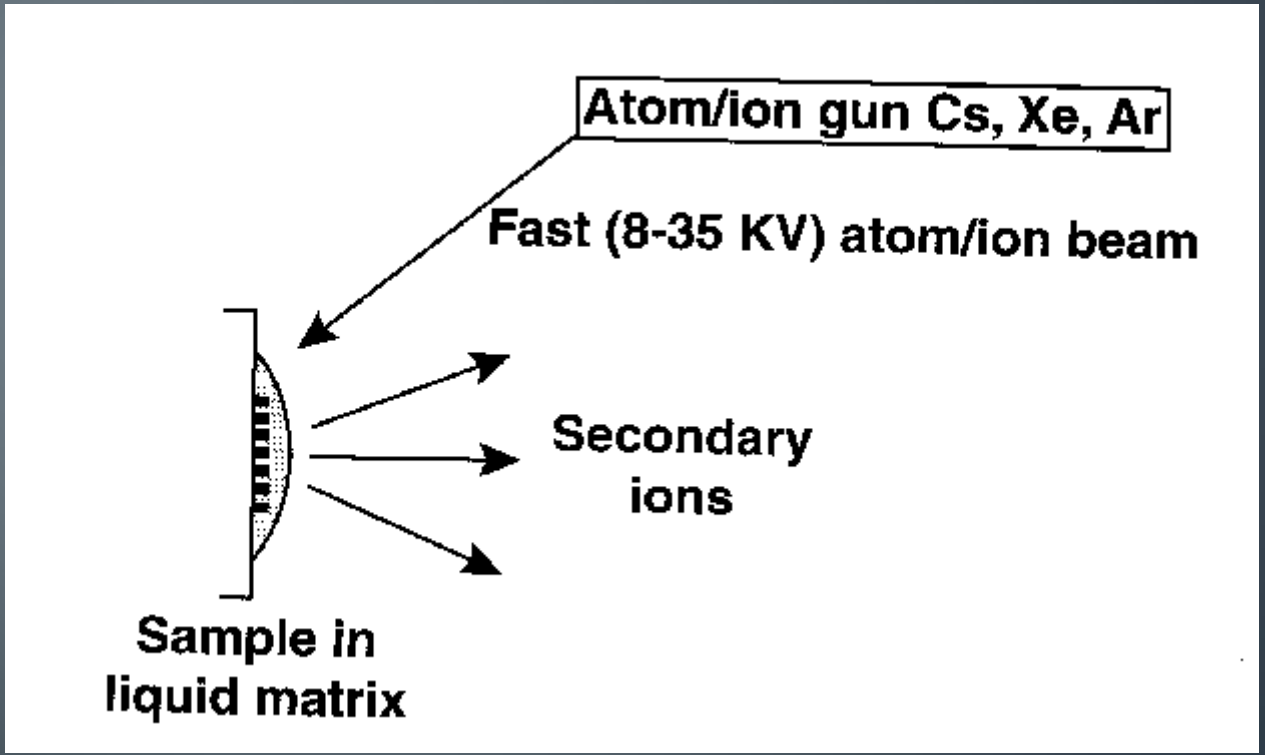
$$M + e^- \rightarrow M^+ + 2e^-$$





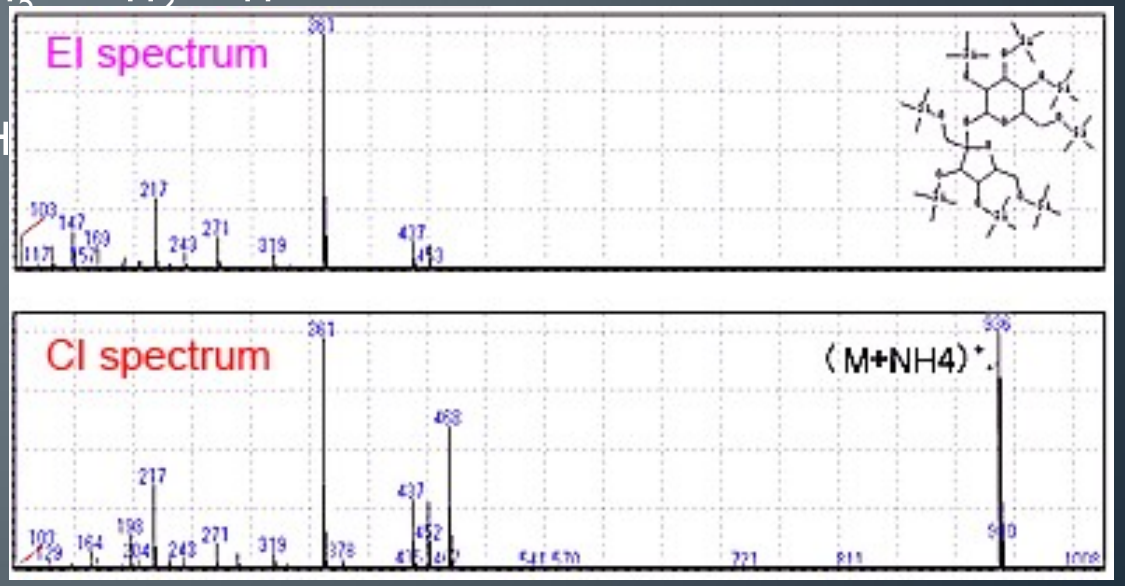
離子化

- 快速原子撞擊法 (fast atom bombardment, FAB)



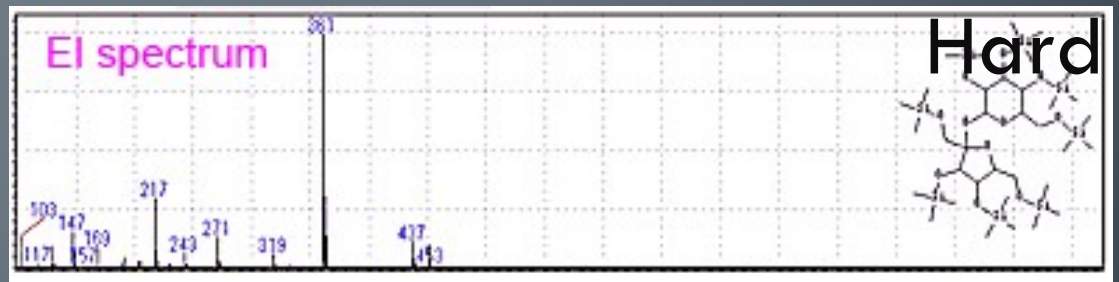
離子化

- 化學離子化法 (chemical ionization, CI)
  - $CH_4 + e^- \rightarrow CH_4^+ + 2e^-$
  - $CH_4^+ + CH_4 \rightarrow CH_5^+ + CH_3$
  - $CH_4^+ + CH_4 \rightarrow C_2H_5^+ + H_2 + H$
  - $CH_5^+ + M \rightarrow CH_4$
  - $C_2H_5^+ + M \rightarrow C_2H$

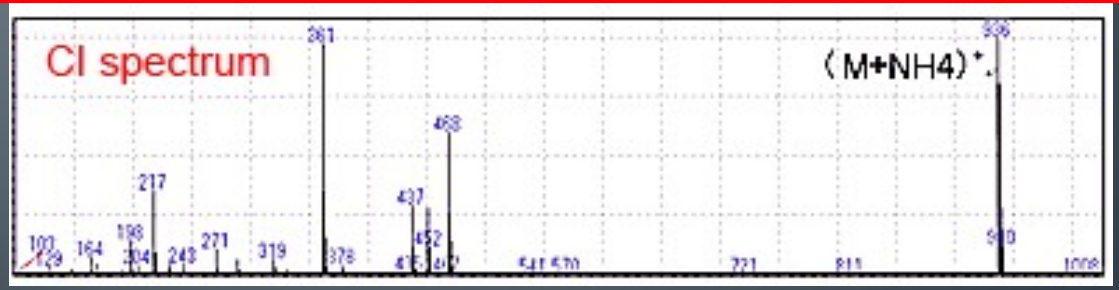


離子化

- Comparison
  - 化學離子化法 → 用手撥掉一個人的眼鏡
  - 電子撞擊法 → 開卡車去撞掉一個人的眼鏡
  - 快速原子撞擊法 → 開高鐵去撞掉一個人的眼鏡

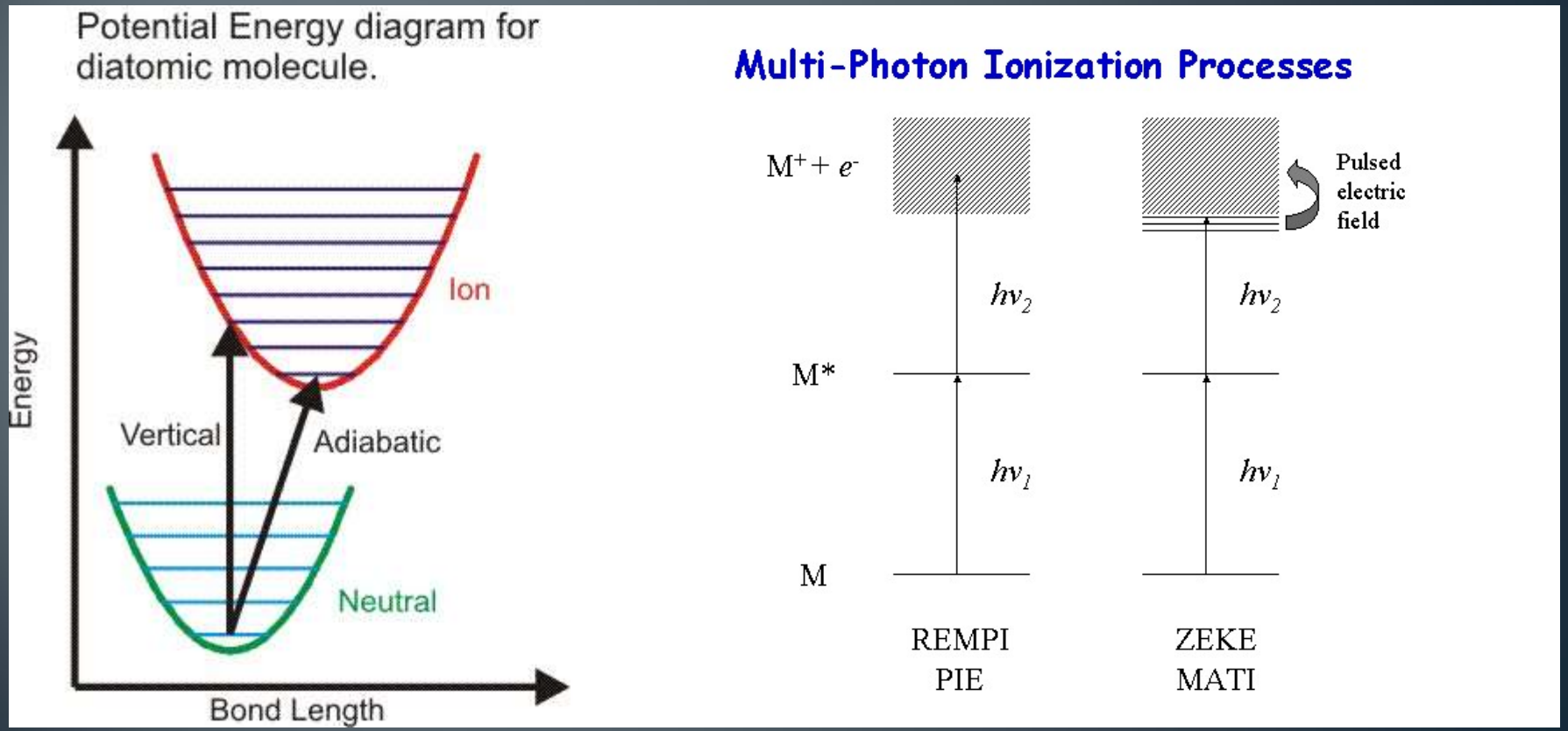


Hard Ionization



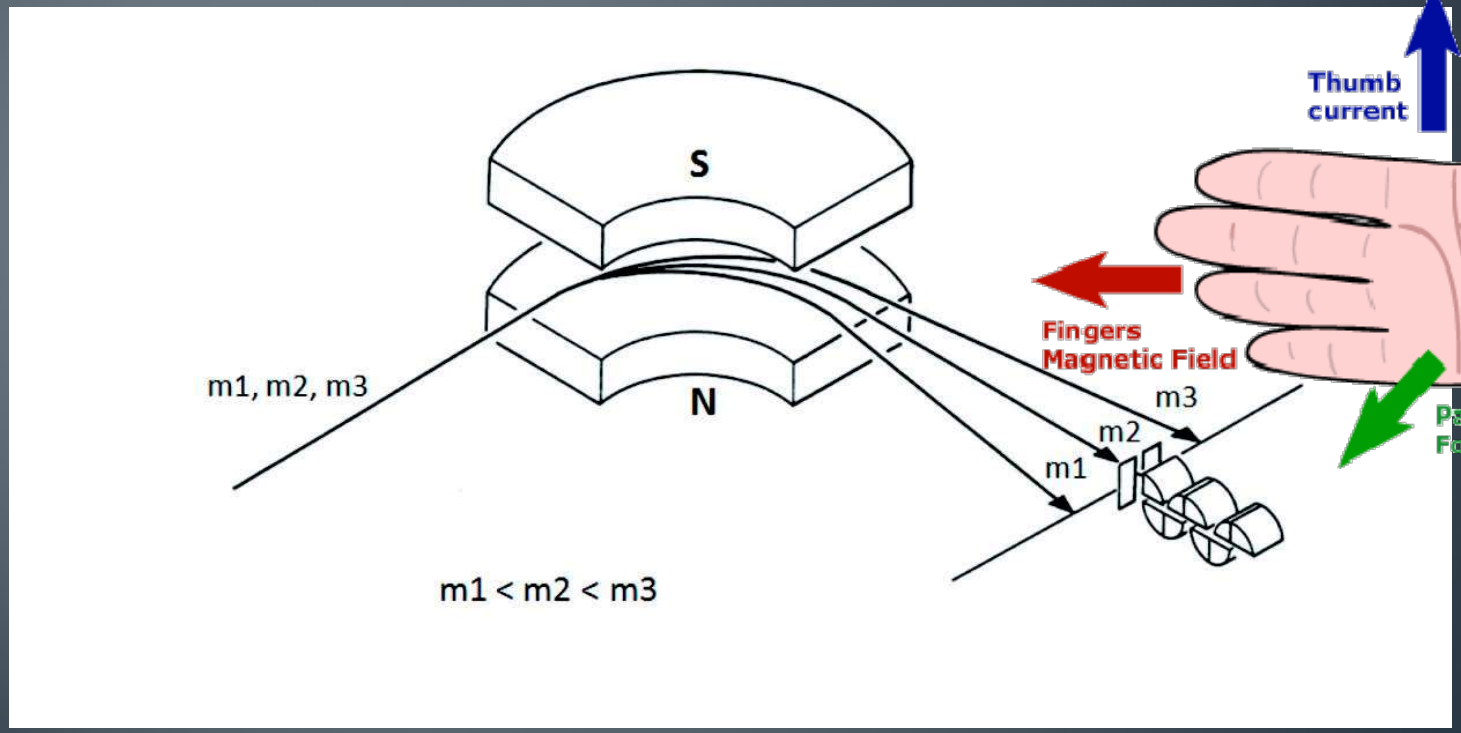
離子化

- 光子游離法 (photon ionization, PI)



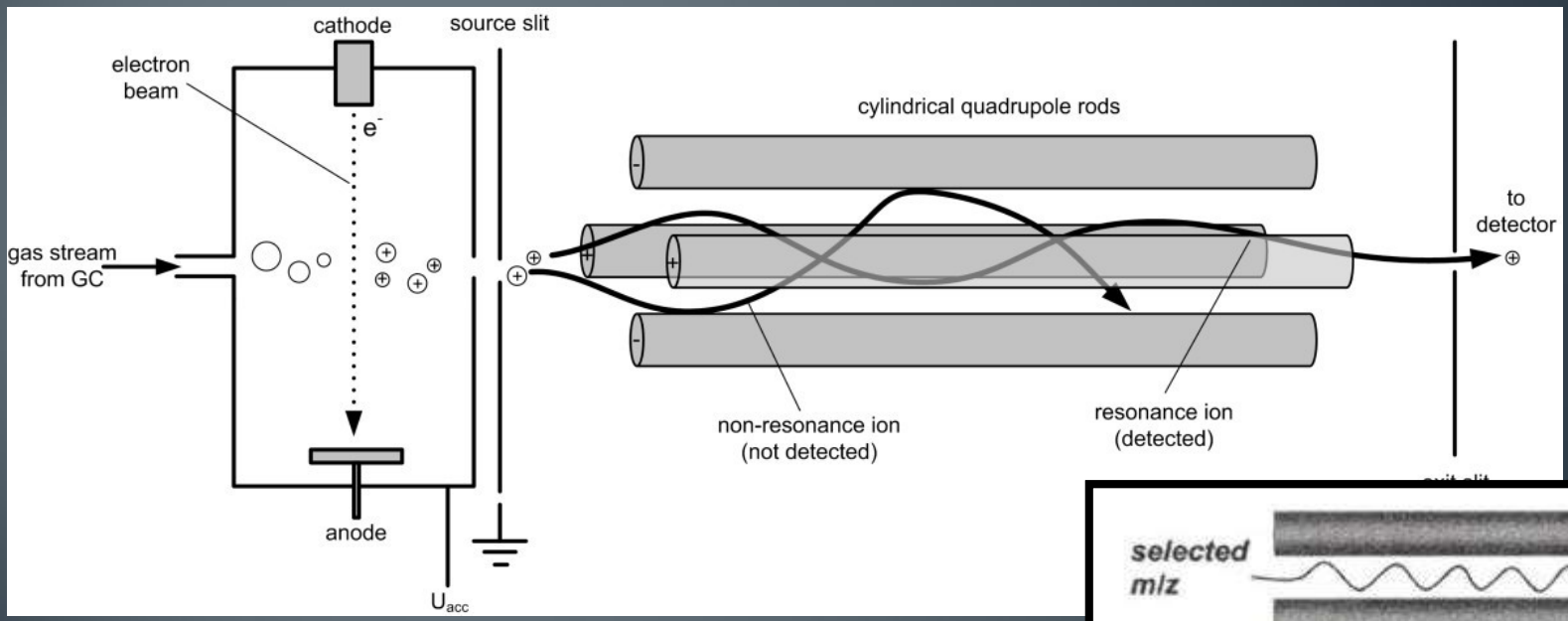
分離不同質荷比，即質量/電荷 (m/z)

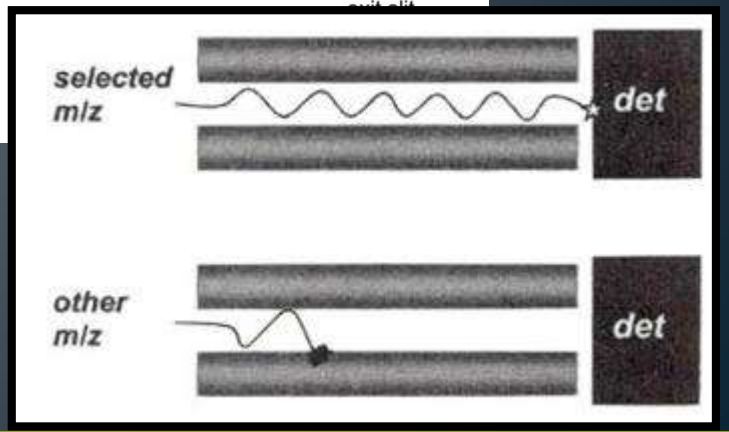
- 質譜儀分類
  - 傳統—磁扇形分析器場 質譜儀



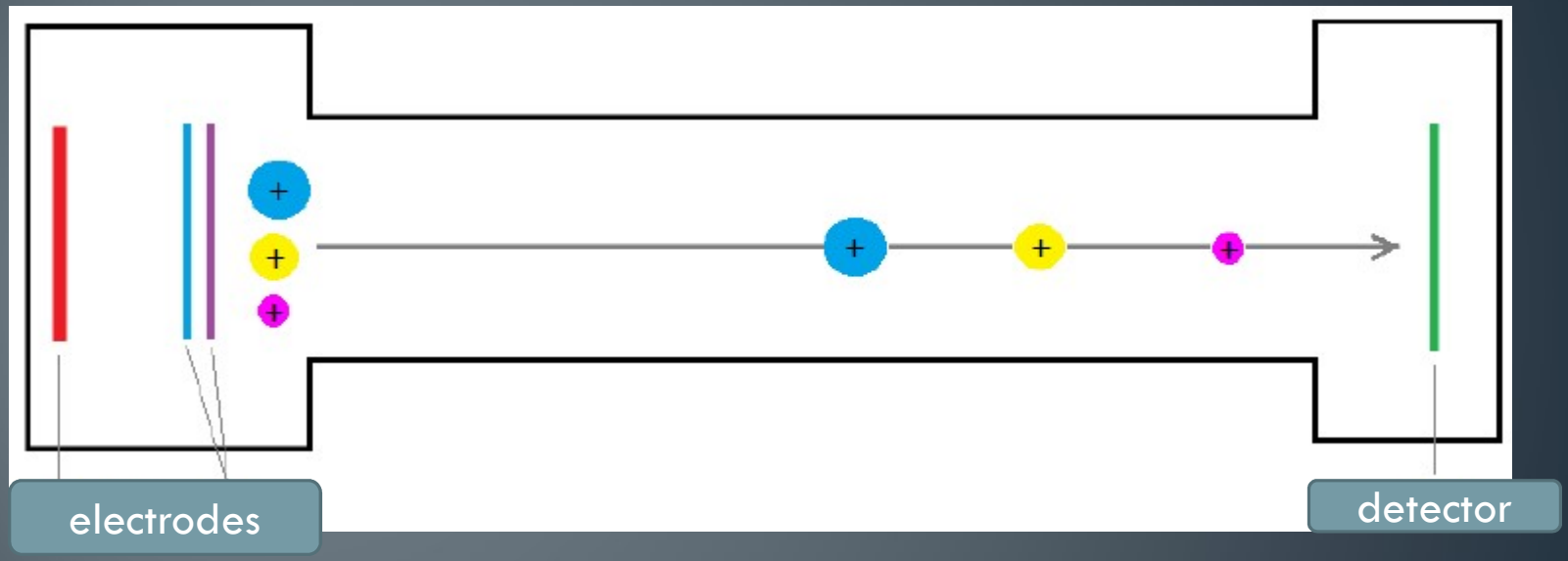
分離不同質荷比，即質量/電荷 (m/z)

- 質譜儀分類
  - 四極質譜儀



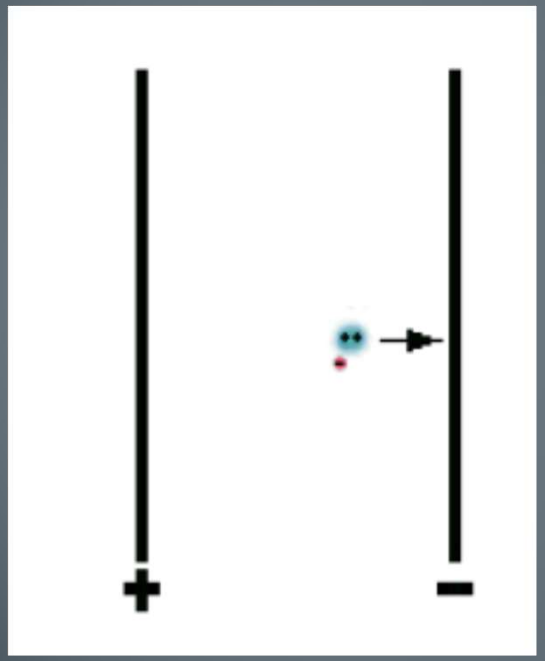


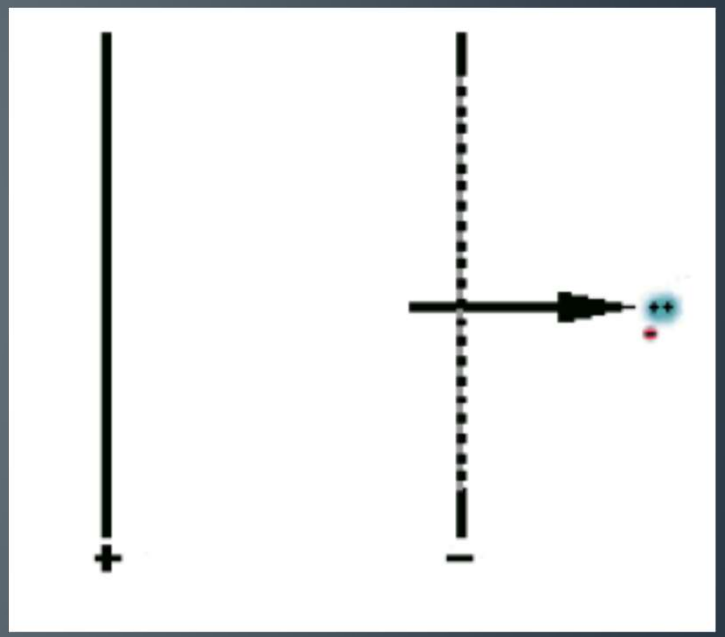
Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀



Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 的 一些概念&原理

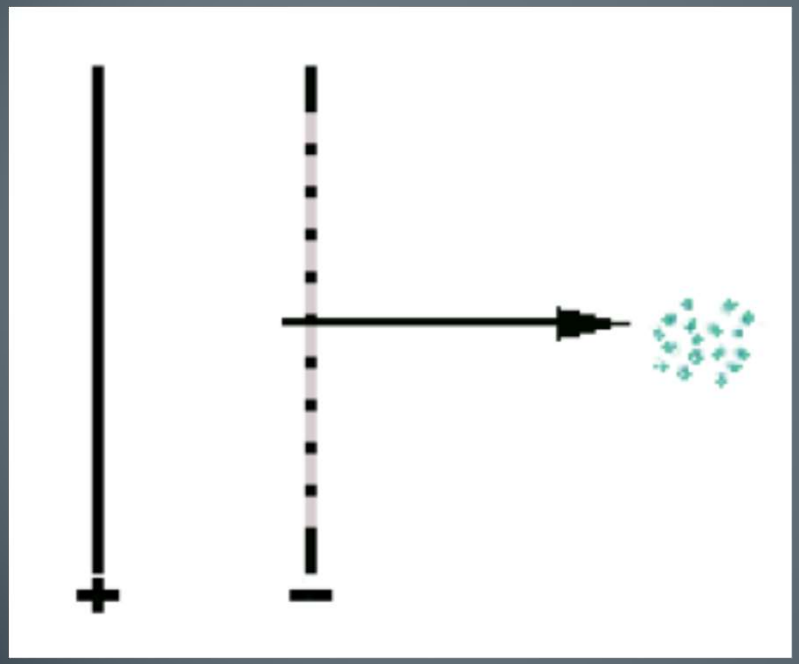
Let them fly away!!

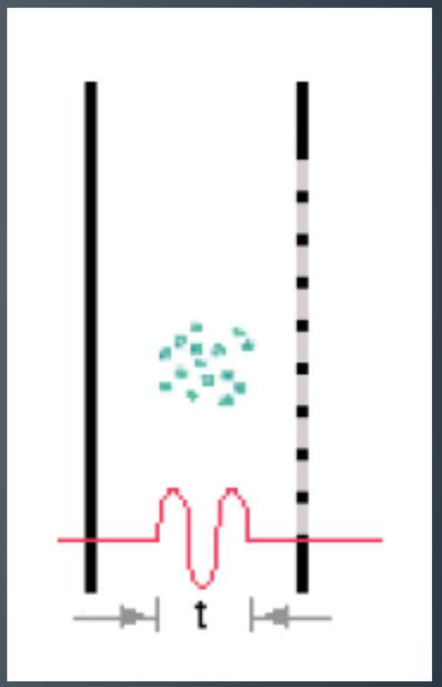




Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 的 一些概念&原理

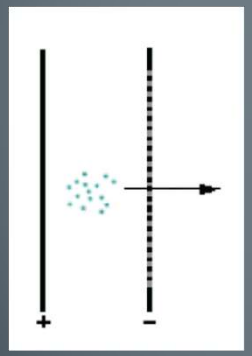
Let them start at the same time!!

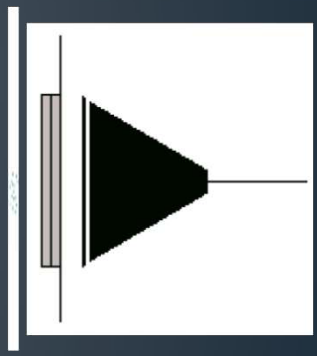




Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 的 一些概念&原理

Let the ions with the same m/z arrive at the same time.





$$\frac{1}{2}m_1v_1^2 = \frac{1}{2}m_2v_2^2$$

$$\frac{m_1}{m_2} = \frac{v_2^2}{v_1^2}$$

Time-of-Flight Mass Spectrometer (TOF MS)
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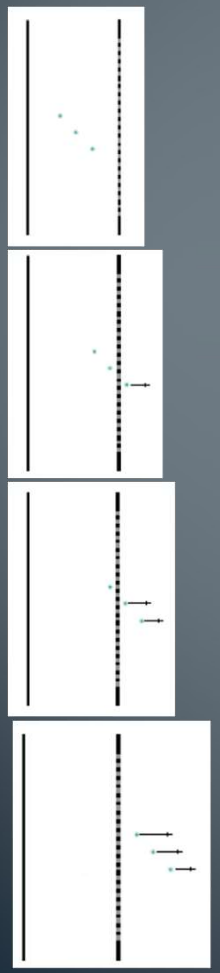

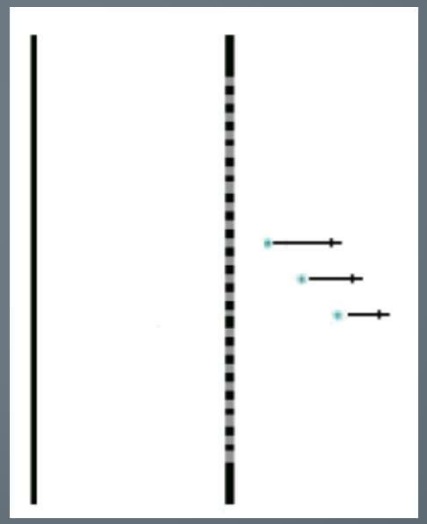

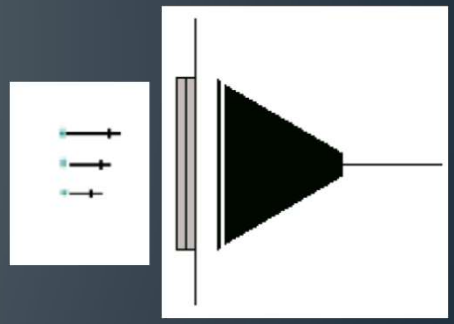

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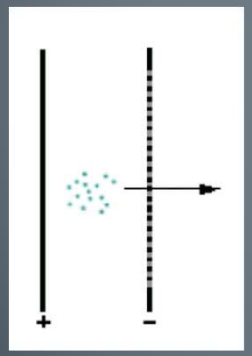

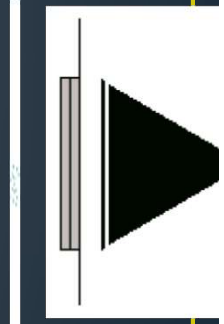

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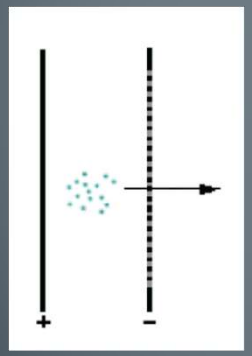

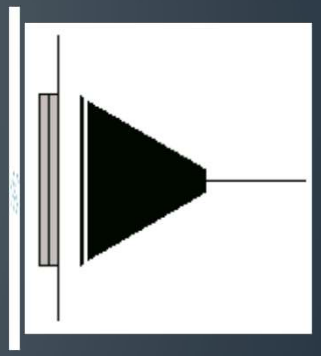

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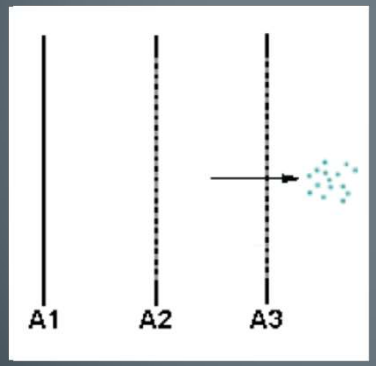
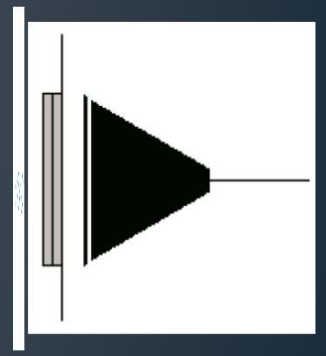
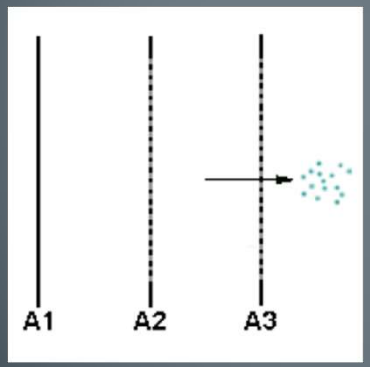
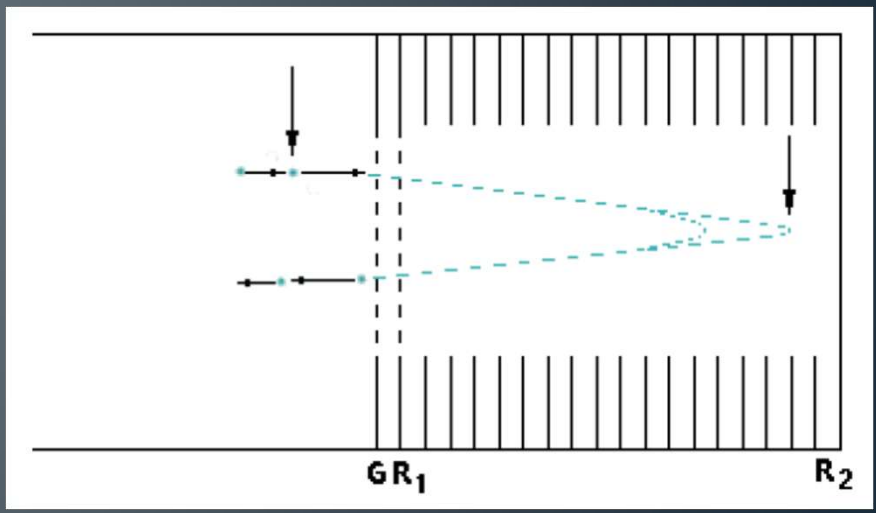




Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 的 一些概念&原理

Let the ions with the same m/z but **different initial KE** arrive at the same time by ion mirror or reflector.





Time-of-Flight Mass Spectrometer (TOF MS)
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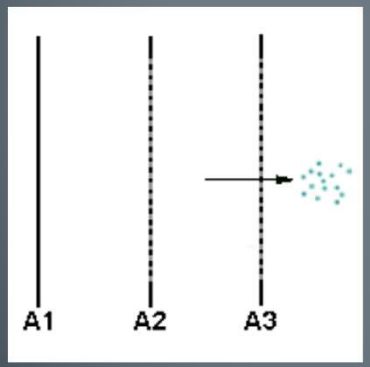
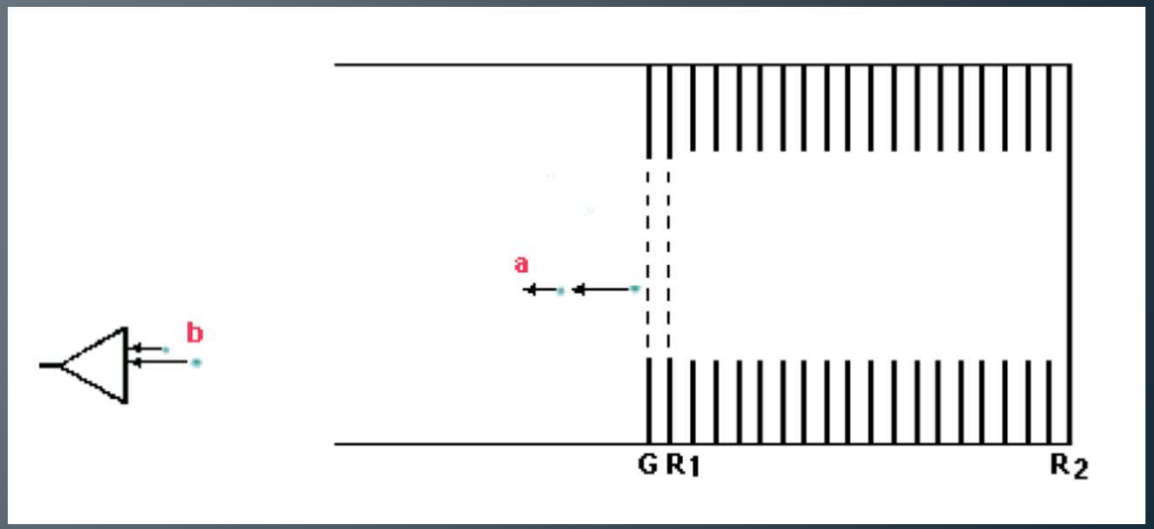
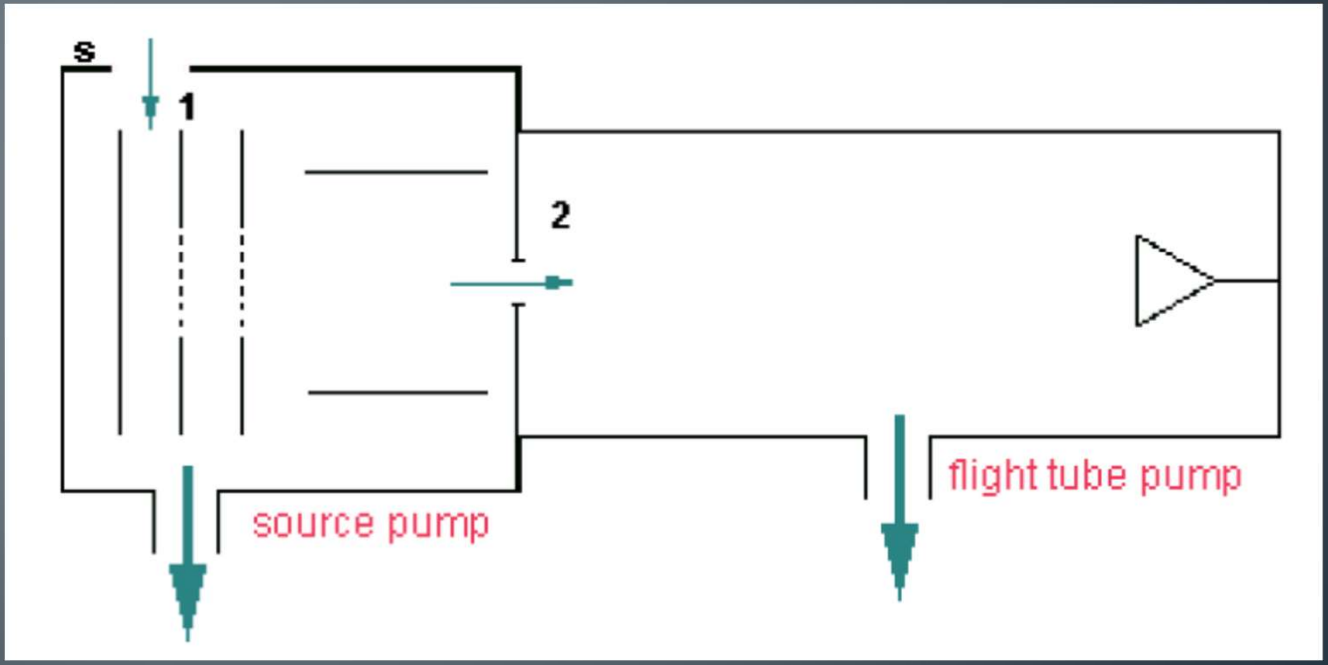


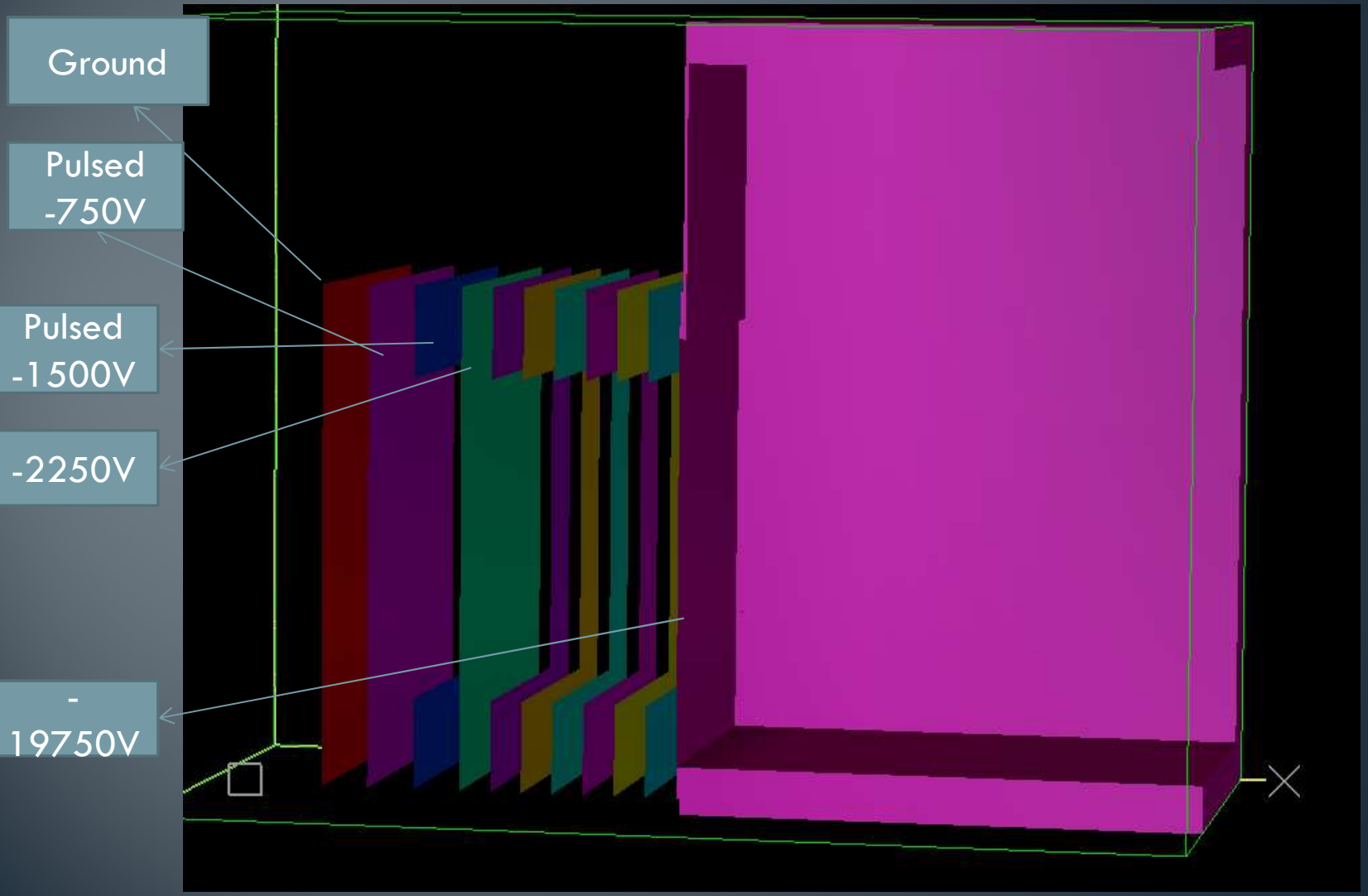


Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 的 一些概念&原理

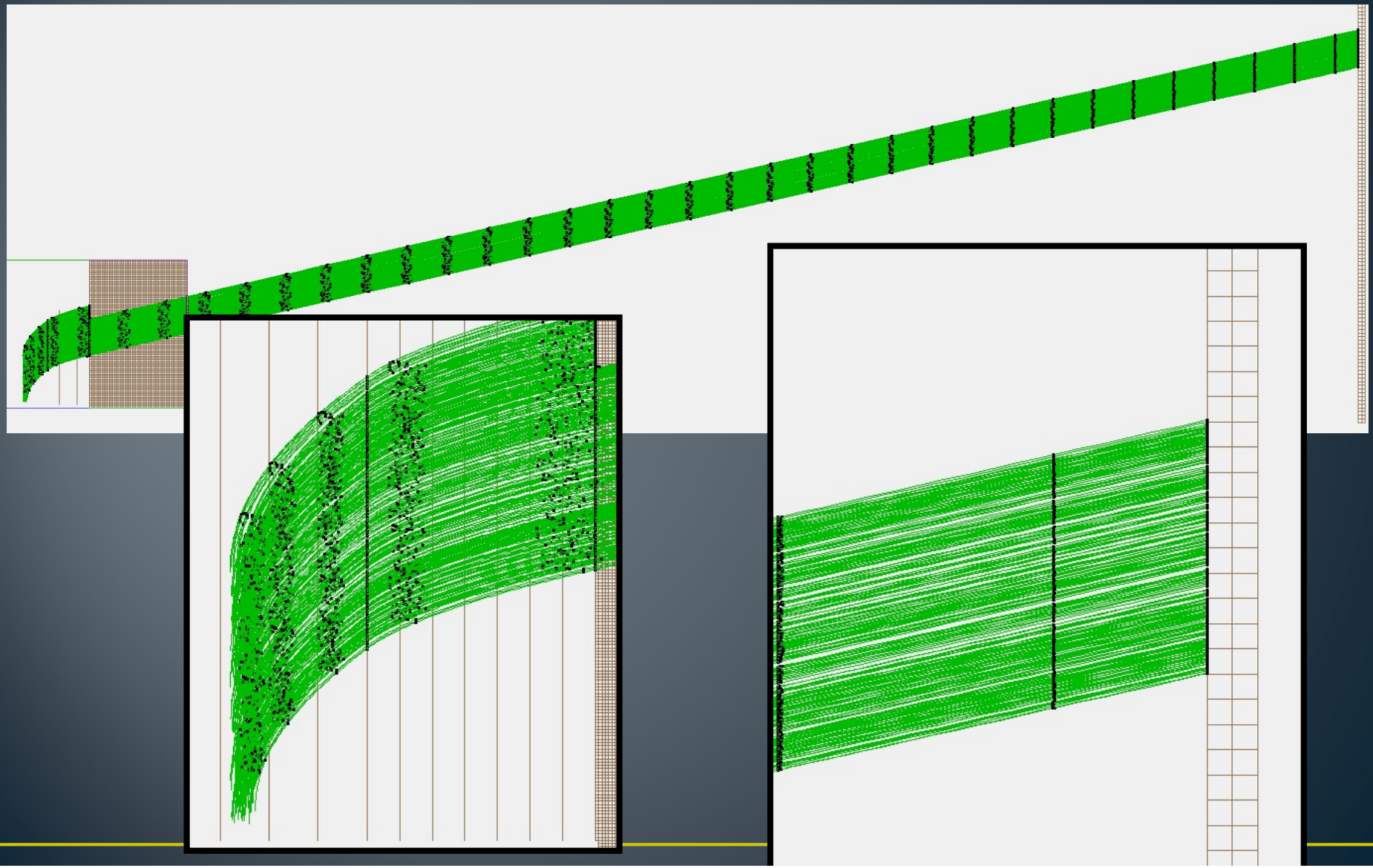
Let the ions with the same m/z arrive at the same time by orthogonal acceleration.



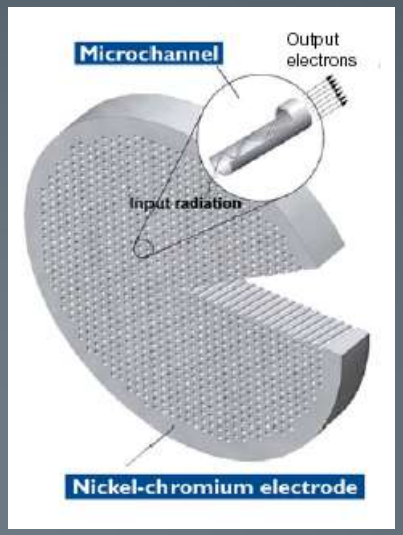
Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 離子飛行的模擬--SIMION

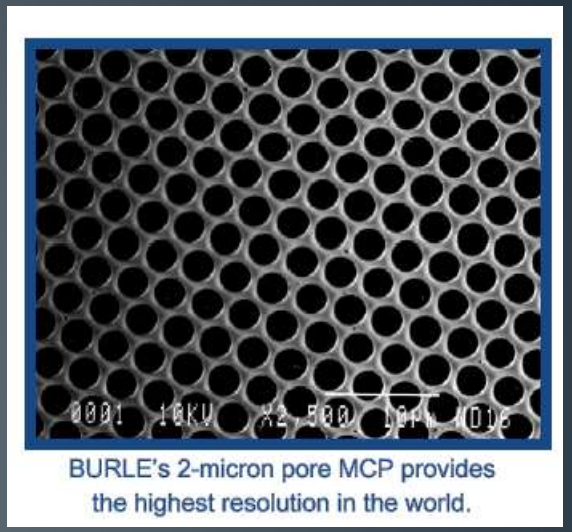


Time-of-Flight Mass Spectrometer (TOF MS)
飛行時間質譜儀 離子飛行的模擬--SIMION

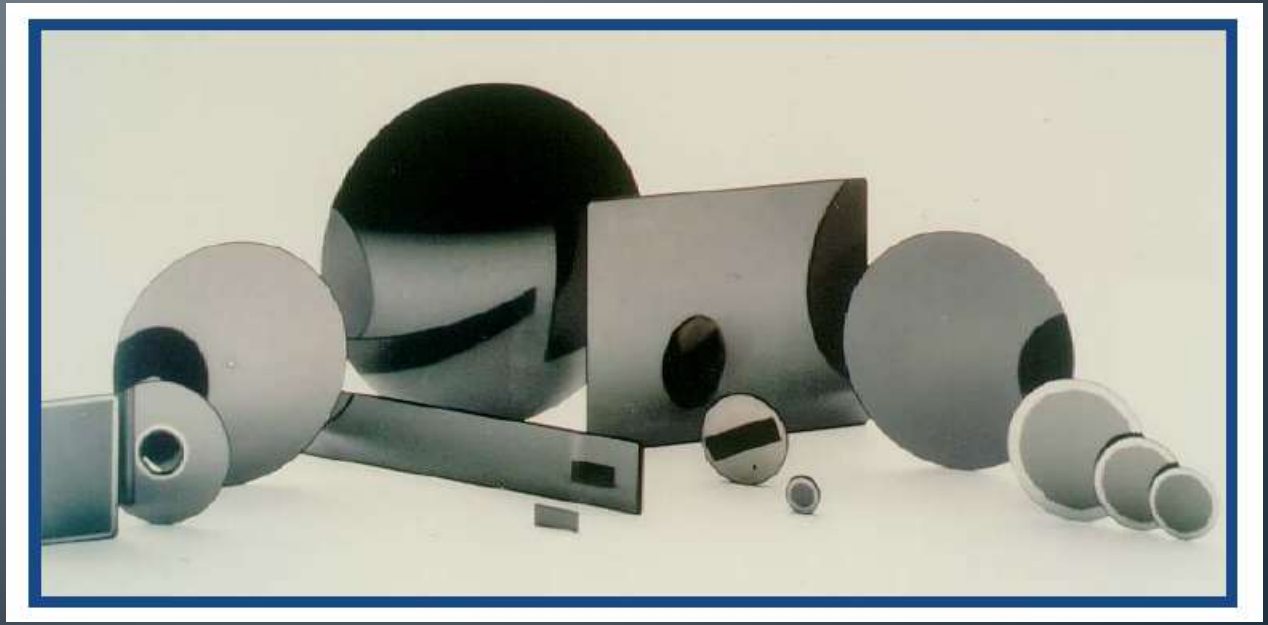


Detector: Multi Channel Plate (MCP)





BURLE's 2-micron pore MCP provides the highest resolution in the world.



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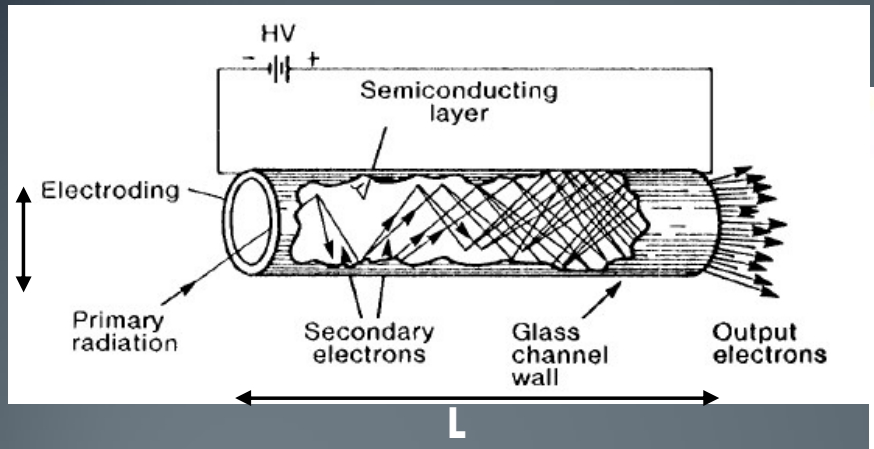
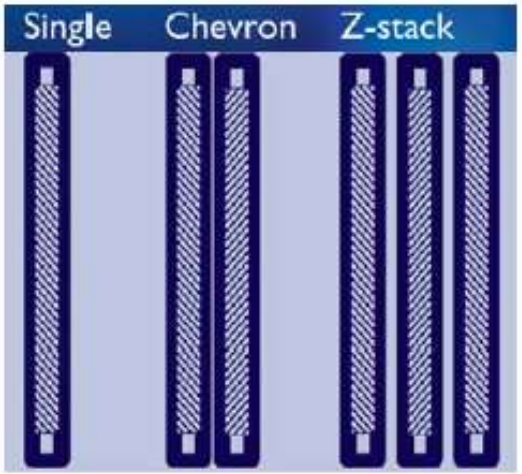
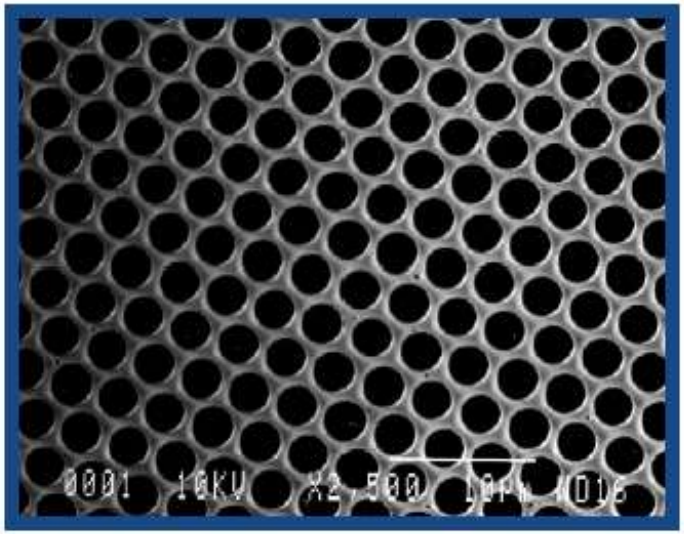


MCP Configurations

Matching the bias currents of the MCP sets allows the set to be operated from a single power supply, which eliminates the need for center tabs and voltage dividers, leading to improvements in spatial resolution and Pulse Height Distribution.





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Coatings

Cesium Iodide (CsI), Copper Iodide (CuI), and Magnesium Fluoride (MgF_2) enhance the detection of ultraviolet photons from 200 to 2000 angstroms. Potassium Bromide (KBr) improves detection efficiency of soft X-rays in the 0.2 to 9 keV range.

Detector: Multi channel plate (MCP)

MCP Performance characteristics

Configuration	L/D Ratio	Maximum Voltage	Gain	Pulse Height
Single MCP	40:1	1000	$>4x10^3$	Neg. Exp.
	60:1	1200	$>1x10^4$	Neg. Exp.
Chevron	40:1	2000	$>4x10^6$	<175%
	60:1	2400	$>1x10^7$	<100%
Z-Stack	40:1	3000	$>3x10^7$	<120%
	60:1	3600	$>2x10^8$	<60%

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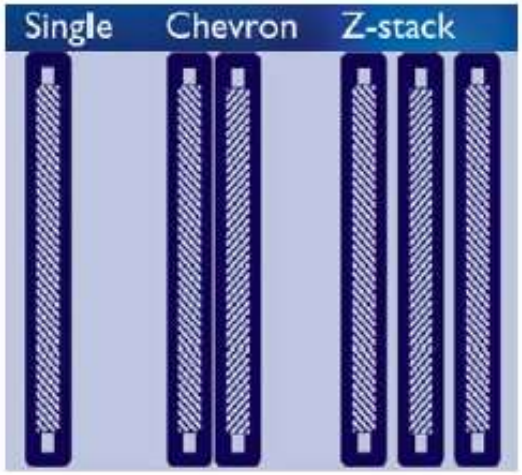


$1x10^7$ electrons x $1.6x10^{-19}$ C/electron = $1.6x10^{-12}$ C

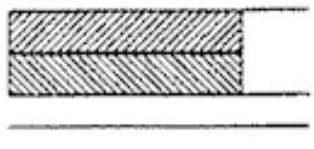
$1.6x10^{-12}$ C / $2x\ 10^{-9}$ sec = 0.8×10^{-4} A

V = IR = 0.8×10^{-4} A x 50 Ohm = 4 mV

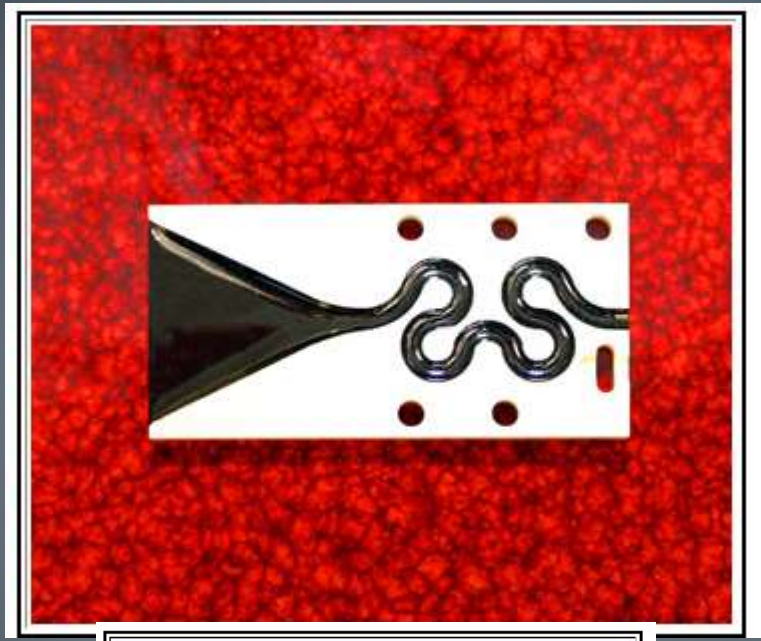
With 5-100 times amplifier → signal will be 20 mV to 400 mV.

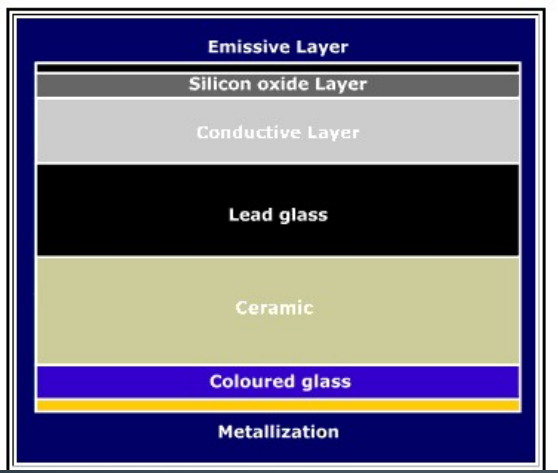
Detector: Multi channel plate (MCP)

Diagrams:

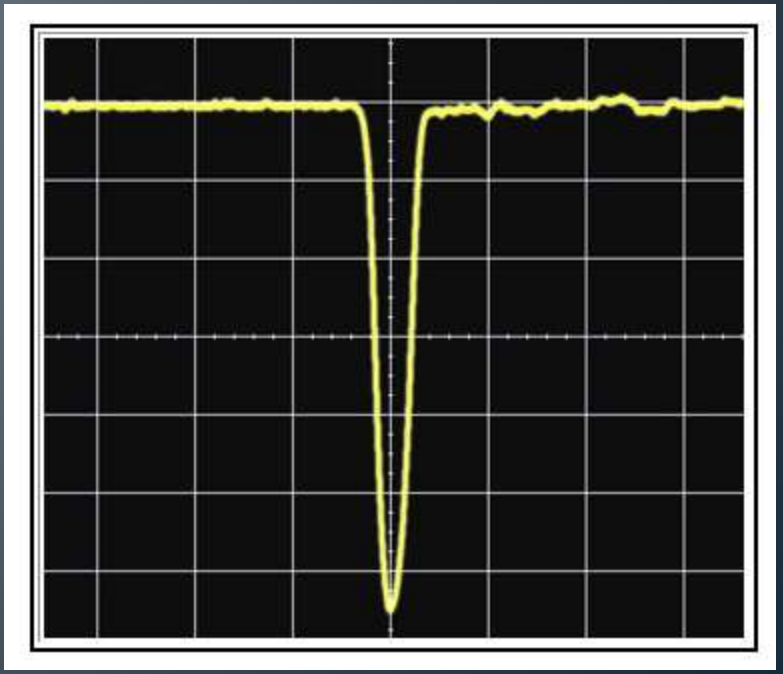
		Pulse Mode (metal anode)	Imaging Mode (Phosphor screen)
Electron/Negative Ion/UV Photon Detector			
	V_i	ground	ground
	V_o	2000v	2000v
	V_a	2050v to 2500v	5000v to 7000v
Positive Ion/UV Photon Detector			
	V_i	−2000v	−2000v
	V_o	ground	ground
	V_a	50v to 500v	3000v to 5000v

CEM
Dr Sjuts channel electron multiplier





It's a detector responding to charged particles, hard and soft X-ray, and UV. Enhance 10^8 with ~2.5KV applied. FWHM = 8 ns.



Replacement of a CEM array for VG CLAM 4 Electron Spectrometer

As a special service we offer the replacement of old glass made CEMs by CEMs Series KBL for electron spectrometer. This example shows the replacement for a VG CLAM4.

Fig. 8 Original CEMs made entirely of glass

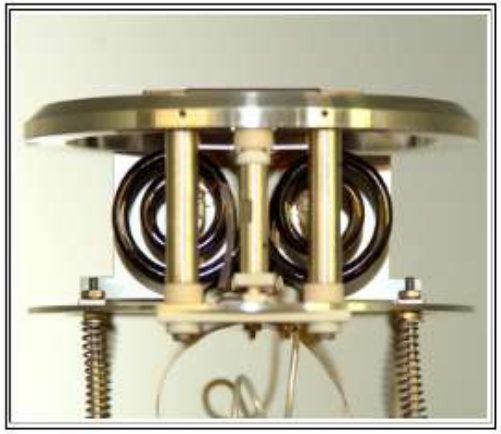
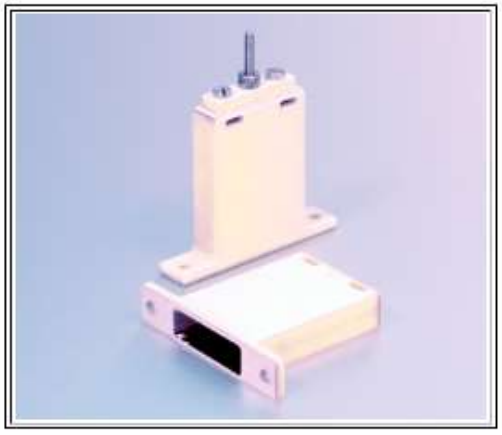


Fig. 9 CEM array before replacement



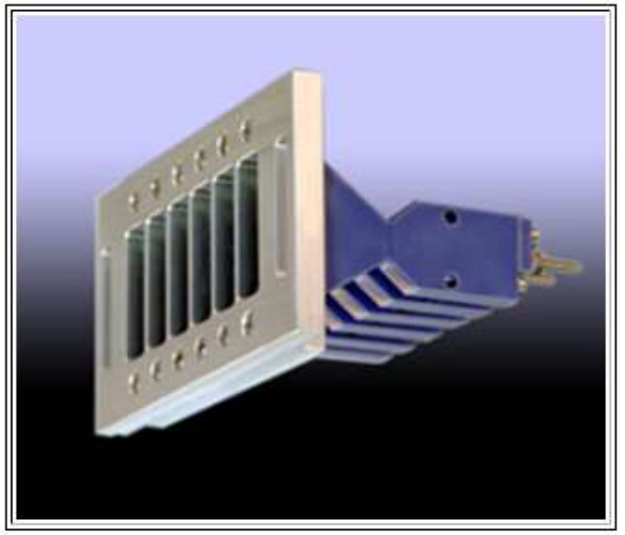
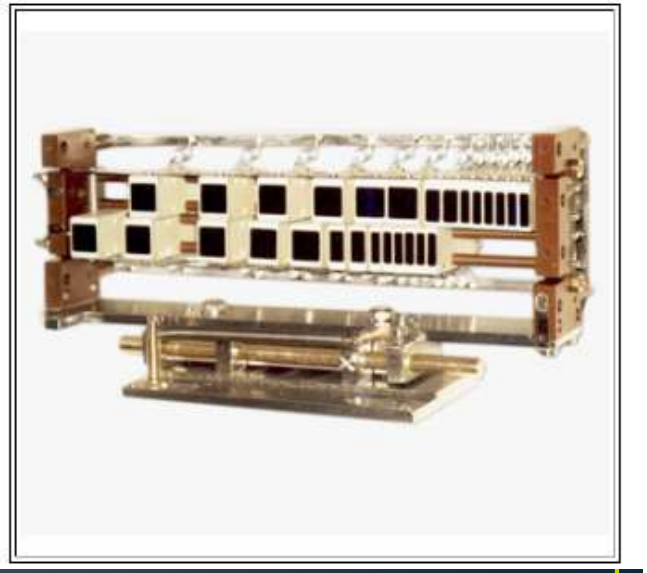
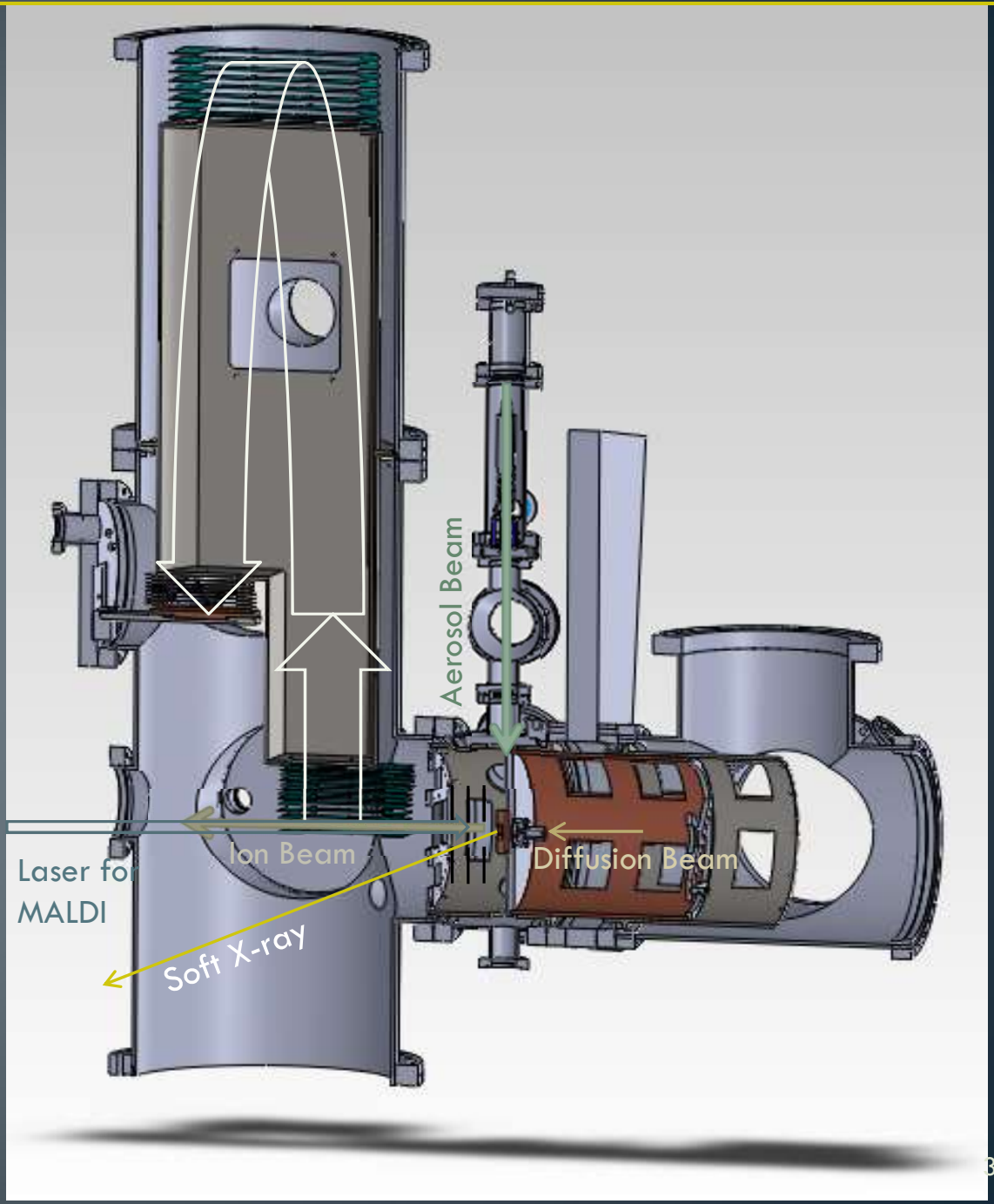


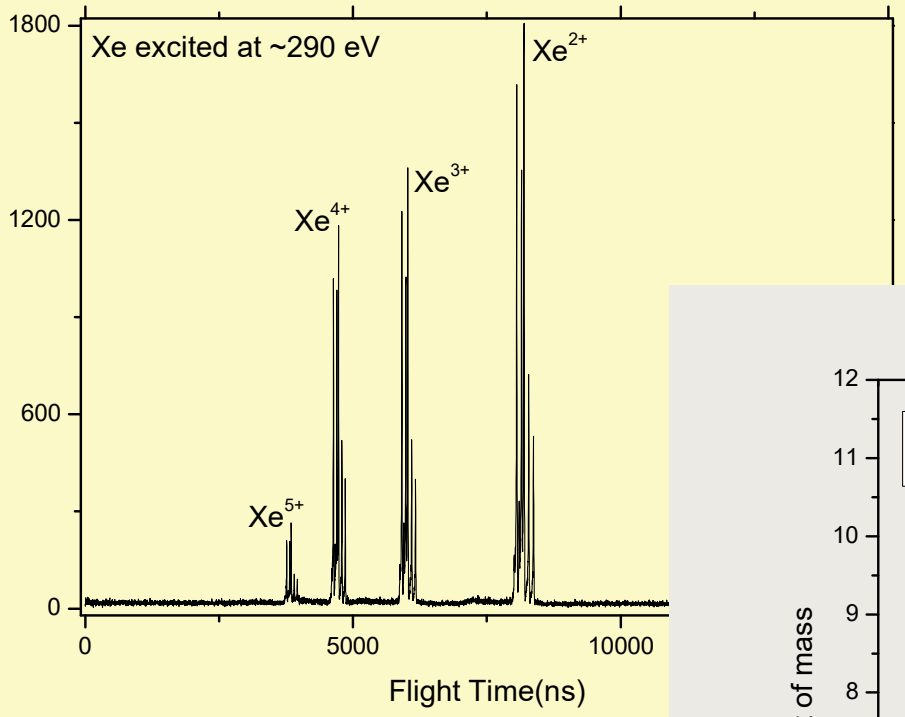
Fig. 6 KBLA1707_6 with front plate



Schematic Diagram



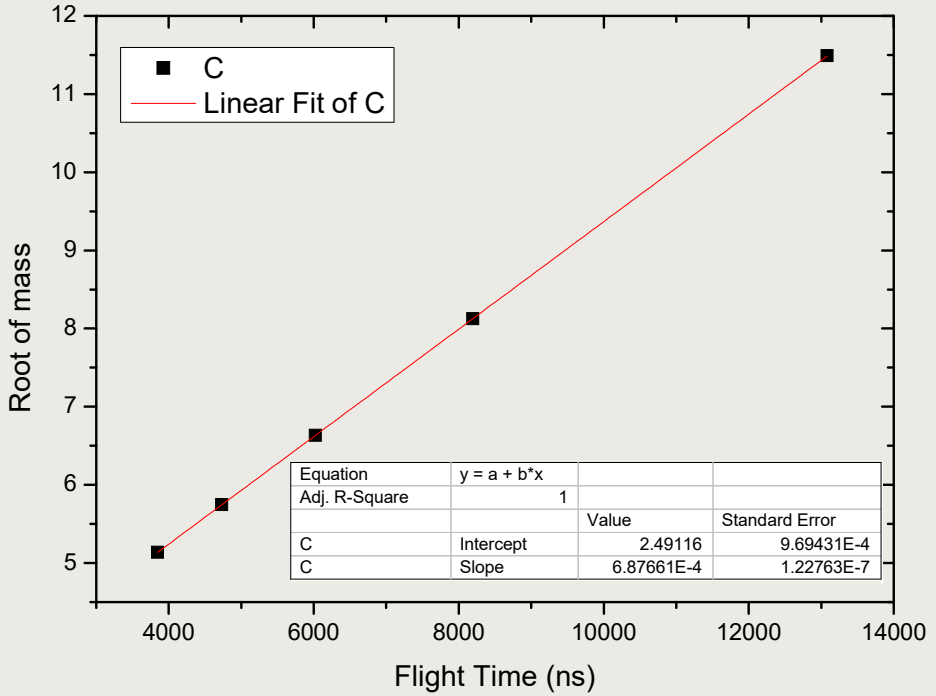
Mass calibration by using Xe



Isotope	Mass / Da	abundance (atom %)
^{128}Xe	127.903	1.92
^{129}Xe	128.905	26.44

$$\frac{1}{2}m_1v_1^2 = \frac{1}{2}m_2v_2^2$$

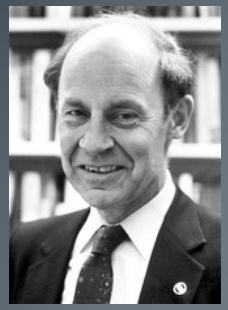
$$\frac{m_1}{m_2} = \frac{v_2^2}{v_1^2} = \frac{t_1^2}{t_2^2}$$

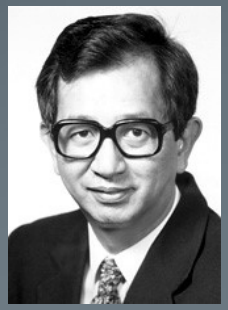


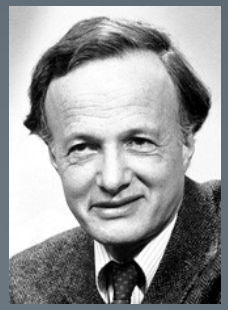
TOF MS利用到的技術

Differential Pumping

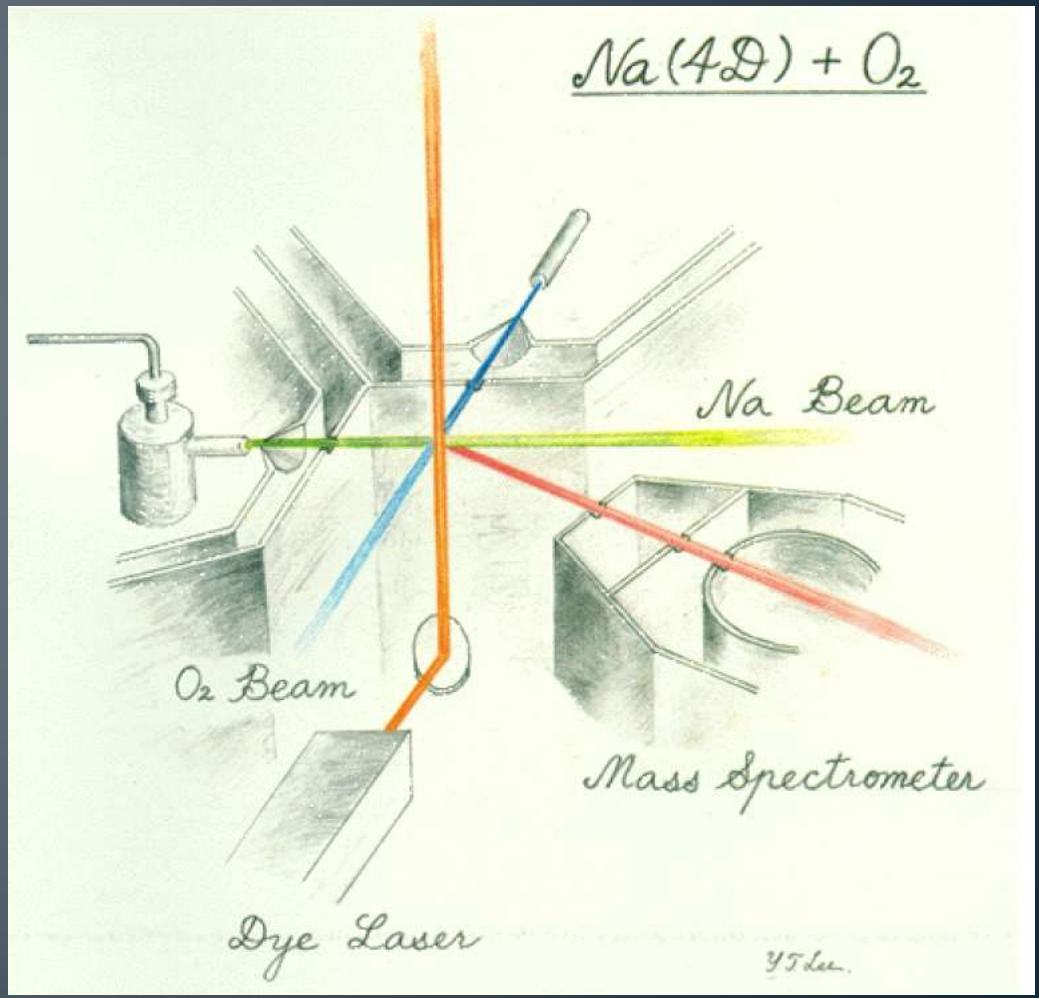
The Nobel Prize in Chemistry 1986
Dudley R. Herschbach, Yuan T. Lee, John C. Polanyi


Dudley R. Herschbach

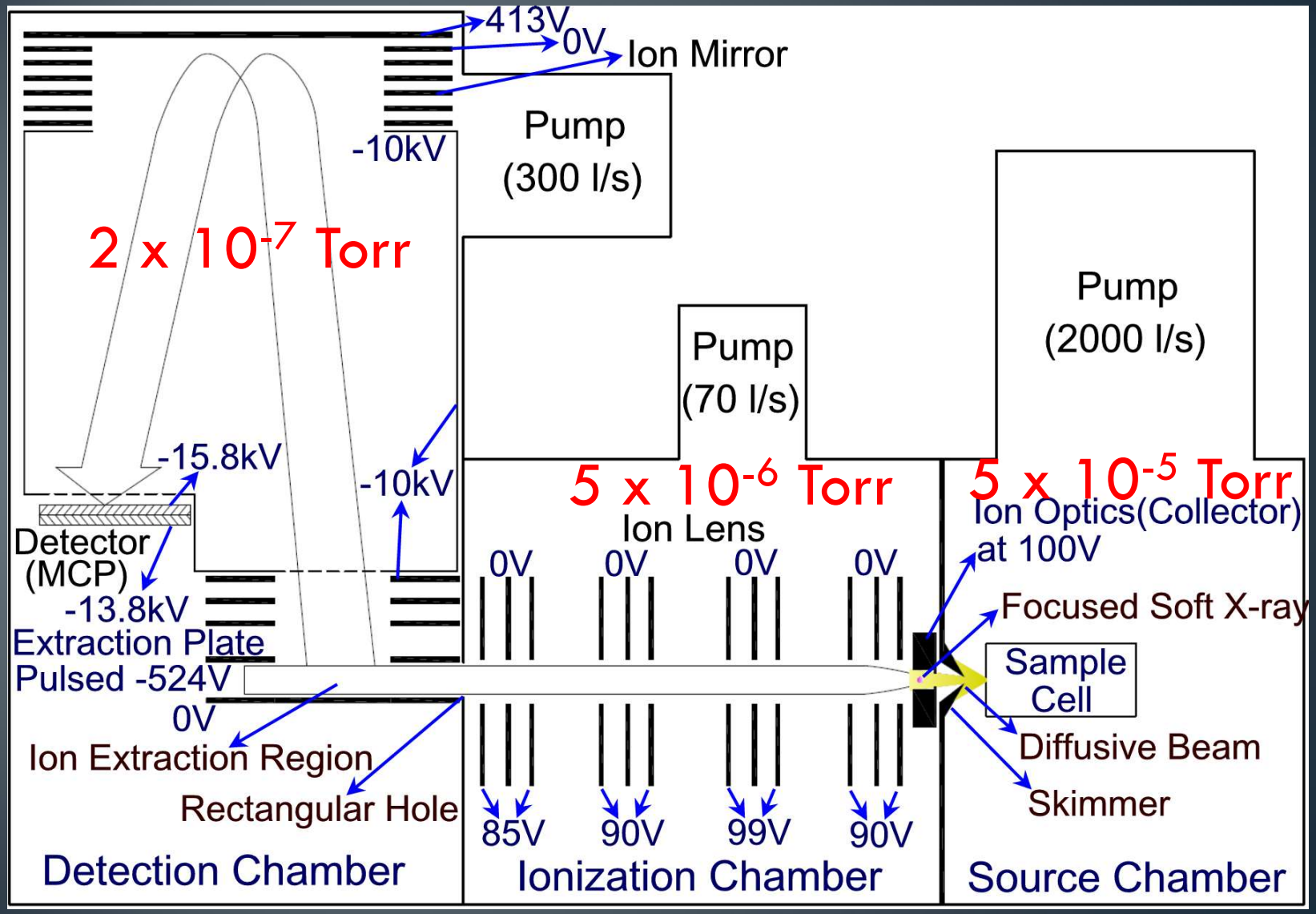

Yuan T. Lee


John C. Polanyi

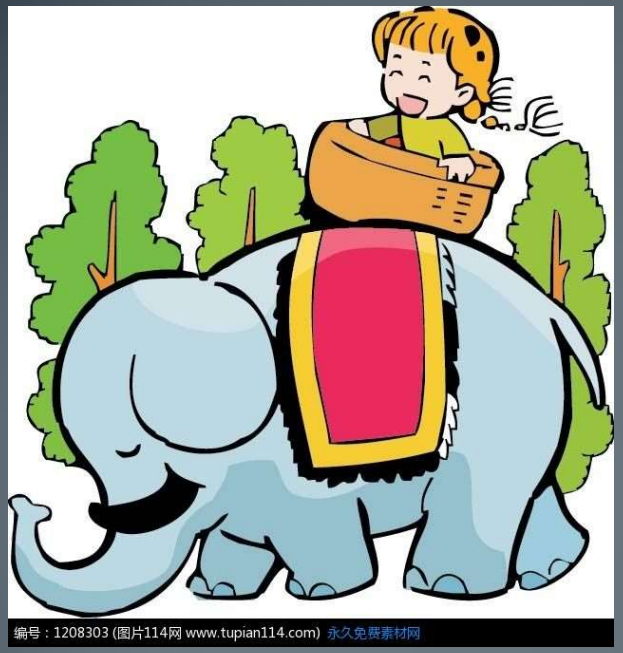
The Nobel Prize in Chemistry 1986 was awarded jointly to Dudley R. Herschbach, Yuan T. Lee and John C. Polanyi *"for their contributions concerning the dynamics of chemical elementary processes".*



Differential Pumping



Differential Pumping



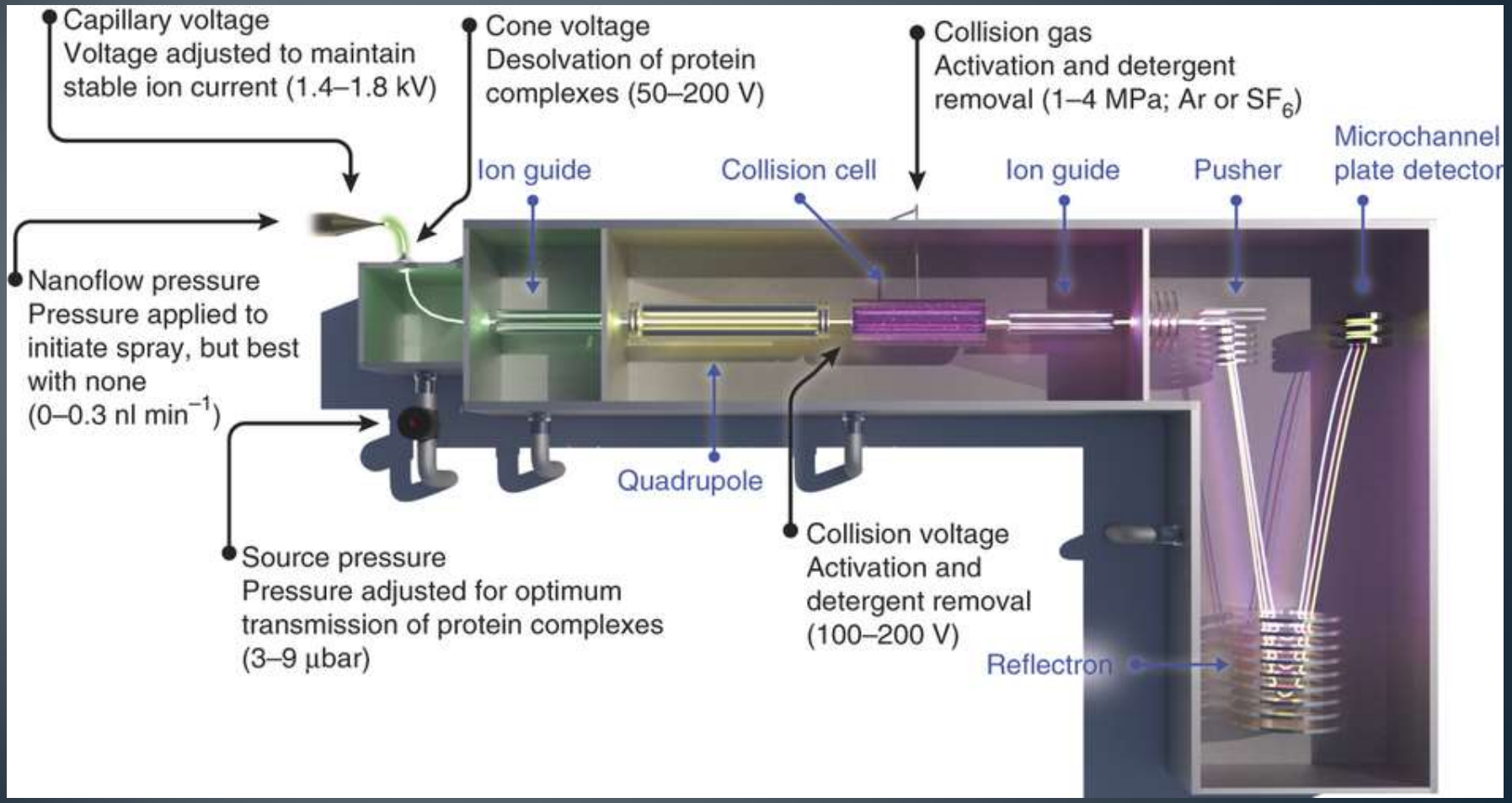
誤差 ± 30Kg

Total 10Kg

誤差 ± 0.3Kg

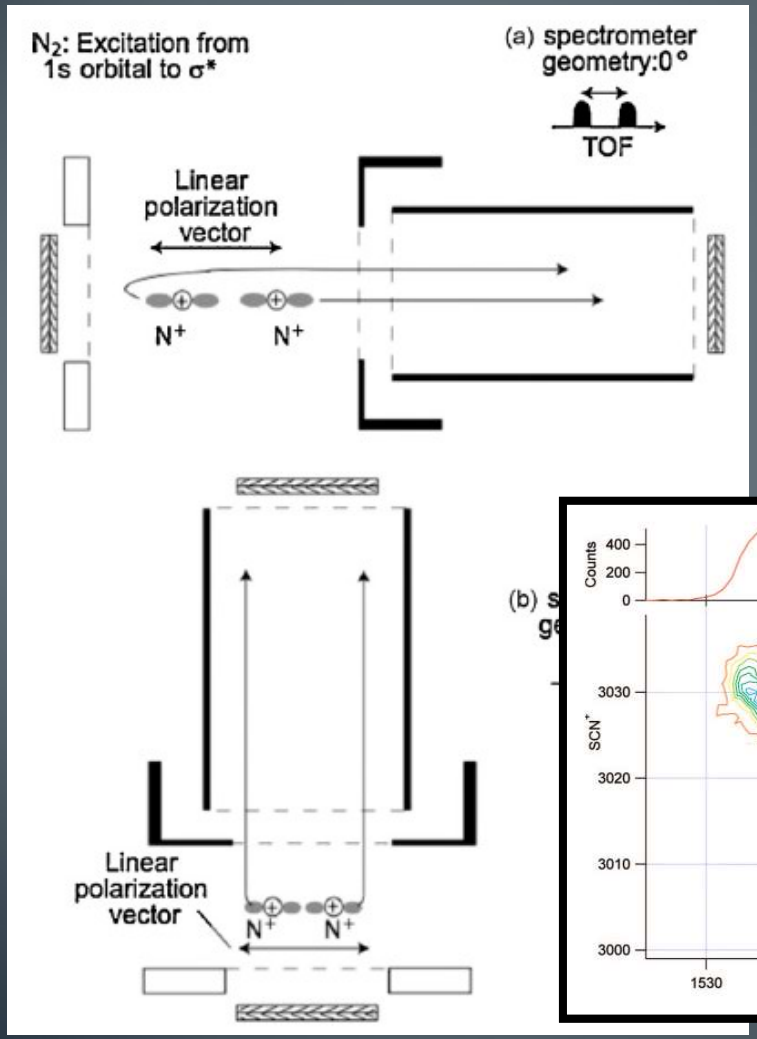
Total 10Kg

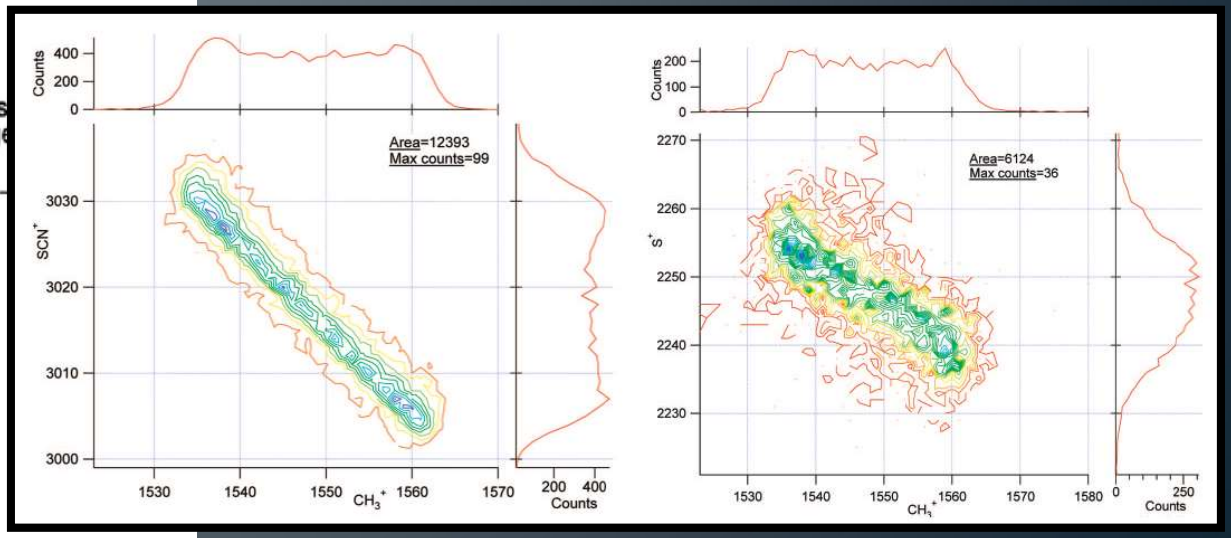
Commercial TOF MS



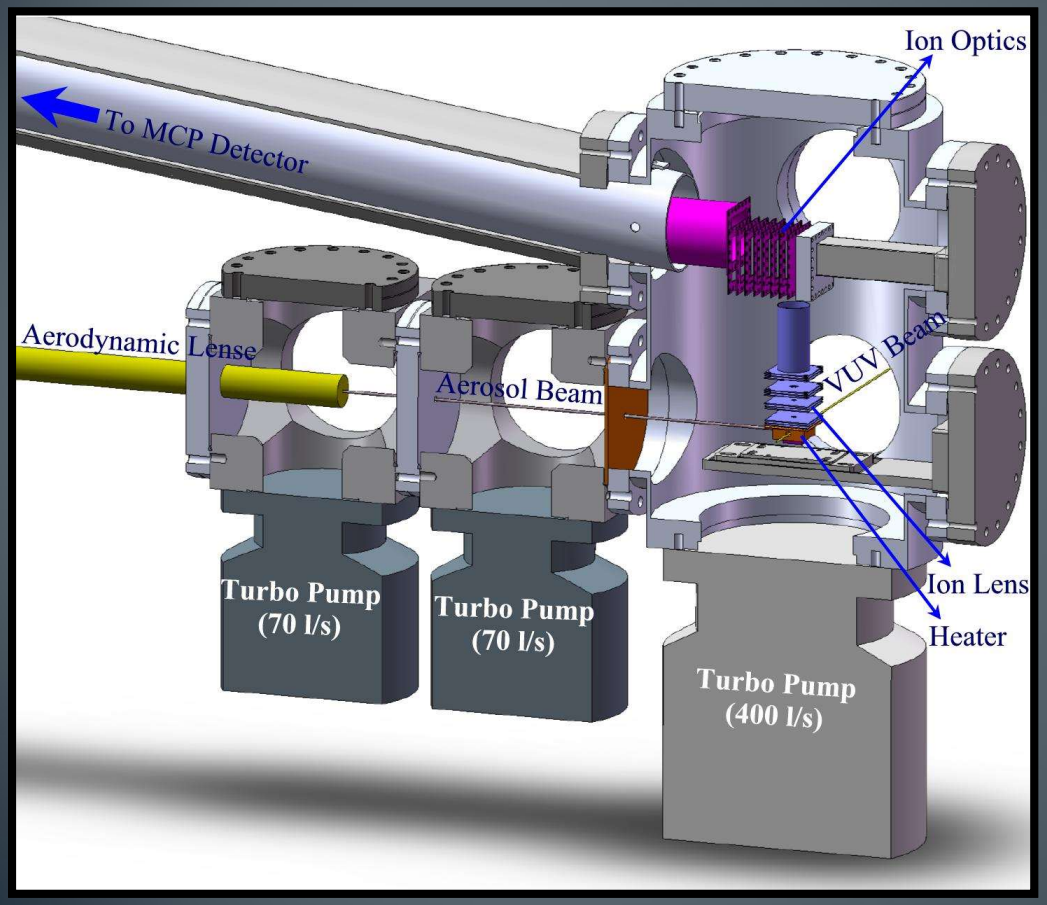
TOF MS目前的應用

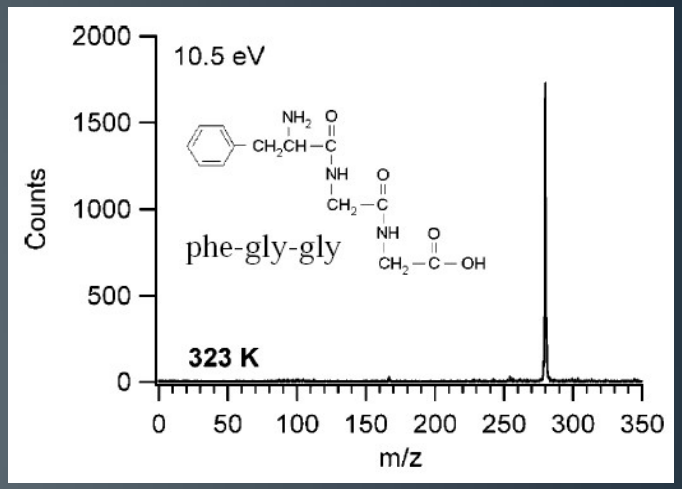
PEPIPICO(coincidence experiment)

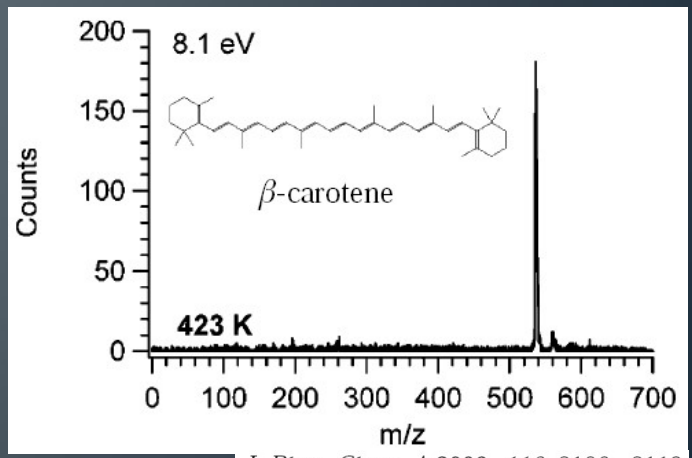




Aerosol (PM 2.5) beam



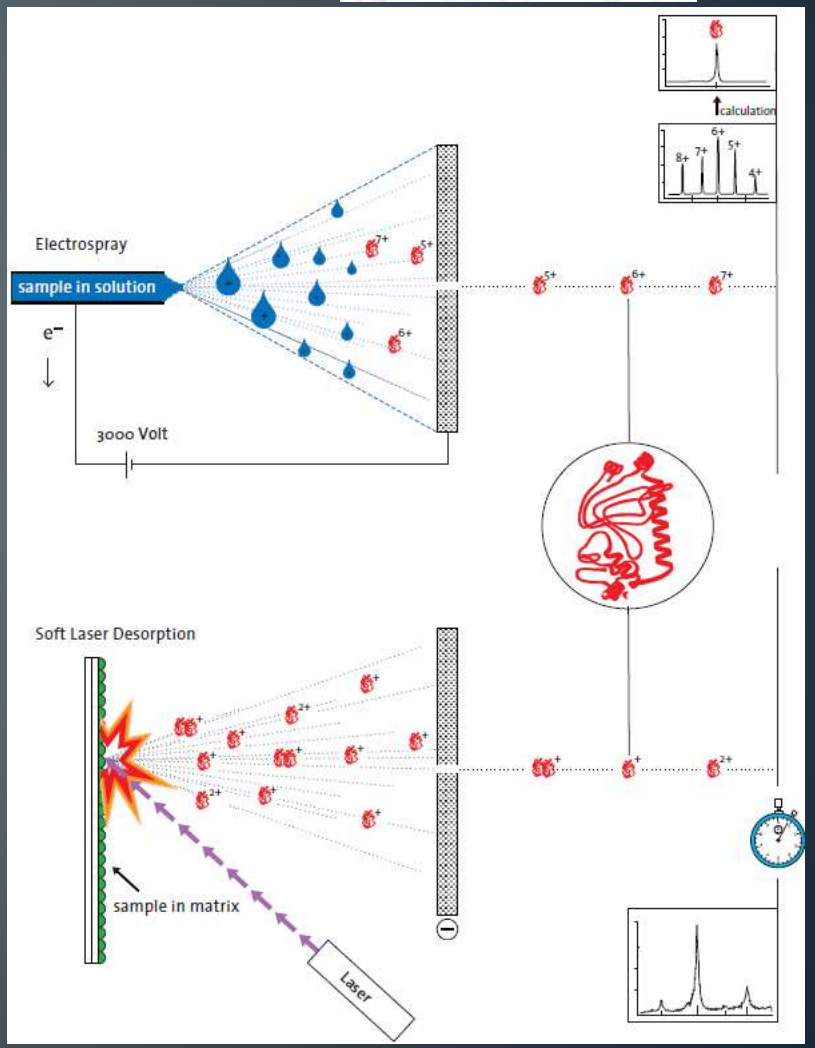




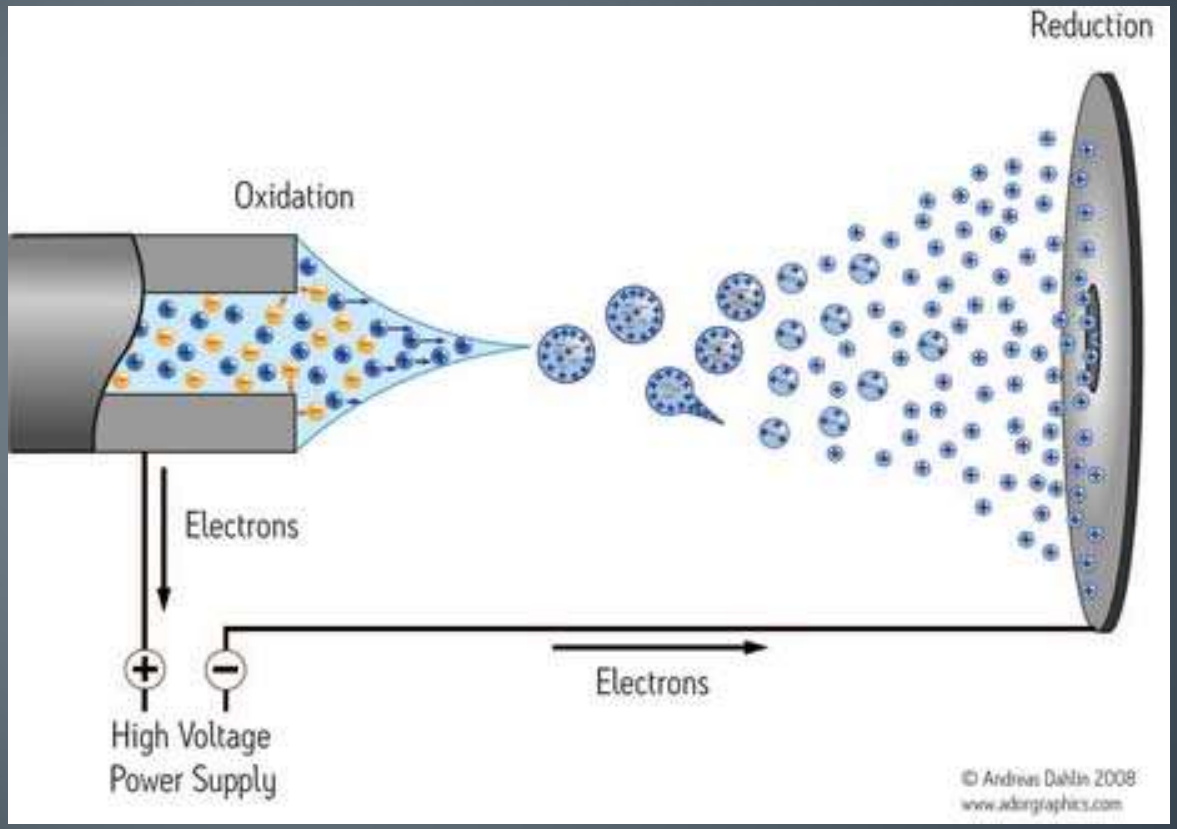
J. Phys. Chem. A **2006,** *110,* 2106−2113

The Nobel Prize in Chemistry

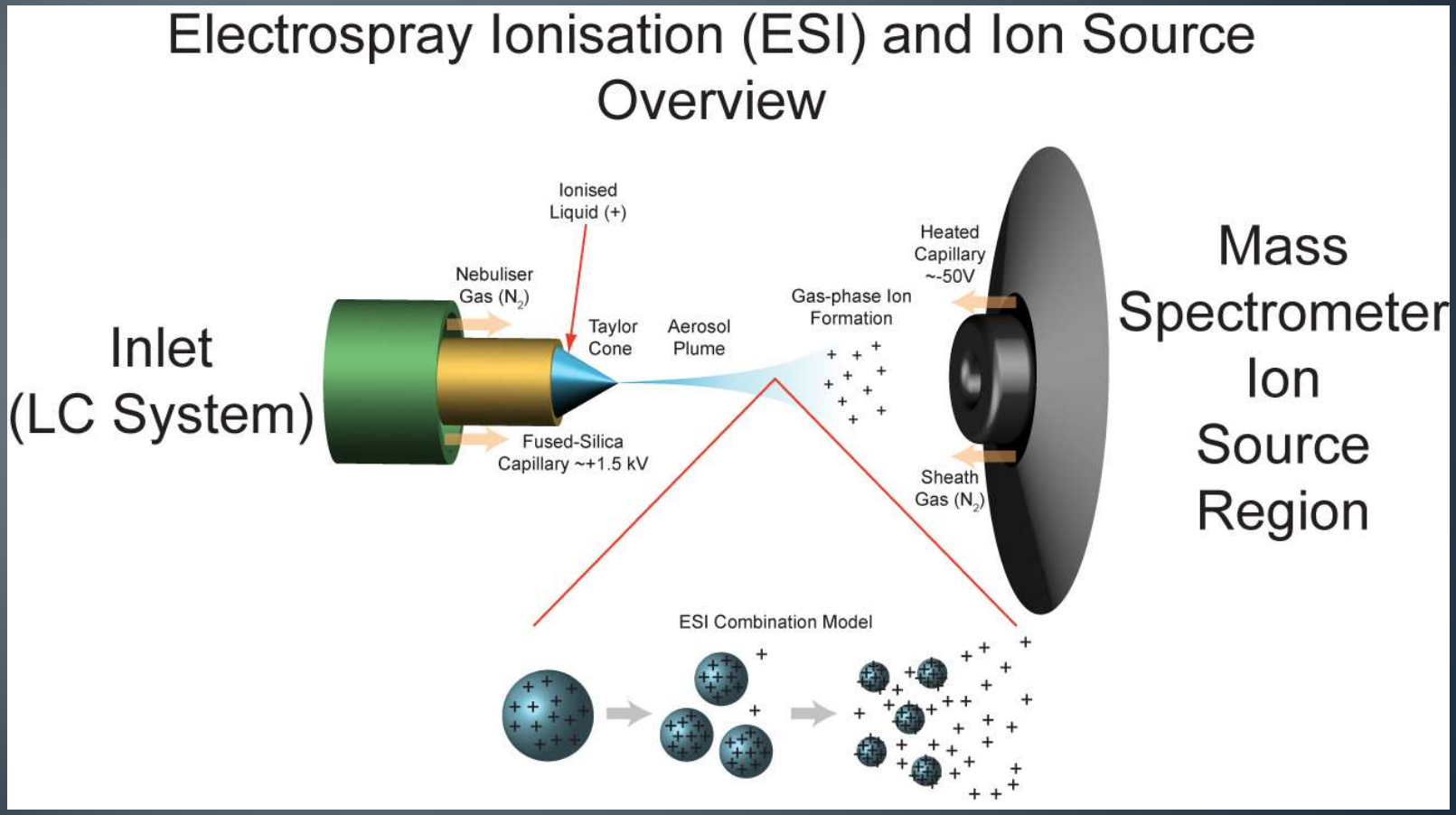
The Nobel Prize in Chemistry for 2002 is being shared between scientists in two important fields: mass spectrometry (MS) and nuclear magnetic resonance (NMR). The Laureates, **John B. Fenn** and **Koichi Tanaka** (for MS) and **Kurt Wüthrich** (for NMR), have contributed in different ways to the further development of these methods to embrace biological macromolecules.



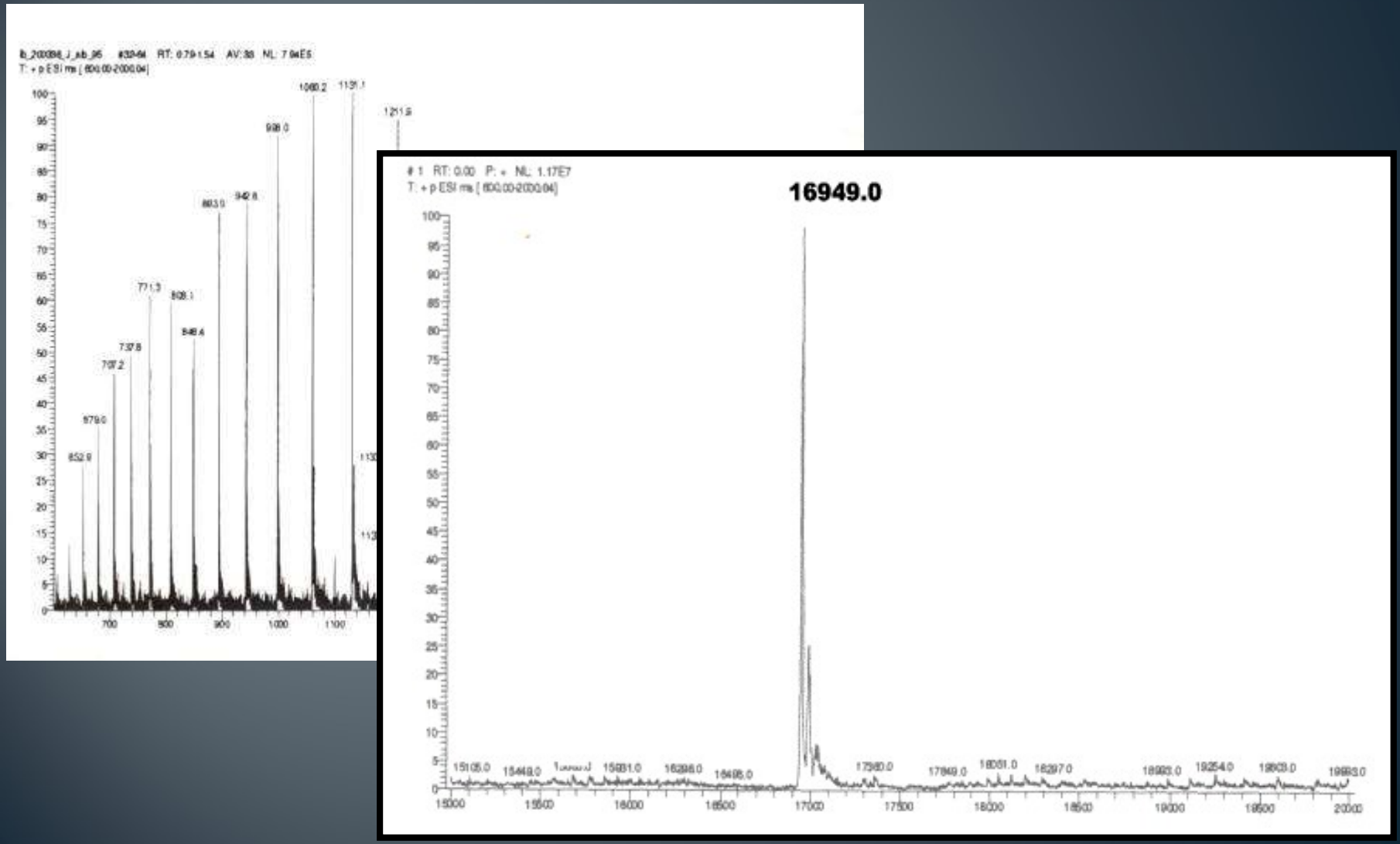
Electro spray ionization



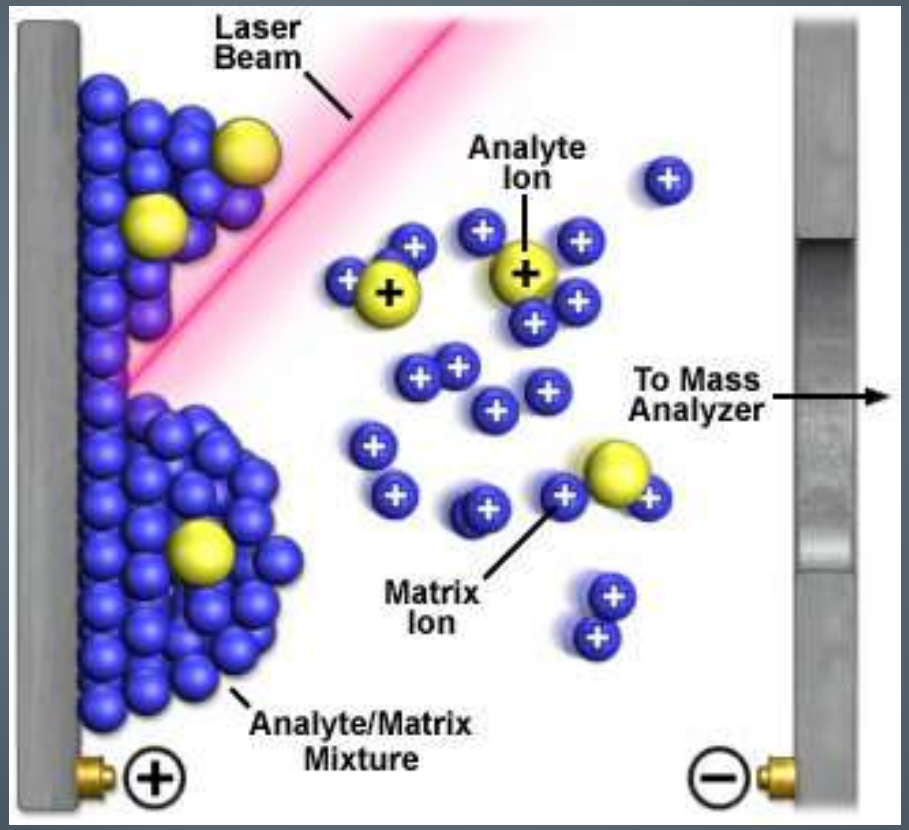
Connection to LC and MS



Electro spray ionization

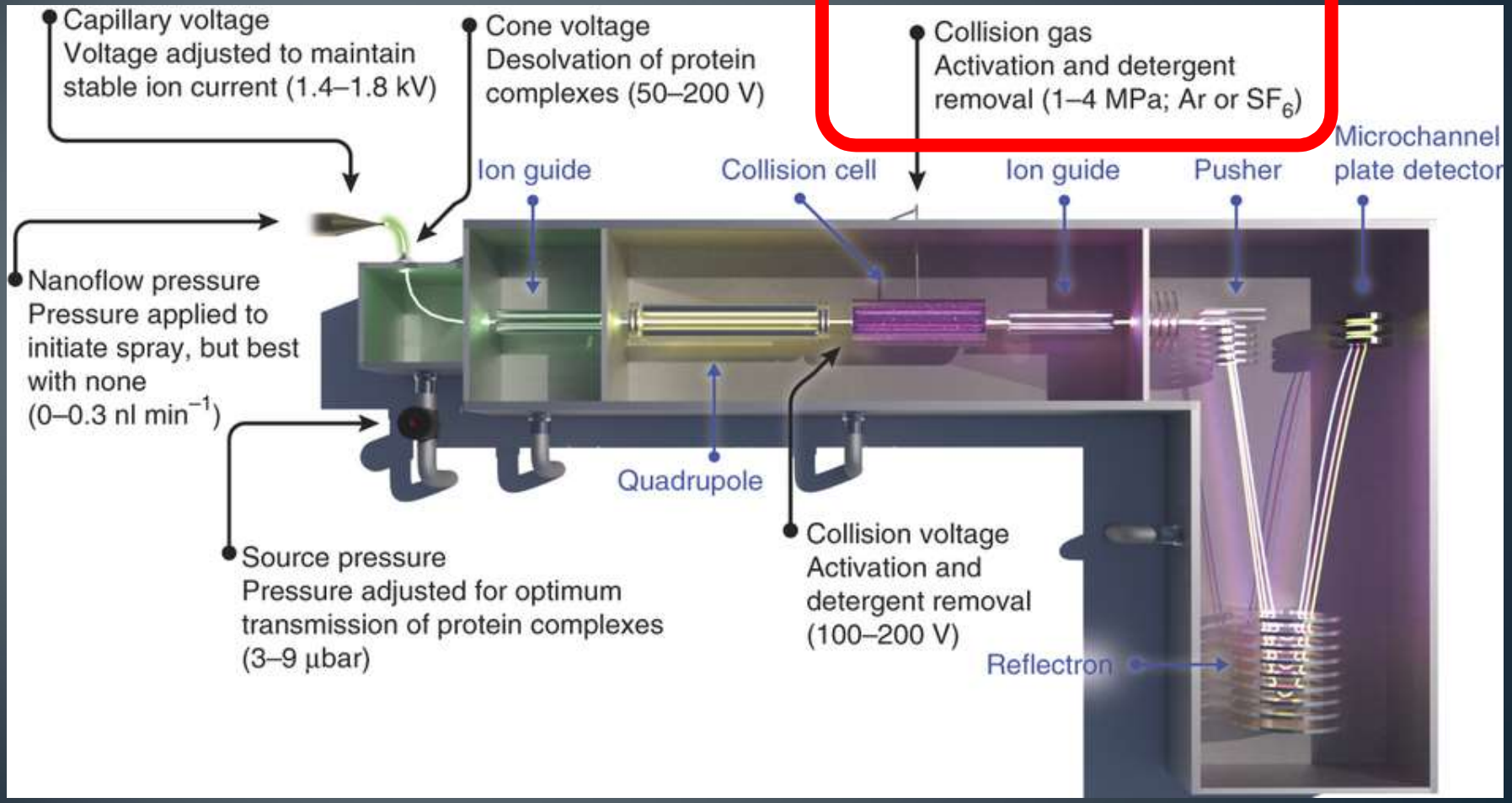


Matrix Assisted Laser Desorption/Ionization (MALDI)

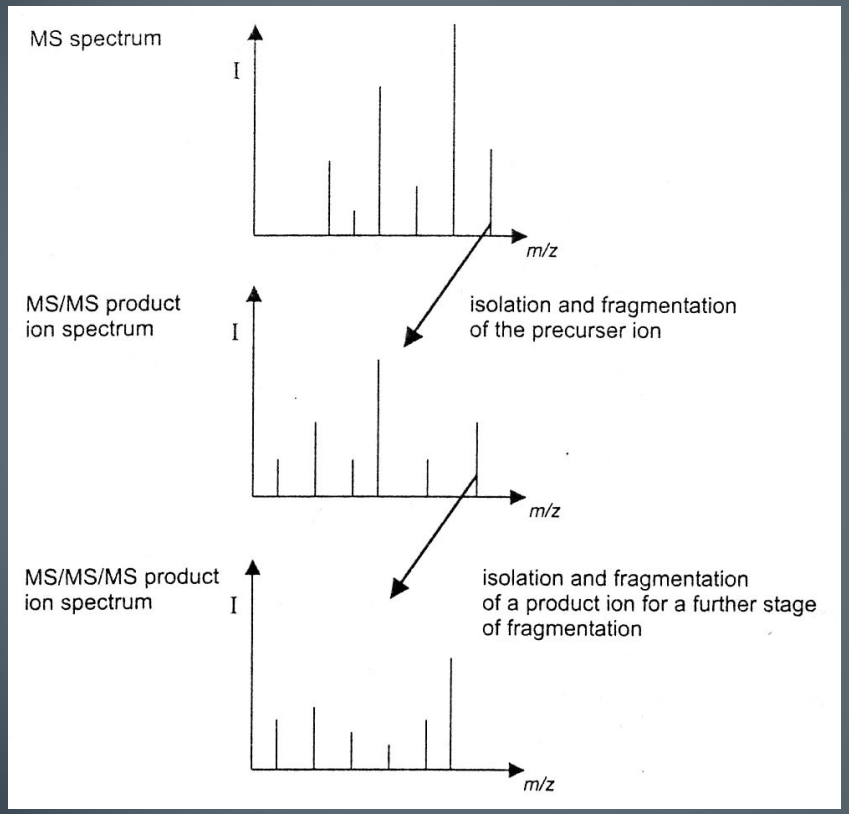


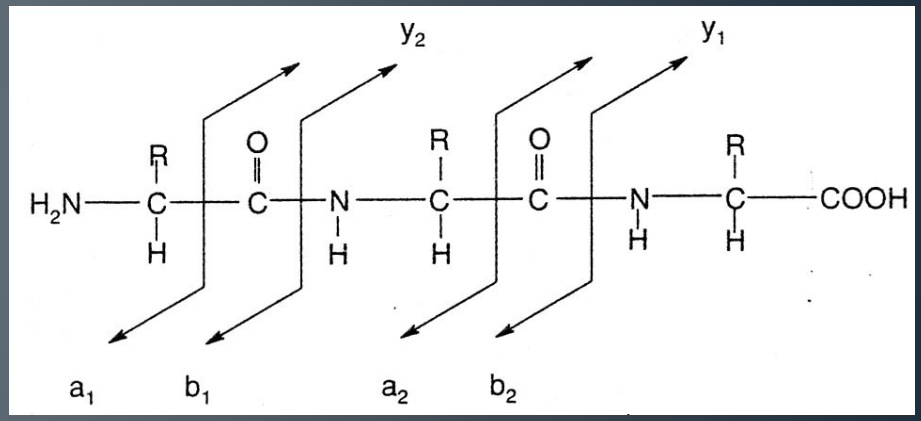
TOF MS

Matrix Assisted Laser Desorption/Ionization (MALDI)

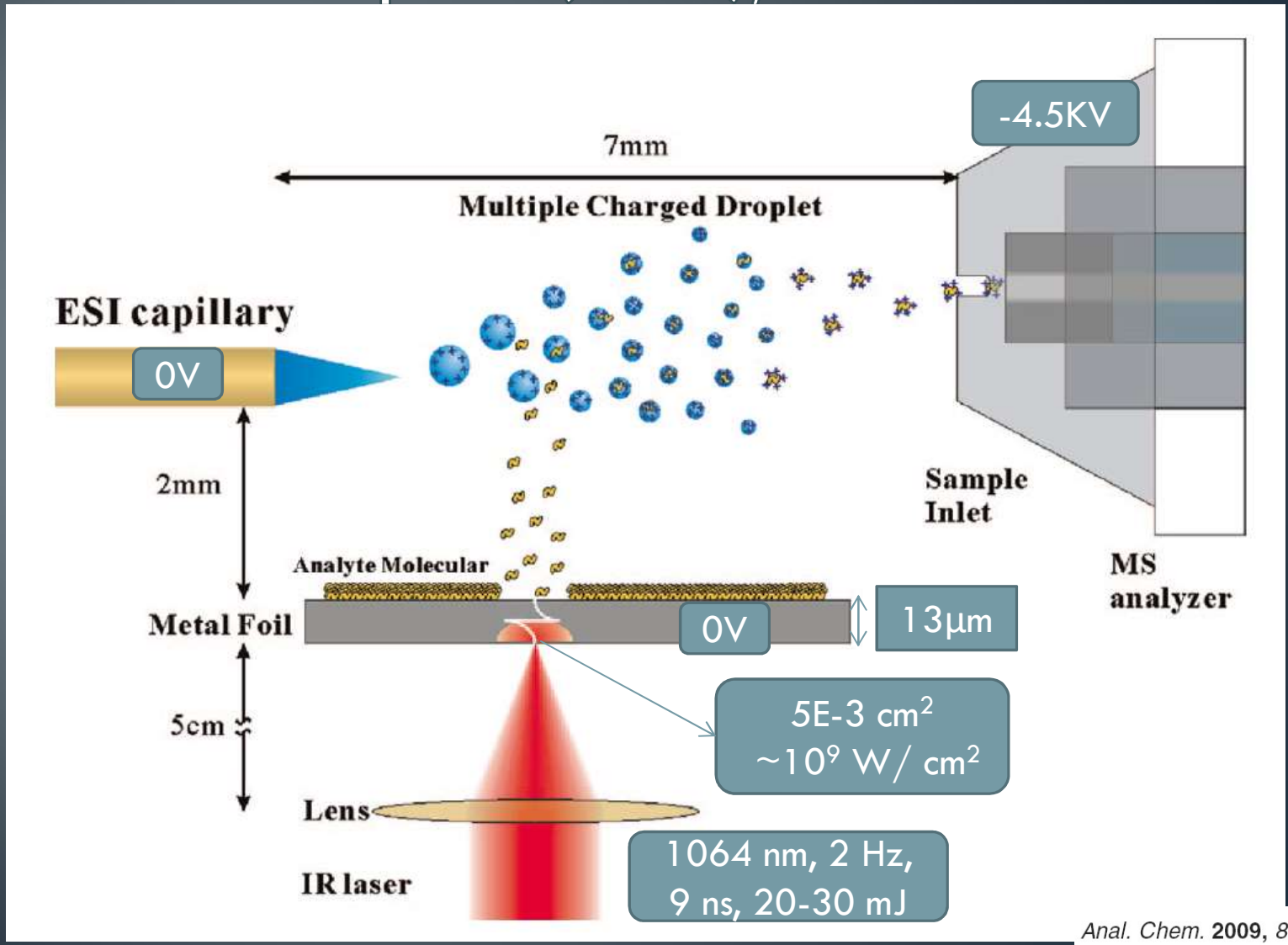


Matrix Assisted Laser Desorption/Ionization (MALDI)





Schematic diagram of Laser-Induced Acoustic Desorption (LIAD)/ESI MS



Anal. Chem. **2009,** *81,* 868–874

Laser Induced Acoustic Desorption (LIAD)

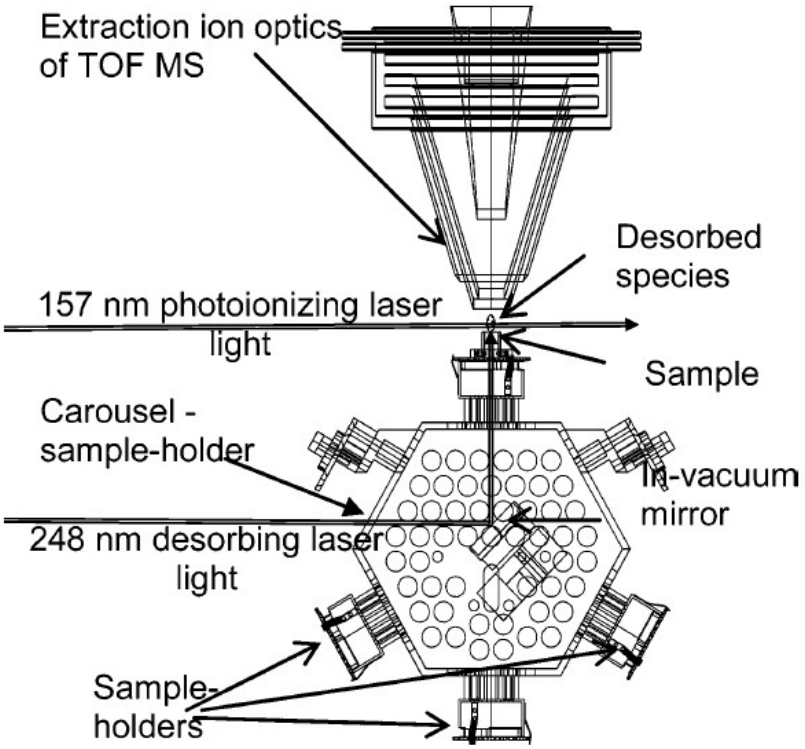
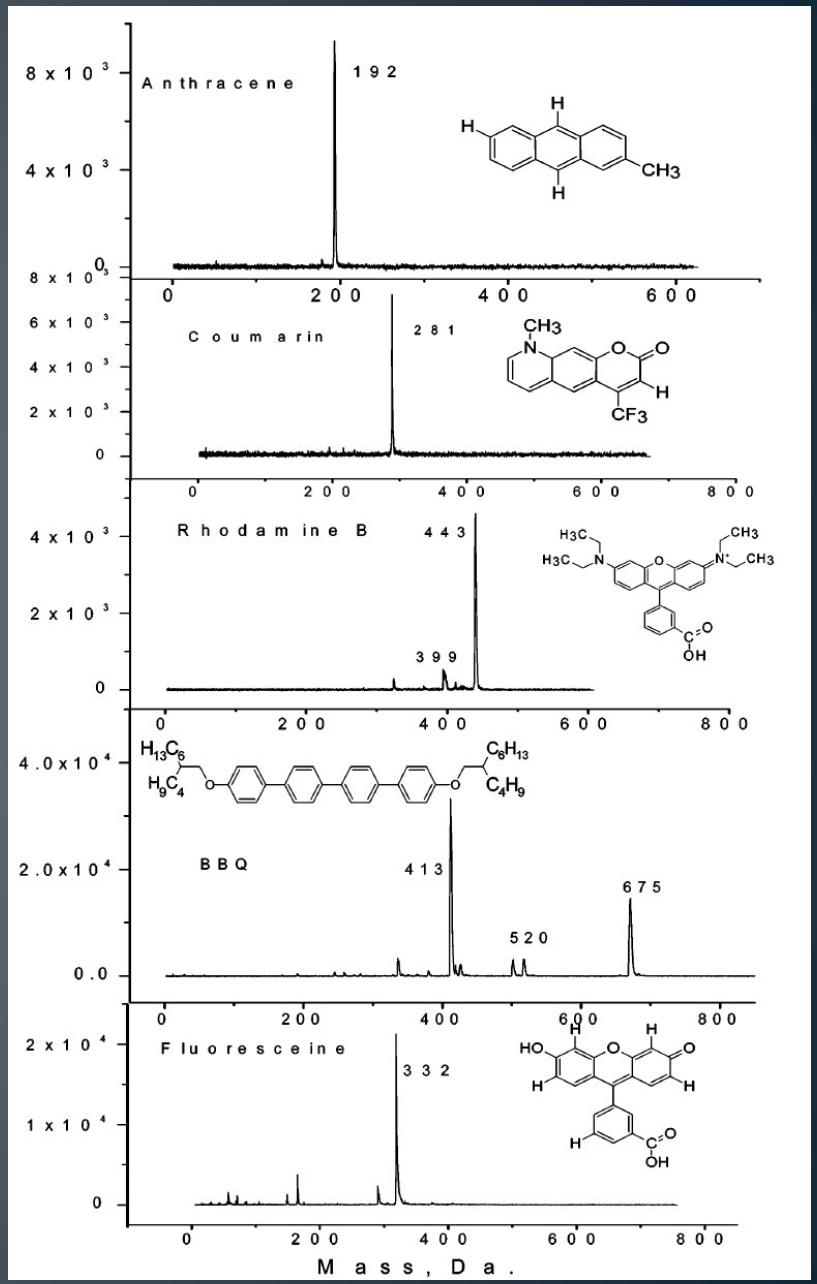
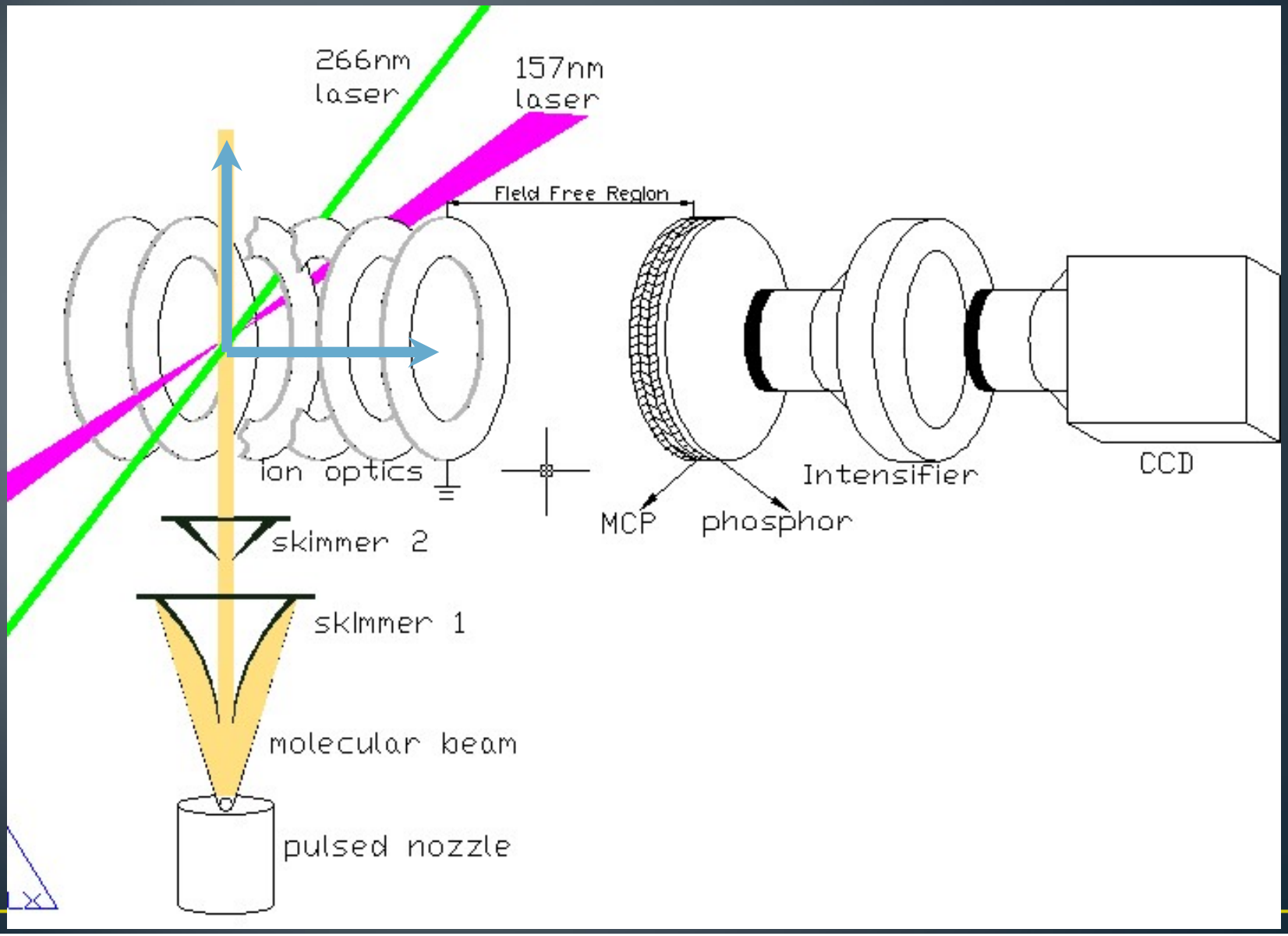


Figure 1. Schematic drawing of the experimental setup.



Anal. Chem. **2007**, *79*, 8232−8241

Time-sliced velocity mapping ion imaging



Time-sliced velocity mapping ion imaging
Ion optics

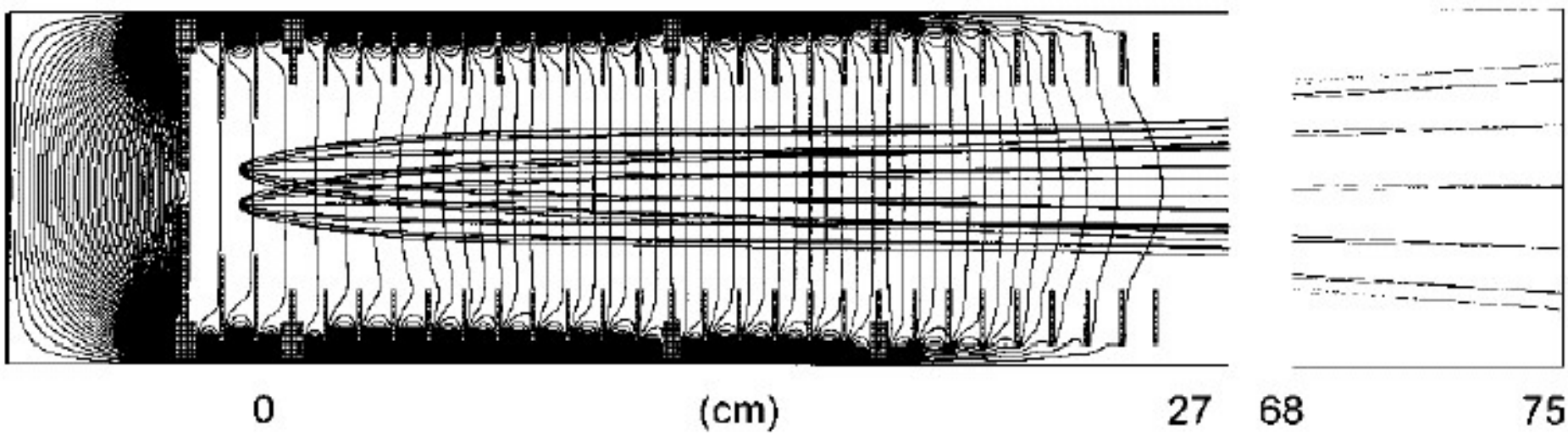


FIG. 1. Computer simulation of the ion optics. The potential contour spacing is 19.6 V/cm at 1000 V ion optics voltage. The ion trajectories shown correspond to ions with 1.2 eV initial kinetic energy sampled every 30°. The two ion born positions are separated by 10 mm. The pitch of the electrode plates was designed to be 1 cm.

Time-sliced velocity mapping ion imaging Ion optics

Conclusion

- Free electron laser, a tool for:
  - Ionization.
  - Excitation.
  - Photo dissociation.
  - …
- TOF MS, a tool for:
  - Detecting ions with m/z values.
  - Measuring velocity, flight times, and fragments……