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Agilent Technologies

Removing interferences with the MS-MS technology in triple quadrupole ICP-MS to improve the analytical detection of inorganic nanomaterials.




Agilent's History in ICP-MS

30 Years of ICP-MS Innovation

Enabling high sensitivity metal analysis

PMS series

First computer-controlled ICP-MS

1987

Enabling routine robust ICP-MS analysis

4500

First benchtop ICP-MS
Cool plasma

1994

Enabling control of common interferences

7500

9 orders detector
ORS cell

2000

Enabling ease of use and productivity

7700

HMI
ISIS-DS
MassHunter SW

2009

Enabling controlled reaction chemistry

8800 ICP-QQQ

World's first ICP-QQQ

2012

A new era in ICP-MS performance

7900

UHMI
ODS detector
ISIS 3

2014

Enabling simplified ICP-MS workflows

7800

Solution ready
Method automation

2015

Flexible, high performance MS/MS

New 8900 ICP-QQQ

Second generation ICP-QQQ

2016

#1 selling ICP-MS !

Current/Future Expectations of ICP-MS

What **analytical** problems remain to be addressed

Even lower DLs

- Lower level trace contaminant analysis in higher-purity and more complex materials (alloys, ceramics, liquid crystal…)

"Unusual" elements

- Increasing need for trace level analysis of elements that aren't typically measured by ICP-MS: Si, P, S, Cl…

Non-polyatomic overlaps

- E.g.: Isobaric and doubly charged overlaps that can't be addressed using helium mode

Very intense backgrounds

- Accurate analysis of analytes that suffer severe background or matrix-based interferences – O_2, N_2, S_2, SO…

Controlling Interferences in ICP-MS

Collision Mode or Reaction Mode

(Helium) Collision Mode

- Employed successfully by Agilent ICP-QMS users since 2001 to control polyatomic interferences in complex sample matrices
- Filters out polyatomic ions using kinetic energy discrimination (KED);
- Ensures accurate analysis of most common analytes in typical samples
- BUT, He mode is not effective for doubly-charged or isobaric overlaps, and is not suitable for ultra-low level analysis

Reaction Mode

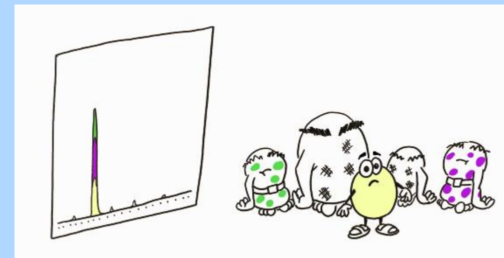
- Can be effective for doubly-charged and isobaric overlaps, and to remove very intense polyatomics
- BUT, reaction chemistry depends on ions in the cell, so results vary if sample composition changes
- Reaction mode on ICP-QMS is often not reliable, and gives errors in variable samples
- **HOW CAN WE MAKE REACTION CHEMISTRY MORE RELIABLE?**

The Answer: ICP-**MS/MS**

Quadrupole ICP-MS (ICP-QMS). Single mass filter, after the cell

No mass selection before cell; ALL ions enter cell and can react

All ions can pass through cell or react to form new product ions

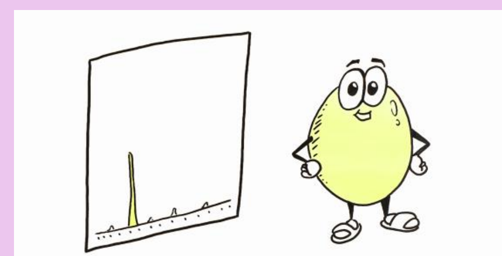


Many different ions can contribute to the measured signal

Triple Quadrupole ICP-MS (ICP-QQQ). Double mass filter, before/after cell

Mass selection before cell; Q1 rejects all masses except target ion m/z. ONLY target analyte and on-mass interferences enter cell. Overlaps at product ion mass are eliminated

Analyte and on-mass interference separated by reaction chemistry



Only the target analyte ions contribute to the measured signal

The New, Second Generation Agilent 8900 ICP-QQQ
Put your ICP-MS results beyond doubt

New Agilent 8900 Triple Quadrupole ICP-MS (ICP-QQQ)

Tandem mass spectrometer uses MS/MS to control interferences

Replaces the highly successful Agilent 8800 – the world's first and only ICP-QQQ

Joins the market-leading Agilent 7800 and Agilent 7900 quadrupole ICP-MS systems

Why ICP-QQQ?
Unique Benefits of MS/MS

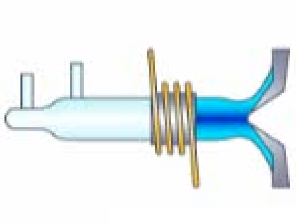
ICP-QQQ is a tandem mass spectrometer – **2 mass filters, Q1 and Q2**

Q1 is positioned before the cell, so controls ions that enter the cell

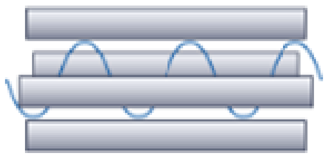
Controlled and consistent reaction processes

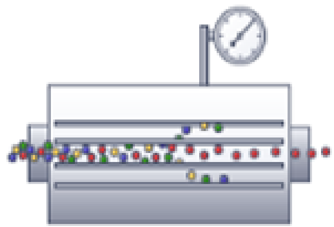
- Removes uncertainty and ensures accuracy when using reaction gases
- Provides consistent and reliable results, even when sample matrix and co-existing analytes change
- Simplifies method development – same gas mode used for all samples
- Enables accurate isotope analysis (no inter-isotope overlaps)
- Removes direct isobaric overlaps; not possible even with high-resolution ICP-MS

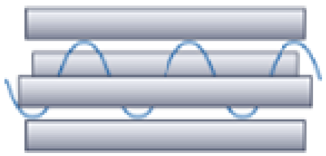
ICP-MS/MS: *How Does it Work?*



ICP (plasma) and Interface: Forms and extracts ions from the sample (just like ICP-QMS)







Q1 – controls ions that enter the cell

- Consistent reactions even if sample composition changes

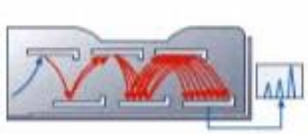
ORS[4] – collision/ reaction gas added

- Ions react and are neutralized or moved
- Product ions are formed

Q2 – selects the target analyte mass

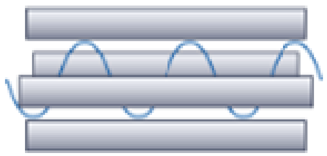
- Interference-free analyte ions passed to EM

EM (detector): Measures the ions that pass through Q2 (just like ICP-QMS)



ICP-MS/MS: *How Does it Work?*

ICP (plasma) and Interface: Forms and extracts ions from the sample (just like ICP-QMS)



Q1 – controls ions that enter the cell

- Consistent reactions even if sample composition changes

Unique aspect of 8900 is MS/MS Mode

- **Q1 rejects ALL ions at masses other than target analyte precursor ion mass**
  - **All existing ions that could overlap an analyte product ion are removed**
  - **All existing ions that could form a product ion overlap at the analyte ion/product ion mass are removed**
  - **Only the analyte and on-mass interference(s) enter the cell**

EM (detector): Measures the ions that pass through Q2 (just like ICP-QMS)

Measurement Options in Reaction Mode

ICP-MS can use **on-mass** or **mass-shift** measurement.

- Choice depends on relative reactivity of analyte and interference(s)

On-mass mode (target isotope measured at its original mass)

- Used when reaction gas is more reactive with the interference than with the analyte
- E.g. Si measured as Si^+ with H_2 reaction gas

Mass shift mode (target isotope measured as a reaction product ion)

- Used when reaction gas is more reactive with the analyte than with the interference
- E.g. S measured as SO^+ with oxygen reaction gas

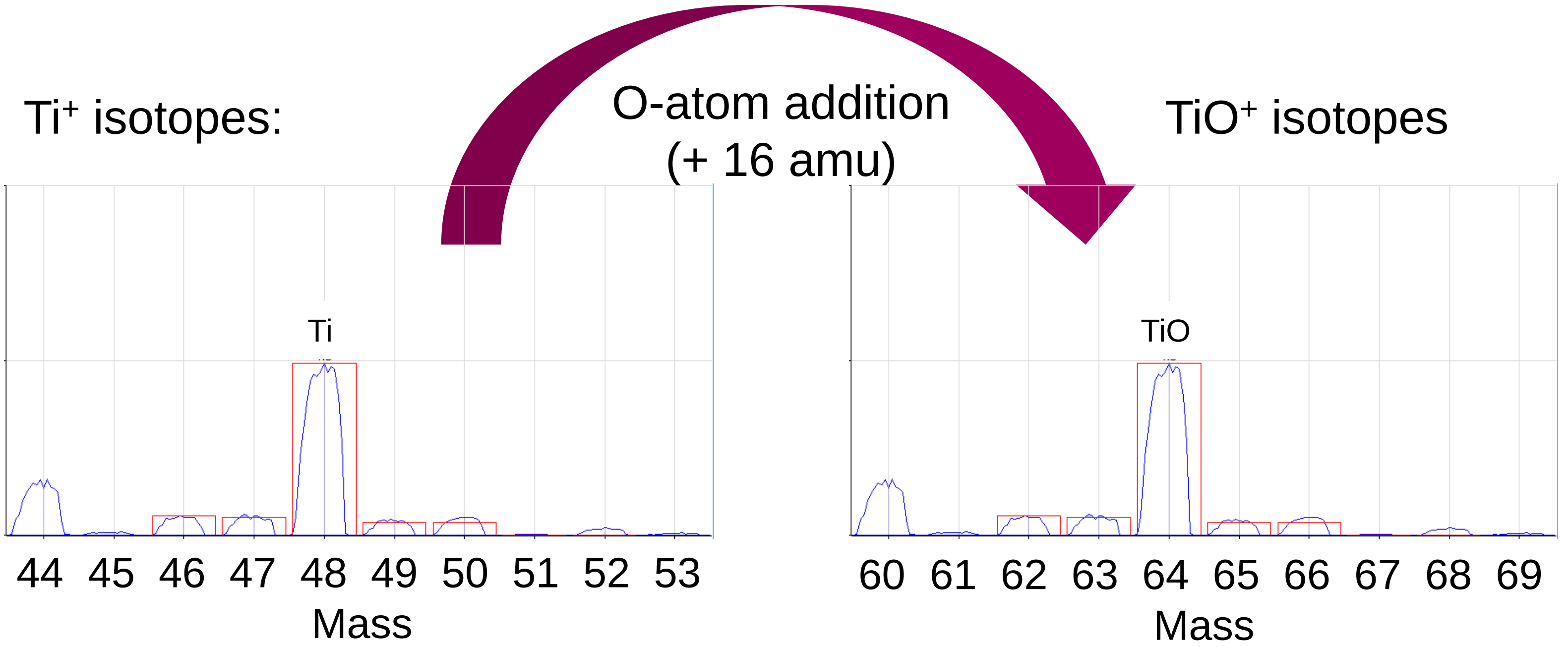
Demonstration of MS/MS Mass-Shift in Practice
Ti Analysis With O_2 Reaction Cell Gas

Many elements can be measured as MO^+ product ions with O_2 cell gas.

Reaction process used is O-atom addition:

Ti^+ **precursor** ions react with O_2 cell gas to form TiO^+ **product** ions:

$$Ti^+ + O_2 \rightarrow TiO^+ + O$$



Comparison of Single Quad vs MS/MS Operation

TiO^+ Product Ions with O_2 Cell Gas

O_2 reaction chemistry works in conventional ICP-QMS or ICP-QQQ cell

BUT ICP-QMS can't control the ions that enter the cell, so TiO^+ product ions can be overlapped by other analyte ions (or product ions).

$^{46}TiO^+$ (mass 62) is overlapped by ^{62}Ni

$^{47}TiO^+$ (mass 63) is overlapped by ^{63}Cu

$^{48}TiO^+$ (mass 64) is overlapped by ^{64}Zn

$^{49}TiO^+$ (mass 65) is overlapped by ^{65}Cu

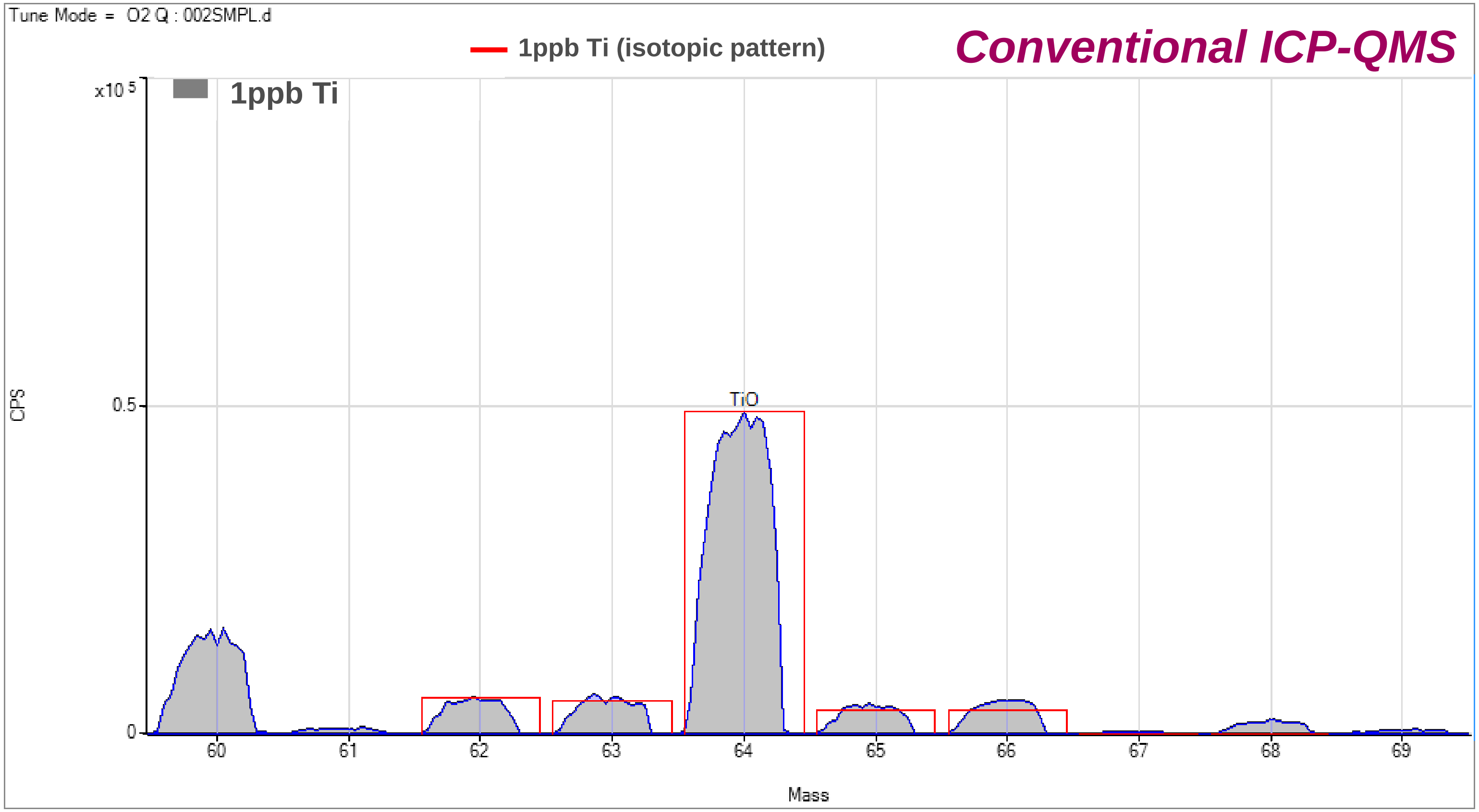
$^{50}TiO^+$ (mass 66) is overlapped by ^{66}Zn

Precursor Ion (Q1)	Product Ion (Q2)	Potential Overlaps from other analytes		
Ti	**TiO**	**Ni**	**Cu**	**Zn**
46	62	^{62}Ni		
47	63		^{63}Cu	
48	64			^{64}Zn
49	65		^{65}Cu	
50	66			^{66}Zn

These overlapping ions **cannot be rejected by a bandpass cell**, because **they are at the same masses as the TiO^+ product ions being measured**

TiO^+ Analysis by Conventional ICP-QMS

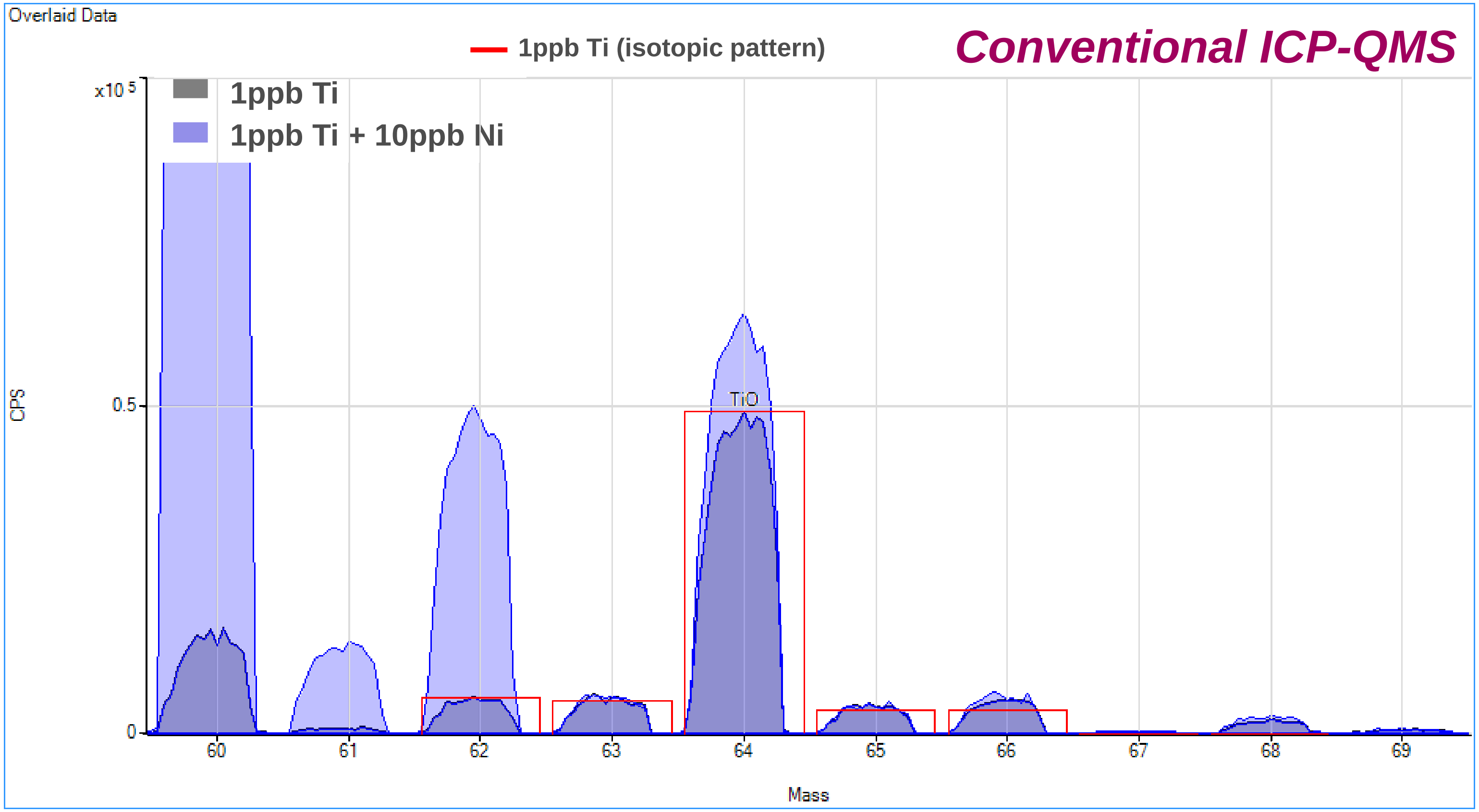
TiO^+ product ions in simple, single-element standard



1 ppb Ti standard – TiO^+ peaks match theoretical isotopic abundances

TiO^+ by ICP-QMS; Other Elements Present

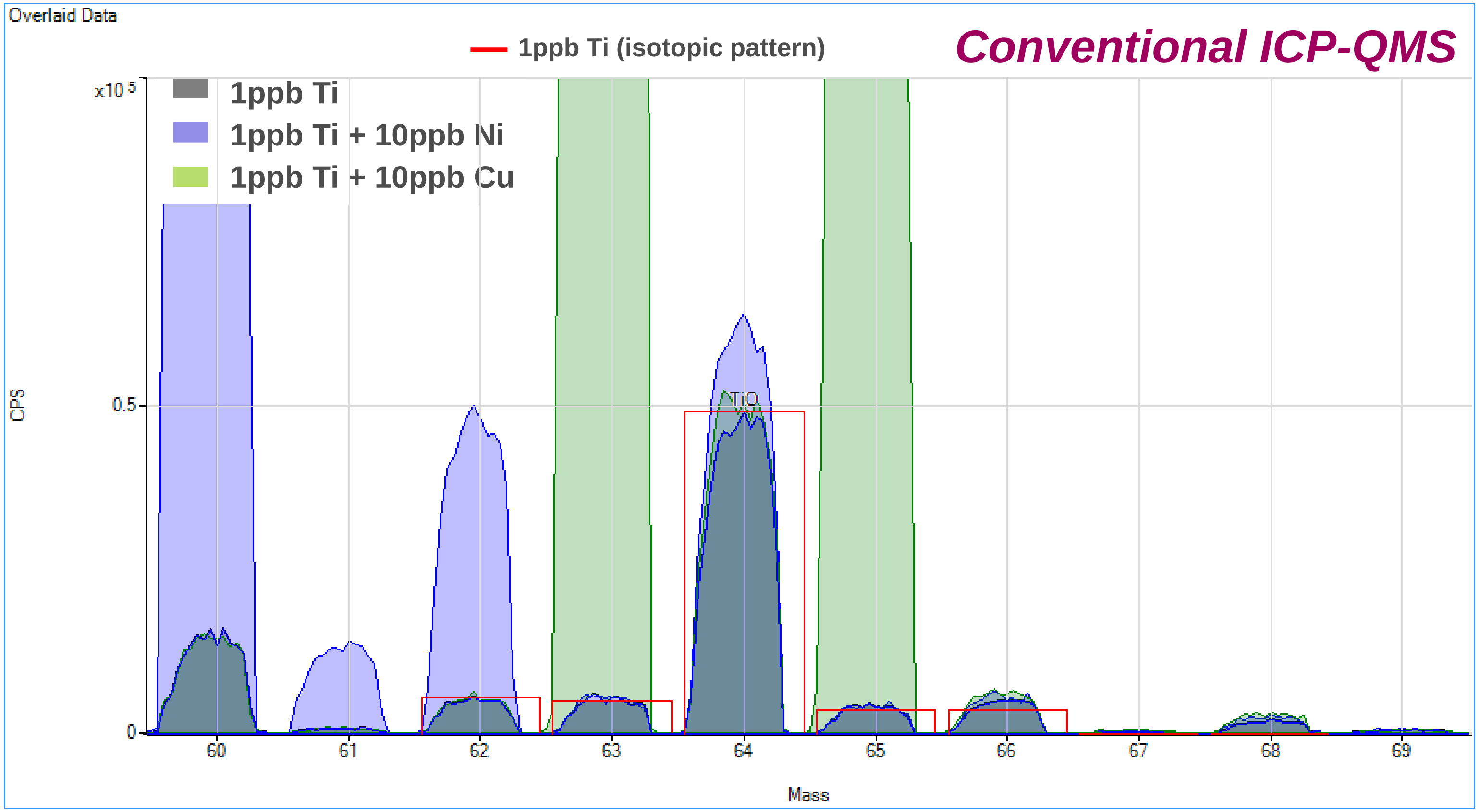
In mixed matrix, TiO^+ product ions are overlapped by other analyte (or matrix) ions. Ti (1 ppb) with Ni (10 ppb) shown below



1 ppb Ti overlaid with 1 ppb Ti + 10 ppb Ni (Ni^+ overlaps TiO^+)

TiO^+ by ICP-QMS; Other Elements Present

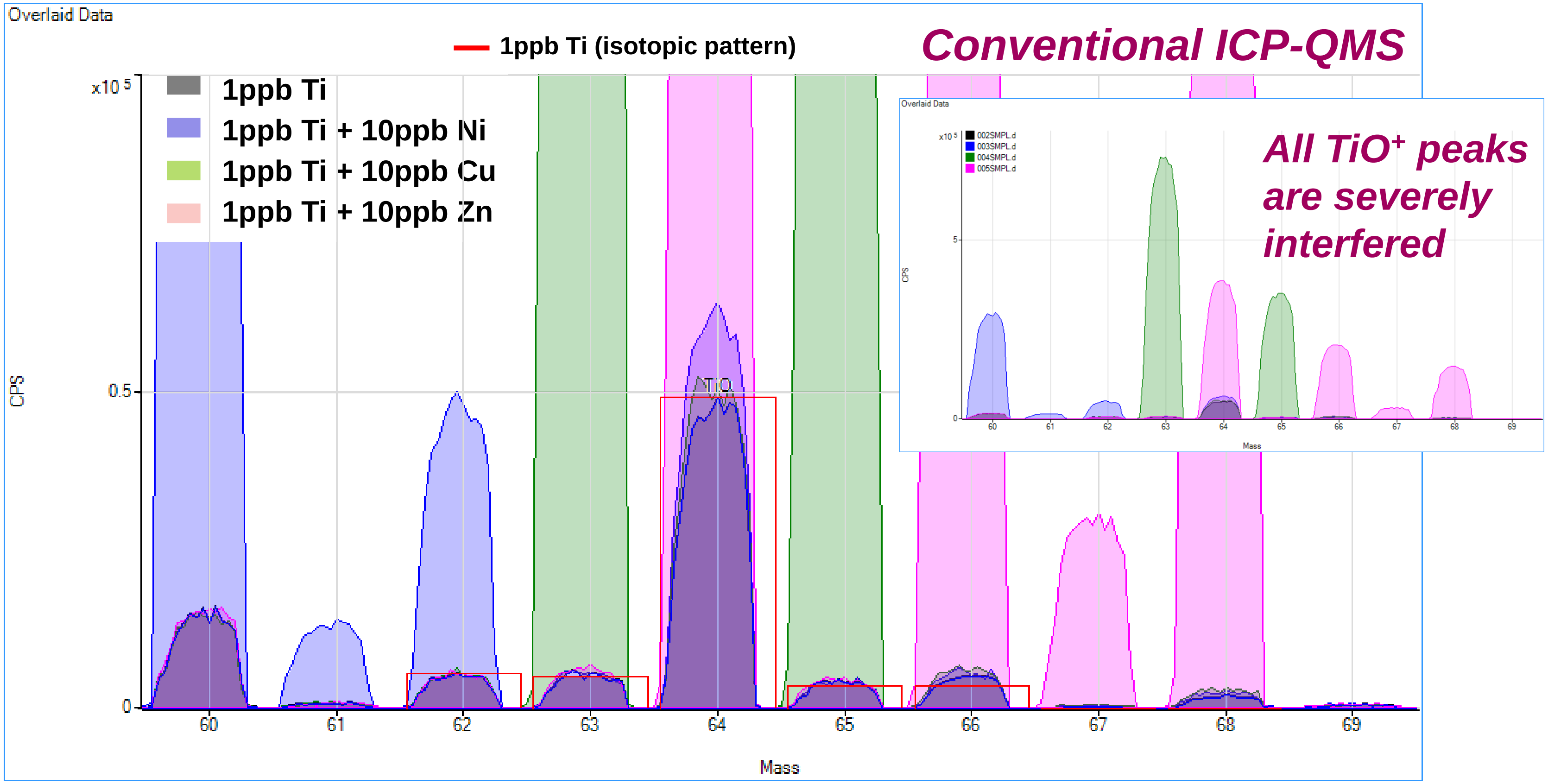
Further analyte (or matrix) ions give further overlaps. Ti (1 ppb) with Ni & Cu (10 ppb) shown below



1 ppb Ti overlaid with 1 ppb Ti + 10 ppb Ni & Cu (Ni^+ & Cu^+ overlap TiO^+)

TiO^+ by ICP-QMS; Other Elements Present

Even in a simple mix of common analytes, all the TiO^+ product ion isotopes are overlapped when conventional reaction cell ICP-QMS is used



1 ppb Ti overlaid with 1 ppb Ti + 10 ppb Ni, Cu, Zn (Ni^+, Cu^+, Zn^+ overlap TiO^+)

TiO^+ with ICP-QQQ (same test samples)

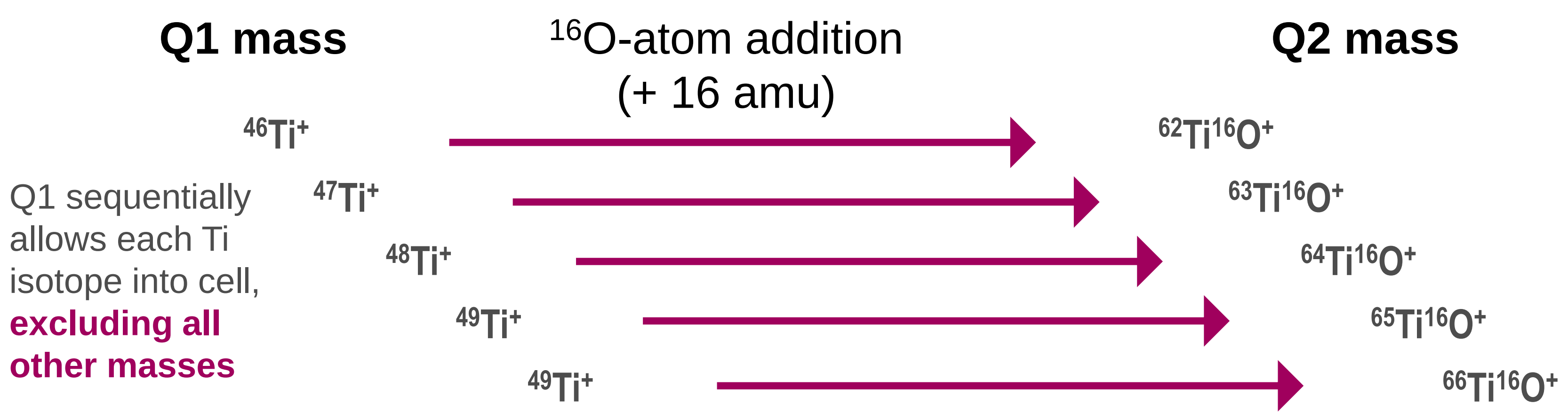
Neutral Gain Scan $Ti^+ \rightarrow Ti^{16}O^+$ with O_2 Cell Gas

Reaction process is still O-atom addition, but **more specific**:

Each Ti^+ precursor isotope enters the cell **alone**; all other Ti isotopes (all other masses) are rejected by Q1

Mass transition is specific (+ ^{16}O), due to fixed Q1 to Q2 mass difference

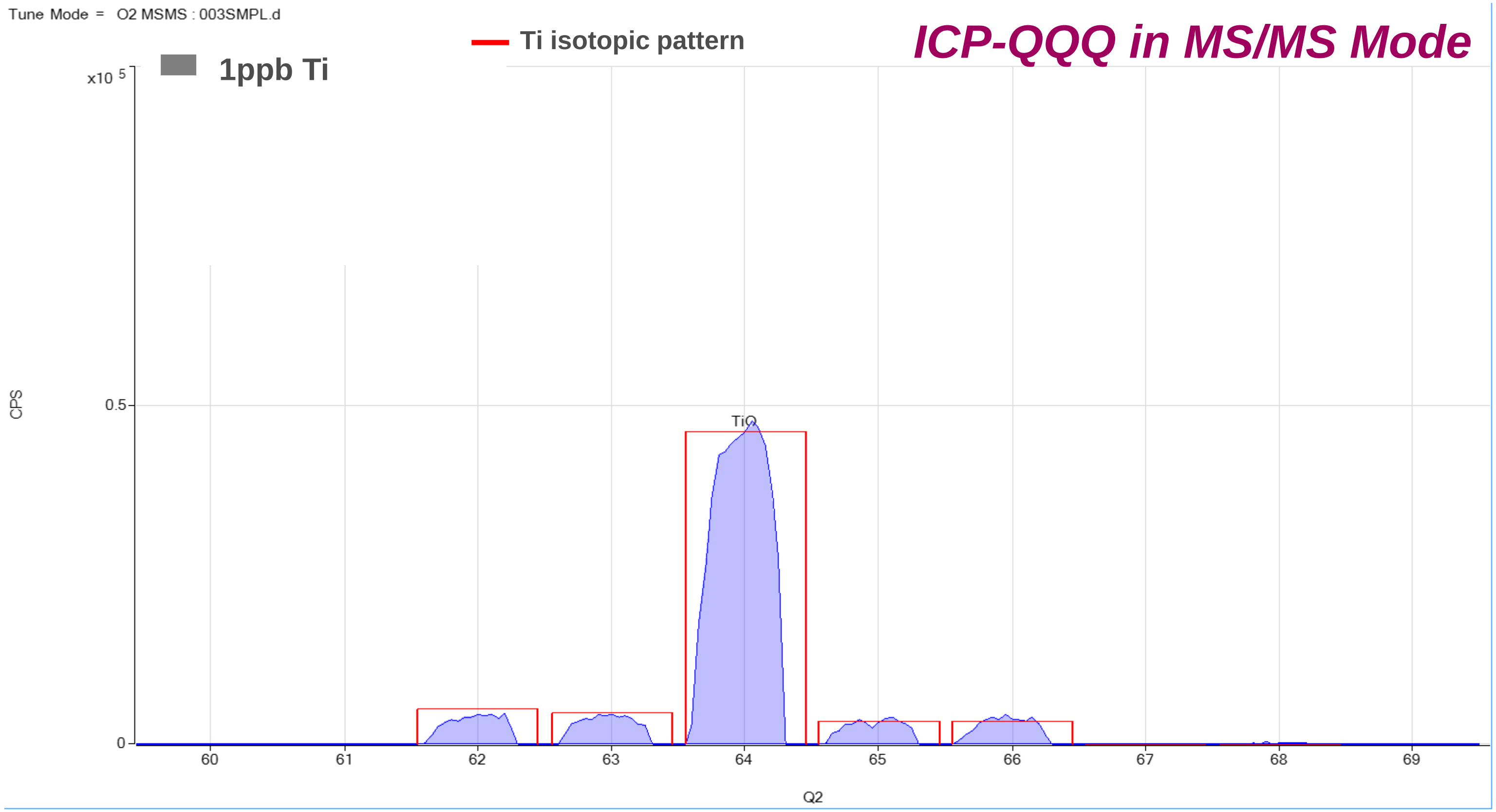
Q2 scans at Q1 mass + 16 to measure $Ti^{16}O^+$ product ions for all Ti isotopes



Each Ti^+ isotope is converted to its $Ti^{16}O^+$ product ion by reaction with O_2 cell gas

TiO^+ Analysis by ICP-QQQ (MS/MS)

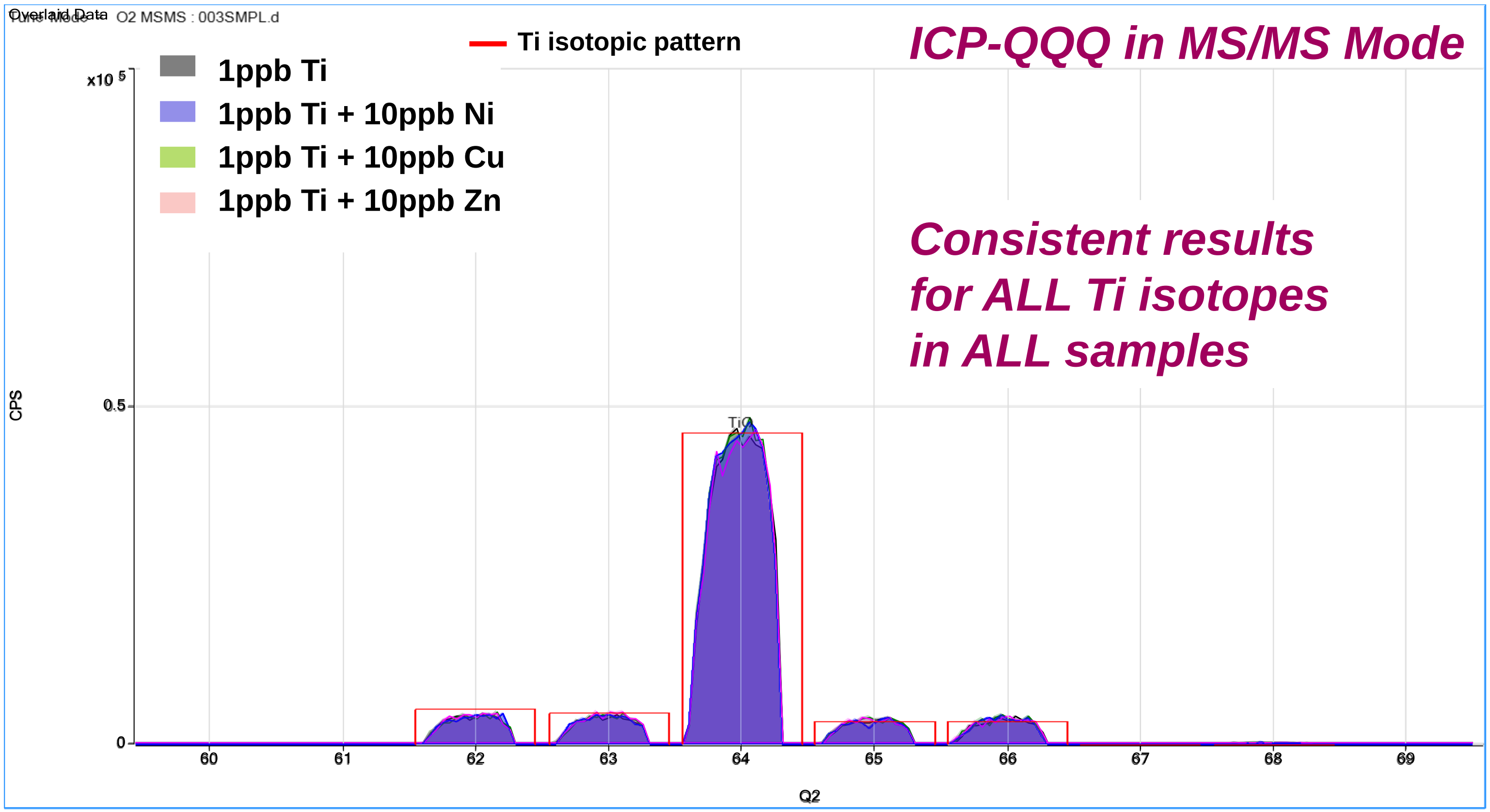
TiO^+ product ions in simple, single-element standard



1 ppb Ti. Ti^+ is converted to TiO^+ with O_2 cell gas – perfect template match

TiO^+ by ICP-QQQ; Other Elements Present

TiO^+ product ions are consistent in all 4 samples; all the Ni, Cu and Zn overlaps are eliminated with the 8900 ICP-QQQ with MS/MS



MS/MS mode - Q1 rejects all pre-existing ions at TiO^+ product ion masses, so there are no overlaps from Ni, Cu, Zn

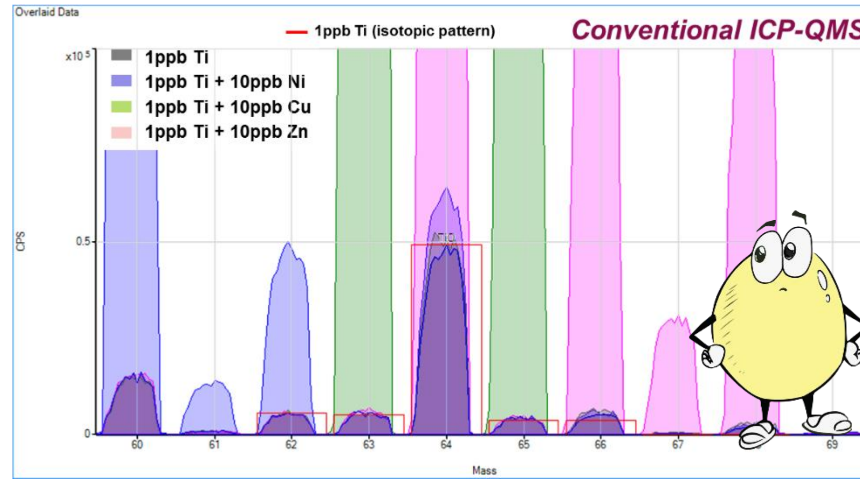
ICP-QQQ; The Benefit of MS/MS is Clear

Comparison of TiO^+ spectrum with ICP-QMS and ICP-QQQ

Top – **"Single-Quad" Bandpass Mode**

All masses between ~ 30 amu and 80 amu enter the cell, so other ions (Ni^+, Cu^+, Zn^+) contribute to signal at TiO^+ isotope masses.

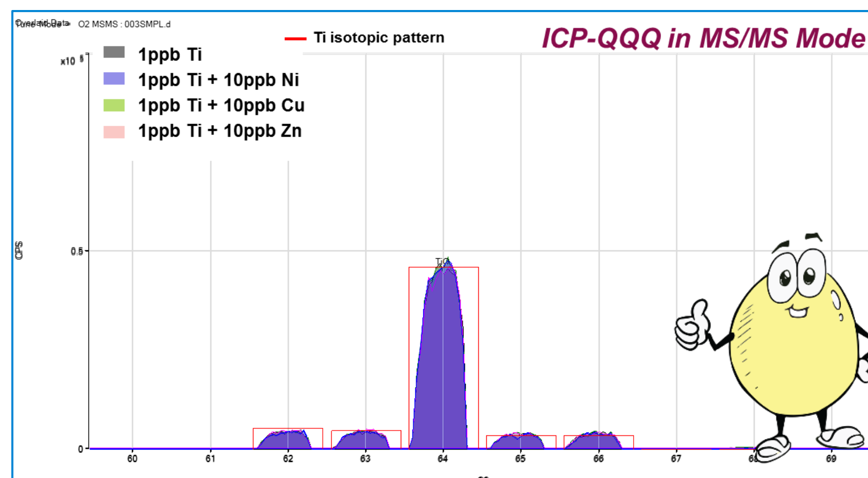
Results are unreliable; ALL Ti isotopes are interfered, and the interferences on the different Ti isotopes are matrix-dependent



Bottom – **Agilent ICP-QQQ in MS/MS Mode**

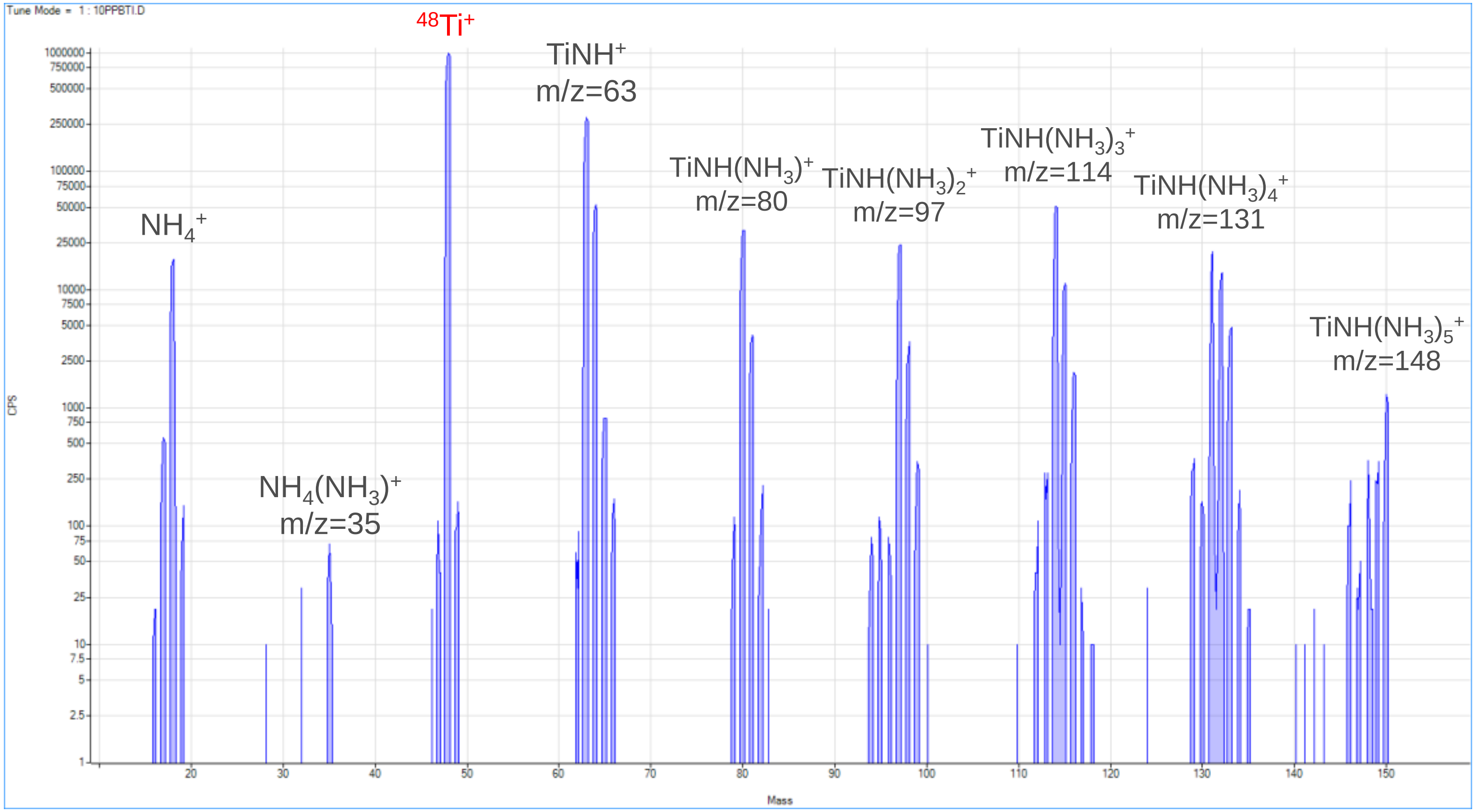
TiO^+ peaks match the theoretical isotope abundance template in all samples.

All Ti isotopes are interference-free; secondary isotopes can be used for confirmation, or for isotopic analysis (isotope ratio or isotope dilution)



Application Example: Ti Analysis with NH_3 Cell Gas

NH_3 mode is often used for Ti analysis, but the product ion spectrum is very complex, due to high reactivity and sequential chemistry with NH_3 cell gas

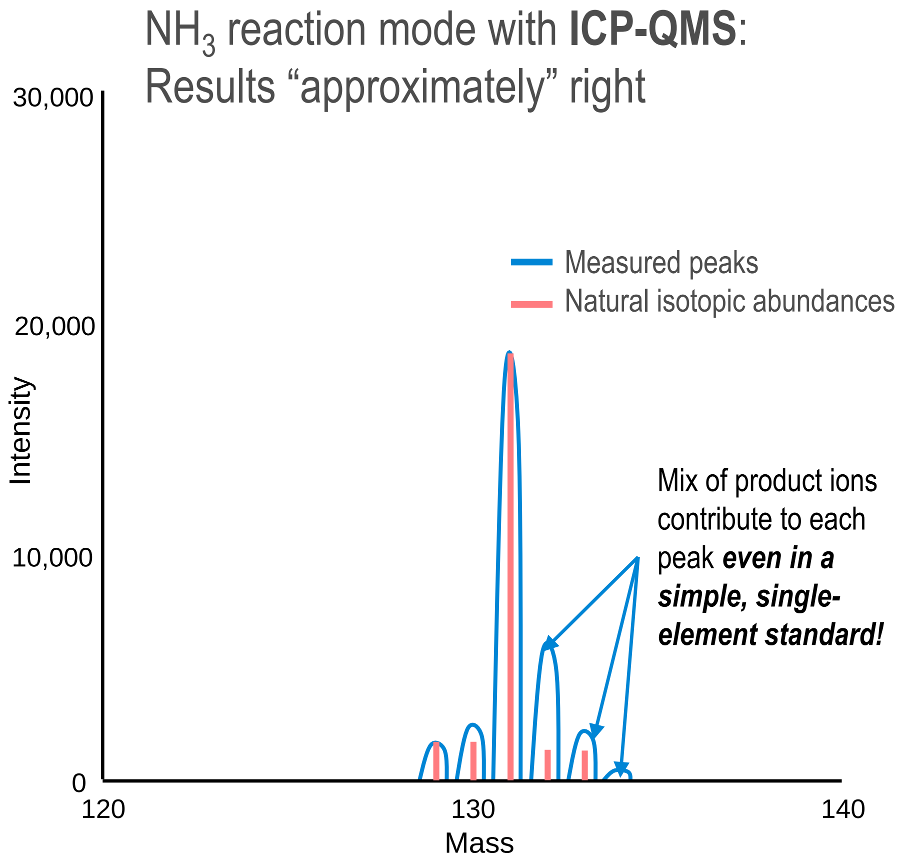


Can MS/MS control complex NH_3 reaction chemistry to ensure reliable results?

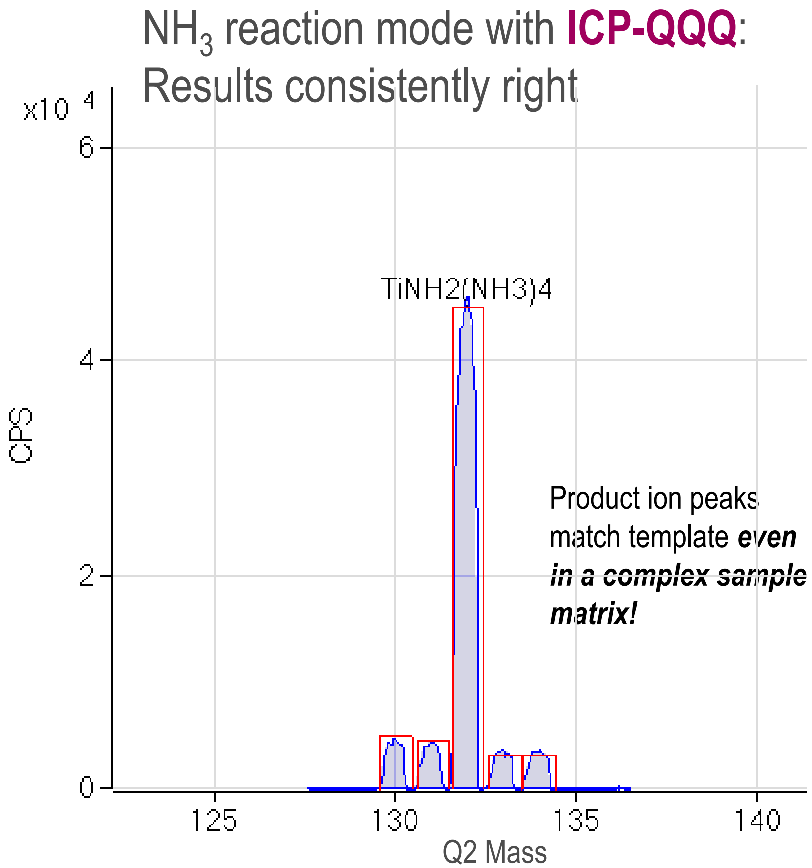
Agilent Technologies

Titanium with NH_3 Cell Gas: ICP-QMS vs ICP-QQQ

Comparison of Titanium Isotopic Abundance Template Fit



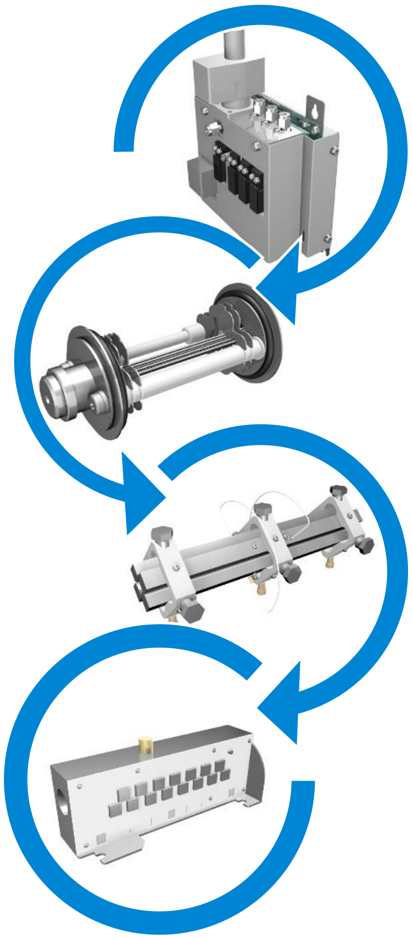
10 ppb Ti standard; NH_3 reaction mode with single MS (ICP-QMS) (based on Thomas, et. al., *Spectroscopy* 28 (11), 28–34 (2013))



10 ppb Ti in complex biological sample matrix; NH_3 reaction mode with MS/MS (ICP-QQQ)

Hardware Developments for Agilent 8900 ICP-QQQ
Engineered for Enhanced Performance

Ensuring Agilent 8900 excels in the most demanding applications



Re-engineered argon gas flow path; specialized materials minimize background contamination for silicon and sulfur (DL < 50 ppt)

ORS^4 collision/reaction cell, with higher frequency and axial acceleration increases sensitivity and controls formation of higher-order cluster ions

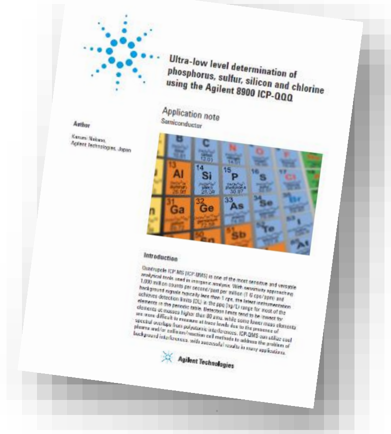
Extended Q2 mass range – up to m/z 275 – allows high-mass product ions to be measured (e.g. U as UO_2^+)

New detector with fast TRA capability (minimum dwell time 0.1 ms) and wide dynamic range (11 orders for 8900 #100/#200; 10 orders for 8900)

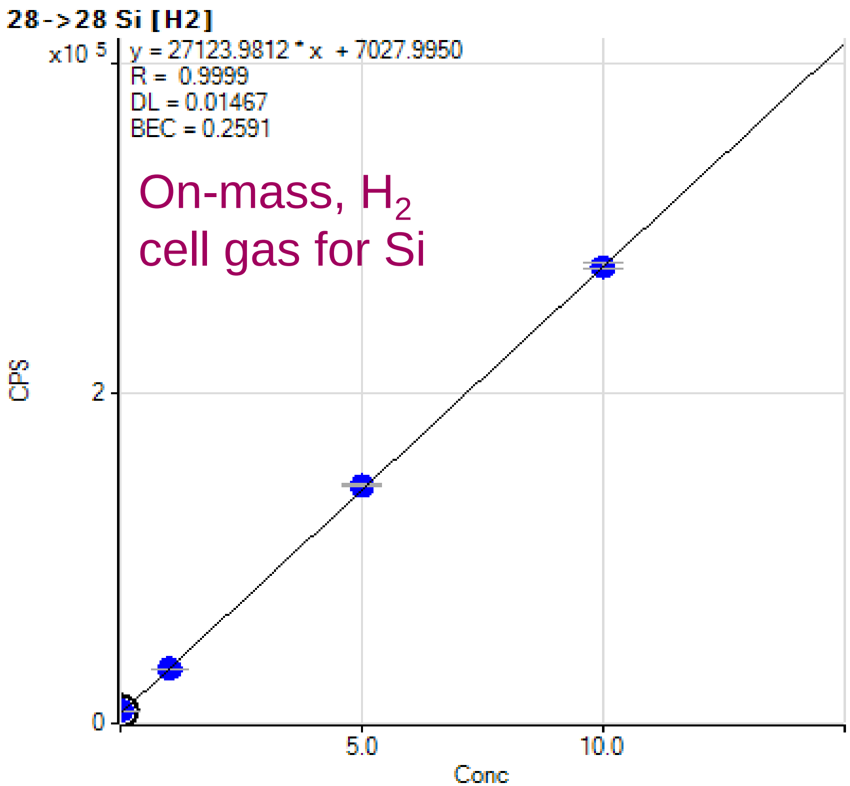
Si and S in UPW on the 8900 ICP-QQQ

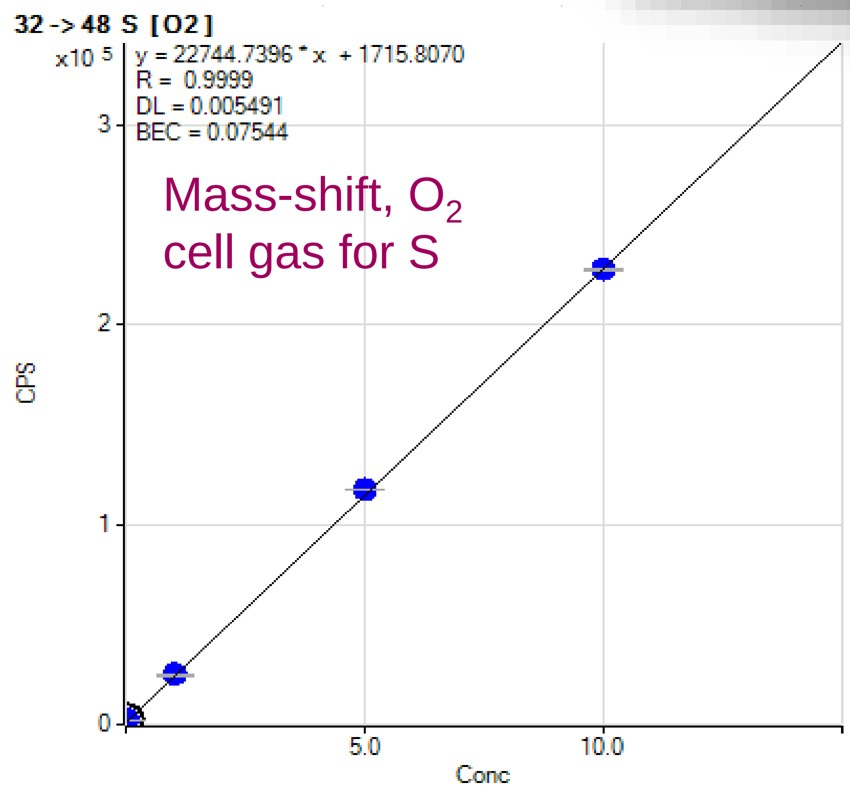
New Ar gas flow system → DL specification < 50 ppt*

5991-6852EN



Calibs show DLs <15 ppt for Si & ~5 ppt for S due to low Si/S Ar gas flow path, high sensitivity, and effective interference removal with MS/MS



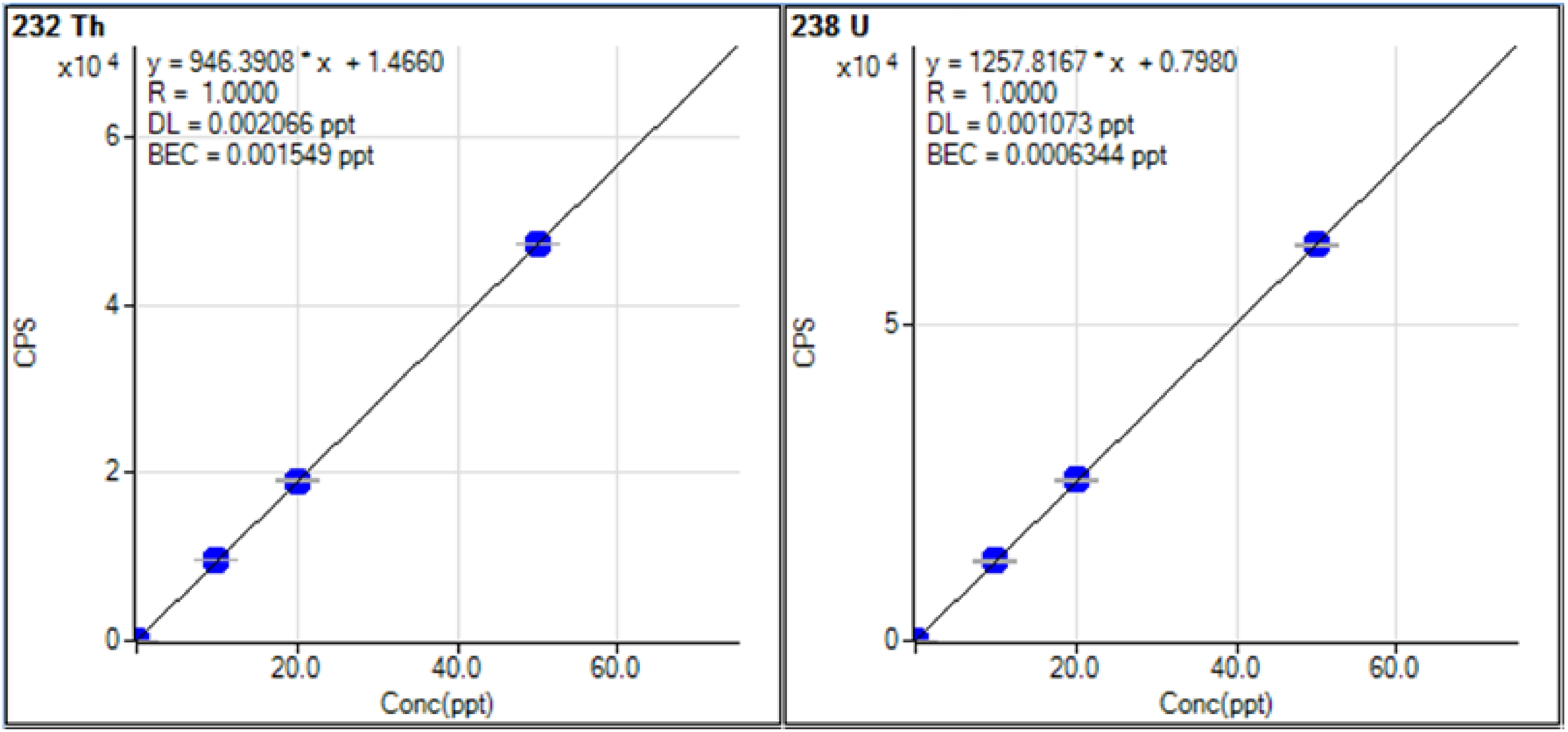


* Performance confirmed by factory test on every 8900 #100 and #200 instrument

New Interface Vacuum, Ion Lens & Axial Acceleration

Higher sensitivity x ~2 for Advanced/Semiconductor Configurations

High sensitivity and ultra-low background (0.2 cps) gives DLs of 1 to 2 ppq – illustrated for Th & U



5991-6553EN


Using ICP-QQQ for UO_2^+ product ion measurement to reduce uranium hydride ion interference and enable trace ^{236}U isotopic analysis

Application note

Environmental, nuclear

Introduction

Agilent Technologies

Extended Mass Range for Q2 – 275 amu

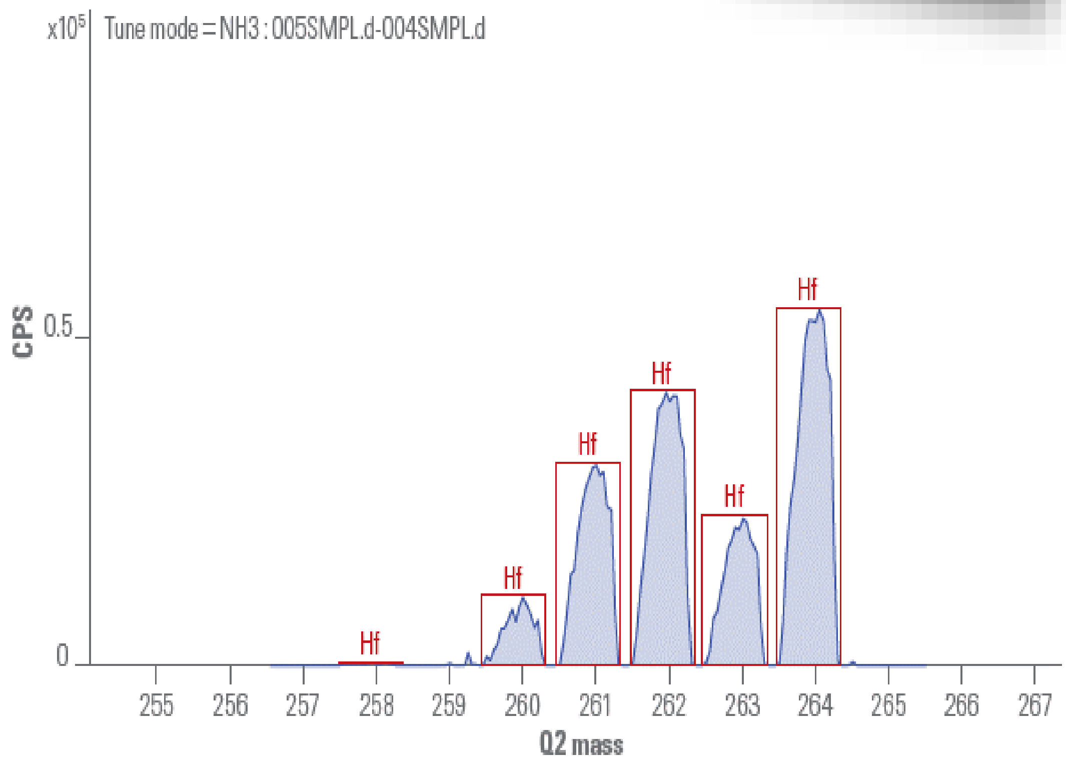
Allows access to high-mass product ions

Some analytes give highest sensitivity for high-order product ions – for example MO_2^+ or NH_3 clusters

Uranium can be measured at high sensitivity as UO_2^+, using O_2 cell gas. $^{238}UO_2^+$ appears at mass 270 – beyond the mass range of the 8800 (max 260)

Many elements can be measured as high-mass ammonia cluster ions

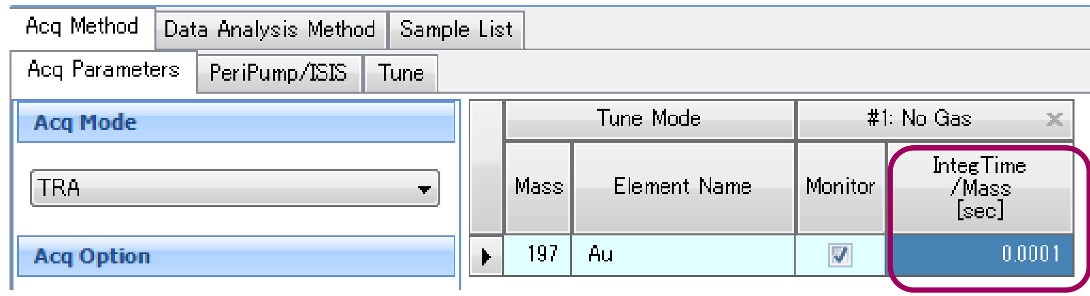
Example of Hf, measured as $Hf(NH_2)(NH_3)_4^+$ at *m/z* 258, 260, 261, 262, 263 and 264 (right)

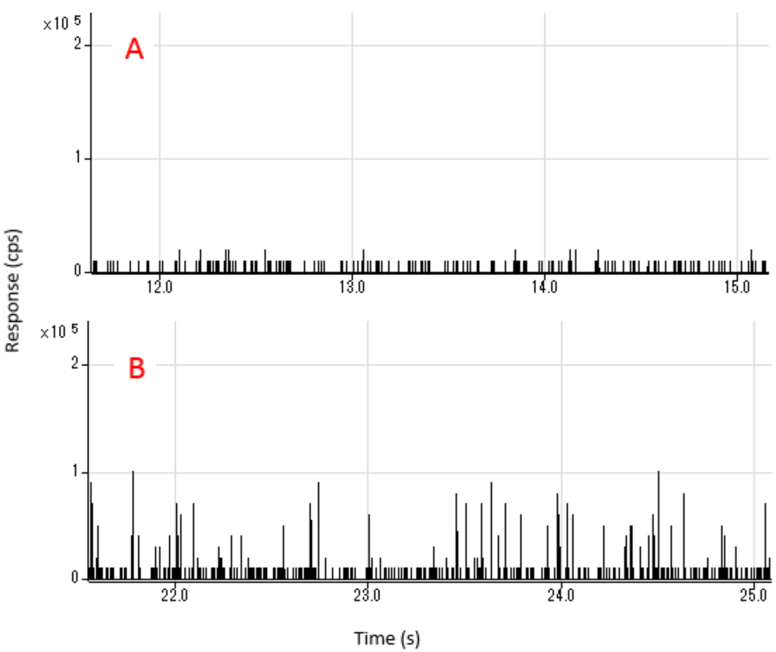


Analysis of 10 nm Gold Nanoparticles
Using fast TRA capability of the Agilent 8900 ICP-QQQ

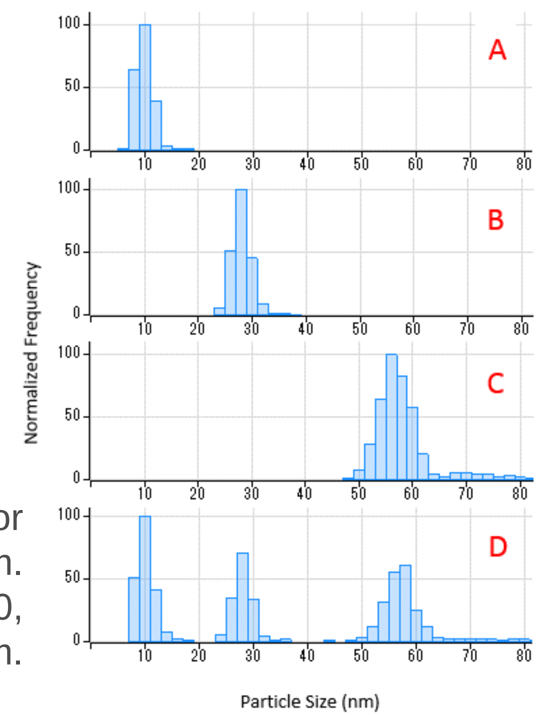
2x reduction in diameter means 8x less signal

8900 can easily detect 10nm Au NPs above background





Au single NP events acquired using fast TRA mode with 0.1 ms dwell time:
A blank (0.01% L-cysteine)
B 10 nm Au NP.

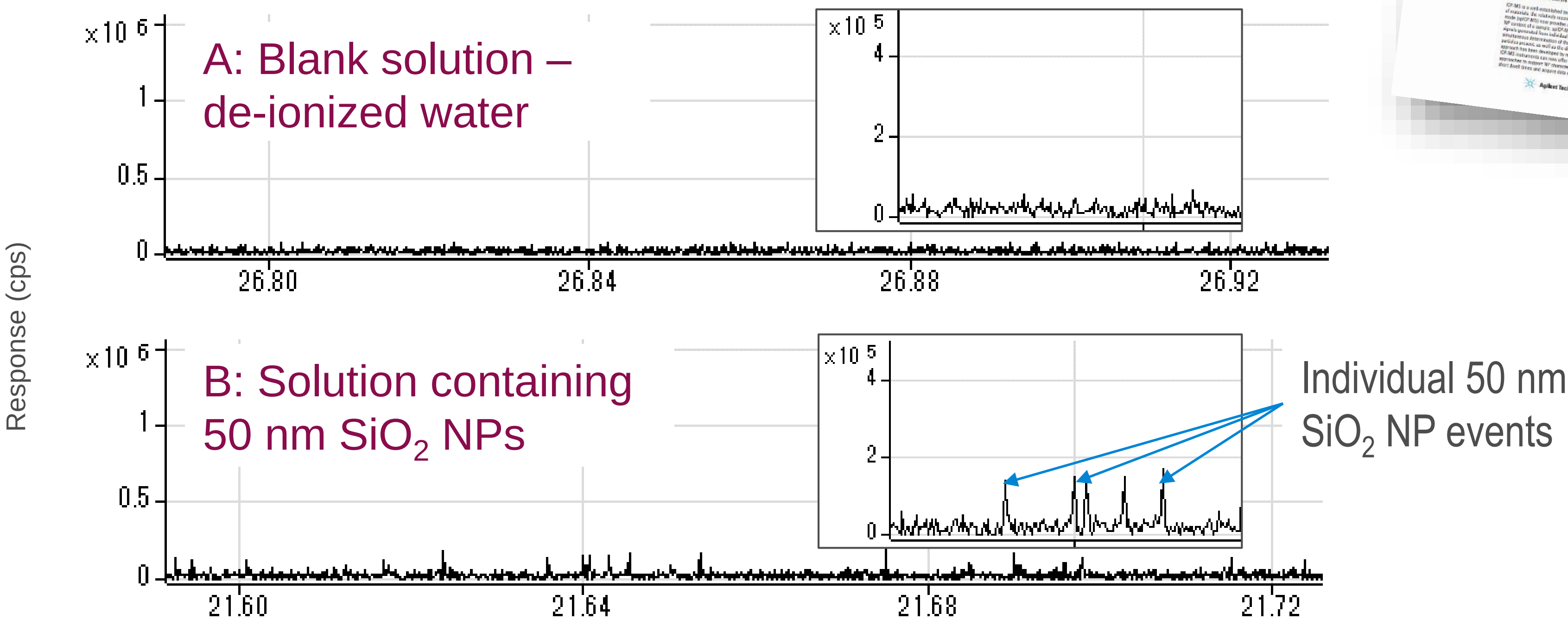


Particle size distribution for Au NPs. A 10 nm. B 30 nm. C 60 nm. D mixture of 10, 30 and 60 nm.

Fast TRA (0.1 ms Dwell) for SiO_2 NPs

Unprecedented detection – not possible with ICP-QMS

5991-6596EN



SiO_2 nanoparticles (NPs) – by far the most important engineered NPs (ENPs) in environment

Low Si background, high sensitivity and effective control of interferences with MS/MS ensure that small (50 nm) SiO_2 NPs can be easily distinguished from background signal

New Agilent 8900 ICP-QQQ
Other Hardware/Performance Improvements

New 4-channel cell gas flow control system

- More cell gases supported: NH_3, CH_4, C_2H_2, C_2H_6, C_3H_4, C_3H_8, CH_3F, CF_4, NO, N_2O, CO, CO_2, N_2
- Max flow of low-flow MFC increased to 1.5 mL/min
- Faster cell gas switching (H_2 → He in 5 sec.)

New ion lens design

- Sensitivity up to 1.2 Gcps/ppm on 8900 (2x higher than Agilent 8800)
  Background < 0.2 cps (*m/z* 9 & 238)

Optional lenses (for #100 & #200)

- Reduced Na & K background with hot plasma
- Applicable to high-matrix, high-purity semicon samples

Agilent ICP-MS and ICP-QQQ

AGILENT QUADRUPOLE ICP-MS

Market-leading matrix tolerance, detection limits, dynamic range and sample throughput

Optimized octopole-based collision/ reaction cell gives **unrivalled interference removal in helium (He) mode**

AGILENT TRIPLE QUADRUPOLE ICP-MS

Matrix tolerance, dynamic range, He mode performance, productivity comparable to Agilent ICP-QMS

Tandem MS configuration allows MS/MS mode for **controlled and consistent interference removal with reactive cell gases**

Thank You!

Your questions…