December 13, 2024

Who am I ?

Toshiyuki Azuma

AMO Physics Laboratory, RIKEN

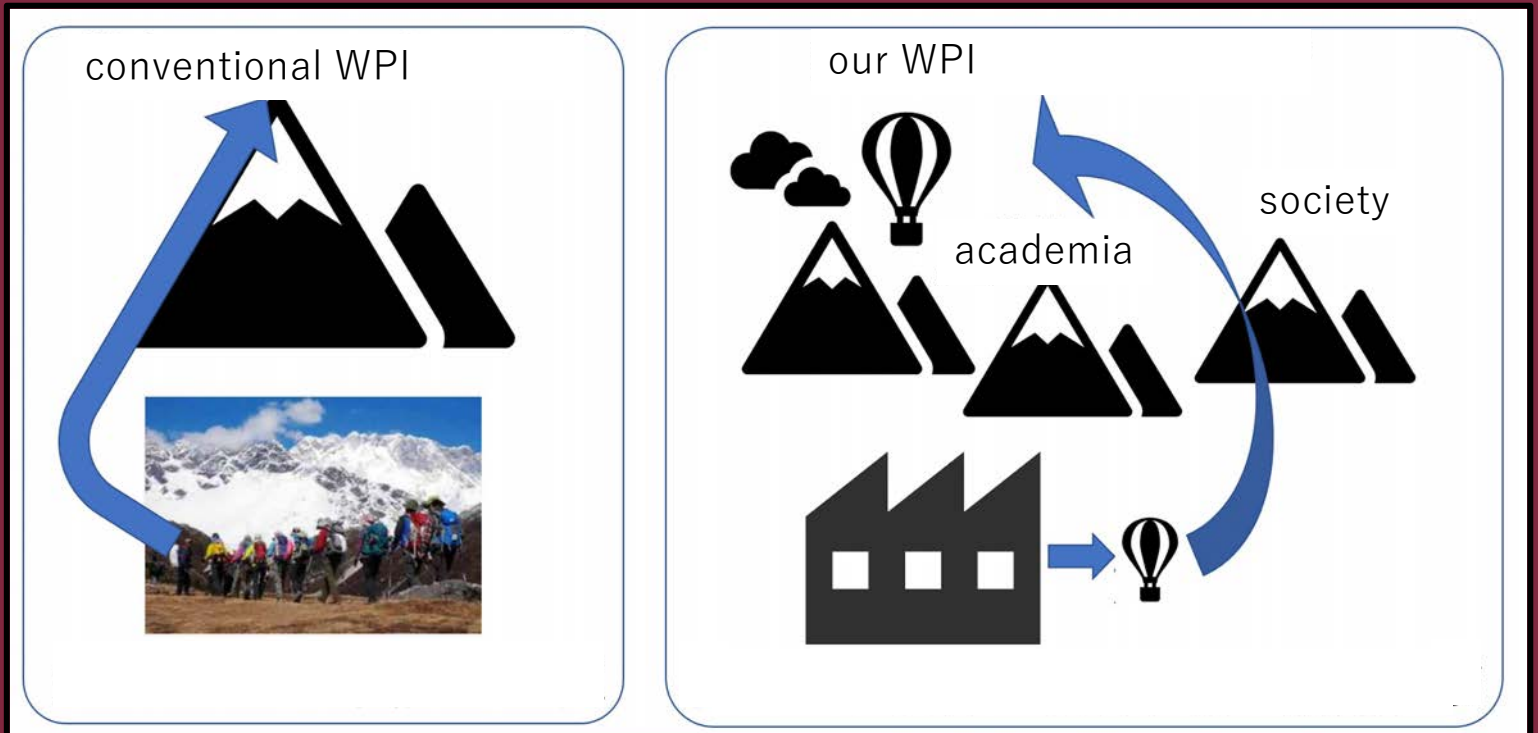
April 10, 2025

What I aim for

Toshiyuki Azuma

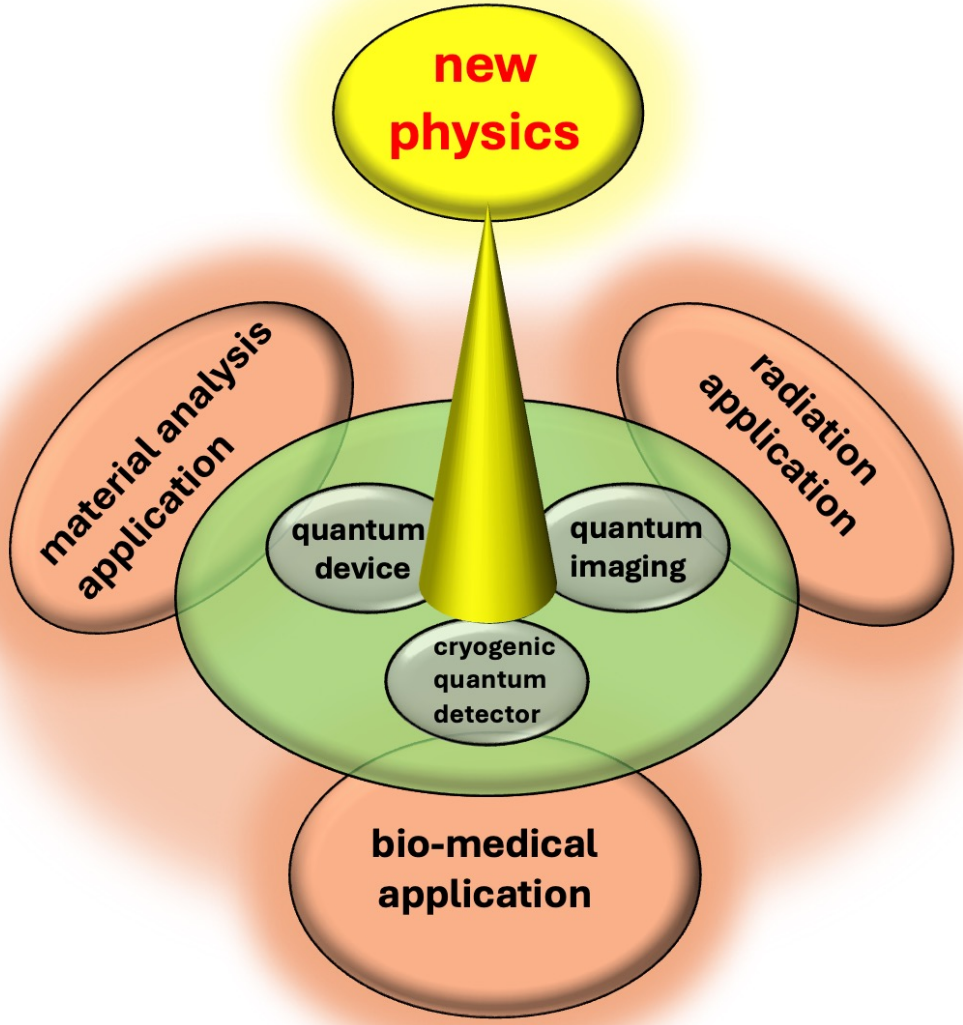
QUP KEK
PRI Pioneering Reseach Institute RIKEN

Original Concept of QUP



As a pioneering hub, it will lead the creation and development of value in higher-level interdisciplinary fields, encompassing not only academic contributions but also the return of value to society.

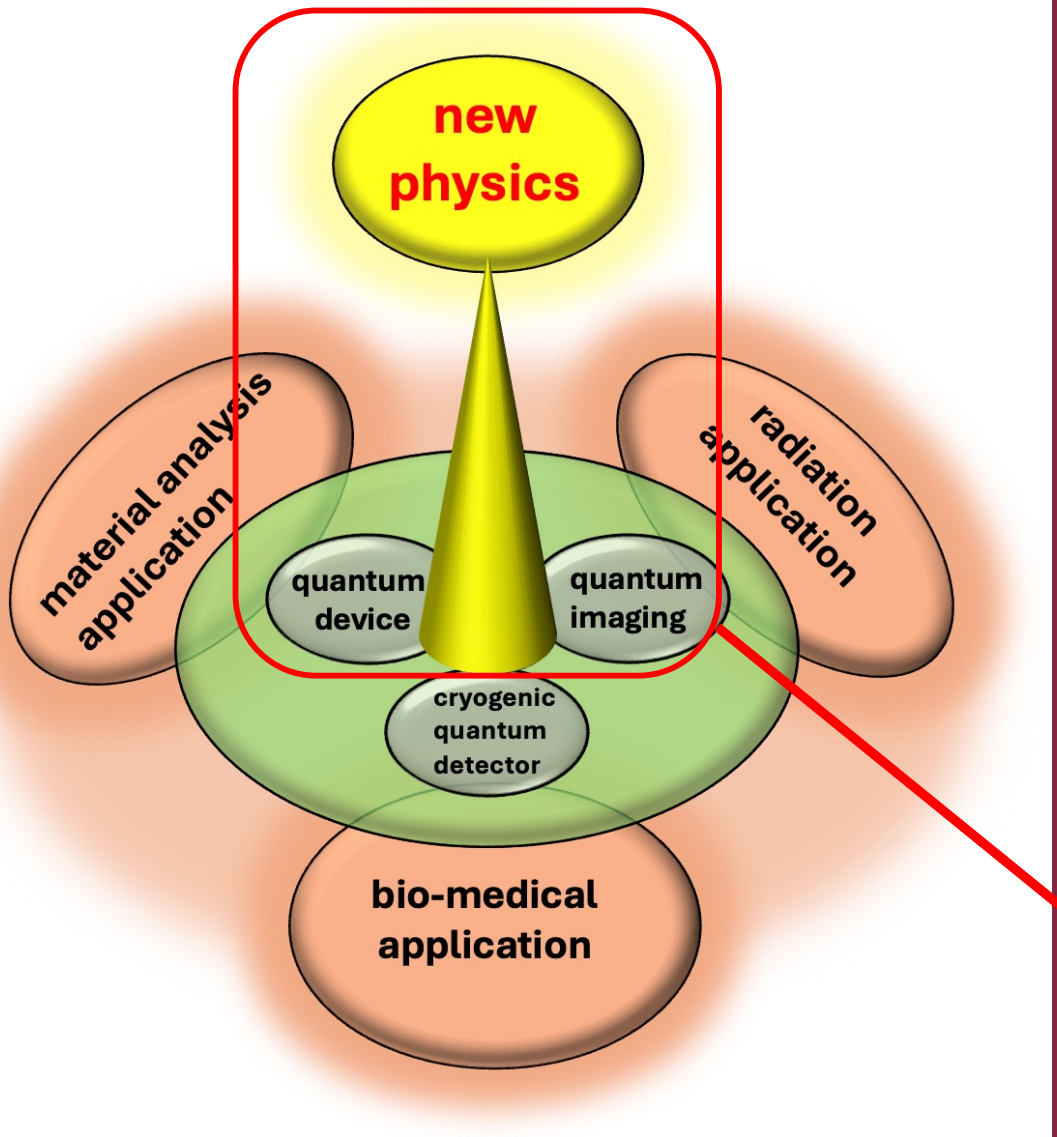
New Concept of QUP



本拠点が検出器や計測手法で切り拓く新たな科学の「頂上」と「地平」

The new QUP pioneers new scientific 'summits' and 'horizons' through detectors and measurement techniques.

New Concept of QUP



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The new QUP pioneers new scientific 'summits' and 'horizons' through detectors and measurement techniques.

Golden pillar

Many summits

Hanagaki-san's talk at the first day

QUP Overview

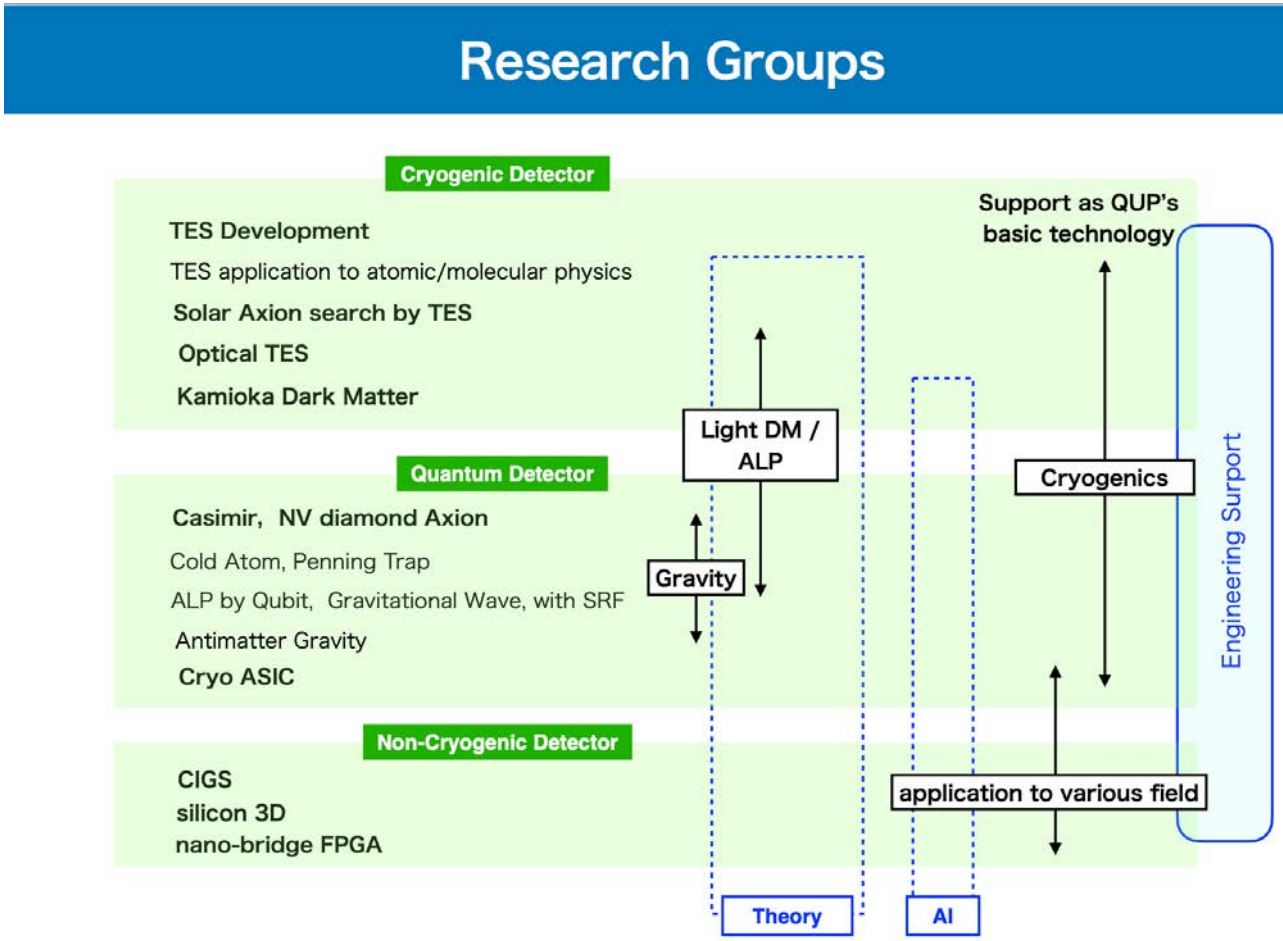
New Eyes to Humanity

- Goals
  - QUP/KEK becomes International hub for measurement system development
  - Reveal mysteries in Universe, Particle, and Life
  - Create interdisciplinary academic area by fusion of wide range of research

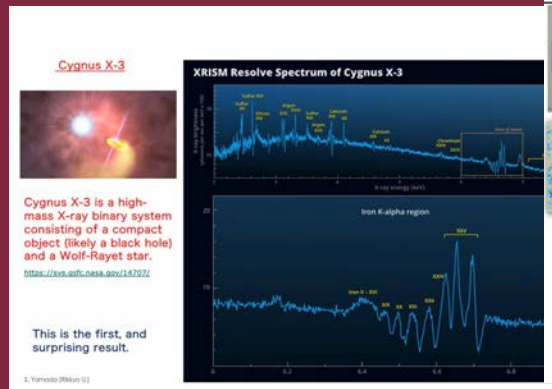
- Strategy
  - Now focus on three categories of detector technology
    - Cryogenics
    - Quantum
    - Non-cryogenics (semi-conductor)
  - Theory and AI groups for cross-connections of different detector groups
  - Develop cutting edge detector technologies, and apply them to various science missions
    → this leads to fusions of different fields
  - Strong collaboration with industry such as Toyota Central R&D Lab

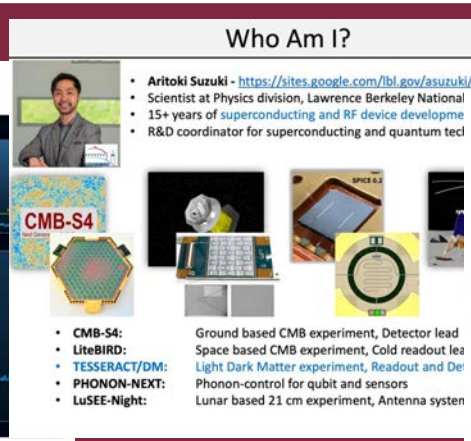
2

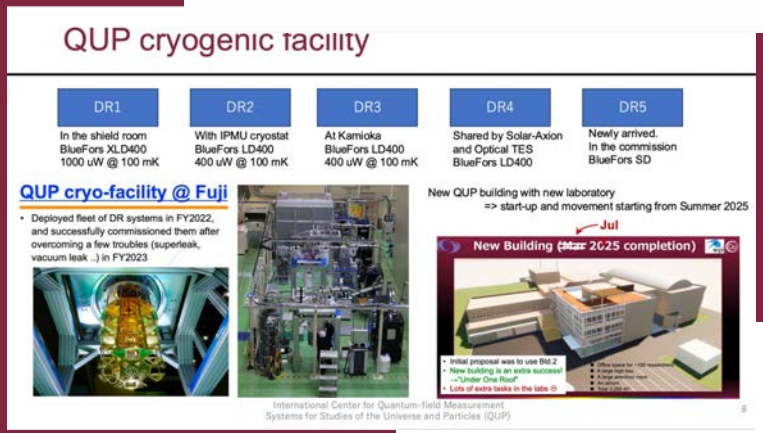
Hanagaki-san's talk at the first day

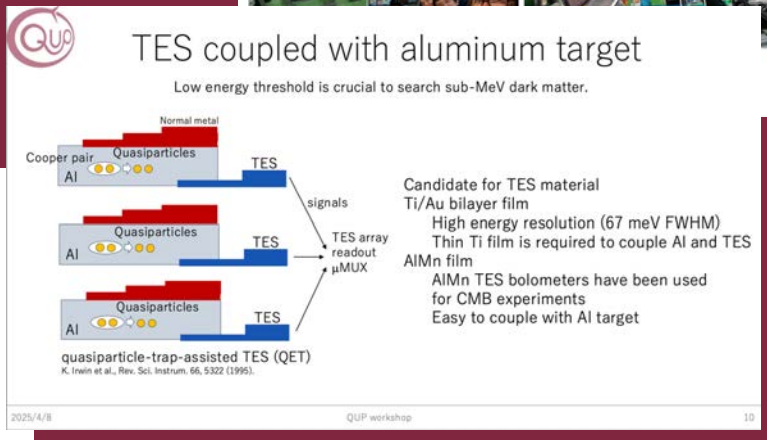


A series of presentations over three days



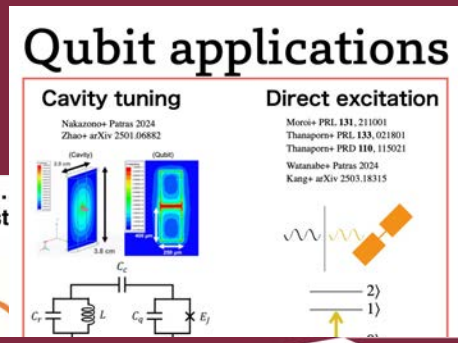


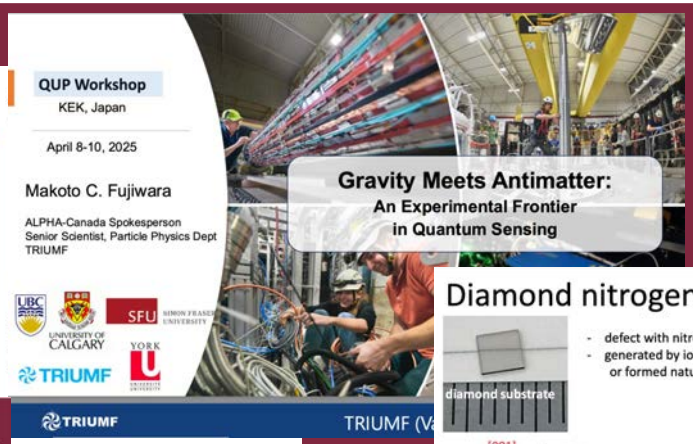


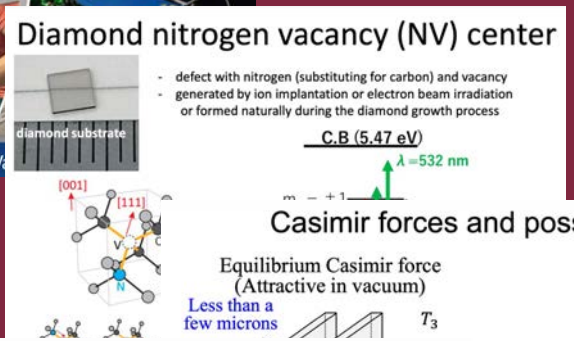


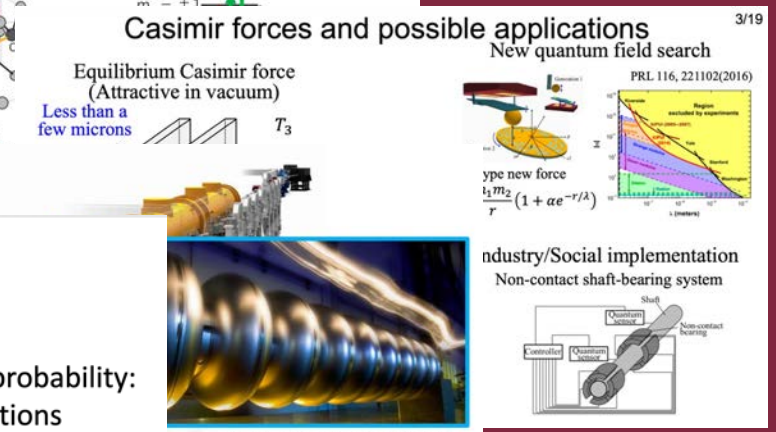
Light dark matter search with quantum technology

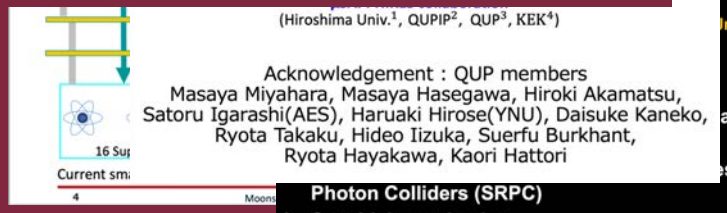
A series of presentations over three days

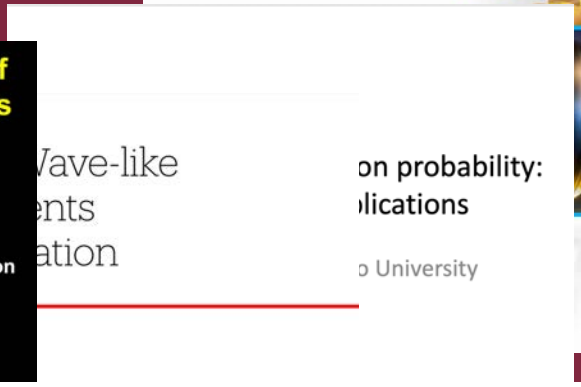












We enjoyed a bunch of presentations in 3 days.

Two good news:

1. Ongoing projects are steadily going forward.

We enjoyed a bunch of presentations in 3 days.

Two good news:

1. Ongoing projects are steadily going forward.
2. The new breeze starts blowing in QUP.

New breeze

Candidates of "New Quantum Eyes"

- Cold Atom / Penning Trap

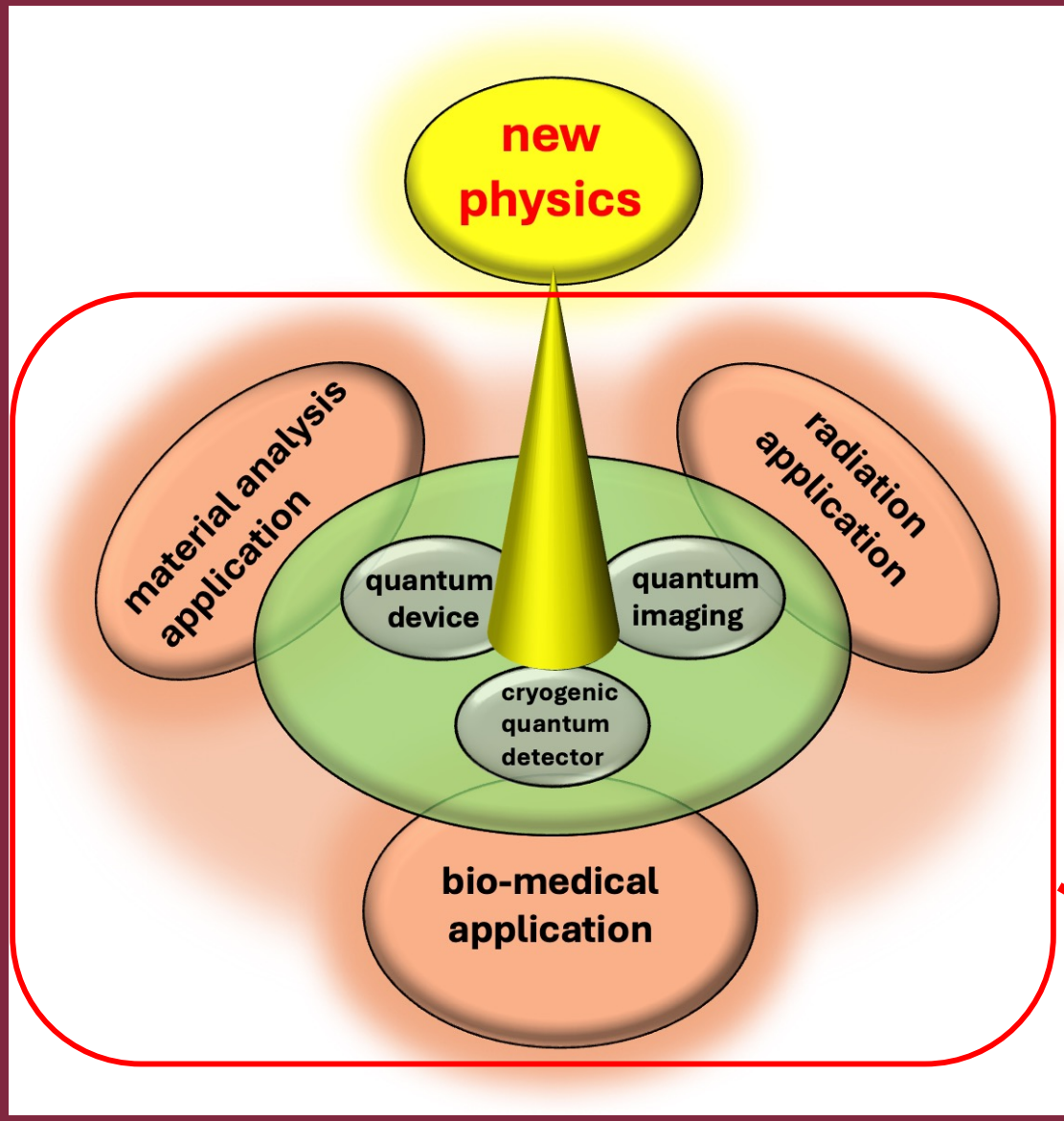
  ← This will be started up near future

- Laser cooling technology
  - Gravity, Clock, Fundamental constants
- Atomic (Nuclear) clock
- High Fines Interferometer for MZ application

- Superconducting cavity as gravitational wave sensor
- Superconducting cavity as memory in quantum computing

  ← A new PI is being hired for these projects

New Concept of QUP



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The new QUP pioneers new scientific 'summits' and 'horizons' through detectors and measurement techniques.

Horizon

Many application

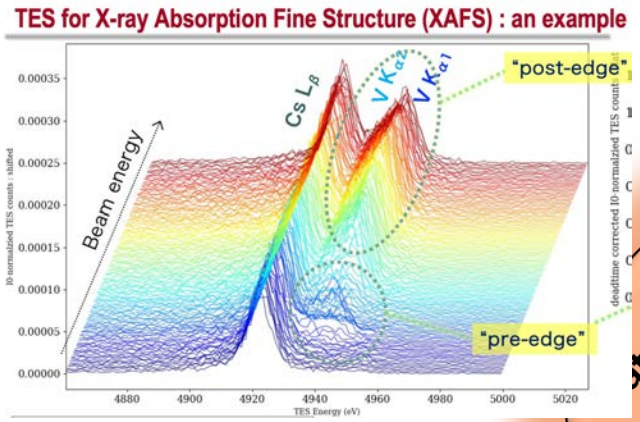
New Concept of QUP

Two news:

1. New breeze will be introduced by a new coordinator.
2. Another symposium will be held soon.

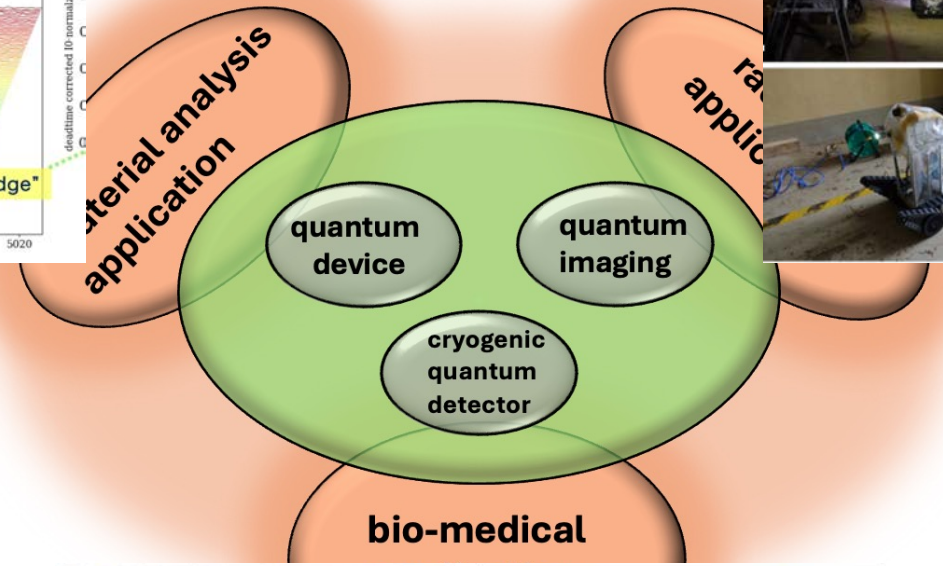
Horizon

New Concept of QUP

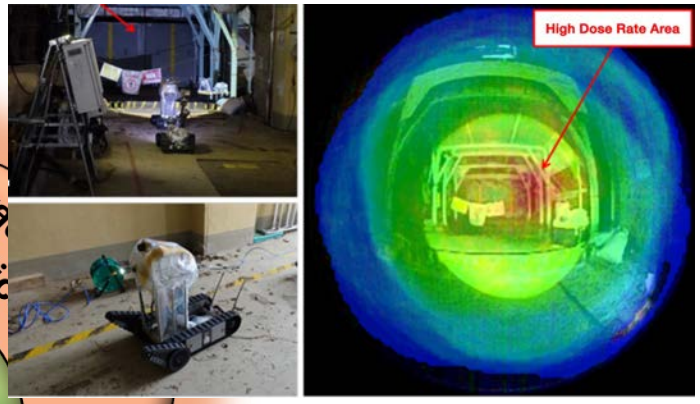


TES detector

Material Analysis application



JAEA

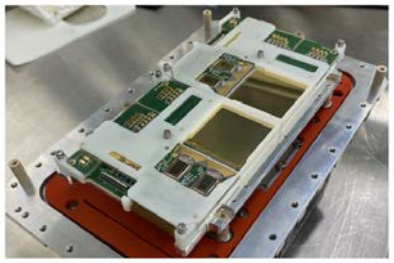


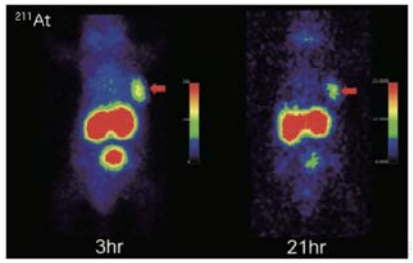
Compton camera

Radiation application

Bio-Medica application

Imaging detector





And ….

What happened to me in 3 months

experiments

What happened to me in 3 months

Installation of two new TES covering 150 keV

collaboration with NIST

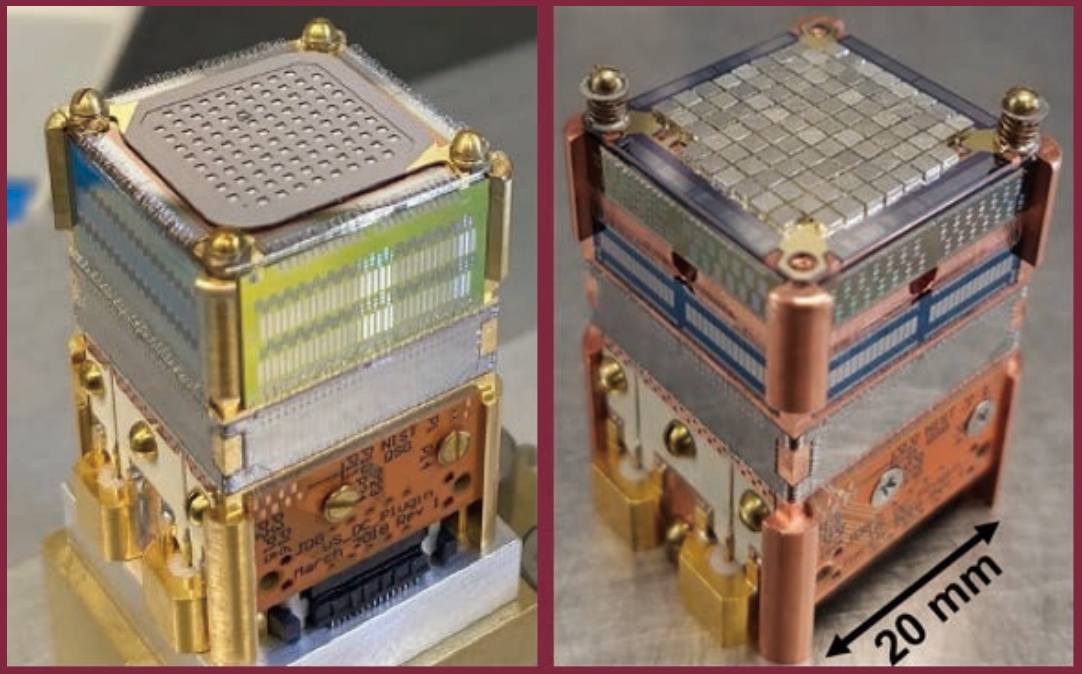


Fig. 1 Photos of 50 keV and 130 keV TES detectors.

	50 keV TES	130 keV TES
Saturation Energy	70 keV	150 keV
Absorber material	Au/Bi	Sn
Absorber thickness	1.85µm / 20µm	120 - 250 µm
Absorber area	0.73x0.73 mm	1.3x1.3 mm
Pixel number	96	96
Total collection area	50 mm^2	160 mm^2
Absorption at 45 keV	22 %	92 %
Absorption at 100 keV	-	26%

Table 1 Specification of two new TES detectors.

What happened to me in 3 months

Just yesterday, transferred from RIKEN to J-PARC (muon beam line)

What happened to me in 3 months

Installation of two new TES covering 150 keV

From AMO Physics to Nuclear Physics

Precise measurement
of nuclear radius of heavy element

All previous figures in the table will be updated.

Precise measurement of charge radius of nuclei

Electron scattering and muonic atom X-ray spectroscopy have comparable experimental precision (~0.01 fm).
A key feature is their ability to measure the absolute value of the radius.
Their model dependencies differ, making them complementary.

	Electron scattering	Isotope shift	Conventional μ X ray spectroscopy
precision	○	◎	○
Absolute value	○	**X**	○
Charge density distribution	○	**X**	#

Preliminary results

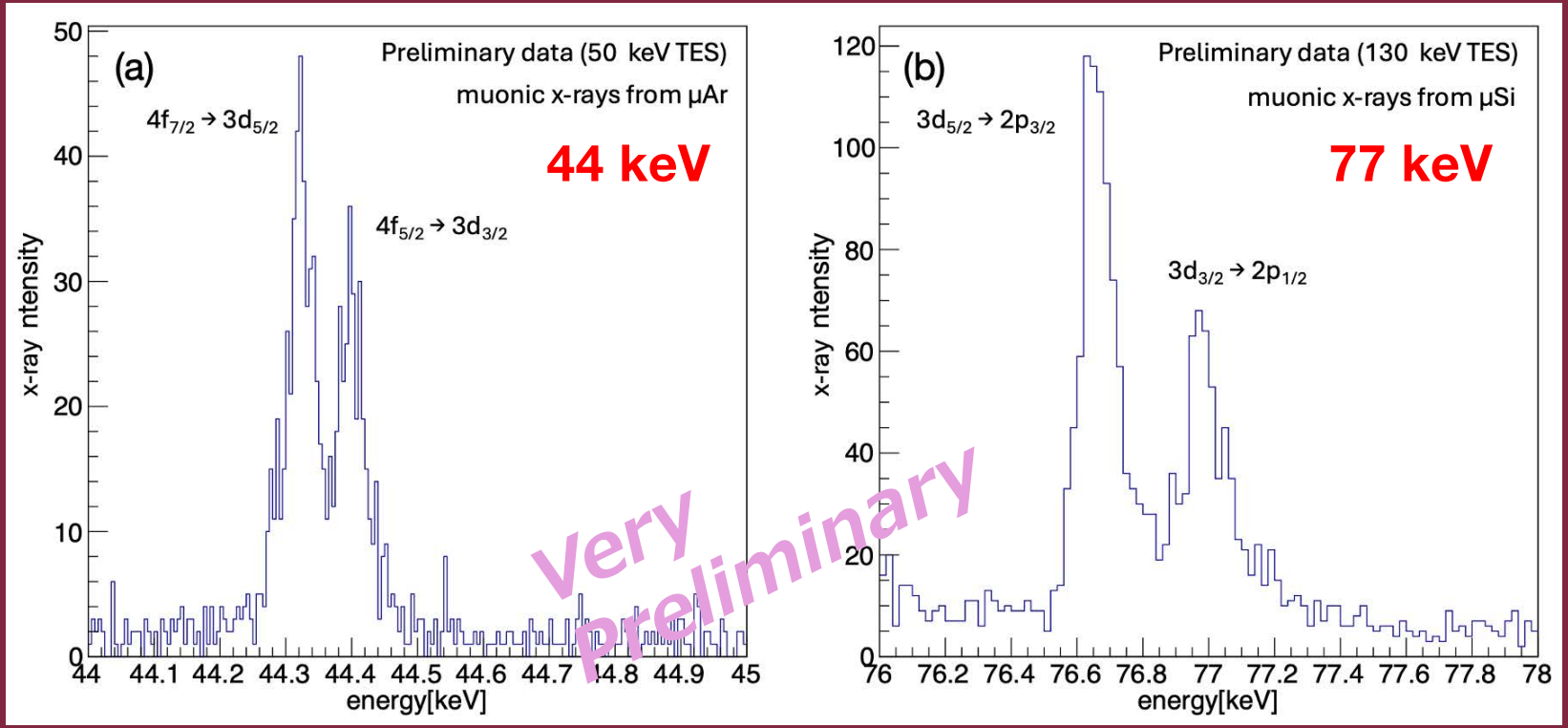


Fig. 2 obtained spectra (preliminary):
(a) 44 keV muonic x-rays from μAr ($4f_{7/2}$-$3d_{5/2}$ and $4f_{5/2}$-$3d_{3/2}$ transitions)
(b) 76 keV muonic x-rays from μ^{28}Si ($3d_{5/2}$-$2p_{3/2}$ and $3d_{3/2}$-$3p_{1/2}$ transitions)

What happened to me in 3 months

theory

What happened to me in 3 months

We submitted one theory paper arXiv:2412.18747v1 [physics.atom-ph]

Orbital Collapse in Exotic Atoms and Its Effect on Dynamics

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[2] *HUN-REN Institute for Nuclear Research (ATOMKI), 4026 Debrecen, Hungary*
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[5] *Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan*
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[7] *Atomic, Molecular and Optical Physics Laboratory, RIKEN, Wako, Saitama 351-0198, Japan*

エキゾチック原子におけるOrbital Collapse

日本物理学会誌 2025年4月号　Butsuri Vol. 80, No. 4 (monthly published by JPS)

最近の研究から

超伝導マイクロカロリメータによるミュオン原子の高分解能X線分光

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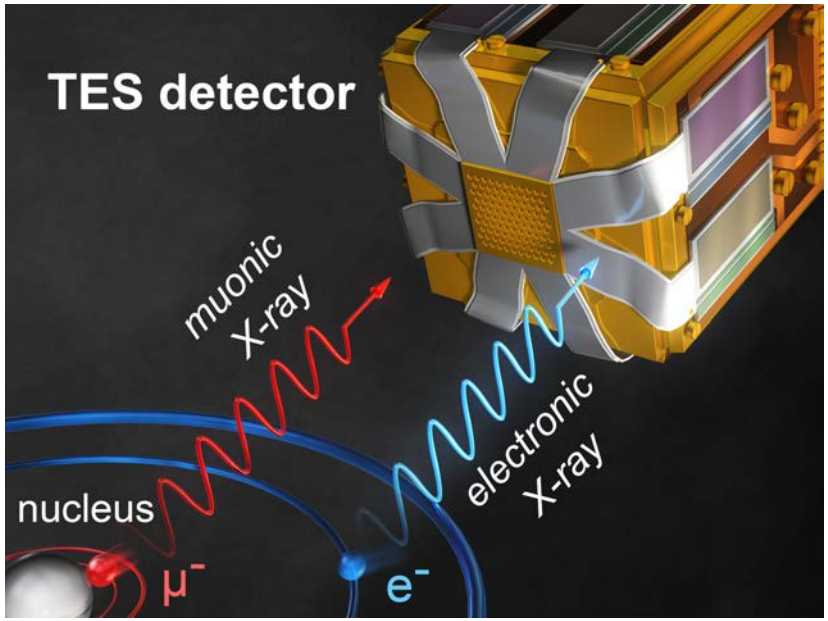
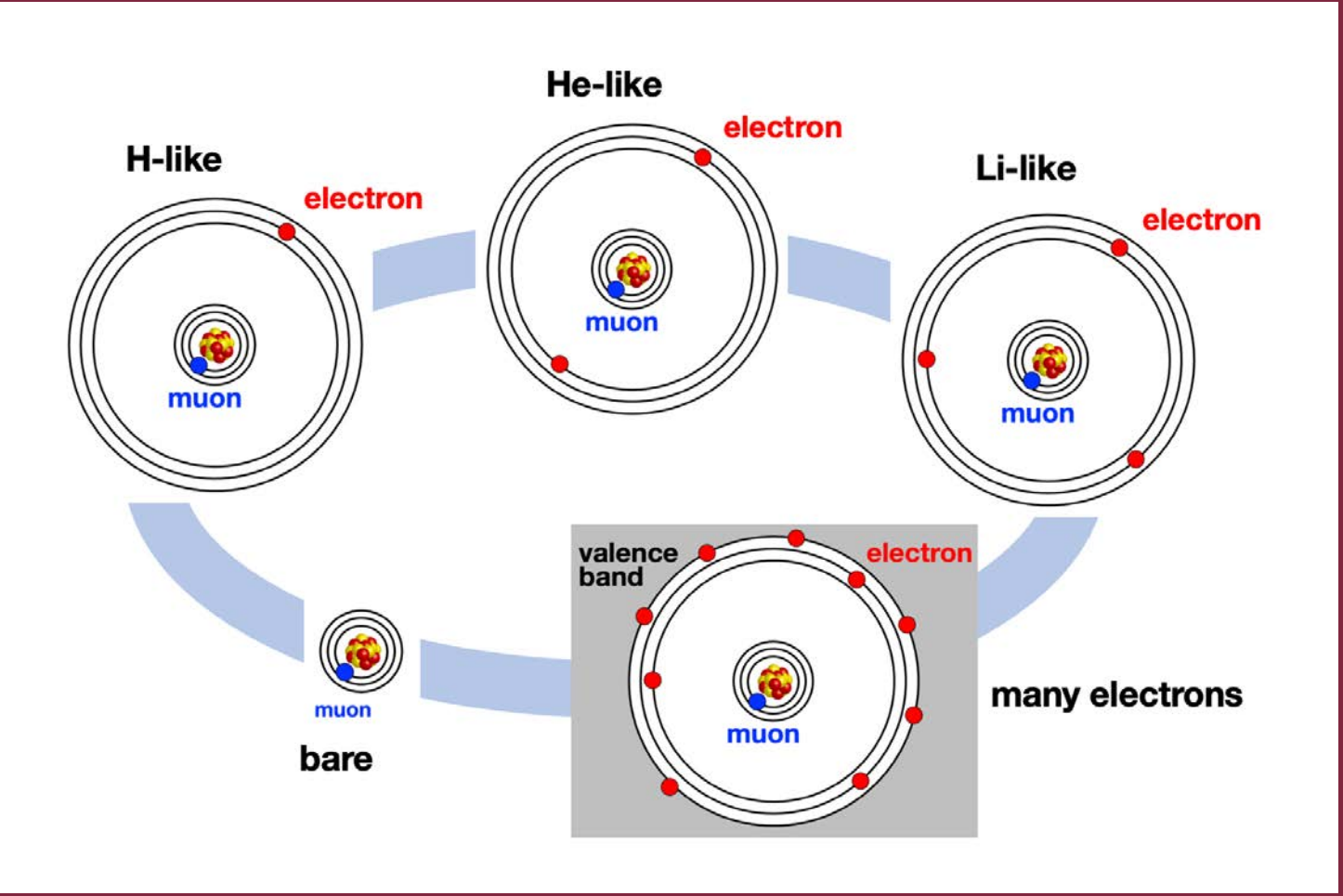
岡田信二 〈中部大学理工学部　sokada@fsc.chubu.ac.jp〉
東　俊行 〈理化学研究所　toshiyuki-azuma@riken.jp〉

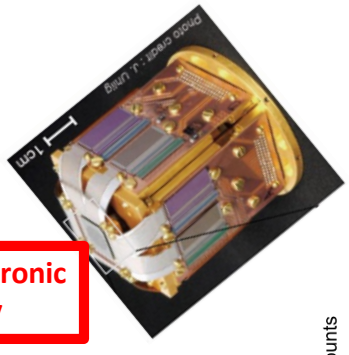


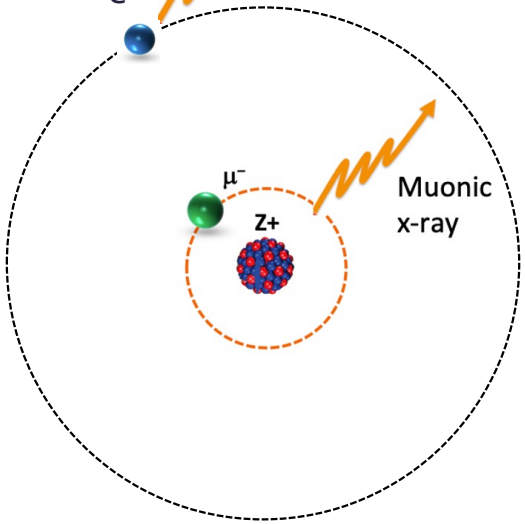
Muonic Atom

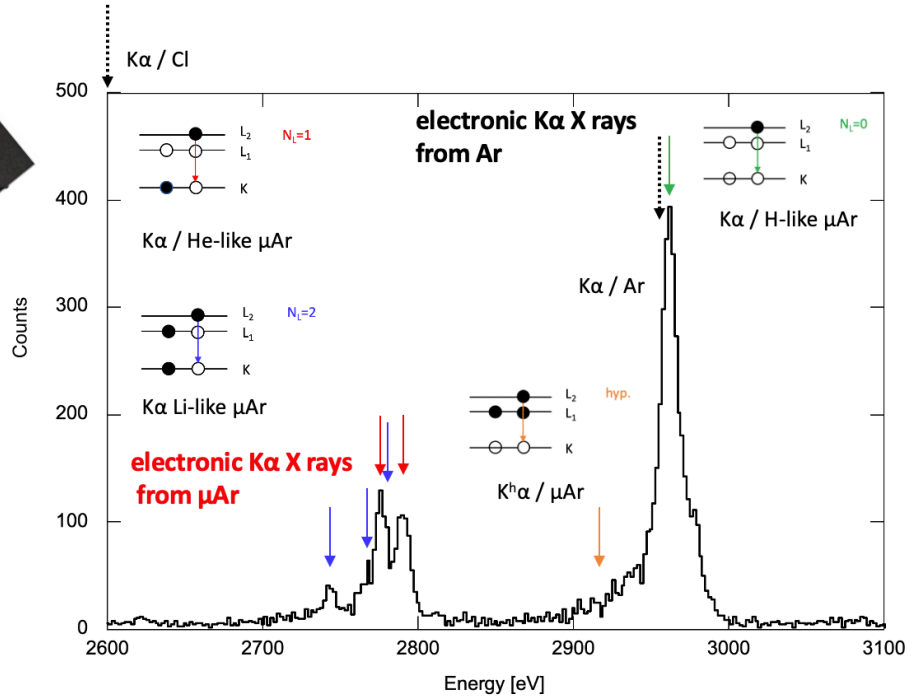

He-like
electron
H-like
electron
Li-like
electron
muon
muon
muon
valence
band
electron
muon
many electrons
muon
bare

Muonic Atom

H-, He-, Li- like muonic Ar
(e, μ, Ar^{18+}) ~ (e, Cl^{17+})

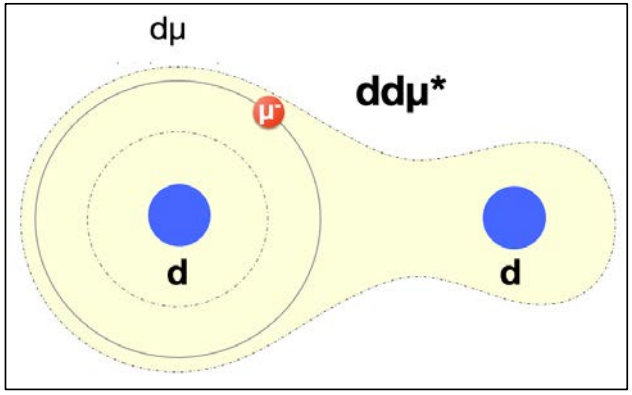




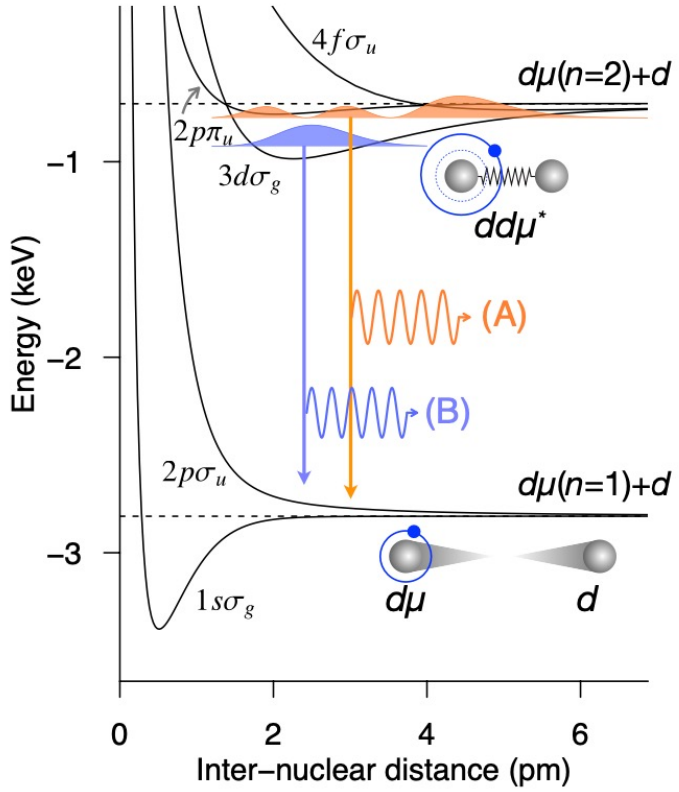


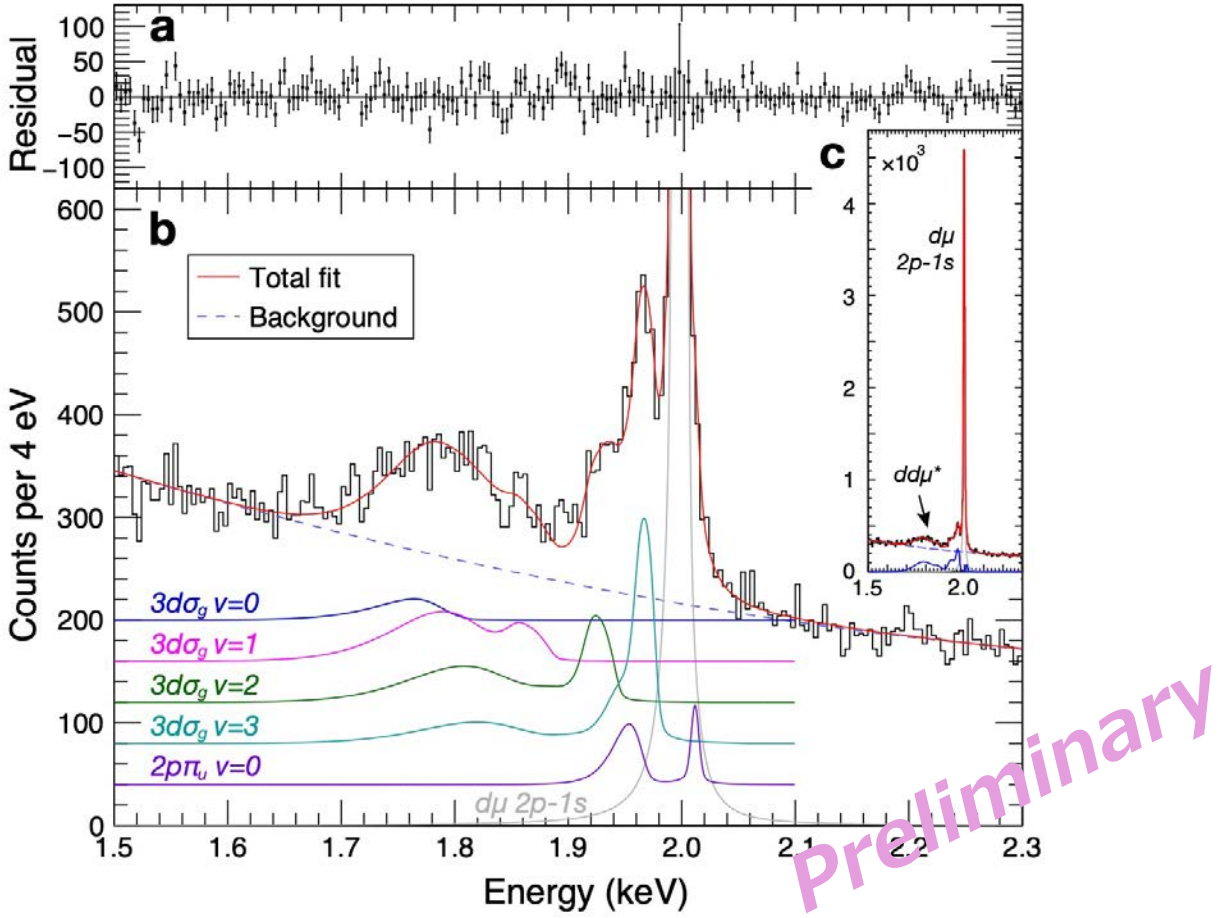
1: 2p
2: 2p hyper-satellite
3: 1s2p $^1P_1$
4: 1s2p $^3P_1$
5: 1s2s2p $^4P_{1/2}$ + 1s2s2p $^4P_{3/2}$
6: 1s2s2p $^2P_{1/2}$ + 1s2s2p $^2P_{3/2}$
7: 1s2s2p $^2P_{1/2}$ + 1s2s2p $^2P_{3/2}$ #2

Muonic Molecule



Muonic Molecule

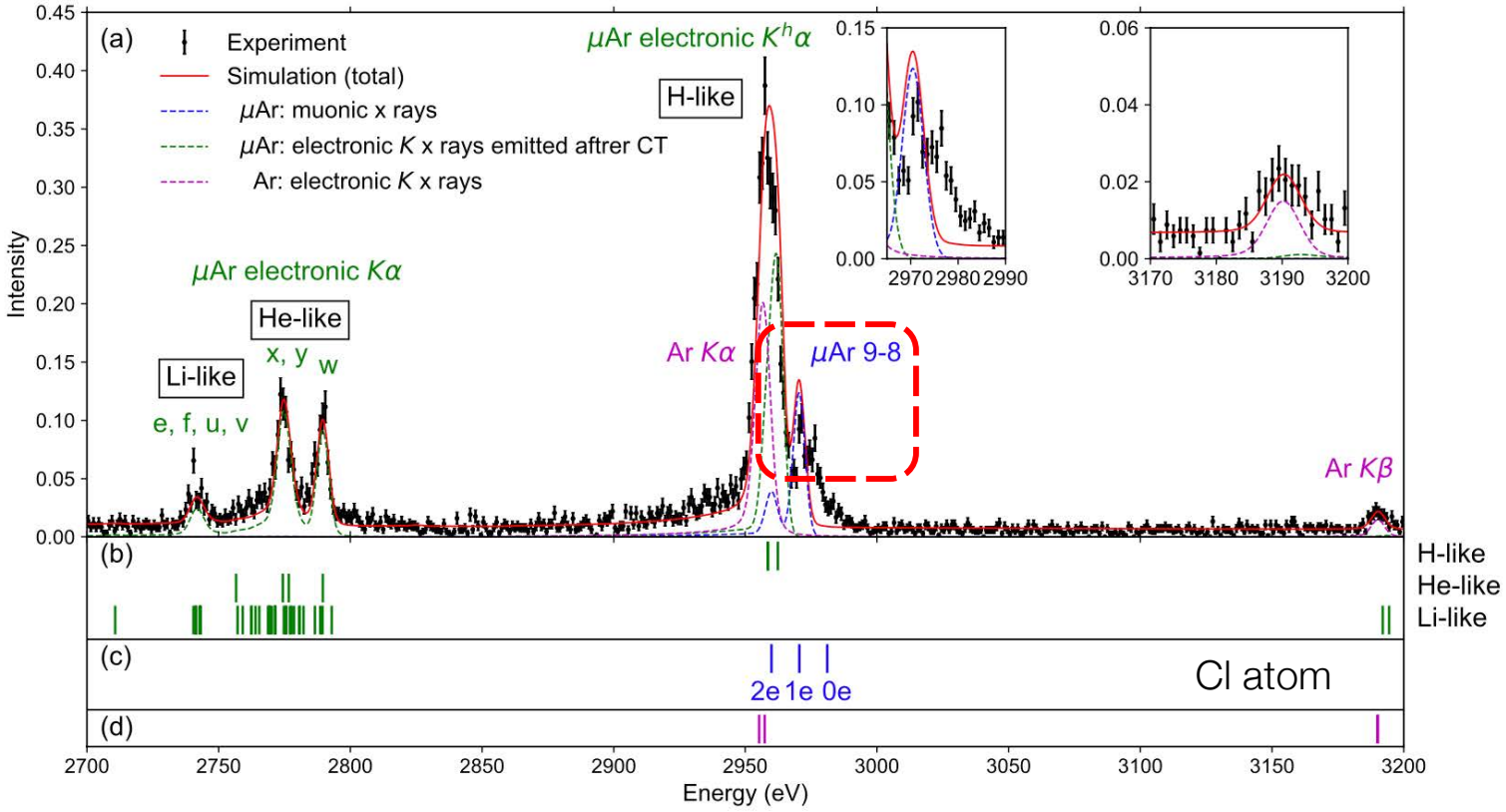




Our puzzle: Initial captured states of muon ?

Simulation Assuming $n_{\mu i} = 37$

This initial condition is required to reproduce muonic x-ray spectrum



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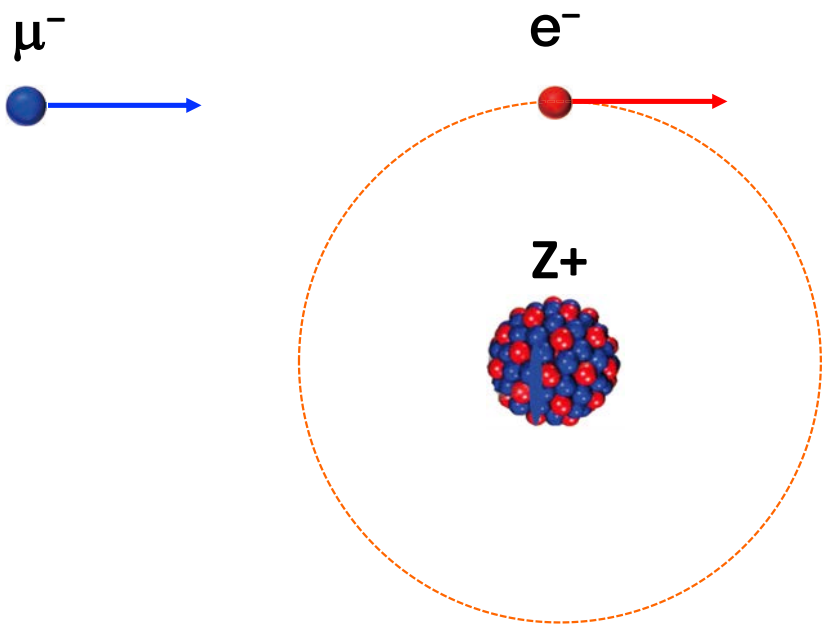


condition:
the same velocities of muon and electron

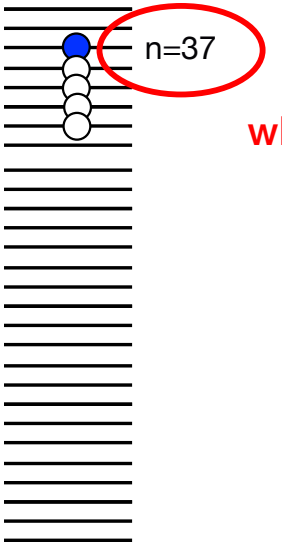
$m_\mu/m_e = \sqrt{207} = 14$?

What happens for multi-electron system ?

muon and electron dynamics in muonic atom

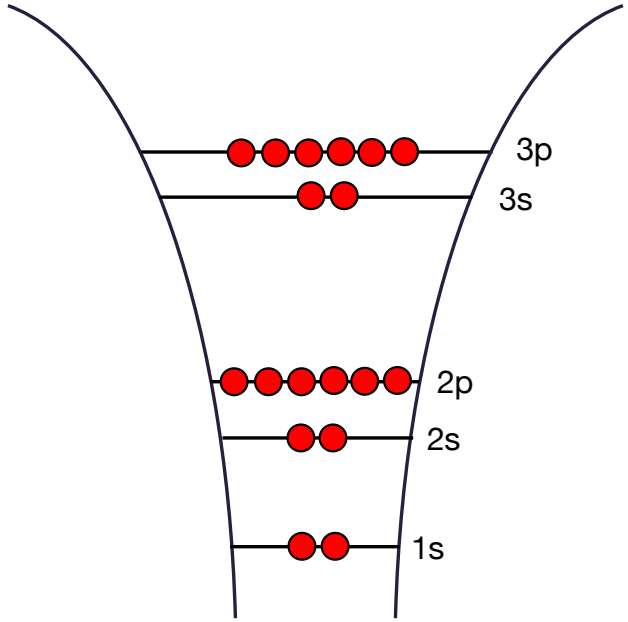
μAr

negative muon



why ?

electron



Enrico Fermi & Maria Göppert Mayer found Orbital Collapse

Enrico Fermi : Nobel Prize 1938

(The Nobel Prize for Physics was awarded for his work on the artificial radioactivity produced by neutrons, and for nuclear reactions brought about by slow neutrons.)

The Thomas-Fermi model treats many-electron systems by considering an active electron and screening the nucleus with other electrons

He speculated OC (1928)

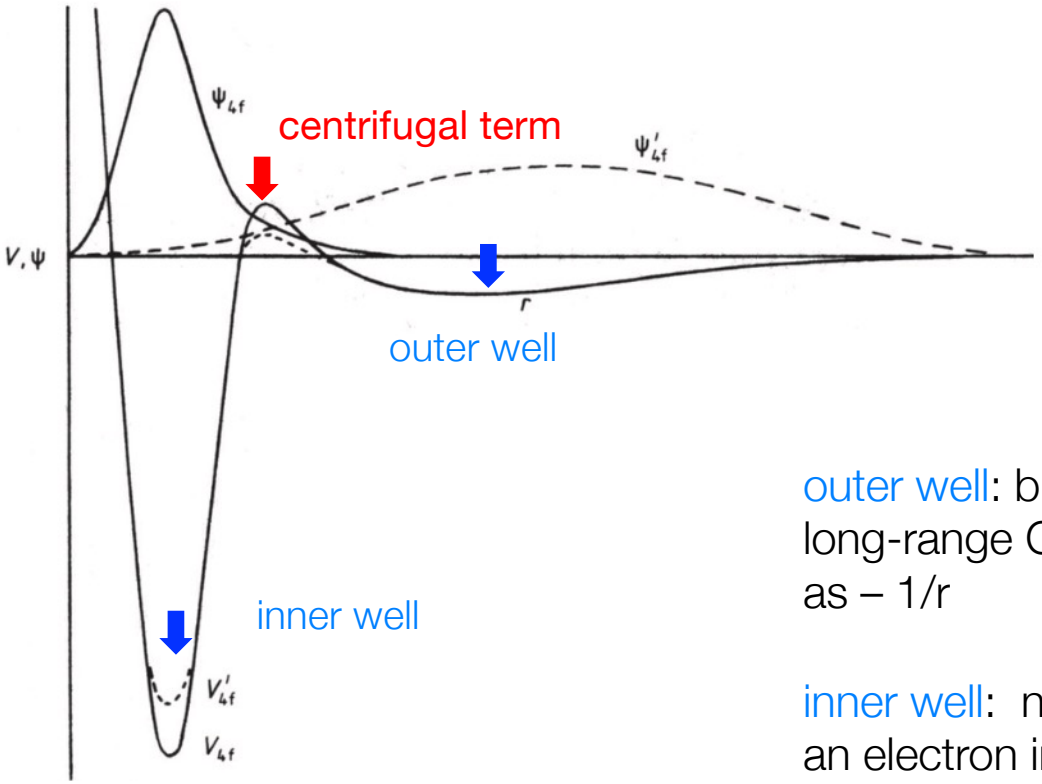
Maria Göppert Mayer : Nobel Prize 1963
nuclear shell structure

She calculated OC (1941)

Collapse of the 4f orbital

sudden decrease in energy and size of the *4f* wave function

For *f* electron of heavy atoms (**Z > ~58**), the effective potential consists of two wells separated by a potential barrier.



the effective potential for *f* electron:

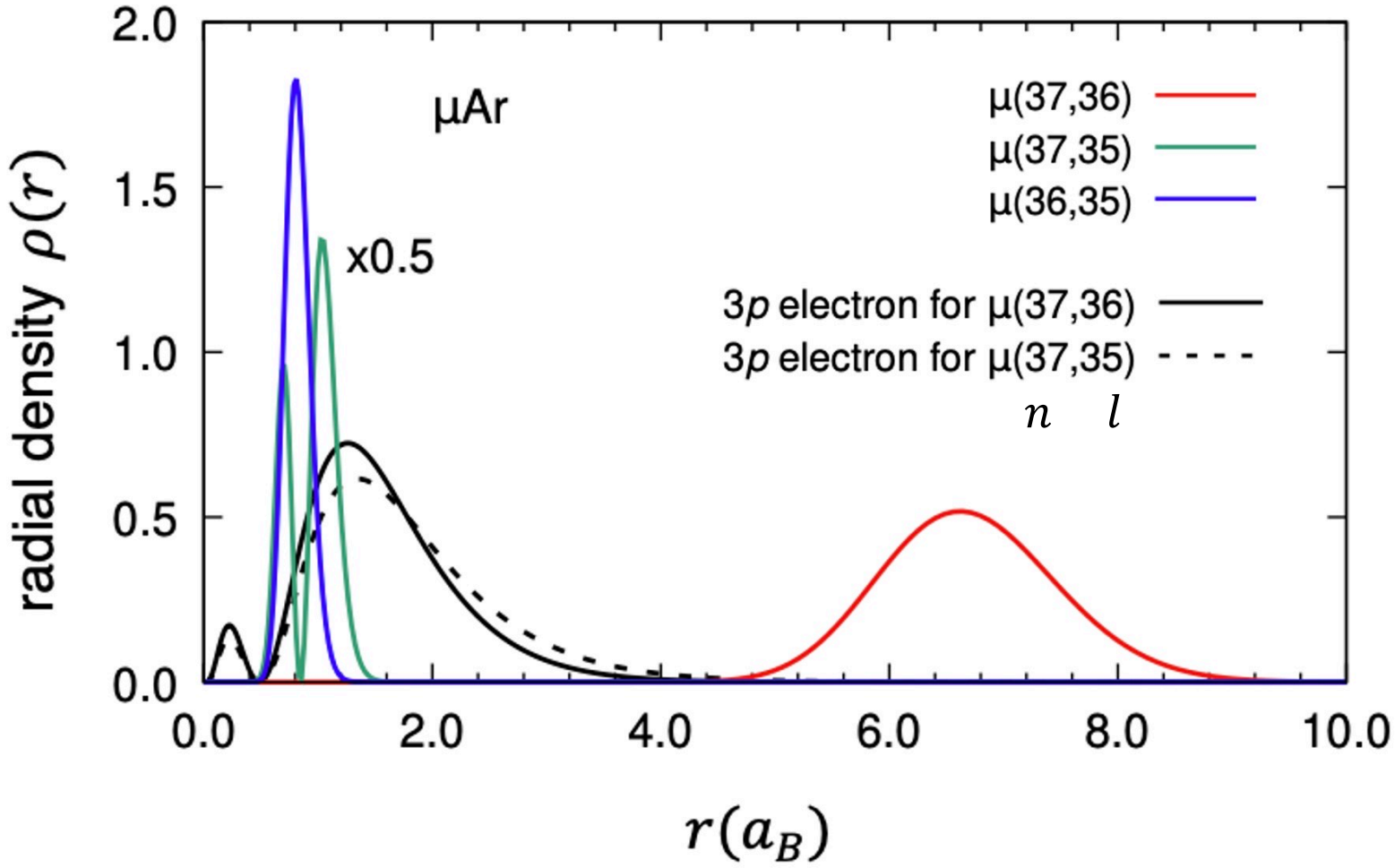
$$V_{eff}(r) = V(r) + l(l+1)/2r^2$$

atomic central potential + centrifugal term ($\propto n$)

outer well: broad and shallow, dominated by long-range Coulpmb potential as asymptotically as – 1/r

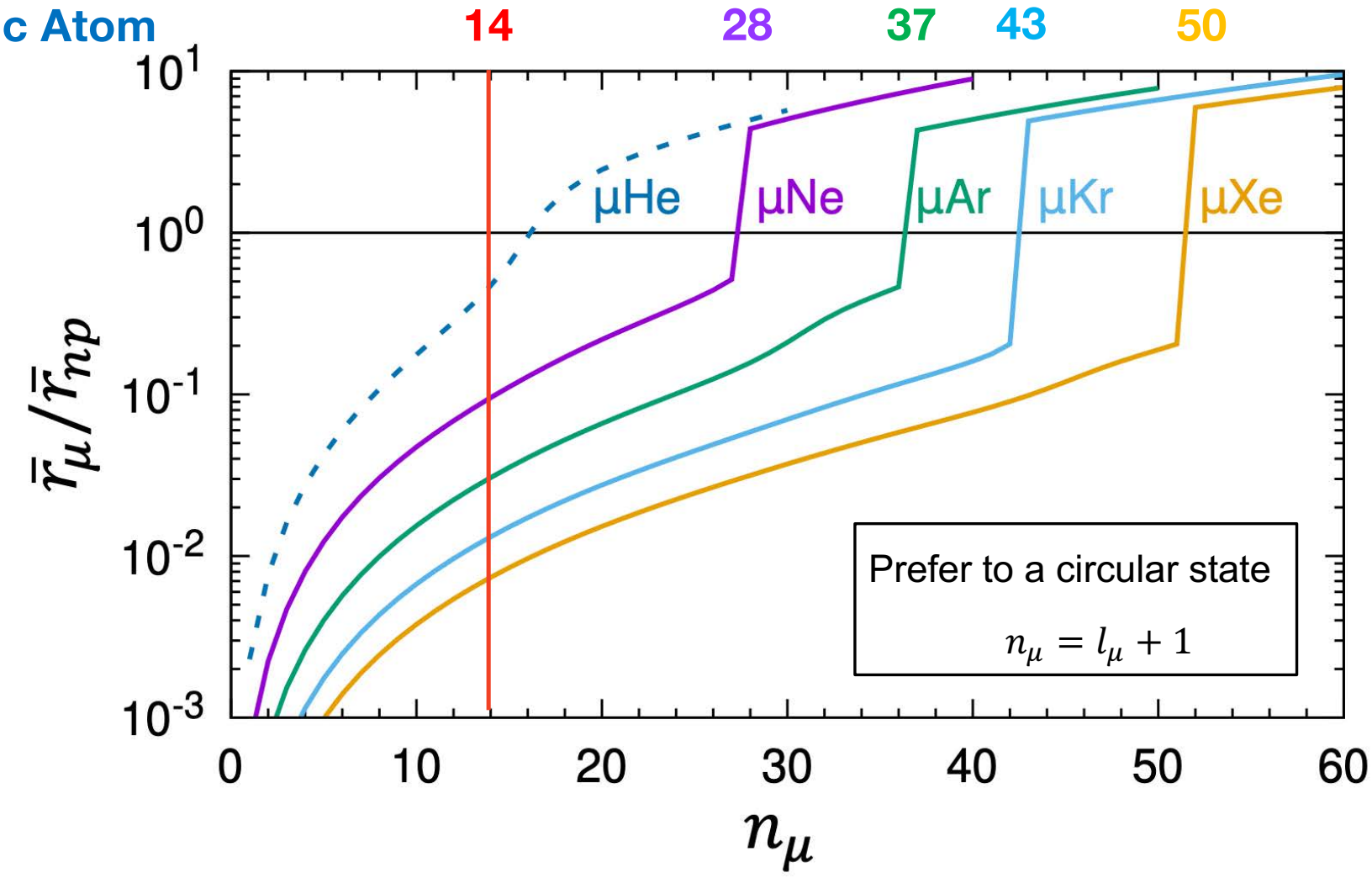
inner well: narrow and deep enough to support an electron in the bound state

Answer to Puzzle: Radial wave function of muon by DFT



Critical n_μ for Orbital Collapse = Initial Capture Level

Muonic Atom

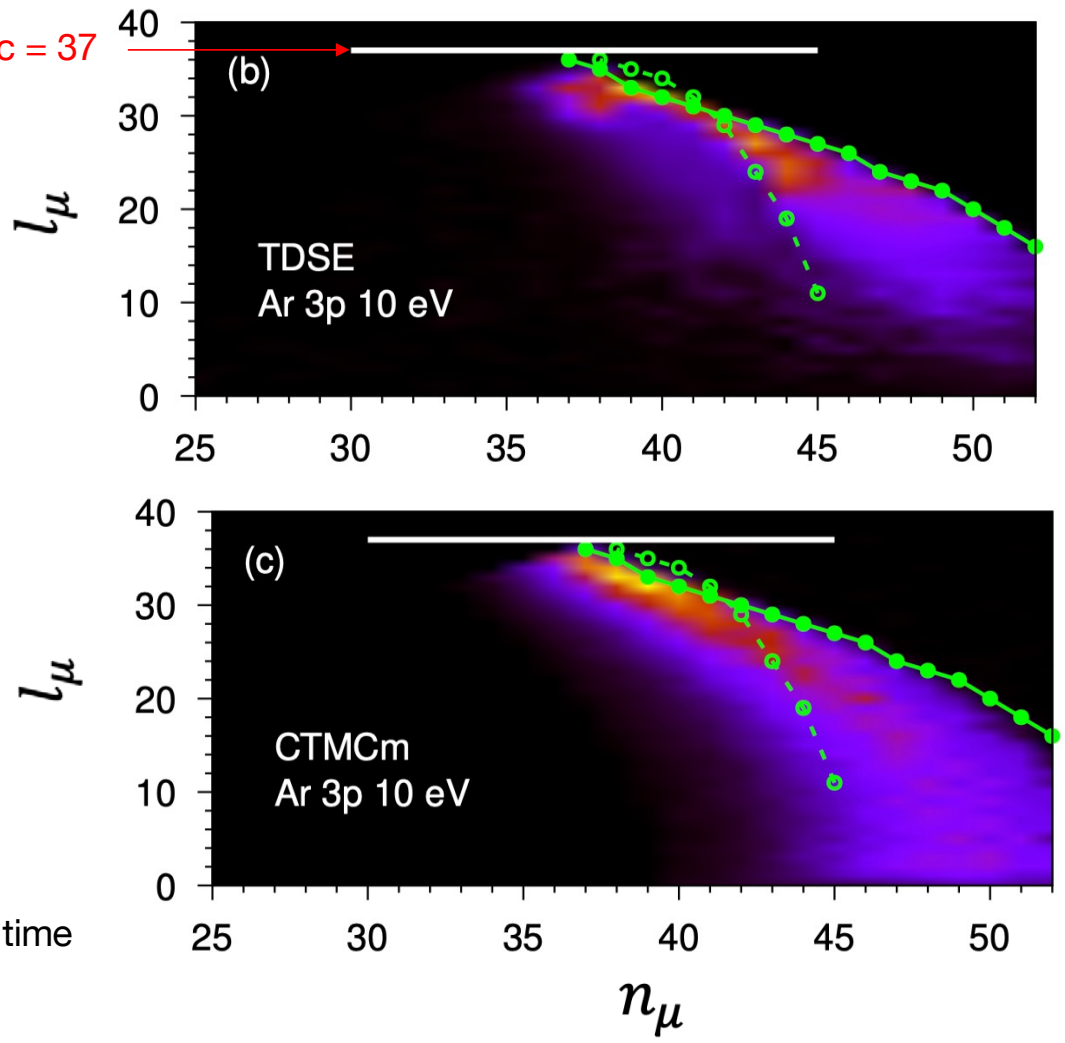


State-specified muon capture probabilities

TDSE
(time-dependent schrödinger equation)

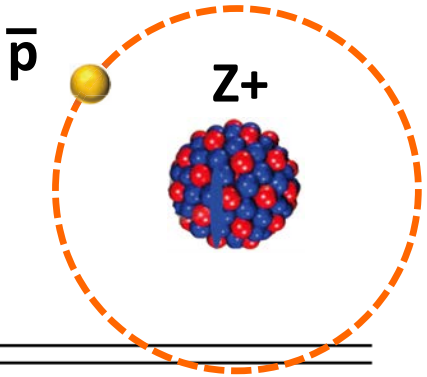
vs

CTMCm
(modified classical trajectory Monte Carlo)



open circles: states with large overlap
solid circles: states with a long interaction time

Equivalent Quantum Angular Momenta of Antiproton (l_c)



Antiprotonic Atom

Atom	Ne	Ar	Kr	Xe
L_c	1.98	2.65	3.03	3.53
l_c ($\bar{p}$: scaled)	84	112	129	150
l_c ($\bar{p}$: DFT)	82	109	125	153

From Yamada-san's talk at the first day

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創造性が開花するには？(How does creativity blossom?)

The following is a quote from "A Century of the Nobel Prize" (P163):

New ideas often emerge from the "borderlands" between different disciplines.

Creative environments can sometimes appear almost chaotic.
... In such unstable states, it becomes easier to go beyond
conventional patterns of thinking and established systems of rules ....

Inspired by this perspective, I have pursued a research that actively seeks the "seeds of new science" -- not only through experimental studies of black holes, X-ray microcalorimeters, and space science, but also by valuing interdisciplinary exploration across different fields.

If things get a bit chaotic, it just means you're getting close to the borderlands of creativity.


創造性を生む環境

「ノーベル賞の百年」P163

ノーベル賞は個人をたたえる。しかし、ほとんどの受賞者にとって、彼らが生きて働いた環境には重要な意味がある。創造の過程は、個々人が置かれた環境に大きく依存している。環境の何が、創造性を刺激するのであろうか。

簡単な質問から始めるのがよいかもしれない。環境とは何か。研究室、建物、都市、国といったものであろうか。地理的にどこにいるかにかかわらず、あるつながりで結ばれた人々の集まりであろうか。仲間内に広がる雰囲気や、意見を交換するときの態度なのであろうか。人生や、そこでの活動の組み立てられ方であろうか。

創造を推し進めるとはどんなものか？都市や、建物や、組織や、人々のつながりなどに共通する、革新が生ずるための前提条件、あるいはそれをさまたげるものが存在する。

創造性が開花する最も重要な前提条件の一つは、そこに知識を持った人々が存在することである。発想や伝統が発展するには、時間が必要である。新たな発展が始まる環境は多様であるかもしれないが、ある特定の環境でのみ実を結ぶ。時代に応じて、いくつかの場所が、際立つ能力を持つ人々を引きつける特別な魅力を見せてきた。

コミュニケーション―個々人やさまざまな分野の間での知識と発想の交換―は、新しい結果をもたらす上で重要である。新しい発想は、異なる分野の間の「境界領域」から湧き上がることが多い。領域を越えた予期せぬ出会いが、知識と発想の新しい組み合わせをもたらすかもしれない。町や建物、組織や人と人のネットワークには、前の凝らない出会いの場が必要である。コミュニケーションや技術的な補助は、人と人との接触が図られ、人々が互いを知り合ったときに、最も大きな効果を発揮する。

創造の過程は、個別性や均一性よりは、むしろ多様性と変化によって促進される。創造的な環境は、ときにはほとんど混沌のようにさえ見える。根本的な改革は、個人においても社会一般においても、ある程度不安定で不確定な状態において始まることが多い。不安定な状態では、慣れ親しんだ思考の型や決まりごとの体系を打ち破るのが容易になる。創造性は、階層性や規則よりも、自由からより多くを受け取るのである。

経済的、あるいはその他の資源は、創造的な活動にとっては必須であるが、それが必ずしも決定的な要因になるわけではない。

創造的な環境を意図的に作り出すことは可能であろうか。そうした環境は、計画に基づいて築くことのできるようなものなのであろうか。それとも、自然にできあがるものなのであろうか。

一人の人間も、一生の間に、成長にとって深い意義を持ついくつかの環境にめぐりあう。多くの人々が、子供時代と教育が将来の仕事に対して持つ意味の大き

Sydney Brenner
2002 Nobel Prize Laureate
in Physiology or Medicine

Progress in science depends on new techniques, new discoveries and new ideas, probably in that order.”

Freeman Dyson
Schwinger–Dyson equation

New directions in science are launched by new tools much more often than by new concepts.
The effect of a concept-driven revolution is to explain old things in new ways.
The effect of a tool-driven revolution is to discover new things that have to be explained.

via Hanagaki-san

Thank you for your contribution to the QUP symposium

Thank you