

# Who am I ?

Toshiyuki Azuma

AMO Physics Laboratory, RIKEN



# What I aim for

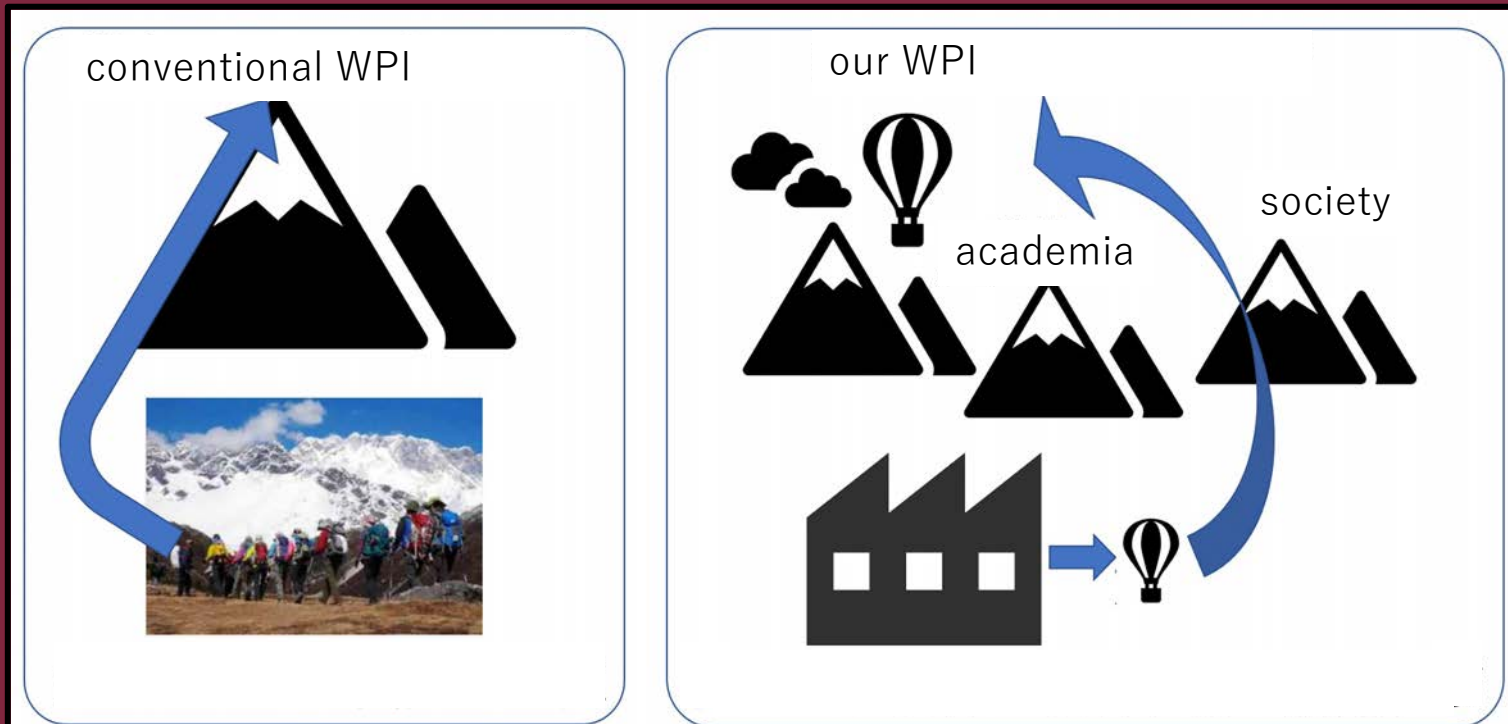
Toshiyuki Azuma

QUP KEK

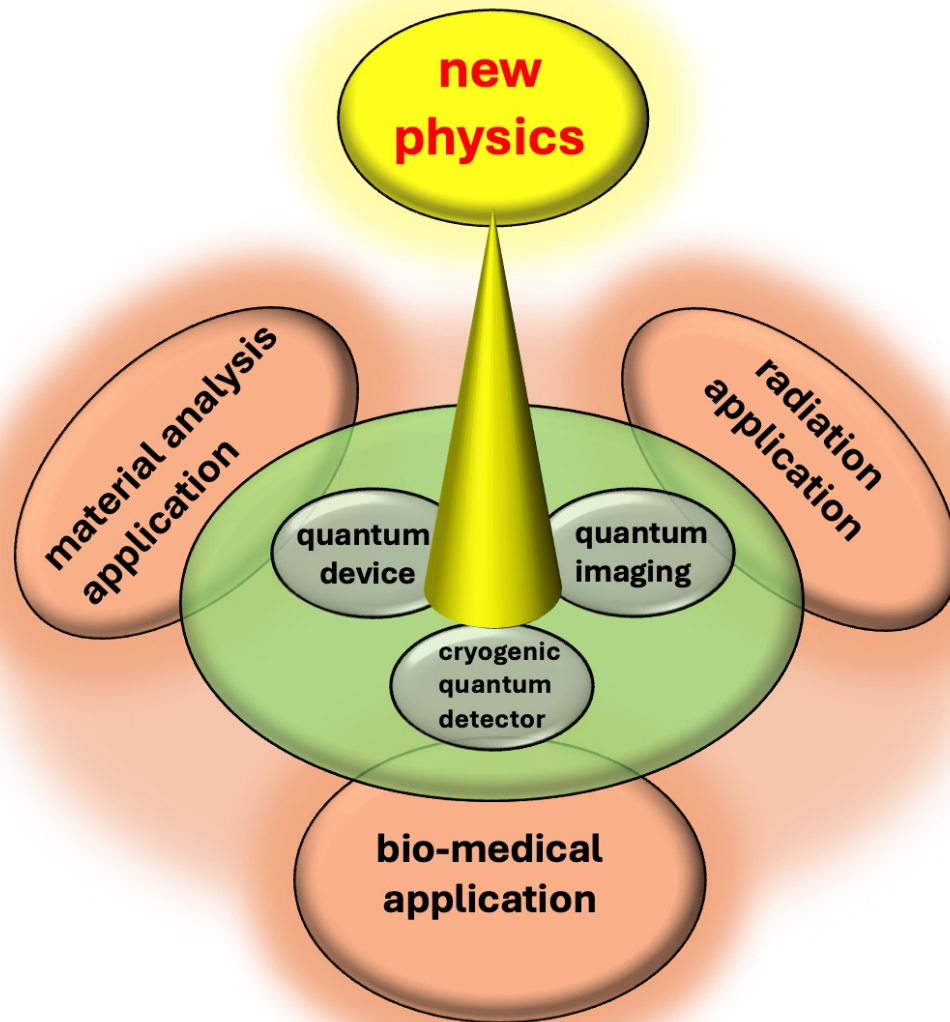
PRI Pioneering Research Institute RIKEN



# 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.**

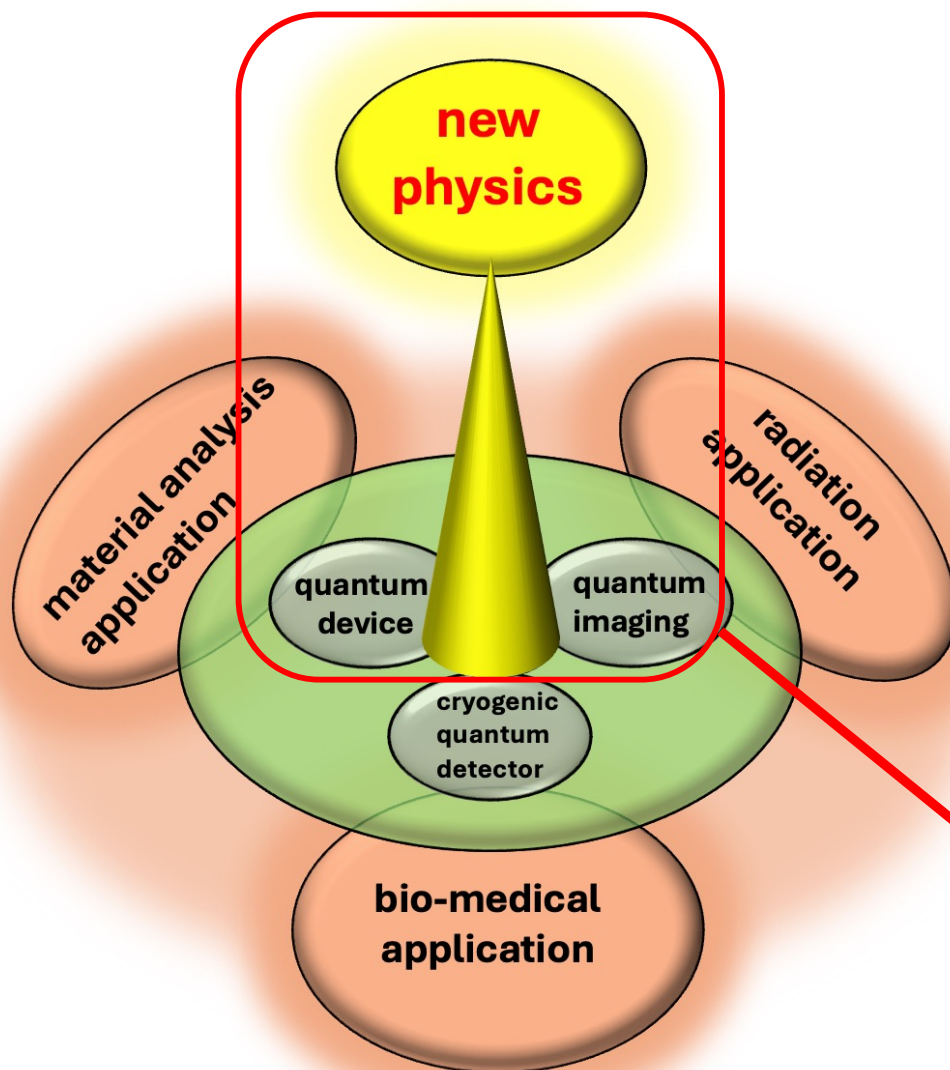


## New Concept of QUP



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.



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

Golden pillar

Many summits

## QUP Overview

### New Eyes to Humanity

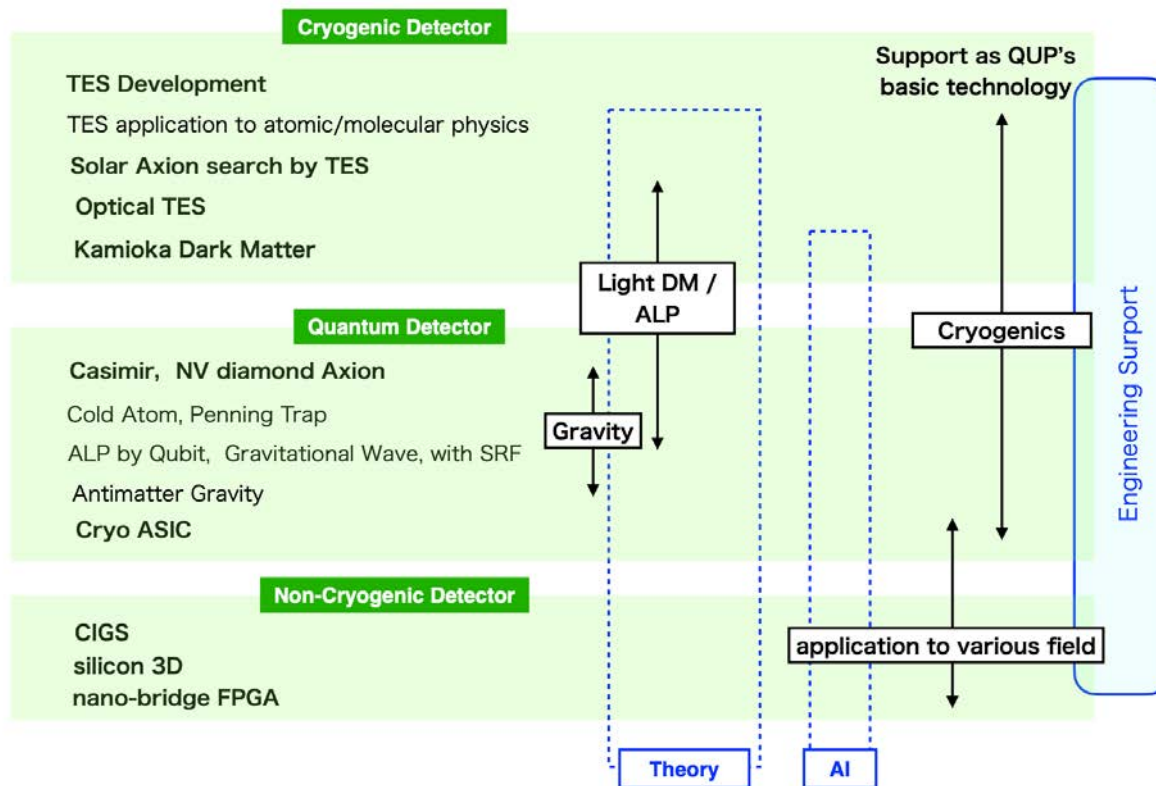
- Goals
  - ▶ QUP/KEK becomes International hub for measurement system development
  - ▶ Reveal mysteries in Universe, Particle, and Life
  - ▶ Create interdisciplinary academic area by fusion of wide range of research
  
- Strategy
  - ▶ Now focus on three categories of detector technology
    - Cryogenics
    - 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



# Hanagaki-san's talk at the first day



## Research Groups



# A series of presentations over three days

**Cygnus X-3**

Cygnus X-3 is a high-mass X-ray binary system consisting of a compact object (likely a black hole) and a Wolf-Rayet star.

<https://xsv.aipr-nea.gov.it/1370/>

This is the first, and surprising result.

XRISM Resolve Spectrum of Cygnus X-3

Iron K-alpha region

### Who Am I?

- Aritoki Suzuki - <https://sites.google.com/lbl.gov/asuzuki/>
- Scientist at Physics division, Lawrence Berkeley National
- 15+ years of superconducting and RF device developme
- R&D coordinator for superconducting and quantum tech

**CMB-S4**

- CMB-S4:** Ground based CMB experiment, Detector lead
- LiteBIRD:** Space based CMB experiment, Cold readout lead
- TESSERACT/DM:** Light Dark Matter experiment, Readout and De
- PHONON-NEXT:** Phonon-control for qubit and sensors
- LuSEE-Night:** Lunar based 21 cm experiment, Antenna system

at the end of FY 2024

QUP

### Where are we now?

- Dilution Refrigerator relocation to Kamioka last November

### QUP cryogenic facility

DR1	DR2	DR3	DR4	DR5
In the shield room BlueFors XLD400 1000 uW @ 100 mK	With IPMU cryostat BlueFors LD400 400 uW @ 100 mK	At Kamioka BlueFors LD400 400 uW @ 100 mK	Shared by Solar-Axion and Optical TES BlueFors LD400	Newly arrived. In the commission BlueFors SD

**QUP cryo-facility @ Fuji**

- Deployed fleet of DR systems in FY2022, and successfully commissioned them after overcoming a few troubles (superleak, vacuum leak ...) in FY2023

New QUP building with new laboratory  
=> start-up and movement starting from Summer 2025

**New Building (Mar 2025 completion)**

- Initial proposal was to use BM-2
- New building is an extra success!
- Under One Roof!
- Lots of extra tanks in the labs!

International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP)

### TES coupled with aluminum target

Low energy threshold is crucial to search sub-MeV dark matter.

Normal metal

Cooper pair

Quasiparticles

Al

TES

signals

TES array readout  $\mu$ MUX

Candidate for TES material

- Ti/Au bilayer film
- High energy resolution (67 meV FWHM)
- Thin Ti film is required to couple Al and TES
- AlMn film
- AlMn TES bolometers have been used for CMB experiments
- Easy to couple with Al target

quasiparticle-trap-assisted TES (QET)

K. Irwin et al., Rev. Sci. Instrum. 66, 5322 (1995).

## Light dark matter search with quantum technology



# A series of presentations over three days

## Qubit applications

**Cavity tuning**  
Nakazono+ Patras 2024  
Zhao+ arXiv 2501.06882

**Direct excitation**  
Moroi+ PRL 131, 211001  
Thanapan+ PRL 133, 021801  
Thanapan+ PRD 110, 115021  
Watanabe+ Patras 2024  
Kang+ arXiv 2503.18315

Hmmm.. look just

**QUP Workshop**  
KEK, Japan  
April 8-10, 2025

**Makoto C. Fujiwara**  
ALPHA-Canada Spokesperson  
Senior Scientist, Particle Physics Dept  
TRIUMF

**Gravity Meets Antimatter:  
An Experimental Frontier  
in Quantum Sensing**

## Diamond nitrogen vacancy (NV) center

- defect with nitrogen (substituting for carbon) and vacancy
- generated by ion implantation or electron beam irradiation or formed naturally during the diamond growth process

**C.B (5.47 eV)**  
 $\lambda = 532 \text{ nm}$

## Casimir forces and possible applications

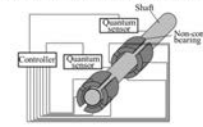
**Equilibrium Casimir force (Attractive in vacuum)**  
Less than a few microns

## New quantum field search

PRL 116, 221102(2016)

type new force  
 $\frac{1}{2} \frac{m_2}{r} (1 + \alpha e^{-r/\lambda})$

## Industry/Social implementation Non-contact shaft-bearing system



## Direct dark matter detection with liquid gas experiments

Muping Chen (QUP-KEK) QUP Workshop 04/09/2025

Based on Chen, Gelmini, and Takhistov, JCAP 12 (2021) 12, 048 [2105.08101] and Bozorgnia, Chen, Gelmini, Kamaha, and Xu, Accepted by JCAP [2408.13664]



(Hiroshima Univ.<sup>1</sup>, QUPIP<sup>2</sup>, QUP<sup>3</sup>, KEK<sup>4</sup>)

**Acknowledgement : QUP members**  
Masaya Miyahara, Masaya Hasegawa, Hiroki Akamatsu,  
Satoru Igarashi(AES), Haruaki Hirose(YNU), Daisuke Kaneko,  
Ryota Takaku, Hideo Iizuka, Suerfu Burkhant,  
Ryota Hayakawa, Kaori Hattori

## Photon Colliders (SRPC) 3. Sensitivity projections

**Testing of scenarios**

University /

at QCD axion

esonant

Wave-like  
elements  
ation

on probability:  
lications

o University

We enjoyed a bunch of presentations in 3 days.

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Two good news:

1. Ongoing projects are steadily going forward.

We enjoyed a bunch of presentations in 3 days.

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Two good news:

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

## Candidates of “New Quantum Eyes”

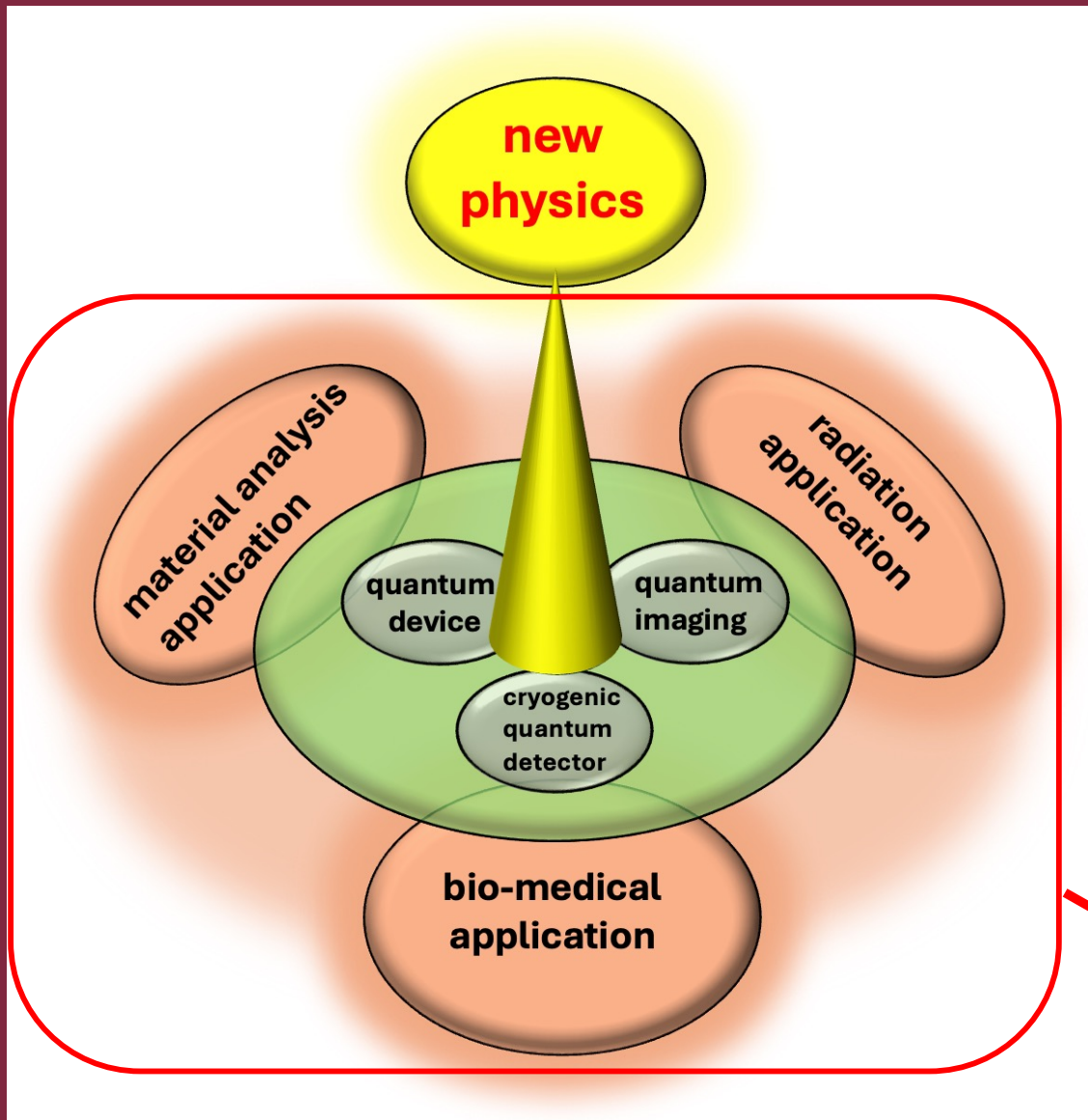
- Cold Atom / Penning Trap
    - ← This will be started up near future
  
  - Laser cooling technology
    - ▶ Gravity, Clock, Fundamental constants
  - Atomic (Nuclear) clock
  - High Fines Interferometer for MZ application
  
  - Superconducting cavity as gravitational wave sensor
  - Superconducting cavity as memory in quantum computing
- }
- ← A new PI is being hired for these projects



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Horizon

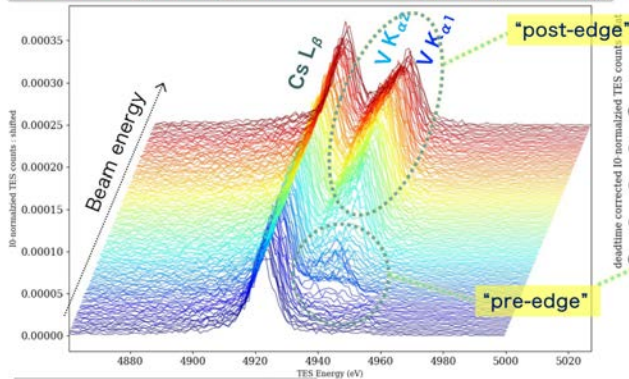
Many application



Two news:

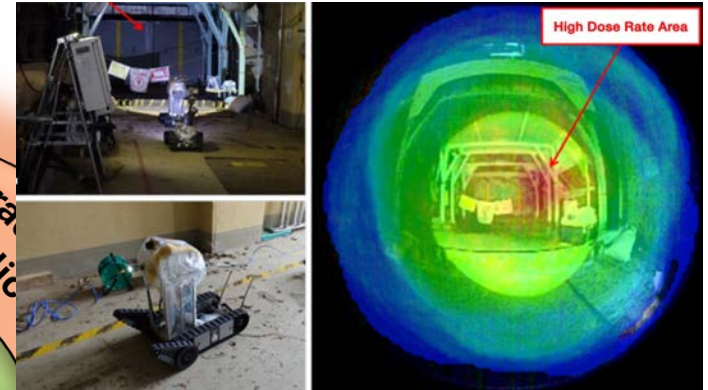
1. New breeze will be introduced by a new coordinator.
2. Another symposium will be held soon.

TES for X-ray Absorption Fine Structure (XAFS) : an example



## TES detector

JAEA

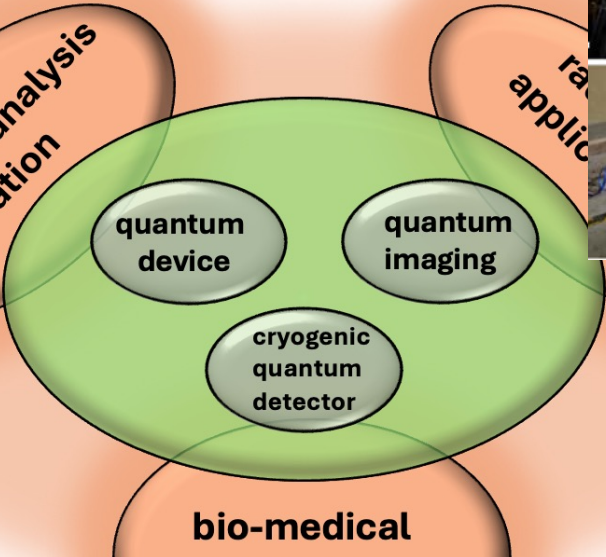


Material Analysis application

material analysis application

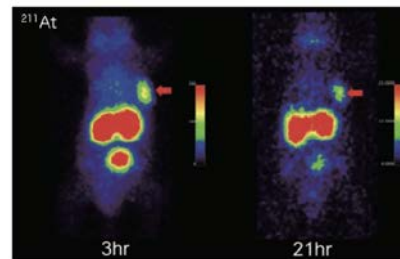
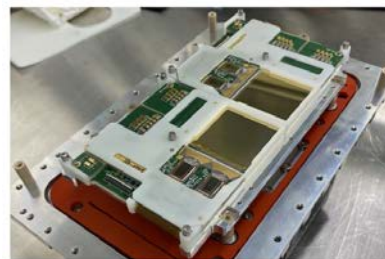
radiation application

Compton camera  
Radiation application



Bio-Medica application

Imaging detector



And ....

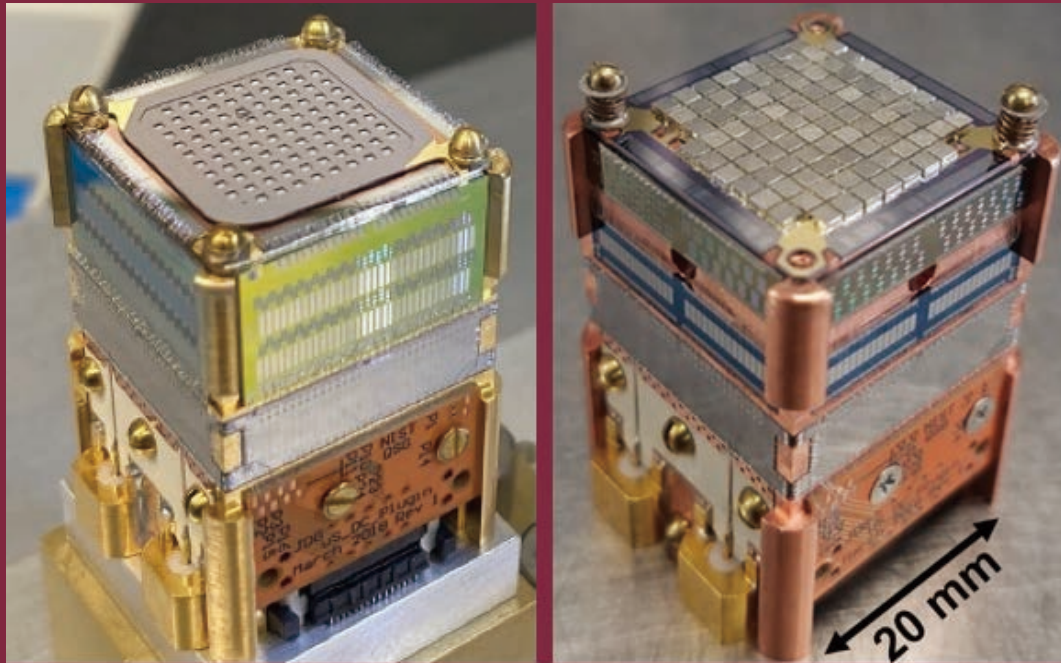
What happened to me in 3 months

experiments



# What happened to me in 3 months

Installation of two new TES covering 150 keV collaboration with NIST



	50 keV TES	130 keV TES
Saturation Energy	70 keV	150 keV
Absorber material	Au/Bi	Sn
Absorber thickness	1.85 $\mu\text{m}$ / 20 $\mu\text{m}$	120 - 250 $\mu\text{m}$
Absorber area	0.73x0.73 mm	1.3x1.3 mm
Pixel number	96	96
Total collection area	50 mm <sup>2</sup>	160 mm <sup>2</sup>
Absorption at 45 keV	22 %	92 %
Absorption at 100 keV	-	26%

**Table 1** Specification of two new TES detectors.

**Fig. 1** Photos of 50 keV and 130 keV 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

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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 ( $\sim 0.01$  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 $\mu$ X ray spectroscopy
<b>precision</b>	○	◎	○
<b>Absolute value</b>	○	X	○
<b>Charge density distribution</b>	○	X	#

# Preliminary results

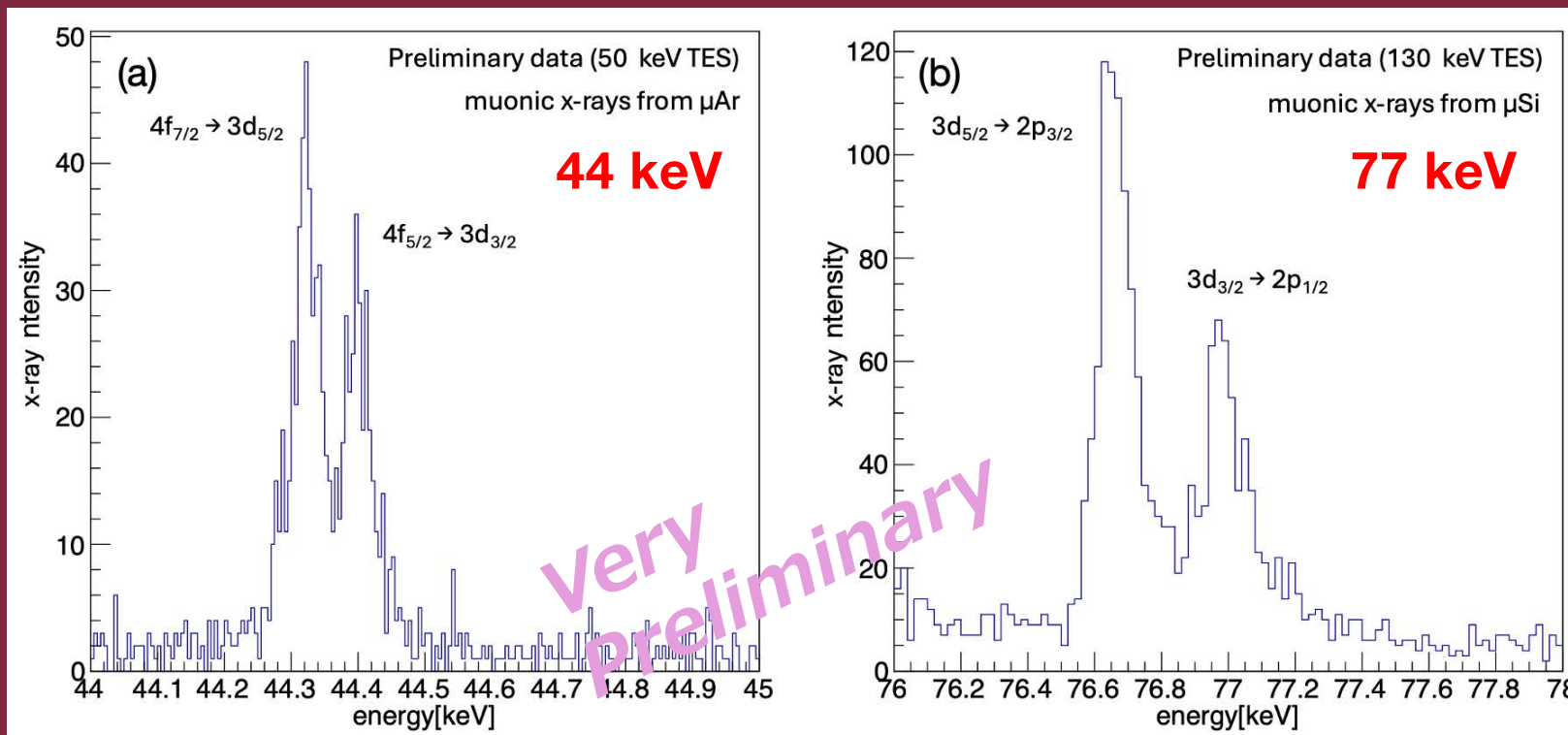


Fig. 2 obtained spectra (preliminary):

- (a) 44 keV muonic x-rays from  $\mu\text{Ar}$  ( $4f_{7/2}-3d_{5/2}$  and  $4f_{5/2}-3d_{3/2}$  transitions)
- (b) 76 keV muonic x-rays from  $\mu^{28}\text{Si}$  ( $3d_{5/2}-2p_{3/2}$  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

X. M. Tong <sup>1,\*</sup> K. Tőkési <sup>2</sup> D. Kato <sup>3,4</sup> T. Okumura <sup>5</sup> S. Okada <sup>3,6</sup> and T. Azuma <sup>7,†</sup>

<sup>1</sup>*Center for Computational Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan*

<sup>2</sup>*HUN-REN Institute for Nuclear Research (ATOMKI), 4026 Debrecen, Hungary*

<sup>3</sup>*National Institute for Fusion Science (NIFS), Toki, Gifu 509-5292, Japan*

<sup>4</sup>*Interdisciplinary Graduate School of Engineering Sciences,  
Kyushu University, Kasuga, Fukuoka 816-8580, Japan*

<sup>5</sup>*Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan*

<sup>6</sup>*Department of Mathematical and Physical Sciences,  
Chubu University, Kasugai, Aichi 487-8501, Japan*

<sup>7</sup>*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



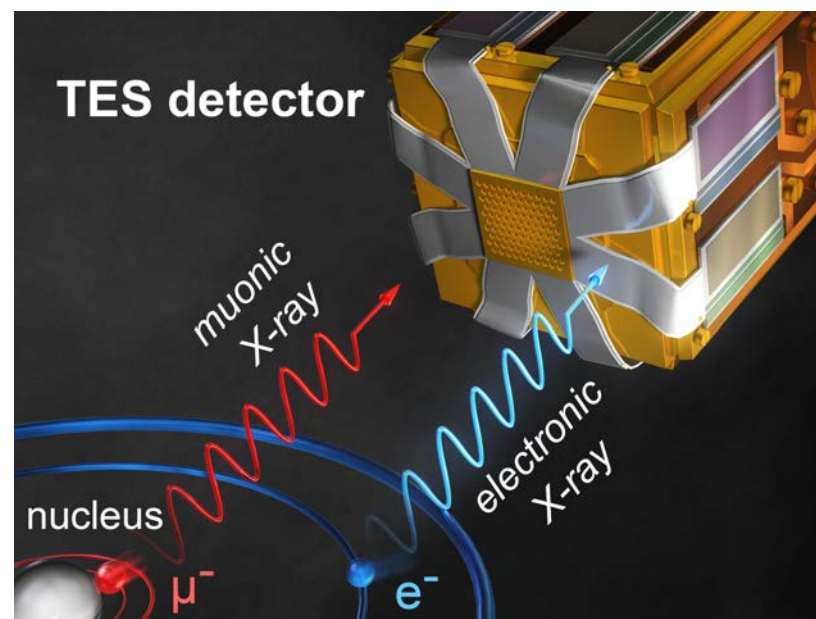
最近の研究から

## 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

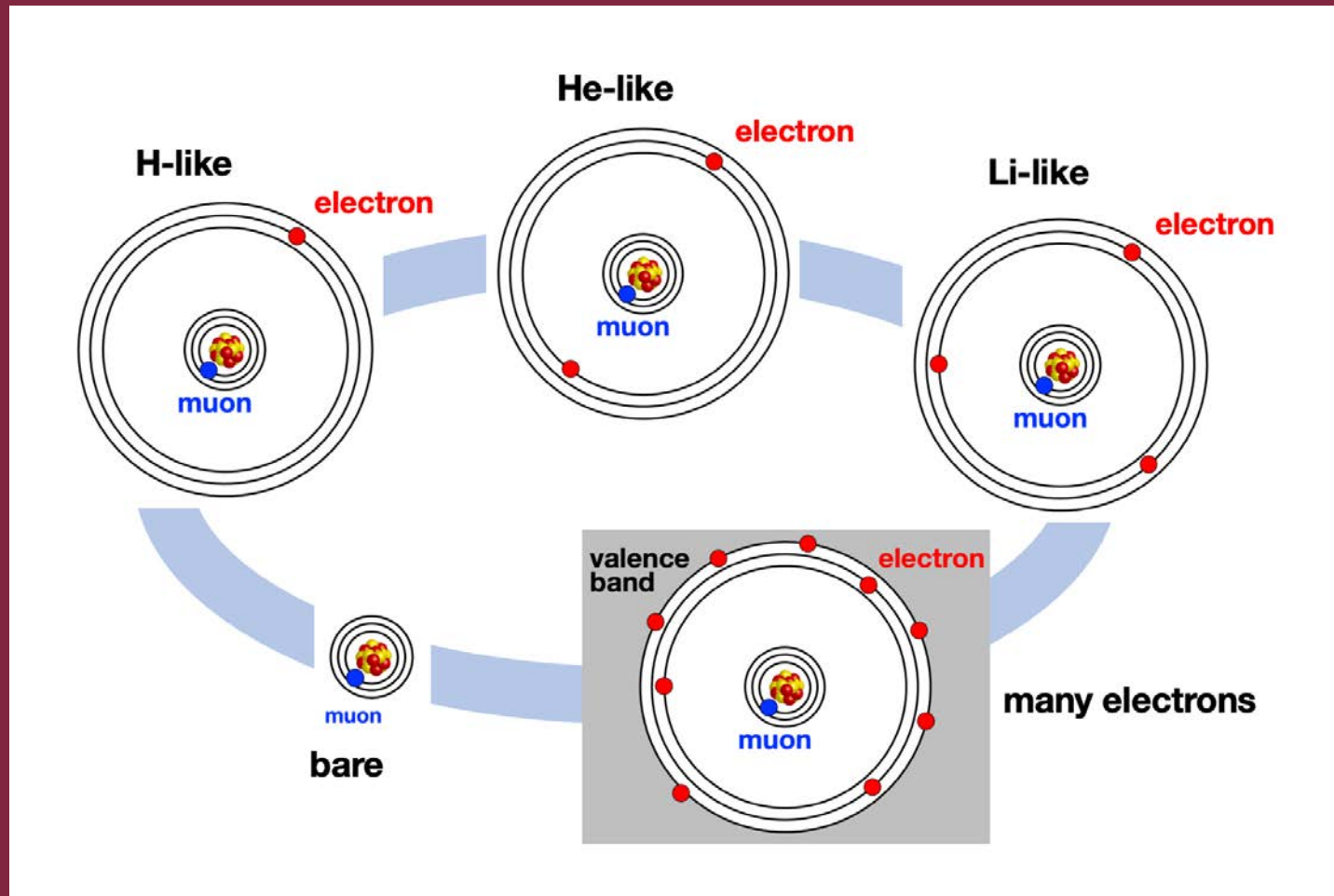
奥村 拓馬 <東京都立大学大学院理学研究科 tokumura@tmu.ac.jp>

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>



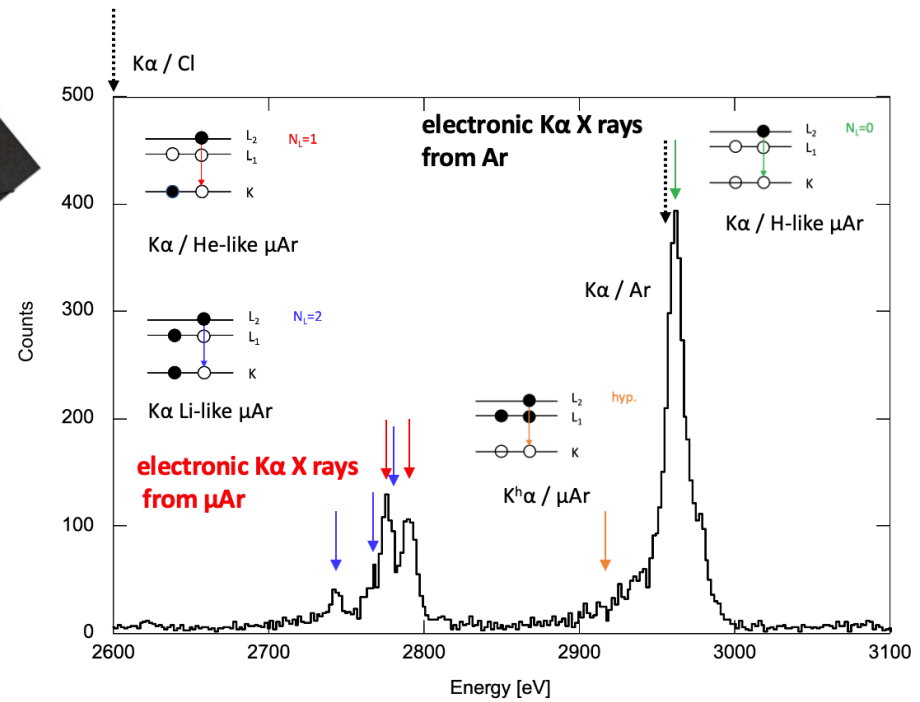
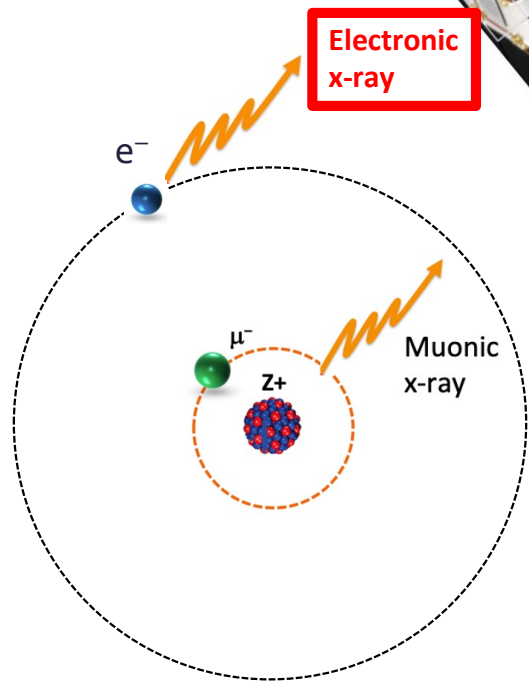
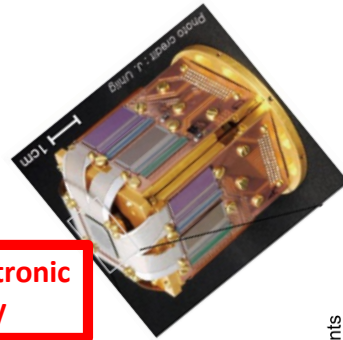
# Muonic Atom



# Muonic Atom

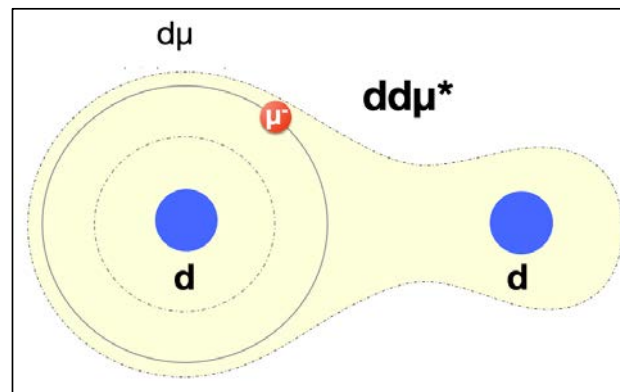


H-, He-, Li-like muonic Ar  
 $(e, \mu, \text{Ar}^{18+}) \sim (e, \text{Cl}^{17+})$

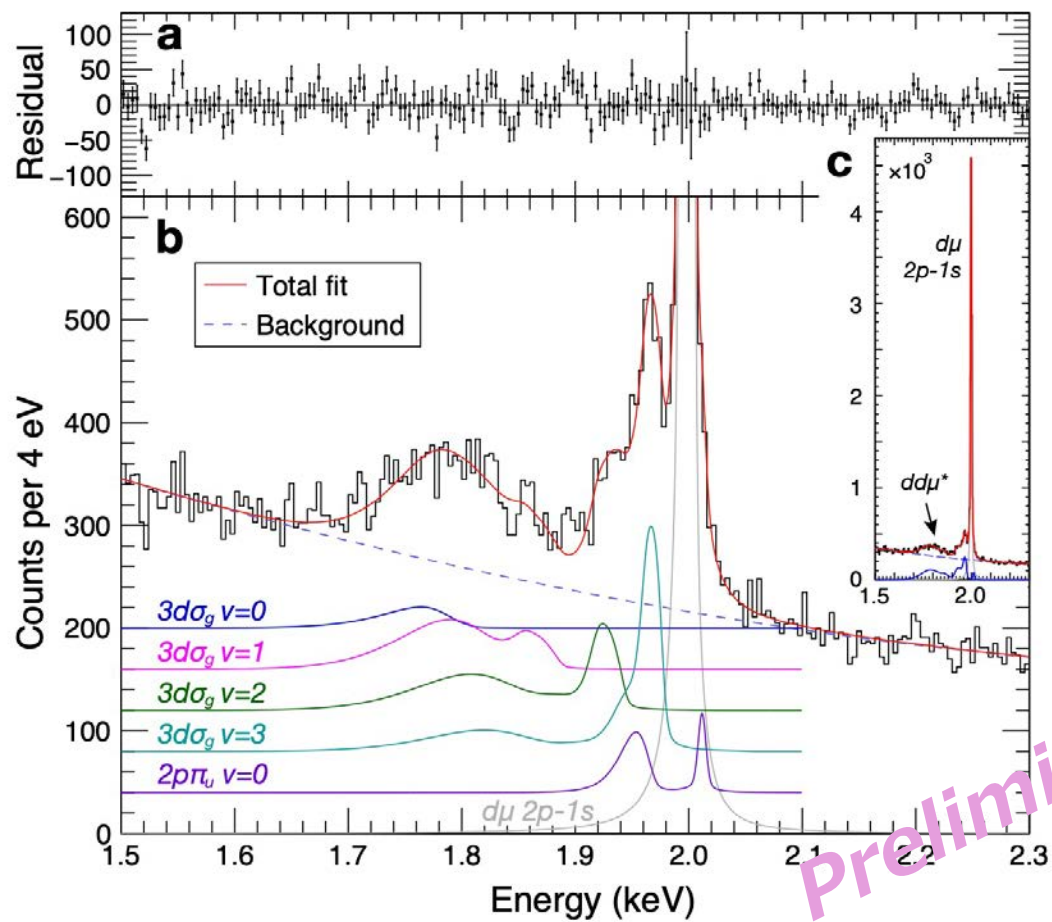
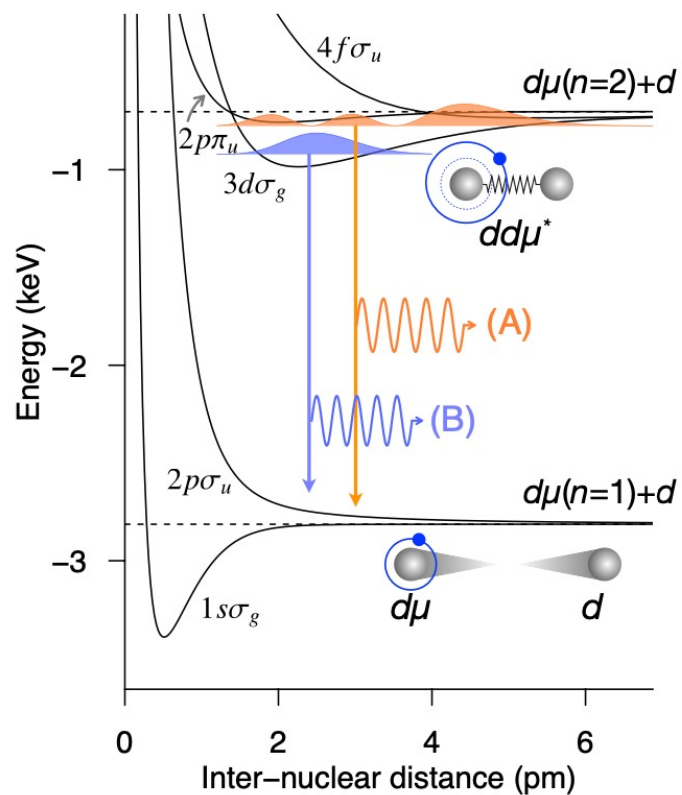


- 1: 2p
- 2: 2p hyper-satellite
- 3: 1s2p <sup>1</sup>P<sub>1</sub>
- 4: 1s2p <sup>3</sup>P<sub>1</sub>
- 5: 1s2s2p <sup>4</sup>P<sub>1/2</sub> + 1s2s2p <sup>4</sup>P<sub>3/2</sub>
- 6: 1s2s2p <sup>2</sup>P<sub>1/2</sub> + 1s2s2p <sup>2</sup>P<sub>3/2</sub>
- 7: 1s2s2p <sup>2</sup>P<sub>1/2</sub> + 1s2s2p <sup>2</sup>P<sub>3/2</sub> #2

# Muonic Molecule



# Muonic Molecule



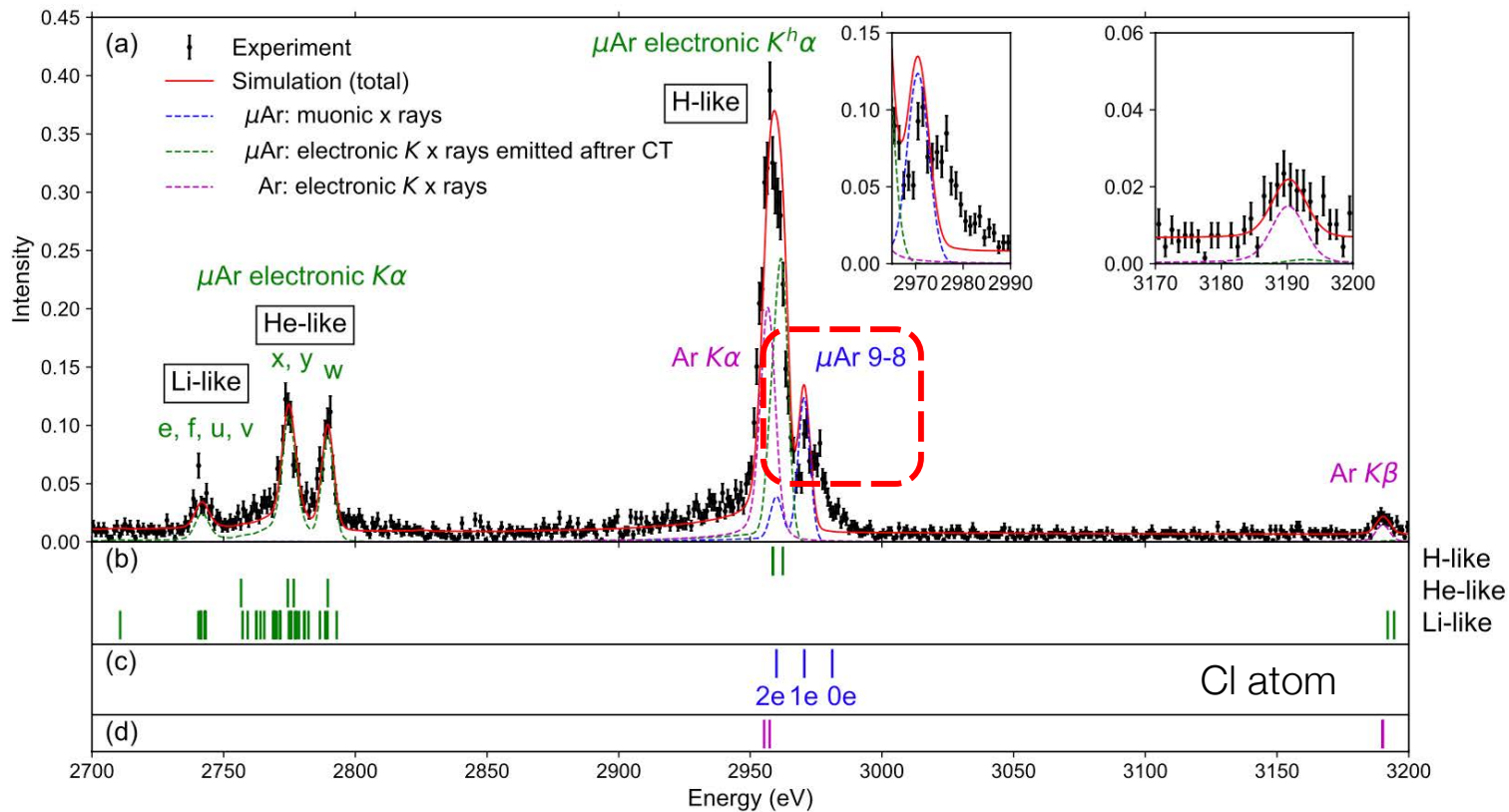
Preliminary



# Our puzzle: Initial captured states of muon ?

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

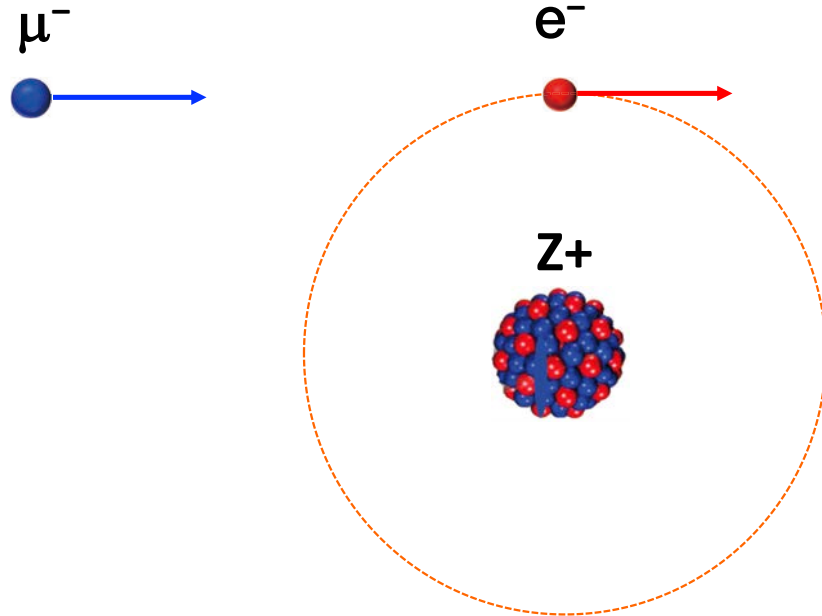
This initial condition is required to reproduce muonic x-ray spectrum





# Our puzzle: Initial captured states of muon ?

[18pA1-9]



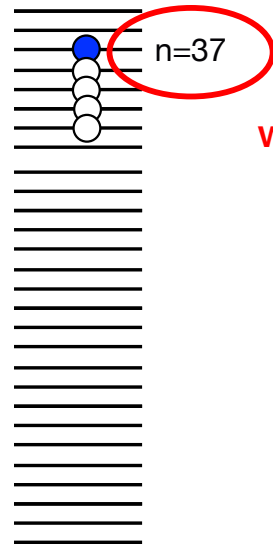
condition:  
the same velocities of muon and electron

$$m_{\mu}/m_e = \cancel{v207} = 14 ?$$

What happens for multi-electron system ?



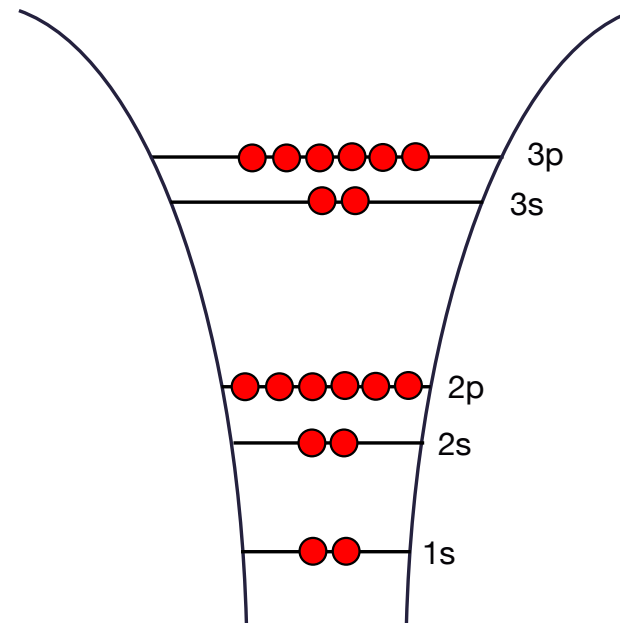
negative muon



why ?

$\mu\text{Ar}$

electron





## Enrico Fermi & Maria Göppert Mayer found **Orbital Collapse**

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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)



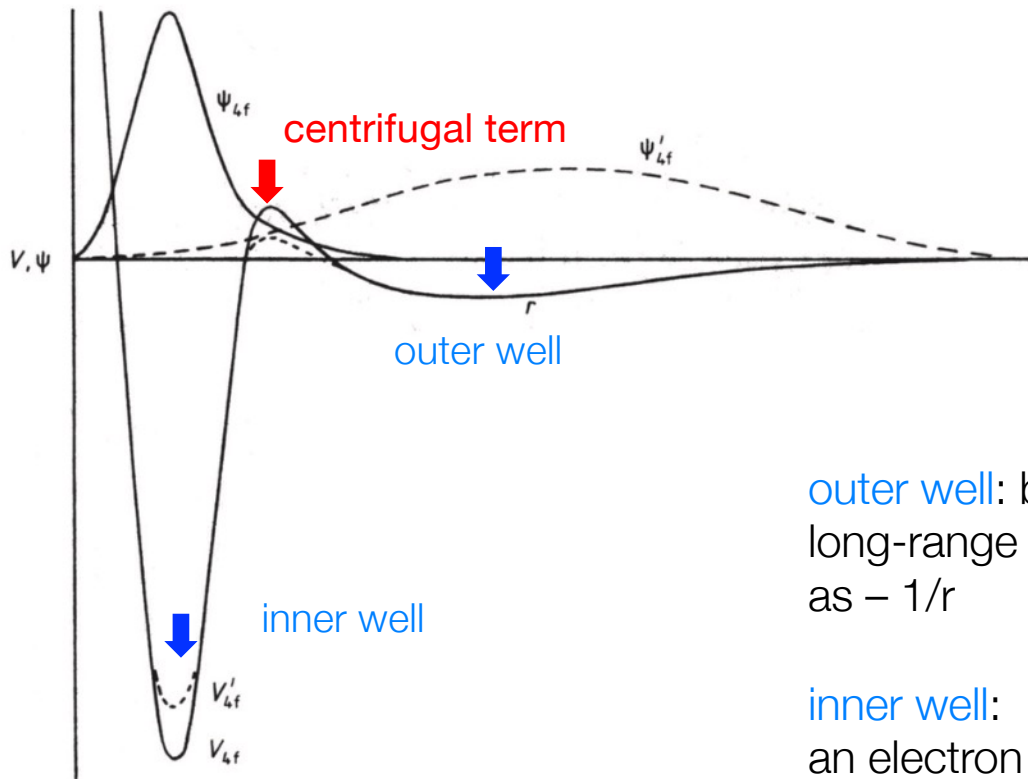
Maria Göppert Mayer : Nobel Prize 1963  
**nuclear shell structure**

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:

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

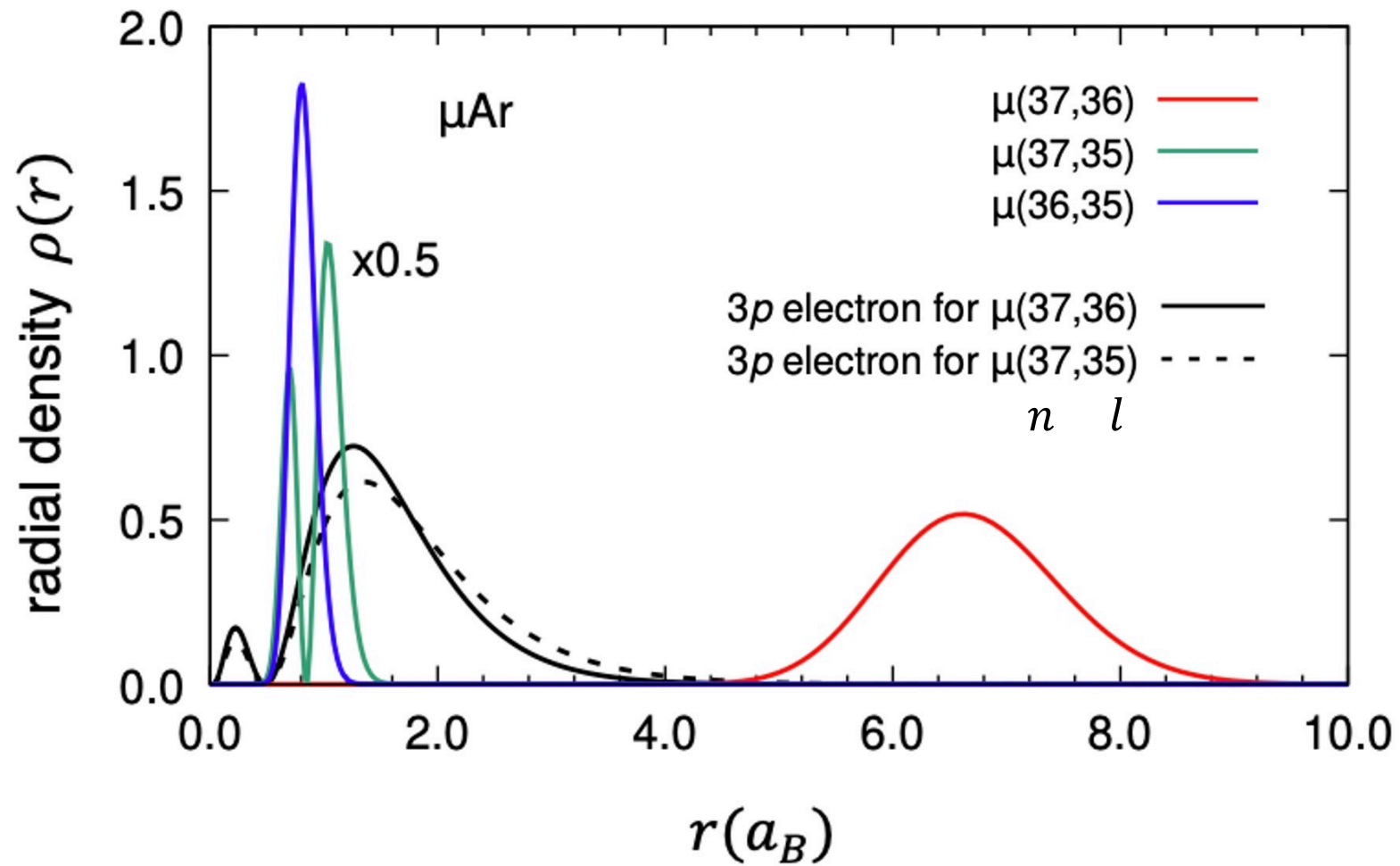
atomic central potential + centrifugal term  
( $\propto n$ )

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



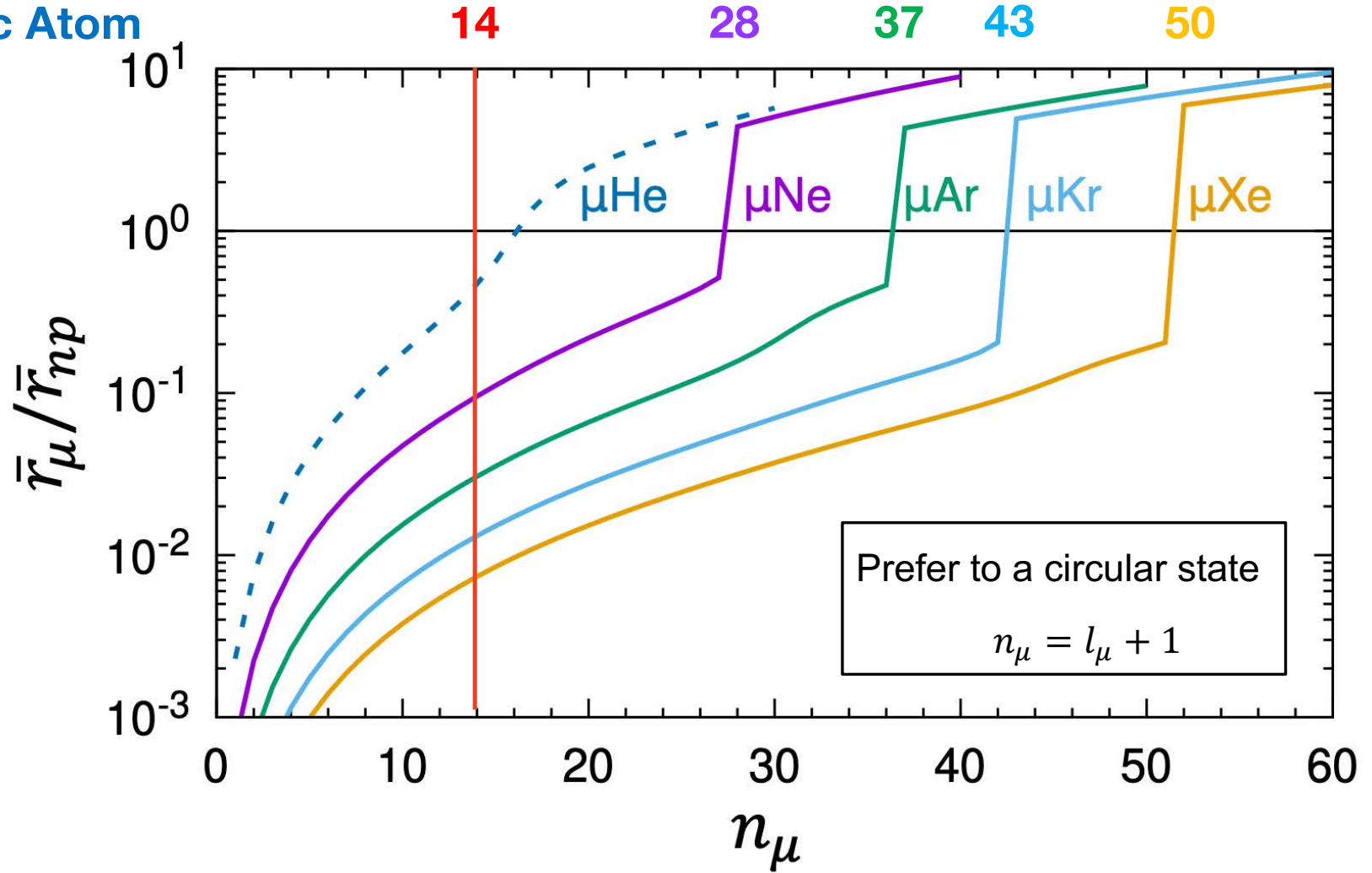
Answer to Puzzle: Radial wave function of muon by DFT





Critical  $n_\mu$  for Orbital Collapse = Initial Capture Level

### Muonic Atom





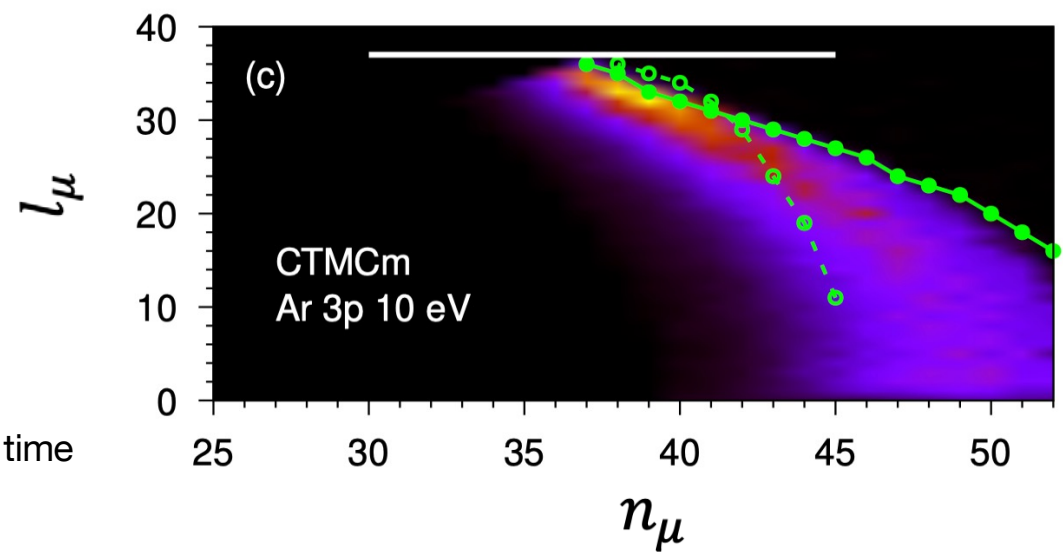
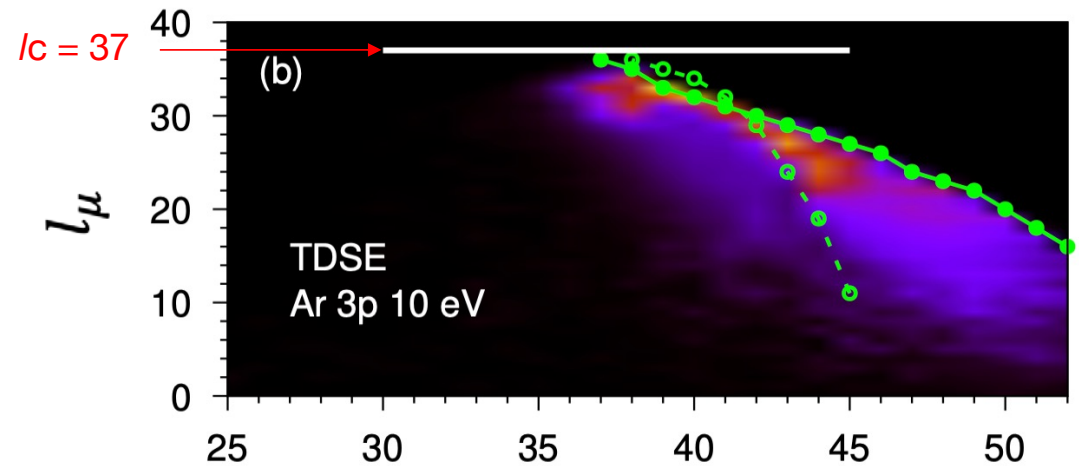
# State-specified muon capture probabilities

TDSE  
(time-dependent schrödinger equation)

VS

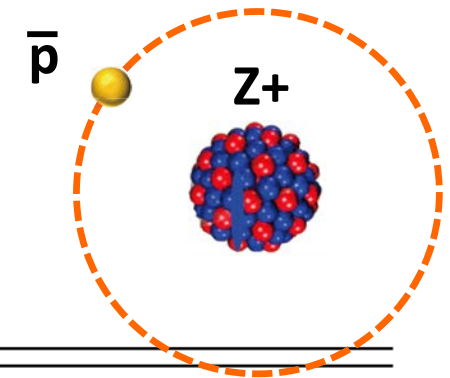
CTMCm  
(modified classical trajectory Monte Carlo)

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



## 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。

異なる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らうか。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、そこでの活動の積み立てられ方であらうか。

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。新たな発想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、独立した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、新しい結晶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、組織や人とのネットワークには、偶の疑わぬ出会いの場が必要である。コミュニケーションや精神的な補助は、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、偶然性や均一性よりは、むしろ多種

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見ええる。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、獨善性や集団よりも、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らうか。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であるか。それとも、自然にできるものなのであろうか。

一人の人間も、一生の間に、成長にとって深い遺産を持ついくつかの環境にめぐりあう。多くの人々が、子供時代と教育が重要な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