Institute Laboratory Assessment Interim Review

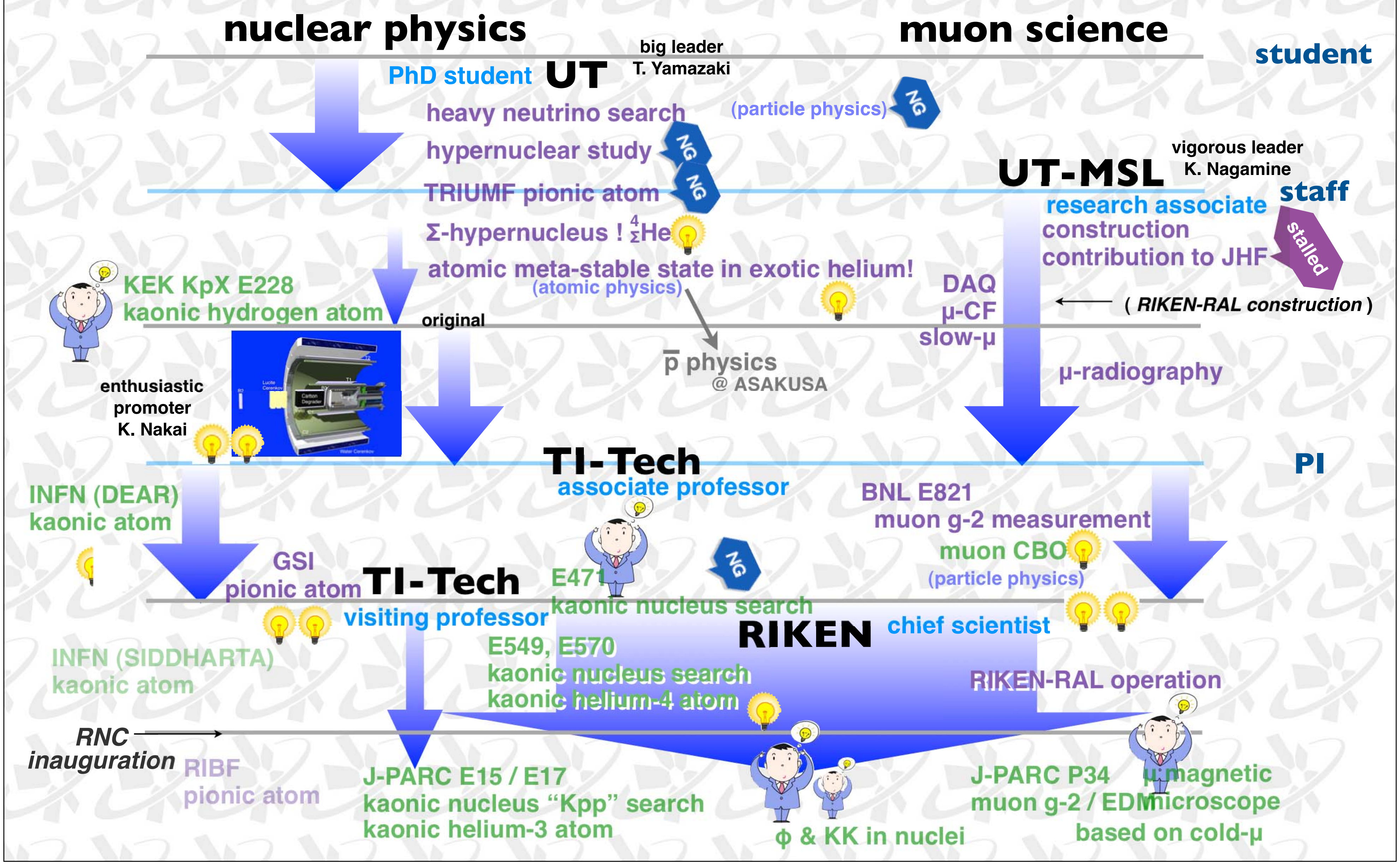
Date: 26/2/2010

Masahiko IWASAKI

Advanced Meson Science Laboratory

The Chief Scientist

Background - Present



RIKEN Nishina Center for Accelerator-Based Science (RNC)

1. Inaugurated in April 2007

(with 80 years of history)

2. Mission

1) Promotion of Accelrator-related Science

Nuclear Physics, Particle Physics, Applications

Kaonic Atoms/Nuclei @ J-PARC / DAΦNE
Muon Science @ RIKEN-RAL / J-PARC ?

2) Operation of RI Beam Factory (RIBF)

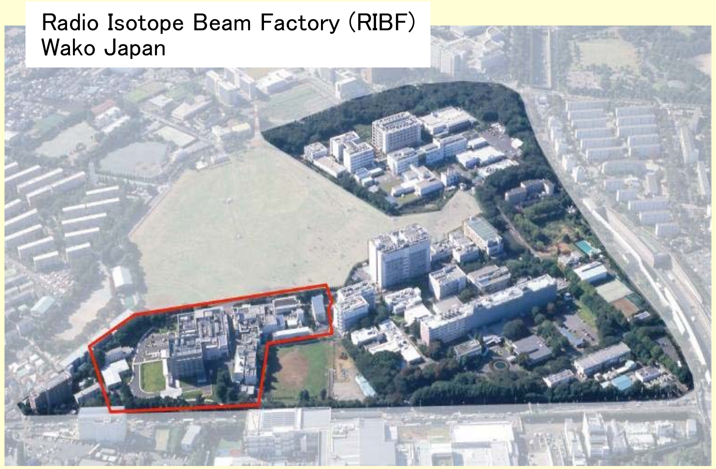
- Most powerful low-energy HI accelerator
- Operation started two years ago
- Open to the users world-wide

Pionic Atoms @ RIBF
In beam Mössbauer @ RIBF

3) International Collaboration

- RIKEN-BNL Research Center
  Spin physics @ RHIC polarized proton collider
- RIKEN RAL Branch
  Promotion of muon science

Cold Muon Generation RIKEN / UT / TITech / KEK / TRIUMF / Tohoku U. / TMU / JAXA
Pulse-Laser driven μSR Yamanashi U. / KEK / UCR / RAL / RIKEN



Advanced Meson Science Laboratory

nuclear physics

mesonic atoms (atomic physics / nuclear physics)

mesons in nuclei (nuclear physics)

Λ in nuclei (nuclear physics)

muon science

μCF : muon catalyzed fusion (chemistry / atomic physics / nuclear physics)

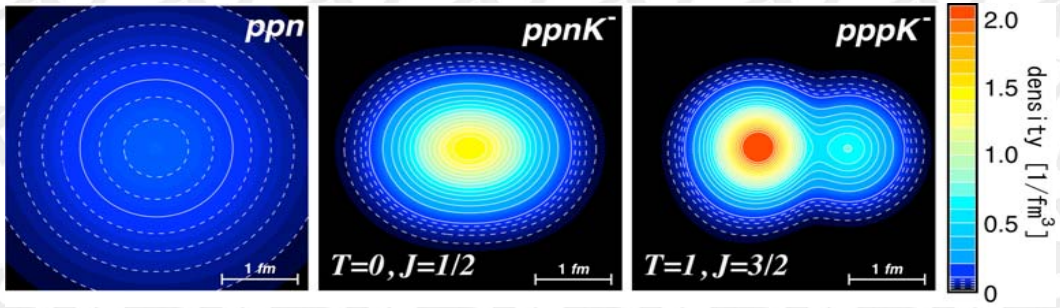
μSR : muon spin rotation / resonance ...
(condensed matter physics)

μA^* : muonic atoms (nuclear physics)

cold-μ : muon magnetic microscope / muon g-2
(particle physics / atomic physics / condensed matter physics)

Mössbauer

in-beam M : RI-beam Mössbauer spectroscopy
(condensed matter physics)

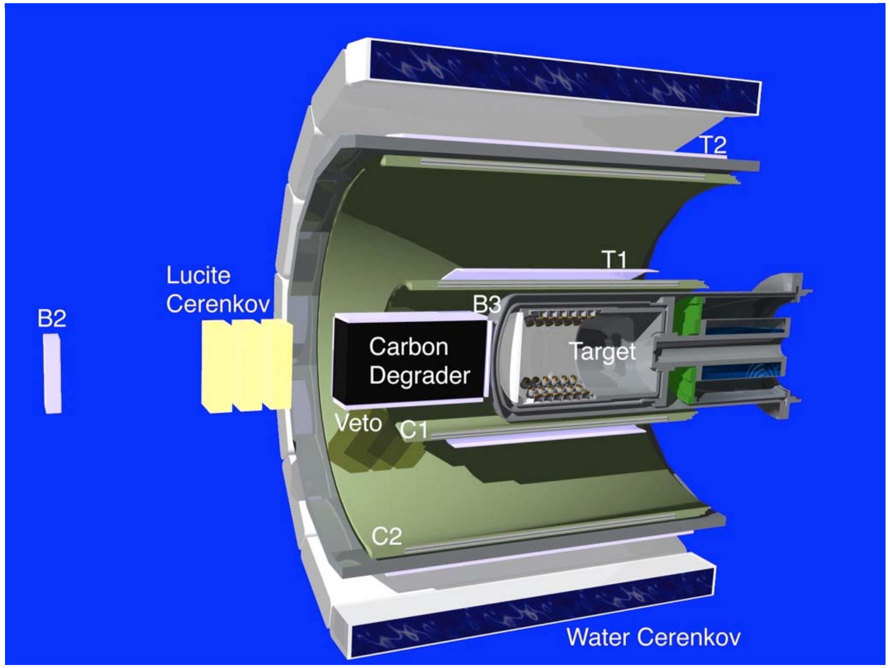


nuclear physics

Background - Present

original

KEK KpX E228
kaonic hydrogen atom



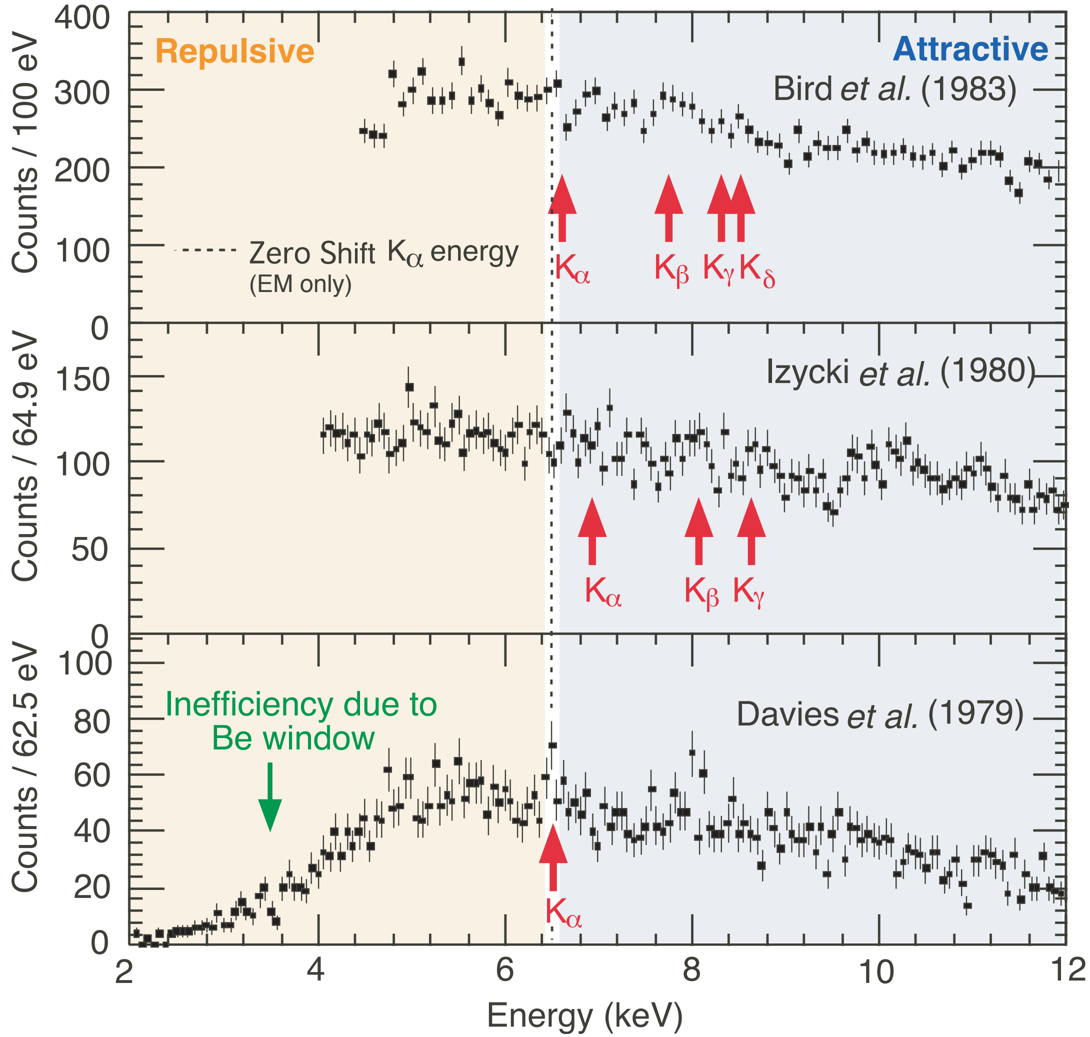
enthusiastic promoter
K. Nakai

funded 2M$ at age 33!

nuclear physics (pre-history)

K. Yazaki's question:

"Why you cannot resolve kaonic hydrogen puzzle?"



Small Signal
- Stark
- Low Hydrogen Density

Huge Background
- Absorption Reaction
- Decay in Flight

kaonic hydrogen puzzle

PHYSICAL REVIEW D

VOLUME 50

1 AUGUST 1994

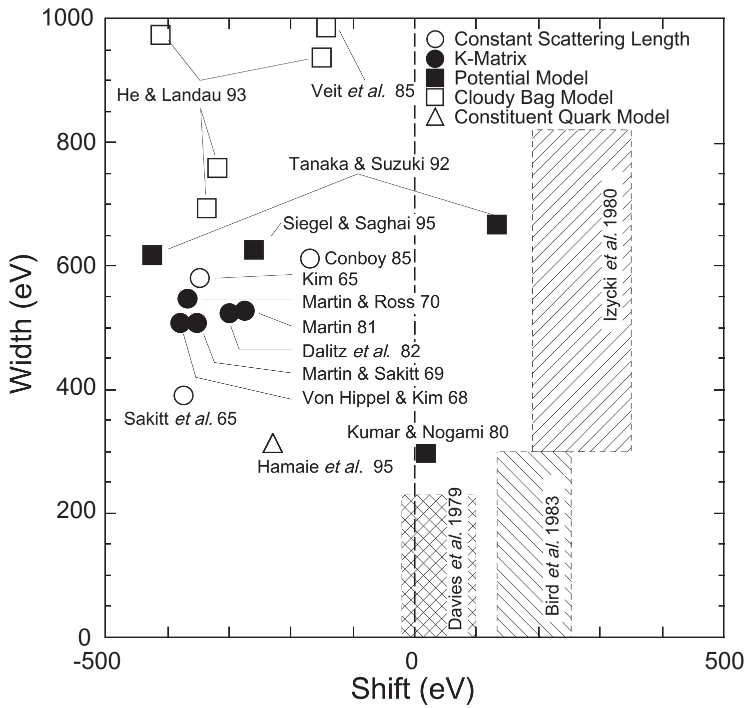
THE Λ(1405) by R.H. Dalitz, Oxford University

....

The present status of the Λ(1405) thus depends heavily on theoretical arguments, a somewhat unsatisfactory basis for a four-star rating. Nevertheless, there is no known reason to doubt its existence or quantum numbers. A measurement of the energy-level shifts and widths for the atomic levels of kaonic hydrogen (and deuterium) would give a valuable check on analysis of the $(\Sigma\pi, N\overline{K})$ amplitudes, since the energy of the K^-p atom lies roughly midway between those for the two sets of data. The three measurement of (ΔE-$i\Gamma$/2) for kaonic hydrogen are inconsistent with one another and require that the sign of $\mathrm{Re}(A_{I=0} + A_{I=1})$ be opposite that deduced from $N\overline{K}$ reaction data (see BATTY 89). Accurate measurements of (ΔE-$i\Gamma$/2) values for kaonic hydrogen are badly needed, but may not be possible until the KAON factory becomes operational.

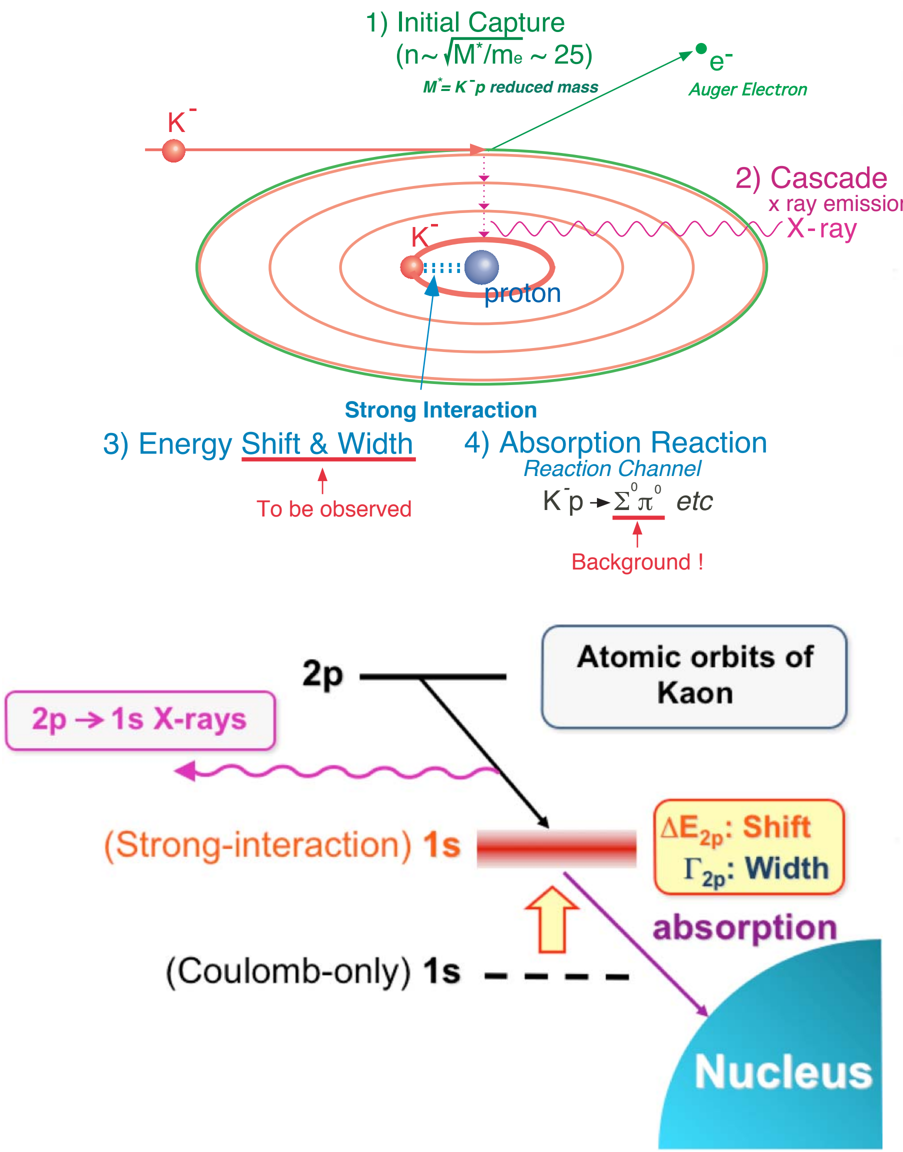
....

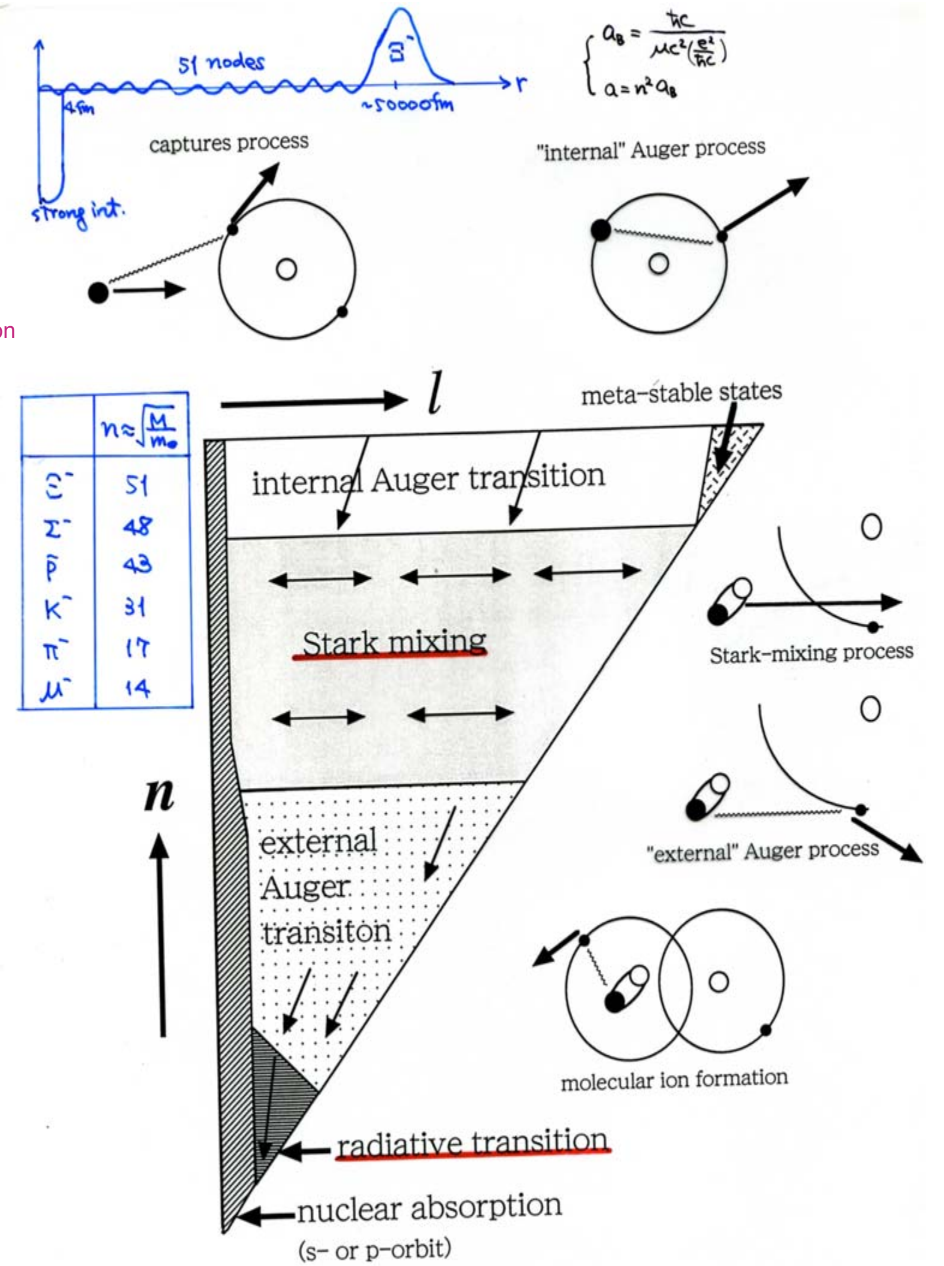
Kaonic Hydrogen Puzzle!



kaonic hydrogen formation

Kaonic Atom Formation



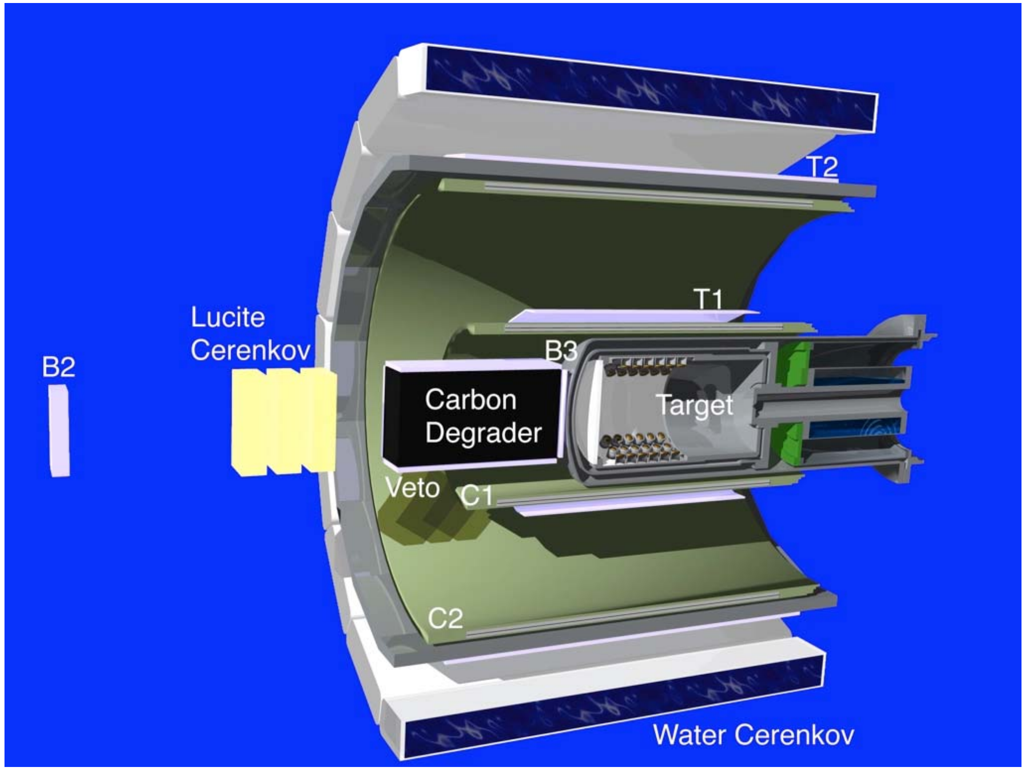


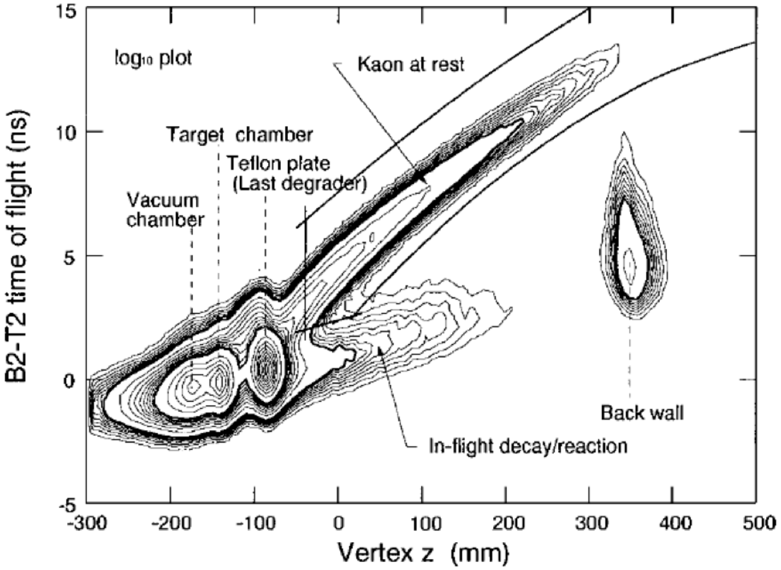
nuclear physics (pre-history)

How to approach kaonic hydrogen puzzle?

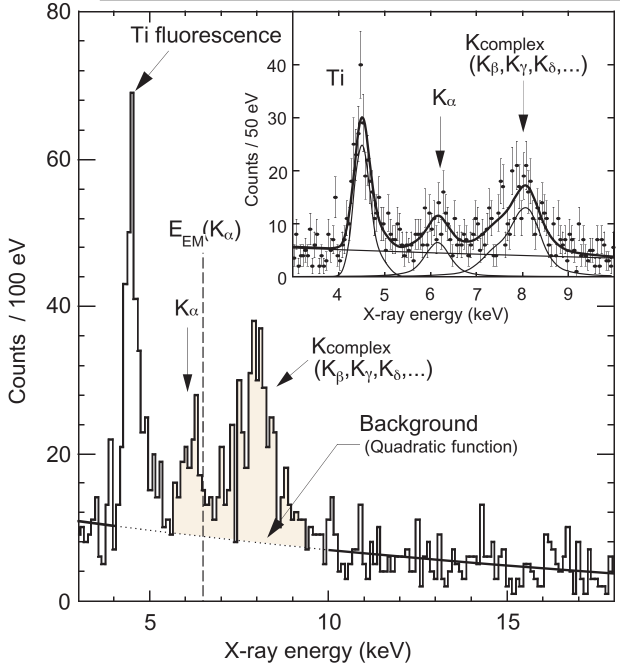
- **Background Free**
  final state tagging
- **Gas Target**
  Stark Free
- **Si(Li) in Hydrogen Gas**

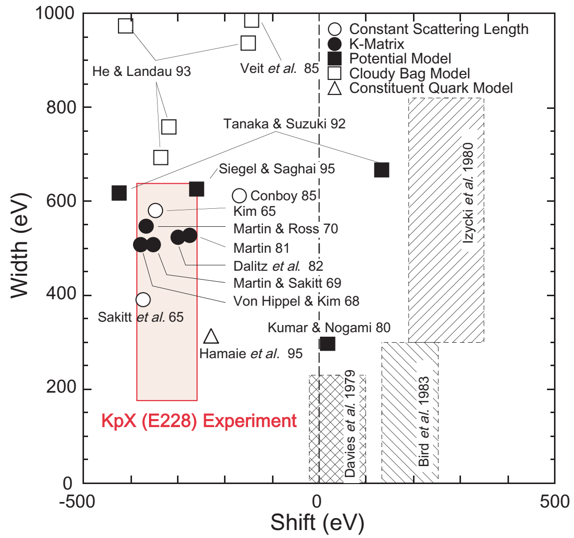
Reaction	Produced Particles	Branching Ratio	$\pi/\mu/e$ Multiplicity (>150 MeV/c)	γ Multiplicity
Free Decay of K^-				
$\mu^-\nu$	$\mu^-\nu$	63.5 %	1	0
$\pi^-\pi^o$	$\pi^-2\gamma$	21.2 %	1	2
$\pi^-\pi^-\pi^+$	$\pi^-\pi^-\pi^+$	5.59 %	0	0
$e^-\pi^o\nu$	$e^-2\gamma$	4.82 %	1	2
$\mu^-\pi^o\nu$	$\mu^-2\gamma$	3.18 %	1	2
$\pi^-\pi^o\pi^o$	$\pi^-4\gamma$	1.73 %	0	4
K^-p Reaction				
$\Sigma^+\pi^-$	$\pi^-2\gamma p$	10 %	1	2
$\Sigma^+\pi^-$	$\pi^-\pi^+n$	10 %	2	0
$\Sigma^-\pi^+$	$\pi^+\pi^-n$	46 %	2	0
$\Sigma^o\pi^o$	$\pi^-3\gamma p$	18 %	0	3
$\Sigma^o\pi^o$	$5\gamma n$	10 %	0	5
$\Lambda\pi^o$	$\pi^-2\gamma p$	4 %	0	2
$\Lambda\pi^o$	$4\gamma n$	2 %	0	4





nuclear physics (pre-history)





The European Physical Journal C

Volume 15 · Number 1-4 · 2000

THE $\Lambda(1405)$

Revised March 1998 by R.H. Dalitz, Oxford University

....

From the measurement of $2p - 1s$ x rays from kaonic-hydrogen, the energy-level shift ΔE and width Γ of its 1s state can give us two further constraints on the $(\bar{\Sigma}\pi, NK)$ system, at an energy roughly midway between those from the low-energy hydrogen bubble chamber studies and those from $qR(\Sigma\pi)$ observations below pK^- threshold. IWASAKI 97 have reported the first convincing observation of this x ray, with a good initial estimate:

$$\Delta E - i\Gamma/2 = (-323 \pm 63 \pm 11) - i(204 \pm 104 \pm 50)\ \text{eV}. \quad (2)$$

the errors here encompass about half of the predictions made following various analyses and/or models for the in-flight K^-p and sub-threshold $qR(\Sigma\pi)$ data. Better measurements will be needed to discriminate between the analyses and predictions. ...., perhaps from the DAΦNE storage ring at Frascati, information vital for our quantitative understanding of the $(\Sigma\pi, NK)$ system in this region. .....

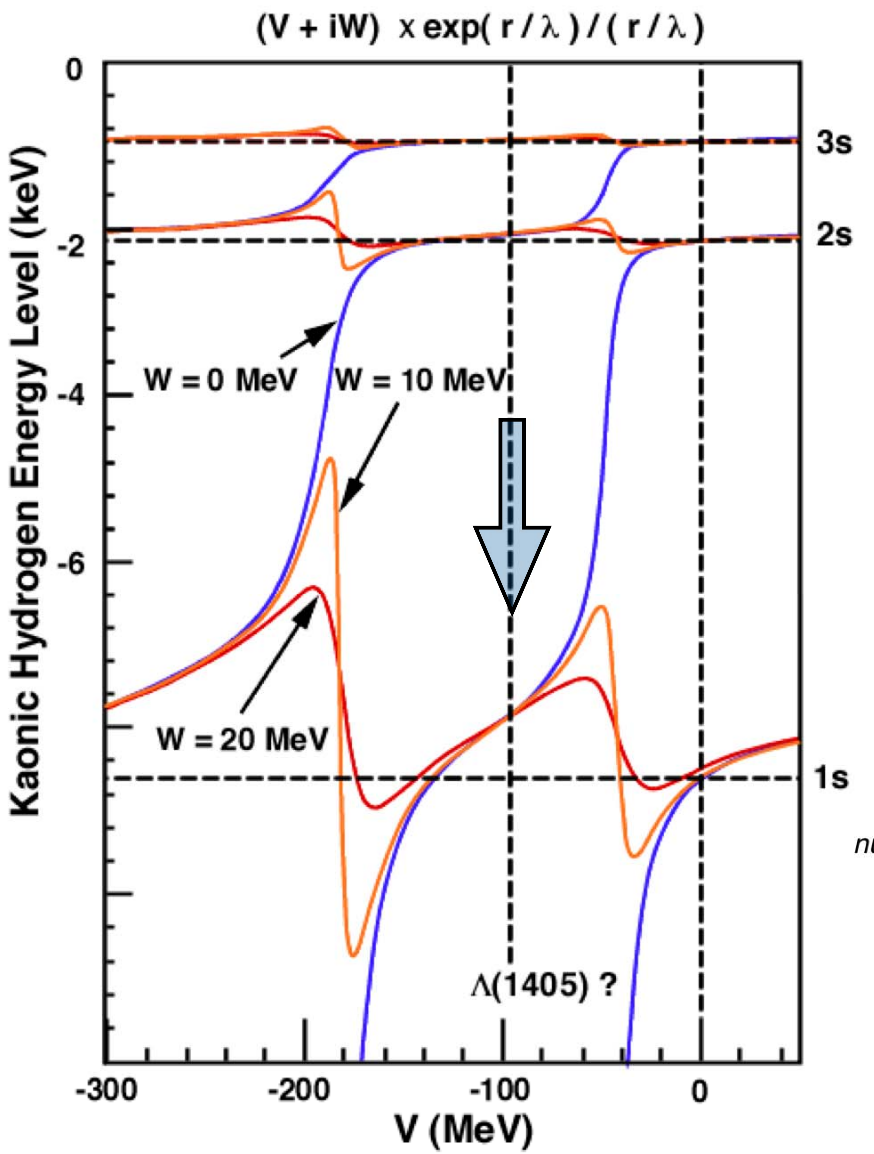
Kaonic hydrogen puzzle was resolved!

Dose $\bar{K}N$ interaction repulsive?

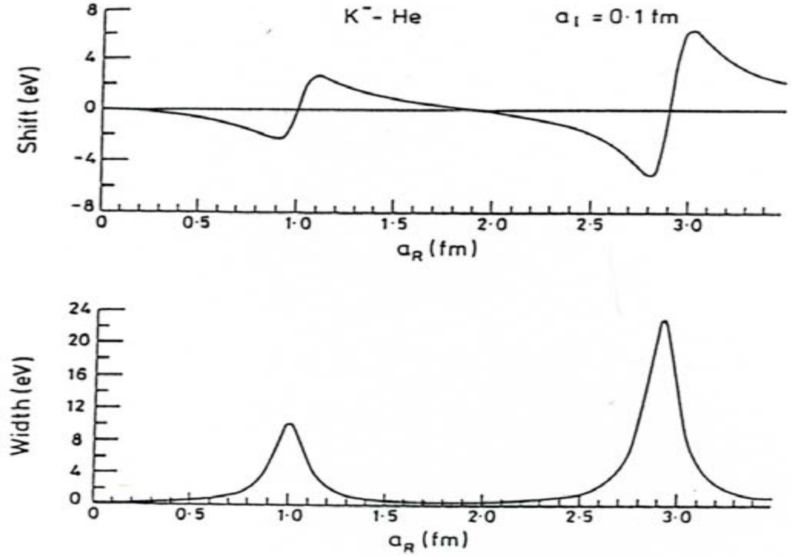
R. Seki, Phys. Rev. C5 (1972) 1196

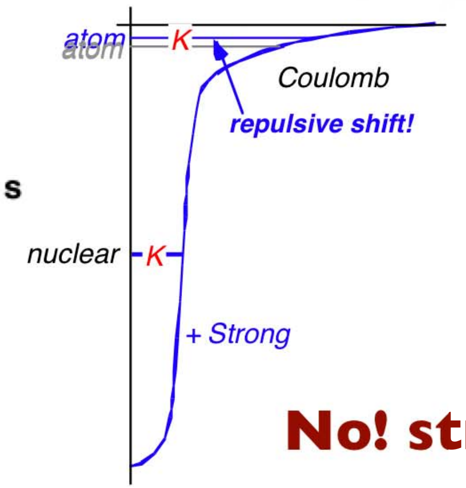
S. Baird et al., Nucl. Phys. A392 (1983) 297

C.J. Batty, Nucl. Phys. A508 (1990) 89c



$$W_0 = -277\ \text{MeV fm}^{-1} \times \bar{a} = -30\ \text{MeV}$$





No! strongly attractive!

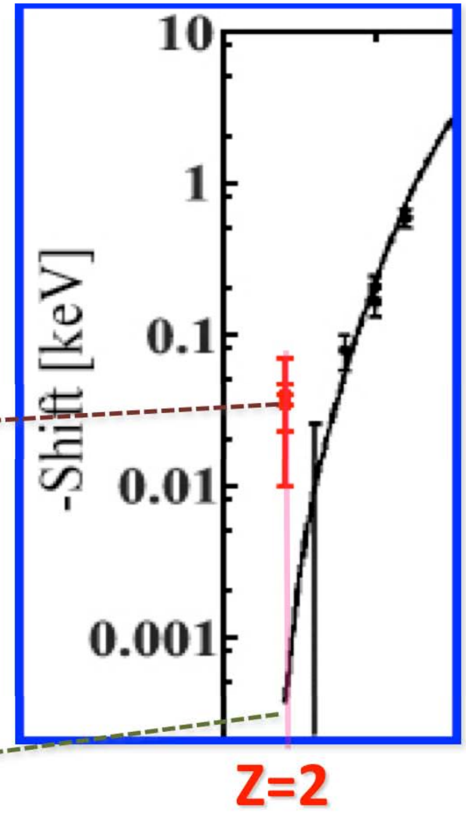
Kaonic helium puzzle

S.Hirenzaki, Y.Okumura,
H.Toki, E.Oset, and A.Ramos
Phys. Rev. C 61 055205

Previous K-^{4}He measurements

	- Shift - ΔE_{2p} (eV)	- Width - Γ_{2p} (eV)
1971	-41 ± 33	$-$
1979	-35 ± 12	30 ± 30
1983	-50 ± 12	100 ± 40
Avg.	-43 ± 8	55 ± 34

shifts and widths of kaon atomic levels



Experimental data:
Very large shift (~40 eV)

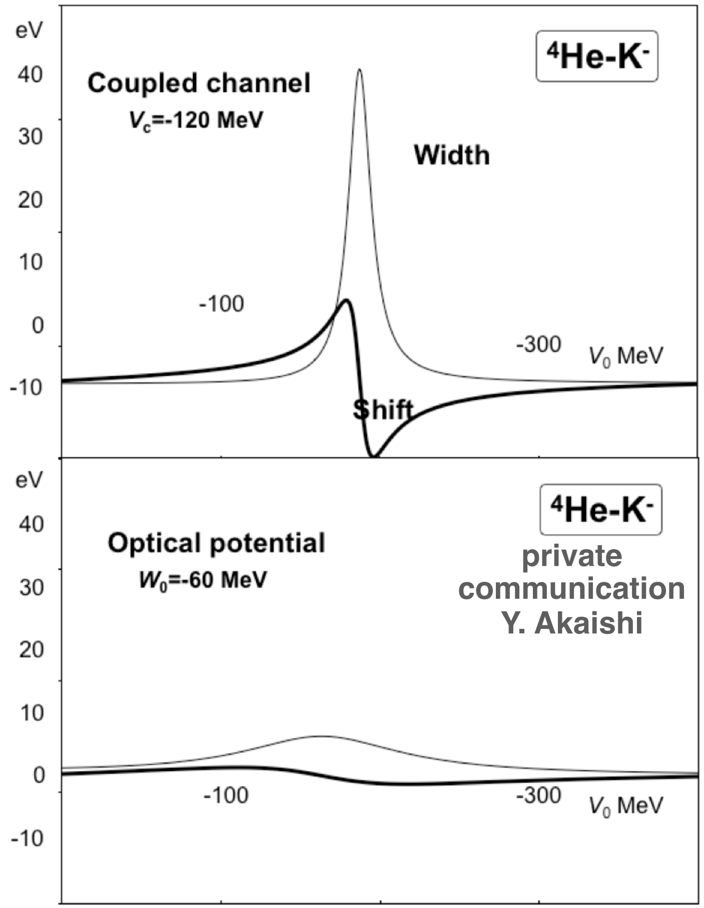
contradict for long !

Optical Model values:
Very small shift (~0 eV)

S. Hirenzaki, Y. Okumura, H. Toki, E. Oset and A. Ramos Phys. Rev. C 61 (2000)

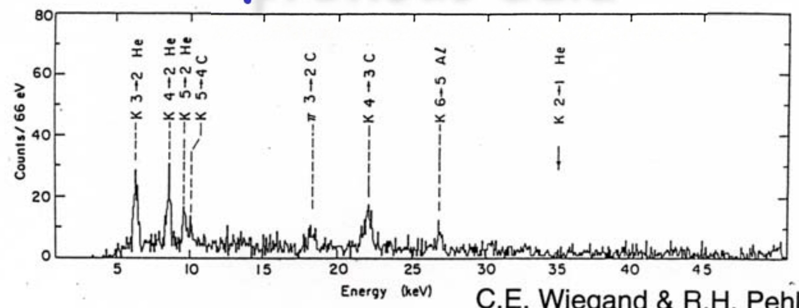
Coupled channel & data

large shift scenario from coupled-channel calculation

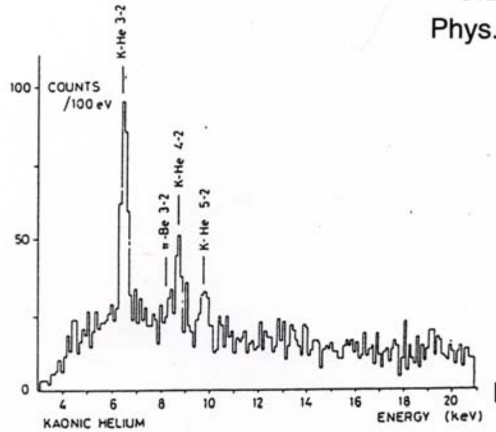


private communication
Y. Akaishi

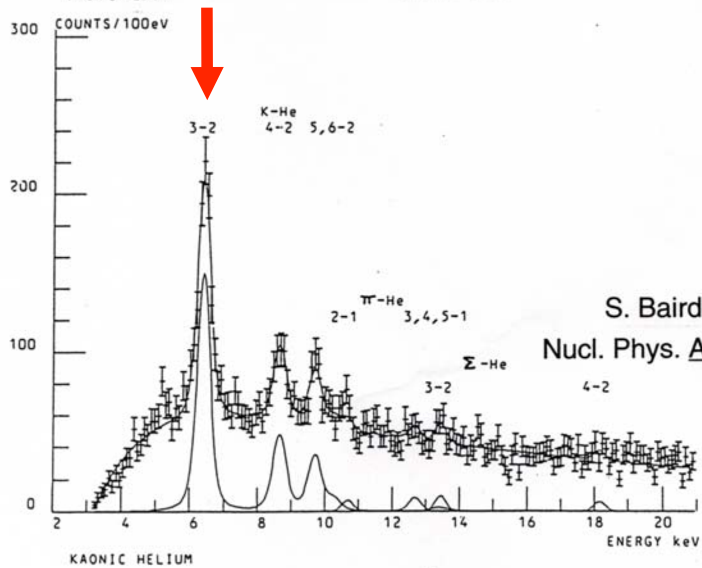
previous data



C.E. Wiegand & R.H. Pehl,
Phys. Rev. Lett. 27 (1971) 1410



C.J. Batty *et al.*,
Nucl. Phys. A326 (1979) 455

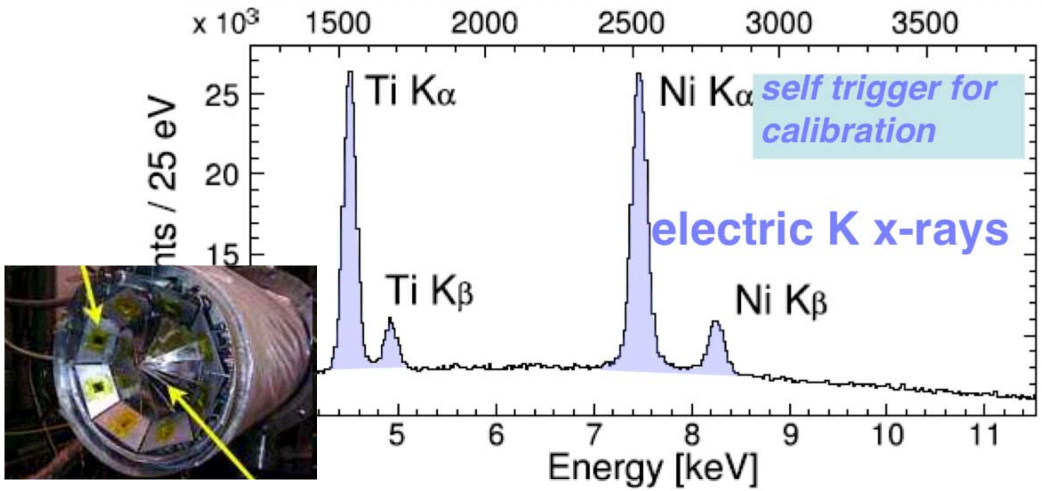


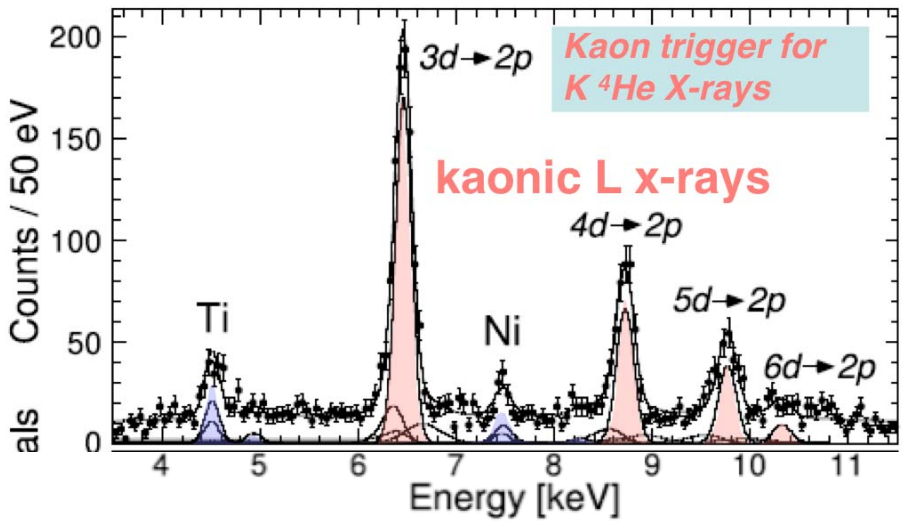
X-ray spectrum measured with $(2.3 \pm 1.2) \times 10^7$ kaons stopping in liquid helium.

S. Baird *et al.*,
Nucl. Phys. A392 (1983) 29

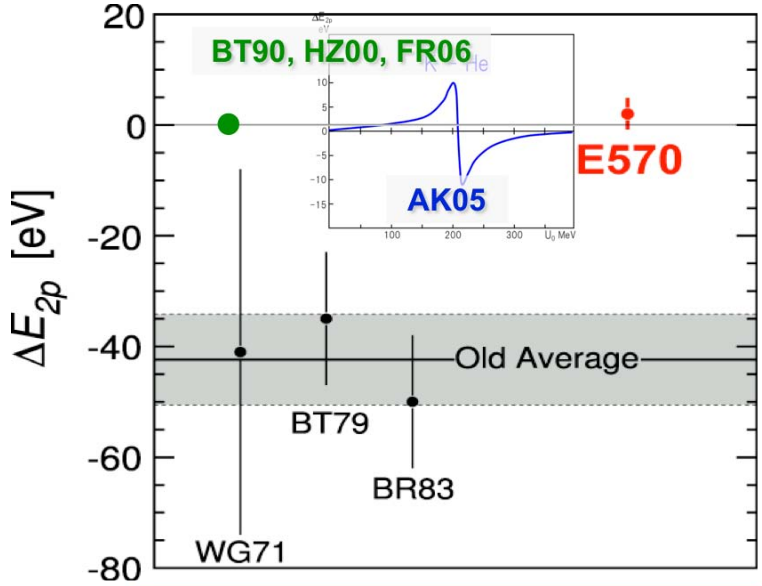
Kaonic helium puzzle was resolved

Success in resolving Kaonic Helium-4 Puzzle by KEK E570





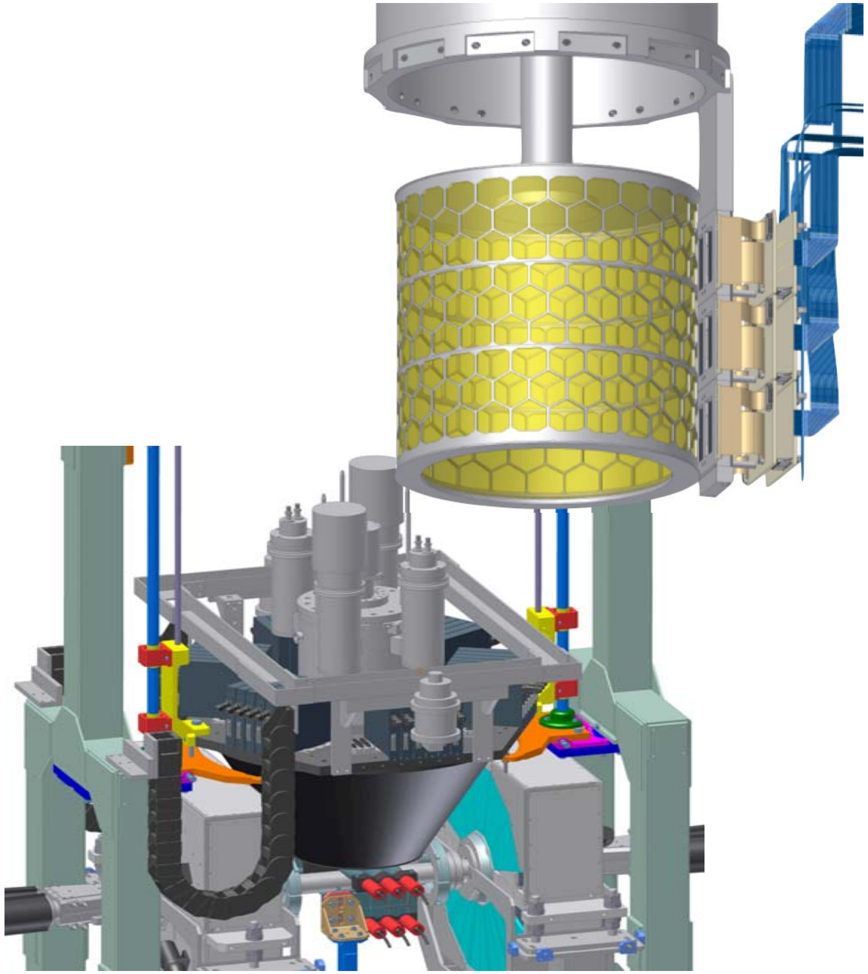
WG71: C. E. Wiegand, R. Pehl, PRL27, 1410 (1971)
BT79: C. J. Batty, et al., NPA326, 455 (1979)
BR83: S. Baird, et al., NPA392, 297 (1983)

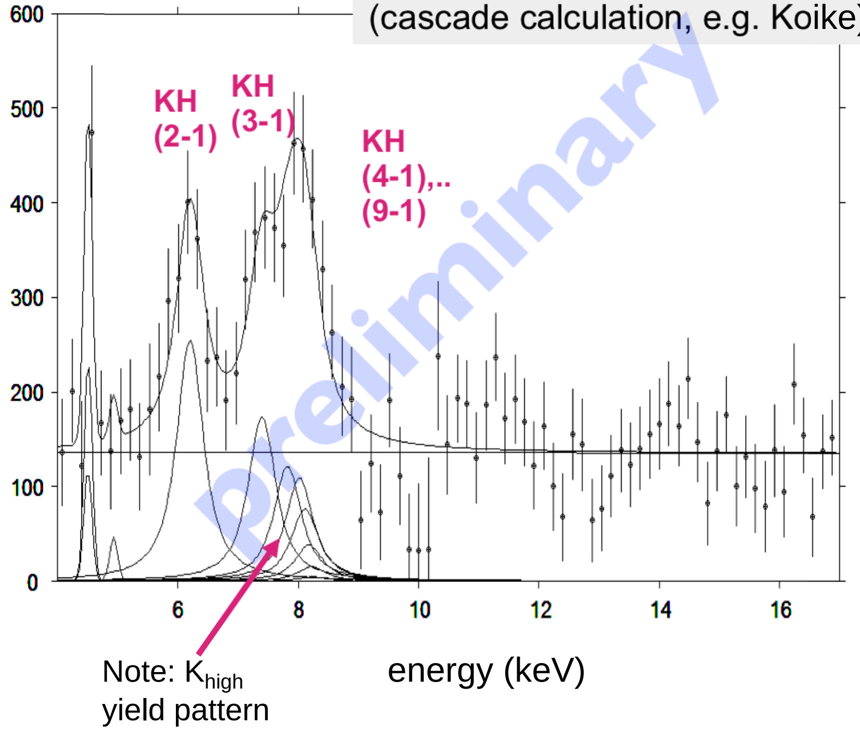


- **BT90**: Global fitting
  C. J. Batty, NPA508, 89c (1990)
- **HZ00**: SU(3) Chiral unitary model
  S. Hirenzaki et al,. PRC61. 055205 (2000)
- **FR06**: Consideration for nonlinearly density dependence (~0.4 eV as the lowest)
  E. Friedman, private communication (2006)
- **AK05**: Coupled-Channel model
  Y. Akaishi, EXA05 proceedings (2005)

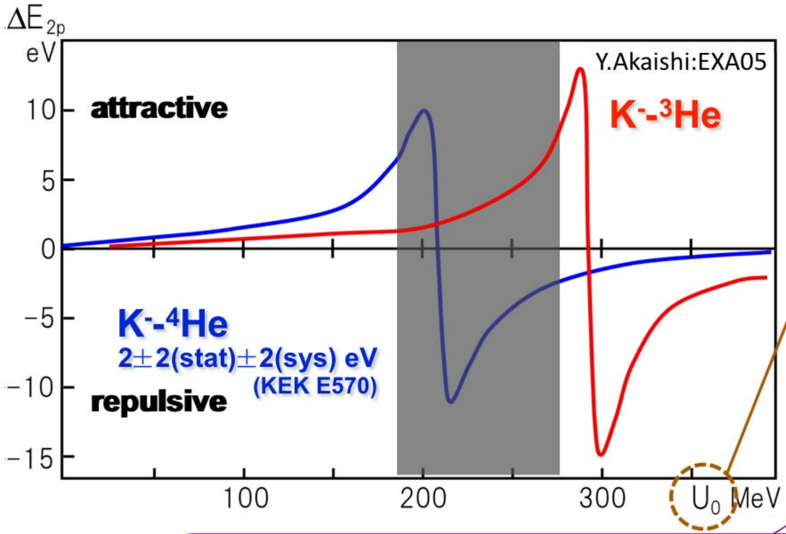
The SIDDHARTA experiment

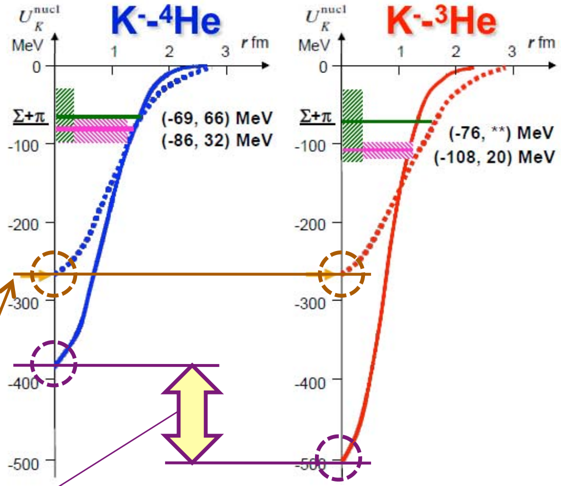
For the signal 8 Voigtians with
given gauss resolution and free identical
Lorentzian width are used for (2-1),.. (9-1)
The position pattern is fixed by the QED values
The intensities of (2-1),(3-1) and (4-1)
are free, those of the higher transitions are
coupled according to theoretical calculations
(cascade calculation, e.g. Koike)





Move to kaonic helium-3 : J-PARC E17



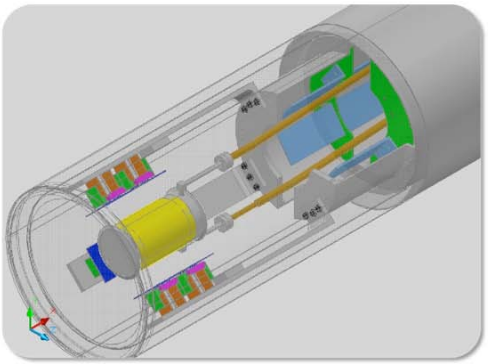


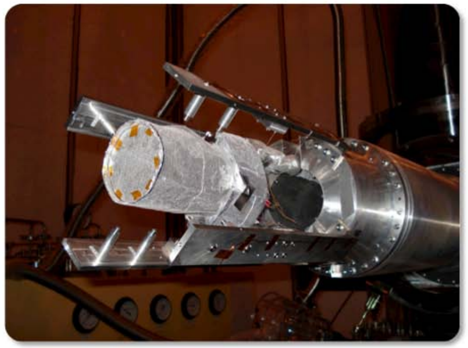
Y. Akaishi and T. Yamazaki Phys. Rev. C **65** 044005 (2002)

By the potential difference,
large difference expected between K^--^{4}He and K^--^{3}He

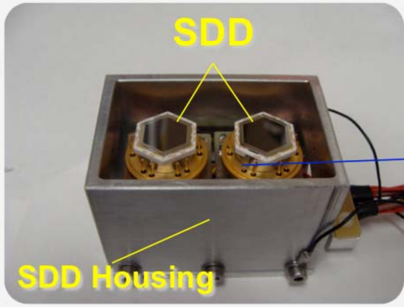
If it observed to be…

- **Large shift** ⇒ **deeply-bound state exist**
- **Zero shift** ⇒ **potential is shallow**

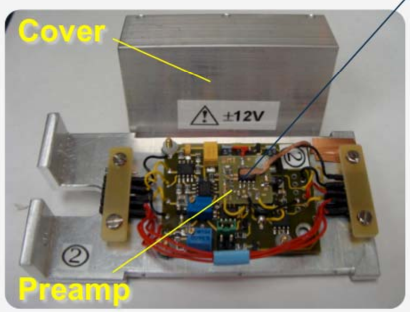




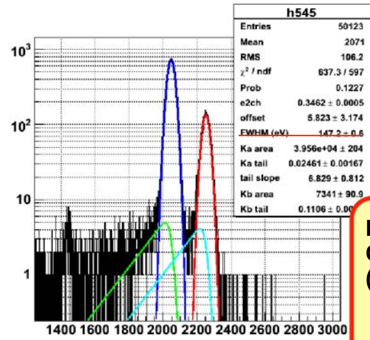
New SDD & Preamp



Effective area: 100 mm²
KETEK products
(http://www.ketek.net./)



KETEK products



SDD Housing Temp.
: 140 K
Preamp Temp.
chip : 246 K
cover : 160 K

Fitted with
Gauss+tail for Kα / Kβ
(common s & tail slope)
Resolution:
~150 eV

What is mass ?

if at rest

$$E = mc^2$$

Standard Model (Gauge Theory) is not end of the story,
Nanbu tells Local Gauge Invariance and Mass is related...

Why quarks do have masses?

--- Toward the origin of the Hadron Mass ---

compound mass ≅ 1 : Σatomic mass
< -10^{-8} chemical energy

atomic mass ≅ 1 : nuclear mass
~ 10^{-4} : electron mass
< -10^{-8} : Coulomb energy

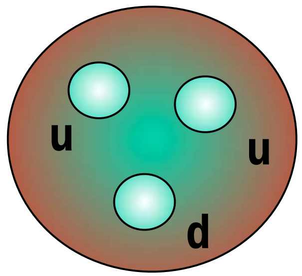
nuclear mass ≅ 0.99 : Σnucleon(hadron) mass
~ -10^{-2} : nuclear binding energy

hadron mass ≅ 0.01 : Σquark mass
How quarks are confined?
: totally unknown
~+0.99 : <$\bar{q}q$> condensation?
spontaneous symmetry breaking?!

Higgs mechanism

U	d	S
5 MeV	10 MeV	100 MeV

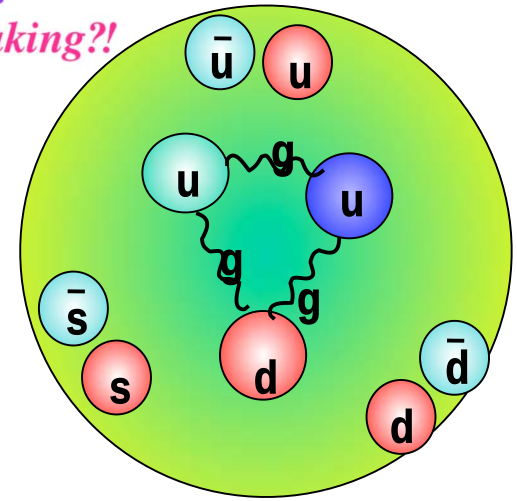
vacuum is filled with higgs!



proton

BUT, m_p is not equal to
$m_u + m_u + m_d$

only few



there are contribution from sea quarks and gluons

and

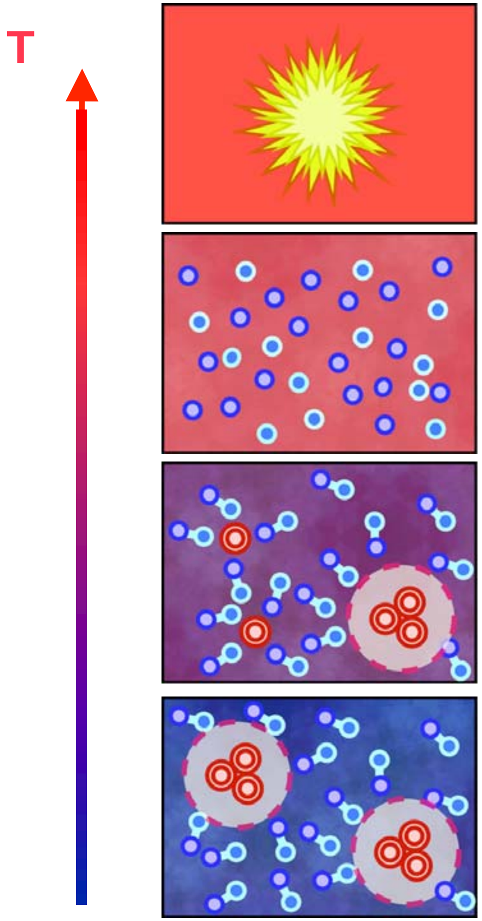
even strangeness in it!

What then happens, if one embed a meson in nuclei?

why proton is heavy?

higgs mechanism give less than 2% of the proton mass
quark anti-quark pair condensation exist? = what is vacuum?

begun by Nanbu



big bang

higgs condensation

T:~ 100GeV

Quark mass ~MeV

$q\bar{q}$ pair condensation

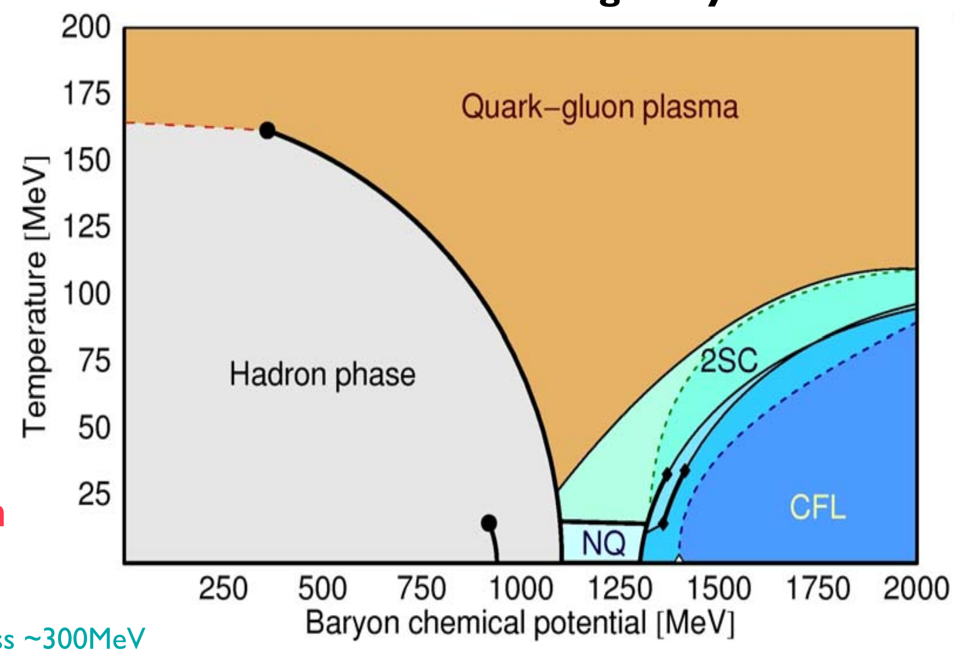
T:~ 200MeV

Quark mass ~300MeV
Baryon formation

present universe（vacuum)

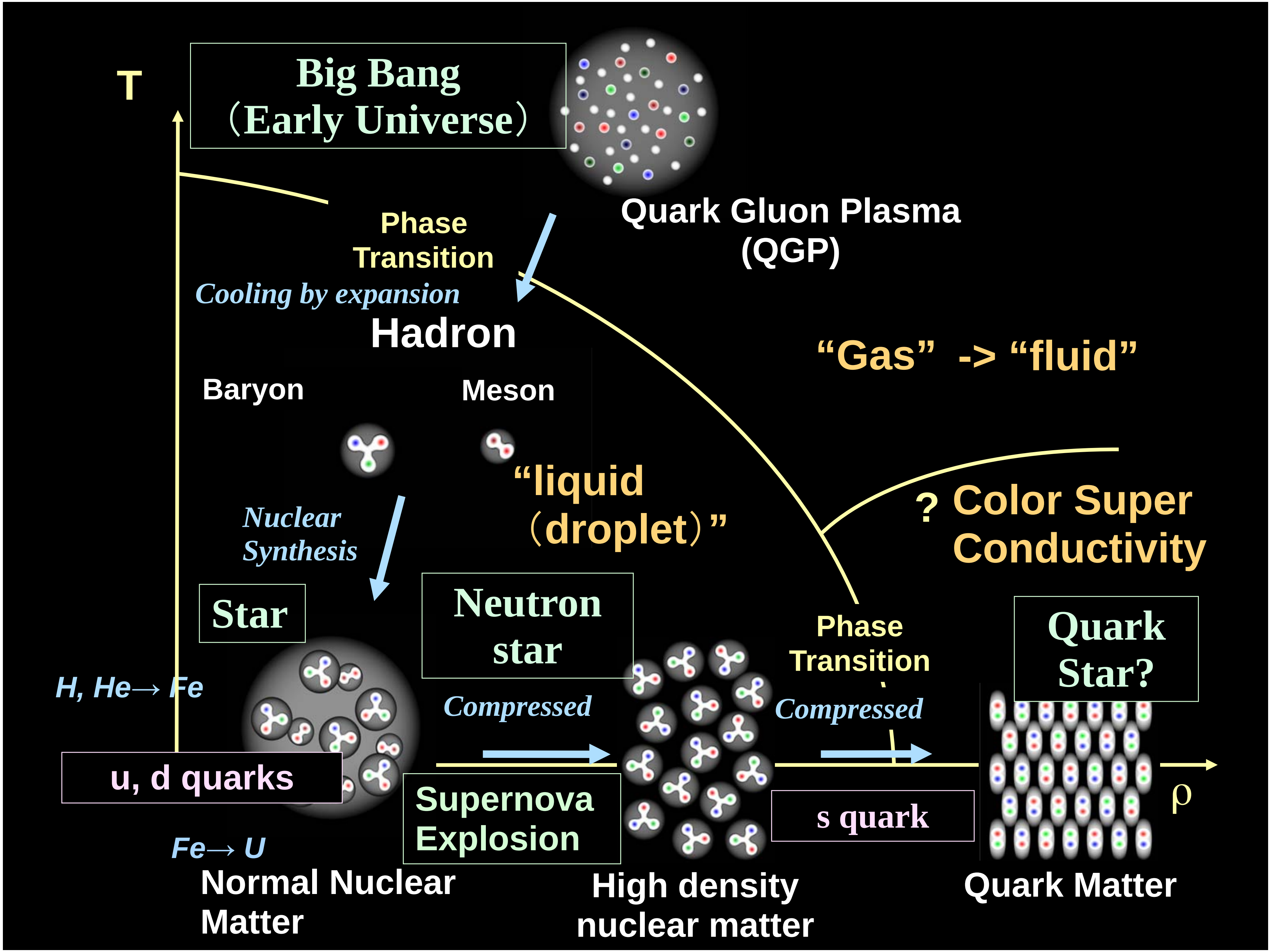
T:~ 0 eV

Baryon mass ~1000 MeV

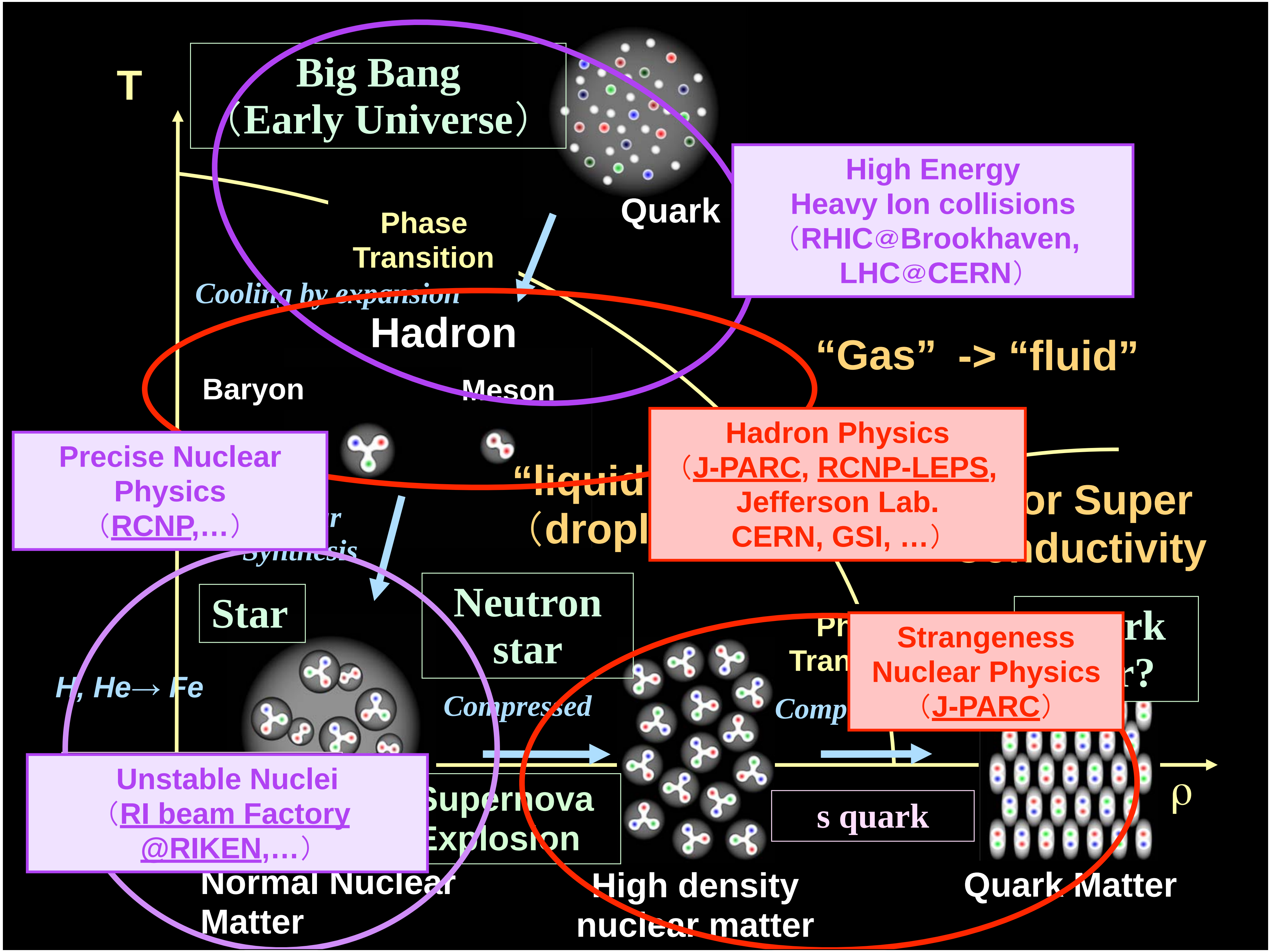


Baryon mass ~0 ?

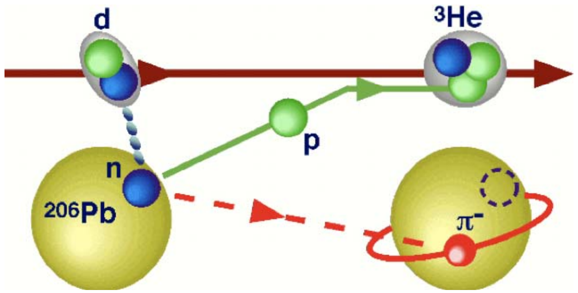
ρ

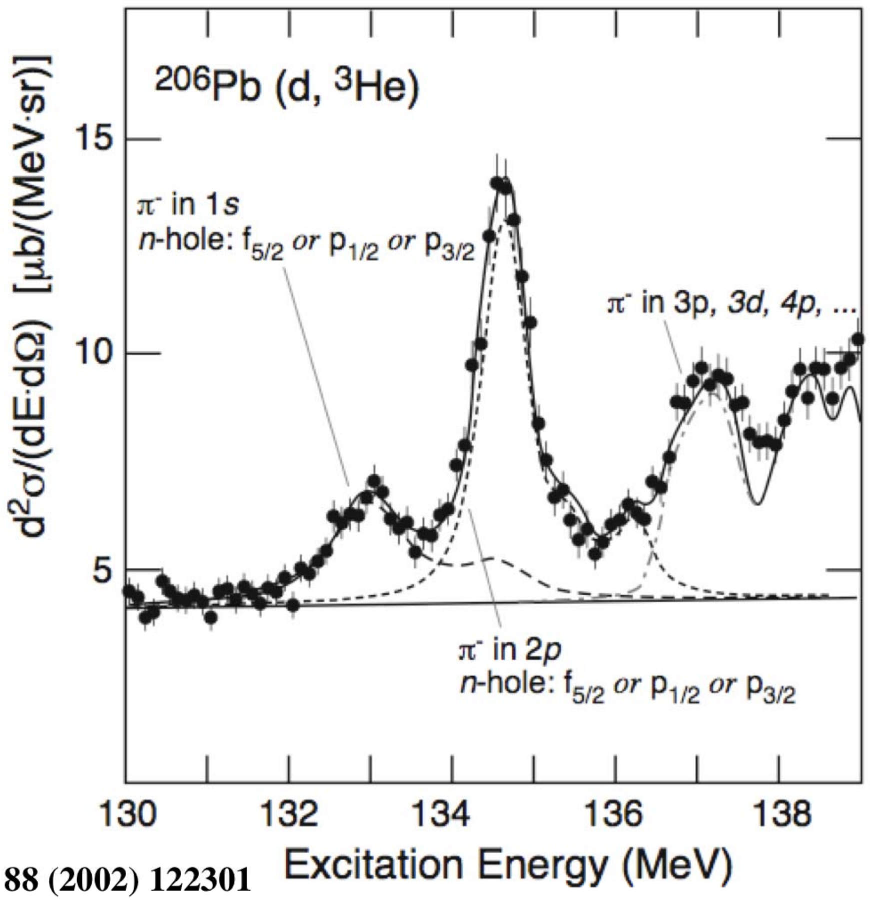


T
Big Bang
(Early Universe)
Quark Gluon Plasma
(QGP)
Phase
Transition
Cooling by expansion
Hadron
"Gas" -> "fluid"
Baryon
Meson
"liquid
(droplet)"
? Color Super
Conductivity
Nuclear
Synthesis
Star
Neutron
star
Phase
Transition
Quark
Star?
H, He→ Fe
Compressed
Compressed
u, d quarks
Supernova
Explosion
s quark
ρ
Fe→ U
Normal Nuclear
Matter
High density
nuclear matter
Quark Matter


T
Big Bang
（Early Universe）
Quark
Phase
Transition
Cooling by expansion
Hadron
Baryon
Meson
High Energy
Heavy Ion collisions
（RHIC@Brookhaven,
LHC@CERN）
"Gas" -> "fluid"
Precise Nuclear
Physics
（RCNP,…）
"liquid
（dropl
Hadron Physics
（J-PARC, RCNP-LEPS,
Jefferson Lab.
CERN, GSI, …）
or Super
nductivity
Star
Neutron
star
H, He→ Fe
Compressed
Strangeness
Nuclear Physics
（J-PARC）
Comp
Tran
s quark
ρ
Unstable Nuclei
（RI beam Factory
@RIKEN,…）
Supernova
Explosion
Normal Nuclear
Matter
High density
nuclear matter
Quark Matter

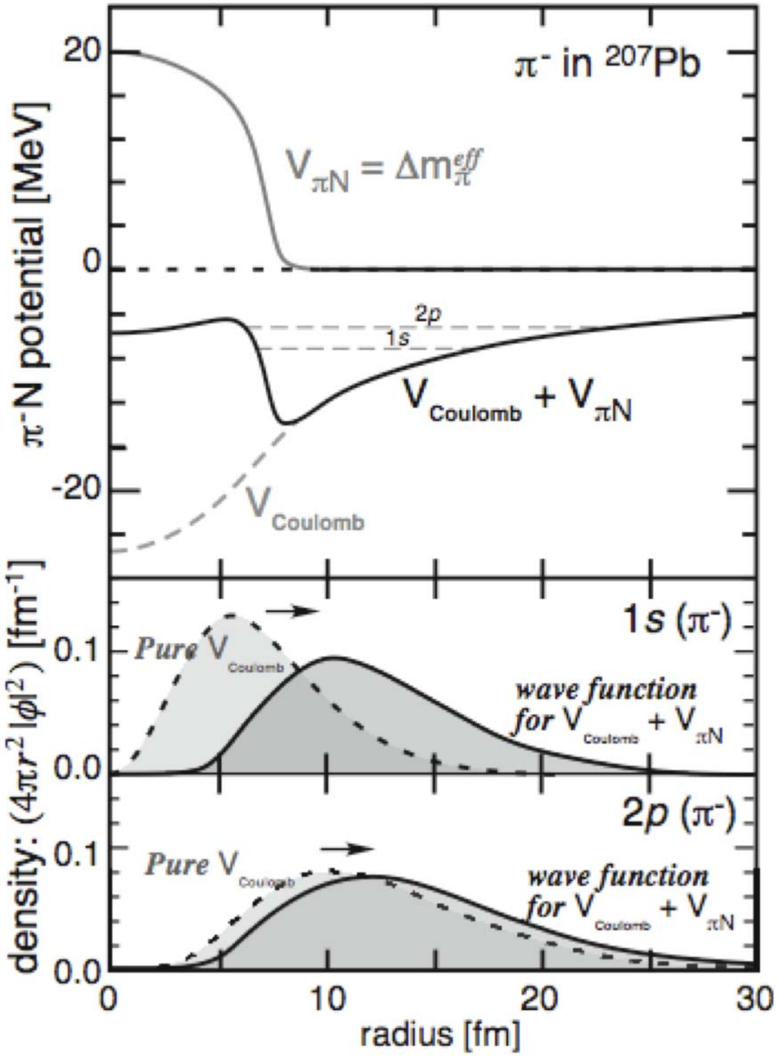
The first meson bound state attached to nuclei!





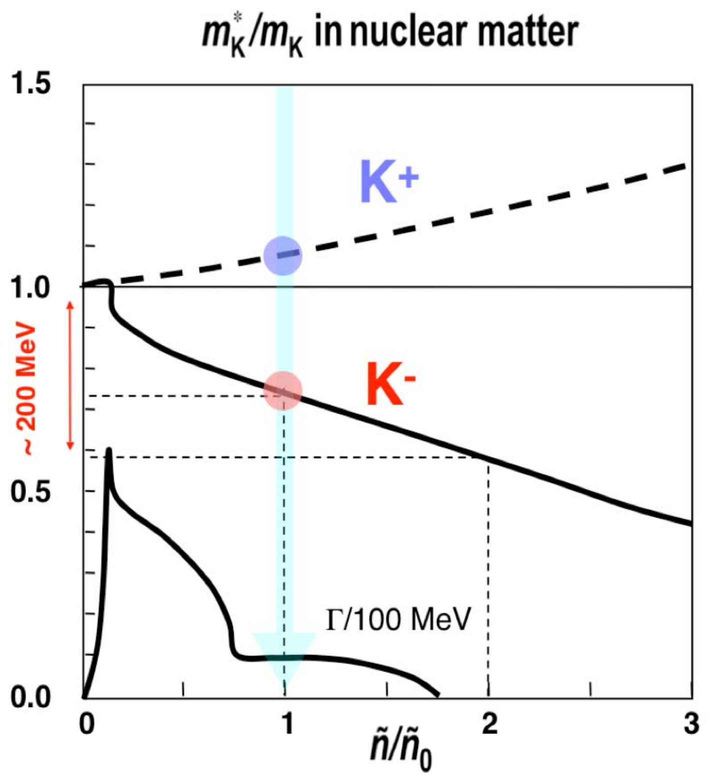
PRL 88 (2002) 122301

π atom

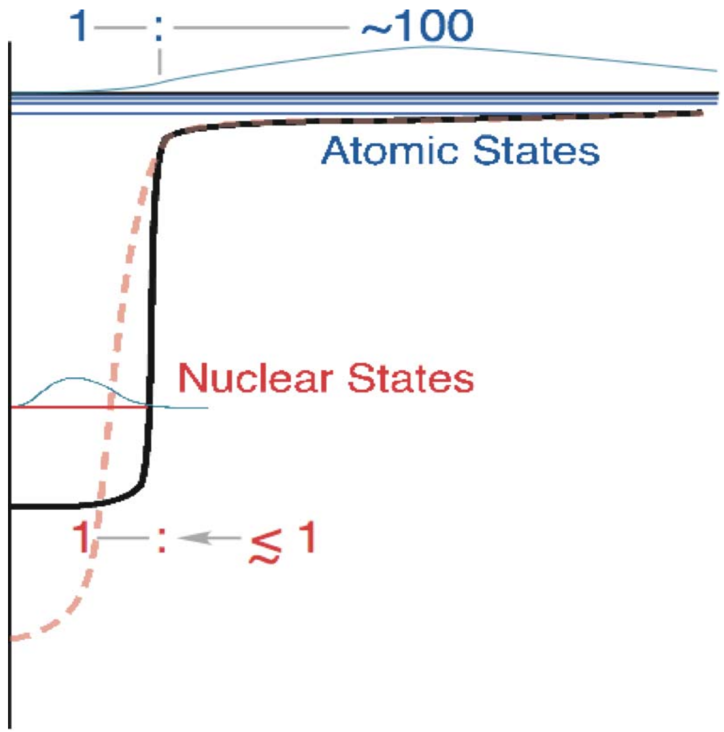


K mesons in nuclei

Because KN s-wave interaction is strongly attractive, something drastic may happen!



T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.



atomic states K at rest

K̄N interaction at normal nuclear density

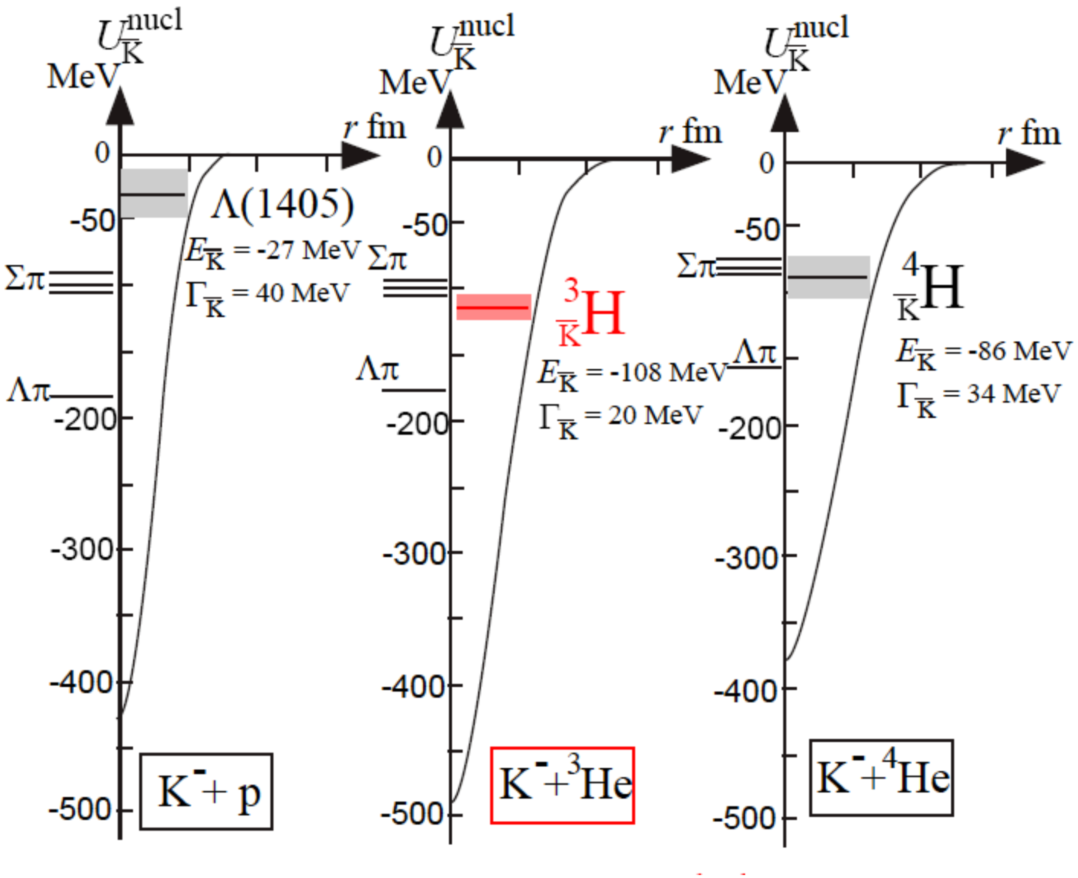
E17: K^- ^{3}He $3d$ - $2p$ x-ray

nuclear states K at 1 GeV/c

K̄N interaction at higher nuclear density

E15: ^{3}He(K^-, n) missing & invariant mass

Embedding K in nuclei?

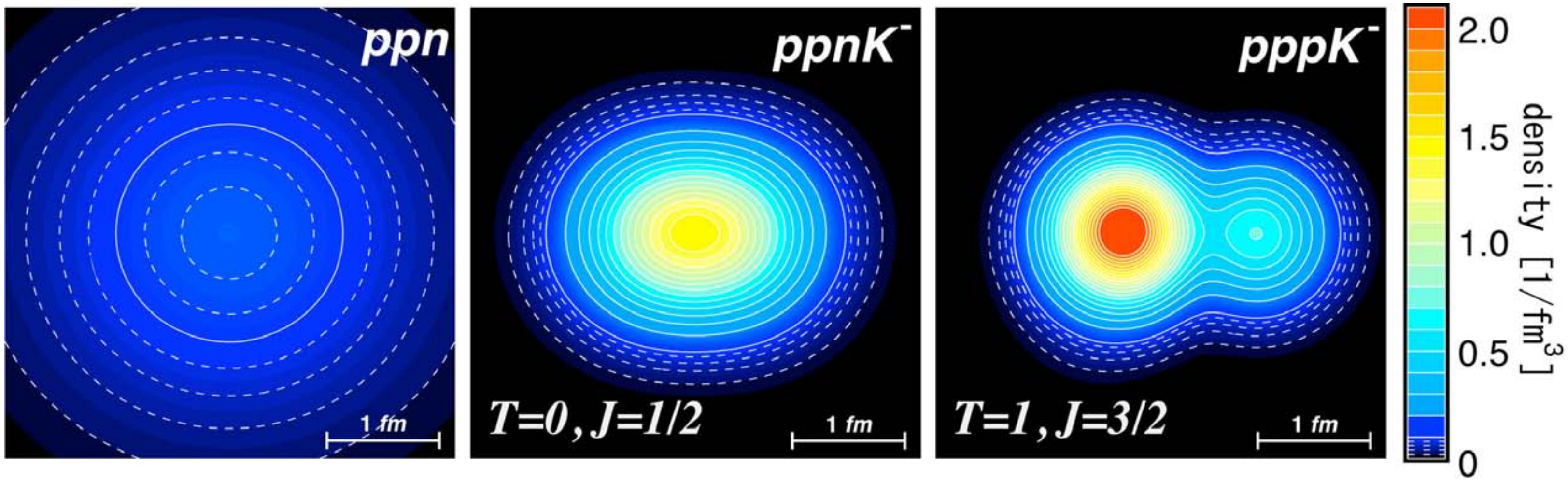


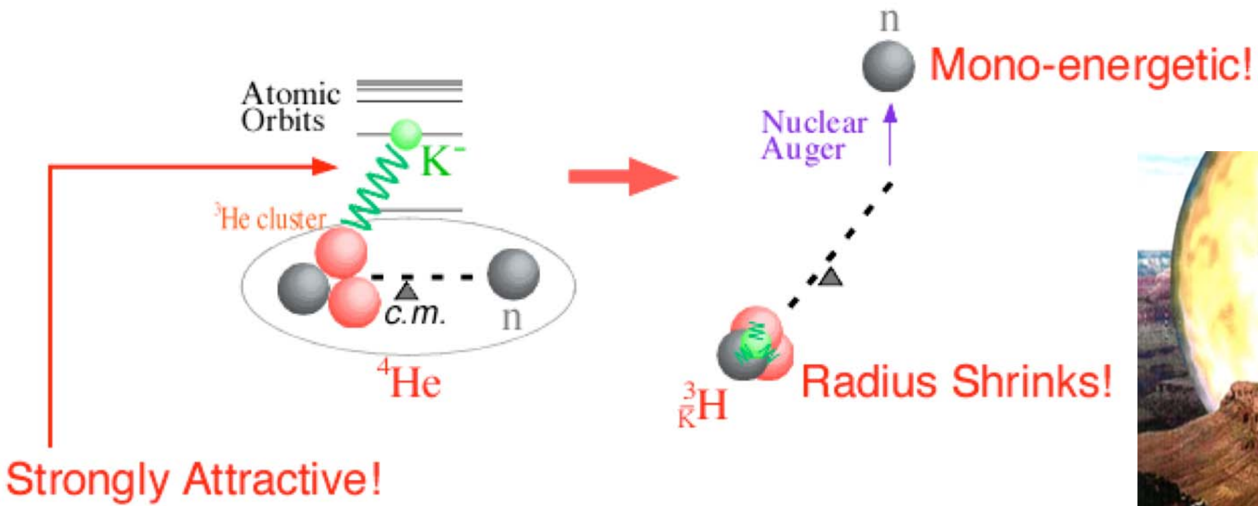
Y. Akaishi & T. Yamazaki : PRC 65 (2002) 044005

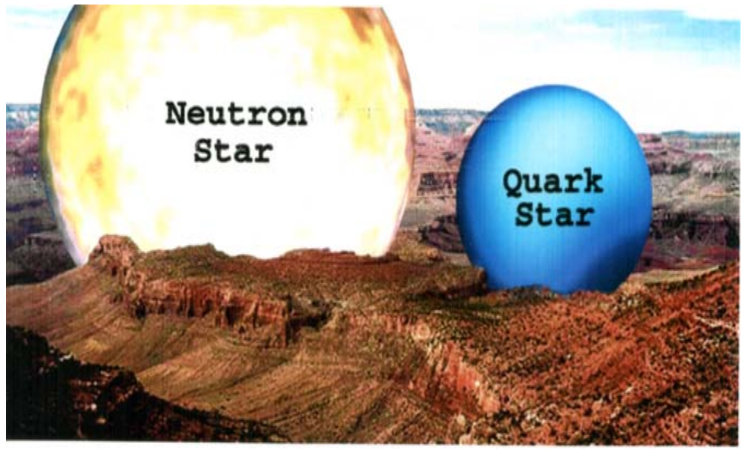
- Deep!
  ~ 100 MeV
  cf: $B_N \sim 10$ MeV
- Narrow!
  ~ 20 MeV
  = meta-stable
- Shrink!
  = high density?

Embedding K in nuclei?

A. Dote et al.
Phys. Rev. C 70 (2004) 044313





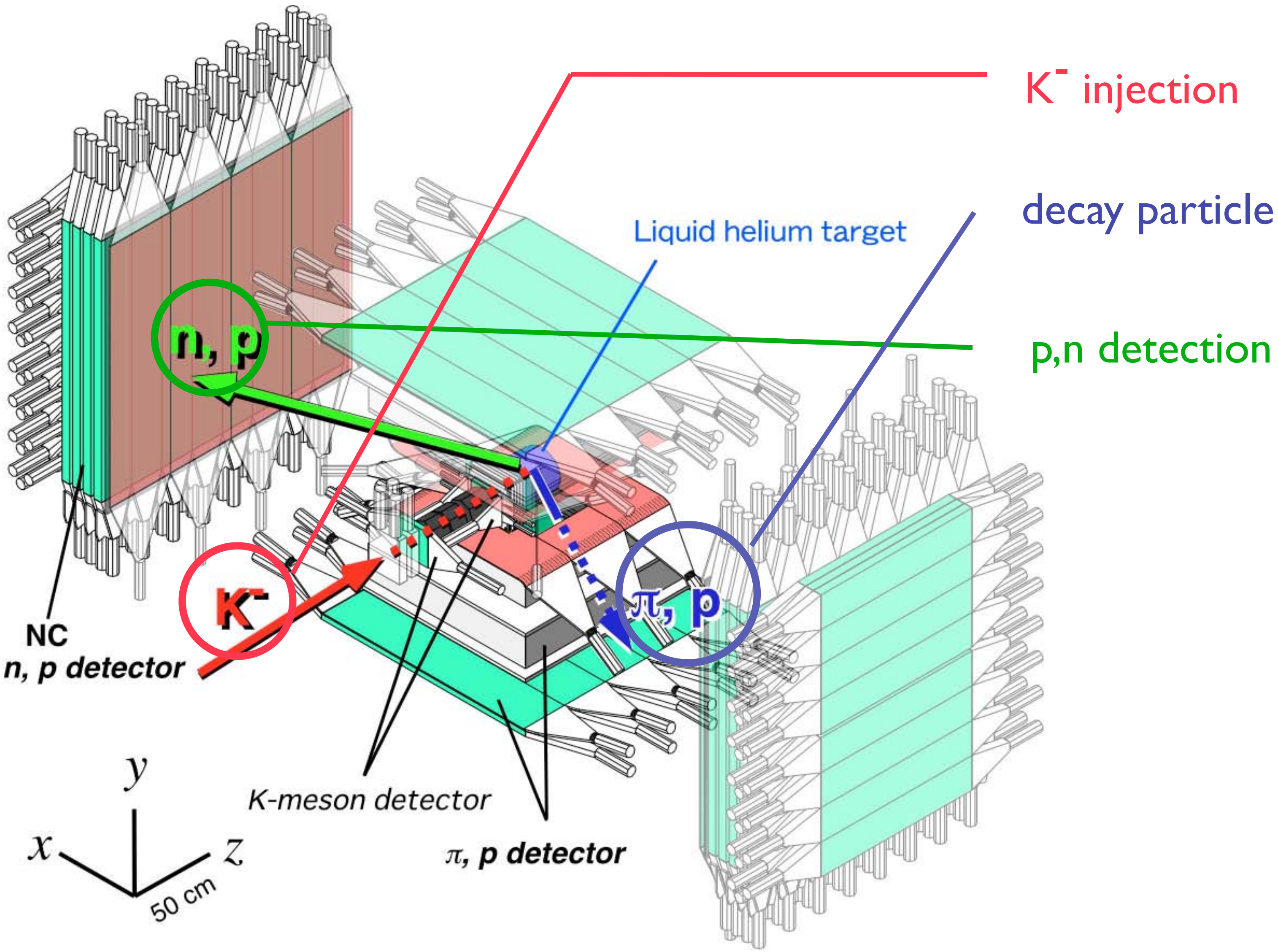


☞ hadron mass

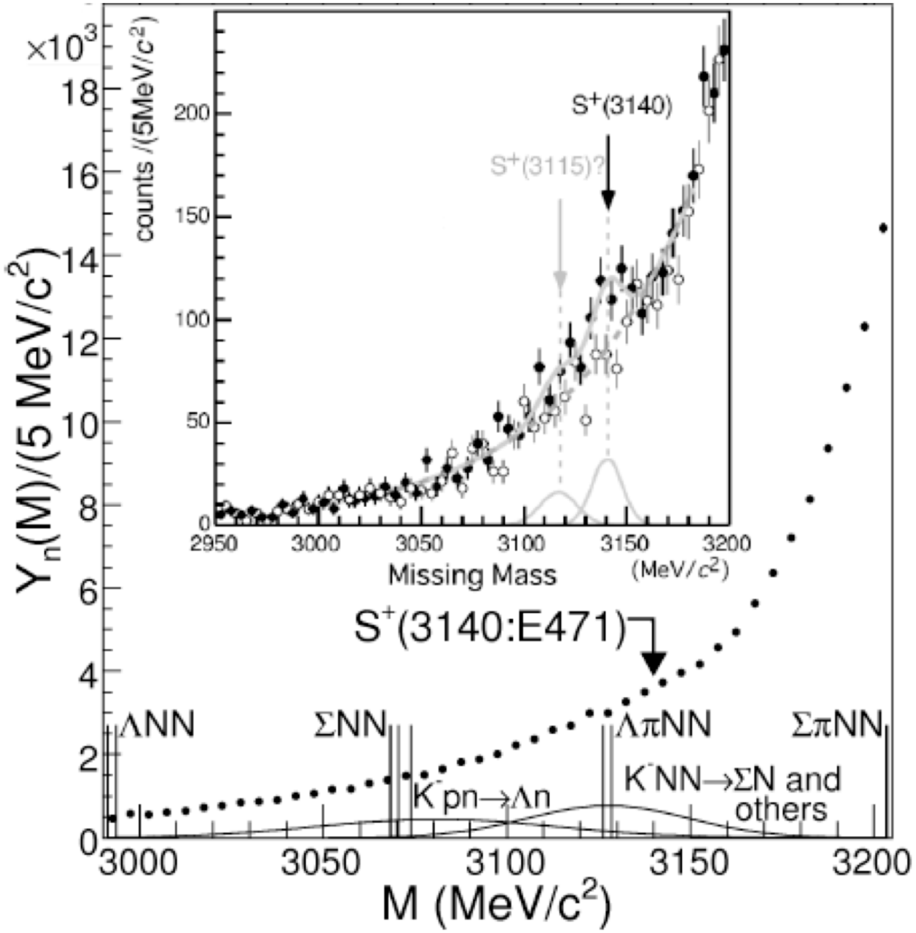
☞ astronomical study $p + e^- \rightarrow K^- + p + \nu_e$?

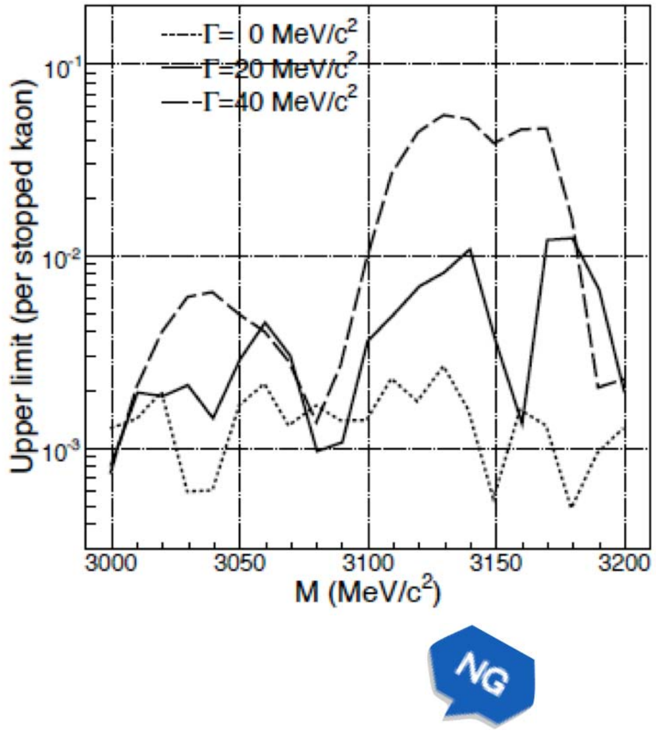
E471 / E549 setup

M. Iwasaki *et al.* : NIM A473 (2001) 286-301



$^4He(K^-, nX^{\pm})$ missing mass spectrum E471/E549/E570

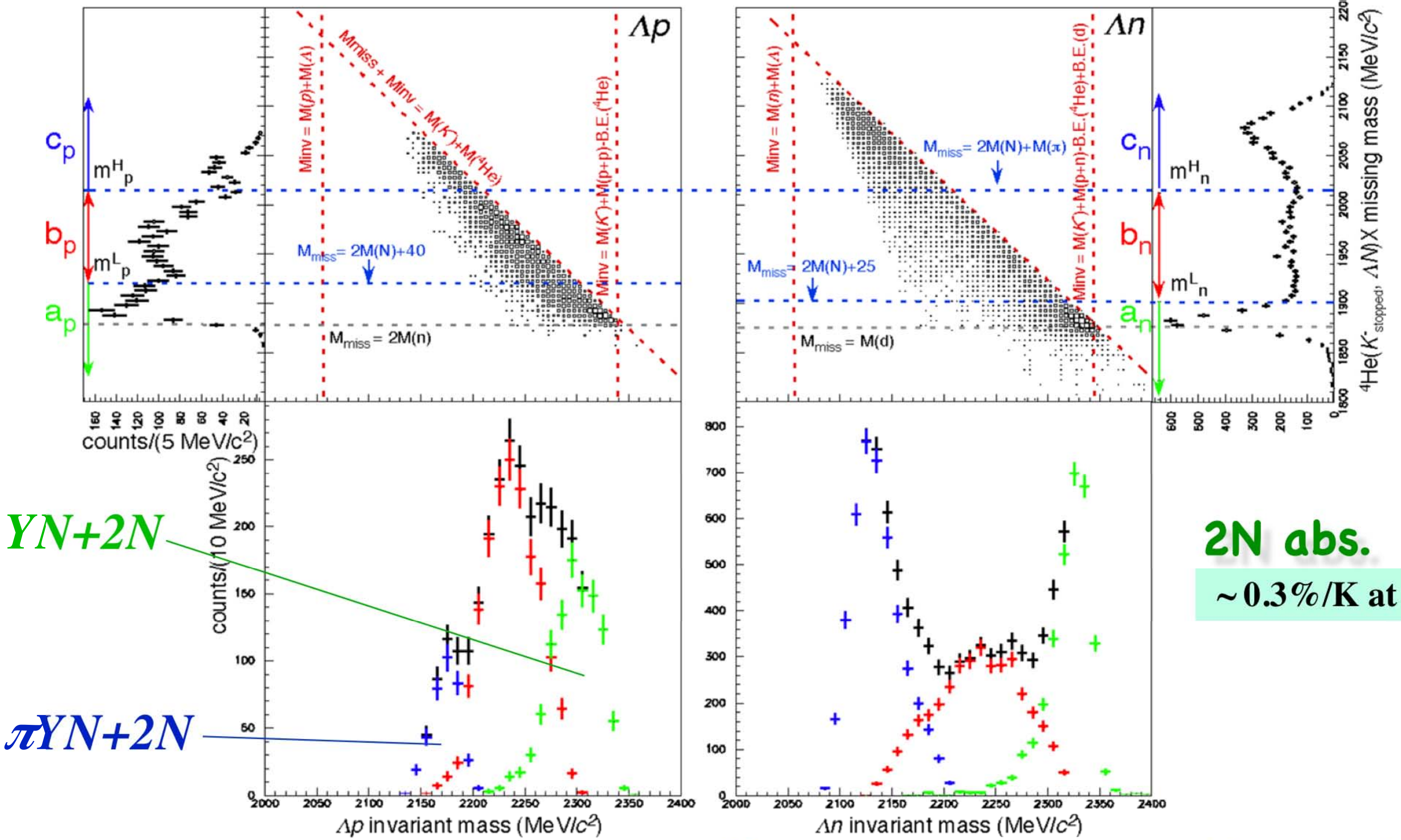




no evidence

wide or week, if peak exist

ΛN correlation observed in E549/E570 (KEK)



2N abs.

~0.3%/K at rest

K^- 'NN'$_{I,S}$ -> ΛN

if 2N abs. separated kinematically
"signal" may appear clearly
→ in-flight kinematics

E549/E570 (KEK) ... Suzuki

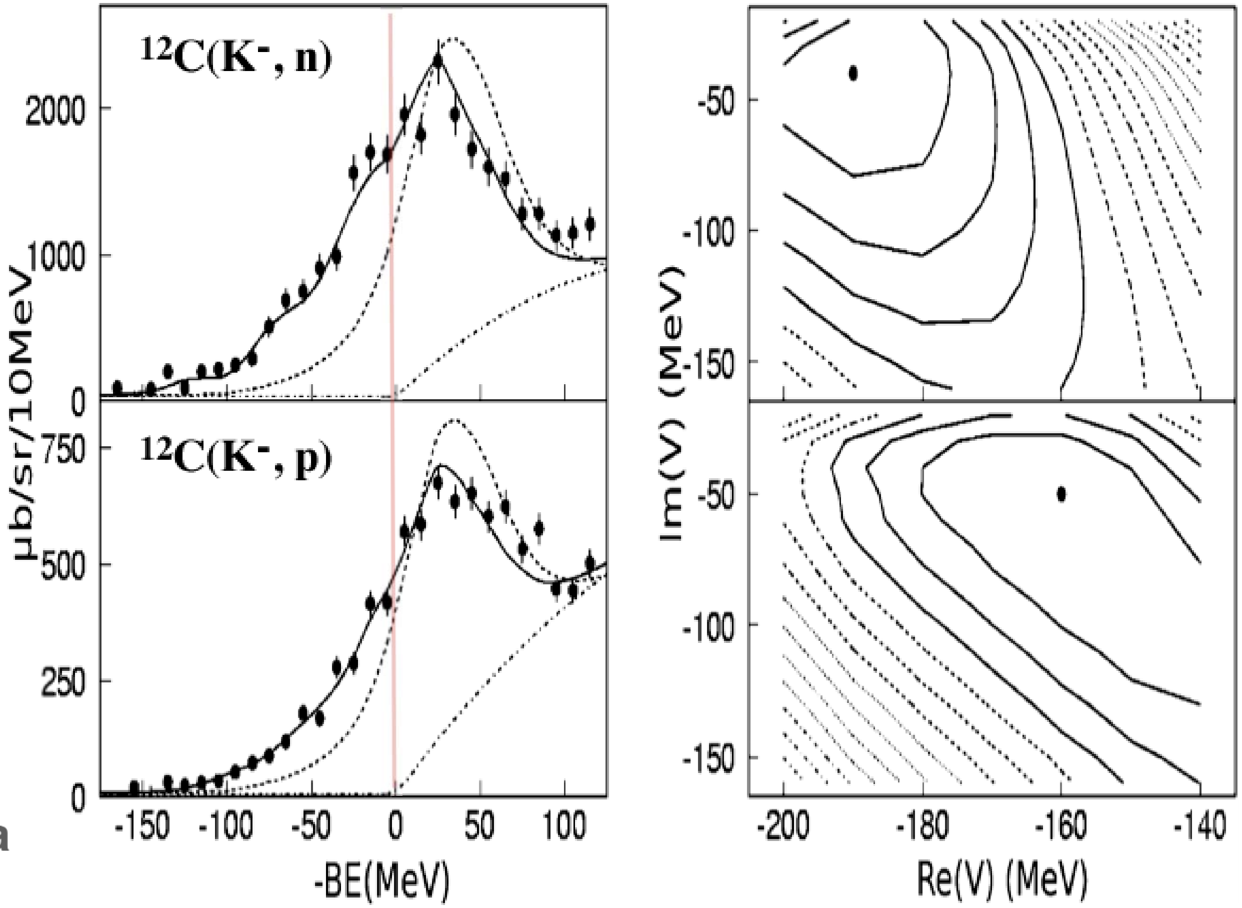
Do not exist? : New data from Osaka group

in-flight (K-, n) reaction @ 1 GeV/c

indicating very deep potential

T. Kishimoto et al., Prog. Theor. Phys. 118 (2007) 181

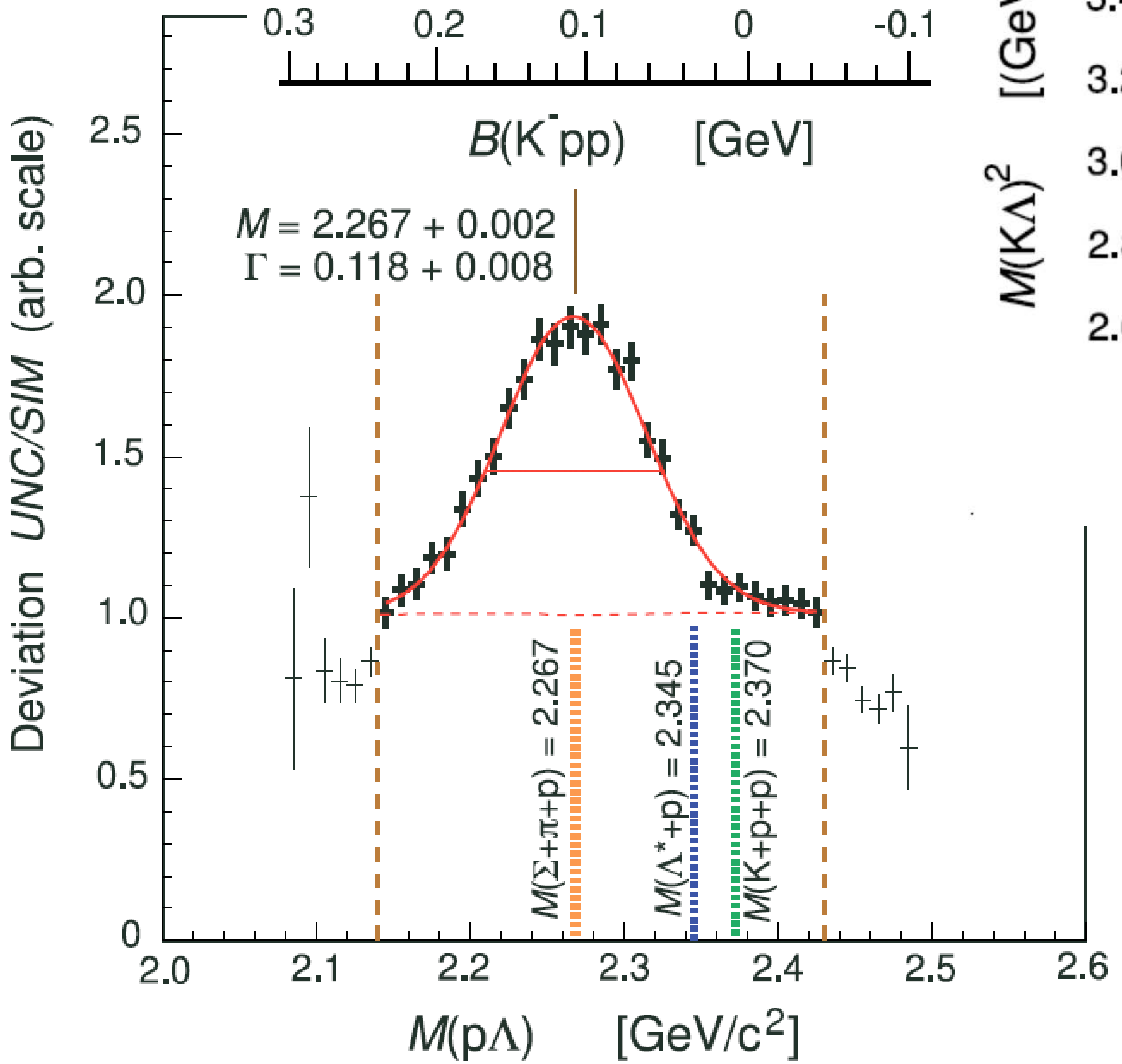
fit = Green's function



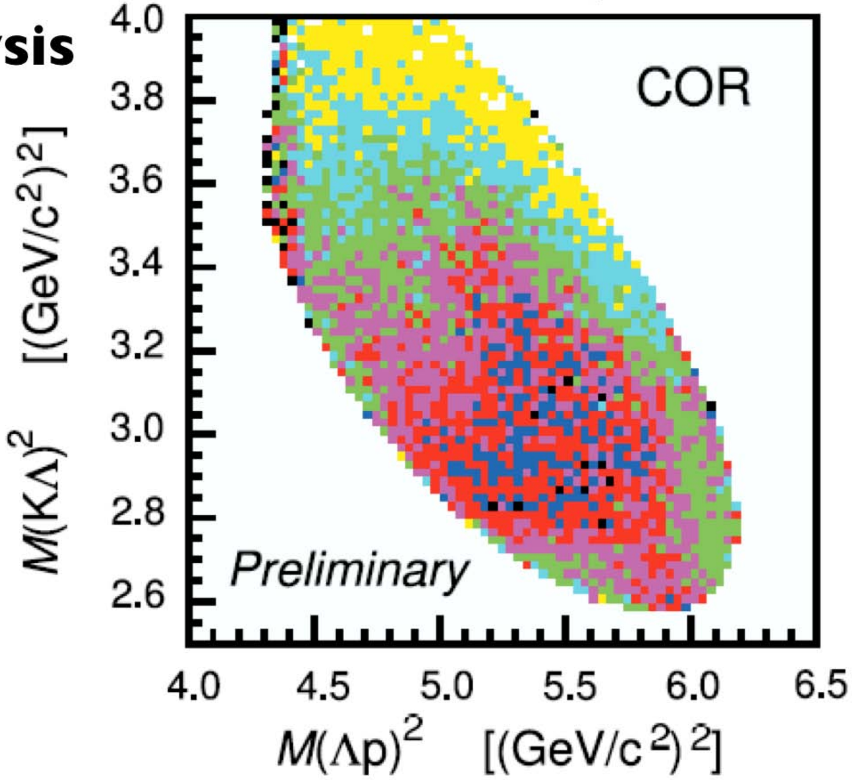
- deep & wide KN pot.
  - Re(V) ~ 200 MeV
  - Im(V) ~ 50 MeV
- lower background
  - in-flight ensures ...
  - 2N process suppressed
  - kinematically separated
  - not seen in the spectra

Do not exist? : DISTO re-analysis

exclusive
$pp \rightarrow K^{+}\Lambda p$ at $T_p = 2.85$ GeV



DISTO experiment:



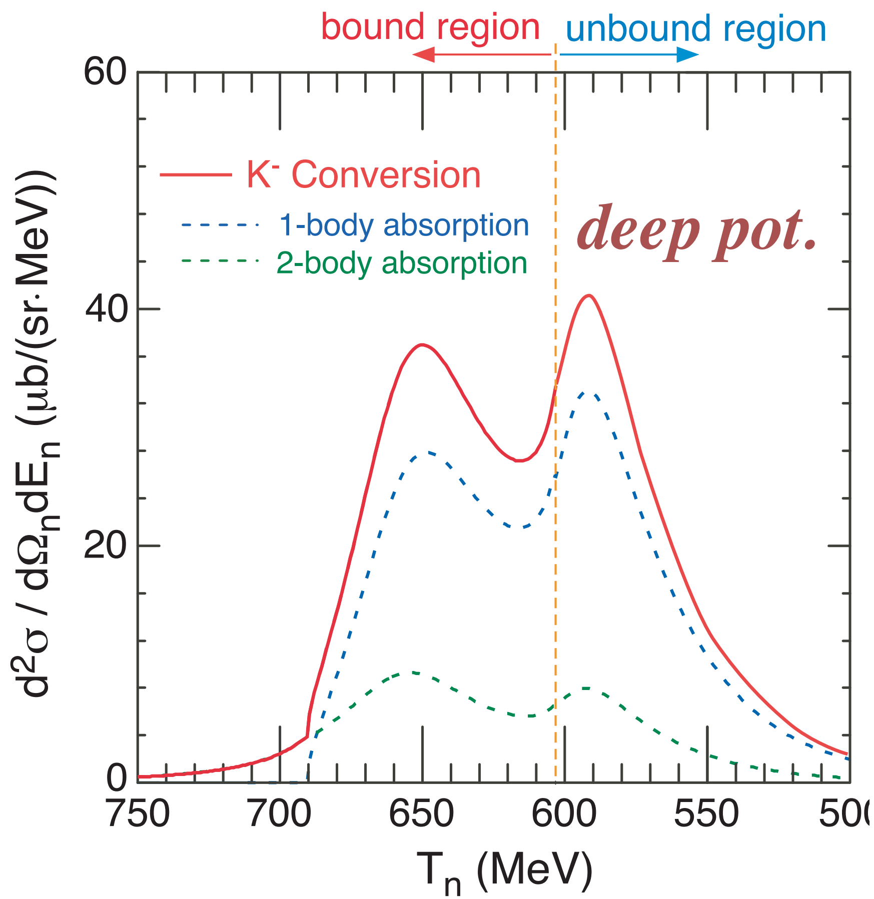
$$\left|\cos\theta_{CM}^{p}\right| < 0.6$$

T. Yamazaki P. Kienle K. Suzuki
arXiv:0810.5182

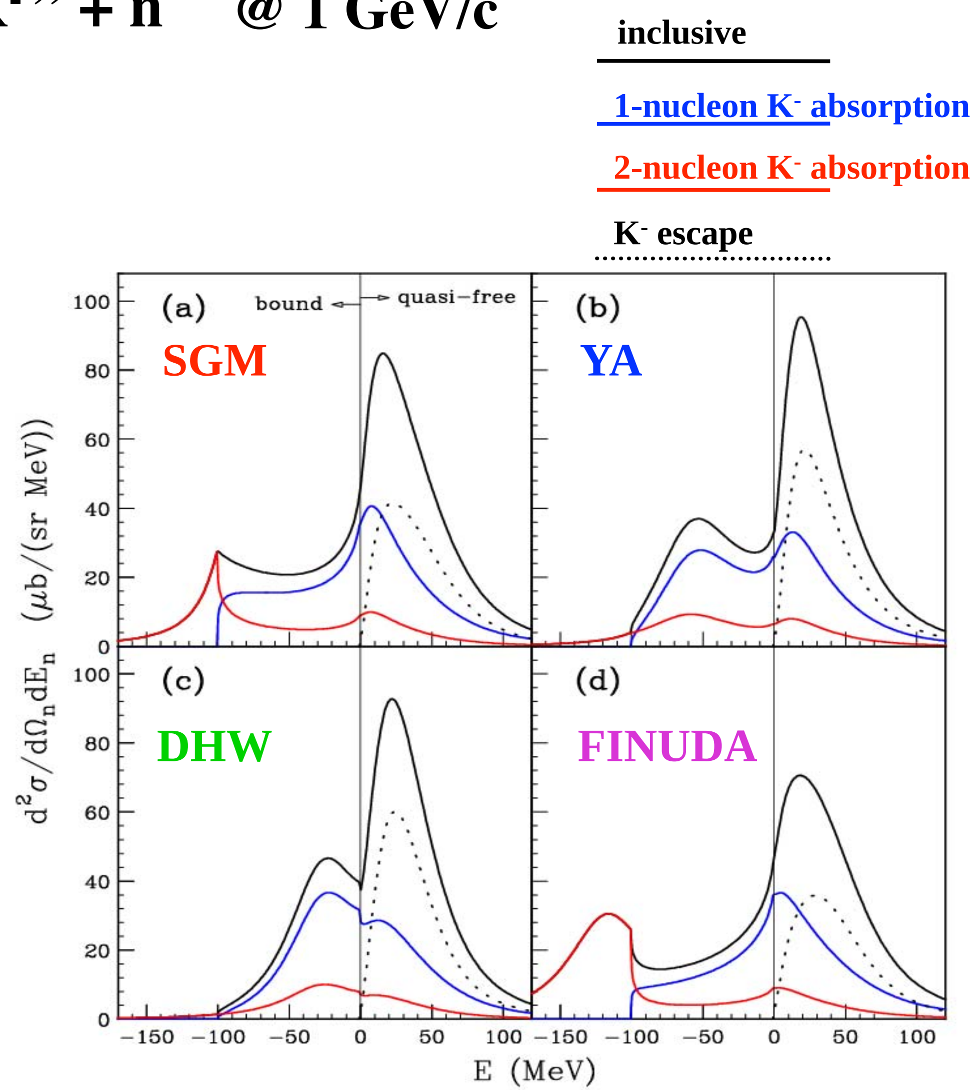
Theoretical progress

$^3He(K^-, n)$ $K^- \, ^3He$ -> "pp K^-" + n @ 1 GeV/c

- bound state will be seen
- yield 5 ~ 40 μb / (sr MeV)
- resolution must < 20MeV



T. Koike, T. Harada, Phys. Lett. B652 (2007) 262



Theoretical progress

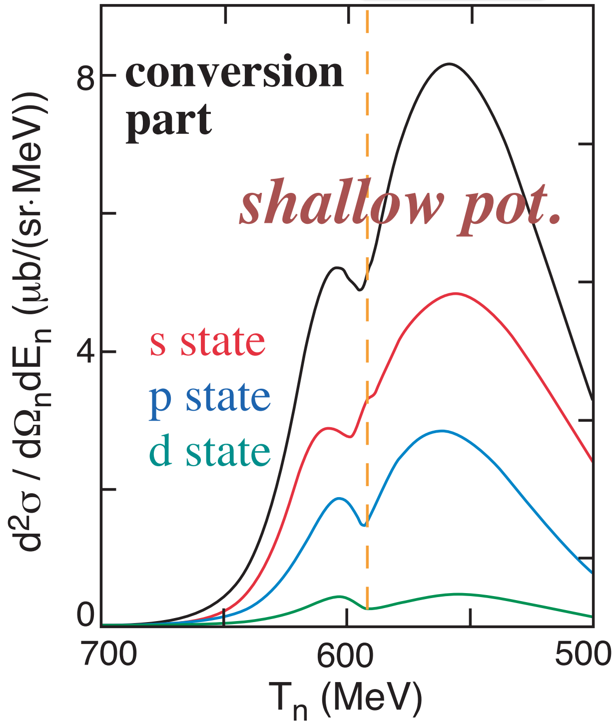
Chiral unitary : shallow pot.

$\Sigma^{\pm}\pi^{\mp}p$ *decay channel can also be tagged*

by $\pi^{+}\ \pi^{-}$ tag

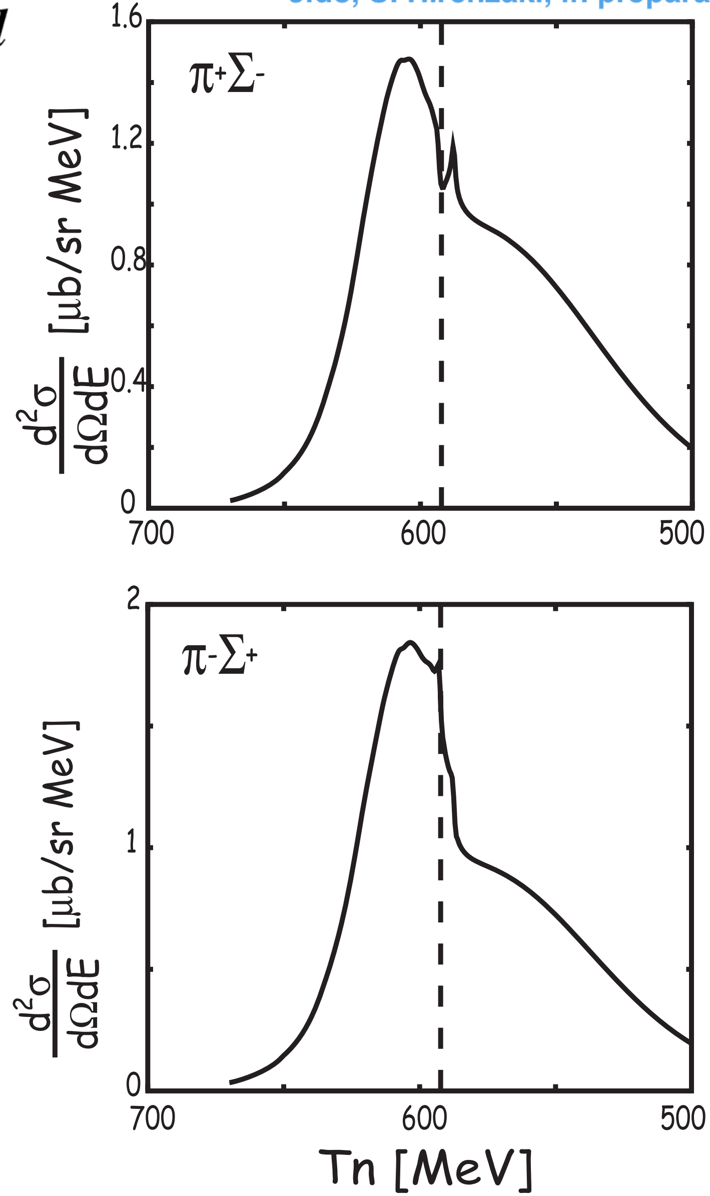
Chiral unitary

^{3}He (K^{-}, n) K^{-} pp



J. Yamagata, S. Hirenzaki, H. Nagahiro, D. Jido, Mod. Phys. Lett. A accepted. Proc. of Chiral07.

J. Yamagata-Sekihara, H. Nagahiro, D. Jido, S. Hirenzaki, in preparation



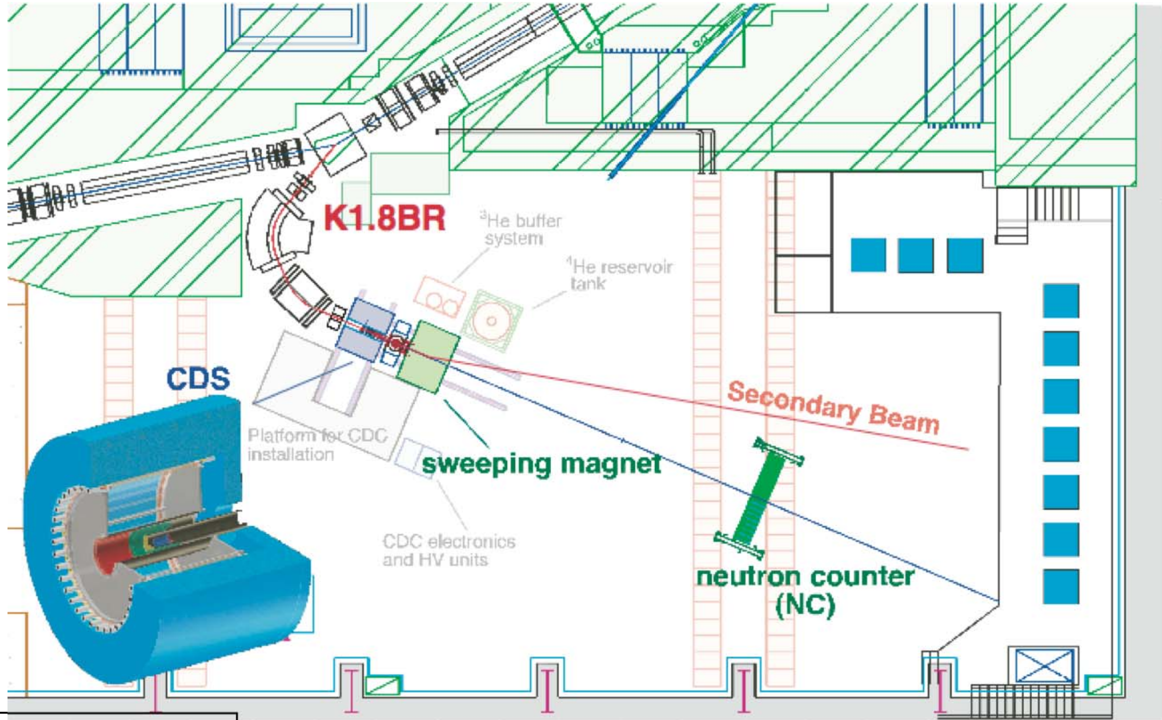
J-PARC: The 1st Experiment– Recoilless K scat.

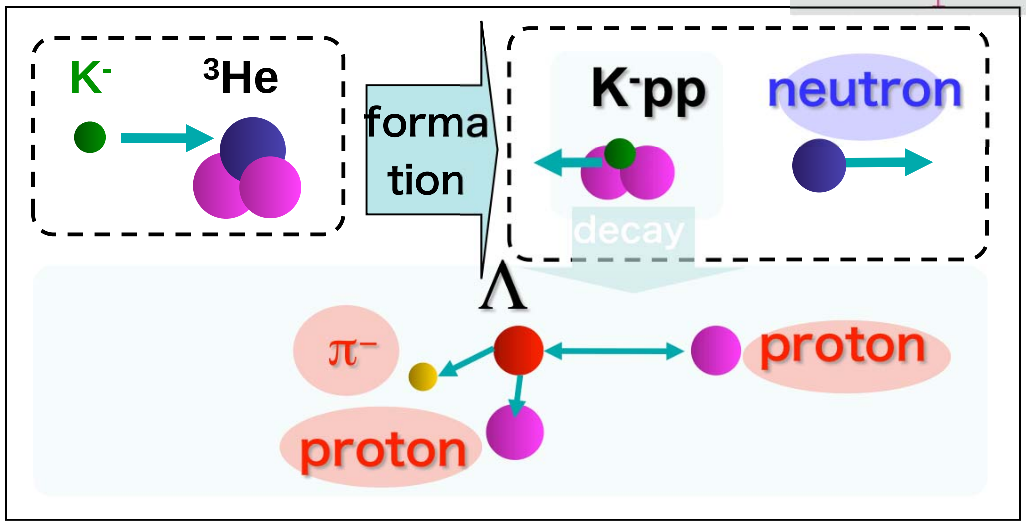
J-PARC E15: ^{3}He(K$^-$, n)

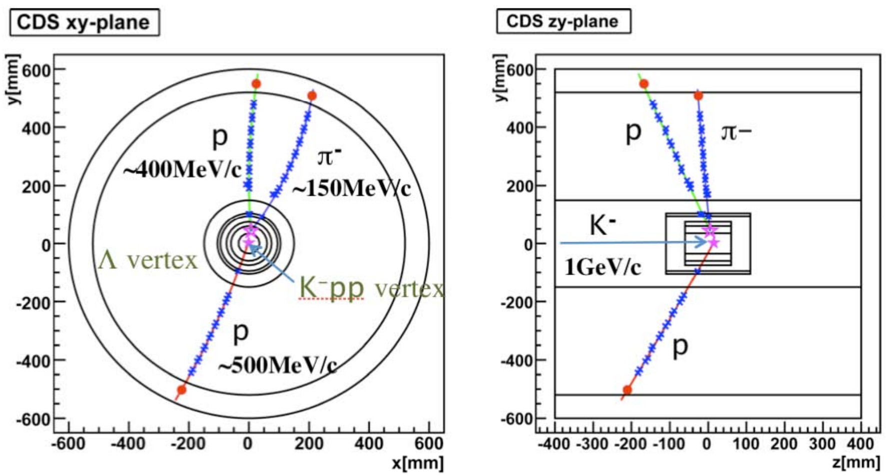
$\overline{\text{K}}$N study by nuclear bound states

K$^-$ ^{3}He -> "pp K$^-$" + n

at 1 GeV/c by both missing & invariant mass







Search for multi-kaonic nucleus (J-PARC LoI)

- The double-kaonic clusters : expected much stronger binding energy and higher density.
- Double-Strangeness production is forbidden for stopped antiproton

	B.E. [MeV]	Width [MeV]	Central-Density
K-K-pp	-117	35	
K-K-ppn	-221	37	$17\rho_0$
K-K-ppp	-103	-	
K-K-pppn	-230	61	$14\rho_0$
K-K-pppp	-109	-	

PL,B587,167 (2004). & NP, A754, 391c (2005).

$$\bar{p} + p \rightarrow K^+ + K^+ + K^- + K^- - 98\ \text{MeV}$$

if deep multi-kaonic nucleus exists, following channel **will open**! ... P. Kienle

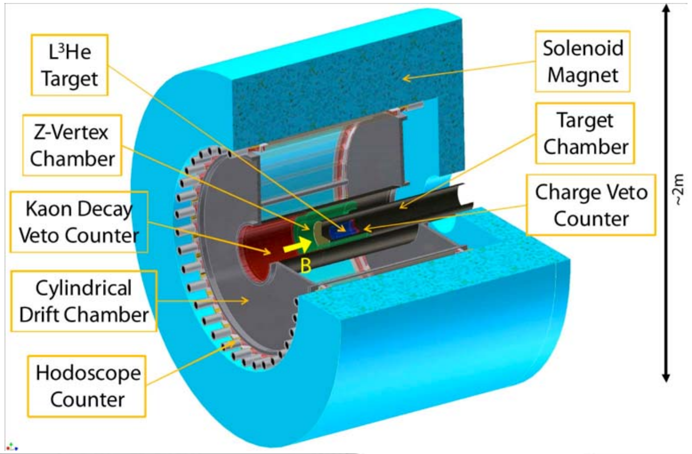
$$\bar{p} + {}^3He \rightarrow K^+ + K^0 + K^-K^-pp + B_{KK}^{pp} - 109\text{MeV} \Rightarrow \text{B.E.=117MeV},\ \Gamma\text{=35MeV}$$

$$K^-K^-pp \rightarrow \Lambda + \Lambda$$

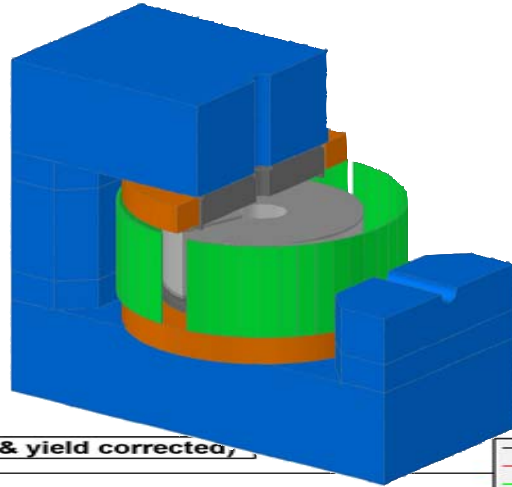
Anti-proton induced in the ^{3}He and detect $K^+K^0\ \Lambda\ \Lambda$ as final state

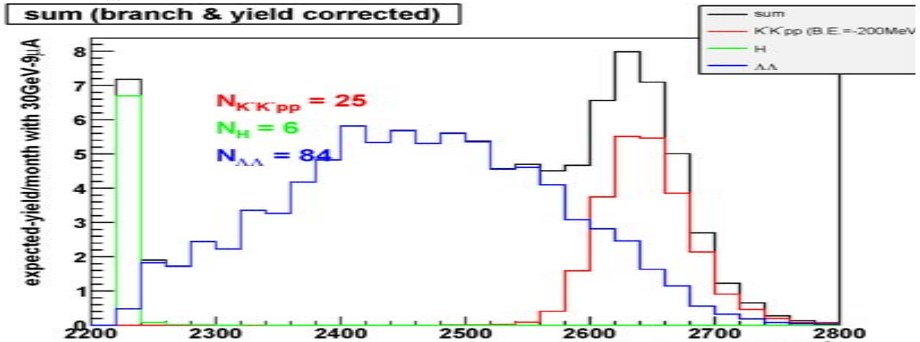
Setup for multi-kaonic nucleus search

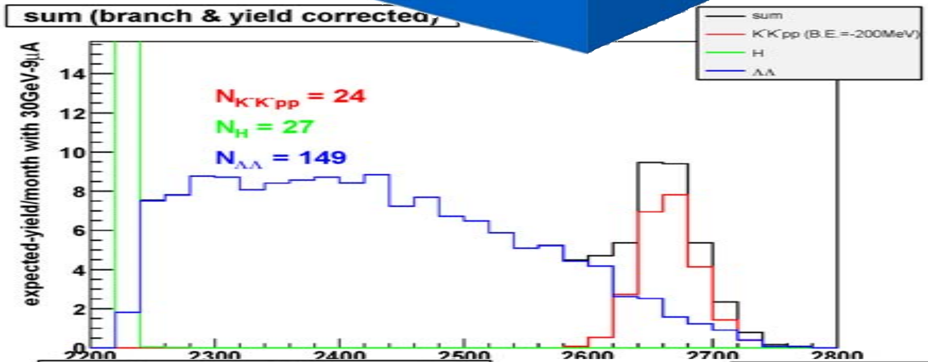
J-PARC E15 type detector

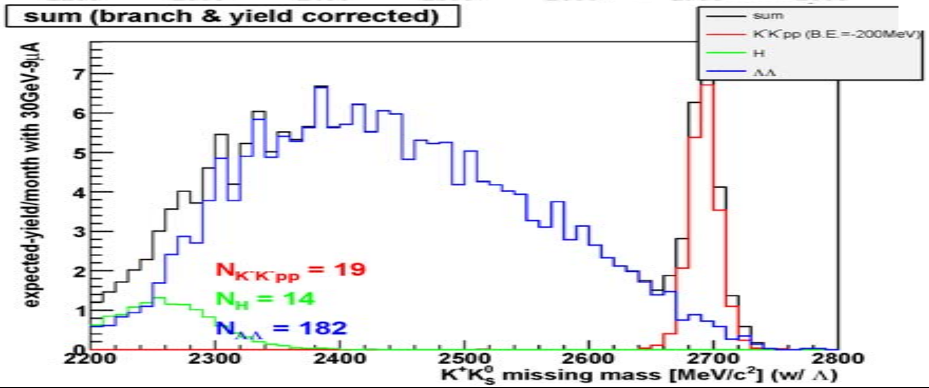


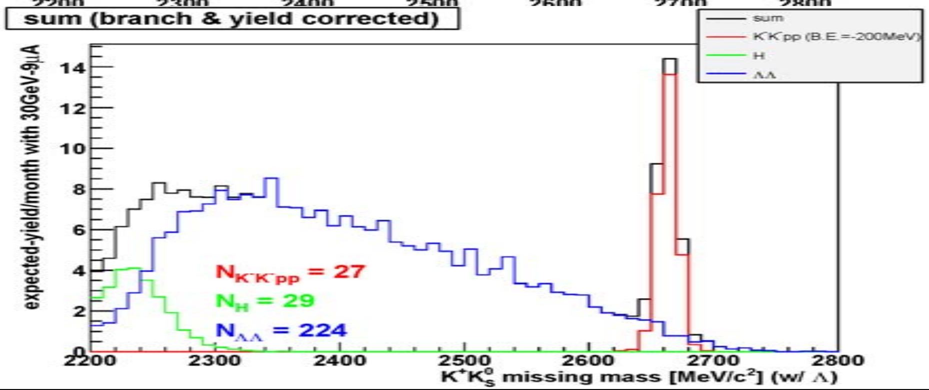
Large acceptance dipole spectrometer





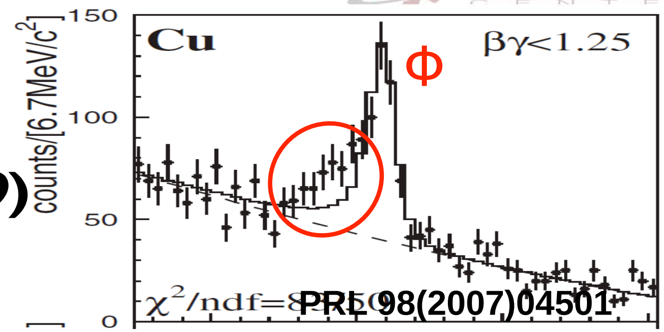


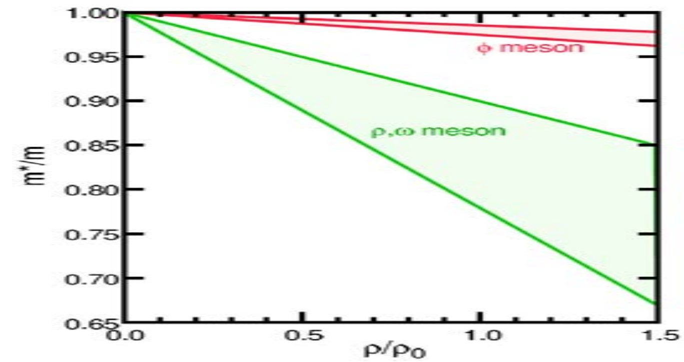




Search for Φ meson nuclear state

(J-PARC P-29)





T. Hatsuda, H. Shiomi and H. Kuwabara
Prog. Theor. Phys. 95(1996)1009

3 % mass shift of φ meson spectra
in p-A reaction has been reported
by KEK-PS E325

QCD sum rule calculation tells us
mass of the φ meson will be reduced ~3%
even in the normal nuclear matter density.

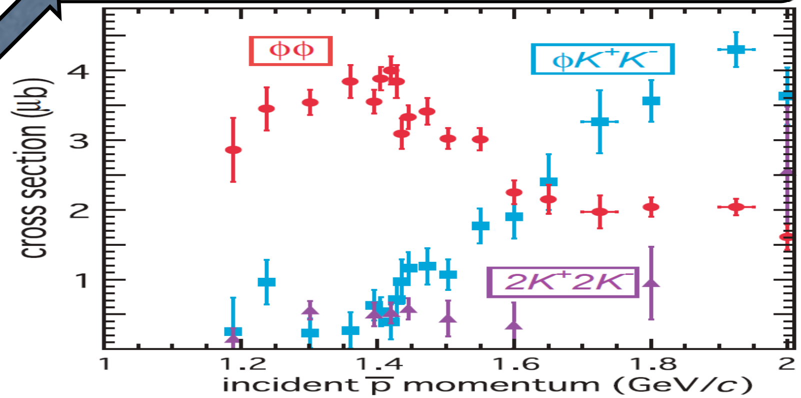
Strong indication
φ-N interaction must be attractive

Question:

whether formation of φ meson bound state
in nuclei will be possible ?

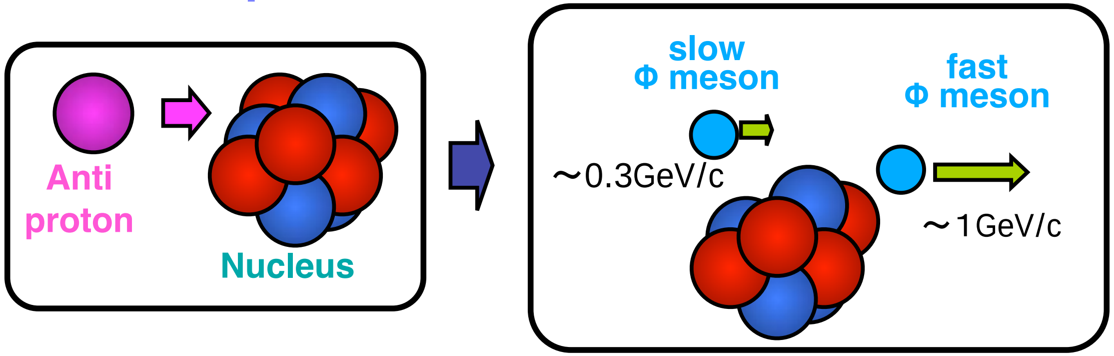
1) as small background process as possible
2) produced Φ meson must have small momentum (~200 MeV/c)

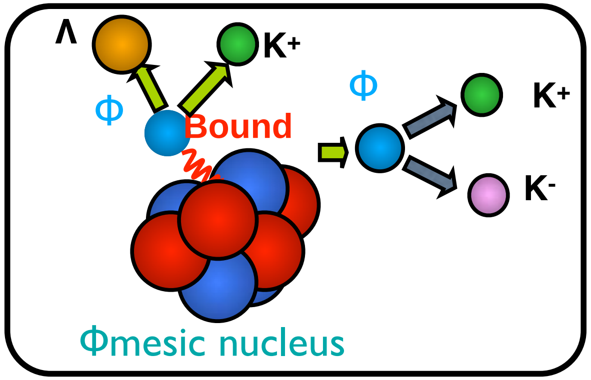
p^{bar}+p →φφ will be
ideal elementary process
for the φ mesonic nucleus formation



Setup for Φ meson nuclear state search

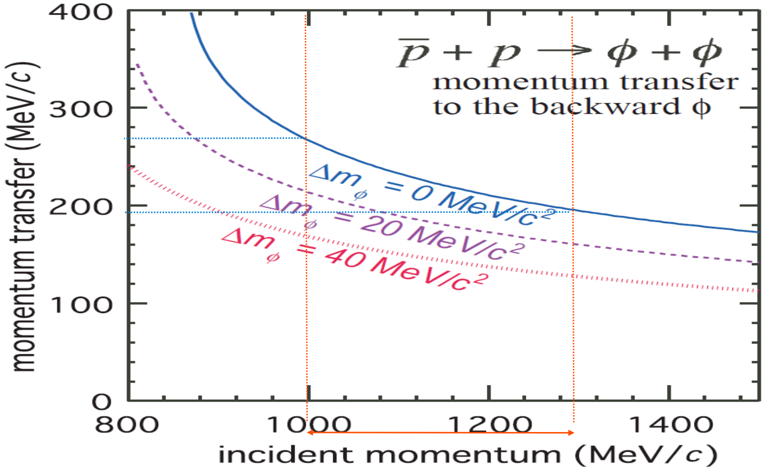
How to produce and detect Φ mesonic nucleus?



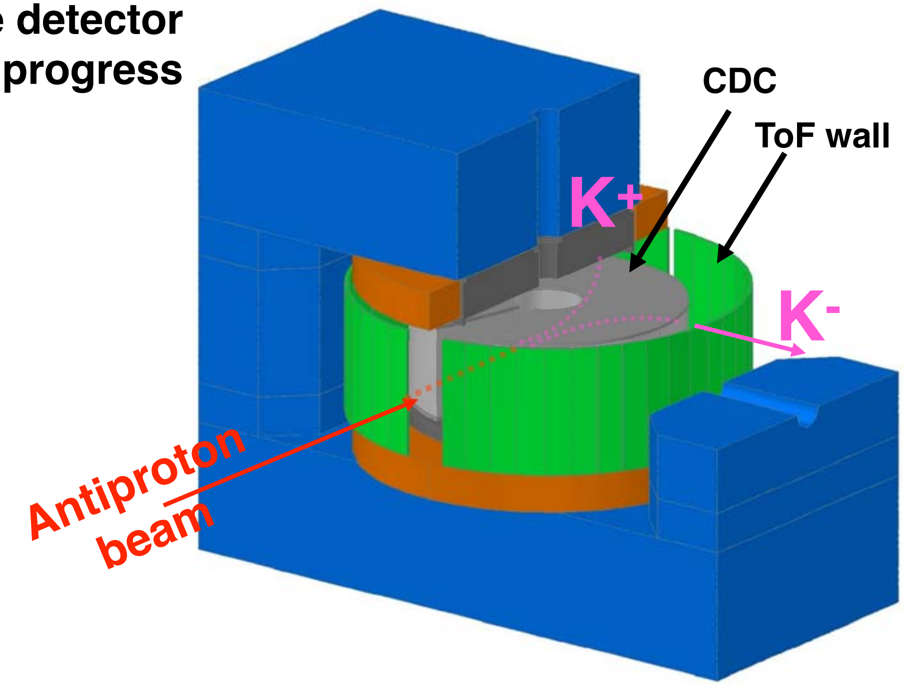


Missing mass using reconstructed forward going ϕ coincidence with K+ and Λ from target

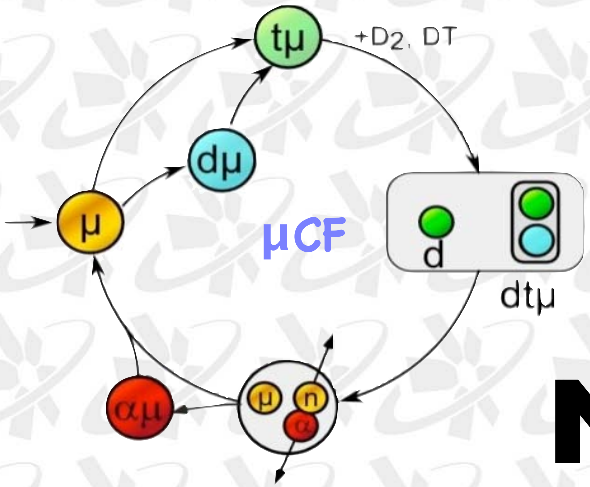
Momentum transfer



Conceptual design for the detector is in progress



If we choose p^{bar} momentum = 1.0 – 1.3 GeV/c
momentum of the ϕ will be 200 – 260 MeV/c



$$\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

beyond Standard Model
a new physics!

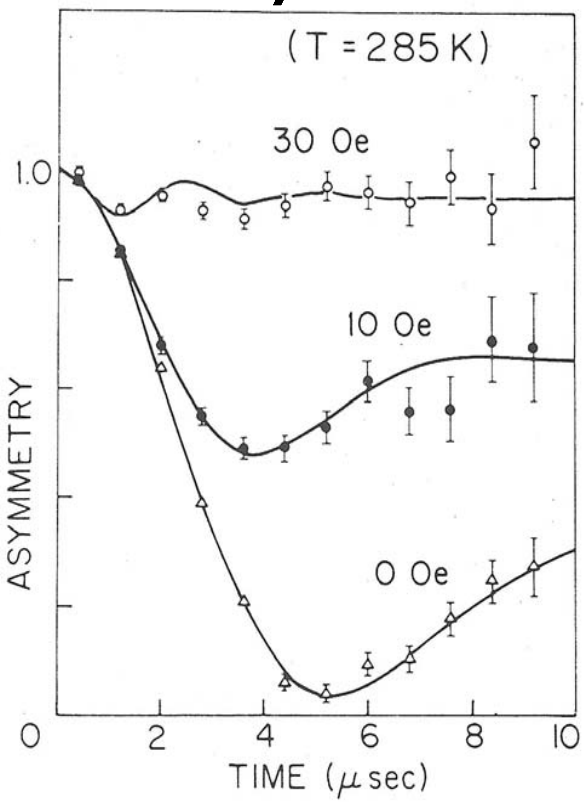
Muon Science

can we make energy?

RIKEN-RAL Muon Facility (RRMF)

Foundation of μSR method

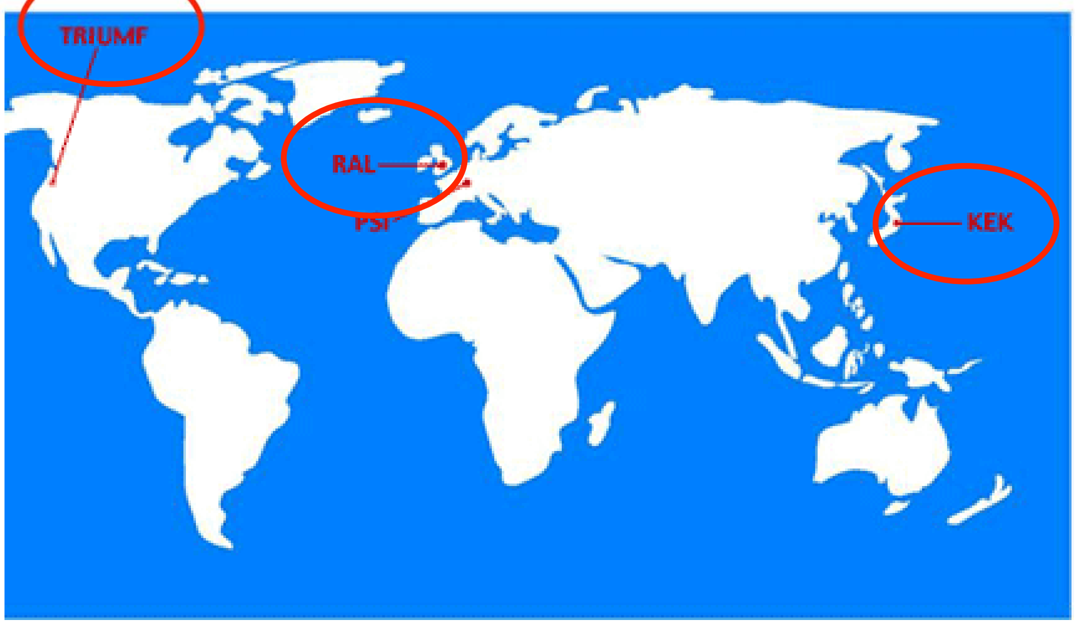
Kubo-Toyabe Function



T. Yamazaki & R.S. Hayano
@ TRIUMF PRB 20(1979) 850

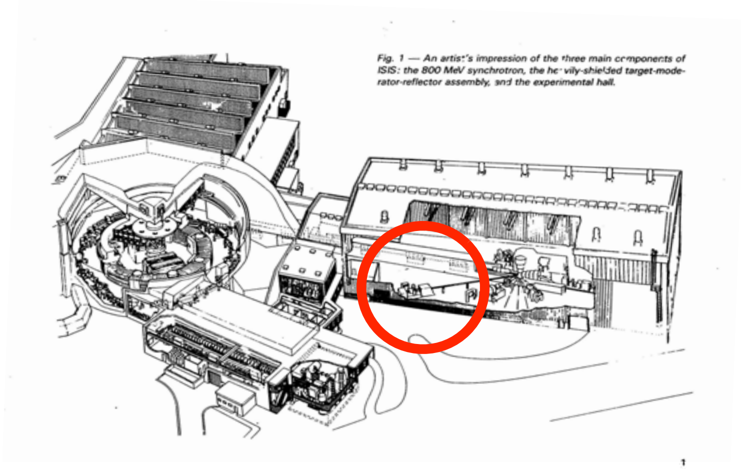
K. Nagamine

Muon Facilities over the world

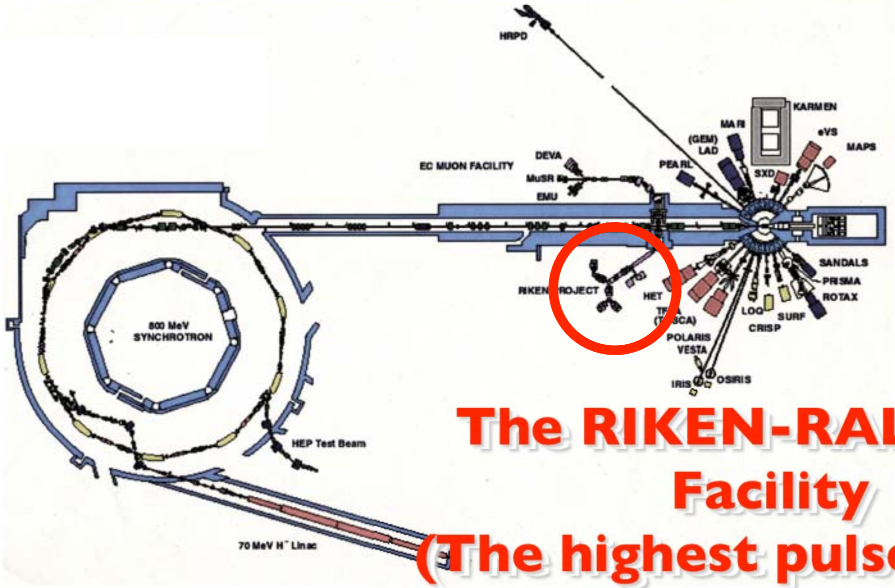


- *UTMSL (shutdown)*
- *RIKEN-RAL*
- *TRIUMF (donated)*

High intensity proton accelerator facility of Rutherford Appleton Laboratory in UK

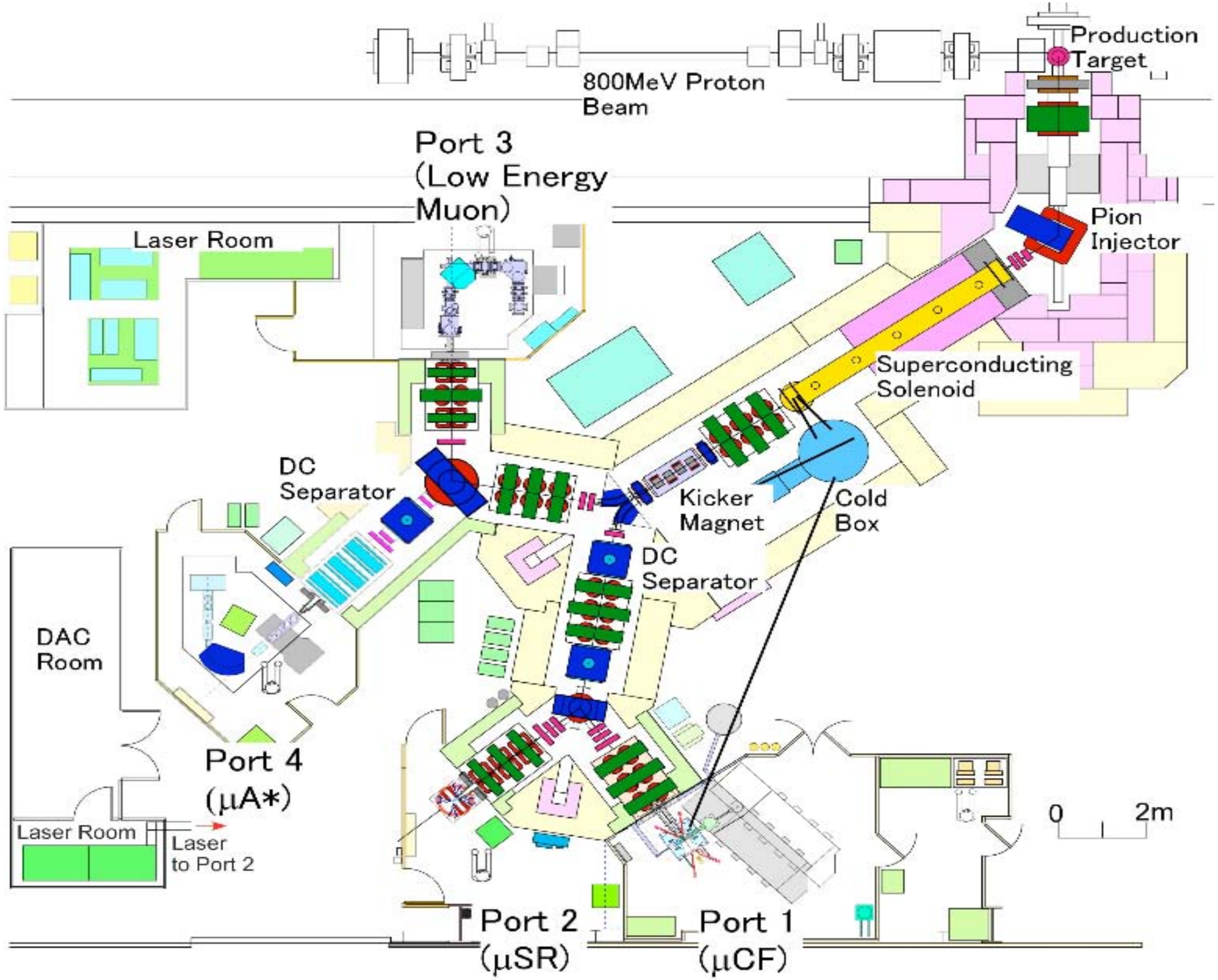


Specification:Energy 800 MeV, Current 300 μA,Repetition 50 Hz, double pulses

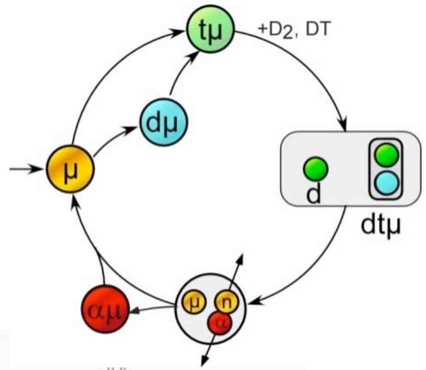


The RIKEN-RAL Muon Facility (The highest pulsed muon beam facility in the world)

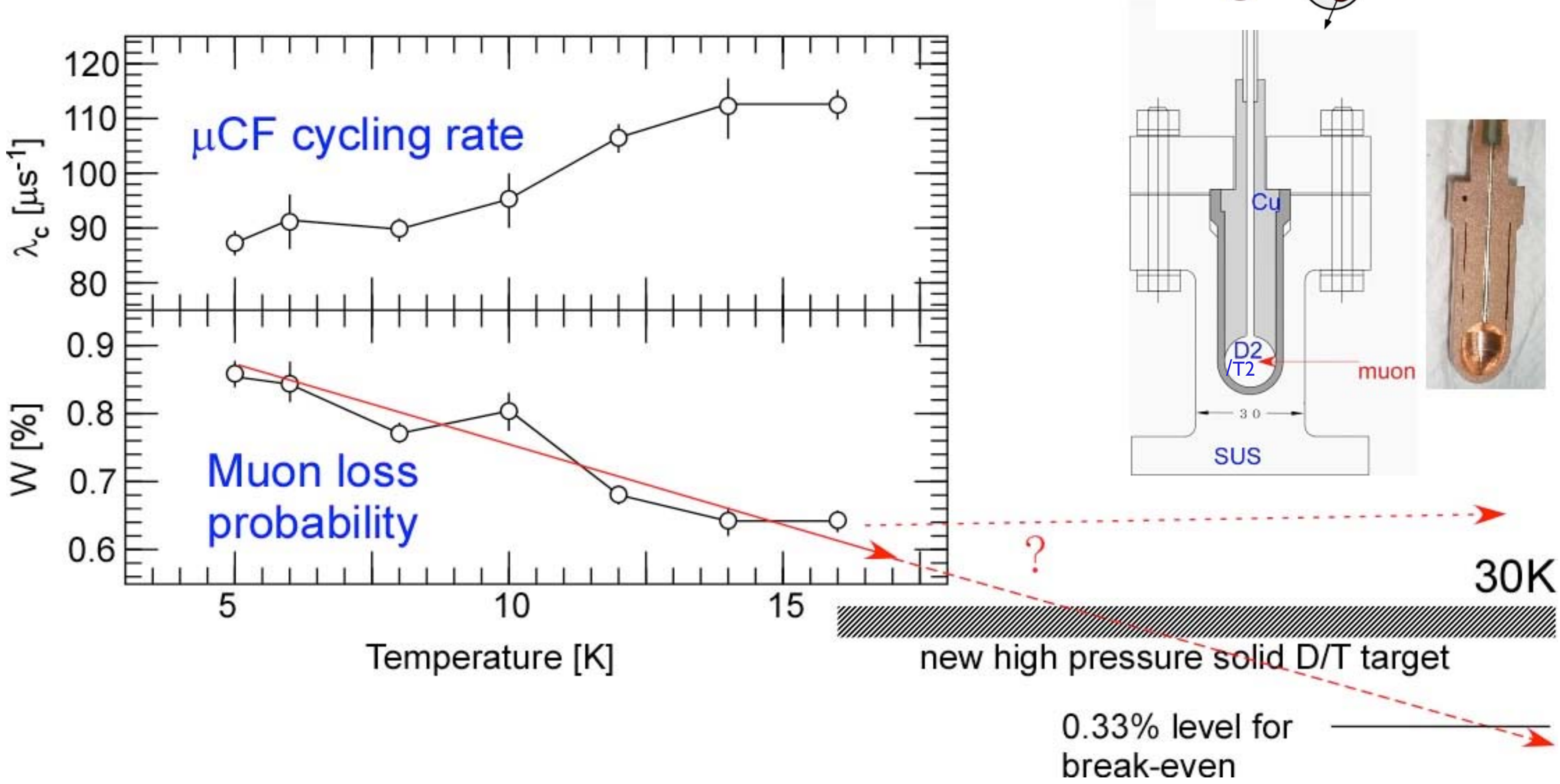
RIKEN-RAL Muon Facility (RRMF) @ 2008



Muon Catalyzed Fusion



Enhancing μCF cycle towards break-even (~300 fusions/muon)
μCF at high density/high temperature solid (liquid, gas)

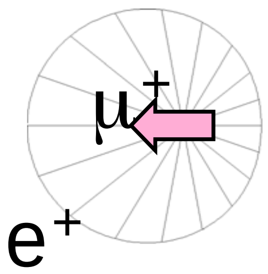


introduction to Muon Spin Rotation (μSR)

- a unique and sensitive probe for the magnetic property

μ-e decay

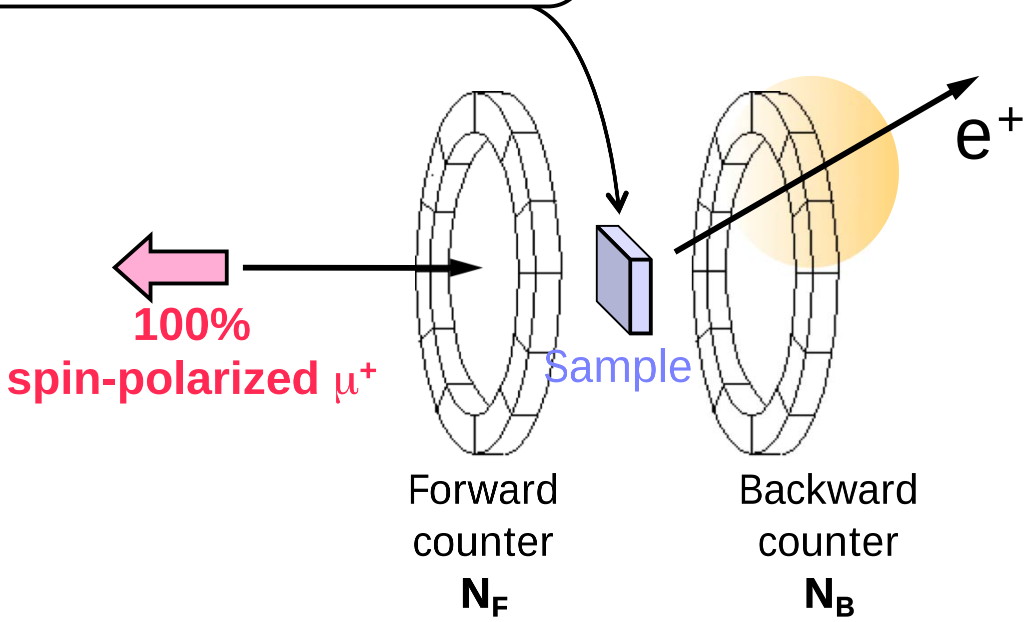
Lifetime
τ_{μ}=2.2μs

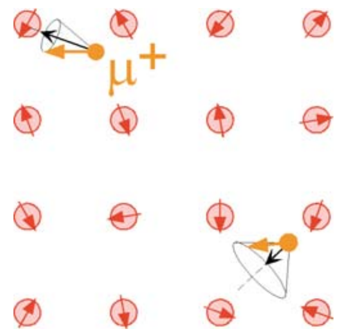


High sensitivity to the magnetic field

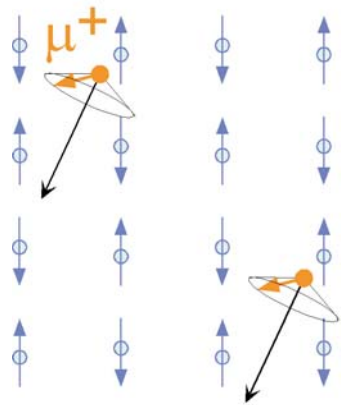
Different time scale from that of NMR

Measurement in zero applied field is possible





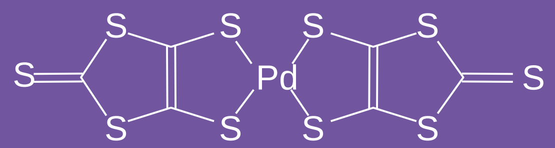
Muon in paramagnetic state



Muon in antiferro-magnetic state

Asymmetry $A(t) = \dfrac{\alpha N_F(t) - N_B(t)}{\alpha N_F(t) + N_B(t)}$

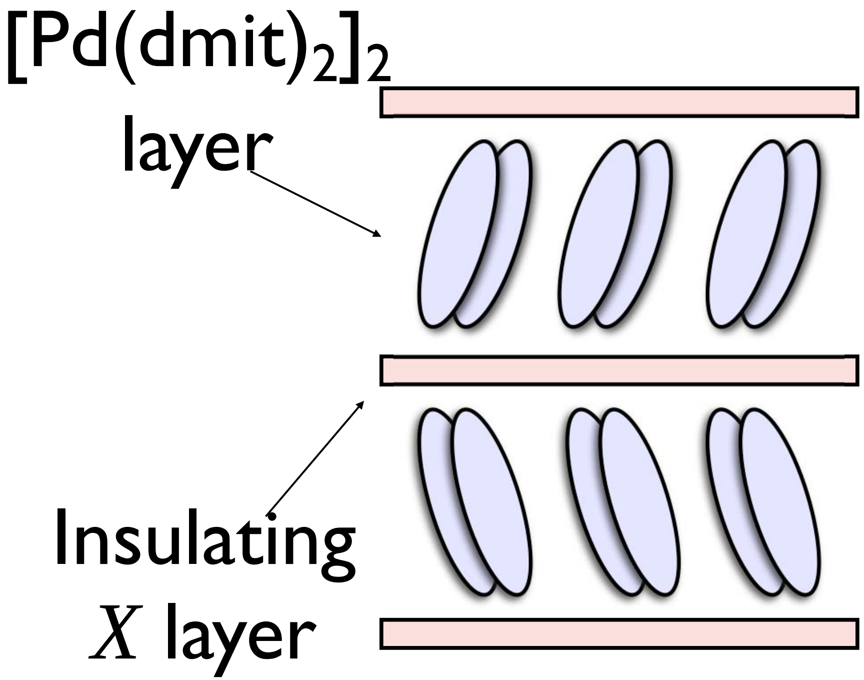
Example of μSR studies on organic material

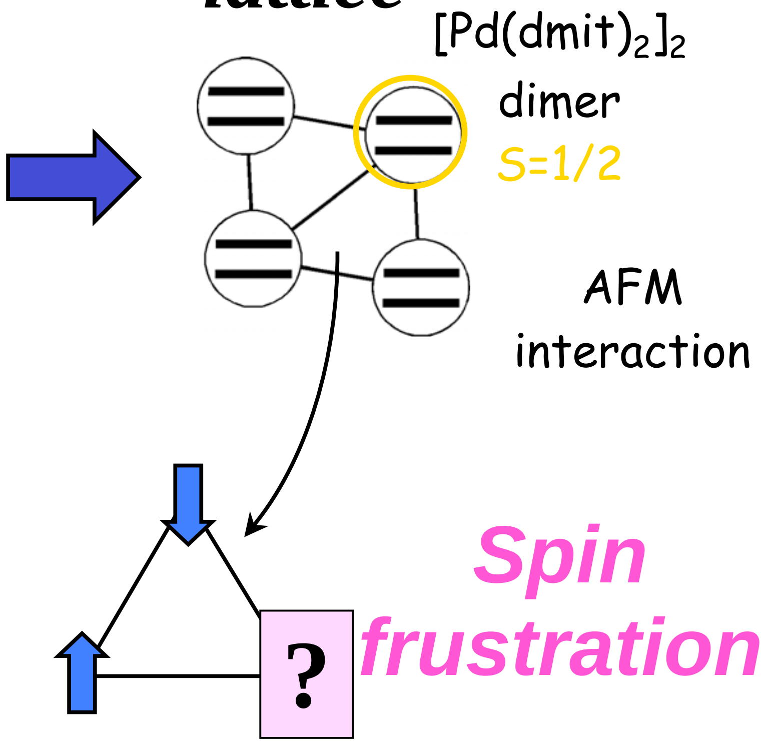


$[Pd(dmit)_2]$

X$[Pd(dmit)_2]_2$ with spin frustration

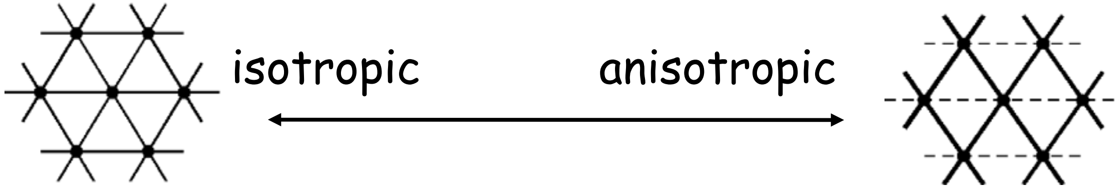
Distorted triangular lattice





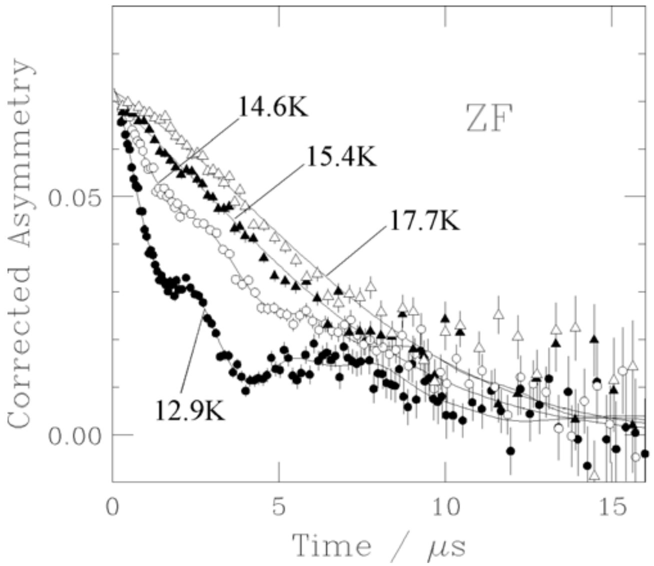
magnetism of 2D distorted triangular lattice by μSR

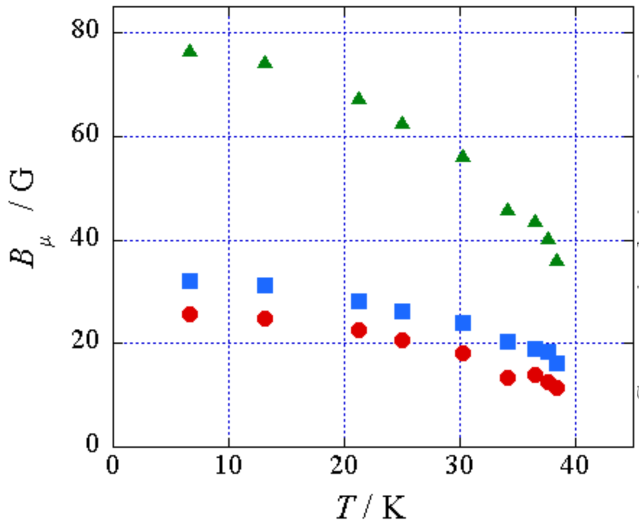
Frustrated ←

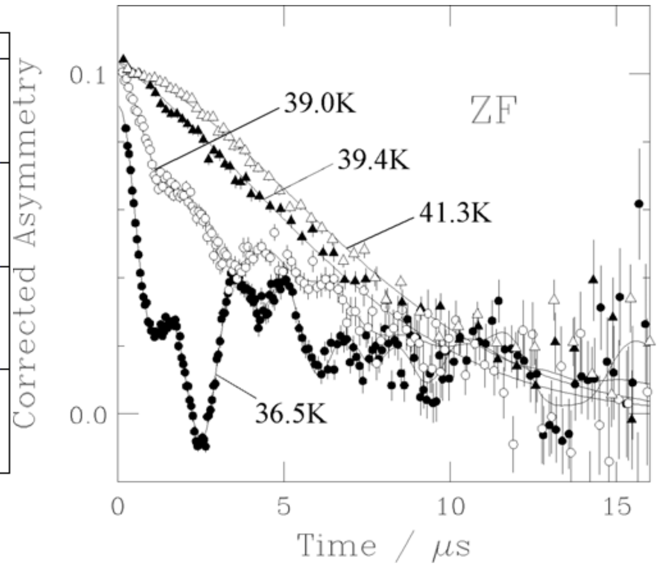


$(C_2H_5)_2(CH_3)_2P[Pd(dmit)_2]_2$

$(CH_3)_4P[Pd(dmit)_2]_2$



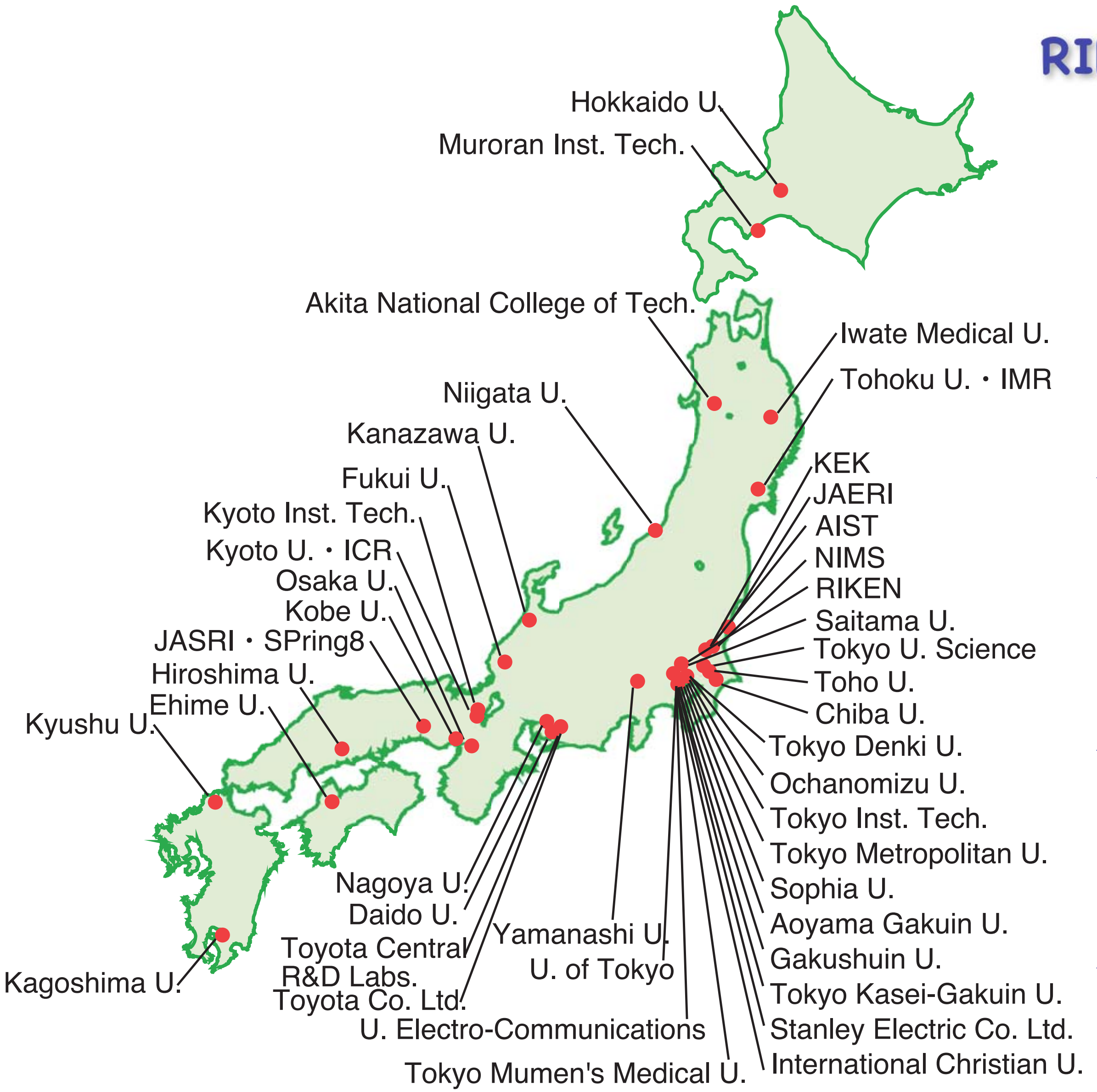




T_N = 14.8 K

T_N = 39.3 K

As a Center of Excellence for muon science



RIKEN-RAL domestic collaboration

- ✓ Collaboration expanding in many universities and research institutes.
- ✓ more than 300 proposals over last 10yrs
- ✓ 120 papers over last 5yrs

RIKEN-RAL Toward 3rd Term

3rd term = *2010/10 ~ 2017/3*

RRMF-AC Meeting

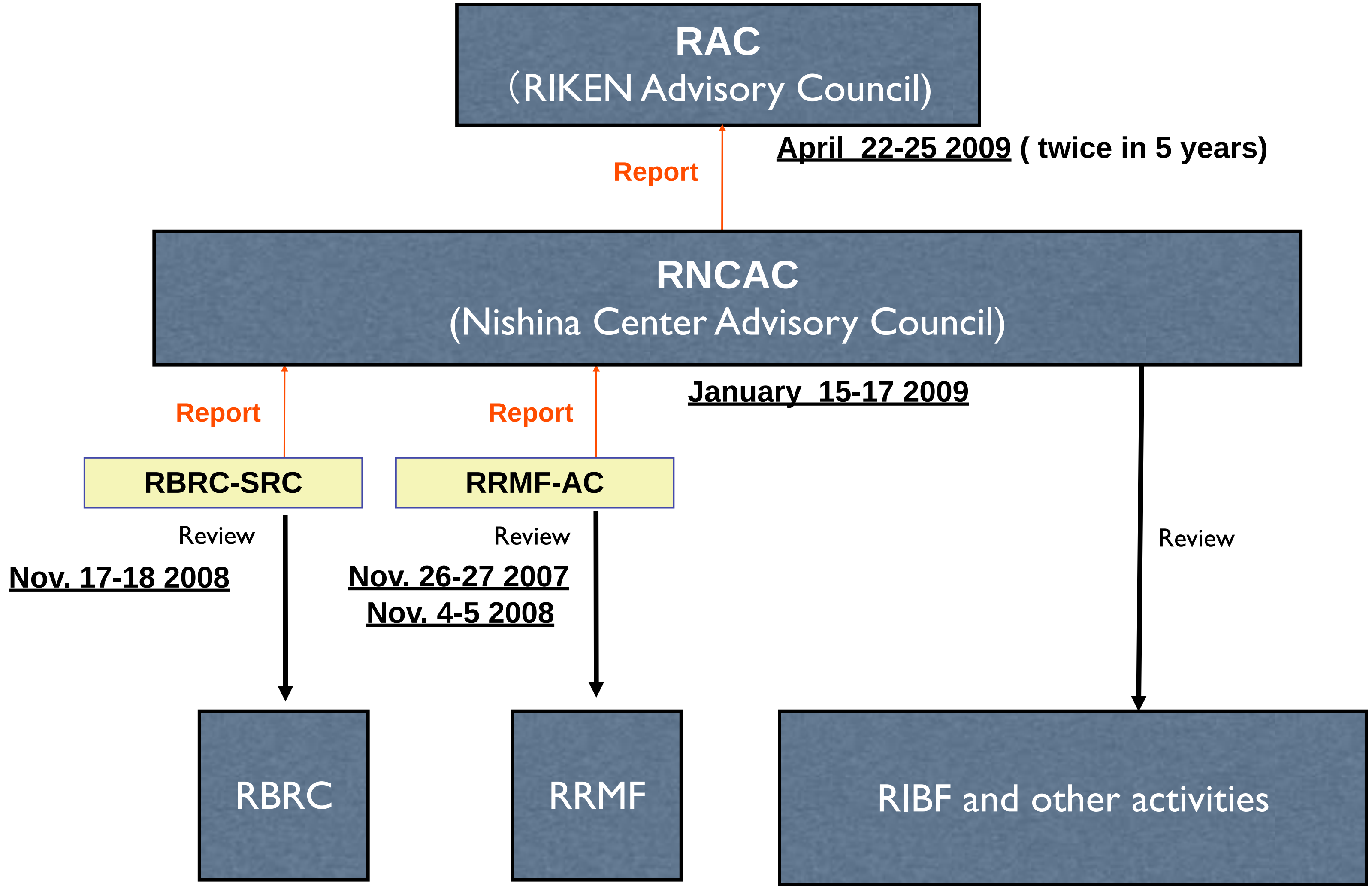
Nov. 26-27, 2007 / Nov. 4-5, 2008

name	iinstitute	job title
Andrew Taylor	RAL / United Kingdom	ISIS Director
Stephen J. Blundell	University of Oxford / United Kingdom	Professor
Kurt N. Clausen	PSI / Switzerland	Department Head of Neutrons and Muons
Jun Imazato	KEK / Japan	Professor
Jean-Michel Poutissou	TRIUMF / Canada	Associate Director
Eiko Torikai	University of Yamanashi / Japan	Professor

A. Taylor, the Chair, visiting President R.Noyori

RRMF-AC: RIKEN-RAL Muon Facility Advisory Committee

Review System and Schedule for RNC



RRMF: RIKEN-RAL Muon Facility (RIKEN-RAL)

NCAC Meeting Jan 15-17, 2009

NCAC: RIKEN Nishina Center Advisory Council

NCAC Executive Report

held in Jan 15-17, 2009

TWO ITEMS CONCERN WITH MuSAC

- NCAC endorses the recommendation of the RIKEN-RAL IAC that *Condensed Matter and Molecular Science* and *Ultra-Slow Muon Source Development* be prioritized as the first of two central pillars of the future RIKEN-RAL facility programme, and given sufficient resources to enable its continued development. The NCAC further supports the IAC recommendation for an extension of the RIKEN-RAL agreement beyond 2010 by at least another 7½ years to 2018.

- NCAC sees future opportunities at J-PARC and suggests that the interested parties explore the establishment of a RIKEN J-PARC Center.

- starting from hadron physics -

S.Gales
Chair of NCAC

RIKEN NISHINA CENTER
独立行政法人 理化学研究所 仁科加速器研究センター

RIKEN-RAL Beyond 2nd Term

2nd term = *1999/10 ~ 2009/9*

Recent focus toward 3rd term

(1) High intensity laser system for slow μ^+ beam production (Port-3)

New muon g-2 measurement / surface μSR = 2~4 kHz slow muon @ RIKEN-RAL

100 times higher intensity (50~100 μJ) of VUV (122 nm) light

Search for efficient muonium-producing target materials

(2) Laser μSR experiments (Port-2)

The laser system under collaboration of Yamanashi U., KEK, UCR, RIKEN-RAL.

"Spinstronics": R-331,R-361 (K.Nagamine), R-327(E. Torikai), "Muonium chemical reaction": R-317(D. Fleming)

"Molecular state": RB-810980(F.L.Pratt), "Muonium state": RB-810217(S.Giblin)

(3) New μSR spectrometer (Port-4)

New multi-segmented (600 ch.) μ-e counters

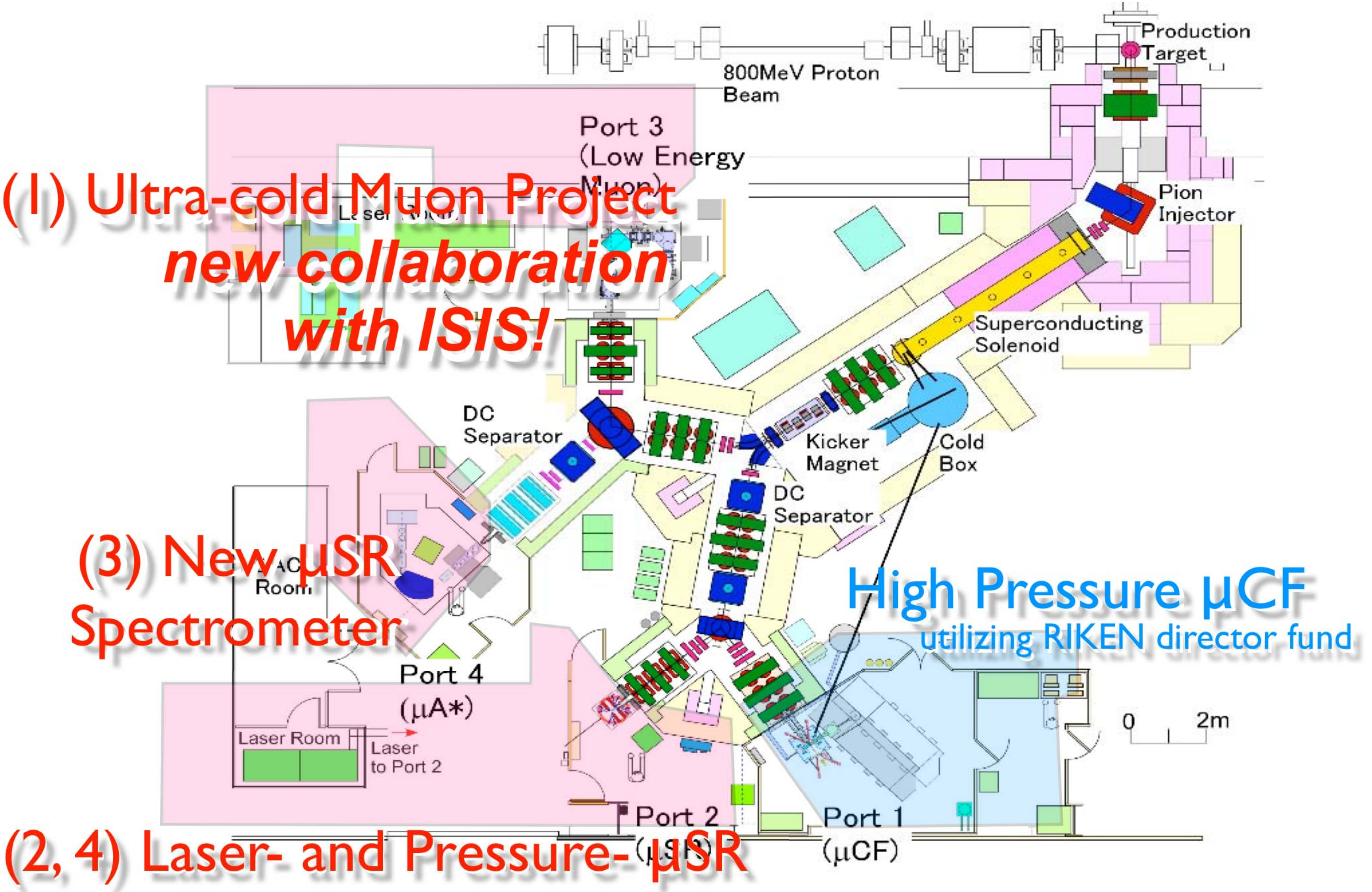
(4) High pressure cell for μSR (Port-2)

Uniqueness of RIKEN-RAL (*vs. J-PARC*)

due to required high-momentum muon beam (thanks to ISIS shorter double pulse time separation)

(5) Remote μSR experiment on demand concept

RRMF Present & Near Future

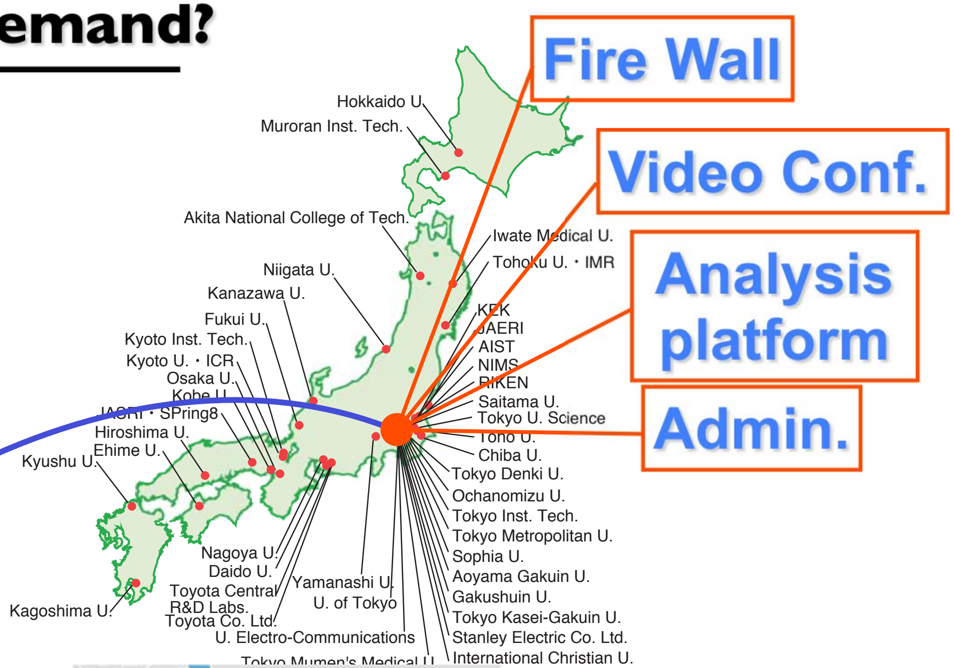


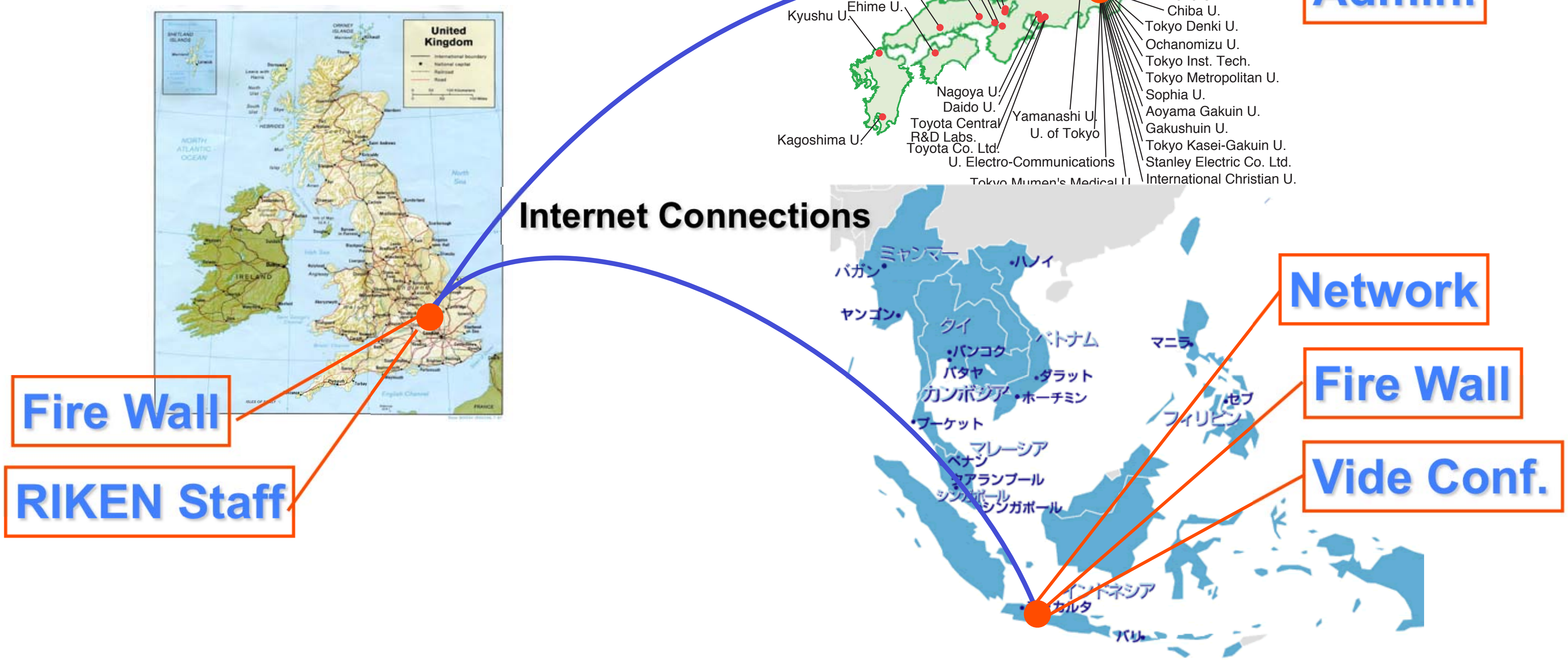
(5) RRMF Remote μSR on demand?

key issues:

- make it like domestic facility to all over the world
- concerns

  How can we maintain μSR specialist?





(2) pulse laser driven μSR

New laser system for laser-μSR (Port-2)

key issues:

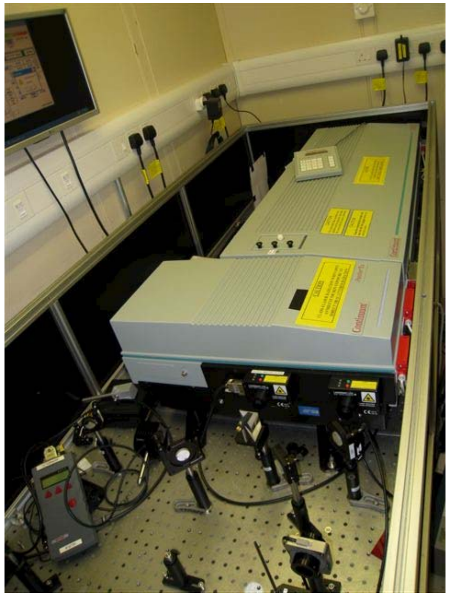
- new collaboration framework

  U.Yamanashi - KEK - UCR - RRMF - ISIS

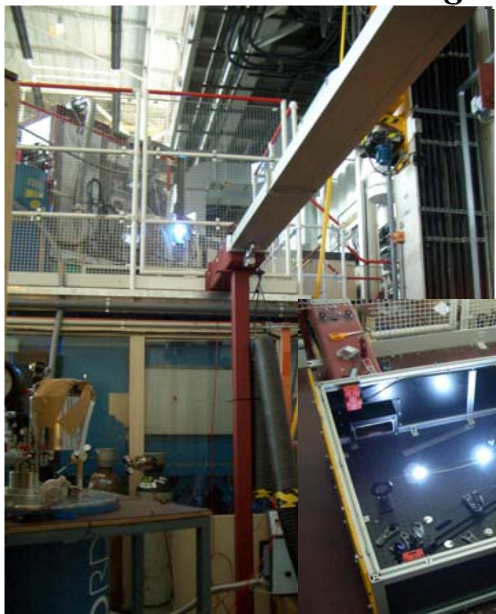
- application to spintronics, chemical reaction study, etc

・Dedicative Lasers

new laser *(U.Yamanashi / KEK)*



laser bridge



laser insertion port

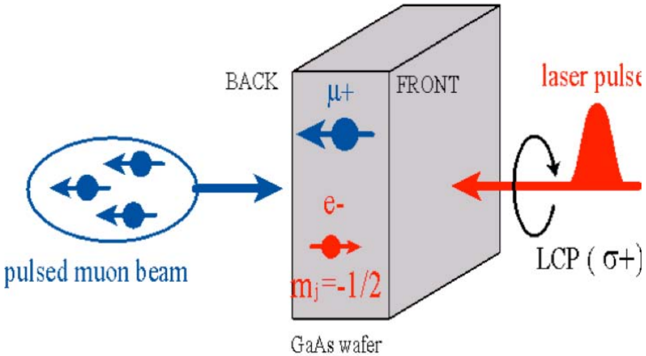
・Low-Temperature Condition (down to 2 K)

improved temperature control

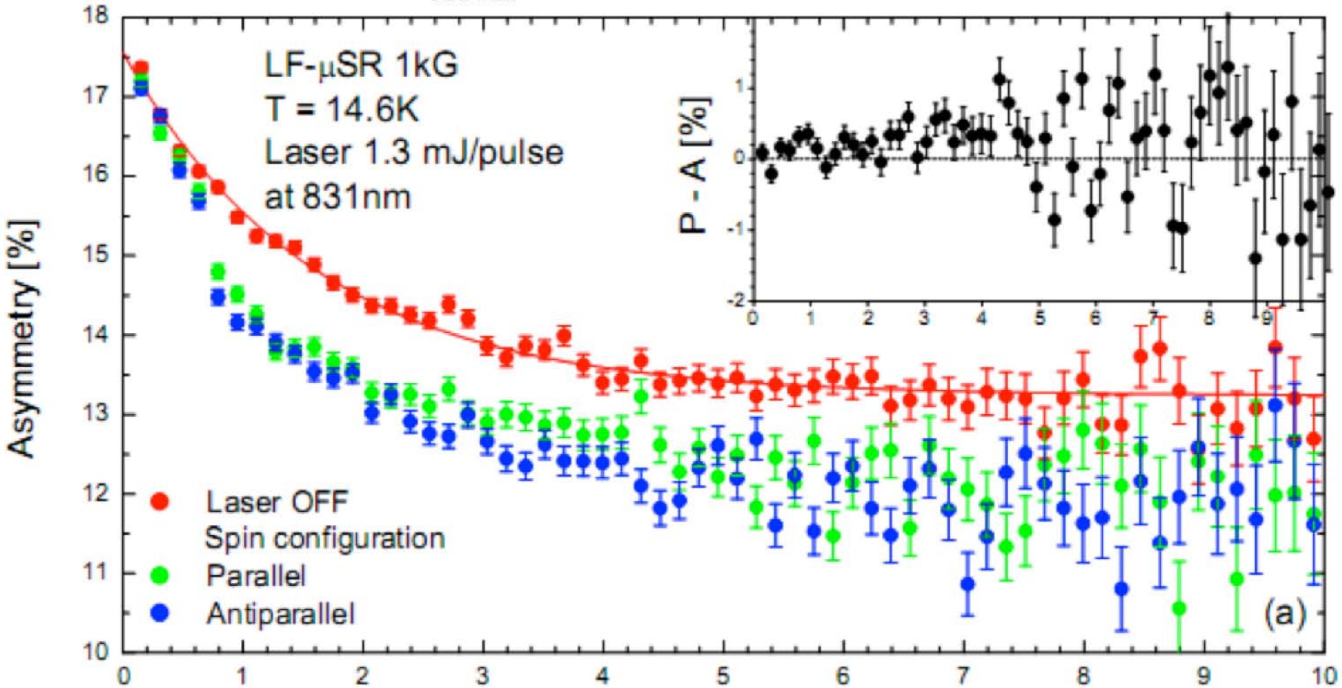
(2) Muons for Spintronics:

Celebrating first successful laser-μSR experiment

New Muonium Method Detecting Conduction Electron Spin Polarization (CESP) in n-type GaAs



Prof. Nagamine, Prof. Tom, Prof. Kawakami, Mr. Yokoyama (UC Riverside), Dr. Shimomura (KEK), Dr. Pratt (ISIS), Dr. Matsuda and Dr. Bakule (RIKEN-RAL) showing their first result of the laser irradiation μSR.
(16 February 2008)



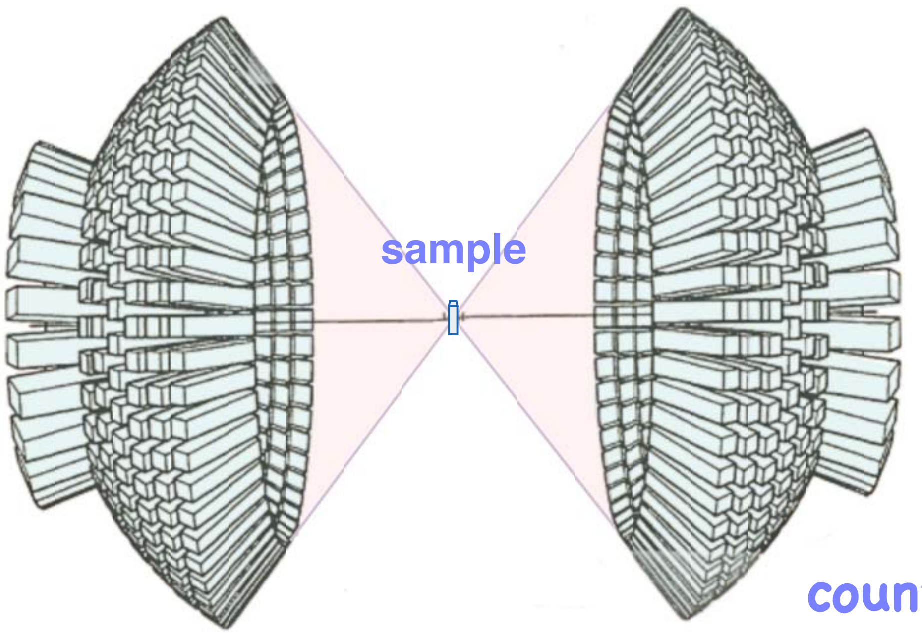
(3) expanding μSR capability @ RRMF

New μSR spectrometer at Port-4

key issues:

- highly segmented direction sensitive detector array
- enhance S/N with Fly-Path operation
- new DAQ and temperature/field control system

supported by "Molecular an ensemble" program
headed by R. Kato



BWD/FWD μ-e counters
(total: 600 channels)

fine-segmented
direction-sensitive
counters viewing the sample

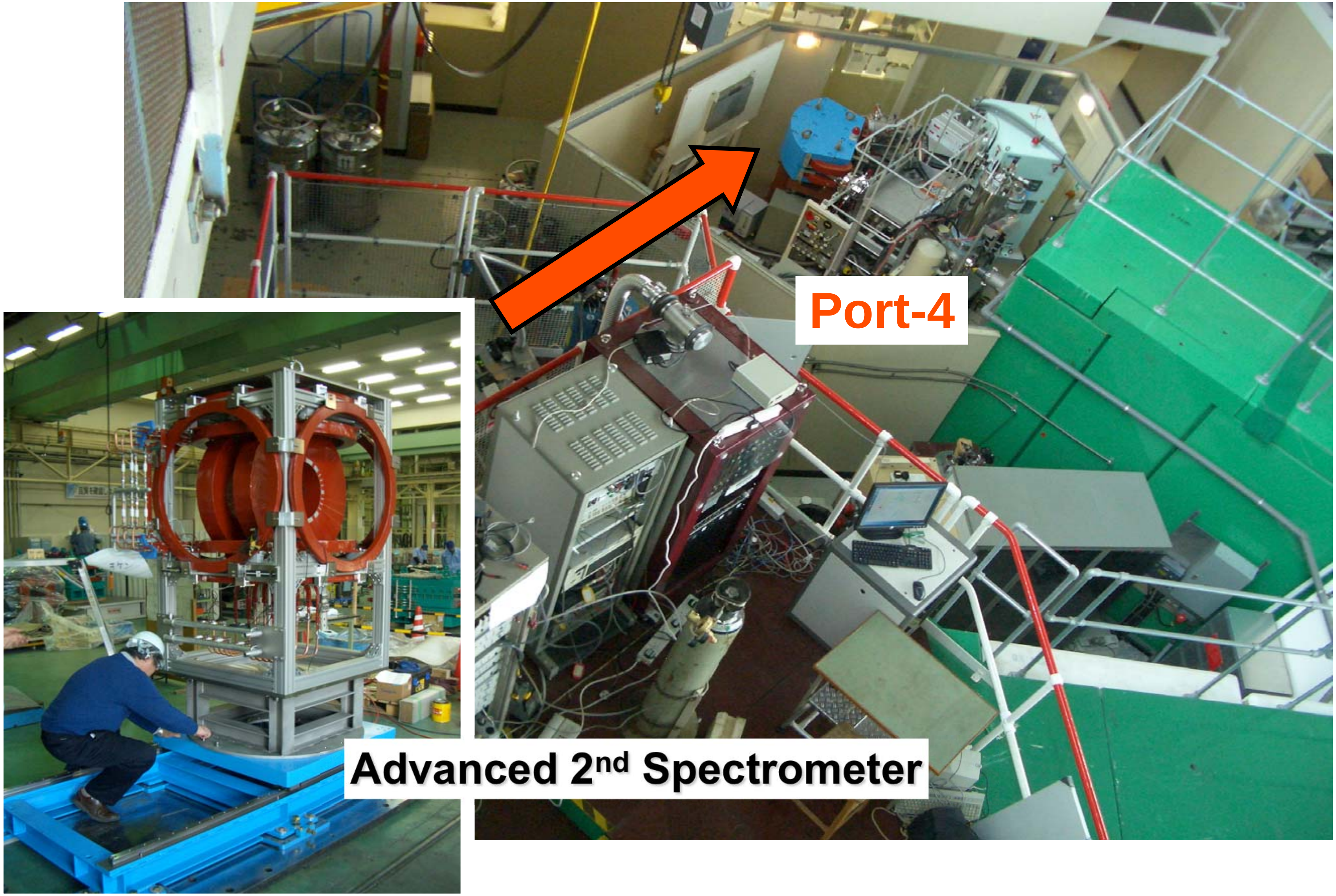
(3) Spectrometer components

half-unit of the μe decay counters

readout fiber connectors and MA-PMT attachment

spectrometer magnet

(3) Spectrometer installation



(4) High Pressure μSR cell

--- try and error for HP-μSR

key issues:

- **intensive work and collaboration RRMF-ISIS**
- **keep try and error**

  to expand capability of available HP region

Higher Pressure than 7 kbar

10 kbar (1 GPa)

(I) ultra-slow μ generation (Port-3)

New laser scheme for g-2 muon source

spot size : 30 x 30 μm^2 x 10 nm

target size : few g → few 10^{th} ng!

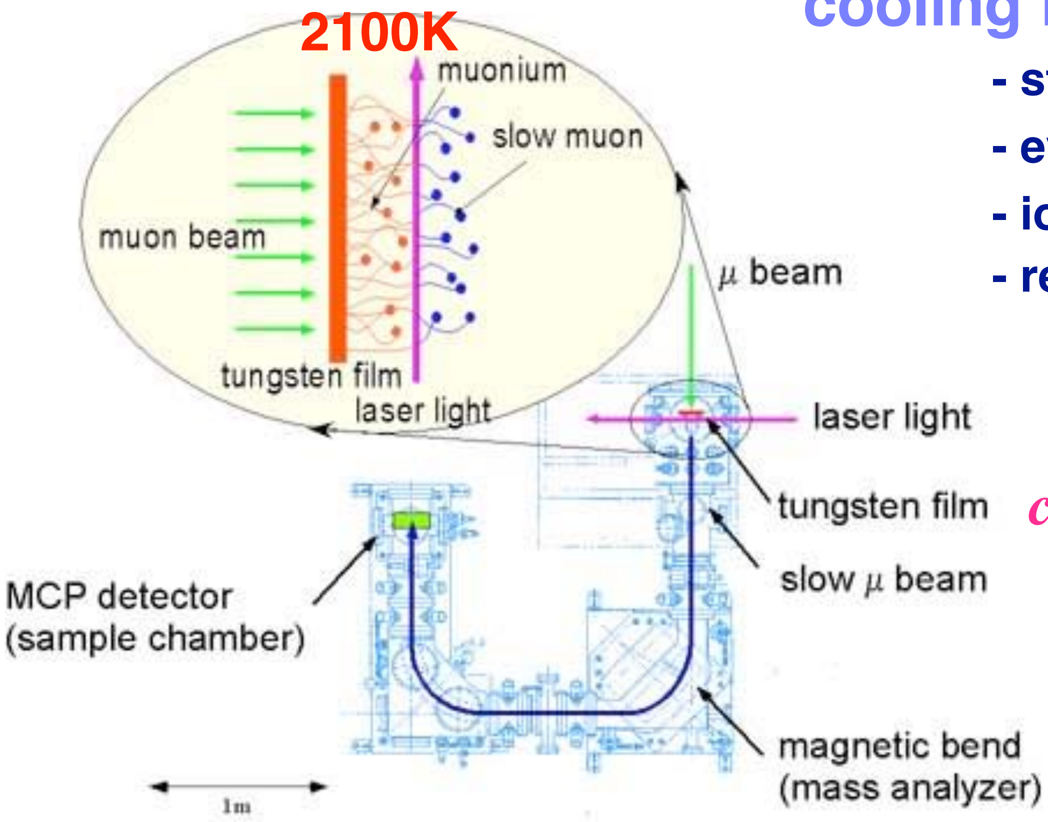
2~3 kHz slow-μ realization at RRMF

key issues:

- **realization of first practical (~100μJ) VUV pulse laser**
  - *muonium laser ionization*
- **realization of low temperature muonium generator**
  - *lower momentum dispersion*:
    - *realization of zero emittance beam (g-2)*
    - *better energy matching by avoiding Doppler effect*
  - *localized, higher density muonium in vacuum*
    - *better special overlapping with laser*
- **interdisciplinary contribution**
  - *surface (material interface) physics by slow muon,*
  - *laser chemistry, etc.*

(I) From “slow muon” to “cold” muon

Previous “slow muon” R&D concept :



cooling from 35×10^9K → 2100K

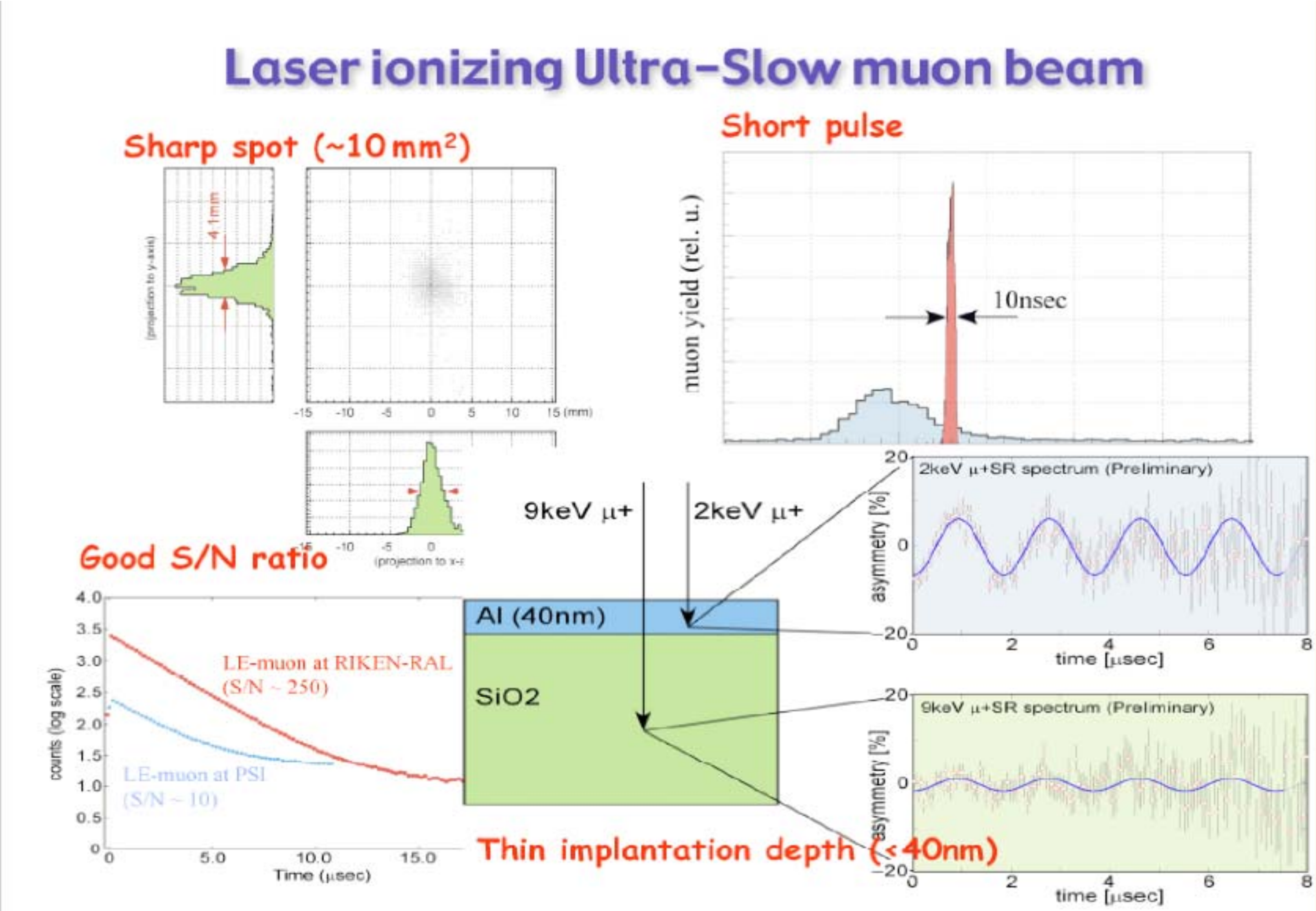
- stop muon in 2100K tungsten foil
- evaporate muonium
- ionize by laser
- re-accelerate and inject to target

collaboration with KEK group at RIKEN-RAL

wish to enhance the activity ...

realize cold muon → 300 → 10K

(I) Present “slow” muon beam quality



spatial, timing, and depth resolution, S/N

⇒ P. Bakule et al, NIM B 266 (Jan 2008) 335

(I) VUV Laser & Muonium Target development

New Laser with Wada solid state laser Lab.

- Difficulty

optical damage:

phase matching loss in non-linear optics:

shallow focus, gas jet Kr cell (avoid window),
pressure control, impurity insertion

⇨ **challenge: muonium polarization recovery**

Nakajima (Kyoto U.) : laser pumping

Muonium generator development

- Cold Muonium generator (room temperature)

⇨ **nano-structured material** *Esashi (Tohoku U.)*

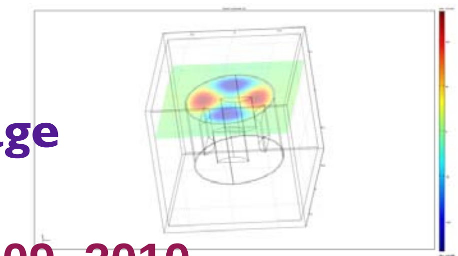
- Further muon beam focus onto muonium generator

⇨ **capillary focusing**

- Improvement of slow muon optics

⇨ **electron microscope technology**

⇨ **Geant4 modeling with PSI package**



- Aiming Time Schedule

basic laser construction in RIKEN-ASI 2009~2010

dedicative slow muon generation R&D using RRMF 2010 ~

Beyond Standard Model by Muon

$$\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

Let's listen to the whispering of muon / nature

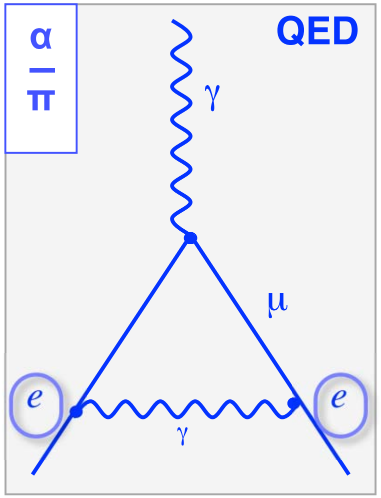
Why muon g-2？

magnetic moment

$$\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

$\vec{\mu}$: magnetic moment
$\vec{s}$: spin
g : gyromagnetic ratio

QED 1st order correction



DIRAC Equation : $g = 2$

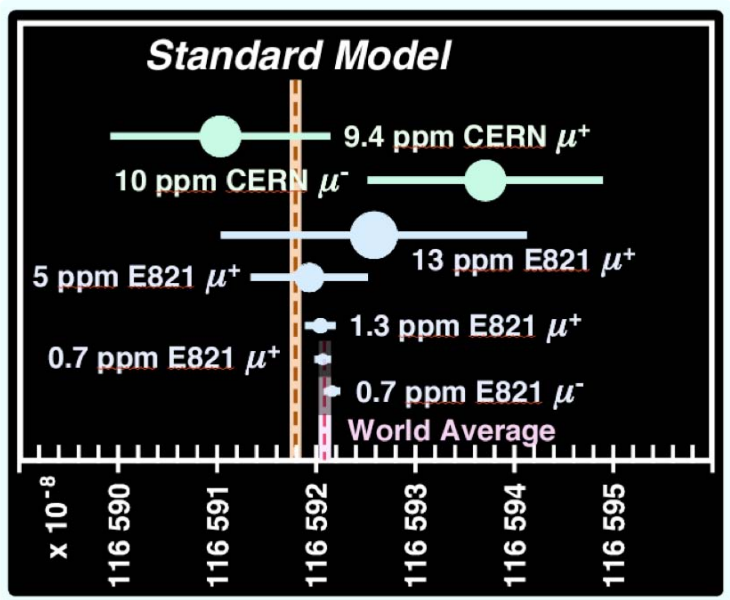
$$\mu = (1+a)\left(\frac{e\hbar}{2m}\right)$$

$$a = \frac{g-2}{2} = \frac{1}{2}\left(\frac{\alpha}{\pi}\right) - 0.3248\left(\frac{\alpha}{\pi}\right)^2 + \ldots.$$

QED補正

inconsistent with SM!

$$\Delta a_\mu^{(\mathrm{today})} = \Delta a_\mu^{(\mathrm{Exp})} - \Delta a_\mu^{(\mathrm{SM})} = (295 \pm 88) \times 10^{-11}$$

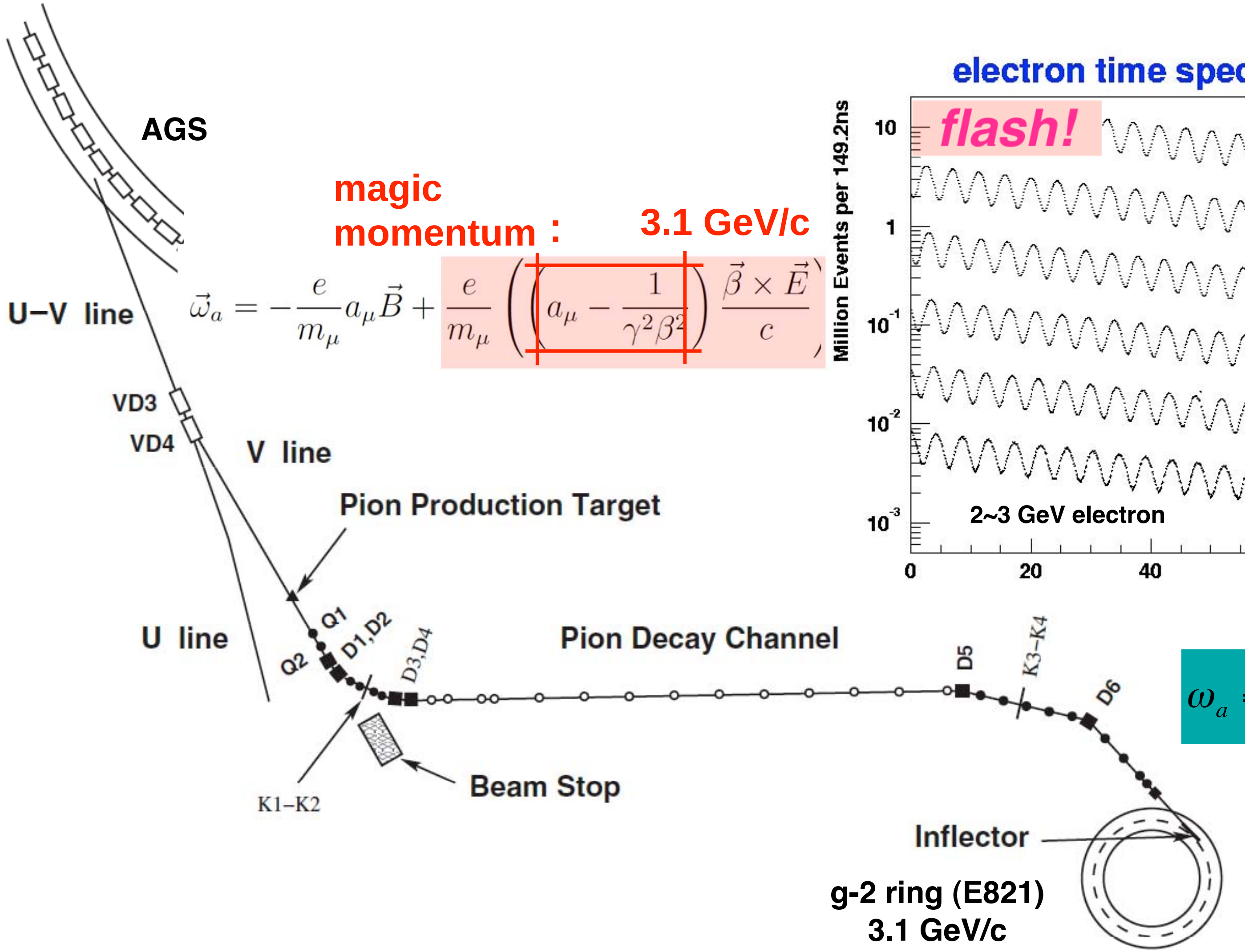


Δa_μ(EXP-SM) ~ $(30 \pm 9) \times 10^{-10}$

beyond standard model？

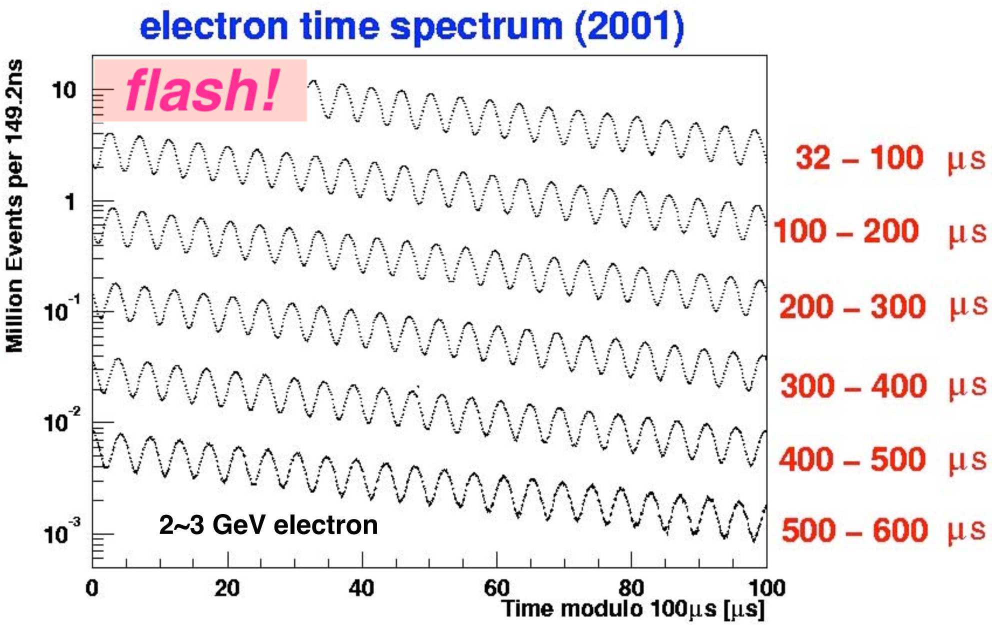
Muon g-2 measurement at BNL E821

- storage muon at magic momentum, and observe forward decay positron by calorimeter

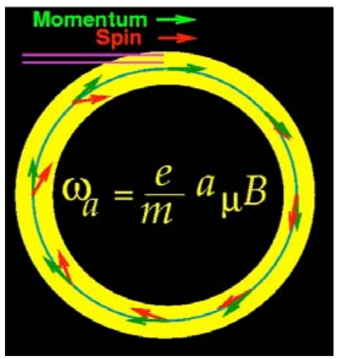


magic momentum : 3.1 GeV/c

$$\vec{\omega}_a = -\frac{e}{m_\mu} a_\mu \vec{B} + \frac{e}{m_\mu}\left(\boxed{a_\mu - \frac{1}{\gamma^2\beta^2}}\right)\frac{\vec{\beta}\times\vec{E}}{c}$$



$$\omega_a = -\frac{e}{m} a_\mu B$$

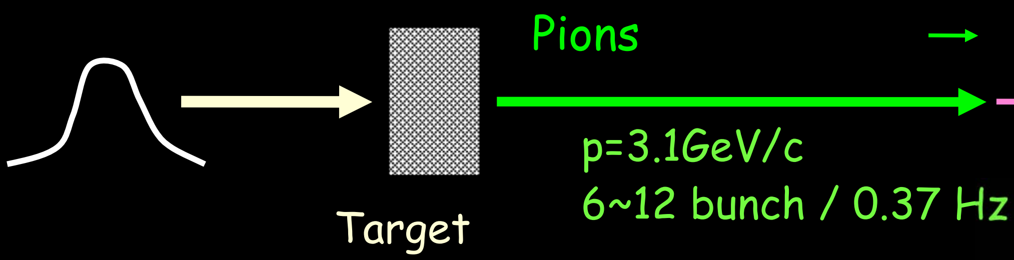


$$\omega_a = \frac{e}{m} a_\mu B$$

BNL E821

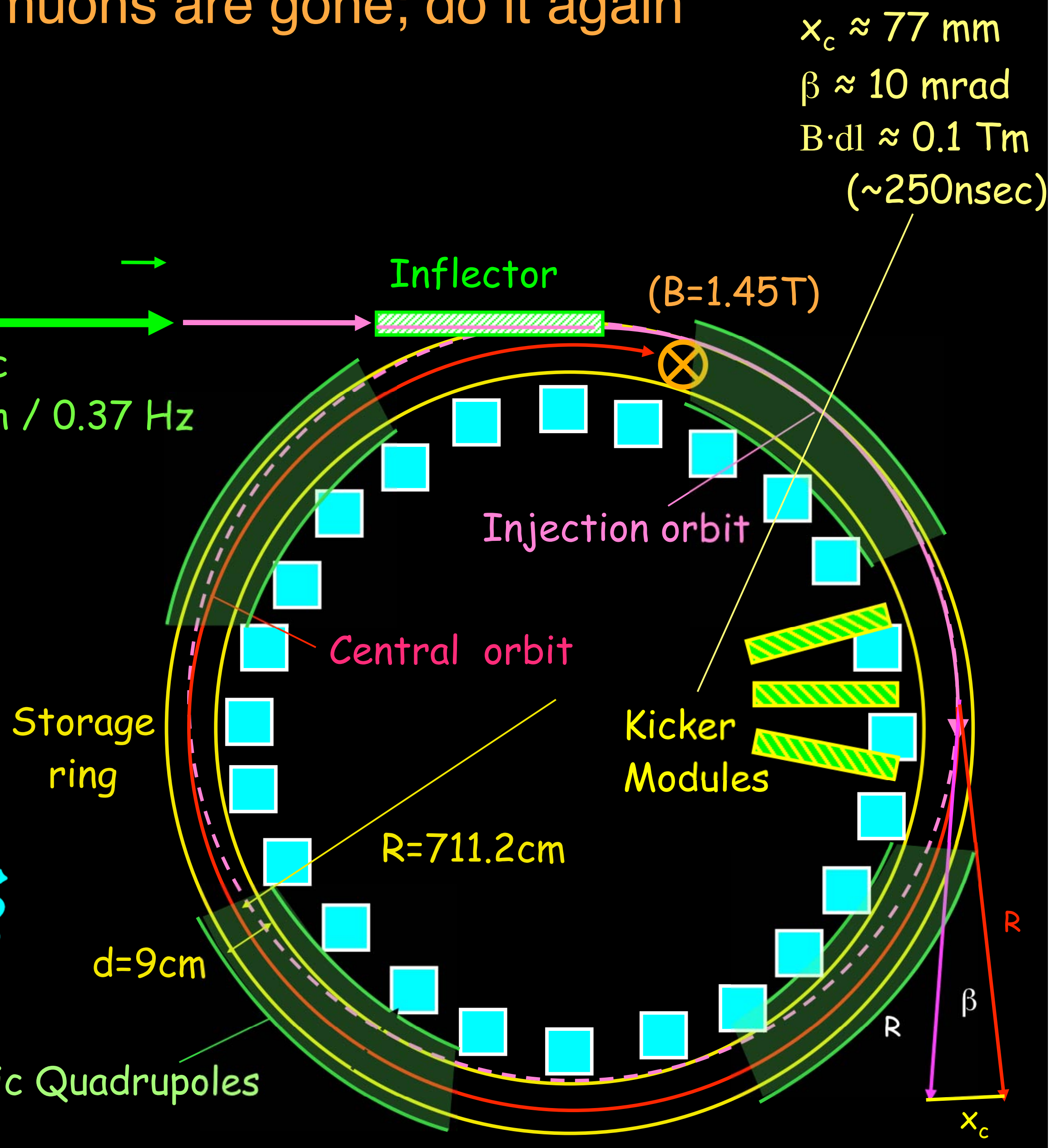
Experimental Technique: fill ring, count until all muons are gone; do it again

25ns bunch of 5 X 10^{12} protons from AGS



- Muon polarization
- Muon storage ring
- injection & kicking
- focus with Electric Quadrupoles
- 24 electron calorimeters

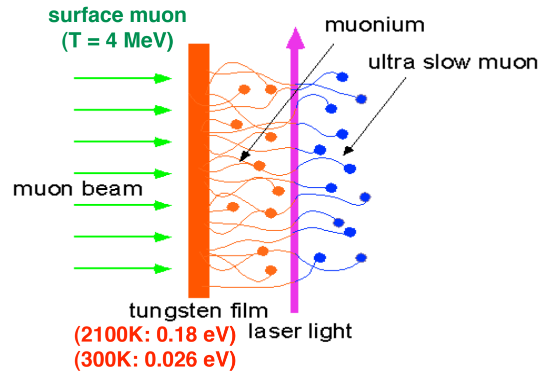
$$\vec{\omega}_a = -\frac{e}{m} a_\mu \vec{B}$$



(thanks to Q. Peng)

BNL g-2 experiment E821

Cold μ for g-2 @ J-PARC P34



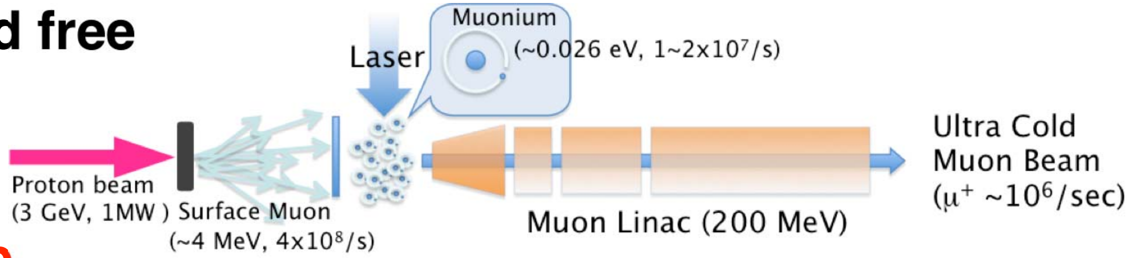
- **No CBO (focusing field off!)**

  muon motion is static

$$\vec{\omega}_a = -\frac{e}{m_\mu} a_\mu \vec{B} + \frac{e}{m_\mu}\left(\left(a_\mu - \frac{1}{\gamma^2\beta^2}\right)\frac{\vec{\beta}\times\cancel{\vec{E}}}{c}\right)$$

- **hadron background free**

  muon re-acceleration

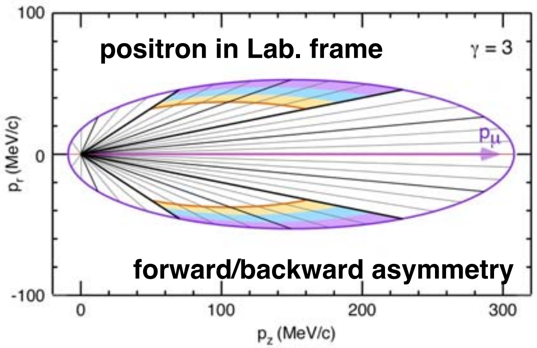


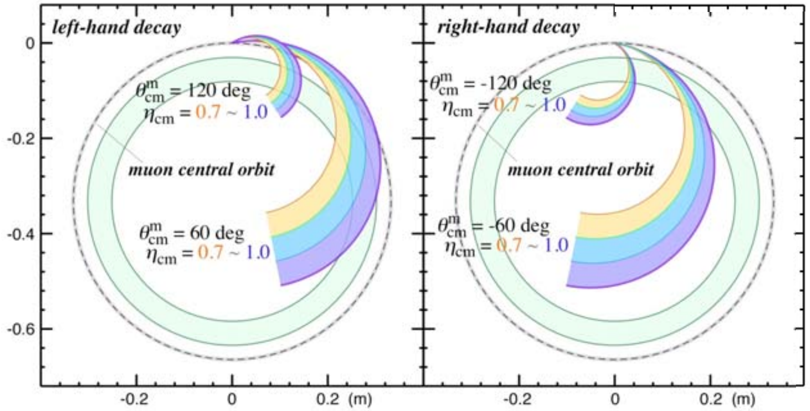
- **statistics vs. pileup**

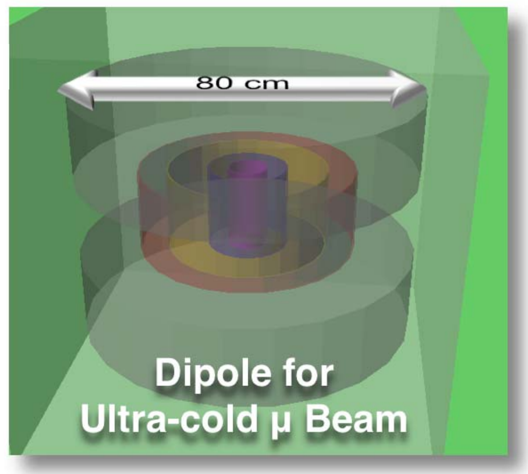
  high intensity / stable VUV laser

- **loss cancel by positron asymmetry**

$$\frac{F - B}{F + B}$$



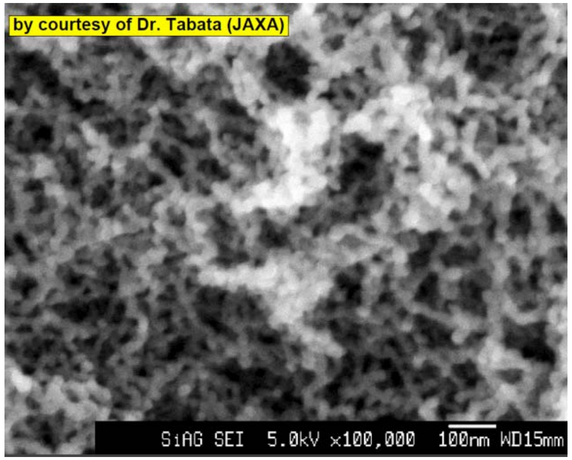


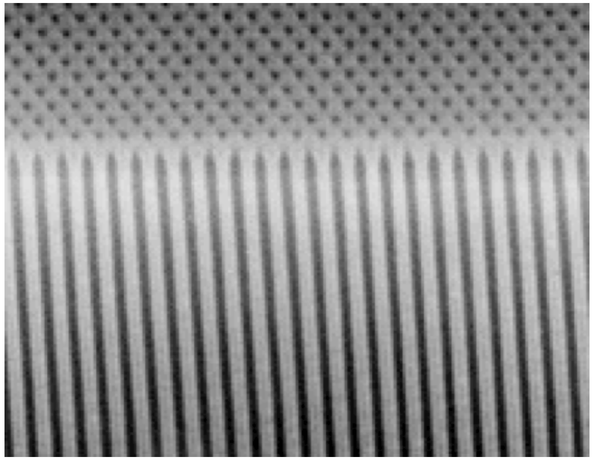


A) Muon Source at Room Temp.

Question: How to minimize emittance $\Delta x \cdot \Delta\theta_x$?
Ans.: Reduce temperature!

Test experiment will be submitted to TRIUMF with A. Olin *etc.*





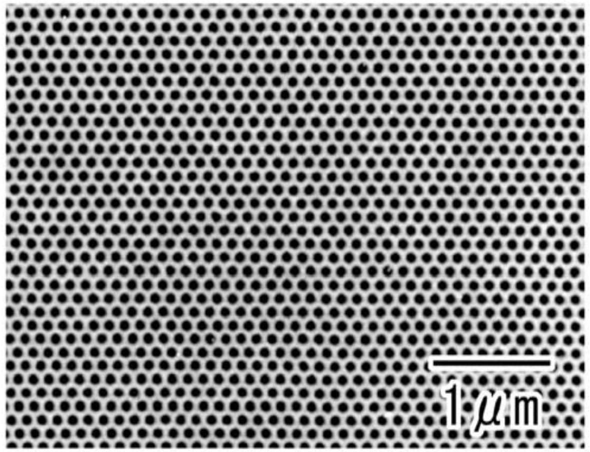


Fig. 1. SEM image of the surface view of the ideally ordered anodic porous alumina.

Aerogel :
SiO_2 cluster

Tabata (JAXA)

Porous Al_2O_3 :
nano-hole array

Masuda (TMU)

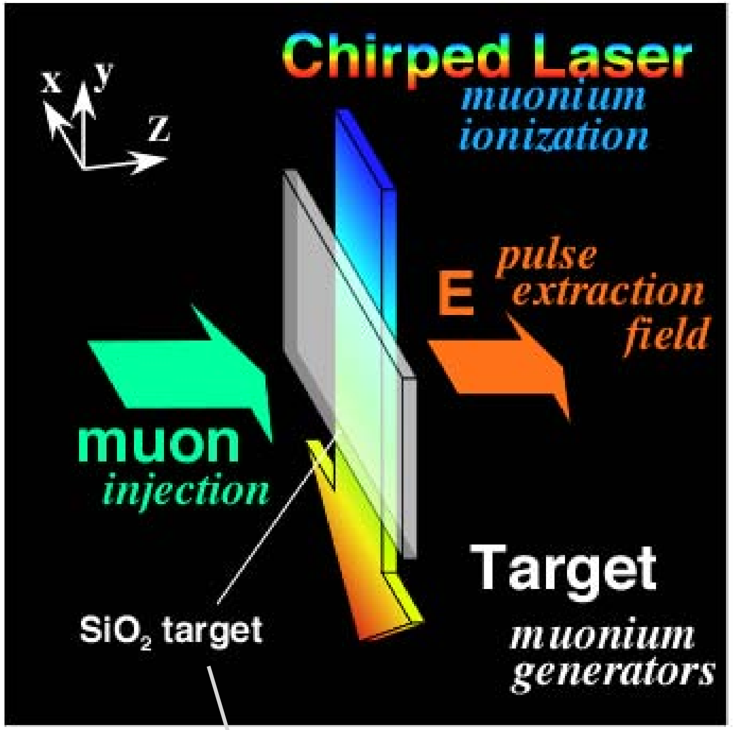
Porous SiO_2 : ?
nano-hole array

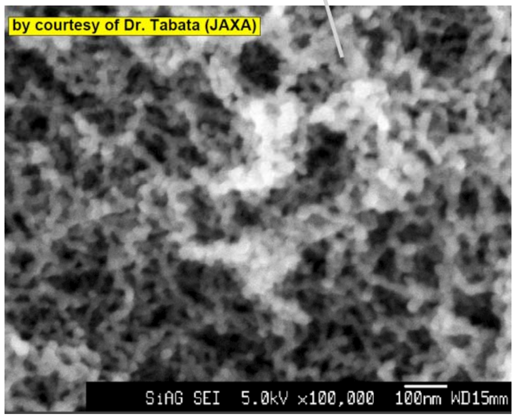
R&D with Esashi (Tohoku U.) group

B) Laser intensity & stability

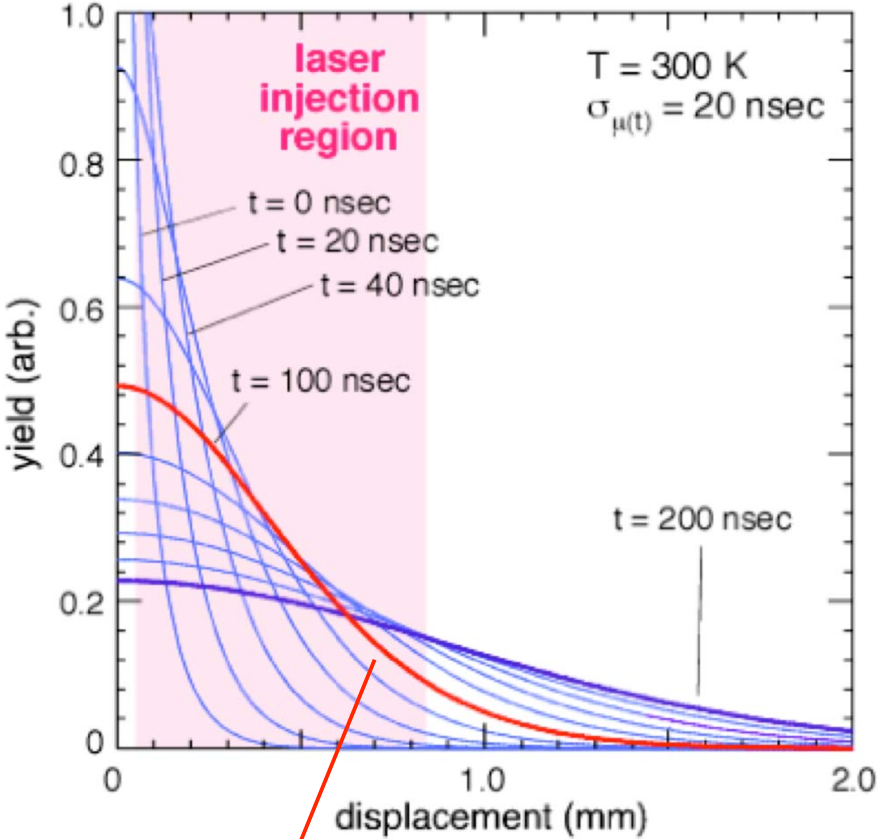
100 times in yield

configuration





muonium time evolution in horizontal direction



sharp laser (Δz_{lp} = 1 mm)

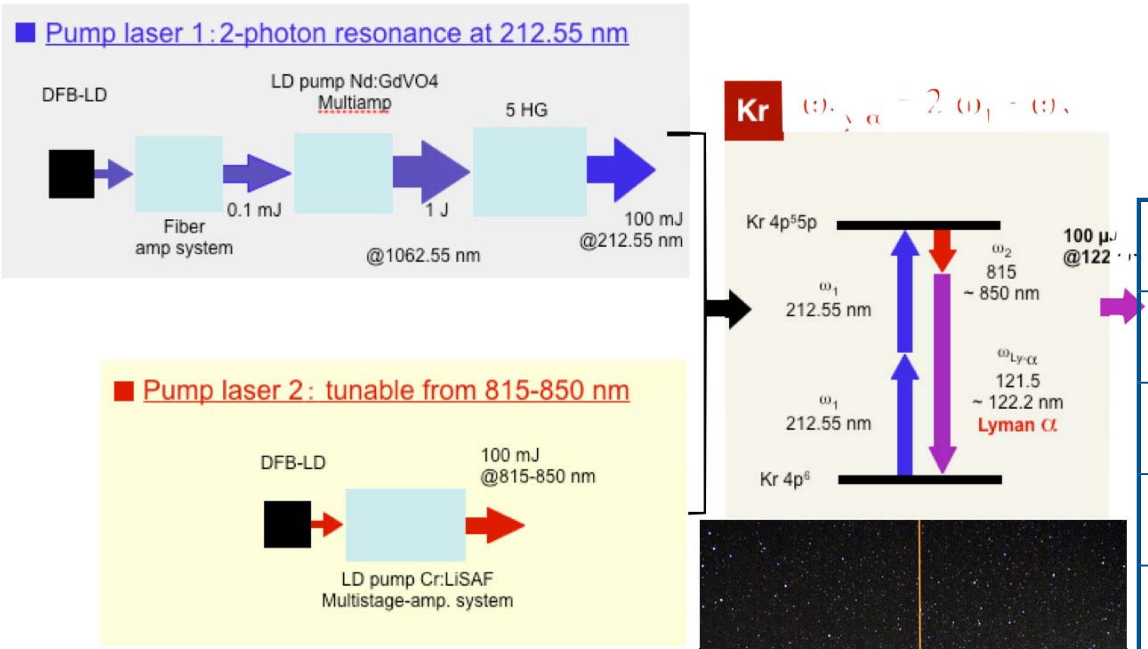
neighbor upon target (0.25 mm apart)

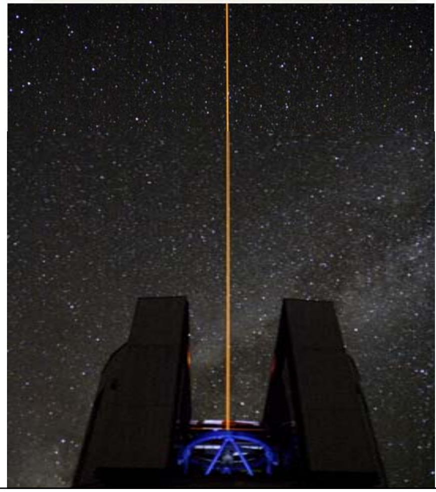
2100K → 300K

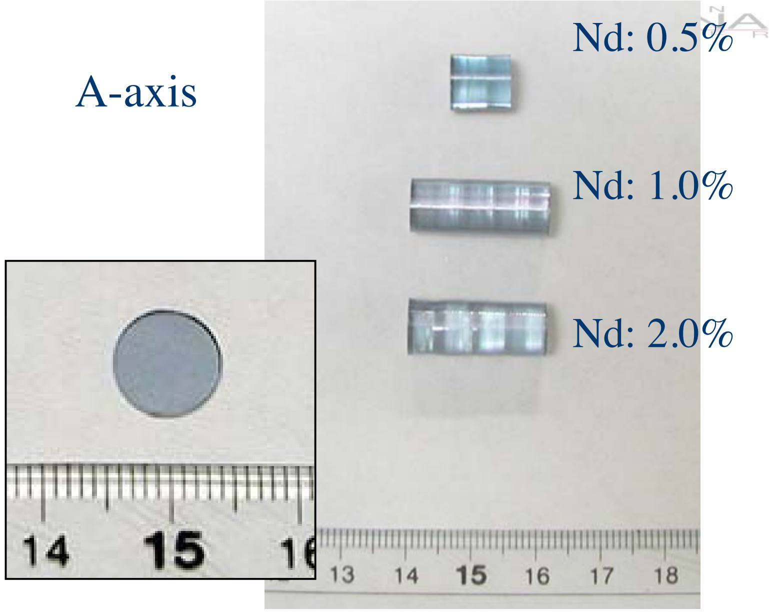
B) Laser intensity & stability

collaboration with Wada group (RIKEN, ASI)

Schematic VUV Laser Diagram



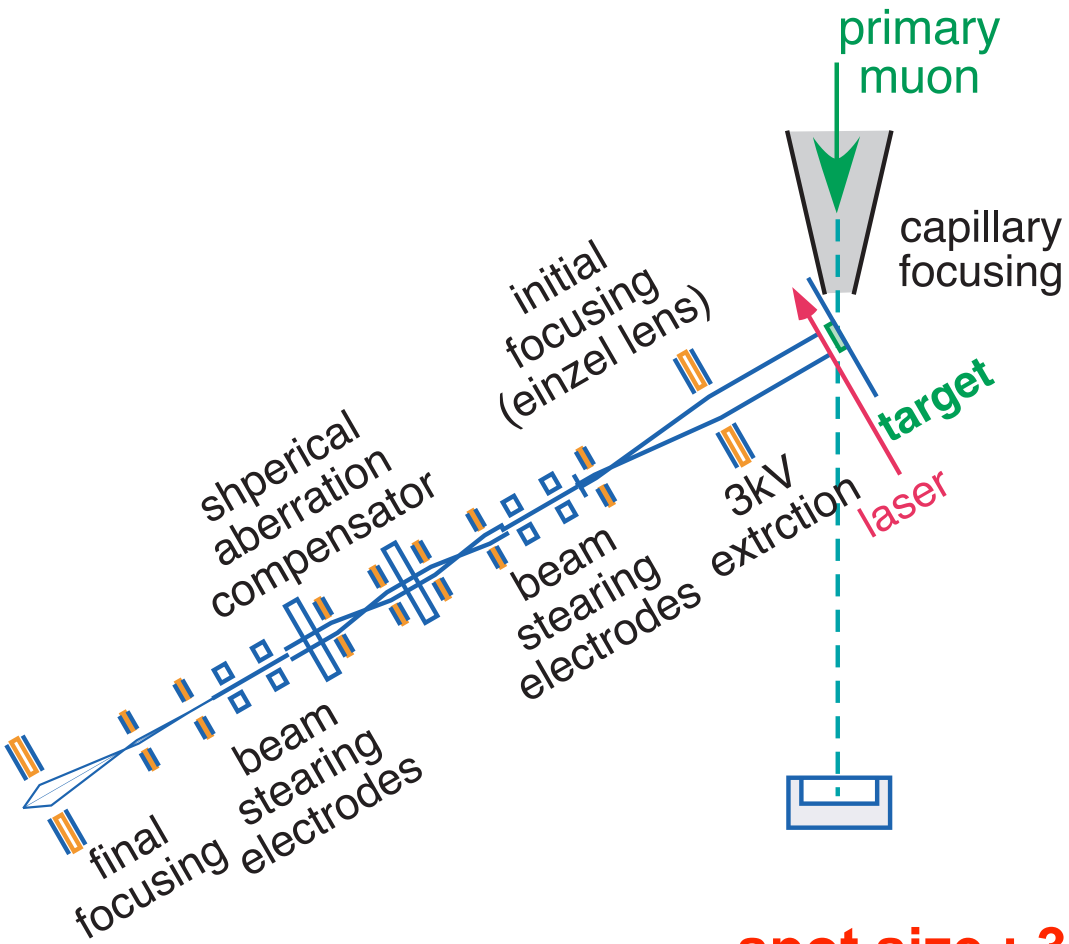




	Nd:YAG	$Nd:YVO_4$	$Nd:GdVO_4$
Thermal conductivity	◎	△	◎
Emission cross-section	○	a-axis ◎ c-axis ○	a-axis ◎ c-axis ○
Lifetime of upper state	◎	○	○
Crystal growth	◎	△	◎
Highly doping	×	△	◎
Wavelength	**1064**	**1064**	**1063**

Fifth harmonics of Kr 1062.75 nm is 212.55 nm!

C) Electron Microscope Technology Application



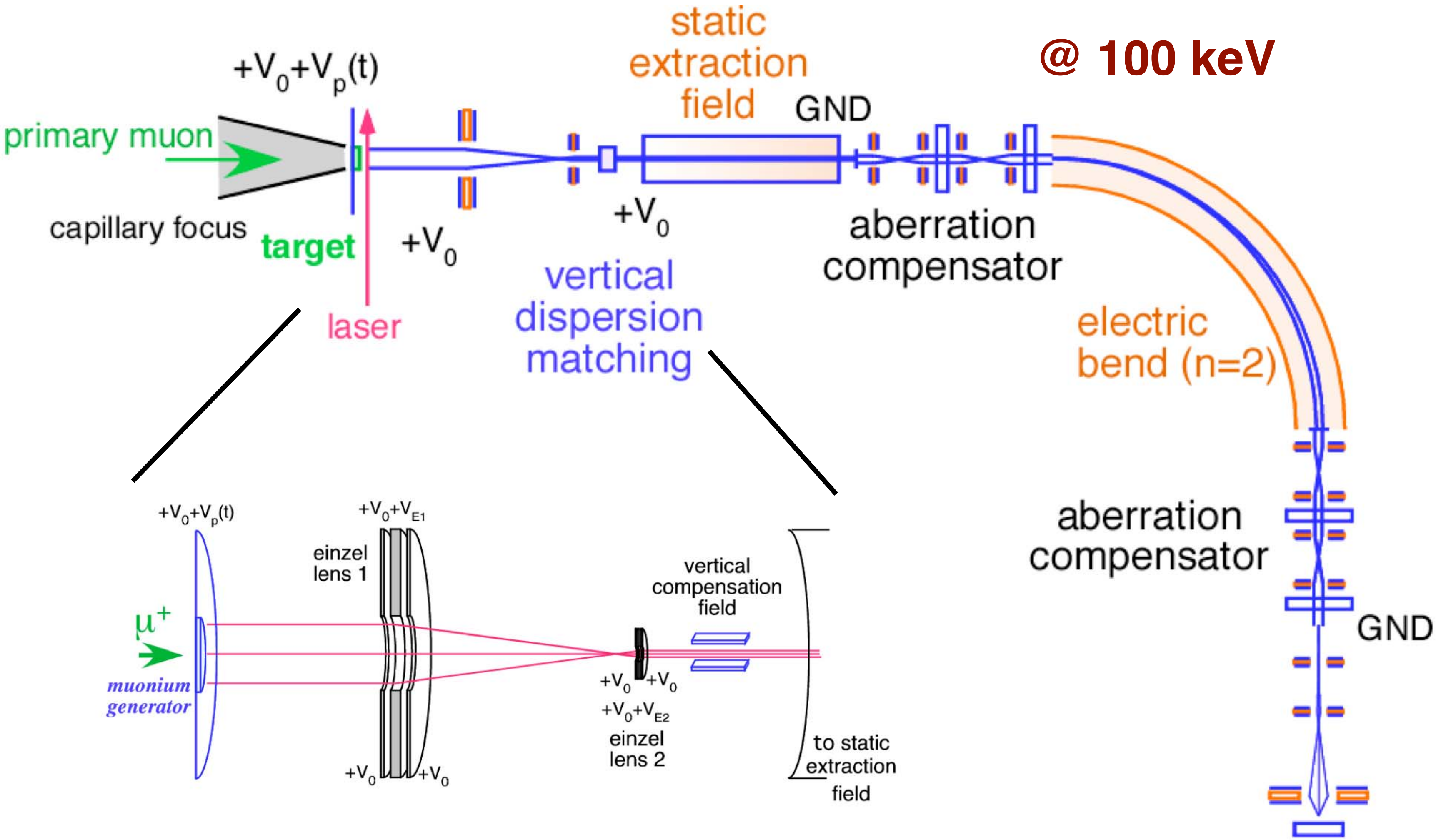
initial test @ 3 keV

spot size : 30 x 30 μm^2 x 10 nm

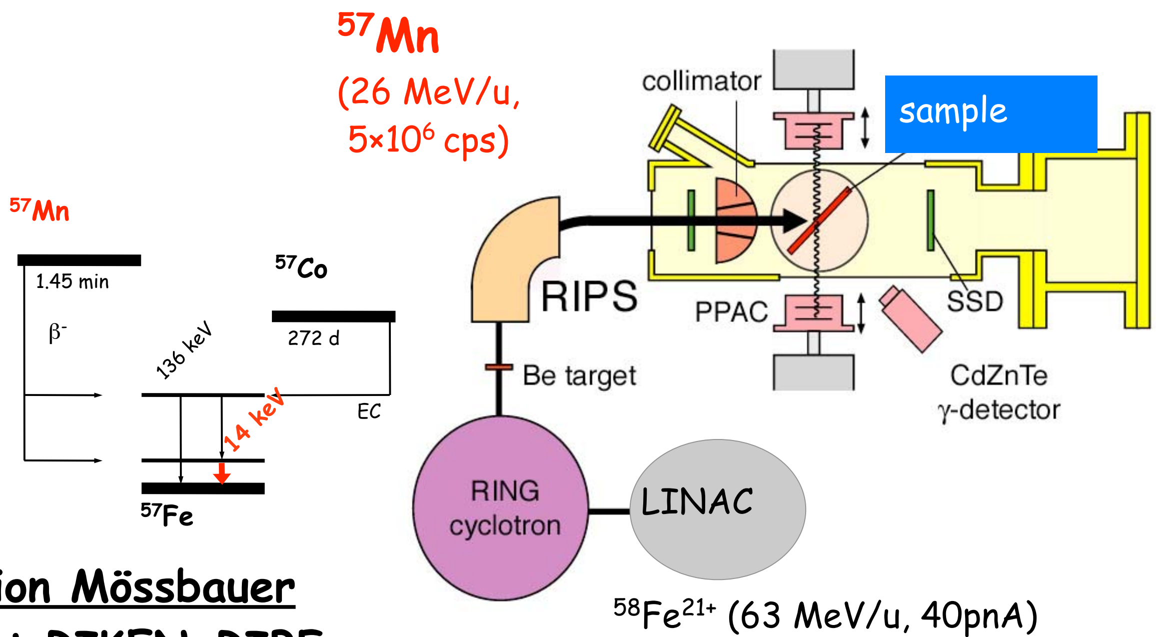
target size : few g → few 10th ng!

2~3 kHz slow-μ realization at RRMF

D) g-2 initial acceleration



Mössbauer spectroscopy



^{57}Mn implantation Mössbauer spectrometer at RIKEN-RIBF

Mössbauer spectroscopy at RIKEN-RIBF

(1) ^{57}Mn implantation Mössbauer spectroscopy

(a) **metastable states** induced by nuclear decays

(b) **atomic jump process** of localized atoms in Si

(2) ^{99}Ru, ^{61}Ni, and ^{83}Kr Mössbauer studies

(a) ^{99}Ru Mössbauer and mSR studies of $CaRuO_3$

(b) magnetic studies of Skutterudites RRu_4P_{12}

(c) catalytic property of NiO

(3) On-line Mössbauer studies using nuclear reactions

(a) **neutron capture** reaction

(b) **negative muon capture** process

(4) Conventional ^{57}Fe Mössbauer spectroscopy

(a) proton-coupled intramolecular electron transfer

(b) oxidizing intermediates in nonheme Fe enzymes

(c) mixed-valence states and spin crossover phenomena

(5) Applications of ß-NMR to materials science

Mössbauer spectroscopy at RIKEN-RIBF

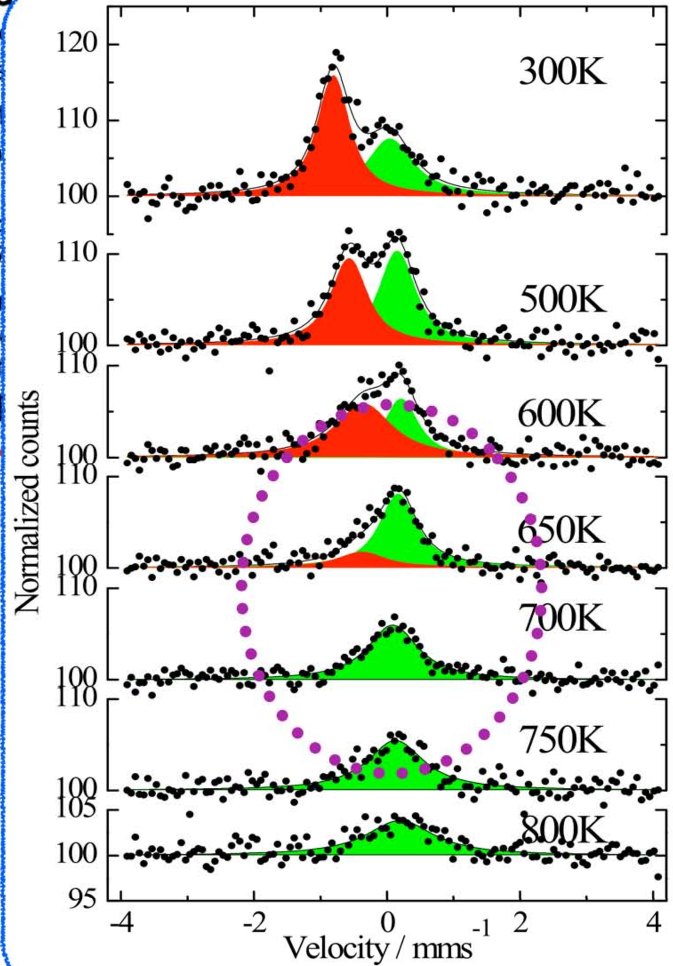
(1) ^{57}Mn implantation Mössbauer spectroscopy
- (a) metastable states induced by nuclear decays
- (b) atomic jump process of localized atoms in Si

(2) ^{99}Ru, ^{61}Ni, and
- (a) ^{99}Ru Mössbauer
- (b) magnetic studies
- (c) catalytic propert

(3) On-line Mössb
- (a) neutron capture
- (b) negative muon c

(4) Conventional ^{57}
- (a) proton-coupled i
- (b) oxidizing interm
- (c) mixed-valence st

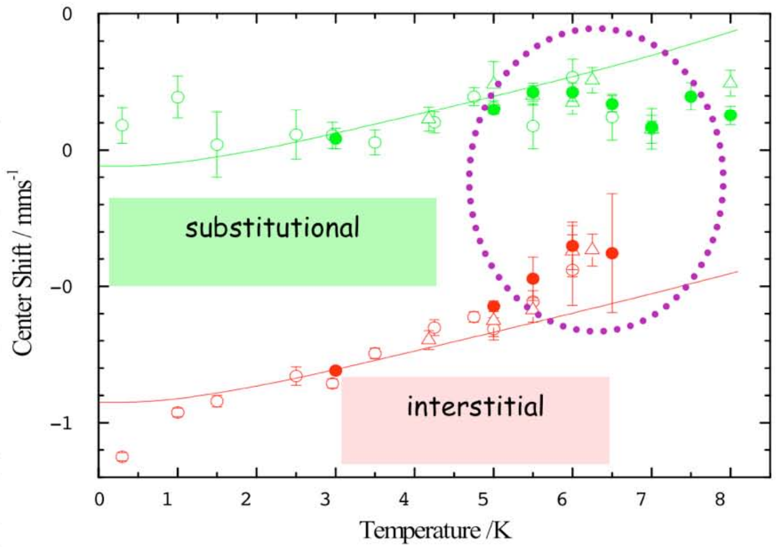
(5) Applications of



(1-b) Fe in Si

Motional averaging

$Fe^{+}_{int.}$ + vacancy = $Fe^{0}_{sub.}$



The dreams/objectives are:

Origin of Matter Mass

Beyond Standard Model

also contribute to other field
by
μ-science and Mössbauer

Thank you for your attention!

Laboratory Management

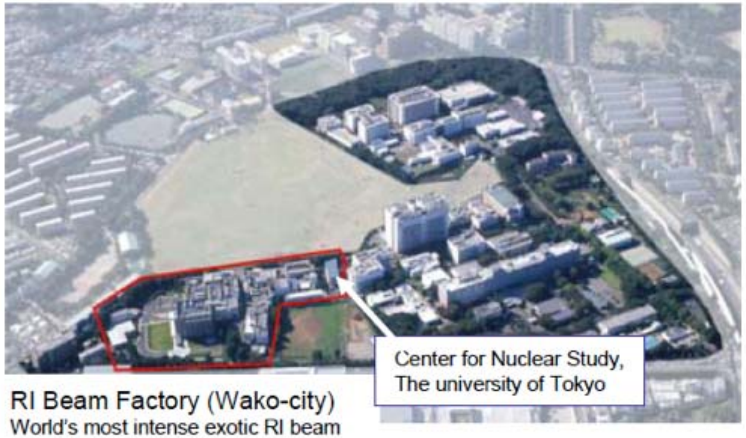
RIKEN Nishina Center
Advanced Meson Science Laboratory

M. Iwasaki

MuSAC

Organization of RIKEN Nishina Center
(established on April 1 2006)

Research Locations



RI Beam Factory (Wako-city)
World's most intense exotic RI beam

RIKEN BNL Research Center
World's first polarized proton beam colliding
High- speed lattice QCD computing

RIKEN RAL Muon Facility
World's most intense pulsed muon beam

President

Advisory Council
RBRC SRC
RRMF-AC

Director
Deputy
Science Adviser

Scientific Policy Committee
Program Advisory Committee
Safety Review Committee
Machine Time Committee
Coordination Committee

Accelerator Division
- Accelerator Development Group
- Accelerator Operation Group

Nuclear Physics Research Division
- Heavy Ion Nuclear Physics Laboratory
- Theoretical Nuclear Physics Laboratory
- Radioactive Isotope Physics Laboratory
- Superheavy Element Laboratory
- Experimental Installations Development Group
- Experimental Installations Operation Group

User Liaison and Support Division
- User Liaison and Support Group

Sub Nuclear System Research Division
- Radiation Laboratory
- Advanced Meson Science Laboratory
- Theoretical Physics Laboratory
- Strangeness Nuclear Physics Laboratory

Accelerator Applications Research Division
- Accelerator Applications Research Group

Safety Management Group

RIKEN BNL Research Center
- Theory Group
- Experimental Group

RIKEN Facility Office at RAL

New Organization Scheme of RNC April 1 2009

RNC: RIKEN Nishina Center
NCAC: RIKEN Nishina Center Advisory Council
RRMF-AC: RIKEN-RAL Muon Facility Advisory Committee

President

NCAC

Advisory Council
RBRC-SRC
RRMF-AC

Director
Deputy
Science Adviser

Scientific Policy Committee
Program Advisory Committee
Safety Review Committee
Machine Time Committee
Coordination Committee

NP-PAC
ML-PAC (including muon)

ML: Material and Life Science

Theoretical Research Division
Theoretical Physics Laboratory
Theoretical Nuclear Physics Laboratory
Strangeness Nuclear Physics Laboratory

Sub Nuclear System Research Division
Radiation Laboratory
Advanced Meson Science Laboratory
RIKEN BNL Research Center
Theory Group
Experimental Group
RIKEN Facility Office at RAL

RIBF Research Division
Heavy Ion Nuclear Physics Laboratory
Radioactive Isotope Physics Laboratory
Superheavy Element Laboratory
Accelerator Group
Experimental Installations Development Group
Research Instruments Group
User Liaison and Industrial Cooperation Group
Accelerator Applications Research Group
Safety Management Group

Transparency to answer my "research philosophy"

I've never ever tried to compile / summarize my "research philosophy".
Research after research, just do it, because its fun!

If I shall make it in a word...

CURIOSITY ?

A proverb: Curiosity killed the cat...

What I try to enforce me ...

Many of them are not my words, though.
And I'm just trying to be...

- Do something what people do not

- Challenge always

- Do not shame if you don't understand, should be shameful if you don't try to understand

- Think hard, when you have trouble. It is a gift!

- Suspect yourself and even your supervisor, avoid self confident

- There should be a way to solve for any problems

- There is no fruitless effort nor pointless failure, what you learn from that is really precious

What I try to enforce me ... cont.

- Your limit comes only when you accept that
- Talk, Listen and Learn with/from others
- Time of adversity provides you true chance
- Accumulate ideas, time of chance is short
- Always be positive, believe that the dream come true
- Do not be obedient, unless you have reason to do so

at last

Even if I should pass away tomorrow, I wish I can tell me
"You did all your best, you are excellent!"

Lab. Members

	Number	Name
Research Staff (permanent position)	9	IWASAKI Masahiko
		MATSUZAKI Teiichiro
		ISHIDA Katsuhiko
		KOBAYASHI Yoshio
		OUTA Haruhiko
		WATANABE Isao
		ITAHASHI Kenta
		OHNISHI Hiroaki
		SAKUMA Fuminori
Special/Foreign Postdoctoral Researchers	3	OHISHI Kazuki
		IIO Masami
		RISDIANA
Research Staff (contract)	8	SUZUKI Takao
		KOIKE Takahisa
		KAWAMATA Takayuki
		ISHII Yasuyuki
		TSUKADA Kyo
		MIZUNO Katsuya
		TOMONO Dai
		YOKOYAMA Koji

Research Collaborative Advisors	4	ITO Atsuko
		AKAISHI Yoshinori
		YAMAZAKI Toshimitsu
		KAMIMURA Masayasu
Visiting Researchers	2	YAGI Eiichi
		NAGATOMO Takashi
Visiting Researchers/Technicians (Lab. Outside)	128	
Junior Research Associates	3	ITO Satoshi
		HIRAIWA Toshihiko
		FUJIWARA Yuya
Student Trainees	3	TOKUDA Makoto
		KOU Hiroshi
		SATAKE Manami
Student Trainees (Lab. Outside)	35	
Assistants	2	SATO Junko
		FUJITA Yoko

hadron

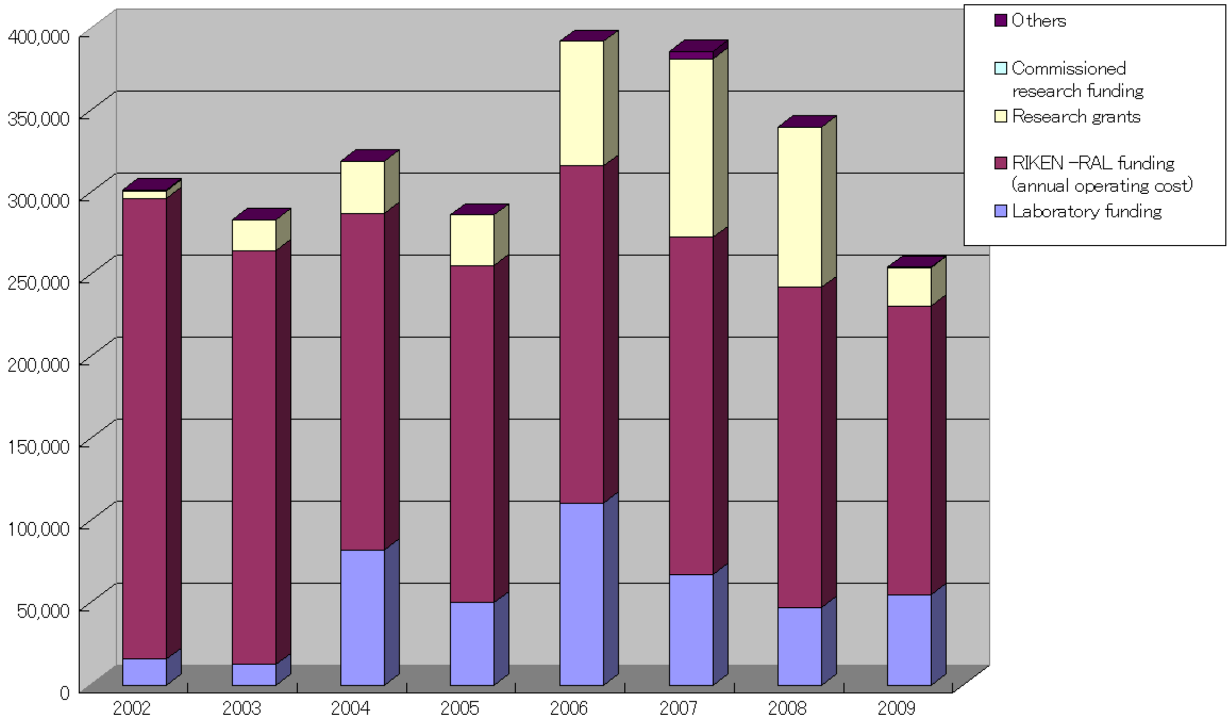
muon

laser

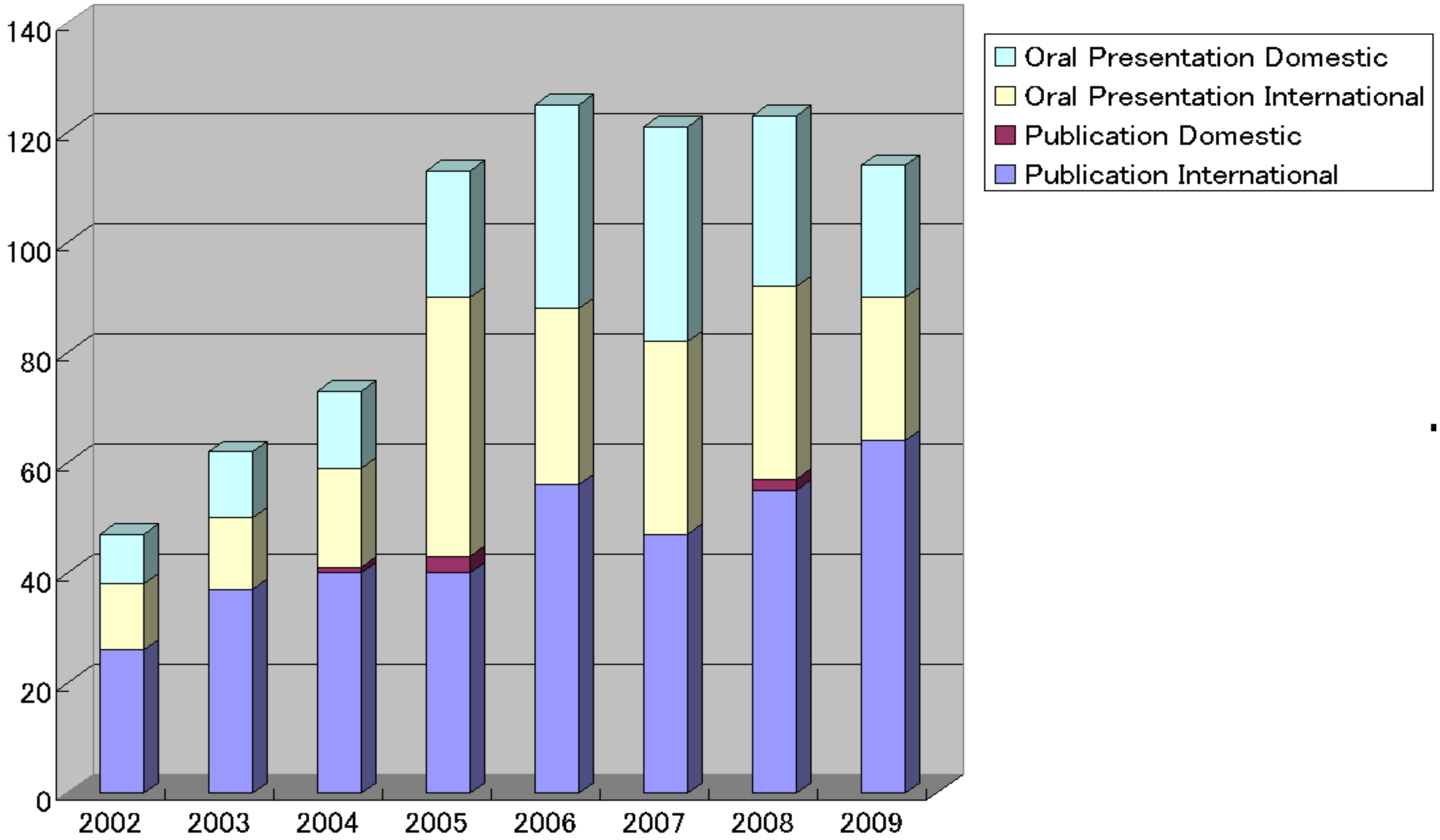
misc.

Budget status

Fiscal year		2002	2003	2004	2005	2006	2007	2008	2009
Governent funding (thru RIKEN)	Laboratory funding	15,800	12,440	82,130	50,180	110,950	67,498	47,150	55,150
	RIKEN -RAL funding (annual operating cost)	280,522	252,135	205,224	205,224	205,224	205,224	194,977	175,479
Research grants		4,650	18,800	31,600	31,000	75,840	108,660	97,610	23,500
Commissioned research funding		420	0	0	0	0	0	0	300
Others		0	0	0	0	0	4,545	0	0
		303,394	285,378	320,958	288,409	394,020	387,934	341,745	256,438

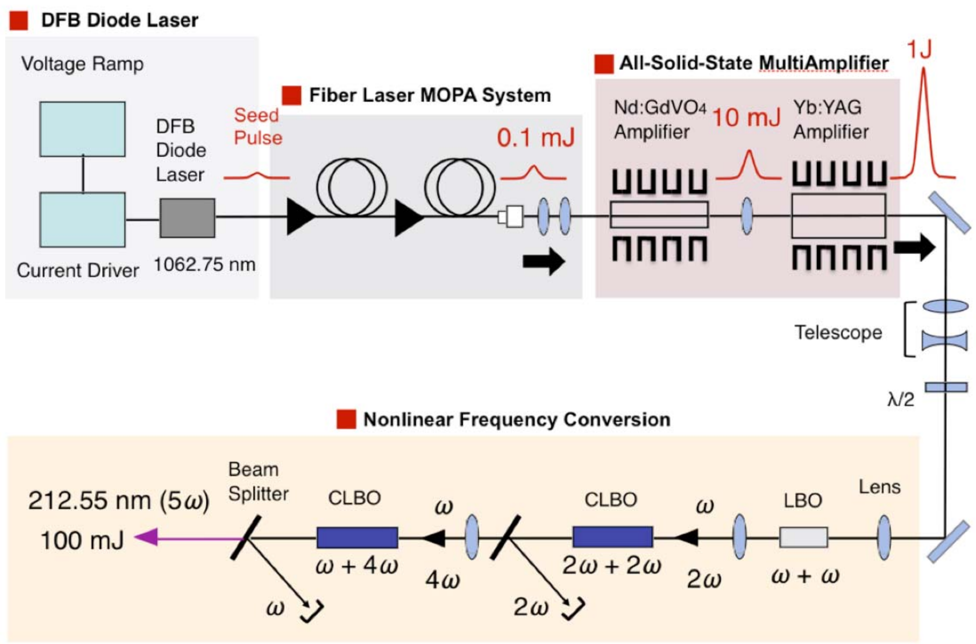


Publications

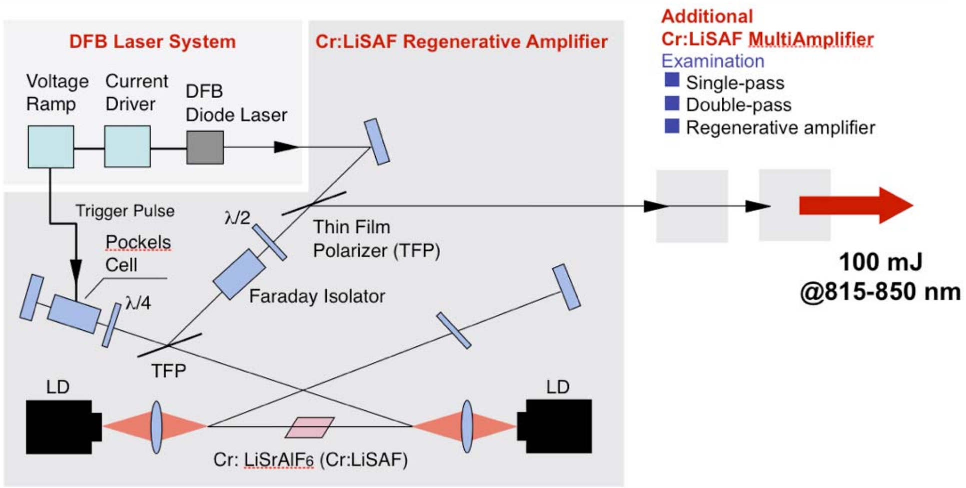


Thank you, now time for question!

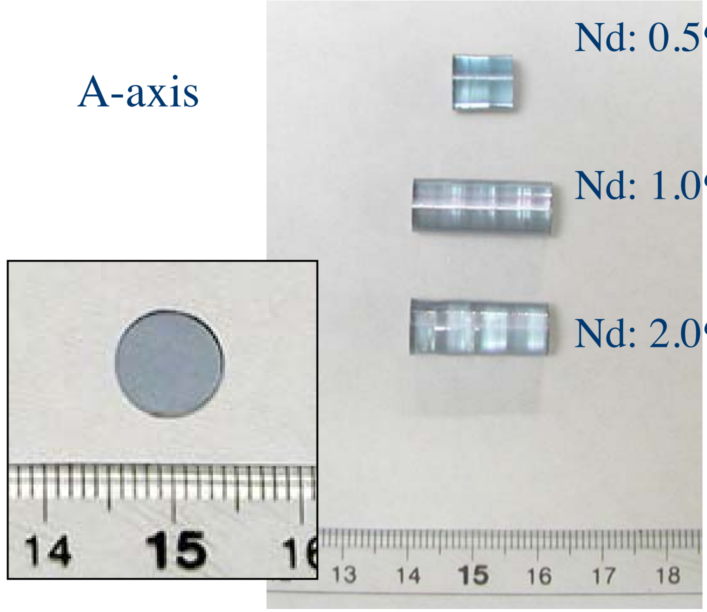
Pump Laser 1



Pump Laser 2



A-axis



	Nd:YAG	Nd:YVO_4	Nd:$GdVO_4$
Thermal conductivity	◎	△	◎
Emission cross-section	○	a-axis ◎ c-axis ○	a-axis ◎ c-axis ○
Lifetime of upper state	◎	○	○
Crystal growth	◎	△	◎
Highly doping	×	△	◎
Wavelength	1064	1064	1063

Fifth harmonics of Kr
1062.75 nm is 212.55 nm!