31st May 2012, 12th International Workshop on Meson Production, Properties and Interaction, Krakow, Poland

Kaonic ^{3}He and ^{4}He measurements in the SIDDHARTA experiment at the DAΦNE collider

INFN-LNF Hideyuki Tatsuno

on behalf of the SIDDHARTA collaboration

SIlicon Drift Detector

for Hadronic Atom Research

by Timing Application

SIDDHARTA Collaboration (2009)

LNF-INFN, Italy

Univ. of Victoria, Canada

Politecnico di Milano, Italy

IFIN –HH, Romania

Stefan Meyer Institut, Austria

INFN Sez. di Roma I and Inst. Superiore di Sanita, Italy

Univ. of Tokyo, Japan

RIKEN, Japan

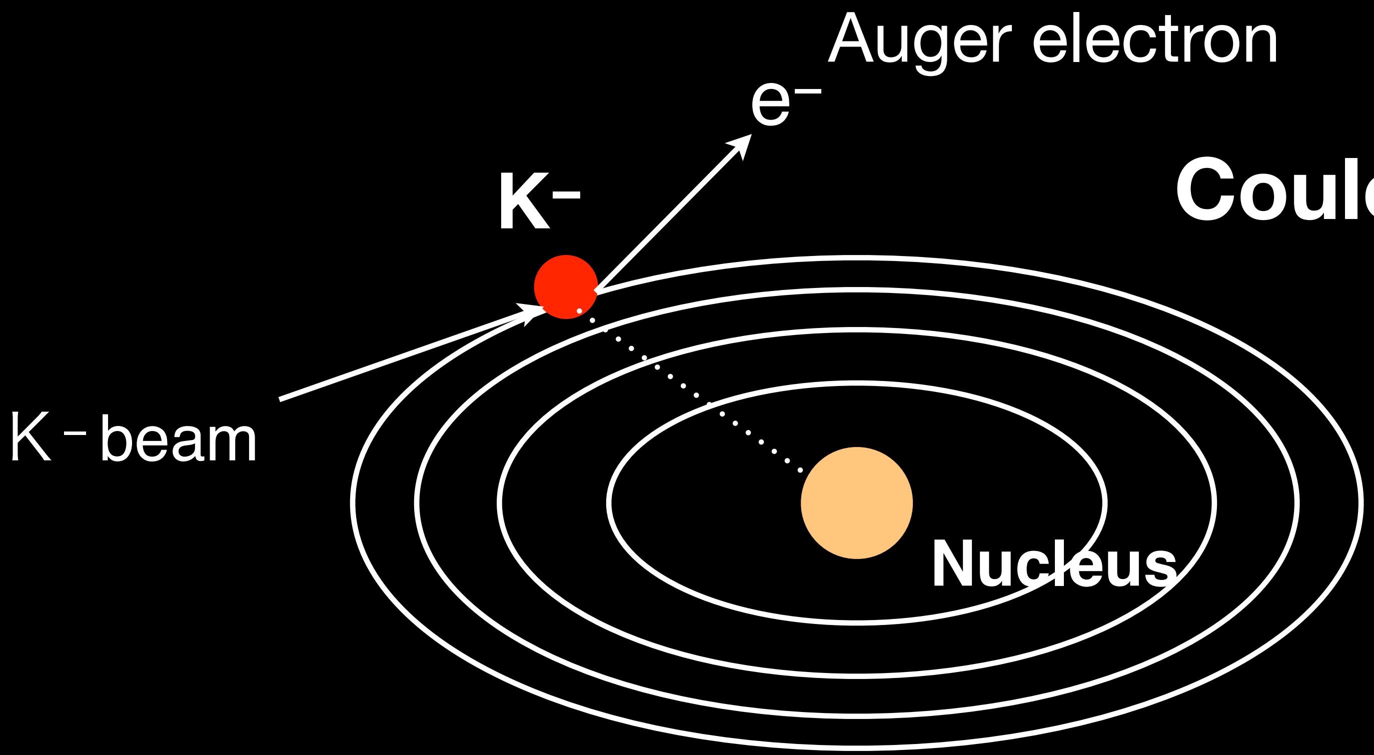
Tech. Univ. München, Germany

9 institutes and 40 persons

Introduction

Kaonic atoms

To study $\bar{K}N$ strong interaction at low-energy limit



Coulomb capture

$$n^* \sim n_e \sqrt{\frac{m_K^*}{m_e}}$$

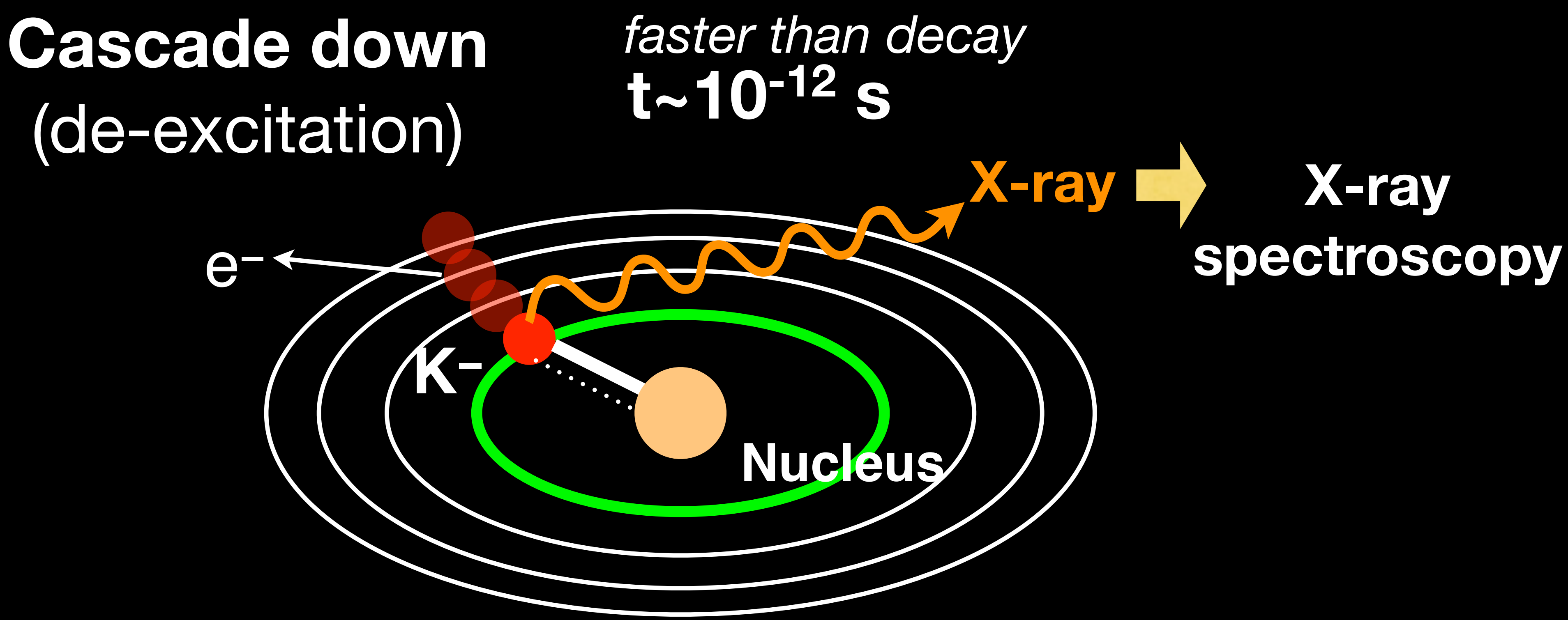
m_K^* reduced kaon mass

$n^* \sim 30$ for ^4He

highly excited states

Kaonic atoms

To study $\bar{K}N$ strong interaction at low-energy limit



Coulomb + **Strong interaction**

Strong-interaction **Shift** and **Width** on the last atomic orbit

SIDDHARTA targets

Z	target	state	orbit	experiment	motivation
1	Hydrogen	gas	1s	KEK-PS E228(KpX) DEAR	K^--p scattering length
	Deuterium	gas	1s?	never	
2	Helium-3	gas	2p	never	K-He puzzle and K-nucl potential
	Helium-4	gas	2p	KEK-PS E570 (liquid)	

Tomorrow 12:30
plenary talk by
J. Zmeskal

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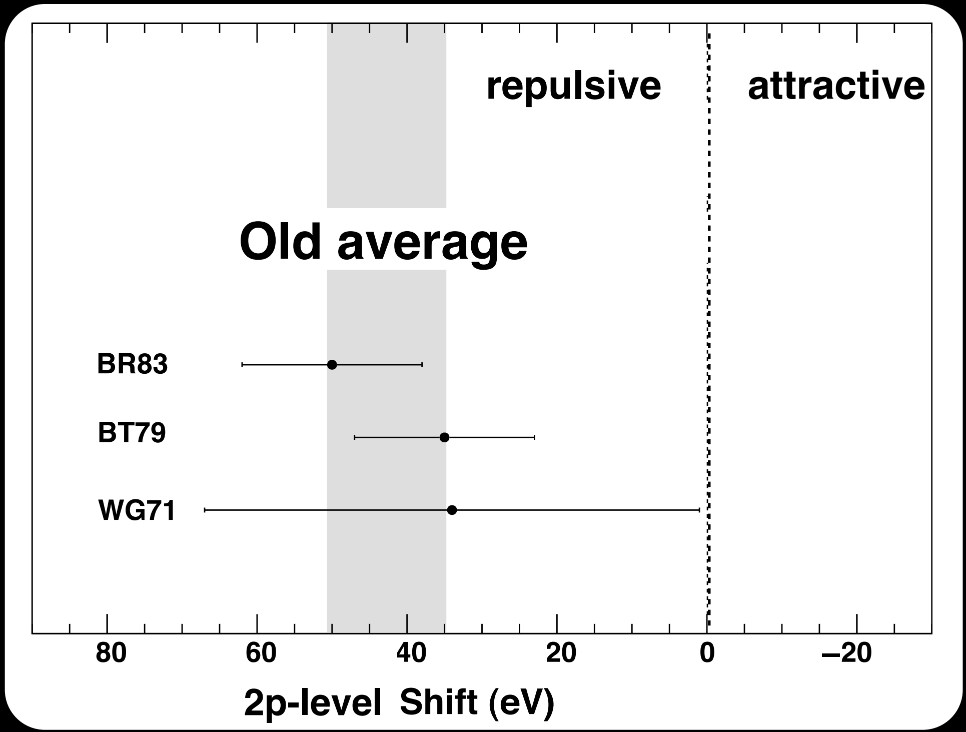
Tomorrow 12:30 plenary talk by J. Zmeskal

This talk: Z=2 sector

Kaonic helium-4 puzzle



HT Thesis

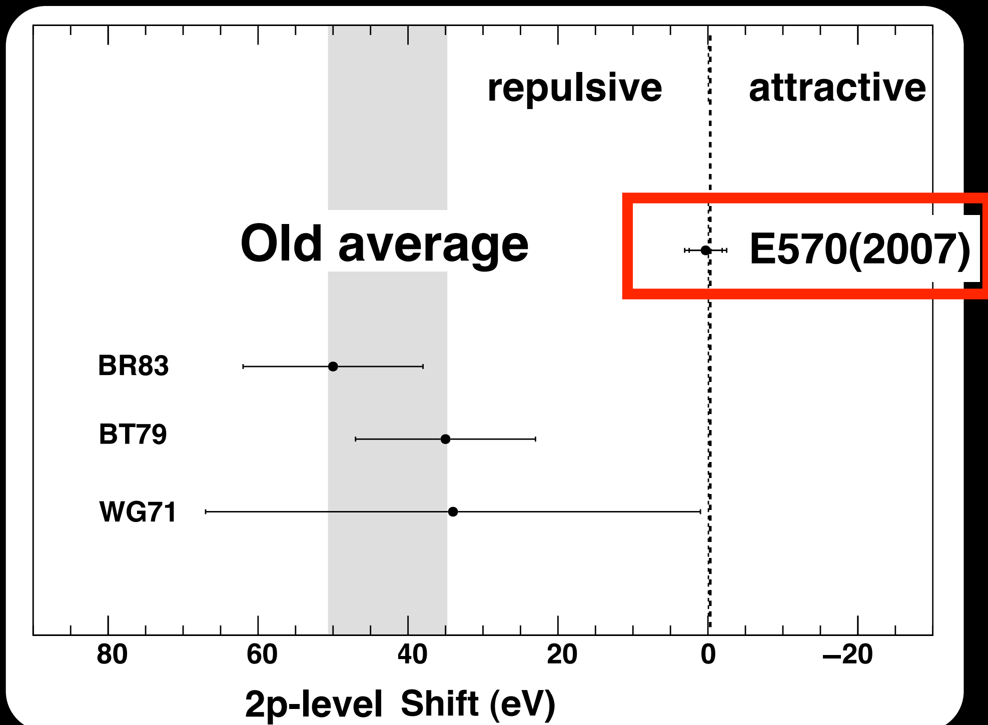
~40 eV
repulsive shift

~0 eV

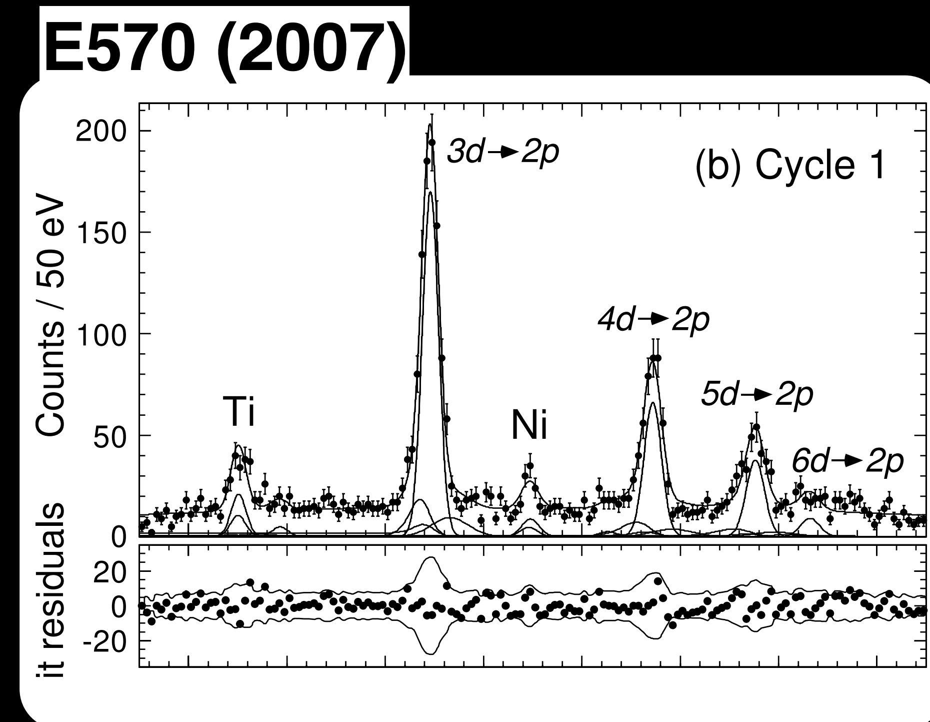
Optical potential model 0.13 eV
*C.J.Batty NPA**508**(1990)89c*
E.Friedman (EXA2011)

Chiral unitary model ~0.5 eV
*S.Hirenzaki et al., PRC**61**(2000)055205*

Kaonic helium-4 puzzle



HT Thesis



*S. Okada et al., PLB **653**(2007)387*

(6 times higher S/N ratio than BR83)

~40 eV
repulsive shift

~0 eV

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Chiral unitary model ~0.5 eV
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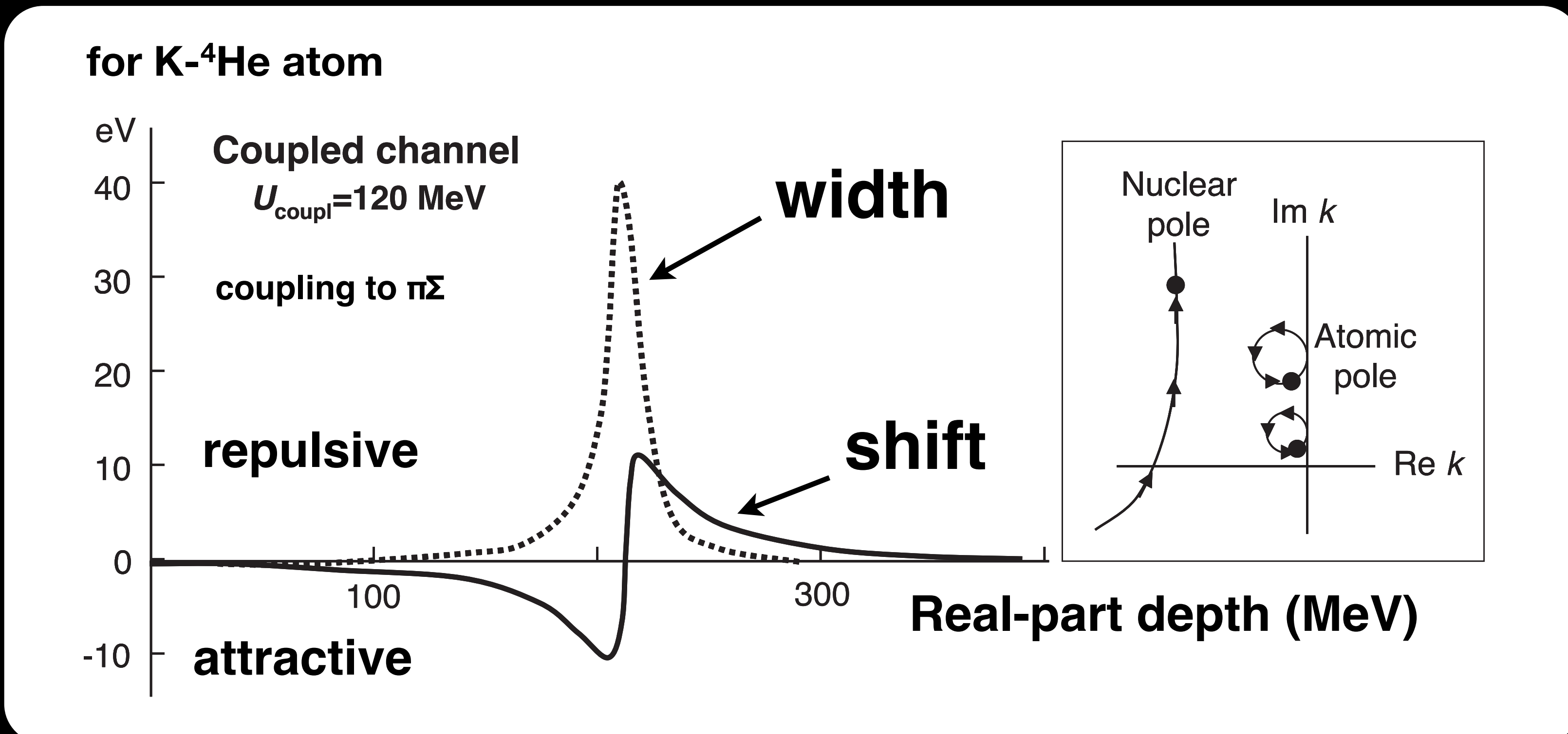
Stopped-K selection

Liquid ^{4}He target

Silicon drift detector (~180 eV FWHM)

Shift and width ↔ K-nucl potential

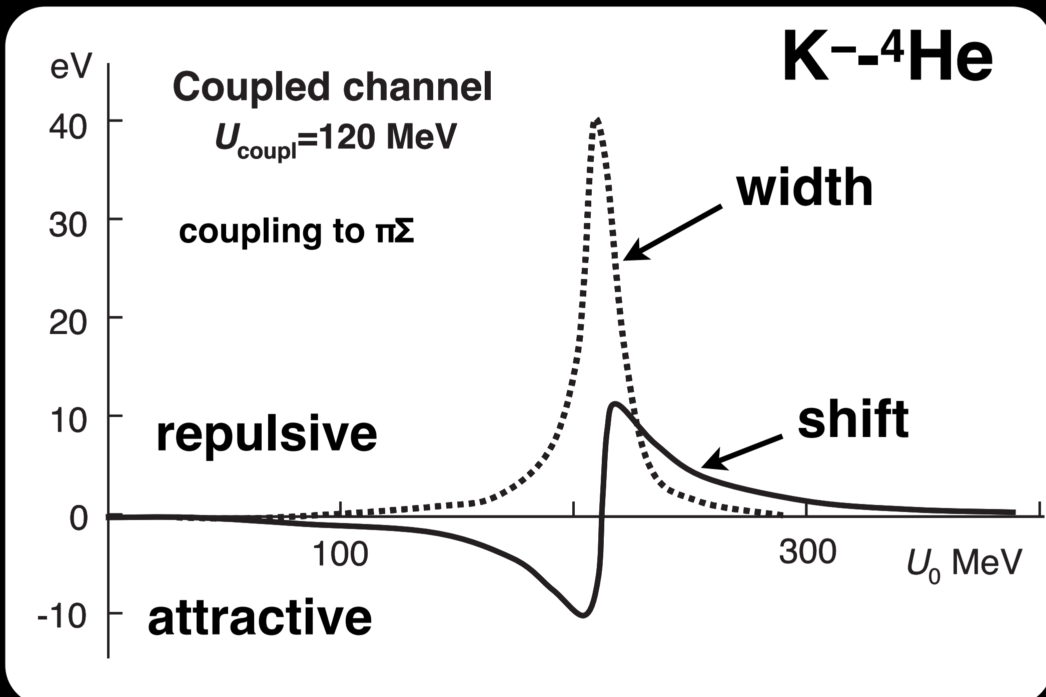
possible shift and large width for K^{-}-^{3,4}He *2p* state by Y. Akaishi
(EXA2005)

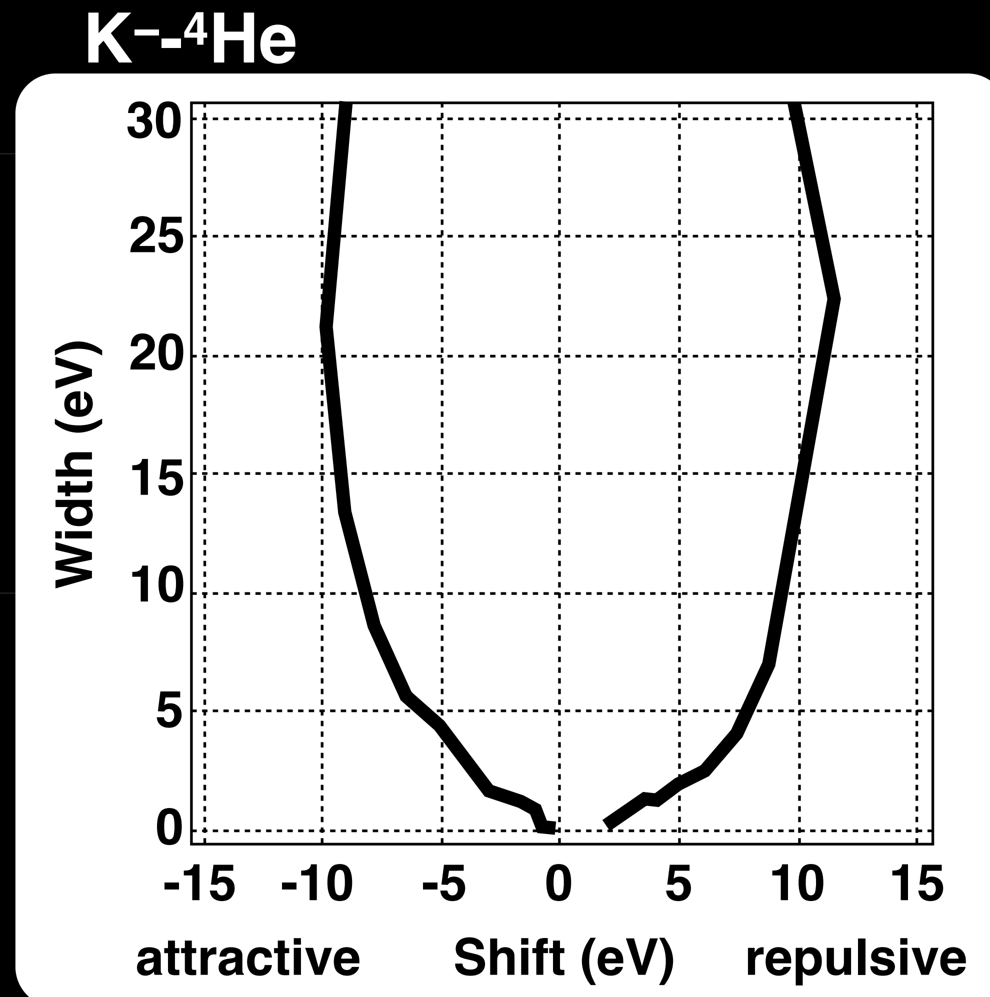


Possible shift and large width when the ***nuclear pole*** approaches the 2p atomic pole in the range of its width

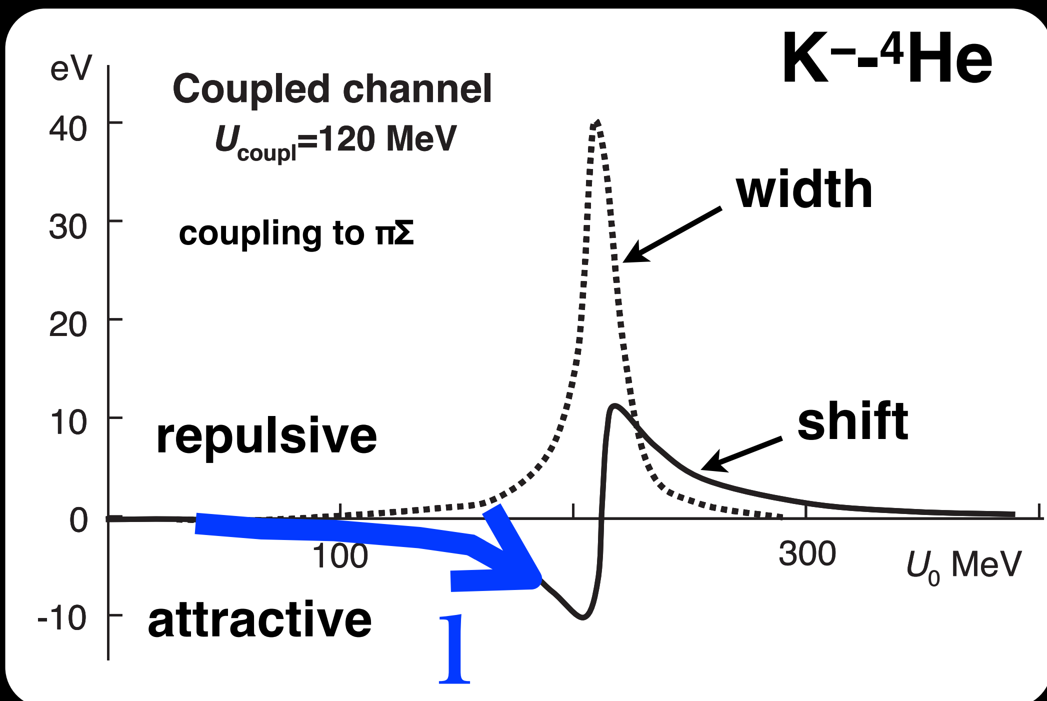
Unique theory to produce large width

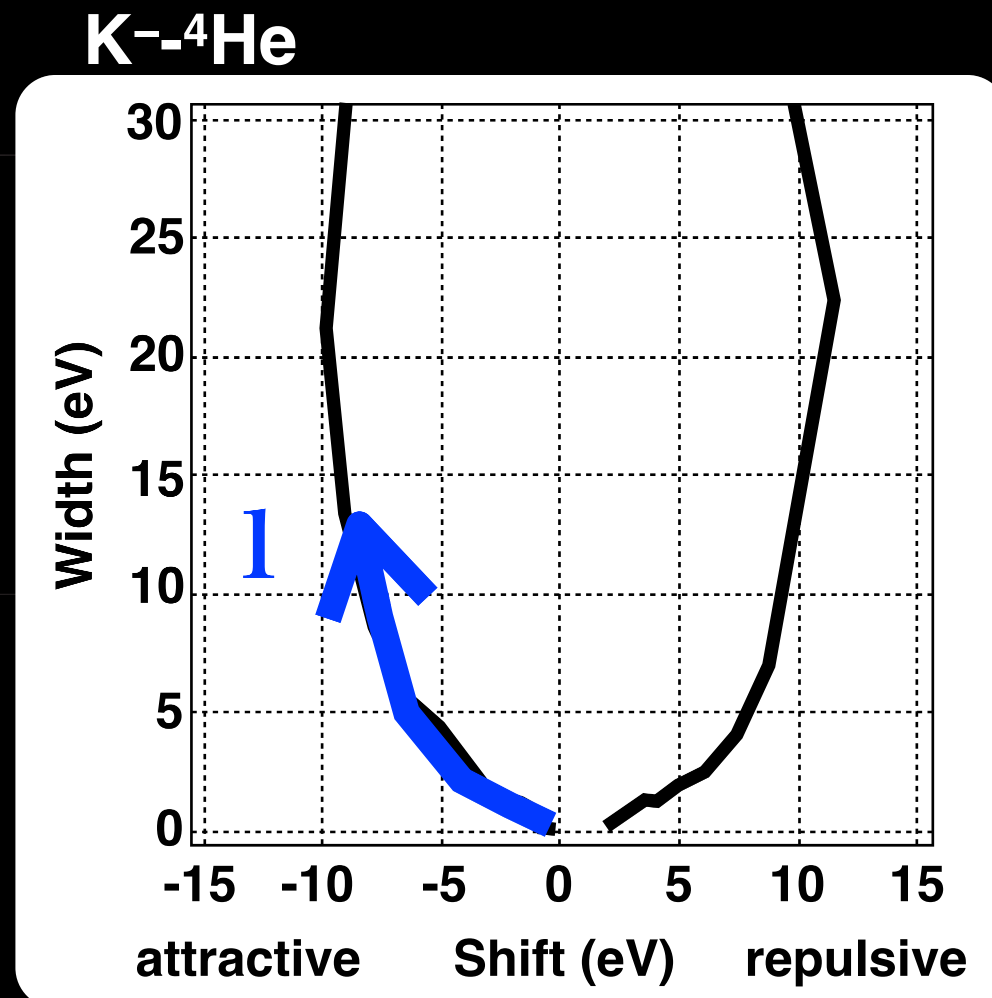
Akaishi's coupled-channel calculation





Akaishi's coupled-channel calculation

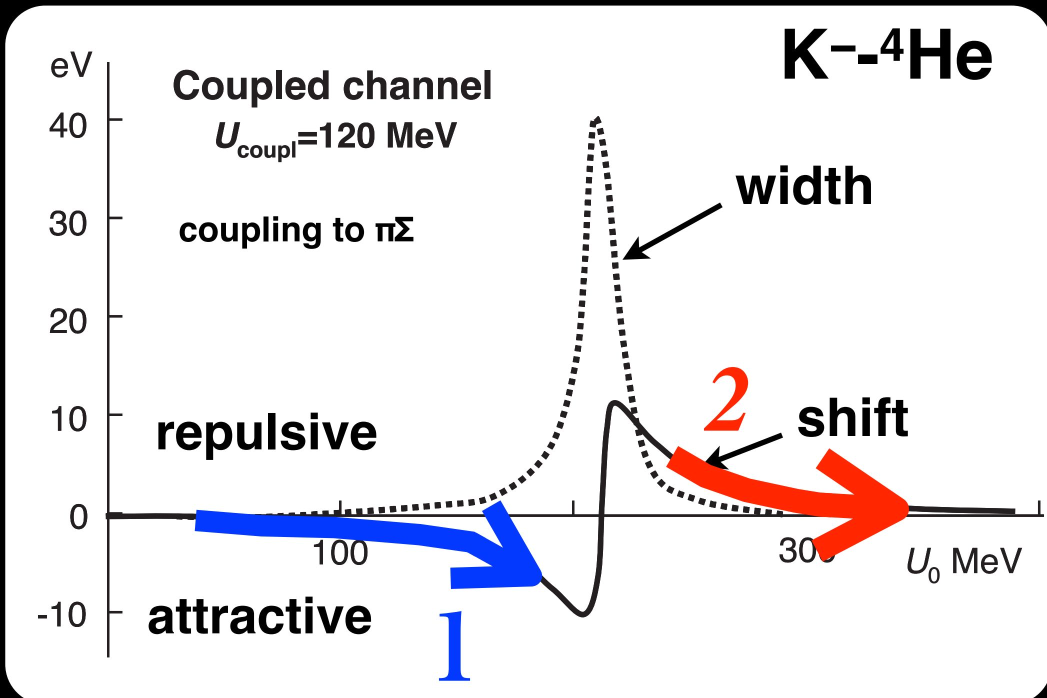


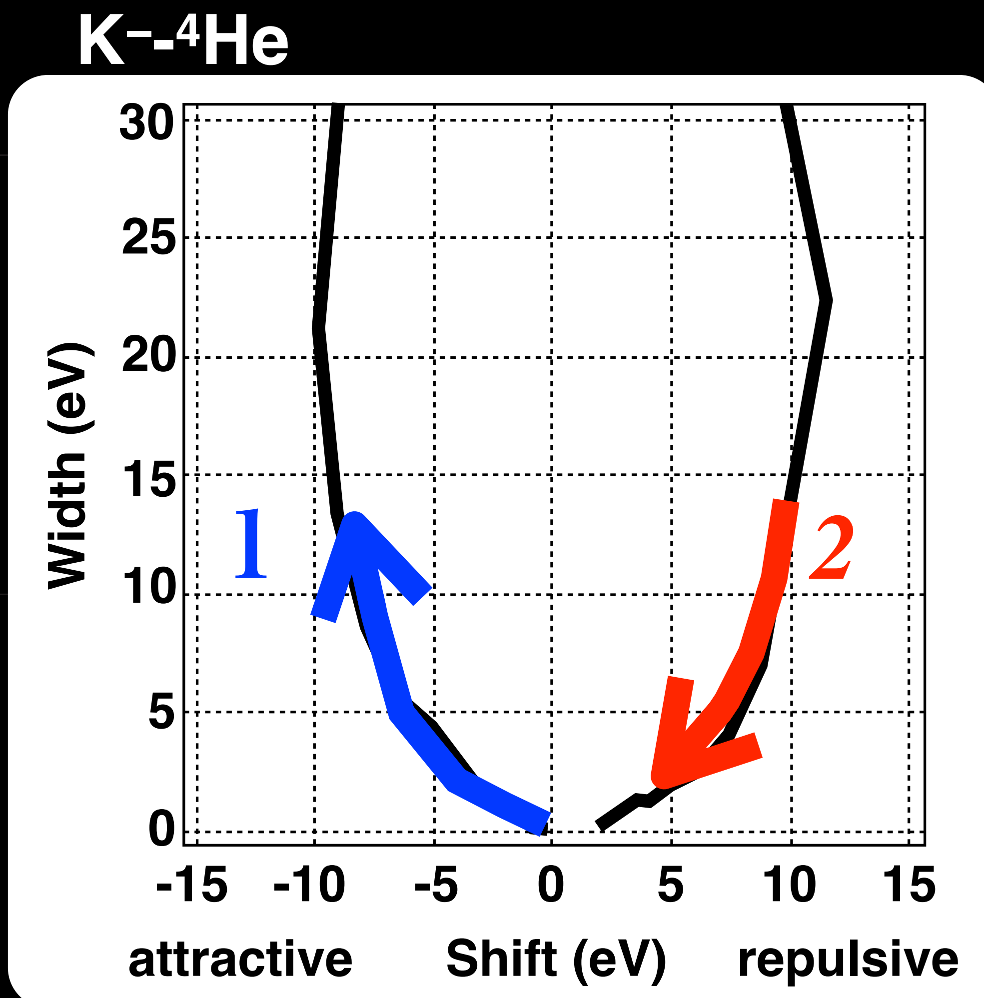


The deeper real-part potential,

1: attractive shift and getting larger width

Akaishi's coupled-channel calculation





The deeper real-part potential,

1: attractive shift and getting larger width

2: repulsive shift and getting smaller width

Optical potential and Chiral unitary model

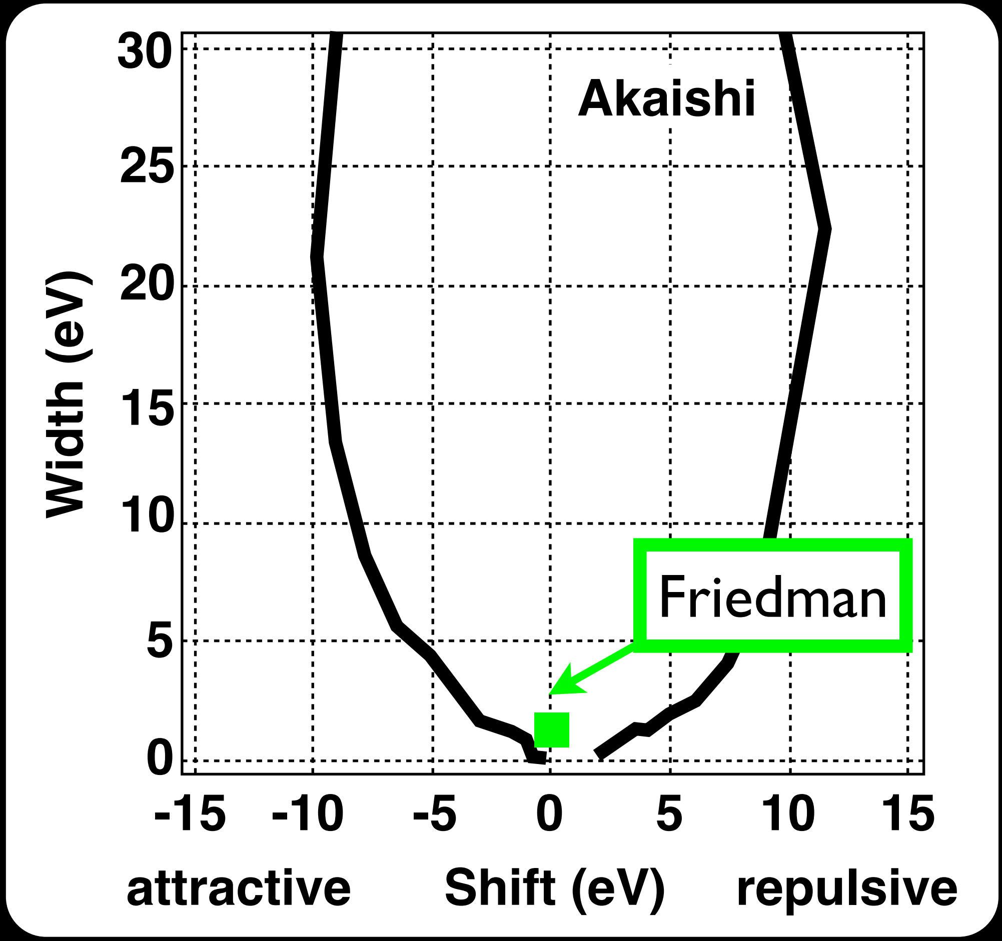
- Phenomenological optical potential (deep potential)

  no shift and **small width (~2 eV)**
  by E. Friedman (EXA2011)
  *also C.J.Batty NPA**508**(1990)89c*

- SU(3) chiral unitary model (shallow)

  no shift and **small width**
  S.Hirenzaki et al., PRC**61**(2000)055205

K^--^{4}He

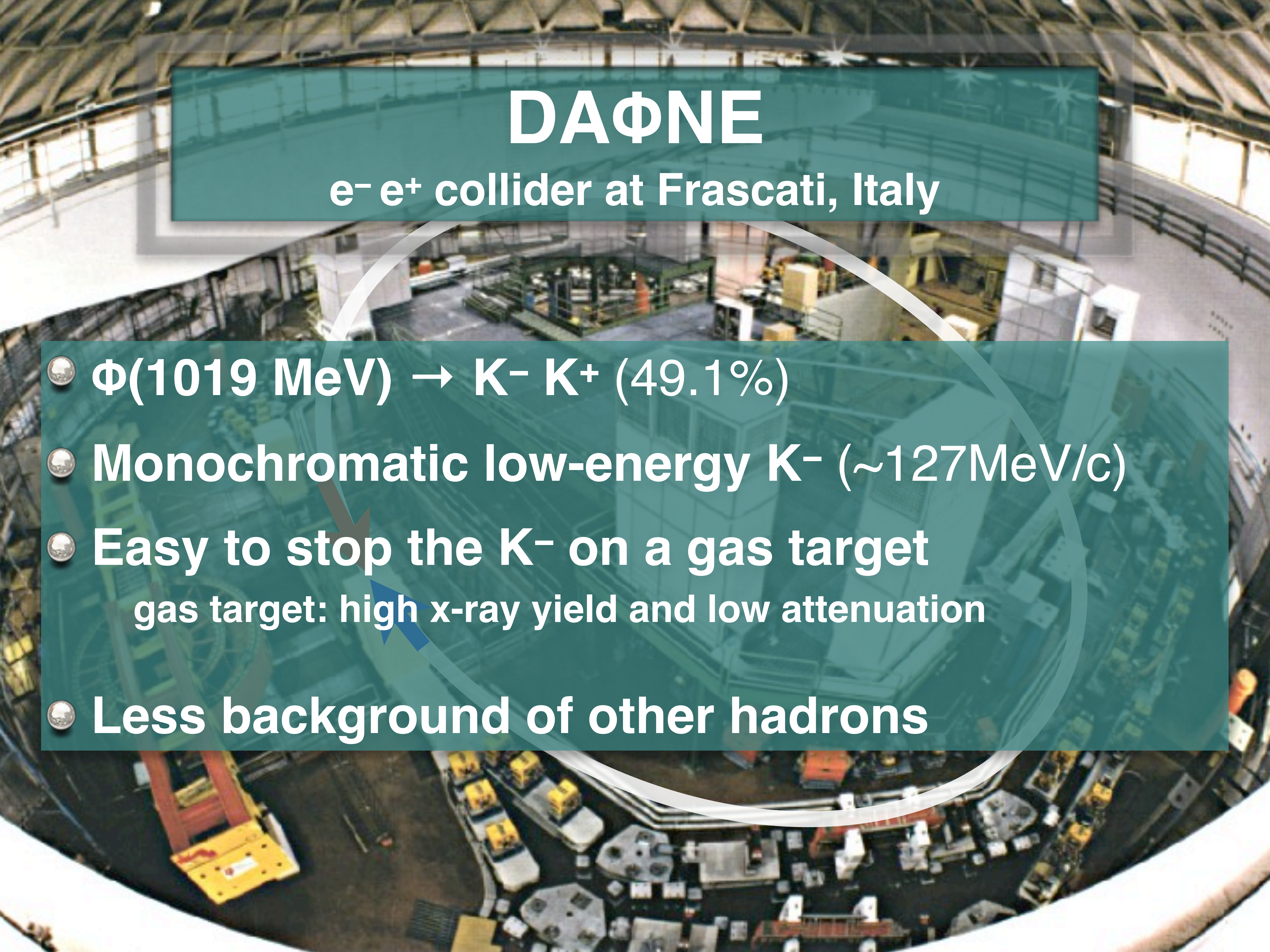


Motivations

- confirmation of E570 with ^{4}He **gas** target
- first measurement of K^{-}-^{3}He X-rays (gas target)
- find out a clue of the K-He nucleus potential

Experiments

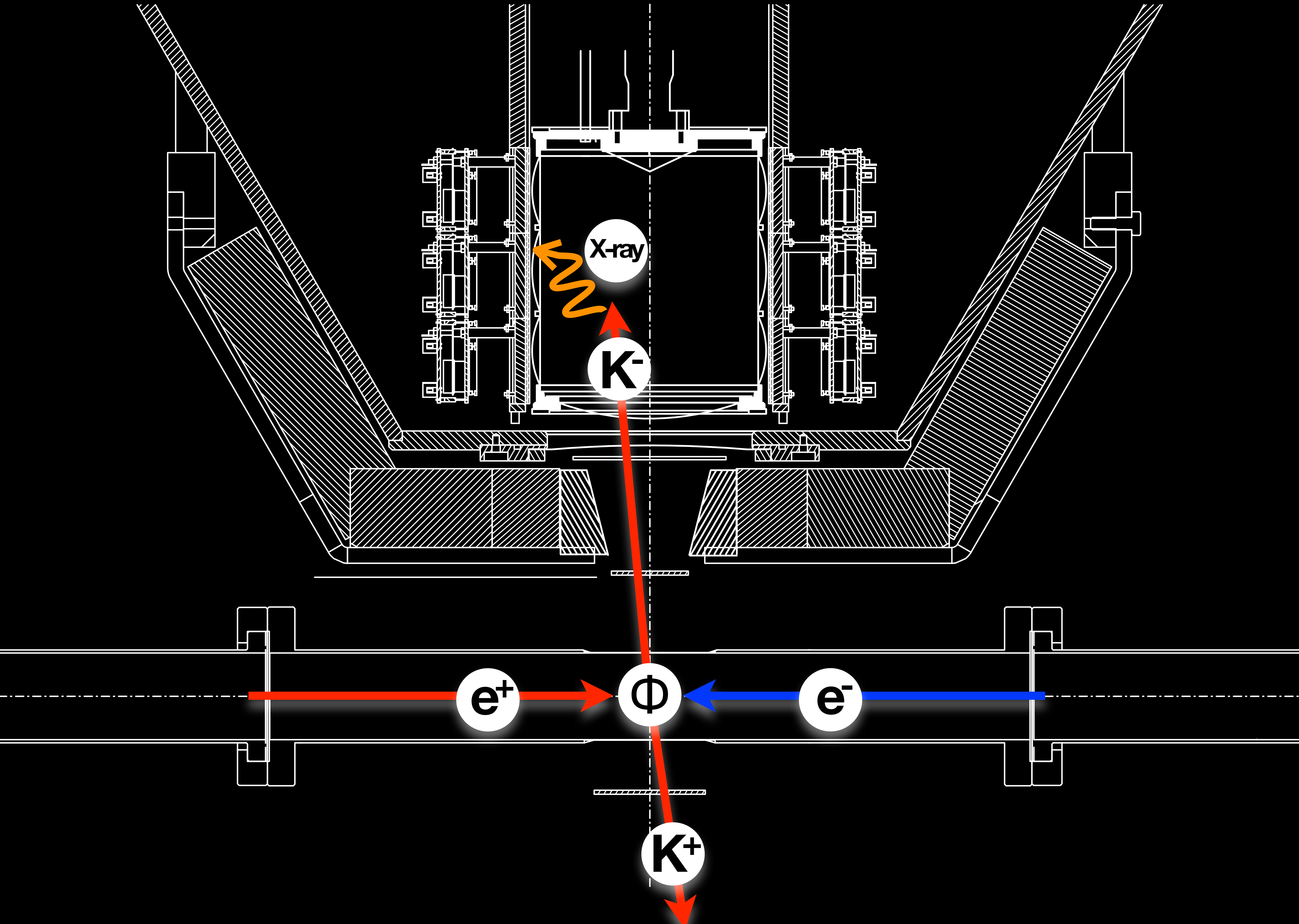
SIDDHARTA at DAΦNE

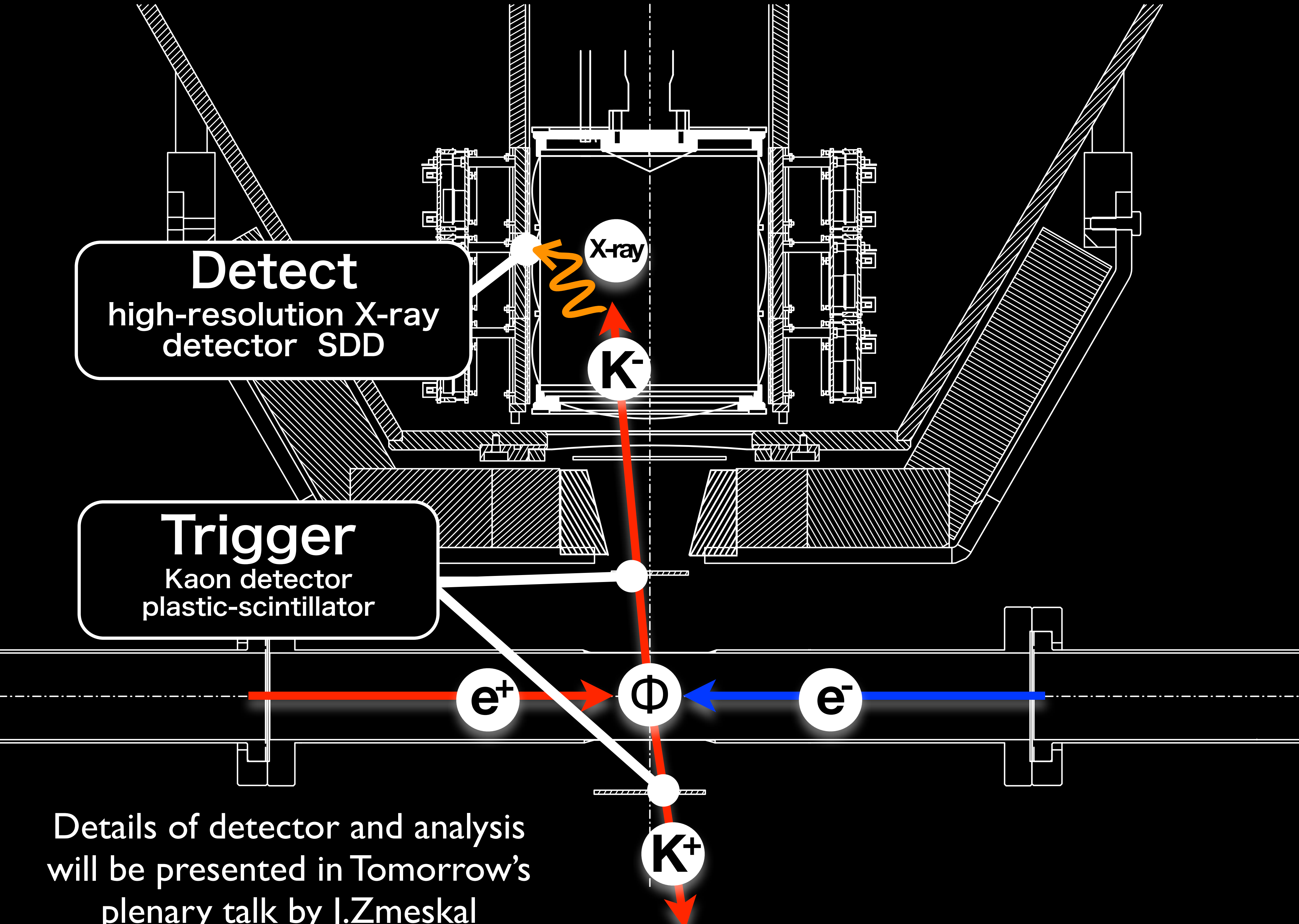


DAΦNE

$e^- e^+$ collider at Frascati, Italy

- Φ(1019 MeV) → $K^- K^+$ (49.1%)
- Monochromatic low-energy K^- (~127MeV/c)
- Easy to stop the K^- on a gas target
  - gas target: high x-ray yield and low attenuation
- Less background of other hadrons


X-ray
K-
e+
Φ
e-
K+



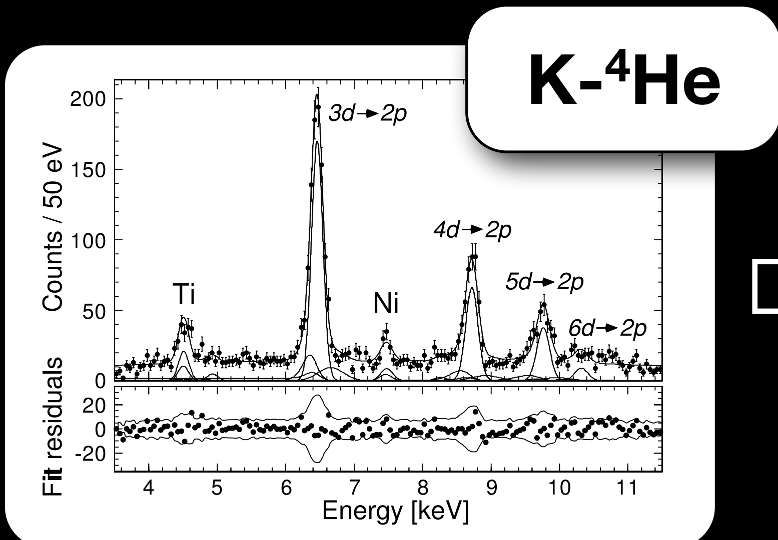
Details of detector and analysis
will be presented in Tomorrow's
plenary talk by J.Zmeskal

SIDDHARTA (2011)

using **144** SDDs

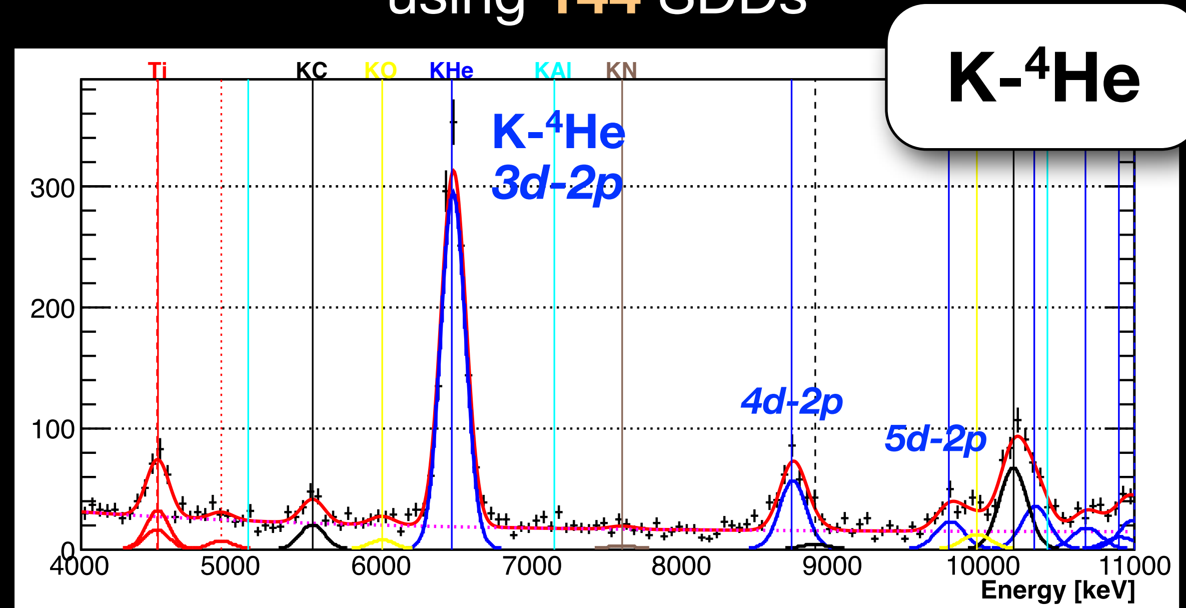
KEK E570 (2007)

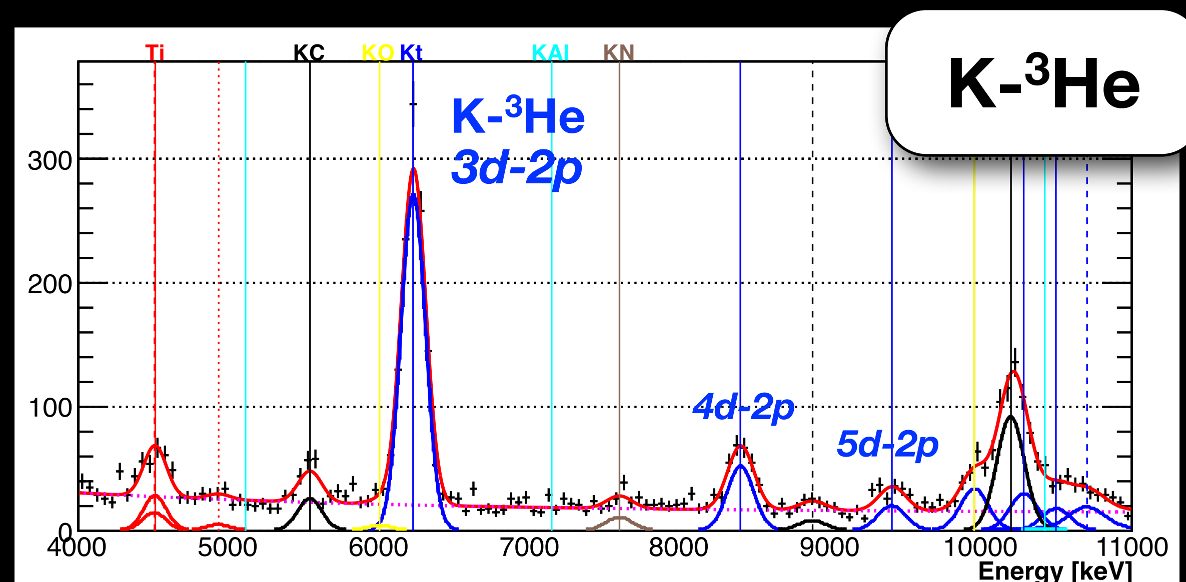
using **8** SDDs



accumulated data

~ 1 month





accumulated data

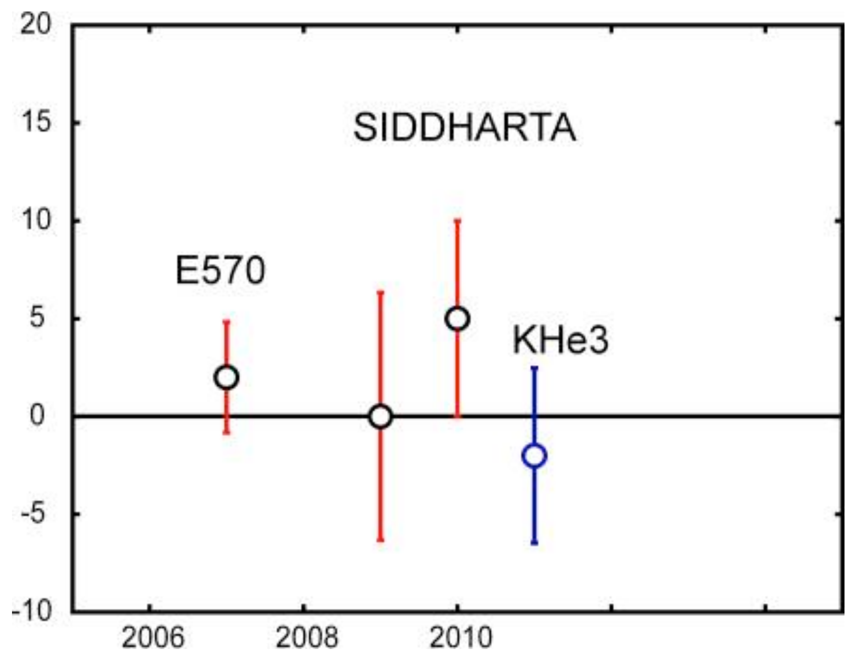
just a few days !

Result

Shift and Width

Strong interaction shift

			Shift [eV]	Publication
KEK-PS E570	K^4He liquid		+2 ± 2(stat) ± 2(syst)	*PLB* ***653***(2007)387
SIDDHARTA	K^4He gas	1st	0 ± 6(stat) ± 2(syst)	*PLB* ***681***(2009)310
		2nd	+5 ± 3(stat) ± 4(syst)	*PLB* ***697***(2011)199
	K^3He gas		-2 ± 2(stat) ± 4(syst)	



***error bar** $= \pm\sqrt{(stat)^2 + (syst)^2}$

- ✓ **Confirmed E570**
- ✓ **No 40-eV large shift**
- ✓ **First result of K^3He**

Motivations

- confirmation of E570 with ^{4}He **gas** target

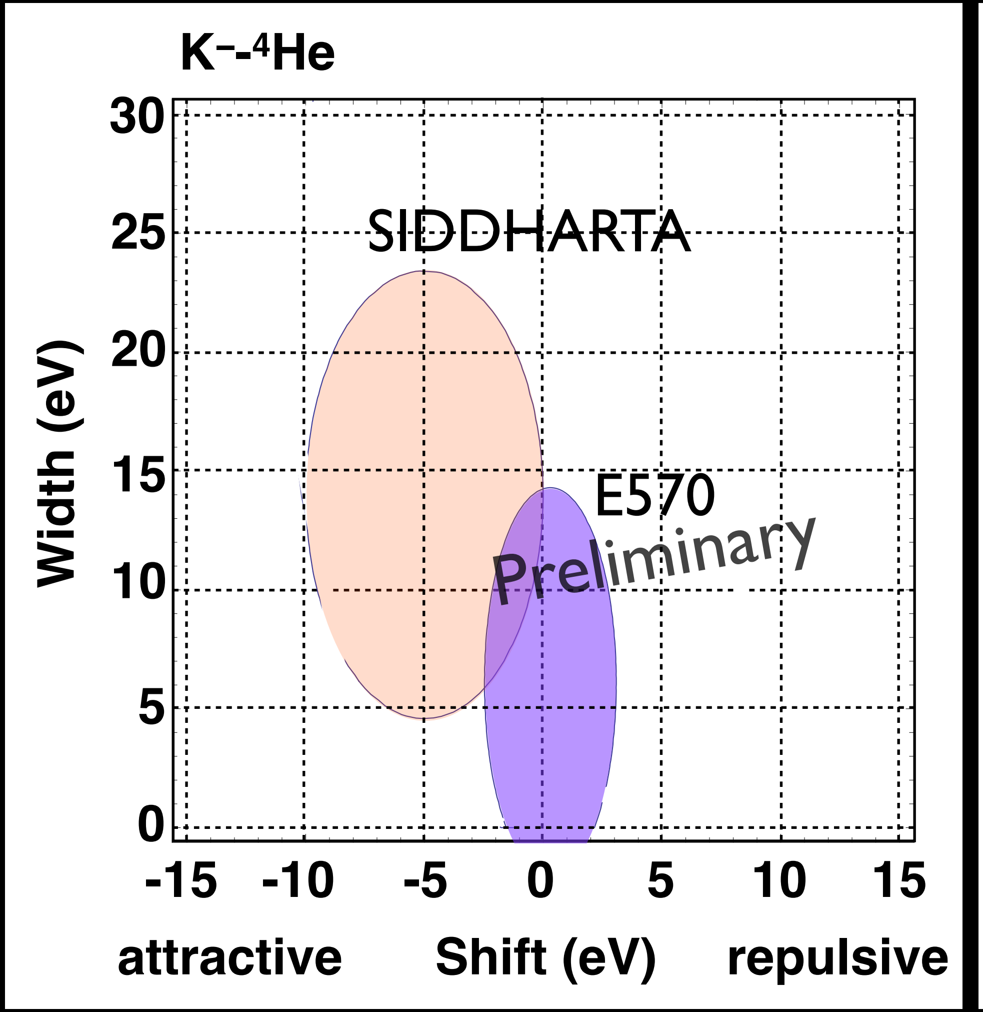
check!

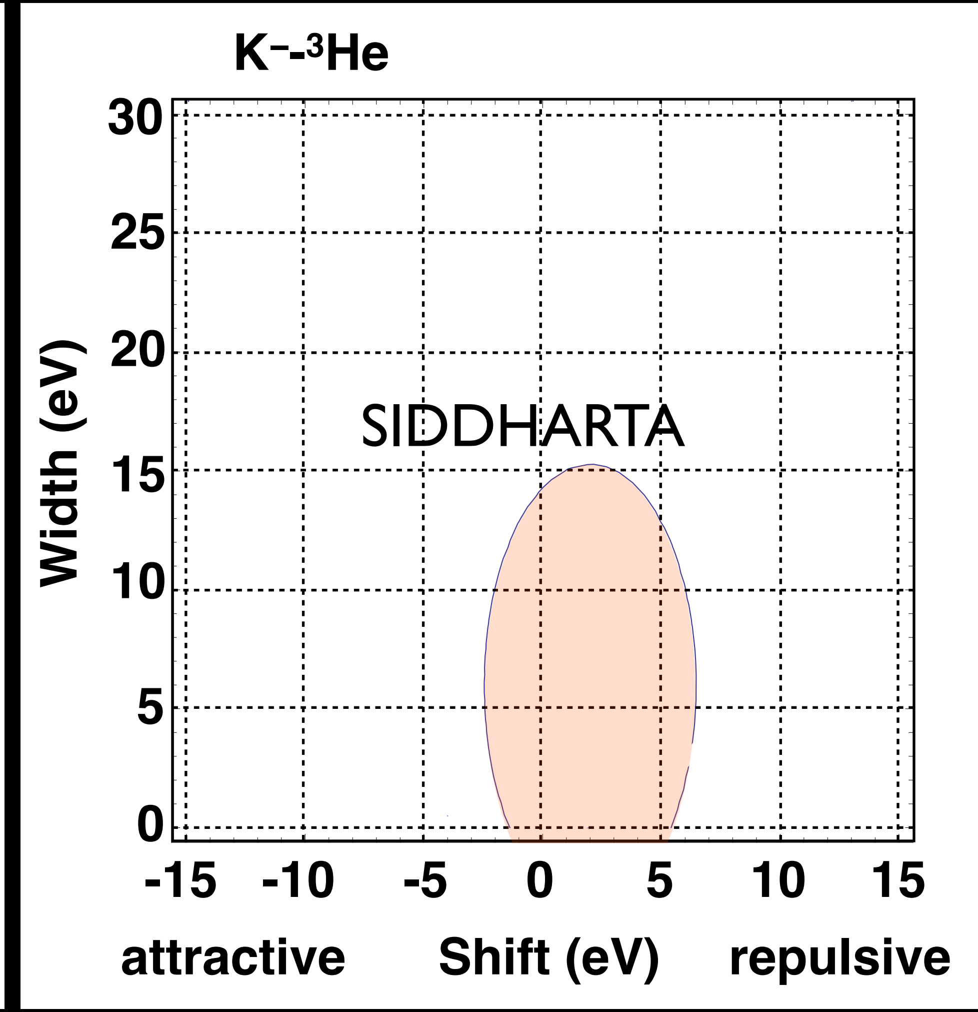
- first measurement of K^--^{3}He X-rays (gas target)
- find out a clue of the K-He nucleus potential

Shift and Width

small shift

large error of widths



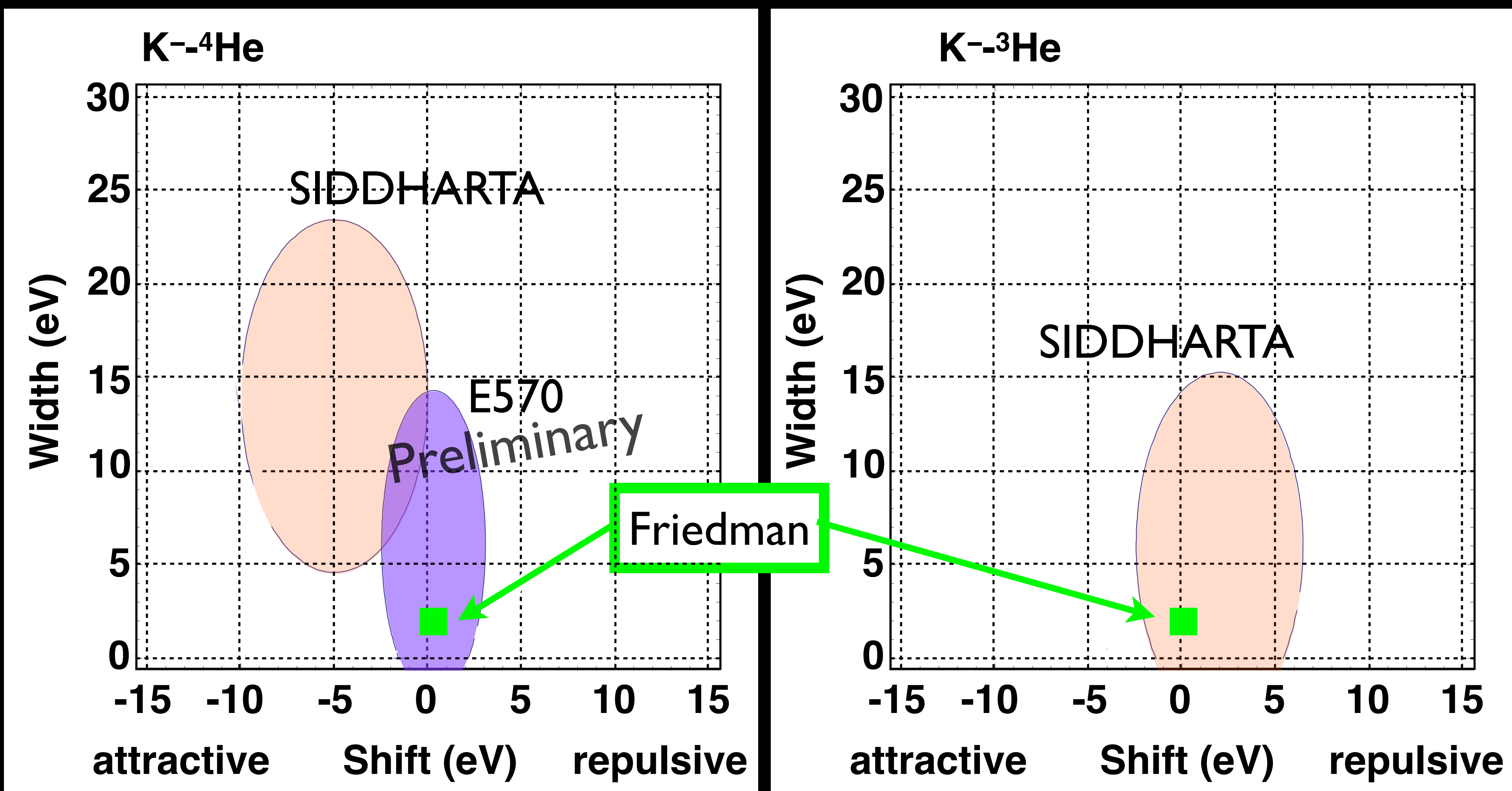


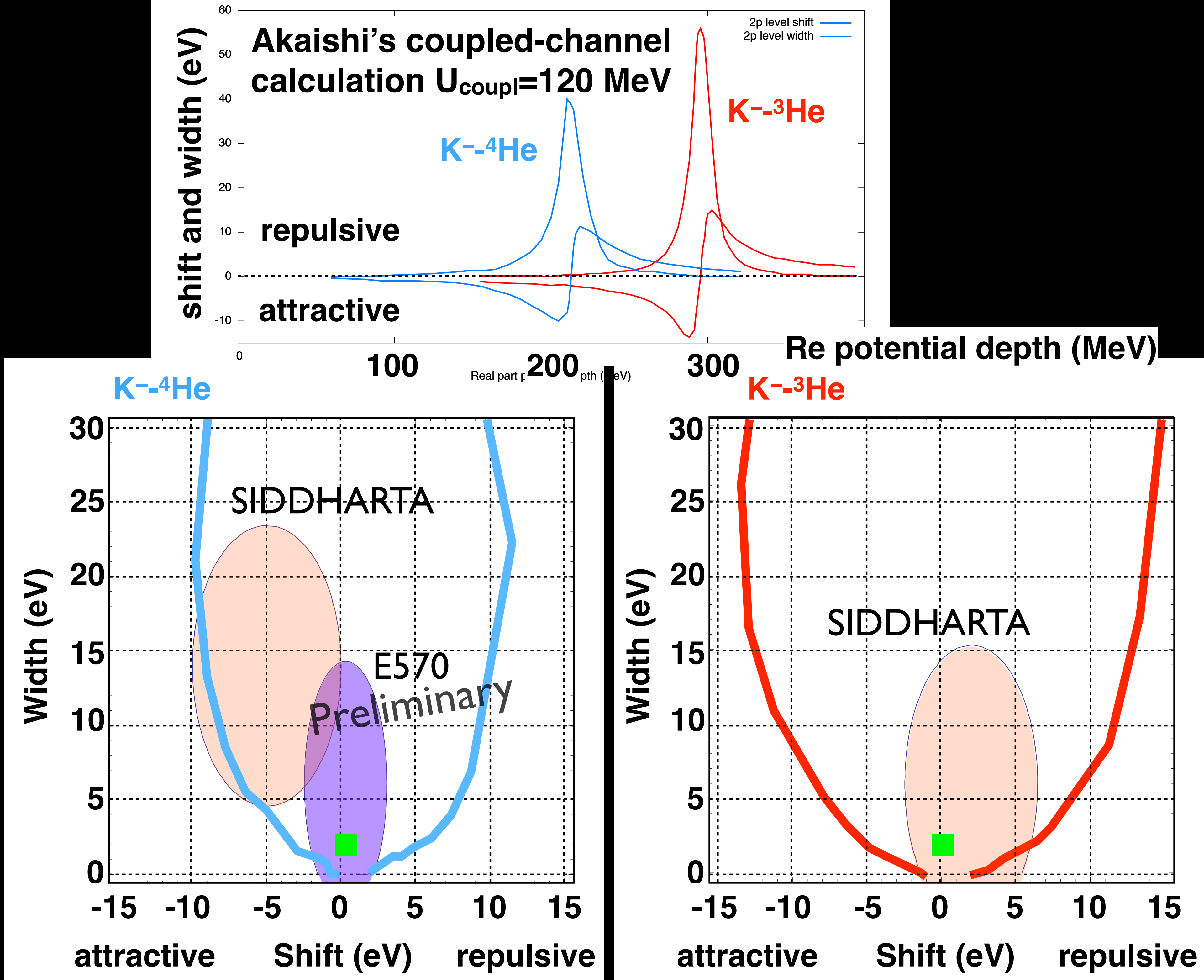
Comparison with theories

- Phenomenological optical potential (deep)
- SU(3) chiral unitary model (shallow)

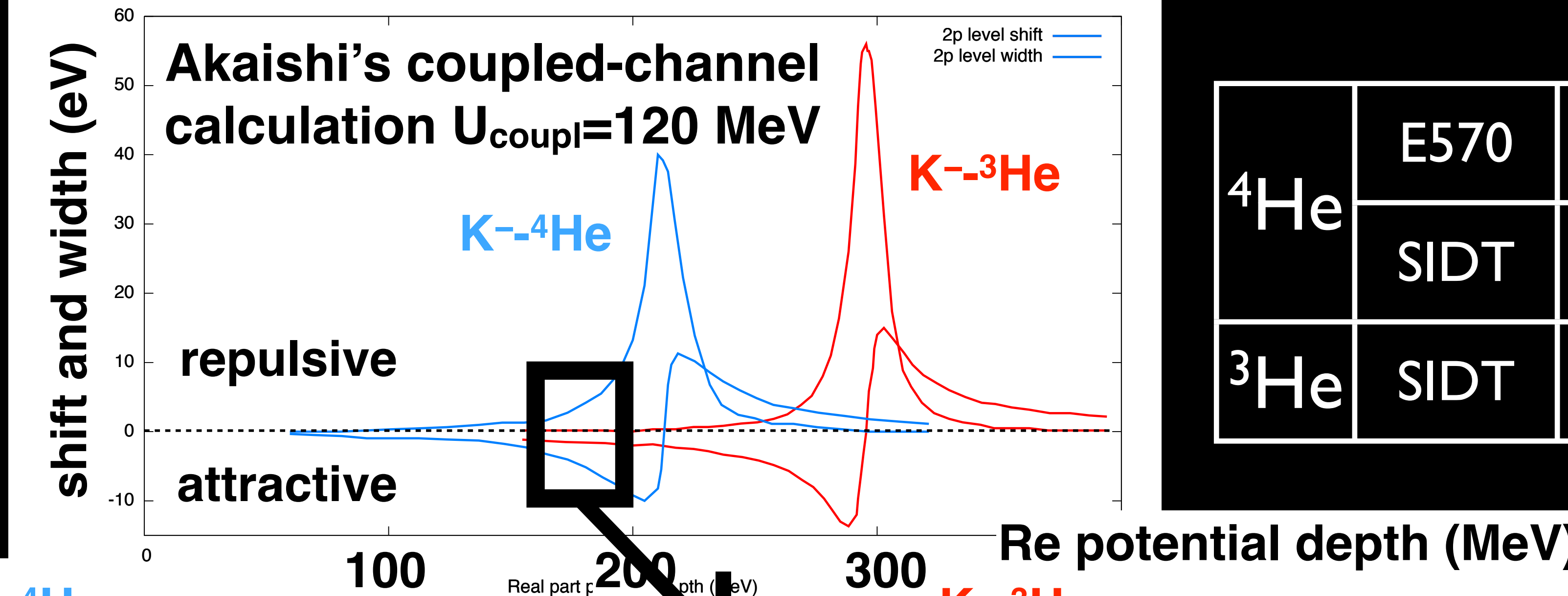
no shift and small width (~2 eV)

^4He	E570	○
	SIDT	△
^3He	SIDT	○

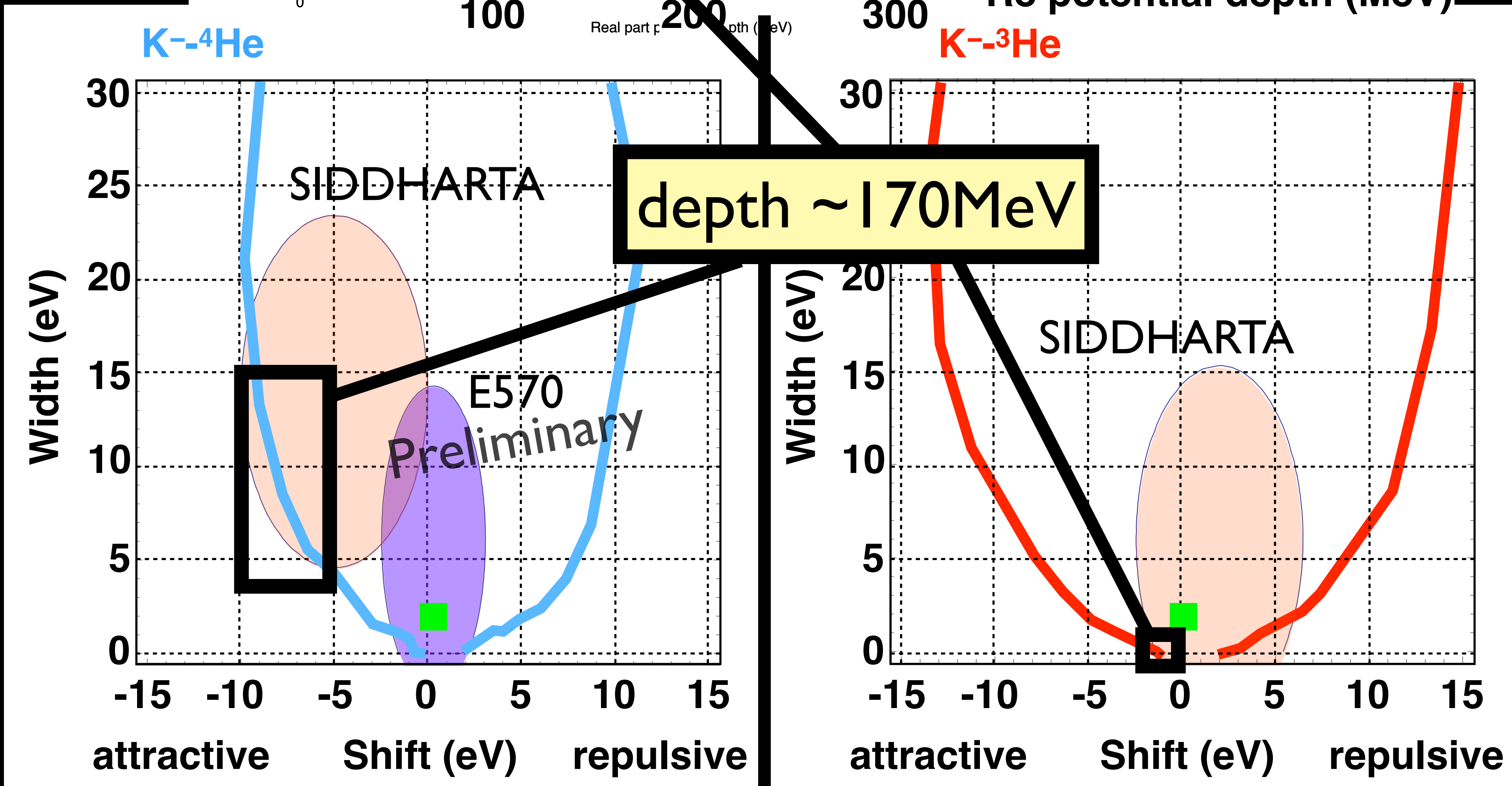


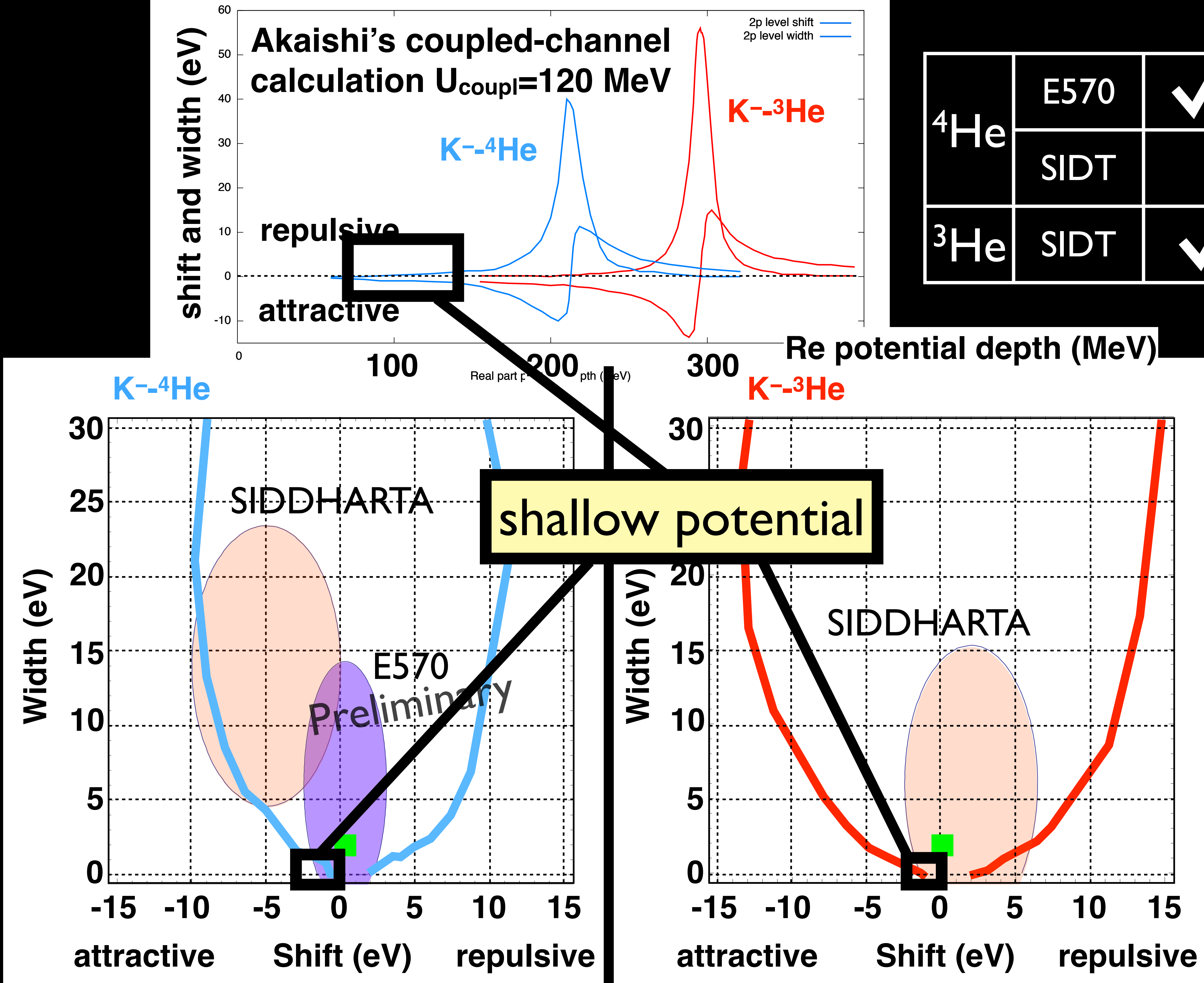


Akaishi's coupled-channel calculation Ucoupl=120 MeV
2p level shift
2p level width
K⁻-⁴He
K⁻-³He
repulsive
attractive
shift and width (eV)
60
50
40
30
20
10
0
-10
0
100
200
300
Re potential depth (MeV)
K⁻-⁴He
SIDDHARTA
E570
Preliminary
Width (eV)
30
25
20
15
10
5
0
-15
-10
-5
0
5
10
15
attractive
Shift (eV)
repulsive
K⁻-³He
SIDDHARTA
Width (eV)
30
25
20
15
10
5
0
-15
-10
-5
0
5
10
15
attractive
Shift (eV)
repulsive

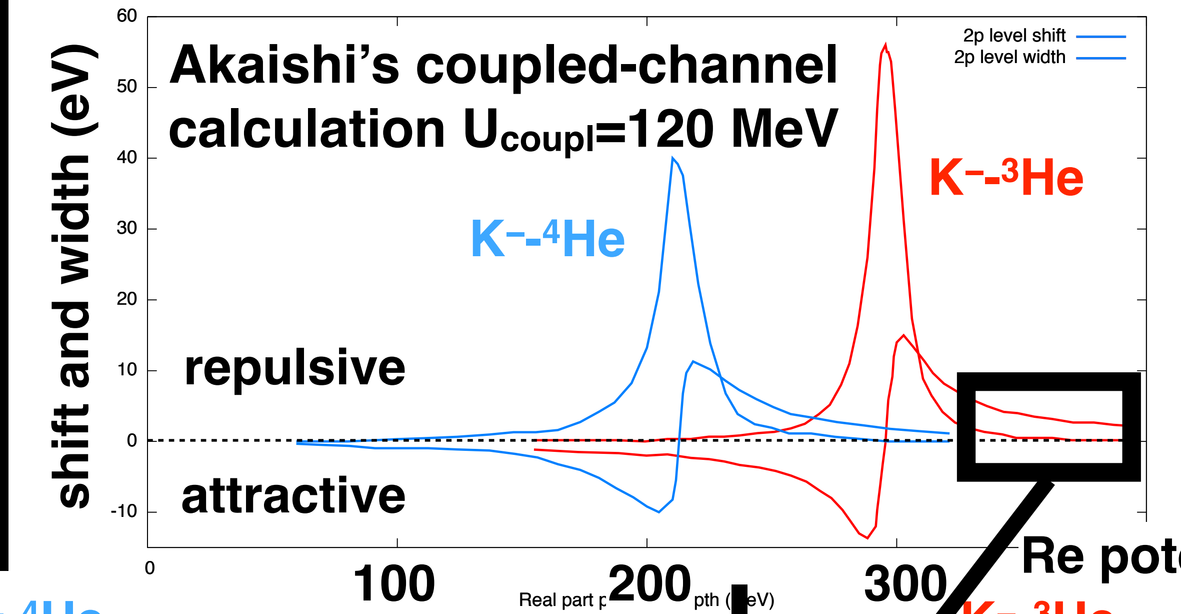


^{4}He	E570	
	SIDT	✓
^{3}He	SIDT	✓

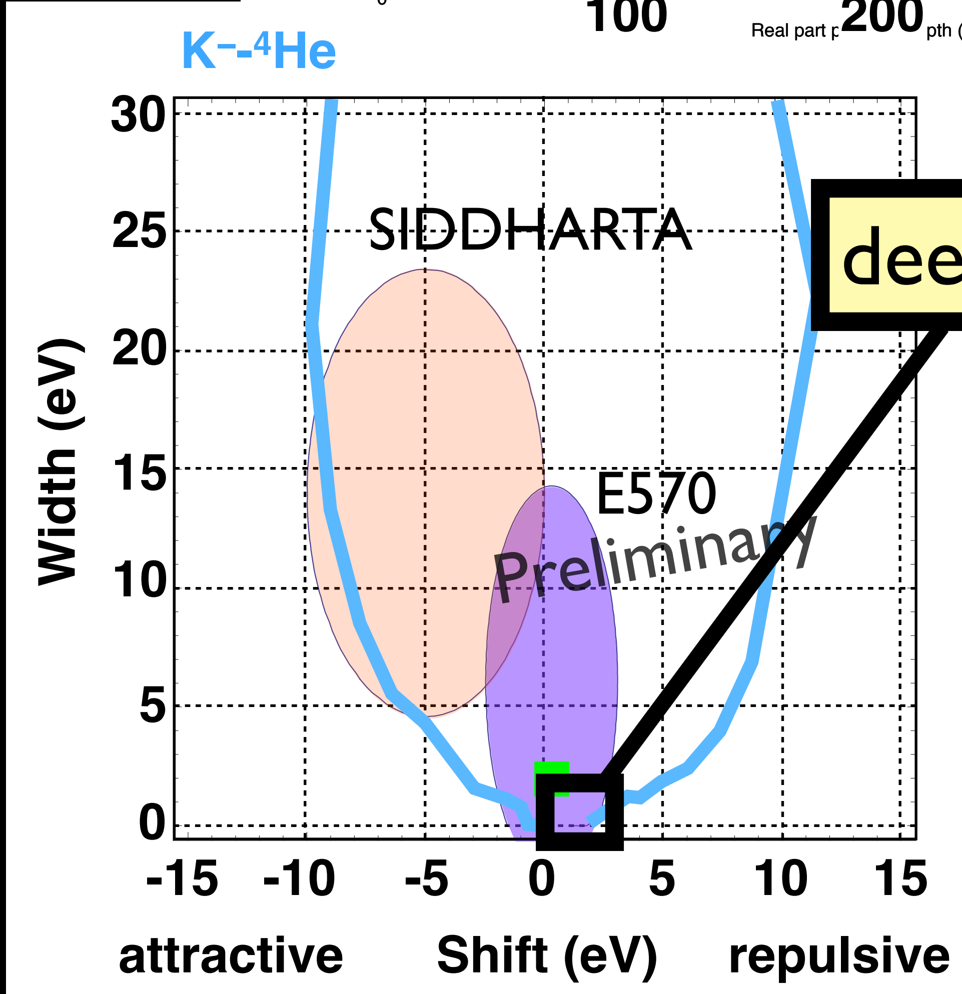


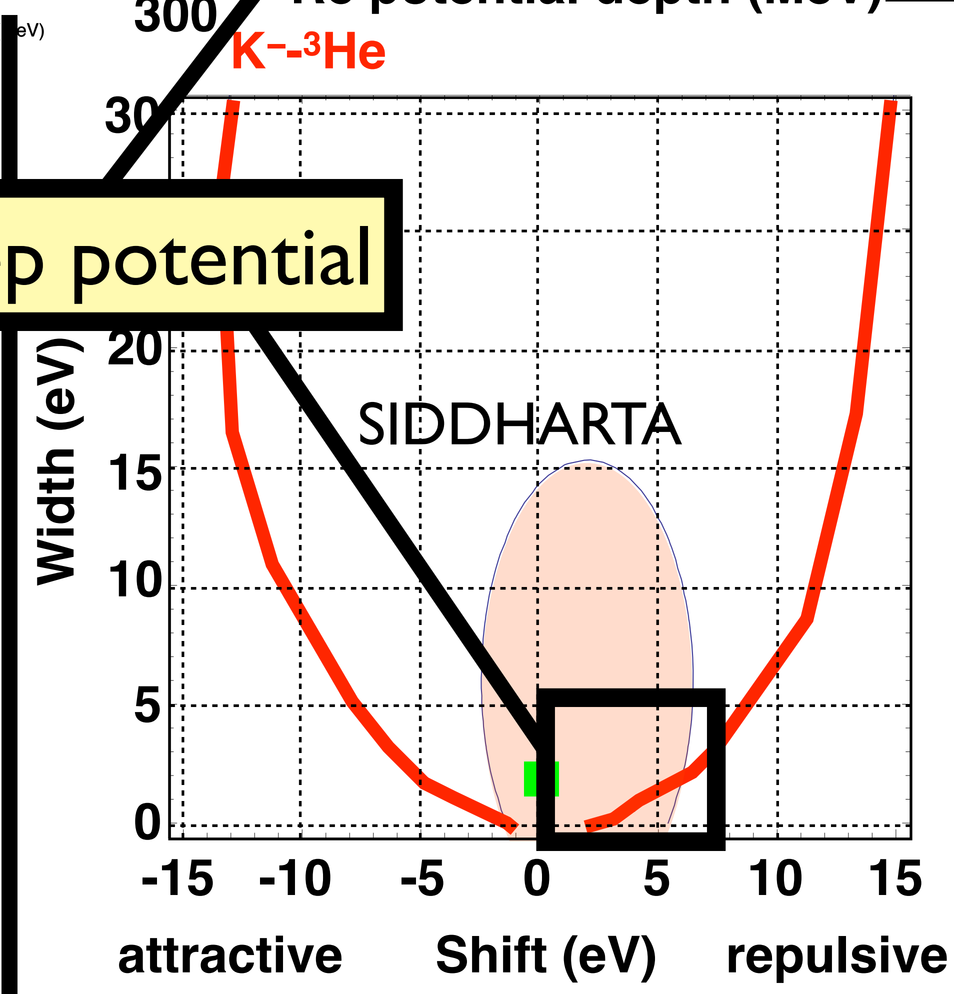


^{4}He	E570	✓
	SIDT	
^{3}He	SIDT	✓



^{4}He	E570	✓
	SIDT	
^{3}He	SIDT	✓





(E570 and SIDDHARTA)

No exclusion of any theory

large error of width → difficult to distinguish

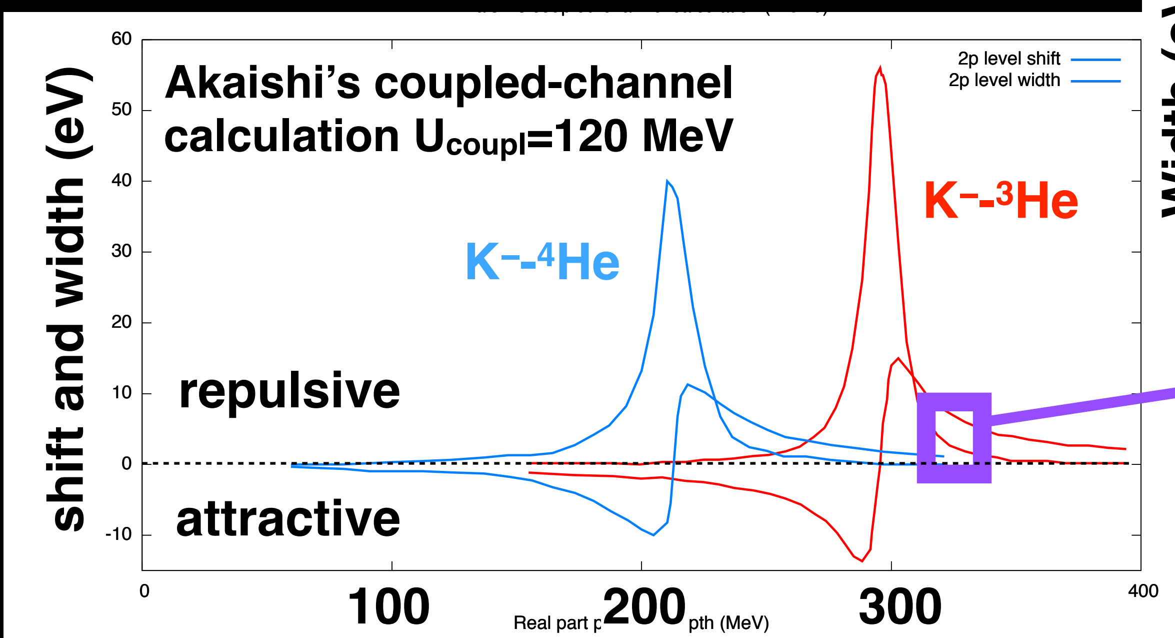
(E570 and SIDDHARTA)

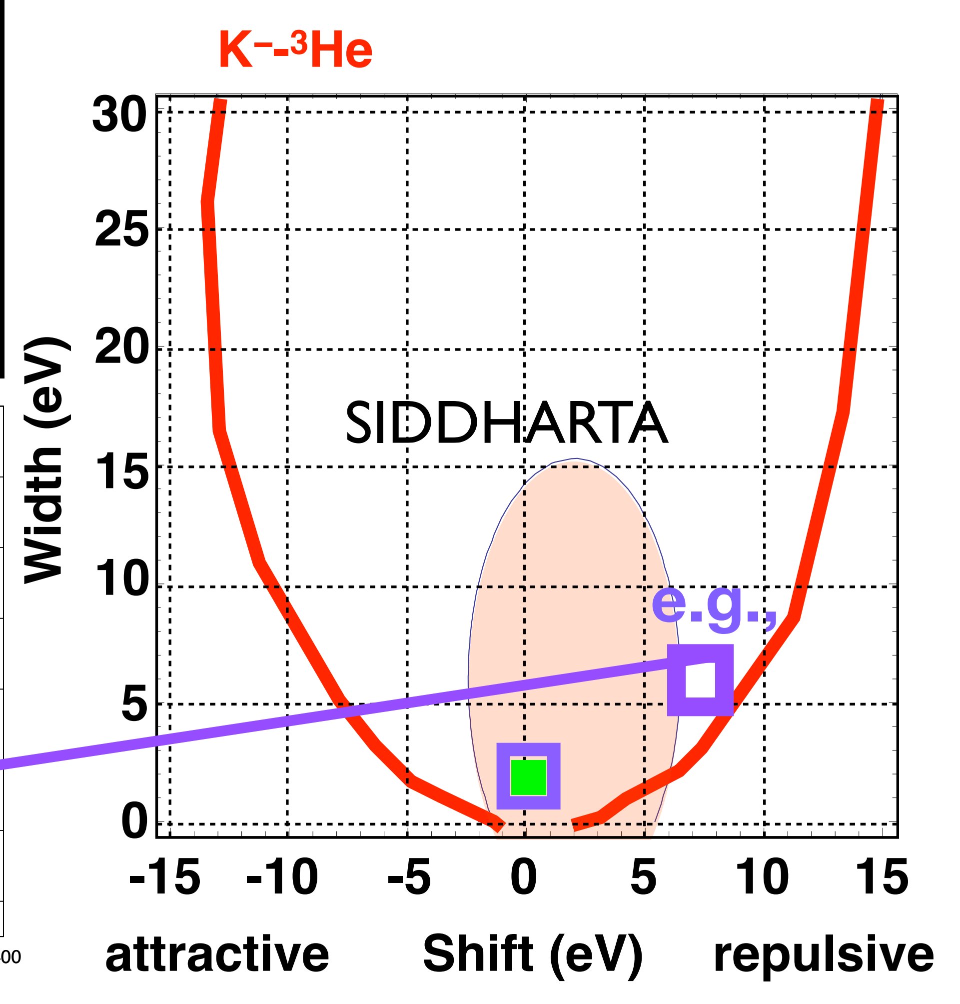
No exclusion of any theory

large error of width → difficult to distinguish

Next experiment

J-PARC E17's goal
distinguish them





Summary

- SIDDHARTA measured K^{-4}He and K^{-3}He *2p*-state strong-interaction **shift** and **width**

- Confirmed E570 with ^{4}He **gas** target

  → no more 40-eV large shift

- First result of K^{-}-^{3}He X-rays (gas target)

  small shift and small width (with large error)

- 'Agreement' with both Akaishi's K-nucl potential and phenomenological / SU(3) chiral-unitary approaches

Outlook for kaonic atom

Akaishi's coupled-channel vs (phenom. / chiral-unitary)

Need more precise measurement

→ *J-PARC E17*

Deep (phenom) vs Shallow (chiral-unitary)

Still open question...

Need other kaonic-atoms *precise* data?

→ *SIDDHARTA2*

SIDDHARTA Collaboration

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(modified affiliations, 2012 May)