8th Int. Conf. on Nuclear Physics at Storage Rings STORI'11

Kaonic helium3 and 4 measurements by the SIDDHARTA experiment at DAFΦNE

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INFN-LNF

on behalf of SIDDHARTA collaboration

09 - 14 October 2011

INFN-LNF, Frascati, Italia

SIDDHARTA

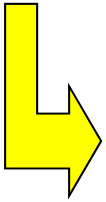
SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

- LNF- INFN, Frascati, Italy
- SMI- ÖAW, Vienna, Austria
- IFIN – HH, Bucharest, Romania
- Politecnico, Milano, Italy
- MPE, Garching, Germany
- PNSensors, Munich, Germany
- RIKEN, Japan
- Univ. Tokyo, Japan
- Victoria Univ., Canada

EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2

The scientific aim

the determination of the ***isospin dependent***
$\bar{K}N$ scattering lengths through a
~ eV measurement of the shift
and *of the width*
of the K_α line of **kaonic hydrogen** and
the *first (similar) measurement* of **kaonic deuterium**



See talk of M. Cargnelli

Kaonic Helium measurements SIDDHARTA experiment

In the framework of the SIDDHARTA experiment we have performed the measurements related with the **Kaonic helium transition to the 2p level (L-lines)**:

- **for first time in a gaseous target for ^{4}He**
- **for the first time ever for K^{3}He**

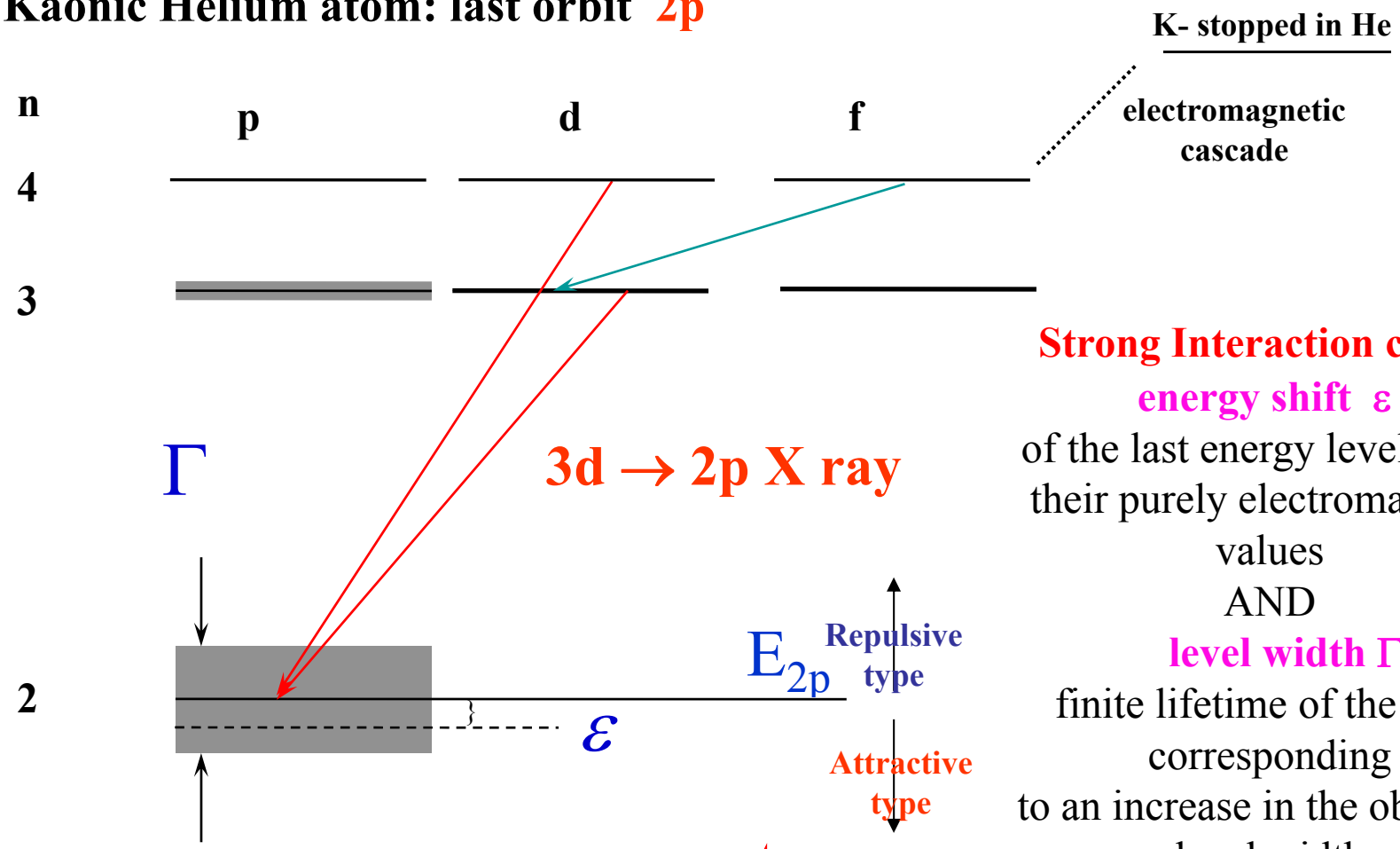
The interest for such type of measurement was rather high due to:

so-called "kaonic helium puzzle"

some theoretical predictions of possible high energy shift

Kaonic Helium atoms

Kaonic Helium atom: last orbit 2p



Strong Interaction causes:

energy shift ε

of the last energy levels form their purely electromagnetic values

AND

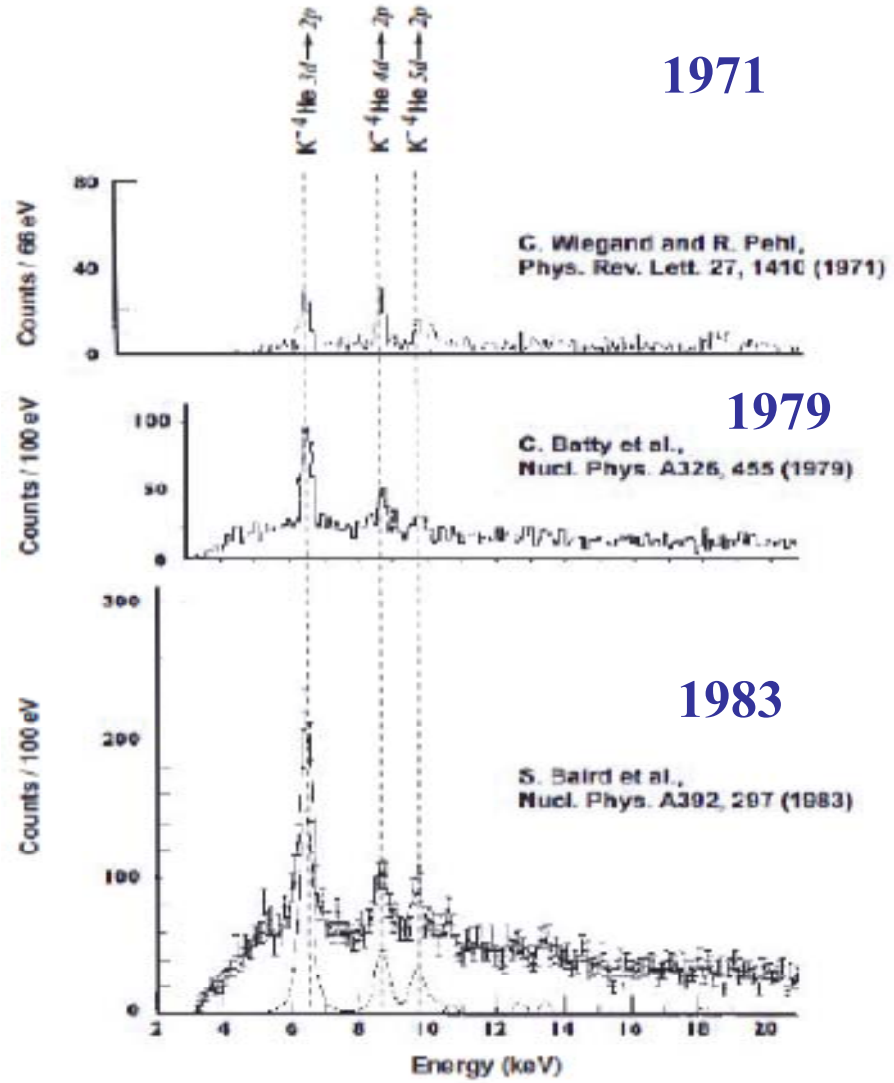
level width Γ

finite lifetime of the state corresponding to an increase in the observed level width

$$\varepsilon = E_{3d \to 2p}(exp) - E_{3d \to 2p}(e.m.)$$

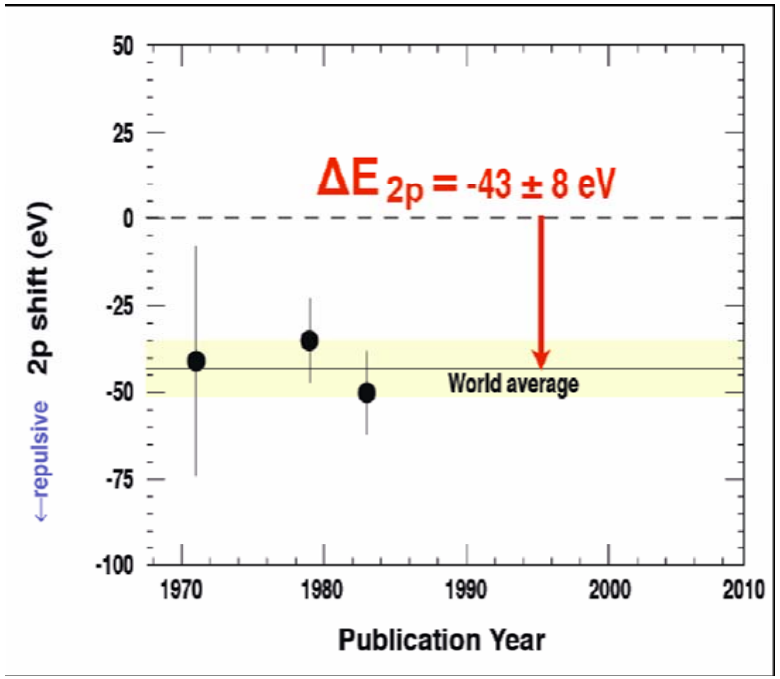
the most suitable transition to observe the strong interaction effects

Kaonic helium atom data (Z=2)



ΔE_{2p}(eV)	Γ_{2p} (eV)
-41±33	-
-35±12	30±30
-50±12	100±40
-43±8	55±34

Average of above



Kaonic helium atoms theoretical values

There are two types of theories compared to the experimental results:

Optical-potential model:

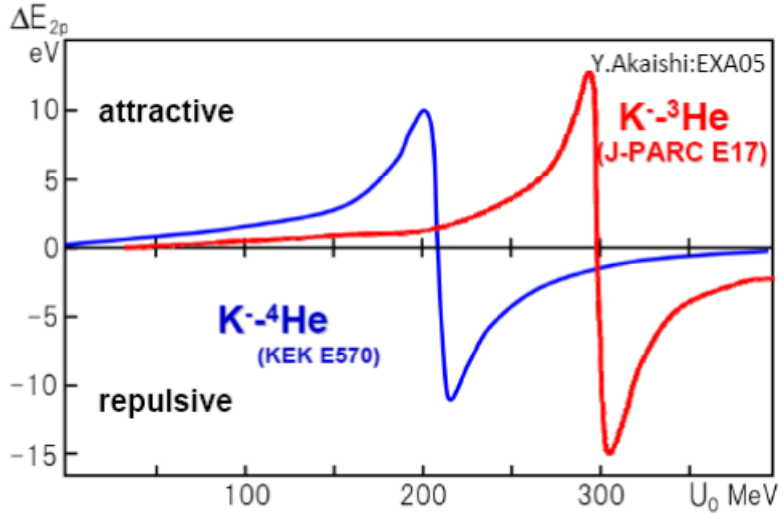
(theoretical calculations based on kaonic atom data)

Shift (eV)	Ref.
-0.13±0.02	Batty, NPA508 (1990) 89c
-0.14±0.02	Batty, NPA508 (1990) 89c
-1.5	Akaishi, Porc. EXA05

Tiny shift ($\Delta E_{2p} \approx 0$ eV)

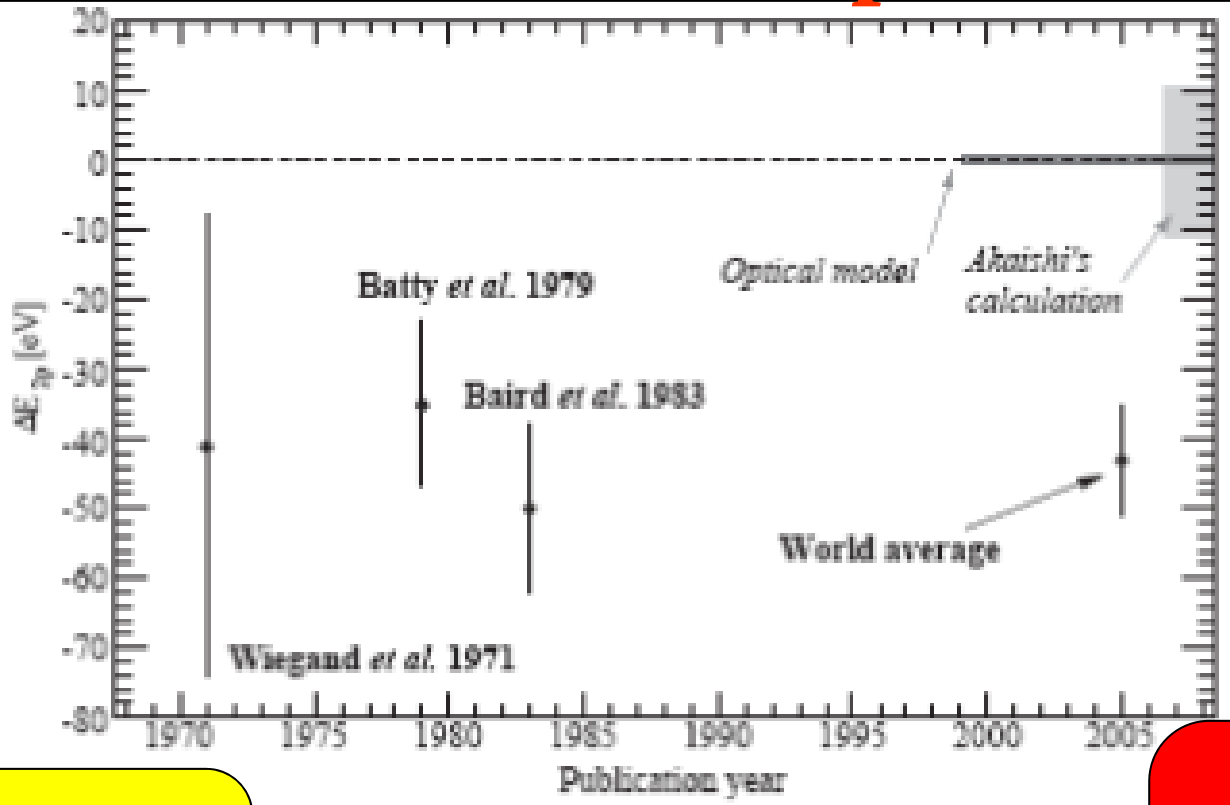
Recent theoretical calculations:

Akaishi-Yamazaki model of deeply-bound kaon-nucleus states



Predicts a possible maximum shift: ΔE_{2p} of ± 10 eV

What is Kaonic helium puzzle?

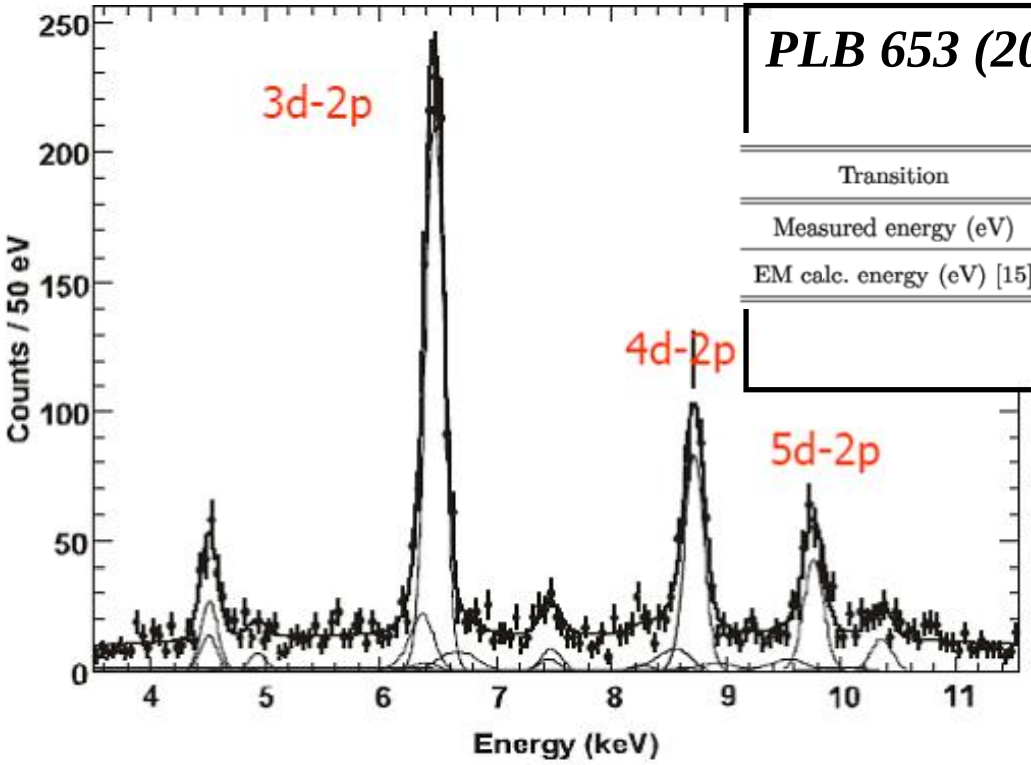


Experiment: Large shift ($\Delta E2p \approx 40$ eV)

Theory: $\Delta E2p \approx 0$ eV or $< \pm 10$ eV

Need a new K-^{4}He X-ray measurement!

New K^4He results by KEK PS E570



PLB 653 (2007) 387

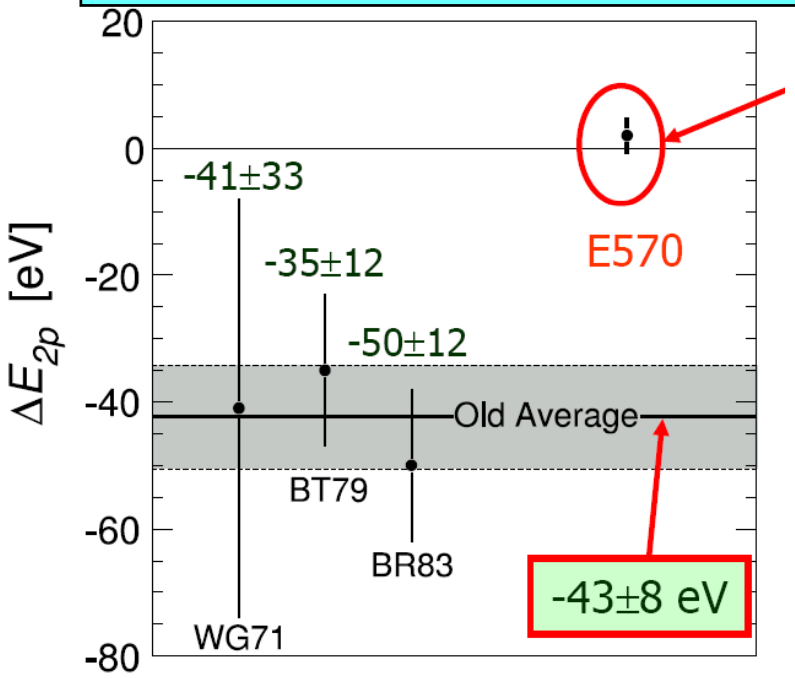
Transition	$3d \rightarrow 2p$	$4d \rightarrow 2p$	$5d \rightarrow 2p$
Measured energy (eV)	6466.7 ± 2.5	8723.3 ± 4.6	9760.1 ± 7.7
EM calc. energy (eV) [15]	6463.5	8721.7	9766.8

K^4He 3d→2p: 1500 events

3x higher statistics
2x better Energy resolution
6x better S/N

ΔE_{2p} =2±2(stat.)±2(syst.) eV)

Solving the kaonic helium puzzle



Theory:
ΔE2p ≈ 0 eV
or
< ± 10 eV

Old experiments:
Large shift
(-43±8 eV)

Difference between the new and the old experiments

E570 experiment:
Small shift
(+2±2±2 eV)

Experimental confirmation need!
SIDDHARTA experiment

SIDDHARTA experiment

$$e^+ + e^- \rightarrow \phi \rightarrow K^+ + K^-$$

Monochromatic, low-momentum kaon beam from DAΦNE (127 MeV/c)

No hadronic background due to the beam line (compare with hadron beam line :e.g with KEK line)

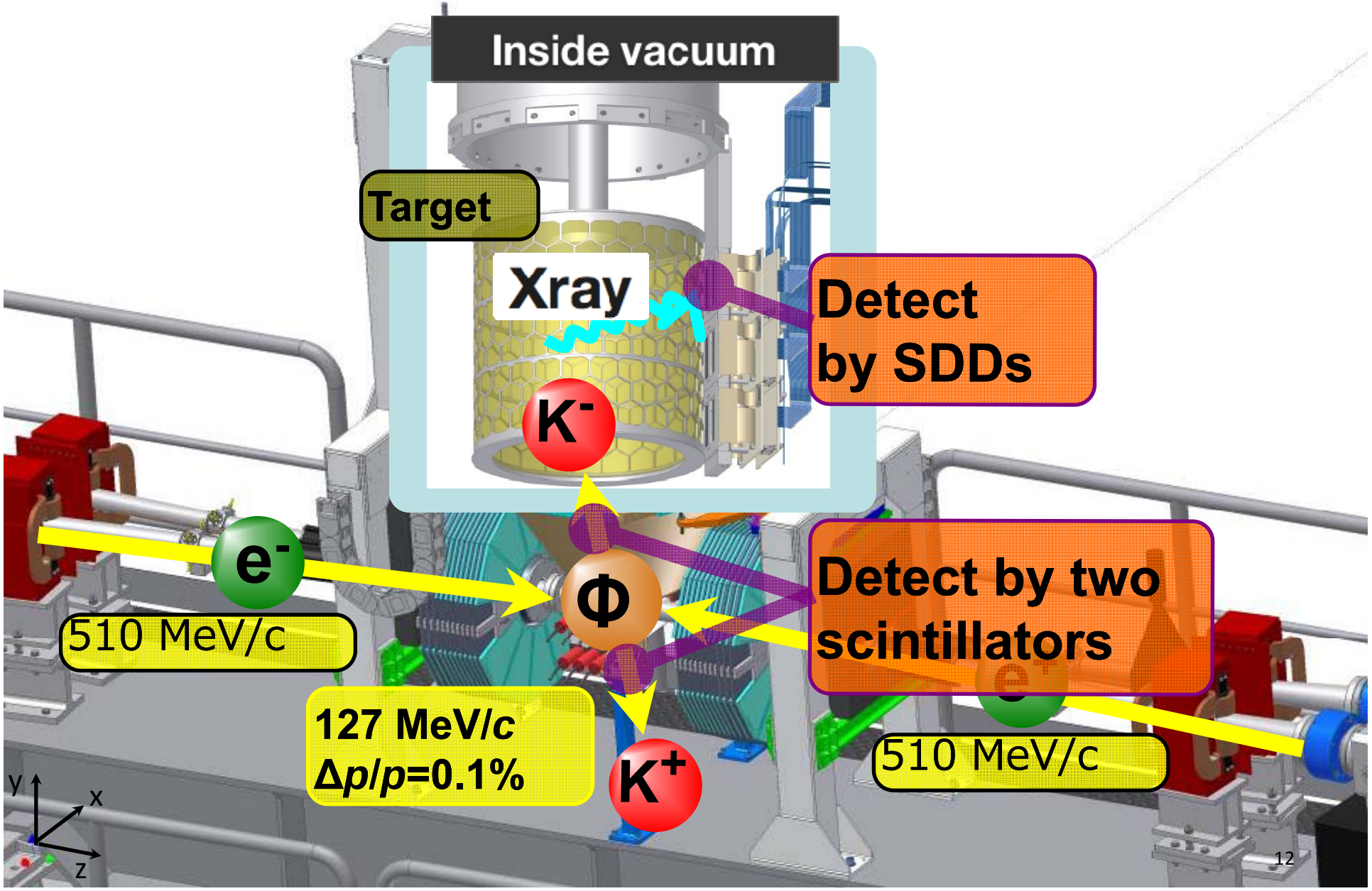
Big advantages of the SIDDHARTA experiment:

• low density gas target with an efficient kaon stopping power (negligible Compton scattering in helium)

•K+K- pair detection

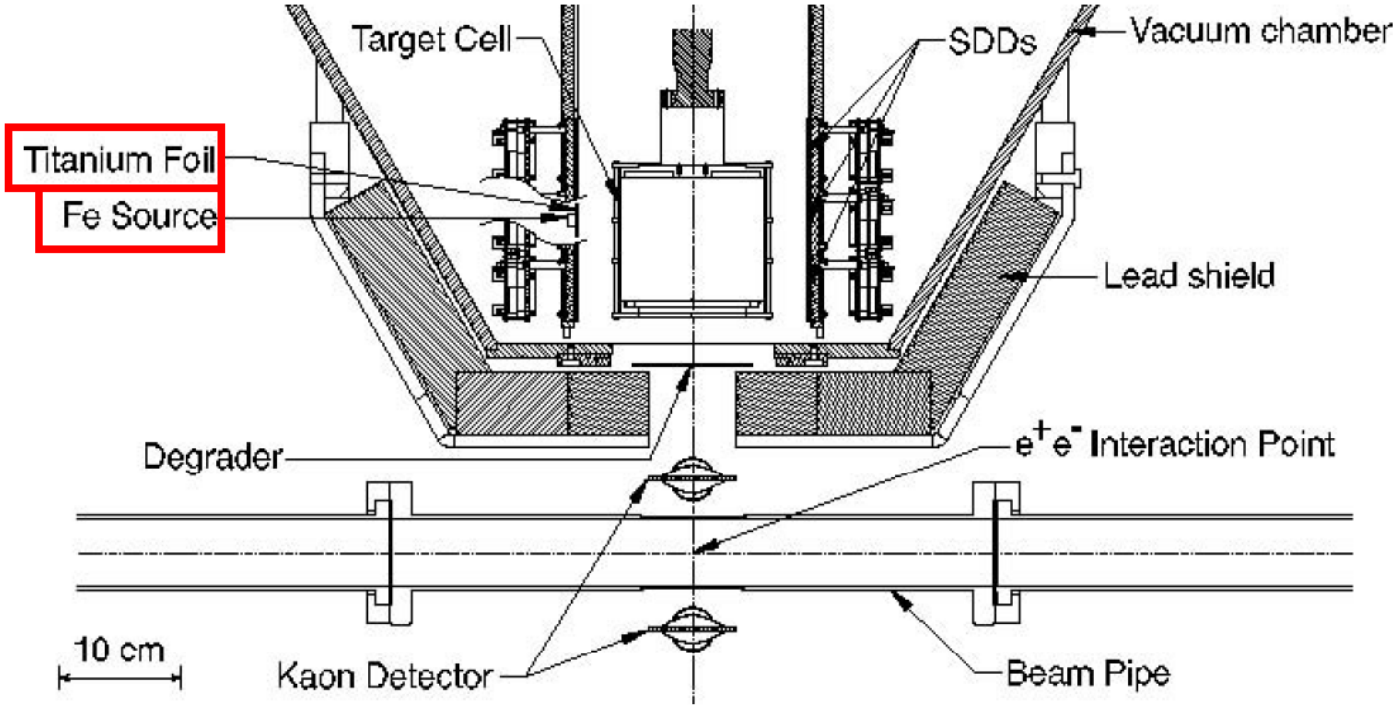
•Silicon Drift Detector (SDDs) as detector

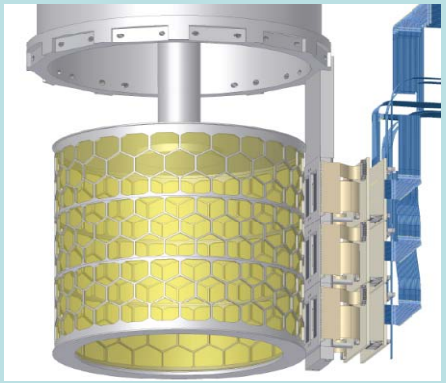
SIDDHARTA overview




SDDs & Target
(inside vacuum)
Kaon detector

The experimental setup





Target size: r = 72 mm height = 155 mm

For He3: Temp. of gas: 20K

Pressure: 1 bar

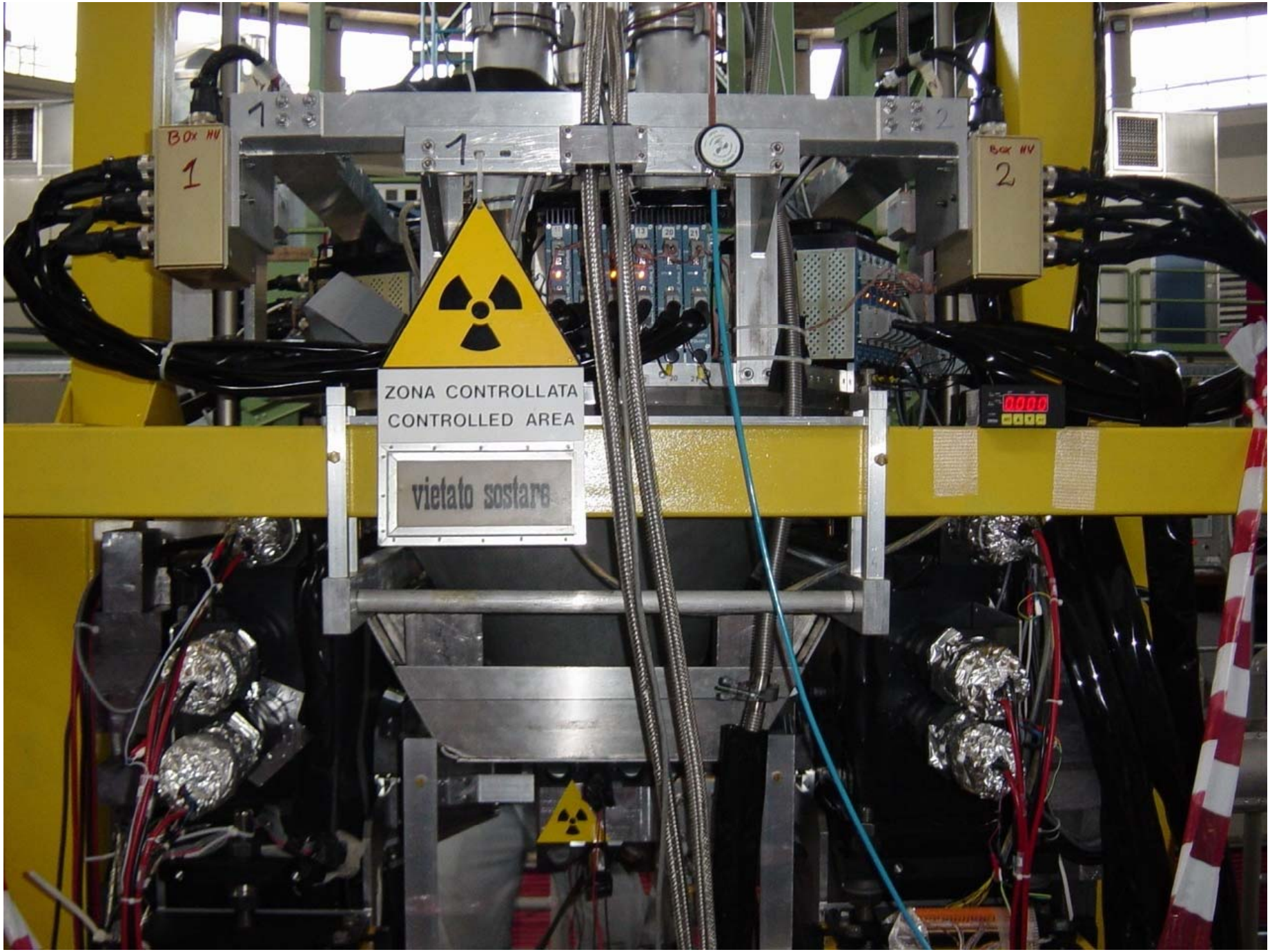
Installed SDD: 144 cm^2

SDD operation temp: 170 K

SDD Energy resolution: ≈150 eV (at 6 keV)

Silicon Drift Detector - SDD

SDD Energy resolution: ≈150 eV (at 6 keV)


BOx HV
1
1
1
2
BOx HV
2
ZONA CONTROLLATA
CONTROLLED AREA
vietato sostare

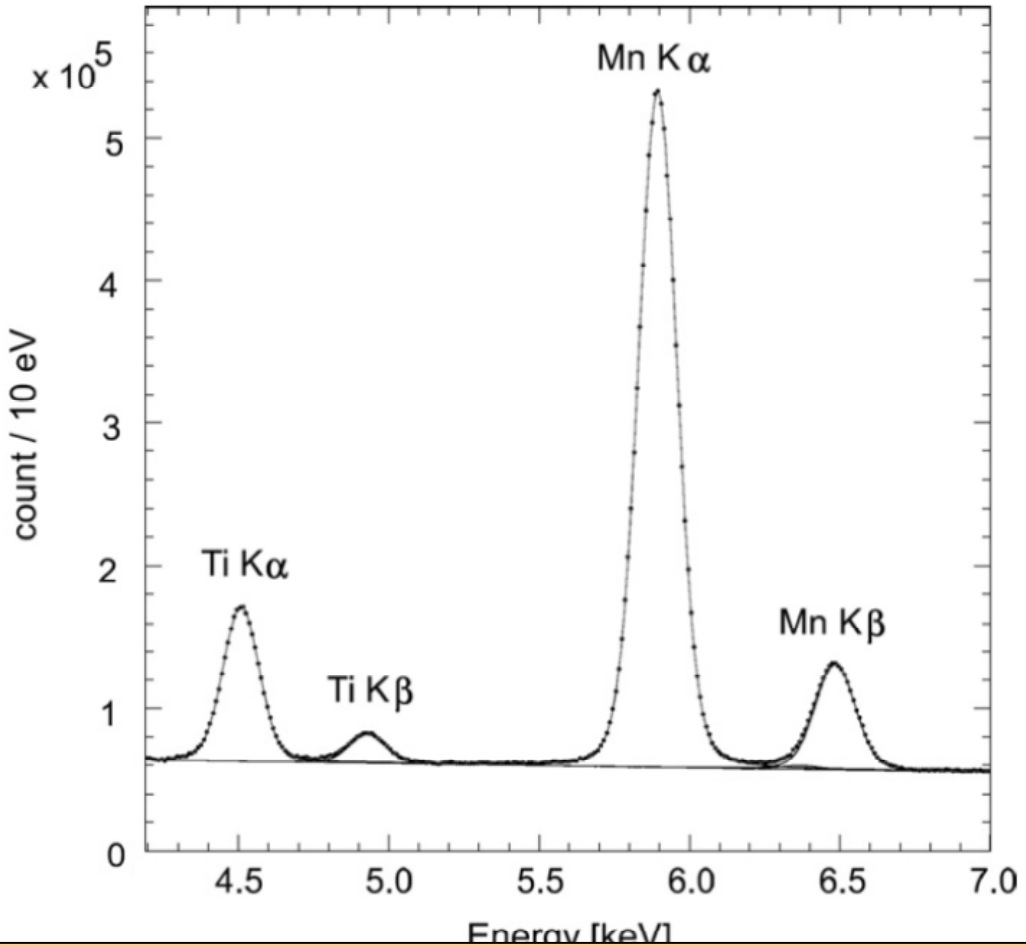
Kaonic ^{4}He data
SIDDHARTA experiment

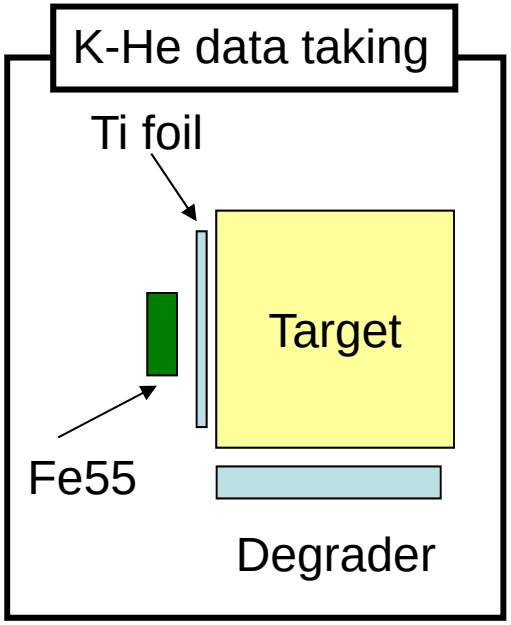
The **Kaonic ^{4}He X-ray data** were taken for about **two weeks in January 2009**.

In this period, an **integrated luminosity of about 20pb^{-1}** was collected.

This corresponds to about **4.7 × 10^6 kaons** detected by the kaon detector.

Energy calibration

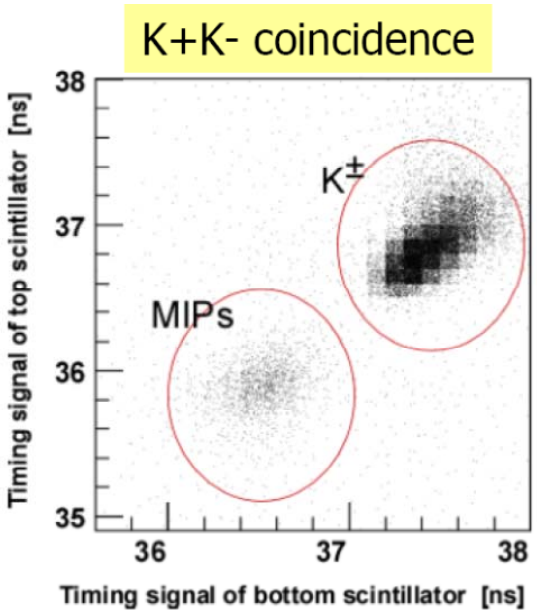


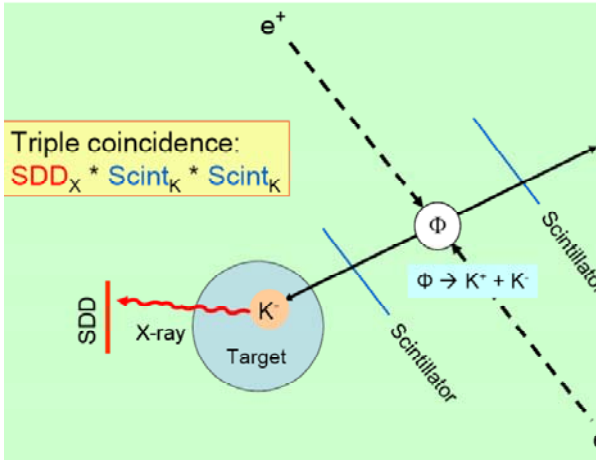


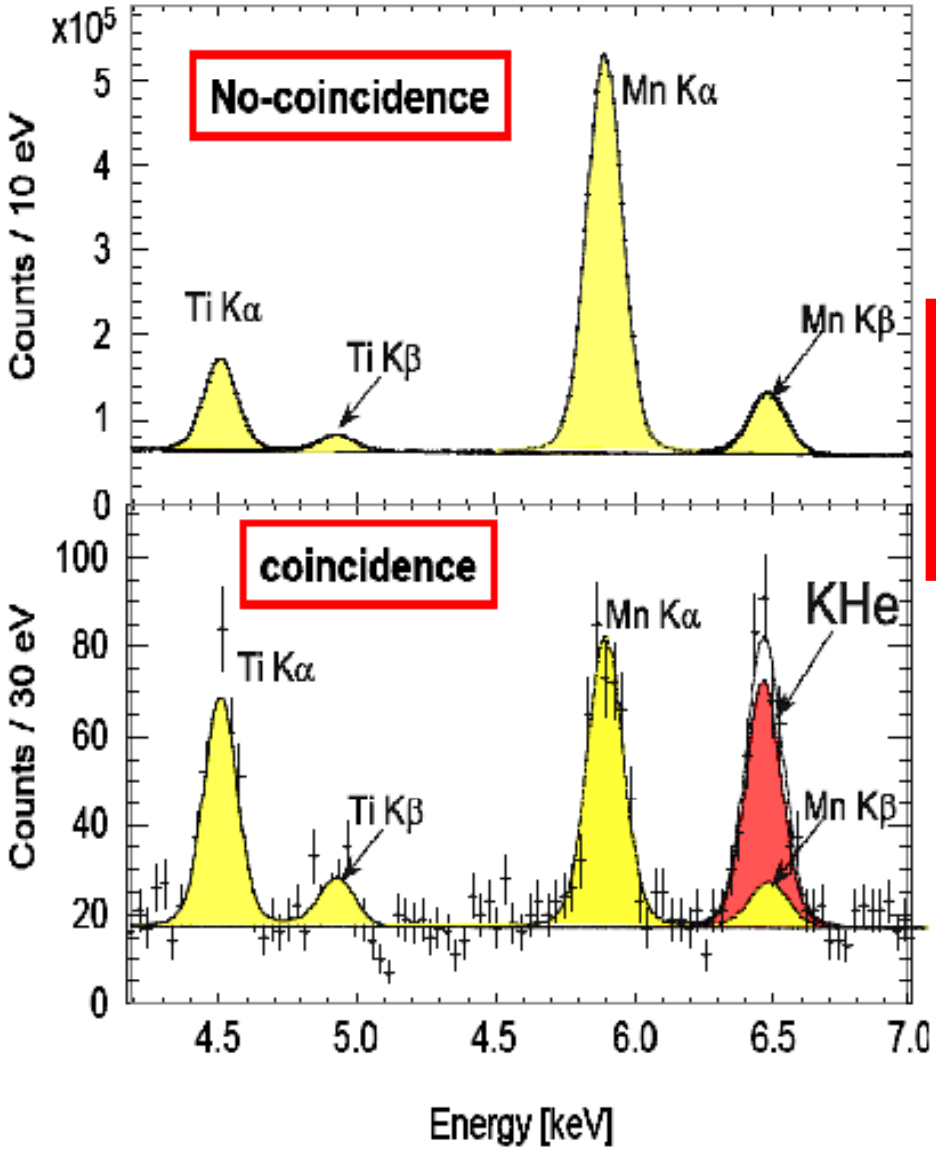
SDD spectrum of X-ray uncorrelated with kaon production.
Ti and Mn X-ray peaks are produced by the ^{55}Fe source in normal condition of beam

Energy resolution: FWHM (@6.4 keV): 151 ± 2 eV

Triple coincidences

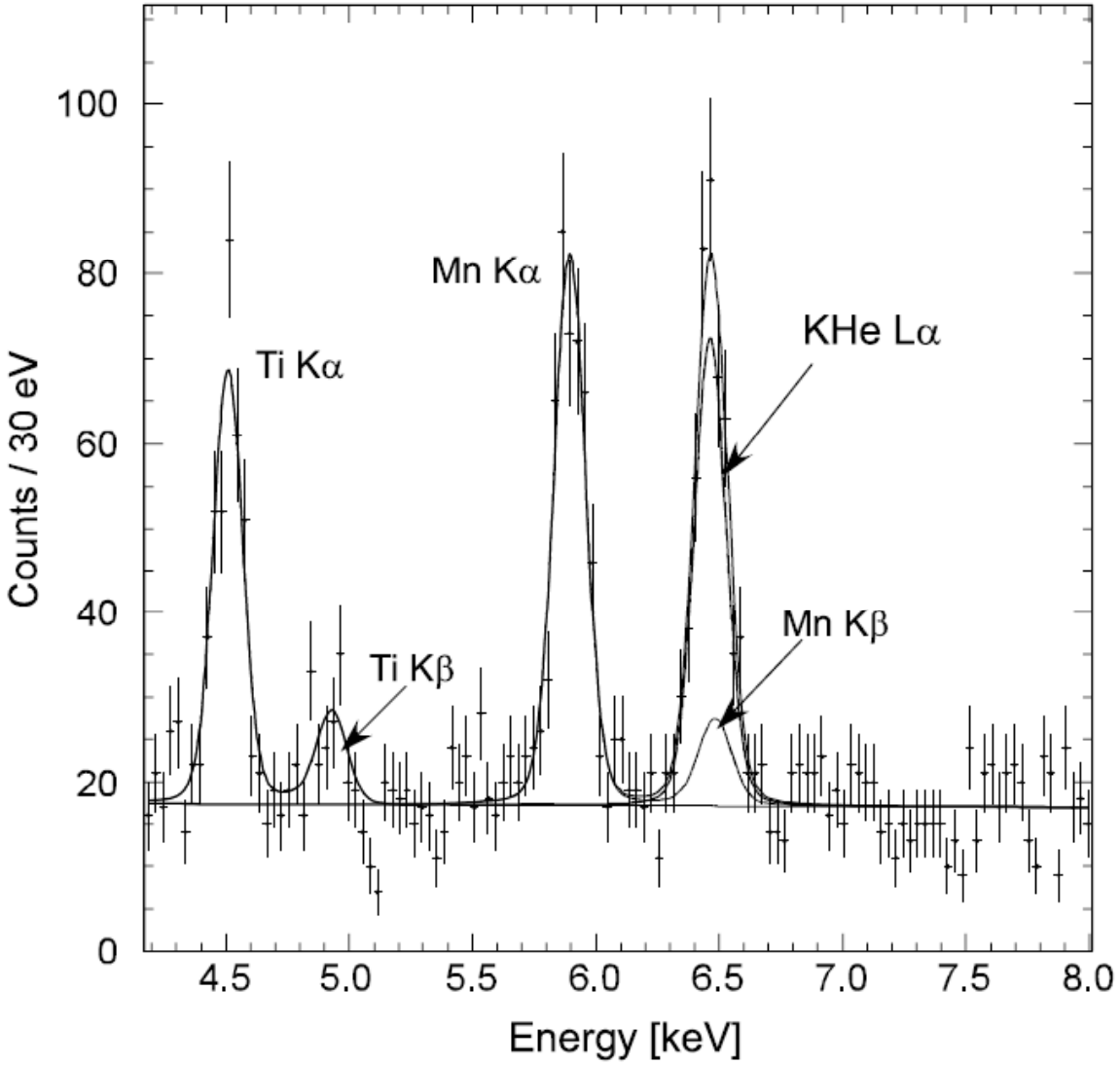






Background suppression more than 10^4

Energy spectrum of K-^{4}He X-rays



Energy of K^{4}He L_α (3d→2p) line:

E_{exp} = 6463.6±5.8 eV

New results of K-^{4}He 2p level shift

E_{exp} = 6463.6±5.8 eV

$E_{e.m.}$ = 6463.5±0.2 eV

$\Delta E = E_{exp} - E_{e.m.} = 0 \pm 6(stat) \pm 2(syst)$ eV

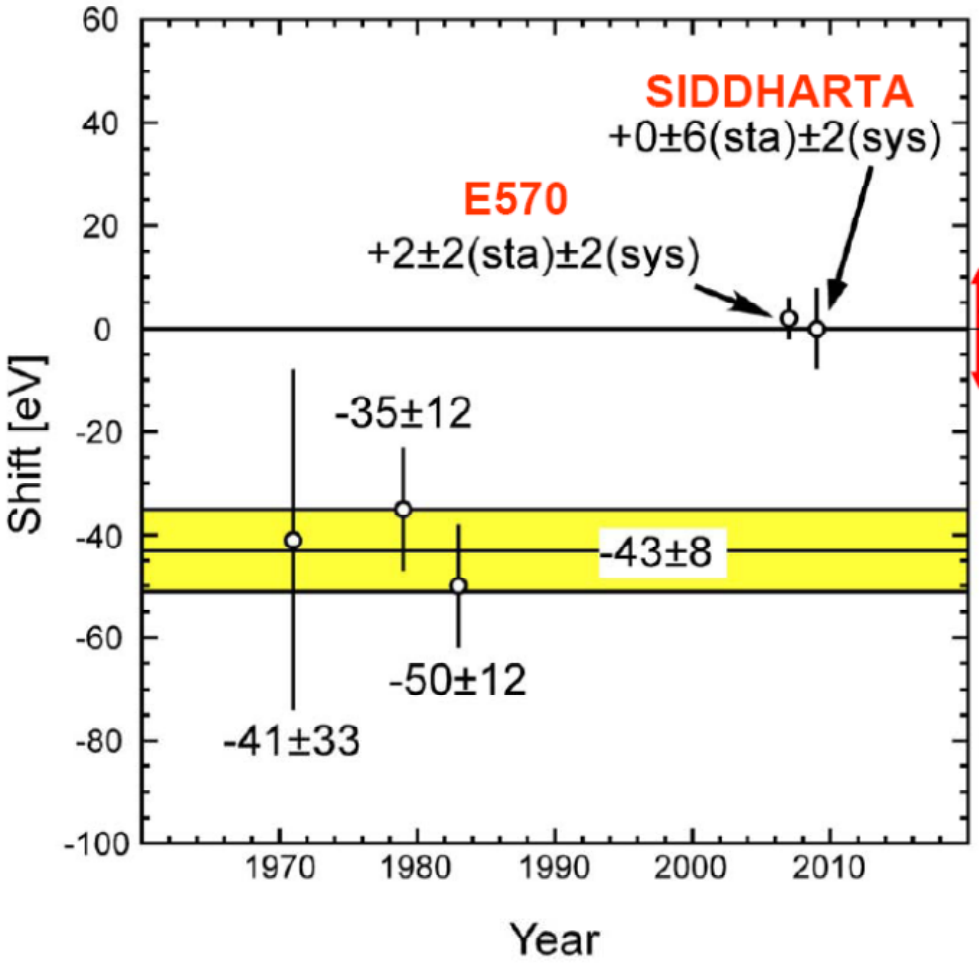
Published in PLB 681(2009) 310-314

ΔE (eV)	Ref.
-41 ± 33	Wiegand *et al.* [5]
-35 ± 12	Batty *et al.* [6]
-50 ± 12	Baird *et al.* [7]
-43 ± 8	Average of above [1,7]
$+2 \pm 2$ (stat) ± 2 (syst)	Okada *et al.* [10]
0 ± 6 (stat) ± 2 (syst)	This work

SIDDHARTA's results is consistent with the results obtained by E570 experiment

"kaonic helium puzzle" solved

Summary of the K-^{4}He shifts



Akaishi Prediction
-10~ +10 eV

Optical model
~0eV

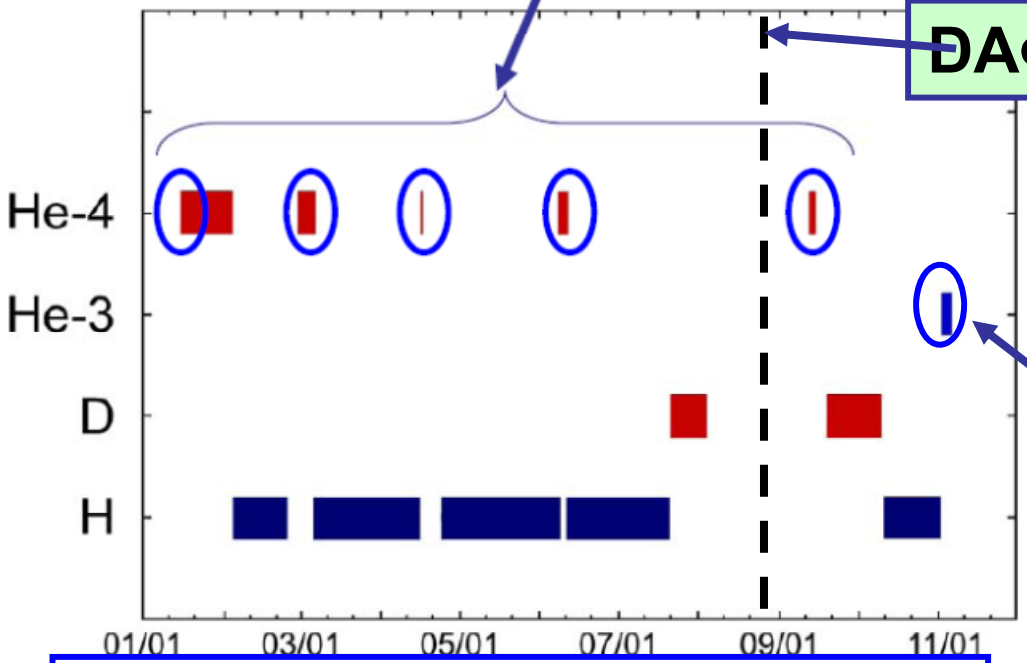
Optical model
Tiny (~ 0eV)

K-nucl model
Small (<±10 eV)

K-He4 exp
Large (-40 eV)

Data taking periods of SIDDHARTA in 2009

K-He4 data without Fe source



DAΦNE shutdown in Summer

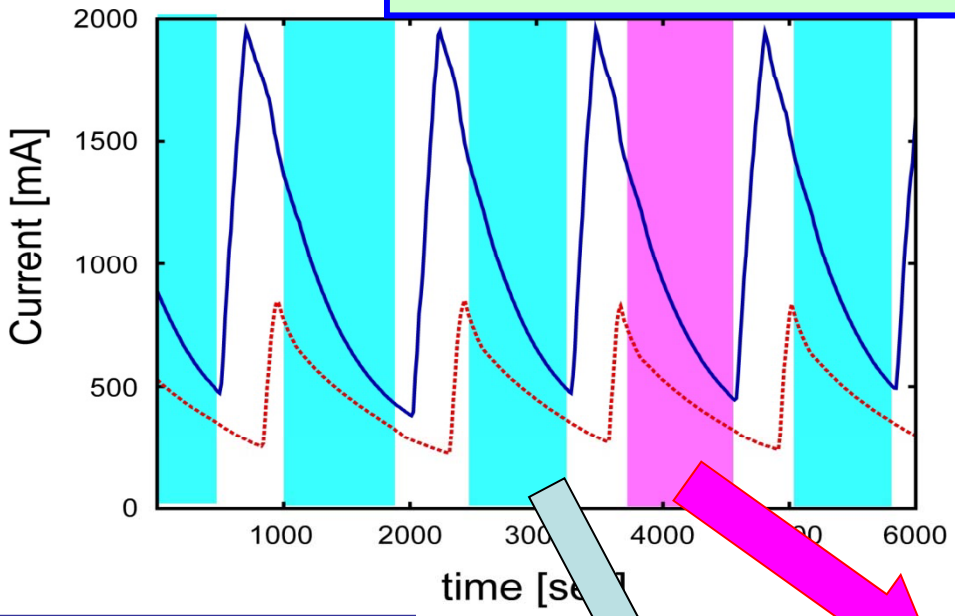
New alignment of setup
→Improve S/N ratio

K-He3 data (~4days)

55Fe source:
Good for reduce sys. error on K-^{4}He
Bad for "background" events on K-H,K-D

Removed ^{55}Fe source in other data

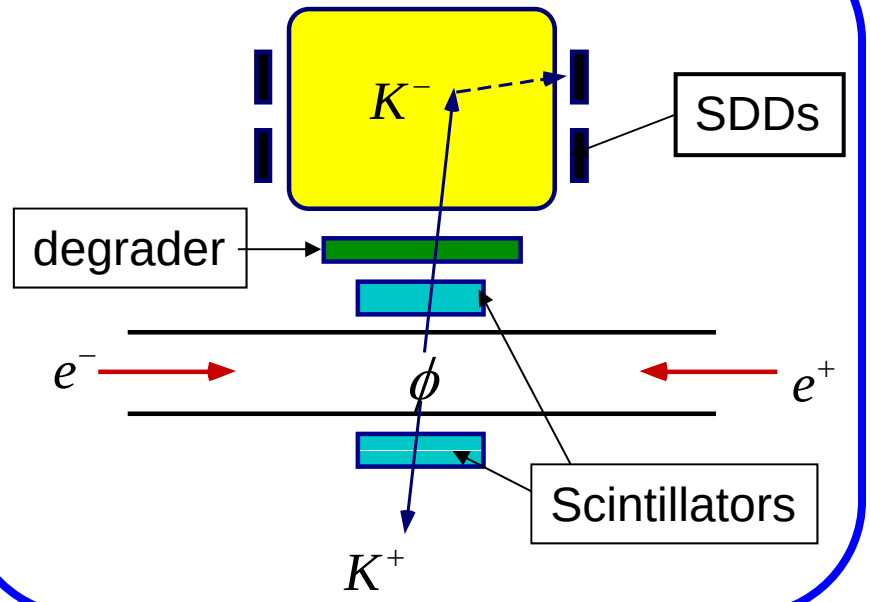
Data taking scheme at DAFNE



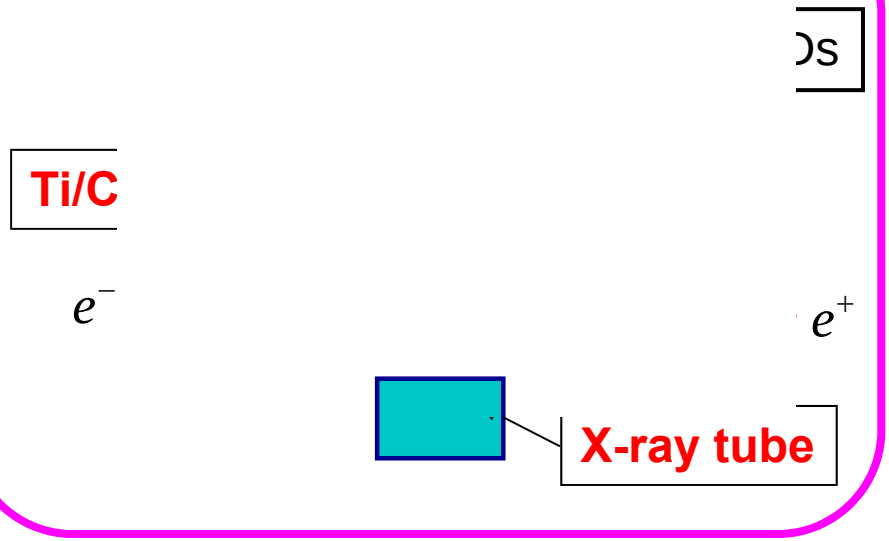
Calibration data with X-ray tube have been collected under the beam condition in regular interval of the production runs.

For that purpose a remote controlled mechanism was built to move away the kaon detector and instead have the x-ray tube in place.

Production data

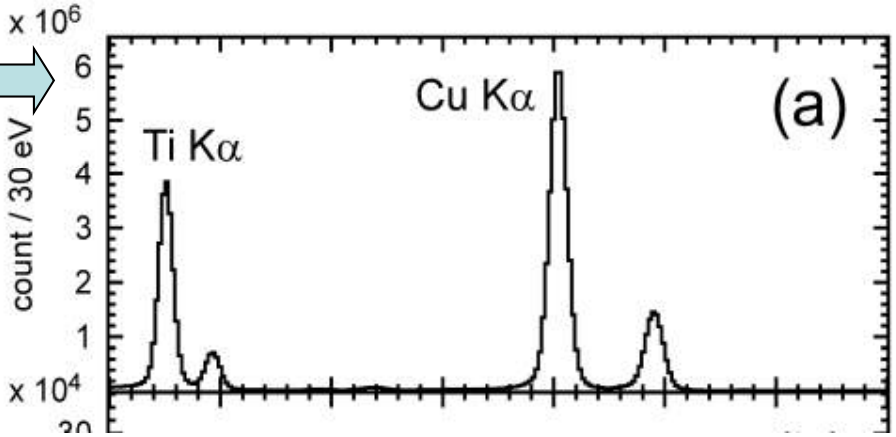


calibration data



SDD X-ray energy spectra

Calibration data with **X-ray tube**



Calibration Ti&Cu

In-beam

X ray tube

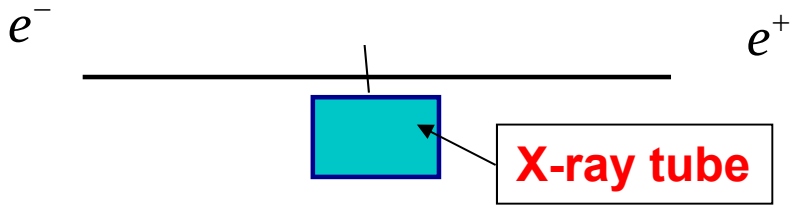
Ti, Cu foils

calibration data

Instead of Fe source,
"X-ray tube" data taken

Ds

Ti/C



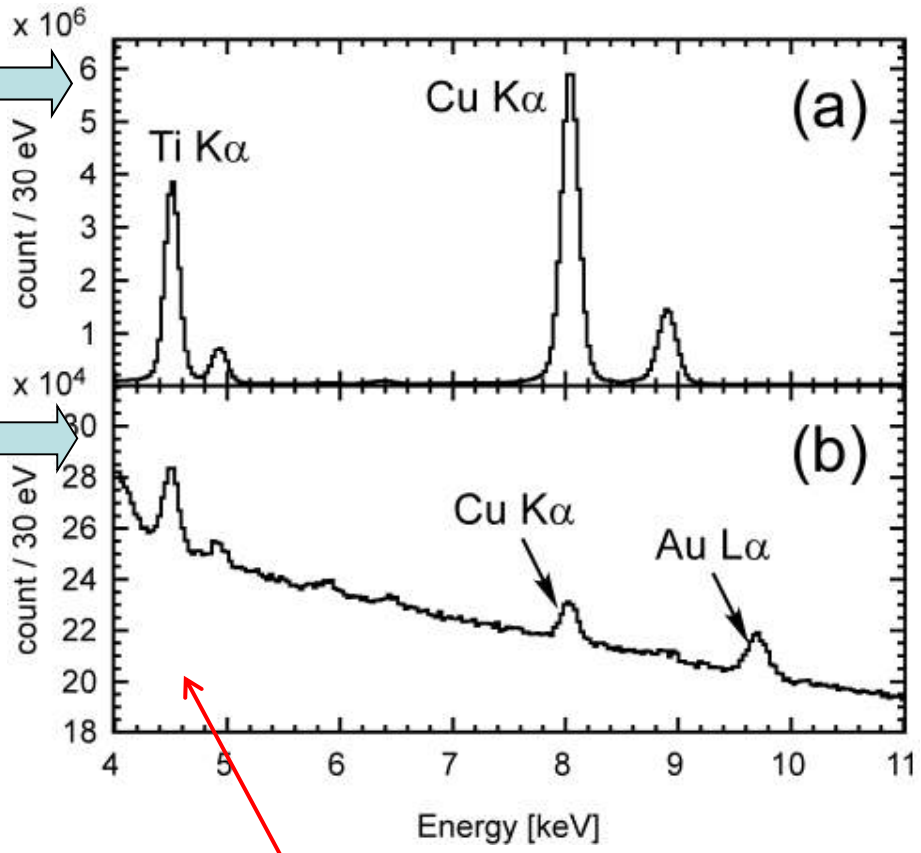
Estimated
systematic error ~ 3-4 eV

SDD X-ray energy spectra

Calibration data with **X-ray tube**

Not correlated to Kaon signals

Production data

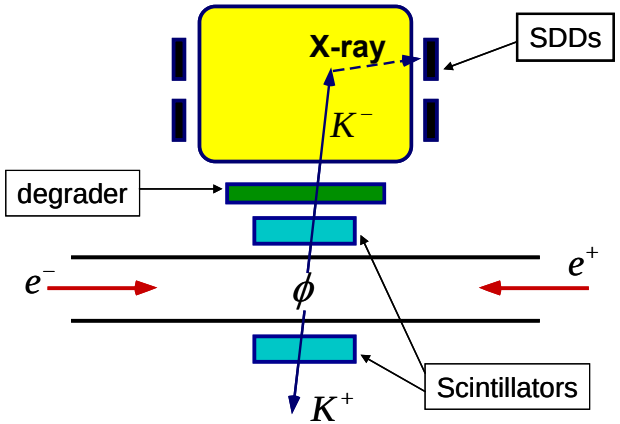


providing large statistics background events + X-Ray lines form the target maetrials induced by the beam background

Calibration Ti&Cu

Energy scale determined by X-ray tube data

Energy spectrum with uncorrected to kaon timing
[Fig. (b)]



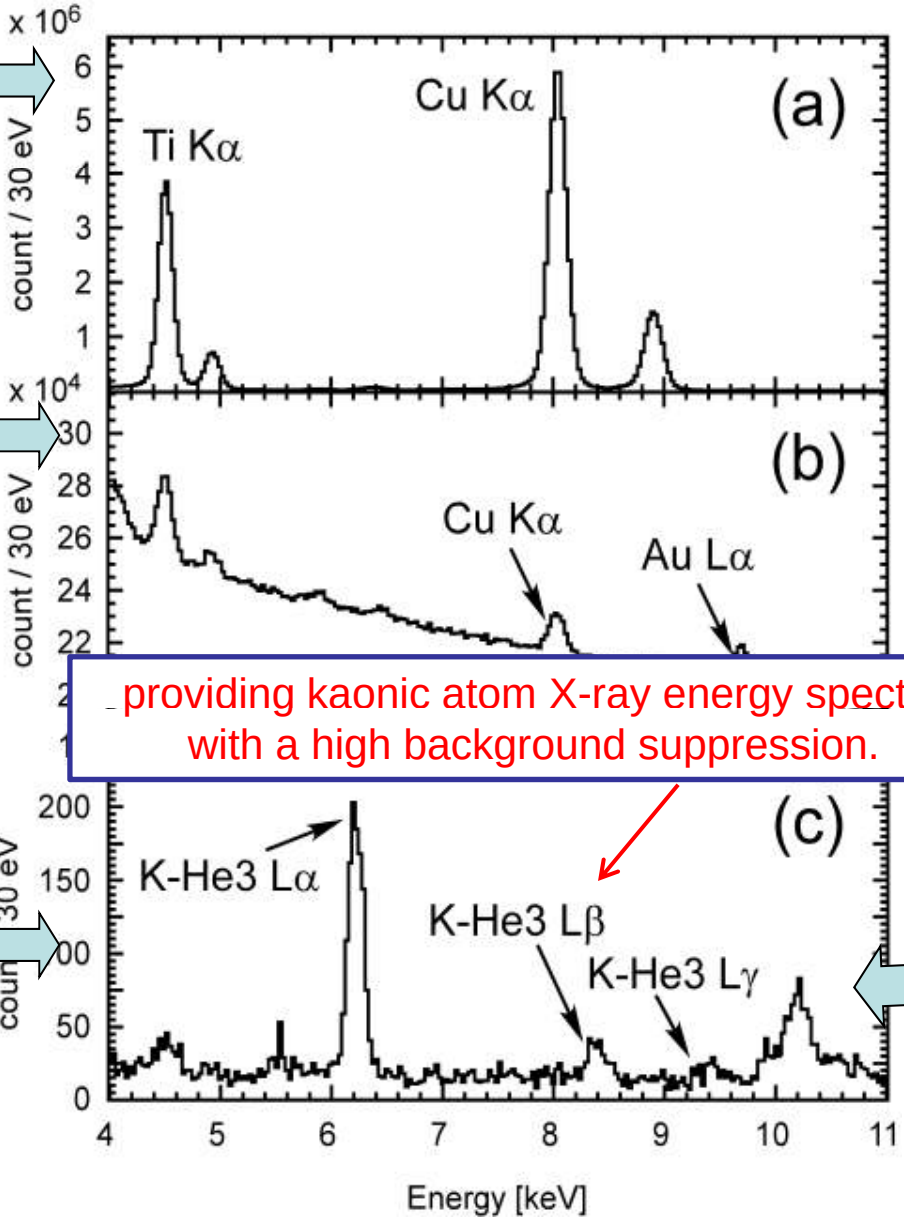
SDD X-ray energy spectra

Calibration data with **X-ray tube**

Not correlated to Kaon signals

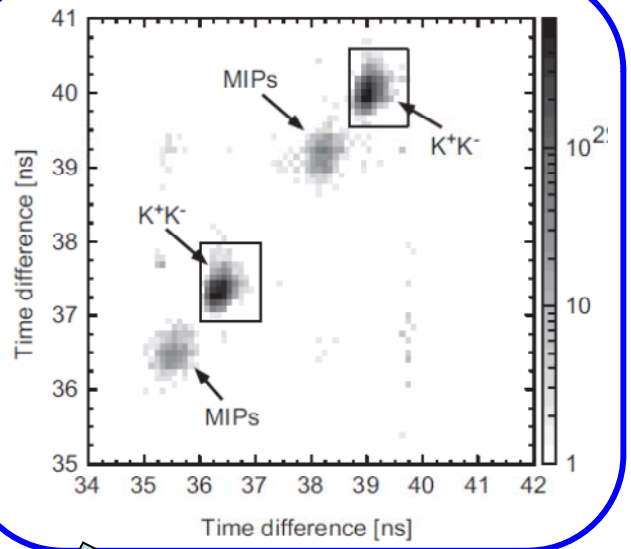
Production data

Selected with K+K- & SDD timing

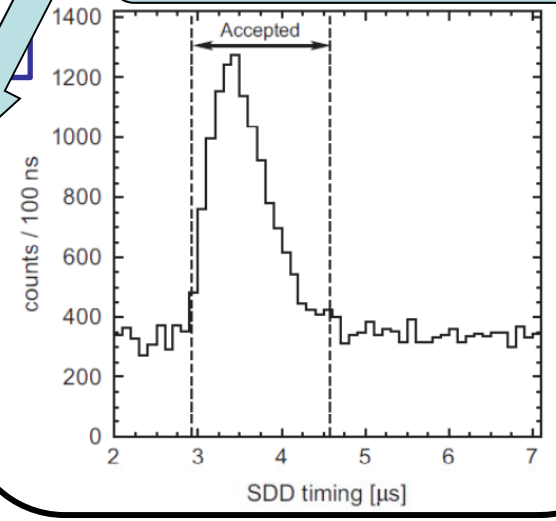


providing kaonic atom X-ray energy spectra with a high background suppression.

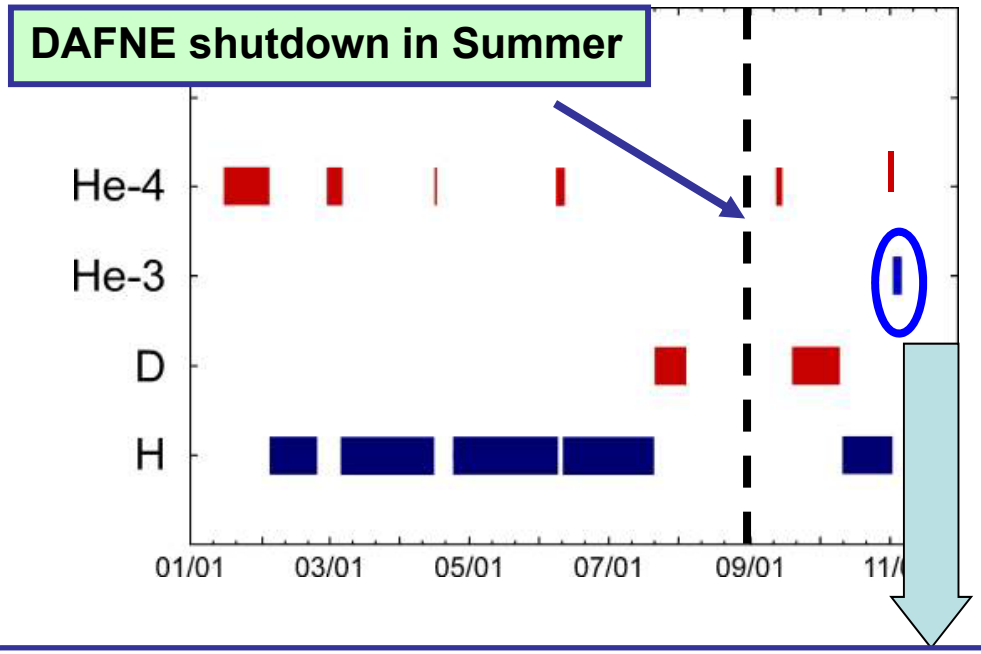
Kaon detector



Time difference between SDD & Kaon detector



Kaonic ^{3}Helium data SIDDHARTA experiment



The **Kaonic- ^{3}He X-ray data** were taken for about **4 days in November 2009**.

In this period, an **integrated luminosity of about 16 pb^{-1}** was collected.

The Kaonic-^{3}He case

There are NOT previous experiments done for the X-ray measurements for Kaonic- ^{3}He

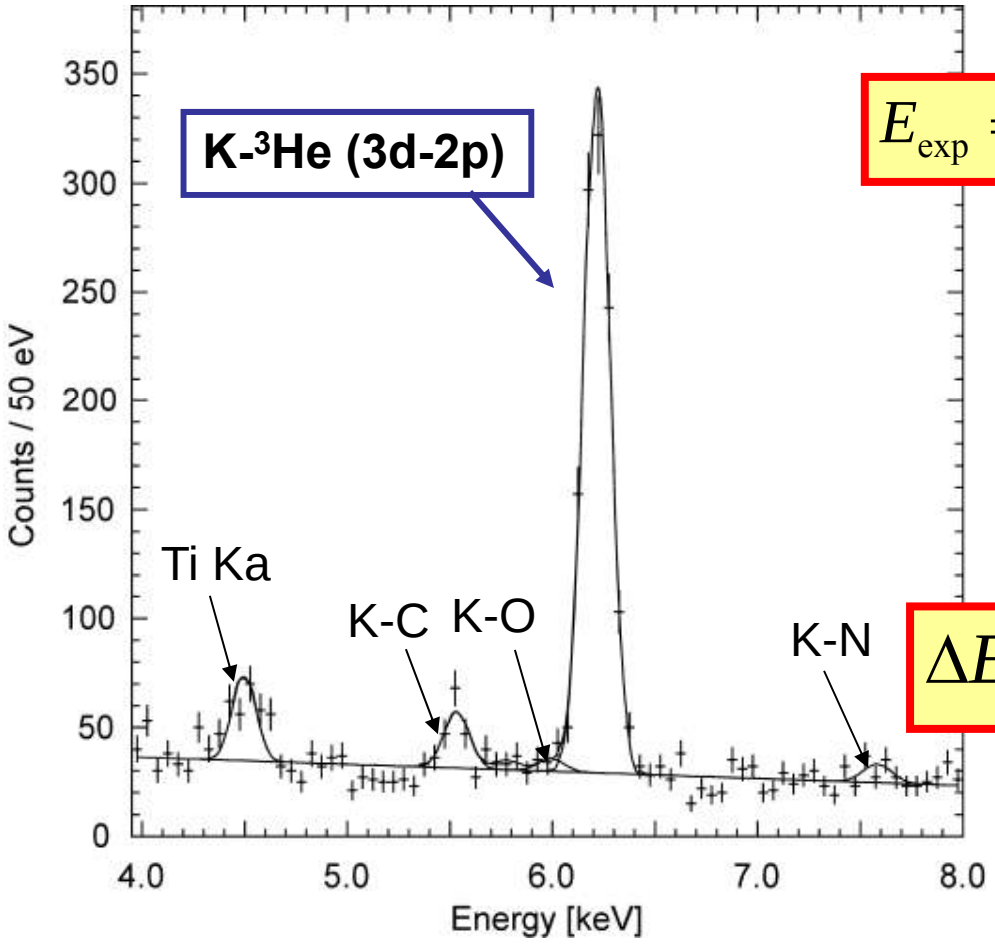
Planned experiments: SIDDHARTA (done);

E17 (to be done)

Transition	Kaonic-^{3}He e.m. (eV)(*)
3d->2p	6224
4d->2p	8399
5d->2p	9406

(*)Zeitschrift fur Physik D 15 (1990) 321

Kaonic Helium-3 energy spectrum



X-ray energy of K-3He 3d-2p

$$E_{\exp} = 6223.0 \pm 2.4(sta) \pm 3.5(sys)\ \text{eV}$$

QED value: $E_{e.m.} = 6224.6\ \text{eV}$

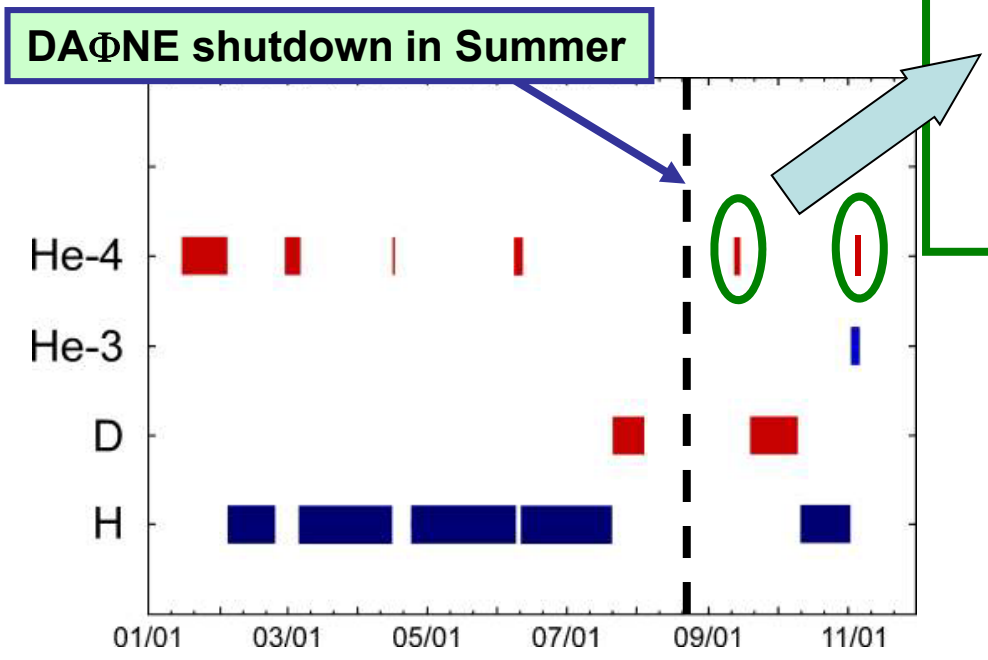
$$\Delta E_{2p} = E_{\exp} - E_{e.m.}$$

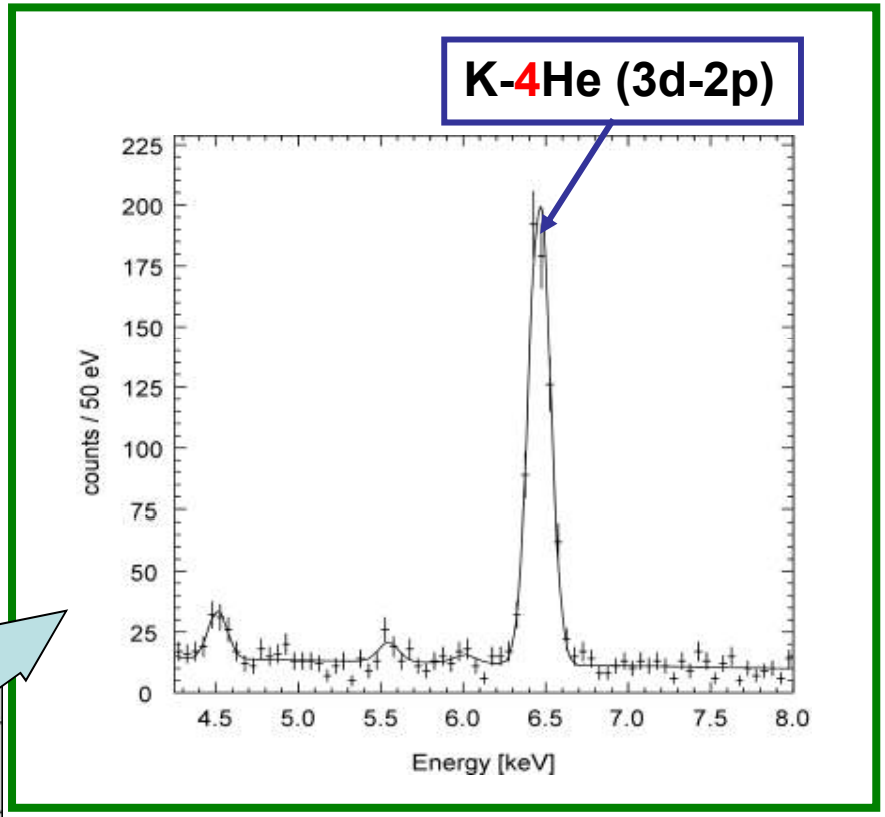
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199

World First !
Observation of K-³He X-rays
Determination of
strong-interaction shift

More date on K-^{4}He 2p level shift



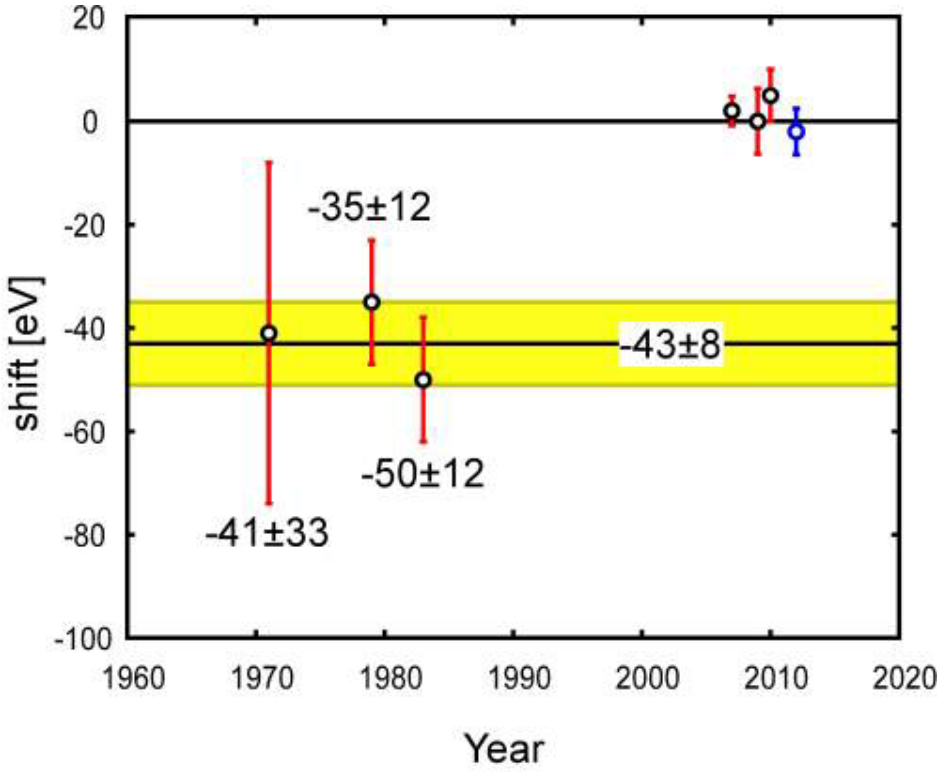


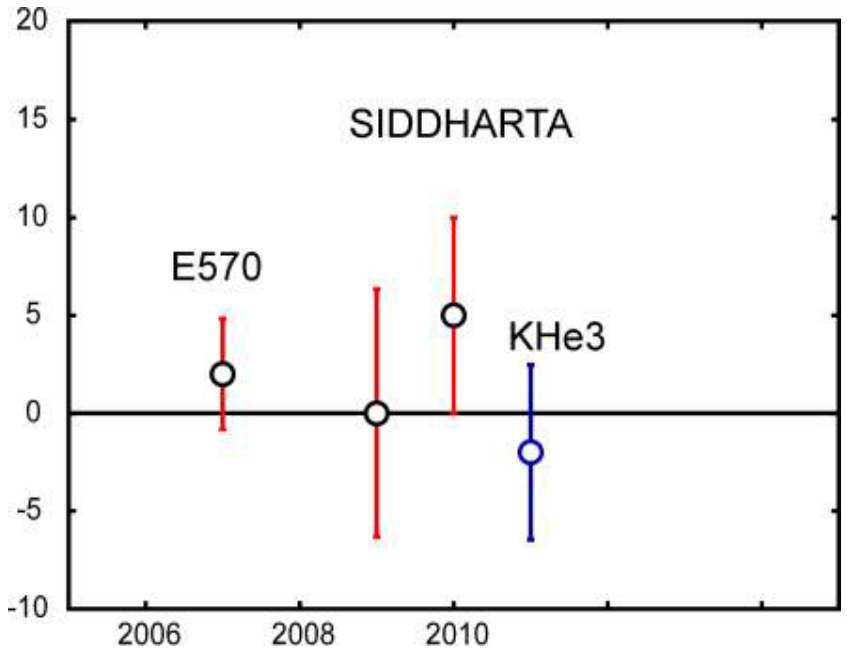
$$\Delta E_{2p} = +5 \pm 3(sta) \pm 4(sys)\ \text{eV}$$

arXiv:1010.4631v1 [nucl-ex],
PLB697(2011)199

Summary of the results

Experiment	Target	Shift [eV]	Reference
KEK E570	Liquid	+2±2±2	PLB653(07)387
SIDDHARTA (He4 with 55Fe)	Gas	+0±6±2	PLB681(2009)310
SIDDHARTA (He4)	Gas	+5±3±4	arXiv:1010.4631, PLB697(2011)199
SIDDHARTA (He3)	Gas	-2±2±4	





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

Conclusions

SIDDHARTA experiment **measured the kaonic helium 3d→2p transitions**:

- for **the first time** in a **gaseous target for ^{4}He**

- for the **first time ever for ^{3}He.**

DAΦNE proves to be a **"ideal" kaonic atom "factory".**

Future plans

The upgrade of the SIDDHARTA experimental setup

SIDDHARTA 2 experiment

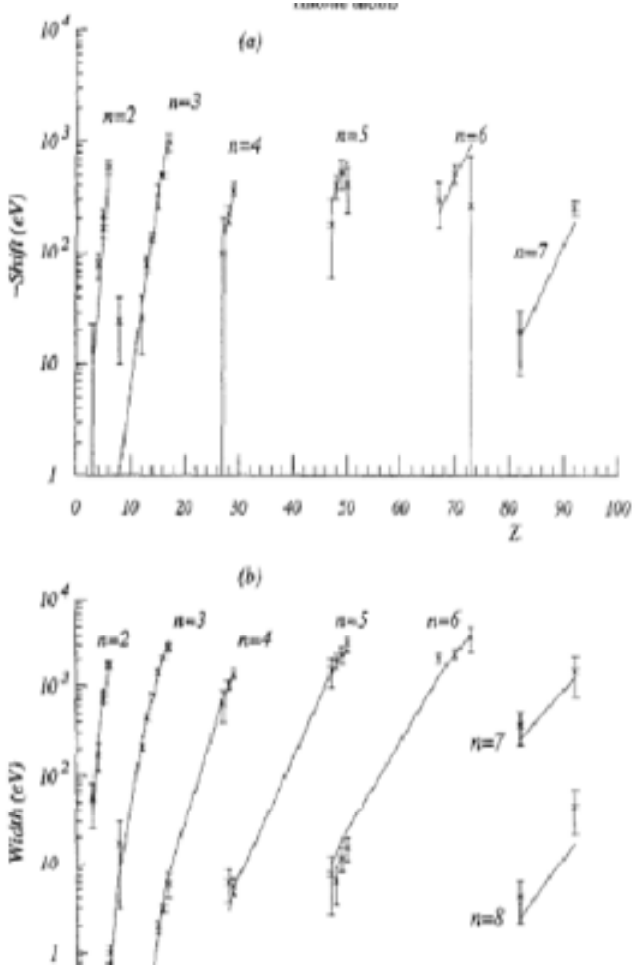
Precise measurements for the X-ray transitions for kaonic deuterium.

Measuring, with higher precision, the X-ray transitions for Kaonic ^{4}He and Kaonic ^{3}He to the 2p level and the first tempt to get the transitions to the 1s level.

Kaonic atoms data (Z>3)

The shift and widths of kaonic atom X-ray energy have been measured using targets with atomic numbers from Z=1 to Z-92, which provide very important quantities for understanding the antiKN strong interaction.

C.J. Batty et al., Physics Reports 287(1997) 385-445



The shifts and widths for kaonic atoms with Z≥3 are systematically well understood;

The optical model expressing the kaonic atom data have been used for calculation of the antiKaonN interaction.

There are discrepancies for:

Kaonic Hydrogen (Z=1)

Kaonic Helium (Z=2)

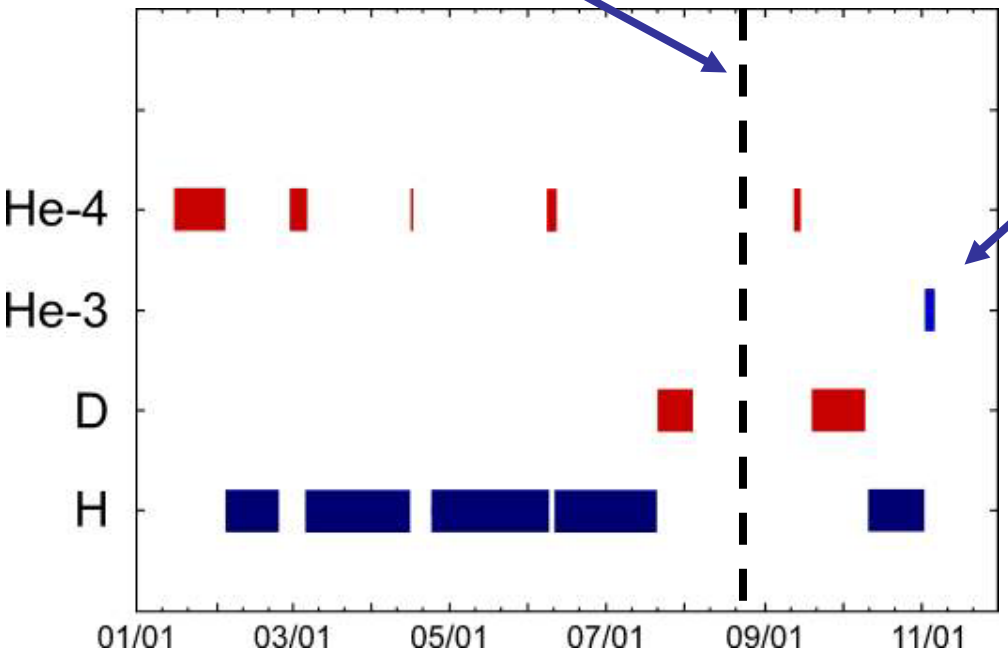
See talk of A. Romero Vidal

Data taking periods of SIDDHARTA in 2009

DAFNE shutdown in Summer

New alignment of setup →Improve S/N ratio

K-He3 data (~4days)



55Fe source:
Good for reduce sys. error on K-^{4}He
Bad for “background” events on K-H,K-D

Removed ^{55}Fe source in other data

Very preliminary K-^{4}He spectrum

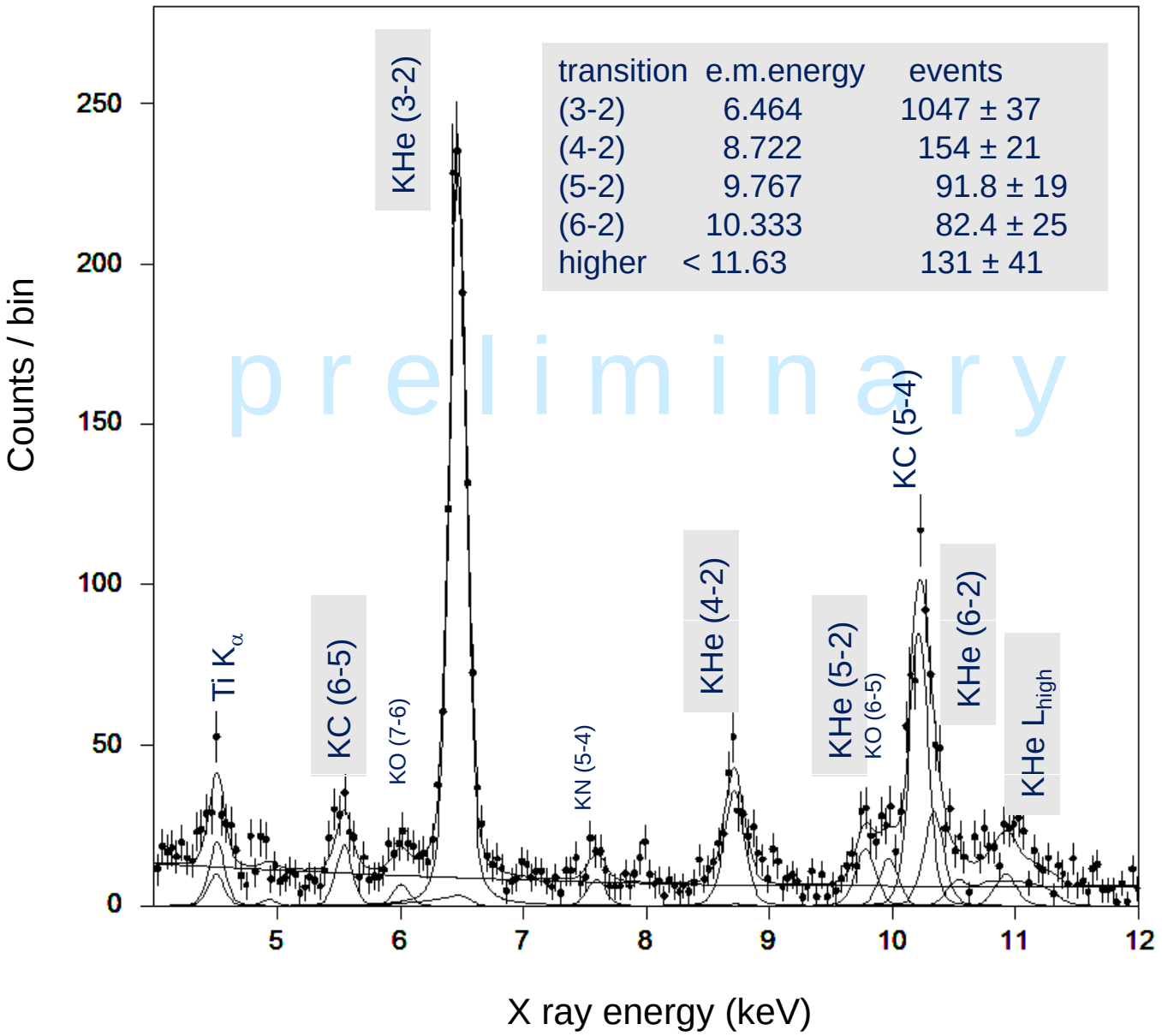
KHe used for **gasstop optimization** + physics interest[1])

data from setup 2 (no Fe55 source)

Higher statistics of the K-^{4}He L lines (L_α, L_β, L_γ)

Smaller statistics in shift, determination of width

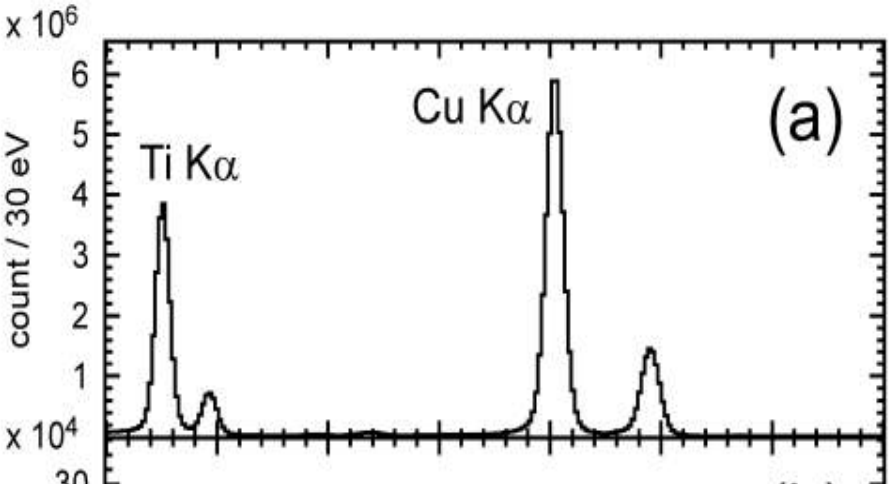
X-ray yield information in gas (for the first time)

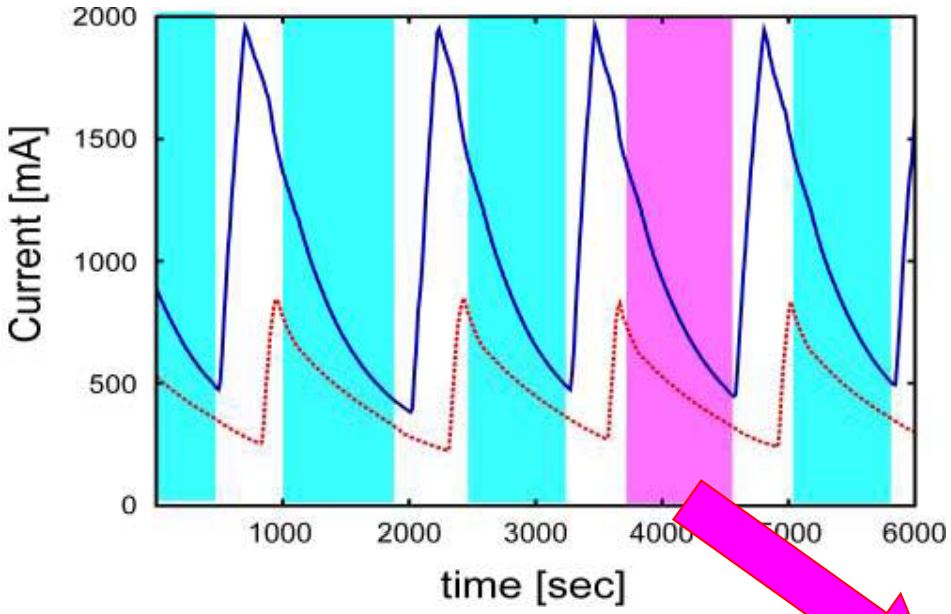


[1]) compare KEK E570 KHe L lines in liquid He, consistent result, first measurement in gas

Data taking at DAFNE -Calibration

Estimated systematic error ~ 3-4 eV





calibration data

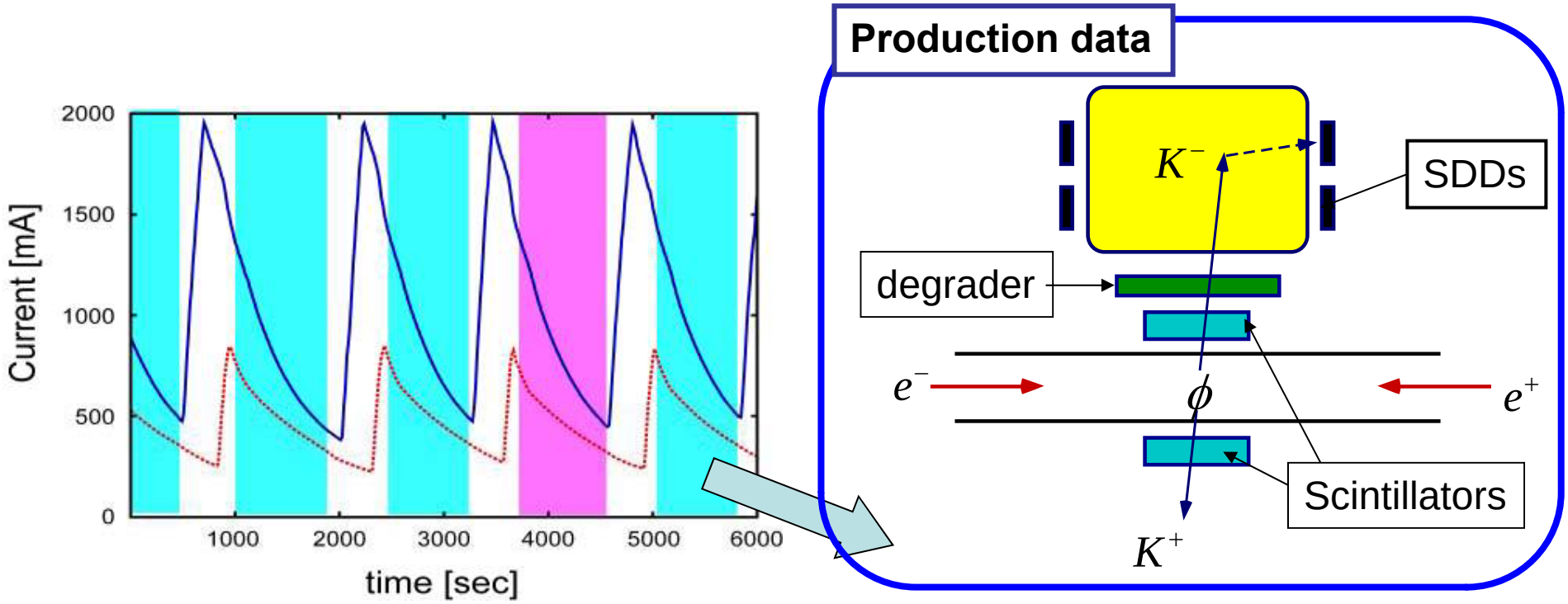
Ti/C

e^-

e^+

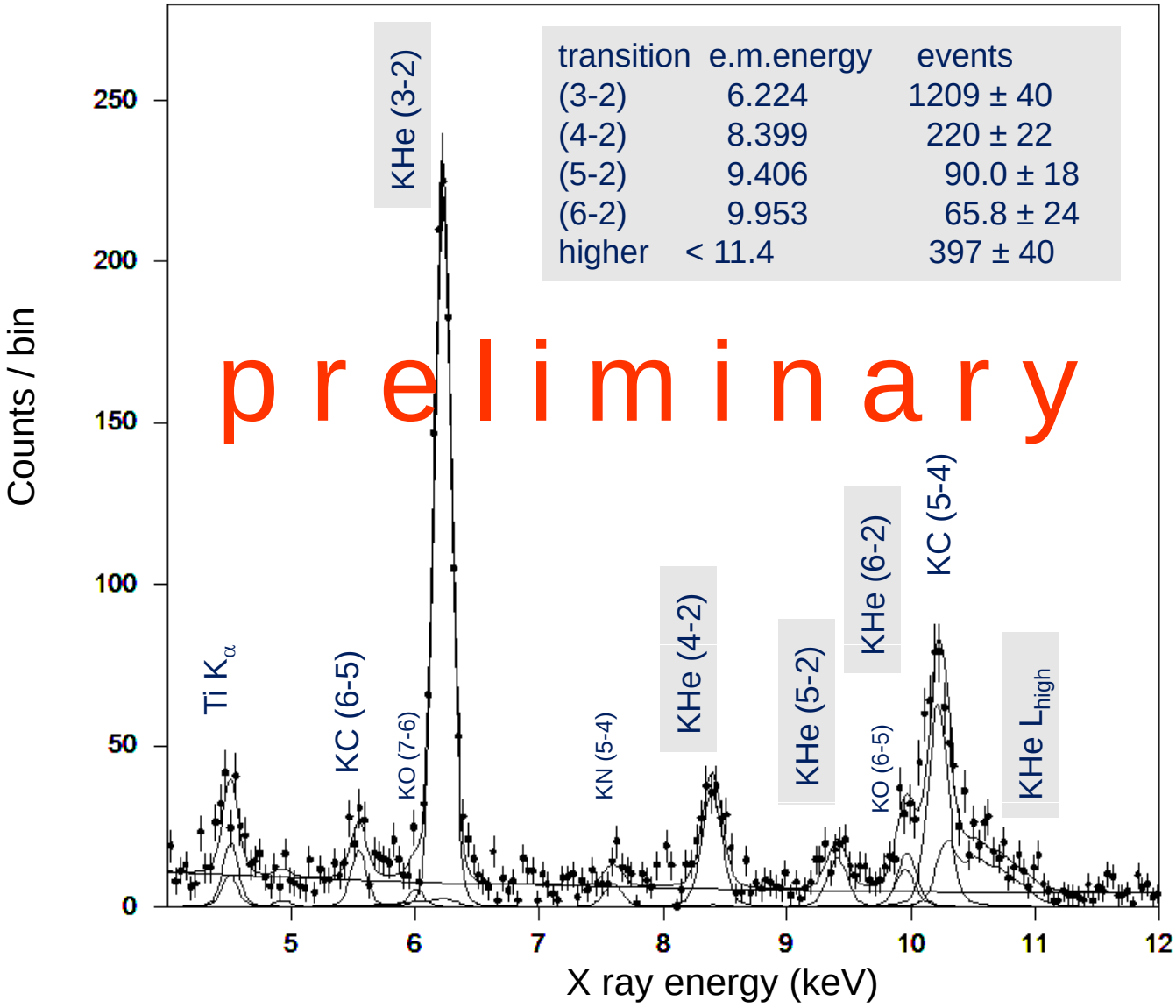
X-ray tube

Data taking at DAFNE - Production



Very preliminary K-^{3}He spectrum

KHe3
never measured
before !



The statistical error for the transition 3d→2p in K ^{3}He is less than 3 eV.

Comparison of results

Kaonic 4He 2p level shift

	Target	Shift [eV]
KEK E570	Liquid	+2±2±2 eV
SIDDHARTA (w/ 55Fe)	Gas	+0±6±2 eV
SIDDHARTA (New)	Gas	+5±3±4 eV

Kaonic 3He 2p level shift

	Target	Shift [eV]
SIDDHARTA	Gas	-2±2±4 eV
J-PARC E17	Liquid	planned

shift $\Delta E_{2p} = E_{\exp} - E_{e.m.}$ $\quad \Delta E_{2p} > 0$ ("attractive" *shift*),

$\Delta E_{2p} < 0$ ("repulsive" *shift*),

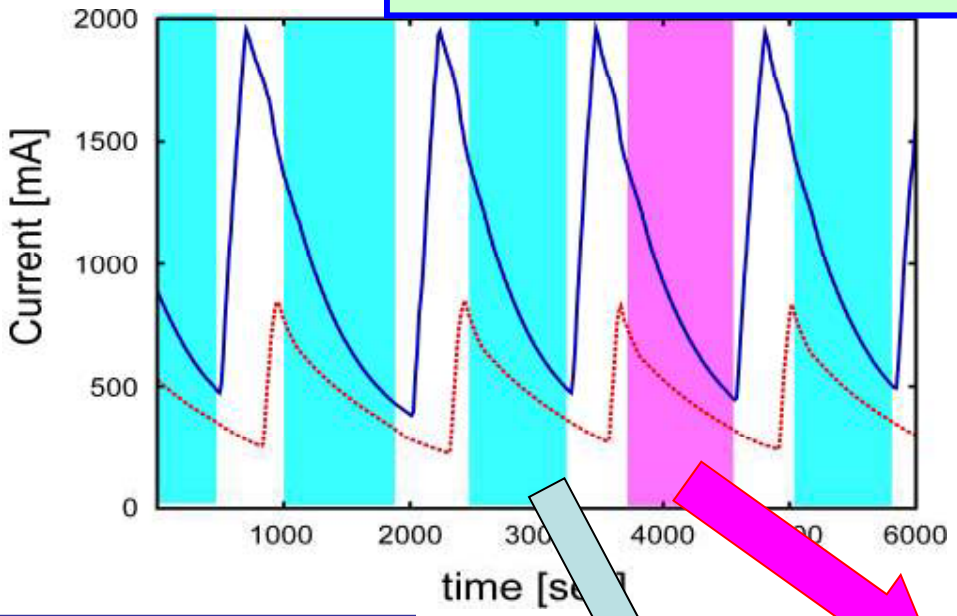
Conclusions (2)

Confirmed the small shift obtained by recent experiment E570 for **Kaonic ^{4}Helium**

The **"kaonic helium puzzle"** for **Kaonic ^{4}Helium** is now **solved**

The preliminary analysis of the **3d→2p transitions for Kaonic ^{3}Helium**, indicate that the **statistic error shift is less than 3 eV.**

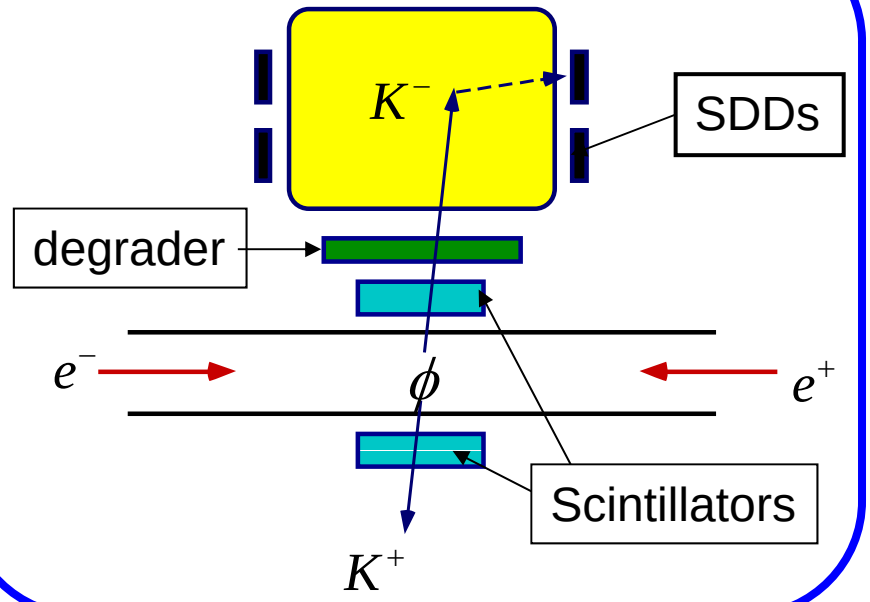
Data taking scheme at DAFNE



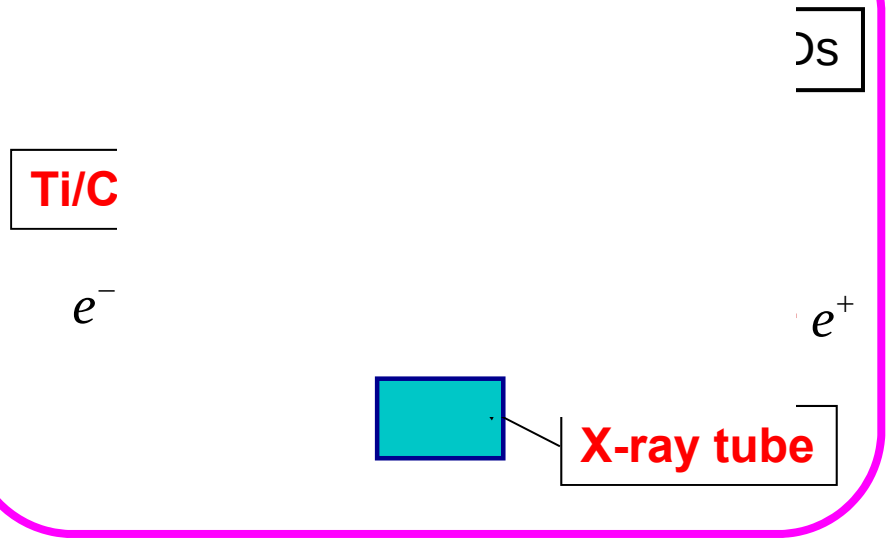
Instead of Fe source,
"X-ray tube" data taken

Estimated
systematic error ~ 5 eV

Production data



calibration data



Setup improvements during summer 2009 shutdown

- rebuilding of the sdds mounts: gain of solid angle of X ray detectors
- replacement of sdd modules: 144 cm^2 detectors operational
- new upper kaon detector: less material in vicinity of target, clean trigger
- improved shielding: new multimaterial and more narrow collimator