Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

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Advancements in Kaonic Atom Measurements: Insights from the SIDDHARTA-2 Experiment at the INFN-LNF DAΦNE Collider

Alessandro Scordo
on behalf of the SIDDHARTA-2 Collaboration,
Laboratori Nazionali di Frascati INFN

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Content

Kaonic atoms

KH and Kd physics case

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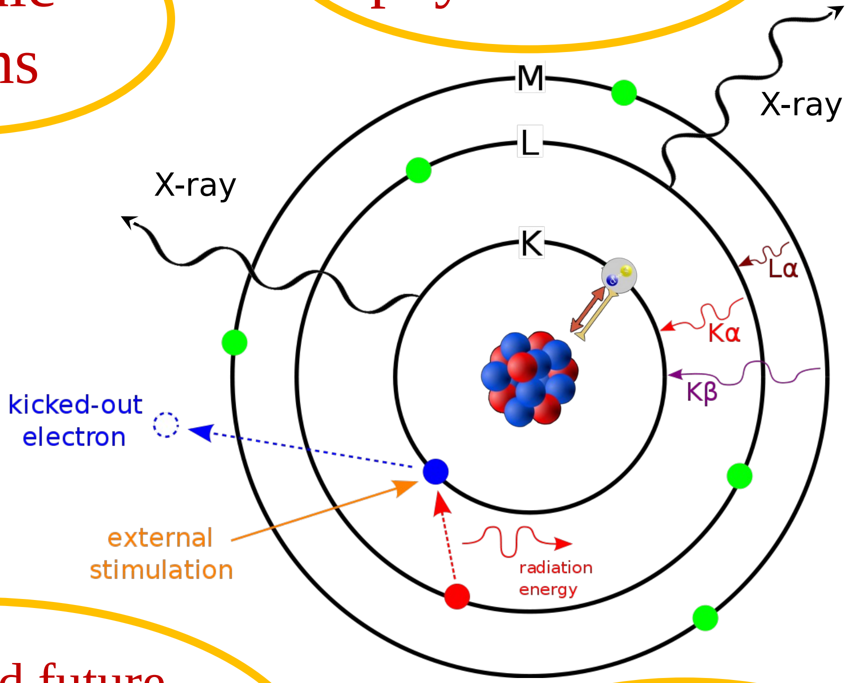
K^- mass puzzle

DAΦNE Φ-factory @ LNF

Present and future Kaonic atoms measurements @ DAΦNE

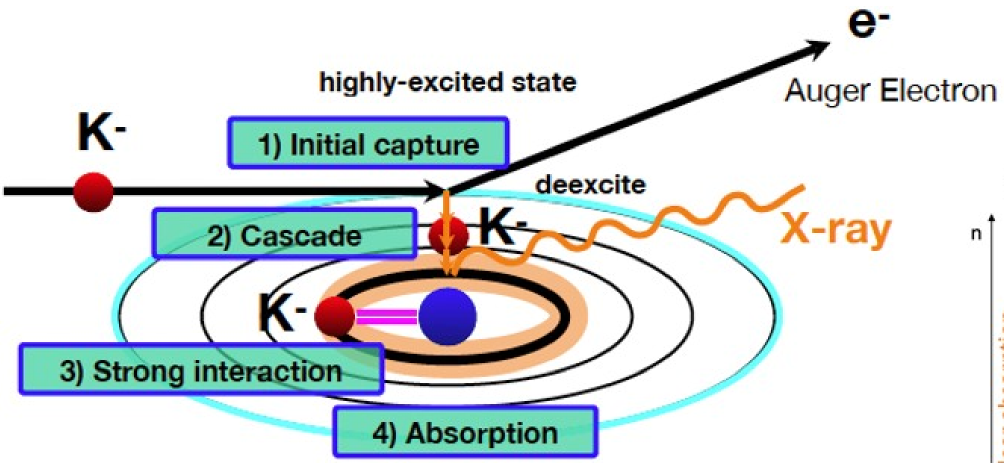


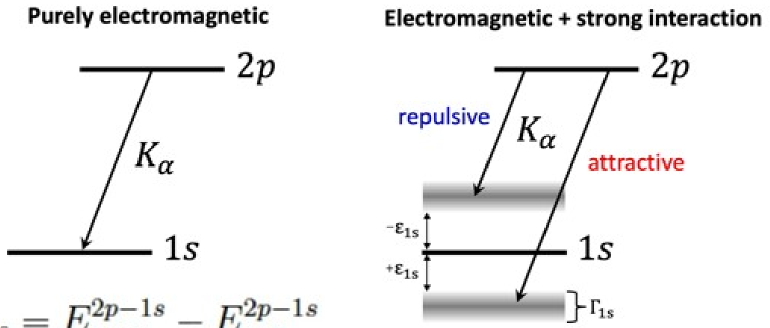
Kaonic atoms

KN(N) interaction AT REST (or at threshold) can't be investigated in collision experiments

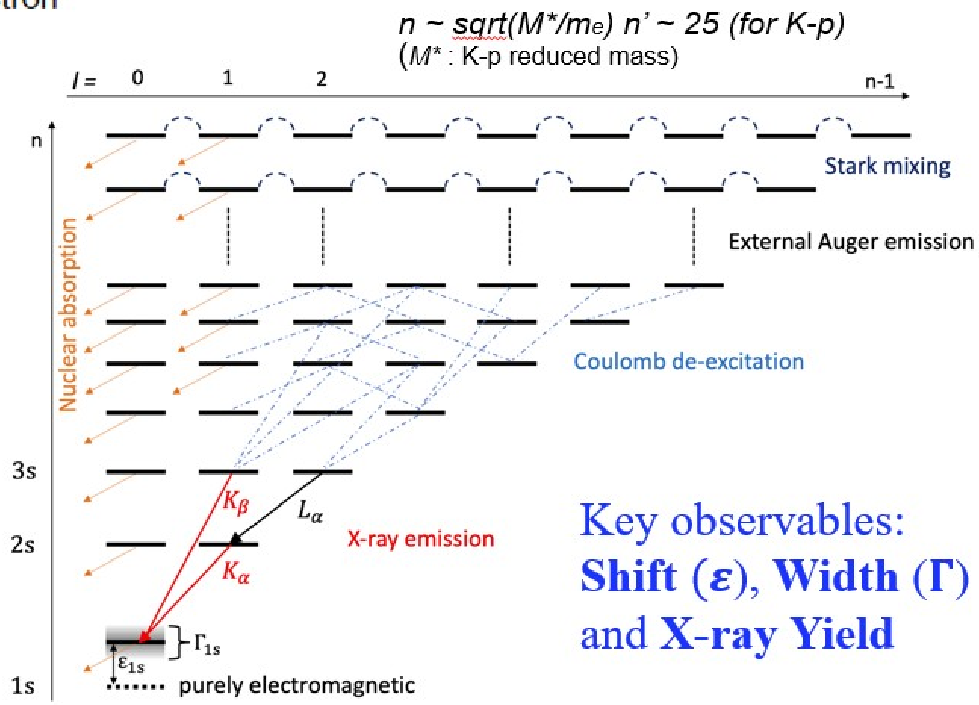
It can't be inferred by extrapolation at zero energy due to the presence of the Λ(1405?) resonance a few MeV below Kp threshold

How can we then obtain reliable information on low energy KN(N) interaction?





$$\varepsilon_{1s} = E^{2p-1s}_{\text{meas}} - E^{2p-1s}_{e.m.}$$



Key observables:
Shift (ε), Width (Γ)
and **X-ray Yield**

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KH and Kd cases

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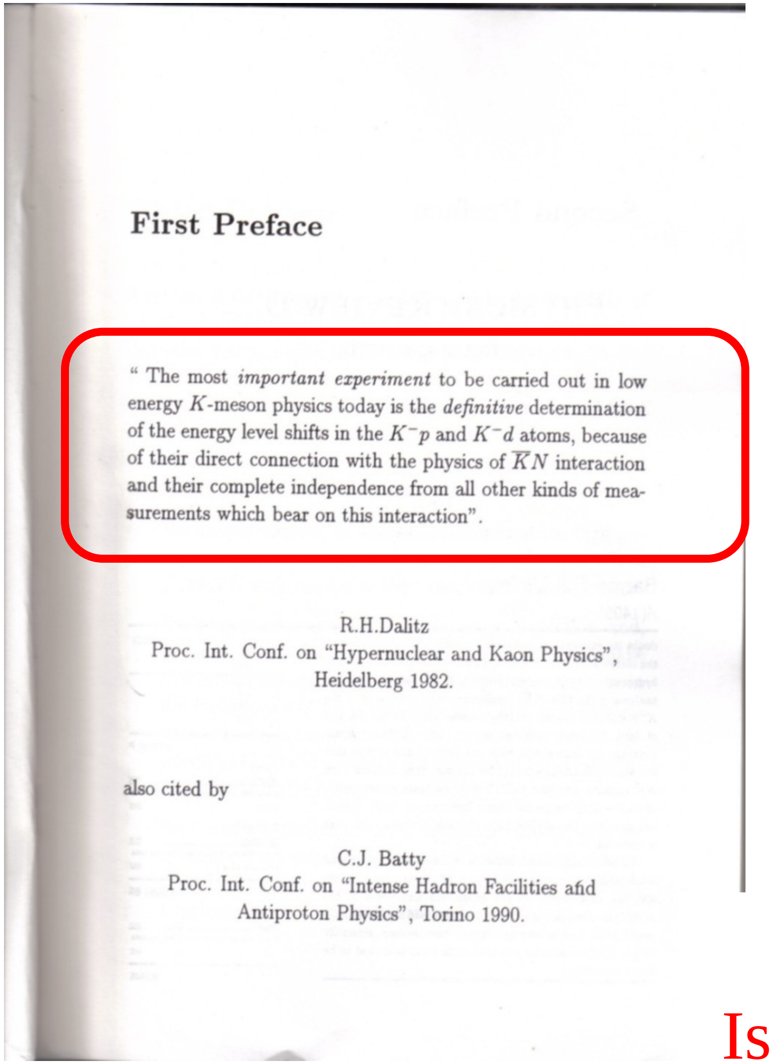


First Preface

" The most *important experiment* to be carried out in low energy K-meson physics today is the *definitive* determination of the energy level shifts in the K^-p and K^-d atoms, because of their direct connection with the physics of $\overline{K}N$ interaction and their complete independence from all other kinds of measurements which bear on this interaction".

R.H.Dalitz
Proc. Int. Conf. on "Hypernuclear and Kaon Physics",
Heidelberg 1982.

also cited by

C.J. Batty
Proc. Int. Conf. on "Intense Hadron Facilities and
Antiproton Physics", Torino 1990.

Combined analysis of the kaonic deuterium and kaonic hydrogen measurements

$$\left(\varepsilon_{1s} - \frac{i}{2}\Gamma_{1s}\right) = -2\alpha^3\mu_c^2 a_{K^-p}\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_{K^-p}\right)$$

(μ_c reduced mass of the K^-p system, α fine-structure constant)

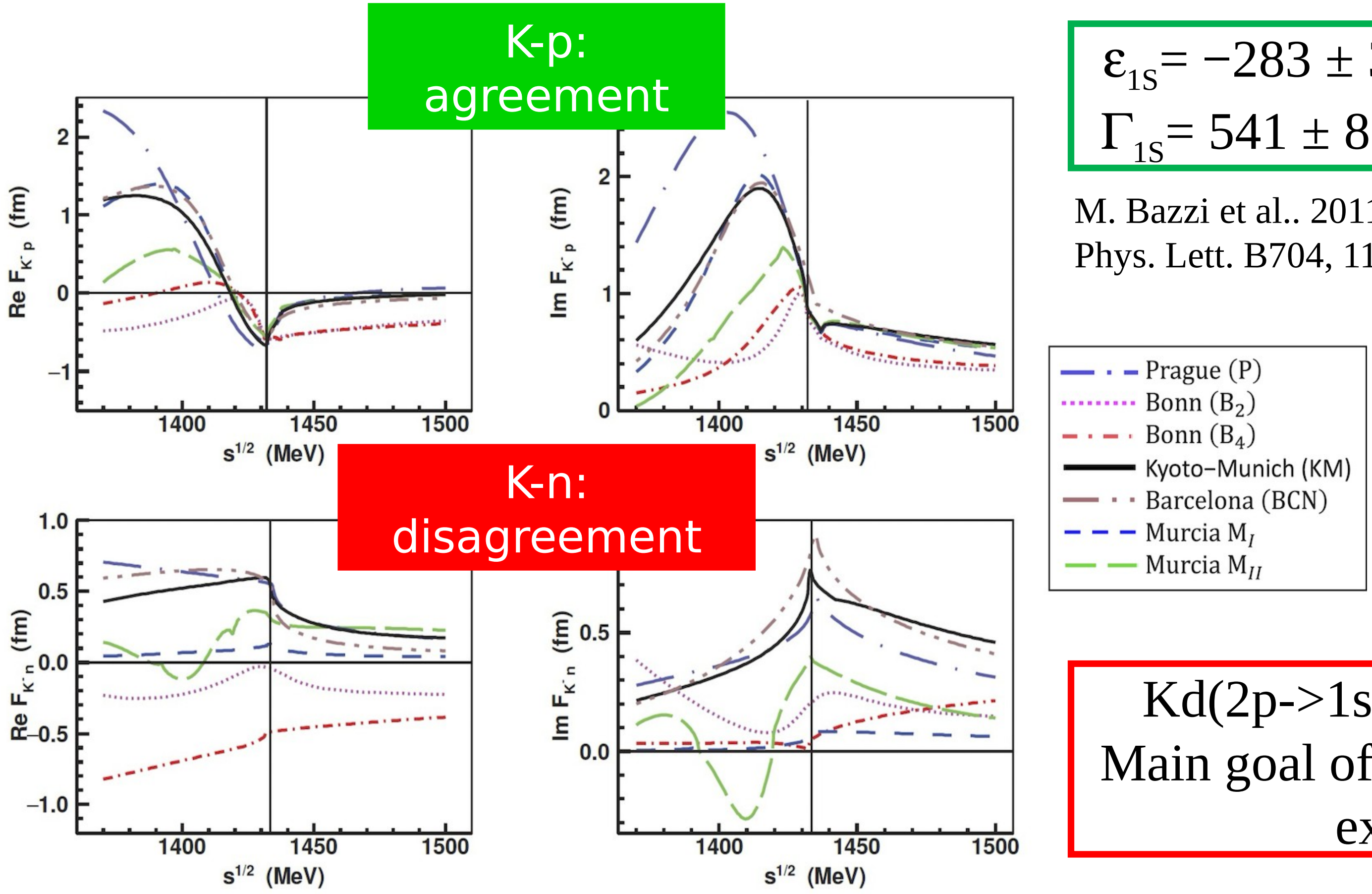
U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$
$$a_{K^-n} = a_1$$

$$a_{K^-d} = \frac{k}{2}\left[a_{K^-p} + a_{K^-n}\right] + C = \frac{k}{4}[a_0 + 3a_1] + C$$
$$k = \frac{4[m_n + m_K]}{[2m_n + m_K]}$$

Experimental determination of the Isospin-dependent K-N scattering length

KH and Kd cases



K-p:
agreement

K-n:
disagreement

$\varepsilon_{1S} = -283 \pm 36(\text{stat}) \pm 6(\text{syst})$ eV

$\Gamma_{1S} = 541 \pm 89(\text{stat}) \pm 22(\text{syst})$ eV

M. Bazzi et al.. 2011. (SIDDHARTA Coll.),
Phys. Lett. B704, 113

Kd(2p->1s) never measured:
Main goal of the SIDDHARTA-2 experiment

Ciepl y, A. et al. From KN interactions to K-nuclear quasi-bound states. AIP Conf. Proc. 2249, 030014 (2020).

Kaonic atoms state of art

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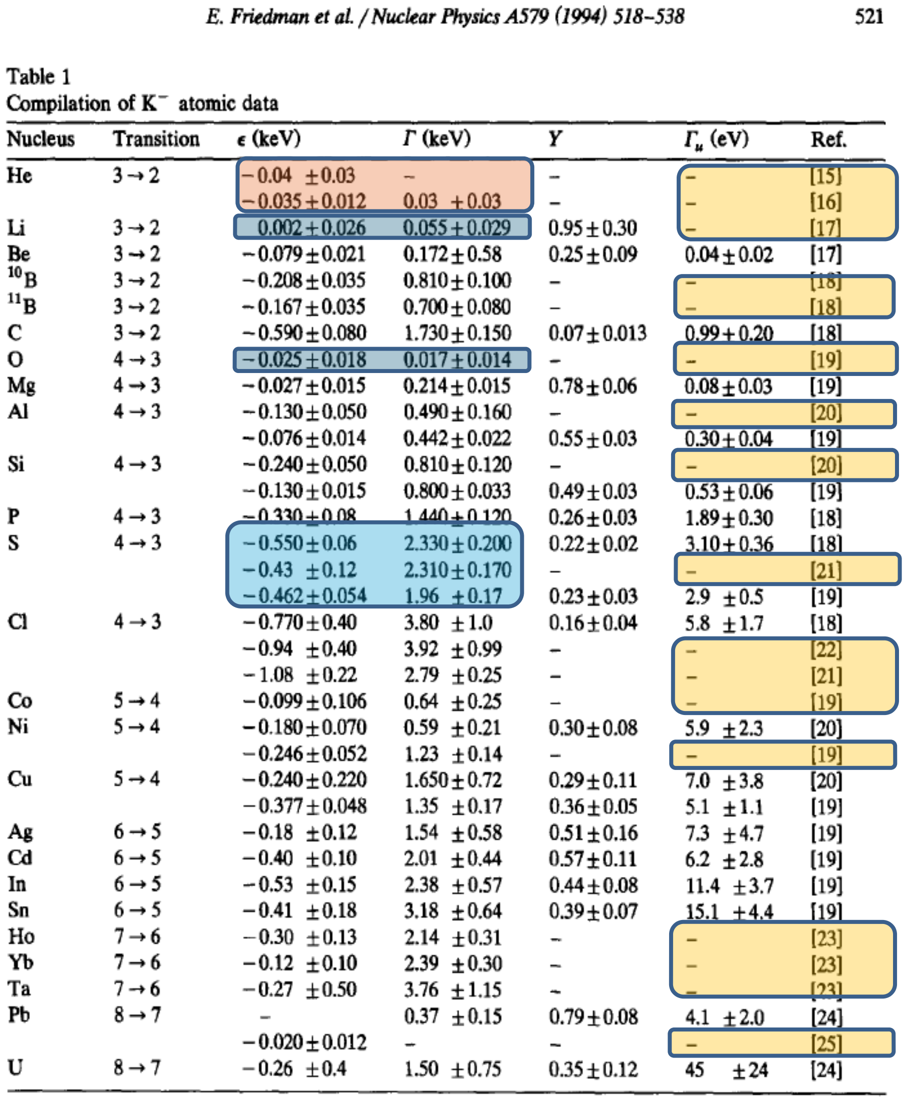

E. Friedman et al. / Nuclear Physics A579 (1994) 518–538 521

Table 1
Compilation of K^- atomic data

Nucleus	Transition	ϵ (keV)	Γ (keV)	Y	Γ_u (eV)	Ref.
He	3 → 2	−0.04 ± 0.03	–	–	–	[15]
		−0.035 ± 0.012	0.03 ± 0.03	–	–	[16]
Li	3 → 2	0.002 ± 0.026	0.055 ± 0.029	0.95 ± 0.30	–	[17]
Be	3 → 2	−0.079 ± 0.021	0.172 ± 0.58	0.25 ± 0.09	0.04 ± 0.02	[17]
^{10}B	3 → 2	−0.208 ± 0.035	0.810 ± 0.100	–	–	[18]
^{11}B	3 → 2	−0.167 ± 0.035	0.700 ± 0.080	–	–	[18]
C	3 → 2	−0.590 ± 0.080	1.730 ± 0.150	0.07 ± 0.013	0.99 ± 0.20	[18]
O	4 → 3	−0.025 ± 0.018	0.017 ± 0.014	–	–	[19]
Mg	4 → 3	−0.027 ± 0.015	0.214 ± 0.015	0.78 ± 0.06	0.08 ± 0.03	[19]
Al	4 → 3	−0.130 ± 0.050	0.490 ± 0.160	–	–	[20]
		−0.076 ± 0.014	0.442 ± 0.022	0.55 ± 0.03	0.30 ± 0.04	[19]
Si	4 → 3	−0.240 ± 0.050	0.810 ± 0.120	–	–	[20]
		−0.130 ± 0.015	0.800 ± 0.033	0.49 ± 0.03	0.53 ± 0.06	[19]
P	4 → 3	−0.330 ± 0.08	1.440 ± 0.120	0.26 ± 0.03	1.89 ± 0.30	[18]
S	4 → 3	−0.550 ± 0.06	2.330 ± 0.200	0.22 ± 0.02	3.10 ± 0.36	[18]
		−0.43 ± 0.12	2.310 ± 0.170	–	–	[21]
		−0.462 ± 0.054	1.96 ± 0.17	0.23 ± 0.03	2.9 ± 0.5	[19]
Cl	4 → 3	−0.770 ± 0.40	3.80 ± 1.0	0.16 ± 0.04	5.8 ± 1.7	[18]
		−0.94 ± 0.40	3.92 ± 0.99	–	–	[22]
		−1.08 ± 0.22	2.79 ± 0.25	–	–	[21]
Co	5 → 4	−0.099 ± 0.106	0.64 ± 0.25	–	–	[19]
Ni	5 → 4	−0.180 ± 0.070	0.59 ± 0.21	0.30 ± 0.08	5.9 ± 2.3	[20]
		−0.246 ± 0.052	1.23 ± 0.14	–	–	[19]
Cu	5 → 4	−0.240 ± 0.220	1.650 ± 0.72	0.29 ± 0.11	7.0 ± 3.8	[20]
		−0.377 ± 0.048	1.35 ± 0.17	0.36 ± 0.05	5.1 ± 1.1	[19]
Ag	6 → 5	−0.18 ± 0.12	1.54 ± 0.58	0.51 ± 0.16	7.3 ± 4.7	[19]
Cd	6 → 5	−0.40 ± 0.10	2.01 ± 0.44	0.57 ± 0.11	6.2 ± 2.8	[19]
In	6 → 5	−0.53 ± 0.15	2.38 ± 0.57	0.44 ± 0.08	11.4 ± 3.7	[19]
Sn	6 → 5	−0.41 ± 0.18	3.18 ± 0.64	0.39 ± 0.07	15.1 ± 4.4	[19]
Ho	7 → 6	−0.30 ± 0.13	2.14 ± 0.31	–	–	[23]
Yb	7 → 6	−0.12 ± 0.10	2.39 ± 0.30	–	–	[23]
Ta	7 → 6	−0.27 ± 0.50	3.76 ± 1.15	–	–	[23]
Pb	8 → 7	–	0.37 ± 0.15	0.79 ± 0.08	4.1 ± 2.0	[24]
		−0.020 ± 0.012	–	–	–	[25]
U	8 → 7	−0.26 ± 0.4	1.50 ± 0.75	0.35 ± 0.12	45 ± 24	[24]

New measurements of Kaonic Helium not confirming the old ones

Many of the available data on “lower levels” have big uncertainties

Some widhts are actually UNmeasured

Many of them are hardly compatible among each other
(Sulfur “puzzle”)

Relative yields with upper levels are not always measured

Absolute yields are basically unknown
(except for few transitions)

New measurements
(with improved precisions)
are important to be performed

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The K^- mass problem

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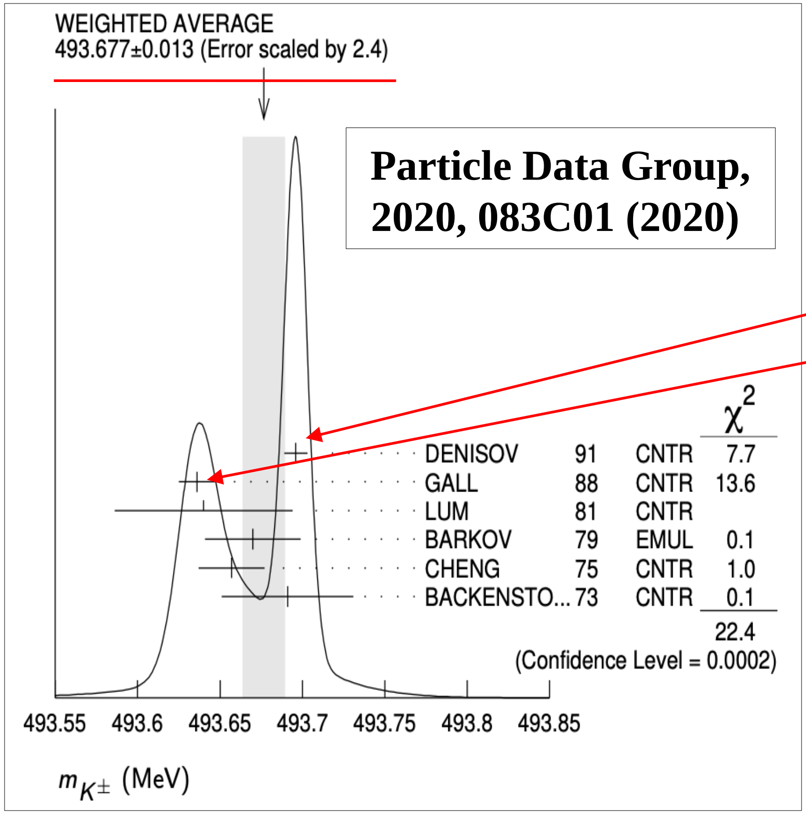
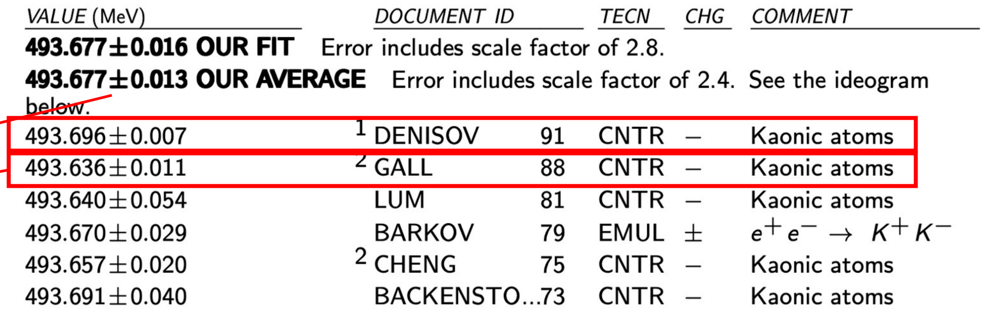


Particle Data Group, 2020, 083C01 (2020)

Large uncertainty 26 p.p.m,
compared to charged pion:
MeV, 1.6 p.p.m



VALUE (MeV)	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
493.677±0.016 OUR FIT Error includes scale factor of 2.8.				
493.677±0.013 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.				
493.696±0.007	[1] DENISOV 91	CNTR	−	Kaonic atoms
493.636±0.011	[2] GALL 88	CNTR	−	Kaonic atoms
493.640±0.054	LUM 81	CNTR	−	Kaonic atoms
493.670±0.029	BARKOV 79	EMUL	±	$e^+e^- \rightarrow K^+K^-$
493.657±0.020	[2] CHENG 75	CNTR	−	Kaonic atoms
493.691±0.040	BACKENSTO...73	CNTR	−	Kaonic atoms

60 keV discrepancy between the two most accurate measurements

Kaon mass precision is still a crucial open issue in strangeness nuclear physics

Kaon mass puzzle can be addressed with HPGe detectors on solid targets (to repeat GALL KPb measurement)

Kaon mass puzzle can be addressed with SDD detectors on gaseous targets (attempt with KNe transitions)

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DAΦNE @ LNF

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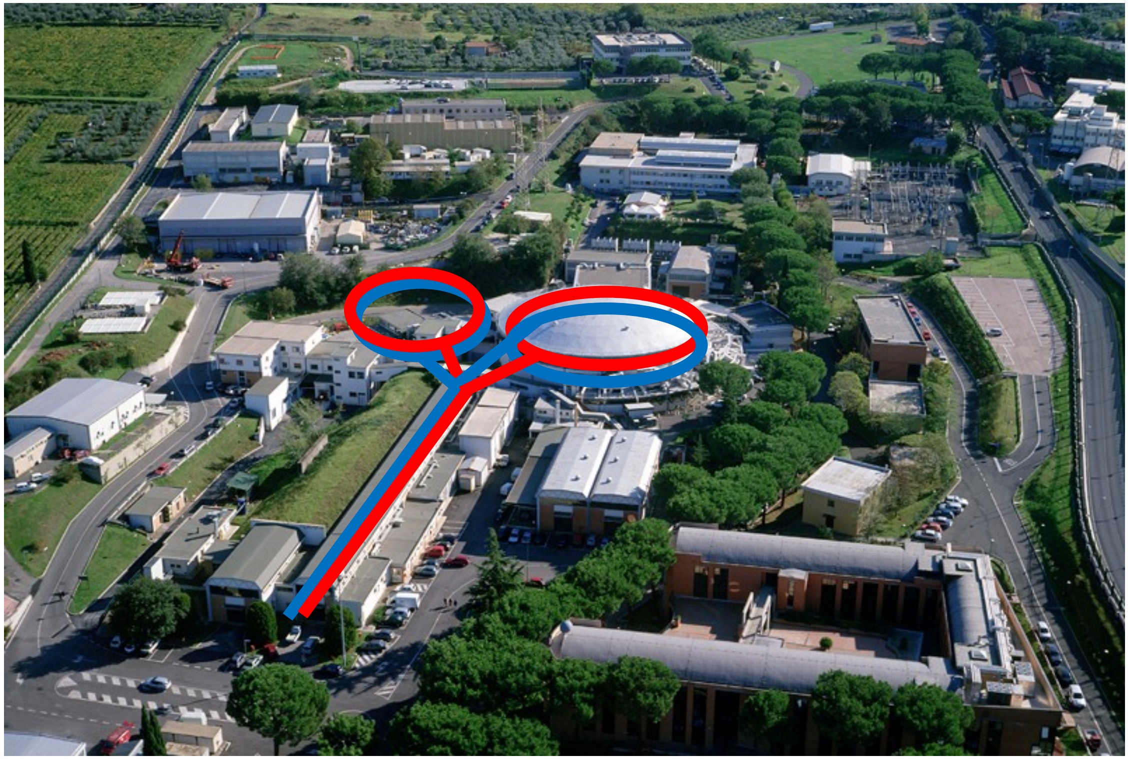
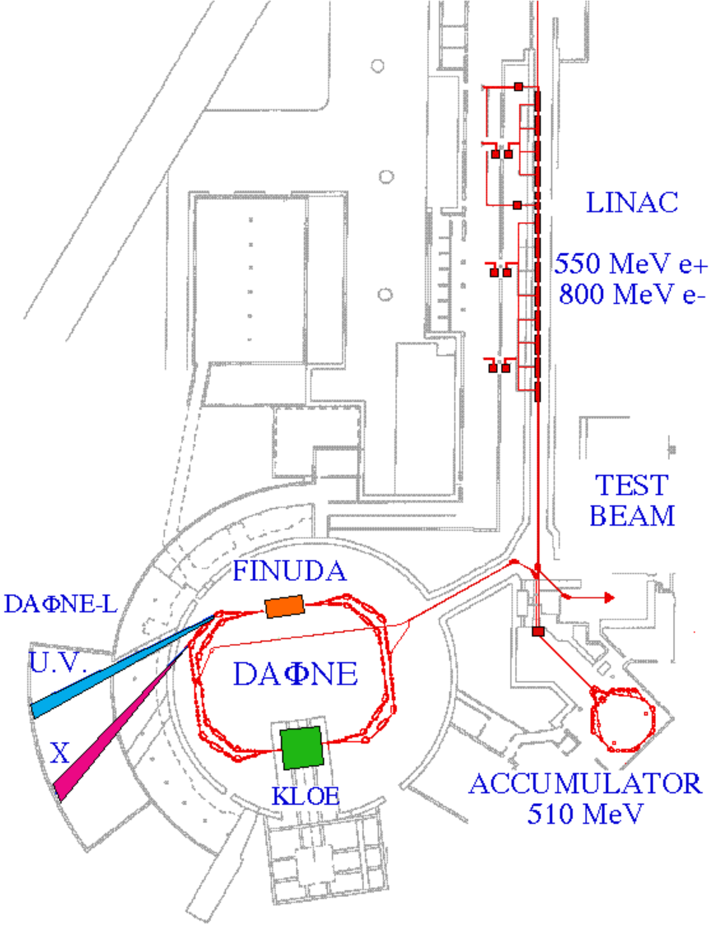
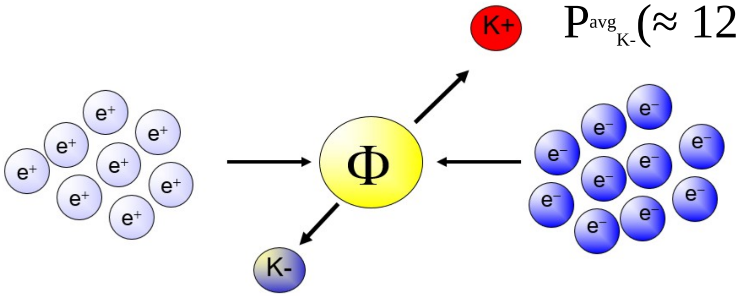


Frascati Φ–Factory complex



P^{avg}_{K-}(≈ 127 MeV)



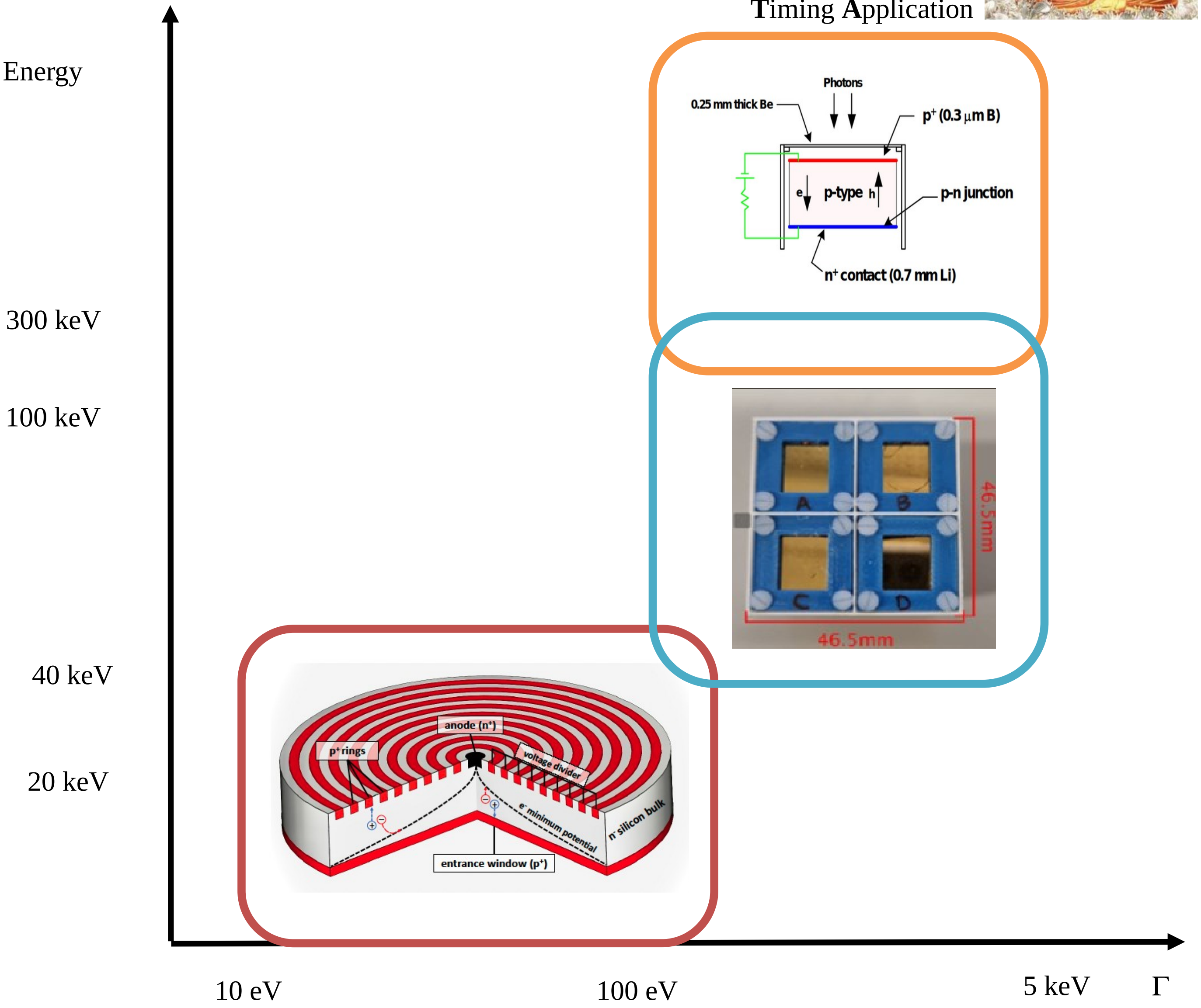
B.R ($\phi \rightarrow K^+ K^-$) = 48,9 %

Transitions: energies and widths. which detector?

SDDs
- 100 eV max resolution
- 4-40 keV range
- High efficiency

Cd(Zn)Te
- 20-300 keV range
- FWHM / E ~ %
- High efficiency
- Room Temperature

HPGe
- 100-1000 keV range
- FWHM / E ~ %
- High efficiency
- Cooling needed



K^{4}He measurement with SDDs

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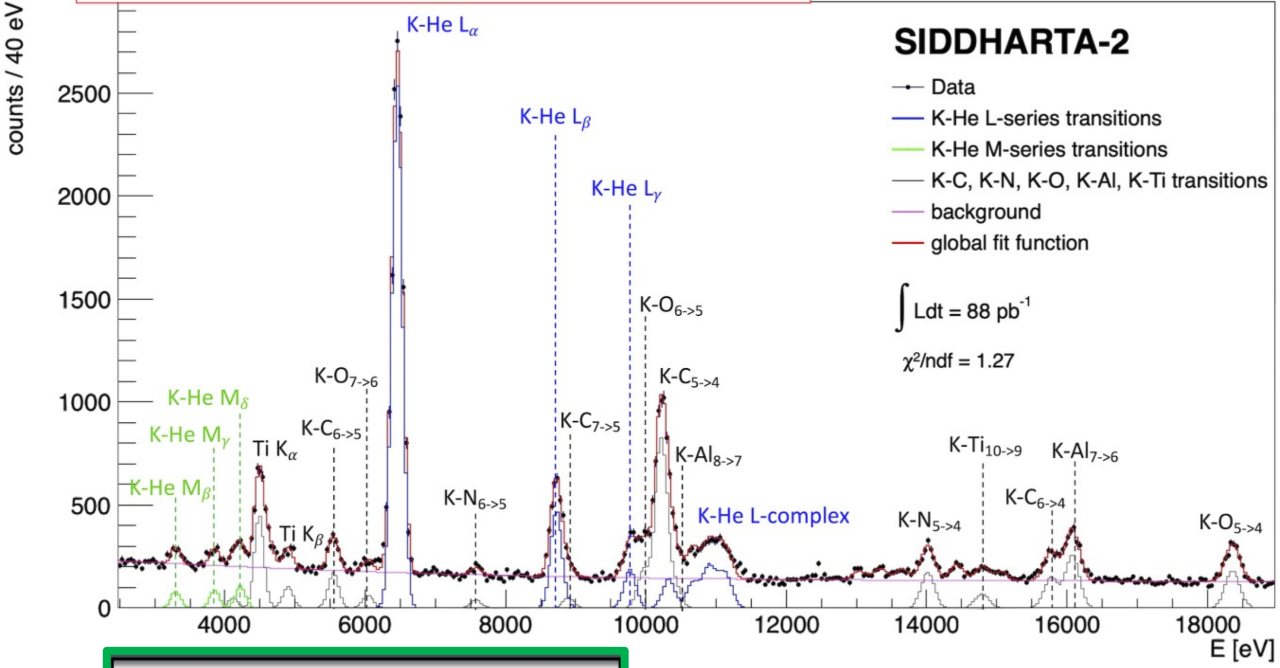
- Most precise measurement of kaonic helium-4 L in gas: 2p level energy shift and width
- First observation of kaonic helium-4 M-series transition (n3d)

$$\varepsilon_{2p} = E^{\mathrm{exp}}_{3d\to 2p} - E^{\mathrm{e.m}}_{3d\to 2p} = -1.9 \pm 0.8\,(\mathrm{stat}) \pm 2.0\,(\mathrm{sys})\ \mathrm{eV}$$

$$\Gamma_{2p} = 0.01 \pm 1.60\,(\mathrm{stat}) \pm 0.36\,(\mathrm{sys})\ \mathrm{eV}$$

- ***no sharp effect of the strong interaction on the 2p level***



First measurement of
K-^{4}He M-series transition

K^4He measurement with SDDs

New experimental data for cascade models calculations
The X-ray yield is the key observable to understand the de-excitation mechanism in kaonic atoms and develop more accurate models.

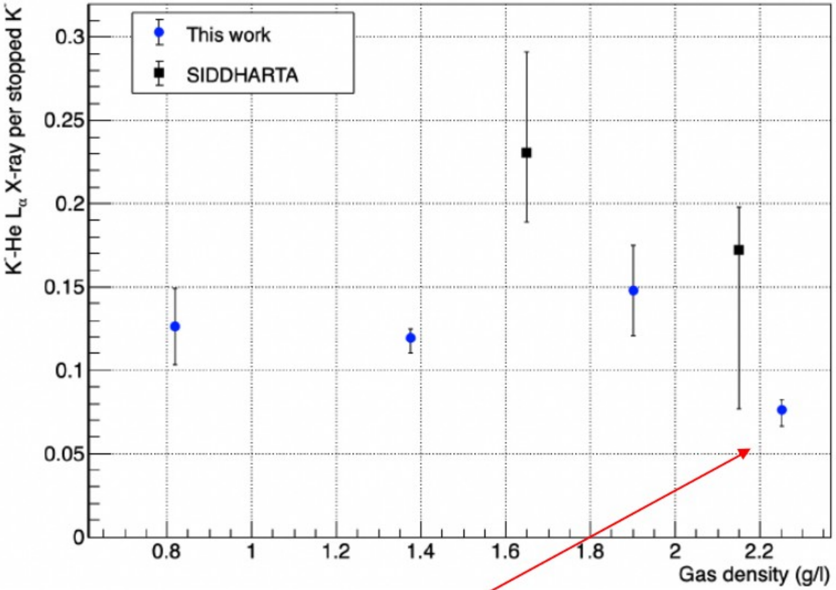
First measurement of
K-^{4}He M-series transition

Density	1.37 ± 0.07 g/l
L_α yield	$0.119 \pm 0.002\,(\text{stat})^{+0.006\,(\text{syst})}_{-0.009\,(\text{syst})}$
M_β yield	$0.026 \pm 0.003\,(\text{stat})^{+0.010\,(\text{syst})}_{-0.001\,(\text{syst})}$
L_β / L_α	$0.172 \pm 0.008\,(\text{stat})$
L_γ / L_α	$0.012 \pm 0.001\,(\text{stat})$
M_β / L_α	$0.218 \pm 0.029\,(\text{stat})$
M_γ / M_β	$0.48 \pm 0.11\,(\text{stat})$
M_δ / M_β	$0.43 \pm 0.12\,(\text{stat})$

Sgaramella F., et al, 2024, *J. Phys. G: Nucl. Part. Phys.* 51 055103

Sirghi D.L., Shi H., Guaraldo C., Sgaramella F., et al., 2023, Nucl. Phys. A,1029 122567

Study of yield density dependence
for the K-^{4}He L transition



First observation of the stark effect in kaonic helium-4

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The VETO-1 system for signal identification

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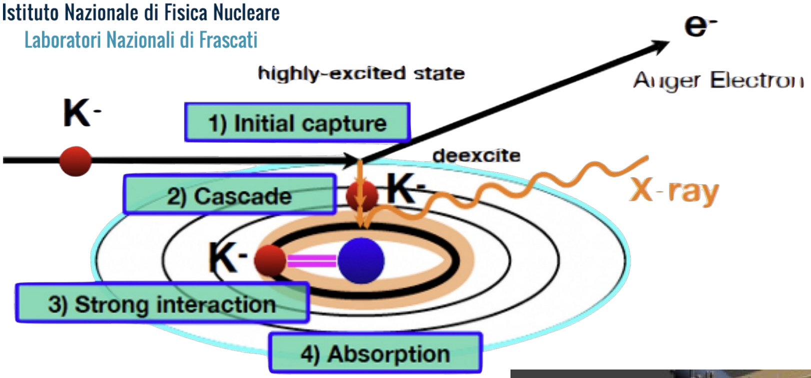
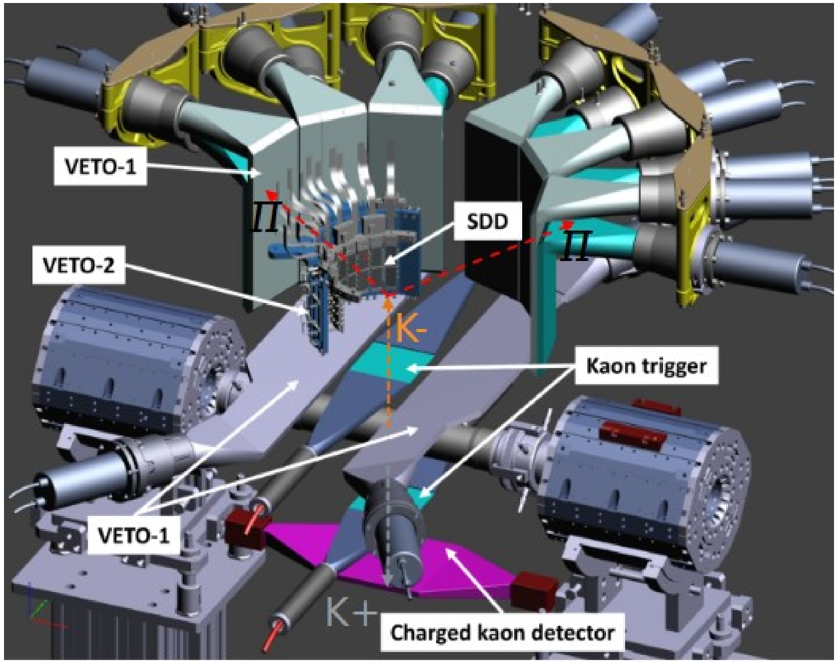


	SIDDHARTA-2 Veto-1 reduction factor	Monte Carlo Veto-1 reduction factor
K-^{4}He L_α	$(8 \pm 1)\%$	4%
K-$C_{5\to4}$	$(48 \pm 4)\%$	44%

SIDDHARTA-2 is equipped with a VETO system that measure the arrival time of charged particles produced after the K$^-$ absorption.

It can be used to asses if a K$^-$ is stopped in a solid or gaseous target



The VETO-1 system takes advantage of the difference of the moderation time of the K- between solid and gaseous targets

The VETO-1 system for signal identification

	SIDDHARTA-2 Veto-1 reduction factor	Monte Carlo Veto-1 reduction factor
K-^{4}He L$_\alpha$	(8 ± 1)%	4%
K-C$_{5\to4}$	(48 ± 4)%	44%

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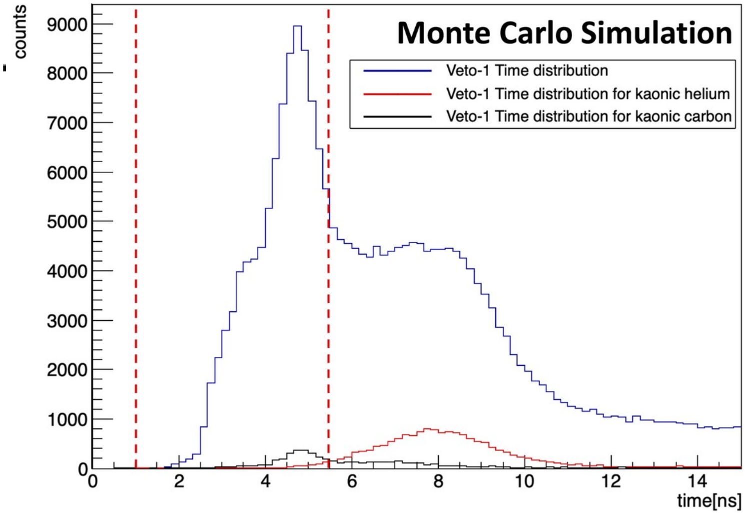
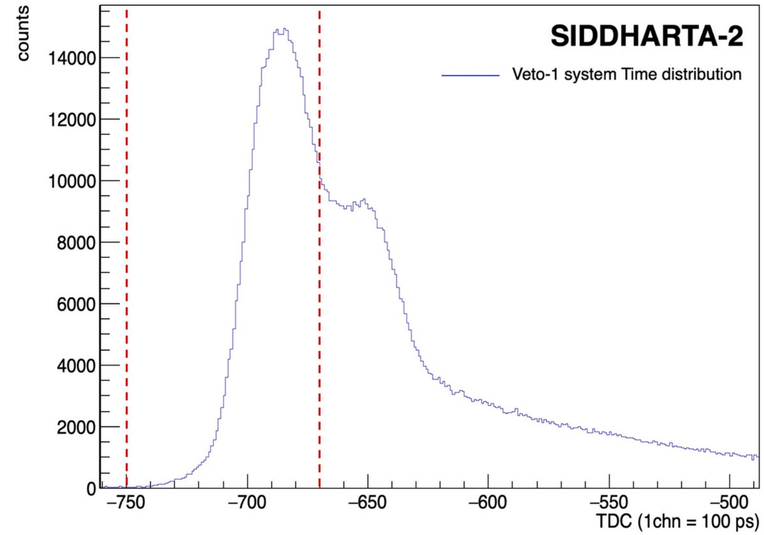
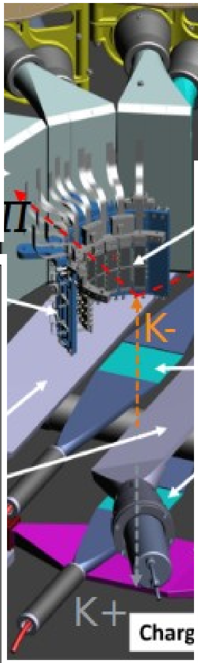
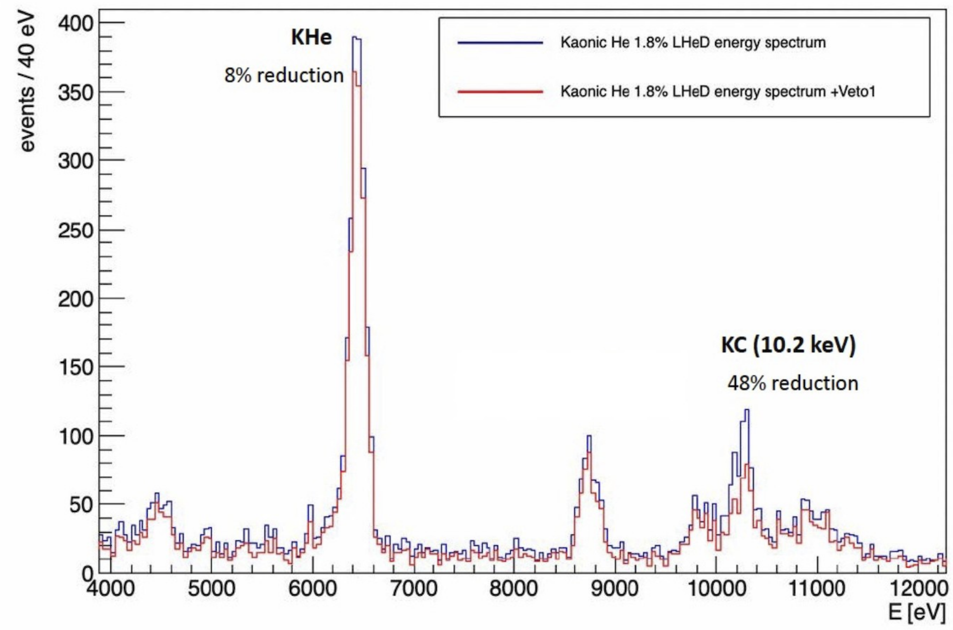


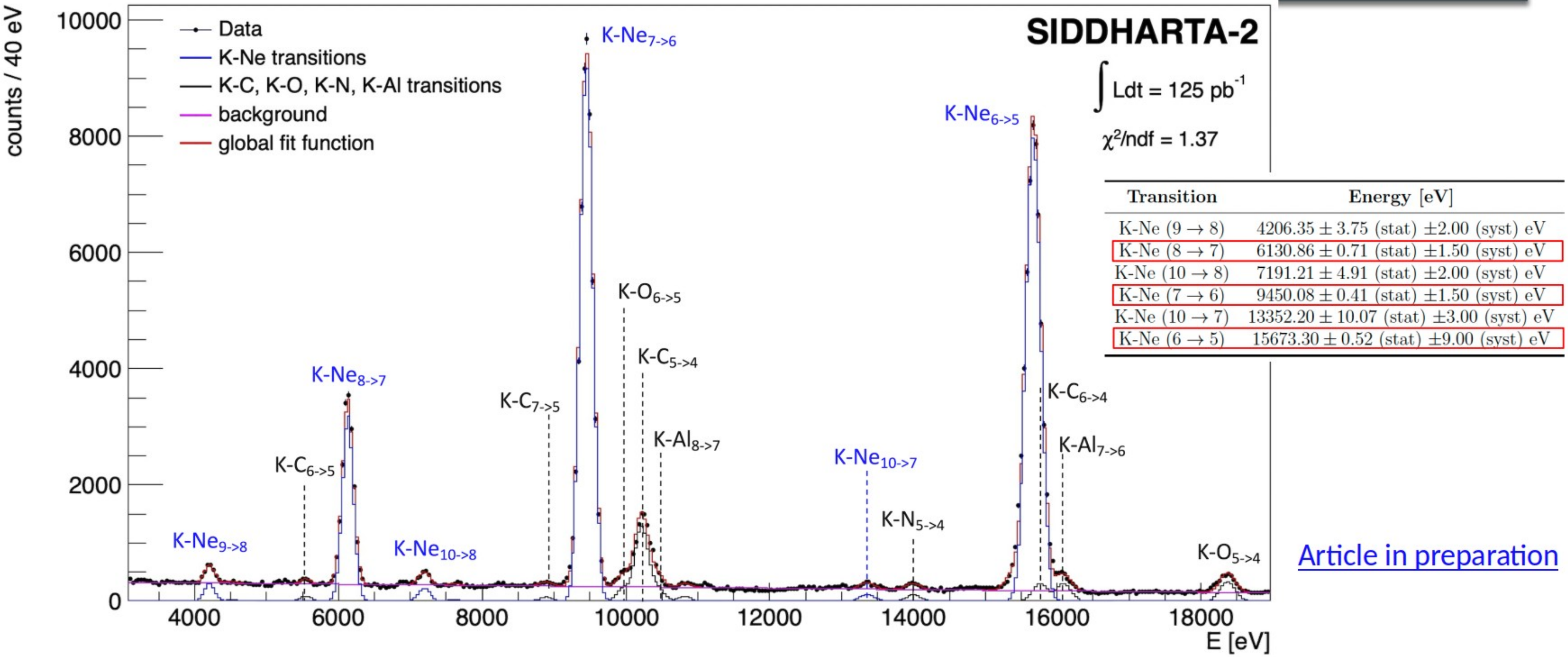






KNe measurement with SDDs

First measurement of kaonic neon X-ray transitions (sub eV statistical accuracy)



Transition	Energy [eV]
K-Ne (9 → 8)	4206.35 ± 3.75 (stat) ±2.00 (syst) eV
K-Ne (8 → 7)	6130.86 ± 0.71 (stat) ±1.50 (syst) eV
K-Ne (10 → 8)	7191.21 ± 4.91 (stat) ±2.00 (syst) eV
K-Ne (7 → 6)	9450.08 ± 0.41 (stat) ±1.50 (syst) eV
K-Ne (10 → 7)	13352.20 ± 10.07 (stat) ±3.00 (syst) eV
K-Ne (6 → 5)	15673.30 ± 0.52 (stat) ±9.00 (syst) eV

Article in preparation

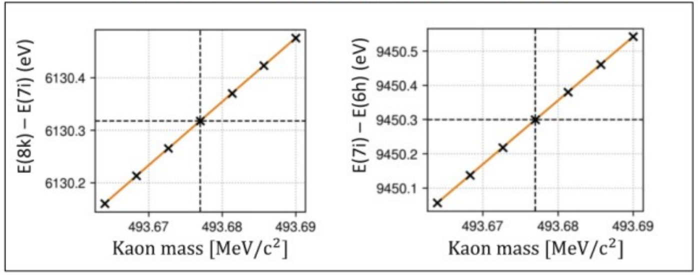
m_{K^-} with KNe

The measurement of kaonic neon high-n transitions can potentially solve the charged kaon mass puzzle

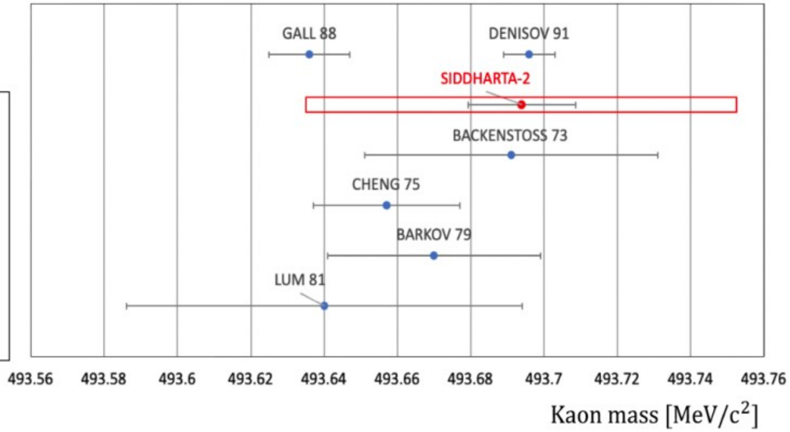
The kaonic Neon measurement to determine the K^- (K^+) mass

Less/different systematic uncertainty with respect to DENISOV 91 and GALL 88 measurements, thanks to the use of a low Z gas target

Kaonic Ne energy transition as function of kaon mass (MCDFGME code)



Santos, J. & Parente, F. & Indelicato, Paul & Desclaux, J.. (2005). X-ray energies of circular transitions and electron screening in kaonic atoms. Physical Review A. 71.10.1103/PhysRevA.71.032501.



$$K-Ne(8\rightarrow 7)=\frac{A_G}{\sqrt{2\pi\sigma}}\cdot e^{\frac{-(E-E_0)^2}{2\sigma^2}} \quad E_0=(m_{8\rightarrow 7}\cdot K_{mass}+q_{8\rightarrow 7})$$

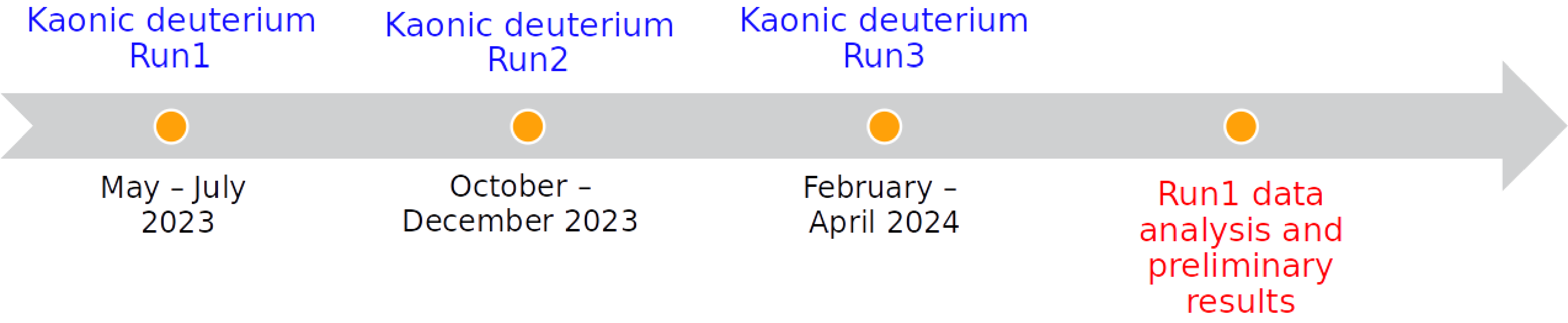
$$K-Ne(7\rightarrow 6)=\frac{A_G}{\sqrt{2\pi\sigma}}\cdot e^{\frac{-(E-E_0)^2}{2\sigma^2}} \quad E_0=(m_{7\rightarrow 6}\cdot K_{mass}+q_{7\rightarrow 6})$$

Measurement	Kaon mass [MeV]
DENISOV 91 [23]	493.696 ± 0.007
GALL 88 [22]	493.636 ± 0.011
LUM 81 [114]	493.640 ± 0.054
BARKOV 79 [115]	493.670 ± 0.029
CHENG 75 [116]	493.657 ± 0.020
BACKENSTOSS 73 [117]	493.691 ± 0.040
This work	493.694 ± 0.015 (stat) ± 0.060 (syst)

Kd (2p->1s) measurement with SDDs

The SIDDHARTA-2 collaboration aims **to perform the first measurement of the strong interaction induced energy shift and width of the kaonic deuterium ground state with similar precision as K-p !**

- **First run** with SIDDHARTA-2 optimized setup for **200 pb^{-1}** integrated luminosity: May – July 2023
- **Second run** - October – December 2023: **344 pb^{-1}**
- **Third run** 2024 - February – April 2024: **435 pb^{-1}**



Kaonic deuterium
Run1

May – July
2023

Kaonic deuterium
Run2

October –
December 2023

Kaonic deuterium
Run3

February –
April 2024

Run1 data
analysis and
preliminary
results

Kd (2p->1s) measurement with SDDs

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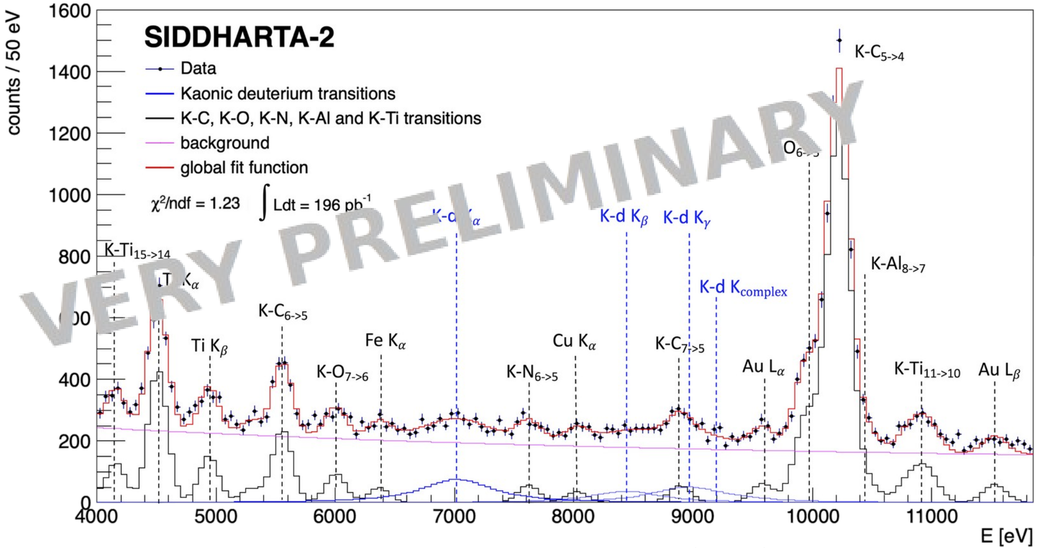


$$f = pol_1(E) + \exp(E) + \sum_i \mathrm{Gauss}(A_{Gi}, E_i, \sigma) + \mathrm{Tail}(A_{Ti}, E_i, \beta, \sigma) +$$

$$A_{\mathrm{Kd}_{2\to1}} \cdot \mathrm{Voigt}(E_{2\to1}, \sigma, \Gamma_{1s}) +$$

$$A_{\mathrm{Kd}_{4\to1}} \cdot A_{rel_{3\to1}} \cdot \mathrm{Voigt}(E^{e.m.}_{3\to1} + \varepsilon^*_{1s}, \sigma, \Gamma^*_{1s}) +$$

$$A_{\mathrm{Kd}_{4\to1}} \cdot \mathrm{Voigt}(E^{e.m.}_{4\to1} + \varepsilon^*_{1s}, \sigma, \Gamma^*_{1s}) +$$

$$A_{\mathrm{Kd}_{4\to1}} \cdot A_{rel_{5\to1}} \cdot \mathrm{Voigt}(E^{e.m.}_{5\to1} + \varepsilon^*_{1s}, \sigma, \Gamma^*_{1s}) +$$

$$A_{\mathrm{Kd}_{4\to1}} \cdot A_{rel_{6\to1}} \cdot \mathrm{Voigt}(E^{e.m.}_{6\to1} + \varepsilon^*_{1s}, \sigma, \Gamma^*_{1s}) +$$

$$A_{\mathrm{Kd}_{4\to1}} \cdot A_{rel_{7\to1}} \cdot \mathrm{Voigt}(E^{e.m.}_{7\to1} + \varepsilon^*_{1s}, \sigma, \Gamma^*_{1s})$$

$$L(E) = \frac{1}{\pi} \frac{\frac{1}{2}\Gamma}{(E - E_0)^2 + (\frac{1}{2}\Gamma)^2}$$

From 2p->1s transition (Kα):

ε_{1s}: -816 ± 53 (stat) ± 2(syst) eV
Γ_{1s}: 756 ± 271 (stat)

From (n>2)->1s transition:

ε_{1s}: -813 ± 56 (stat) ± 2(syst) eV
Γ_{1s}: 751 ± 280 (stat)

Are we sure that the signal comes from the gaseous D_2 target?

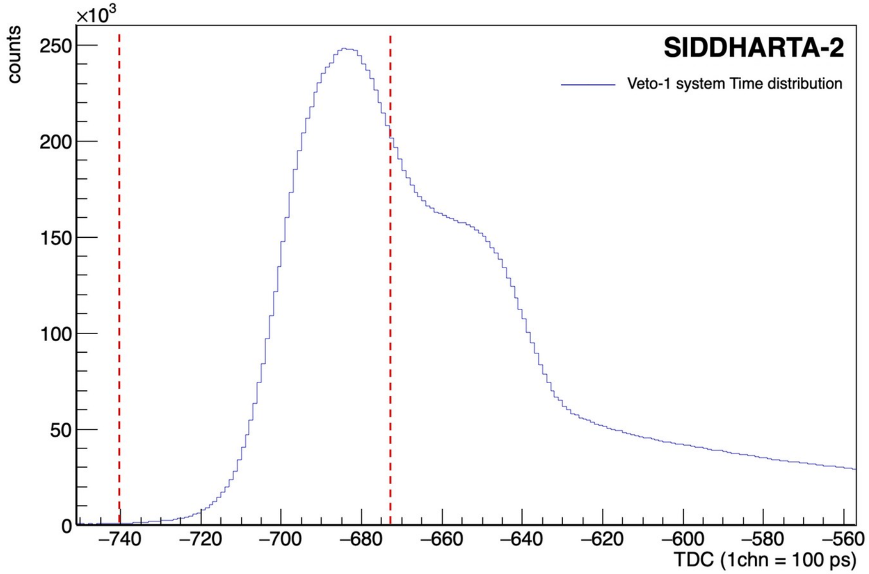
"The **most important experiment to be carried out in low energy K-meson physics today** is the **definitive determination of the energy level shifts in the K−p and K−d atoms**, because of their direct connection with the physics of N interaction and their complete independence from all other kinds of measurements which bear on this interaction".

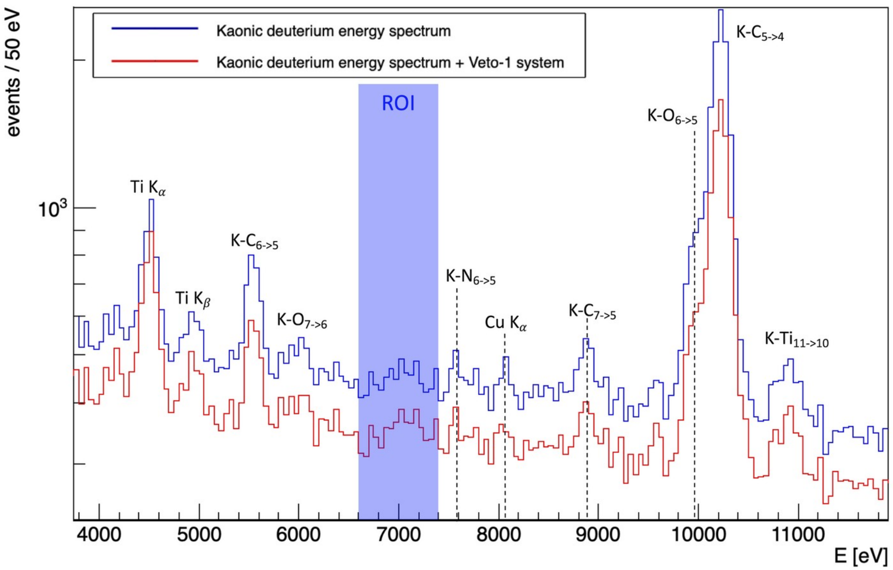
R.H. Dalitz (1982)

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Kd (2p->1s) measurement

SIlicon **D**rift
Detectors for
HAdronic **A**tom
Research by
Timing **A**pplication





	SIDDHARTA-2 Veto-1 reduction factor	Monte Carlo Veto-1 reduction fact
K-d K_α	$(11 \pm 3)\%$	4%
K-$C_{5\to4}$	$(44 \pm 4)\%$	46%
K-$C_{6\to5}$	$(39 \pm 5)\%$	45%
K-$C_{7\to5}$	$(48 \pm 4)\%$	46%

	SIDDHARTA-2 Veto-1 reduction factor	Monte Carlo Veto-1 reduction factor
K-^{4}He L_α	$(8 \pm 1)\%$	4%
K-$C_{5\to4}$	$(48 \pm 4)\%$	44%

Signals in the ROI are actually produced in the D_2 gaseous target

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Kd (2p->1s) measurement with SDDs

SIlicon **D**rift
Detectors for
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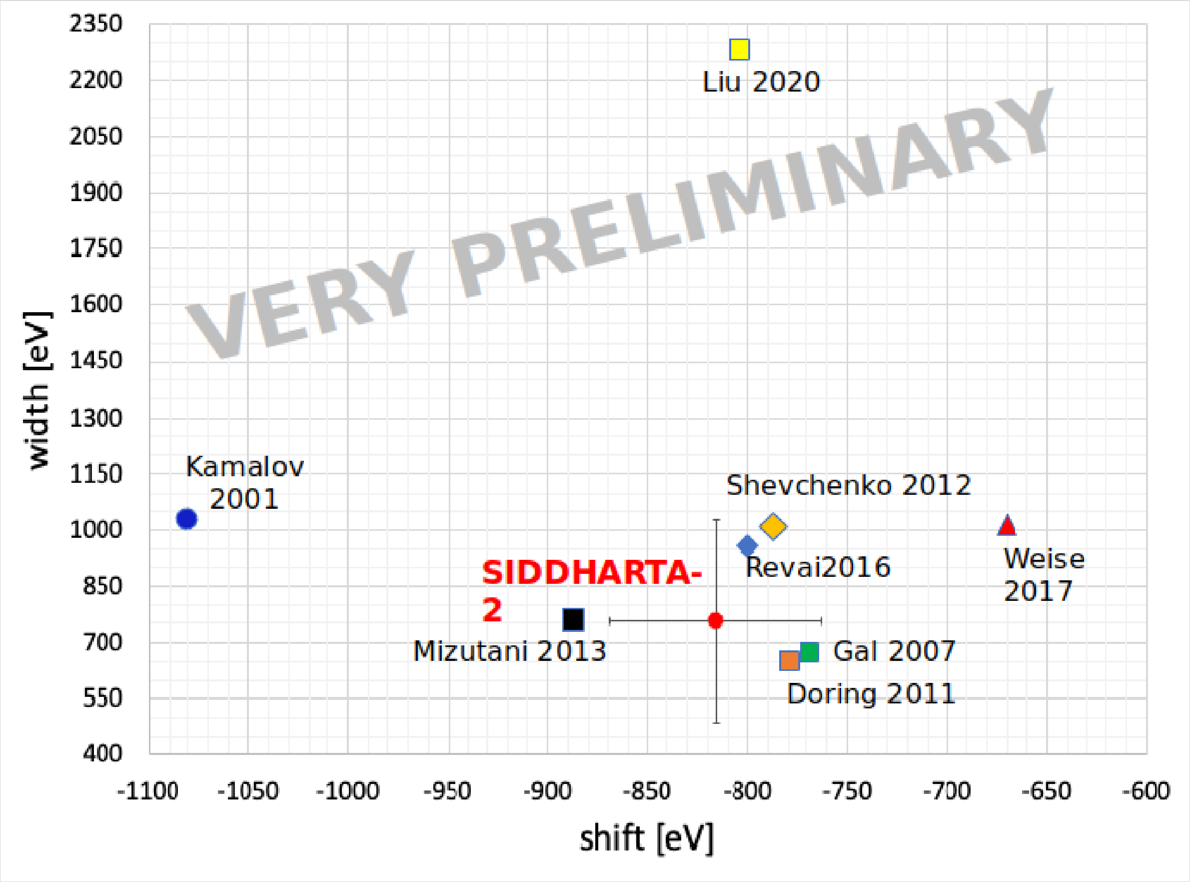
Research by
Timing **A**pplication

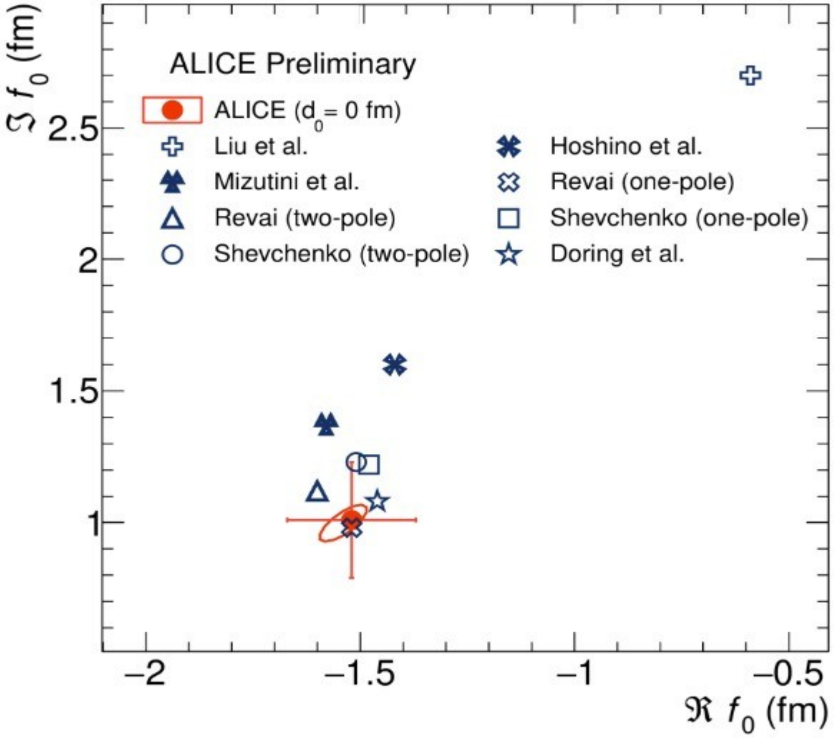
$\varepsilon_{2p\to1s}$: -816 ± 53 (stat) ± 2(syst) eV
$\Gamma_{2p\to1s}$: 756 ± 271 (stat)

The analysis of the full dataset can potentially improve the statistical accuracy by a factor 2

(precision similar to kaonic hydrogen measurement)



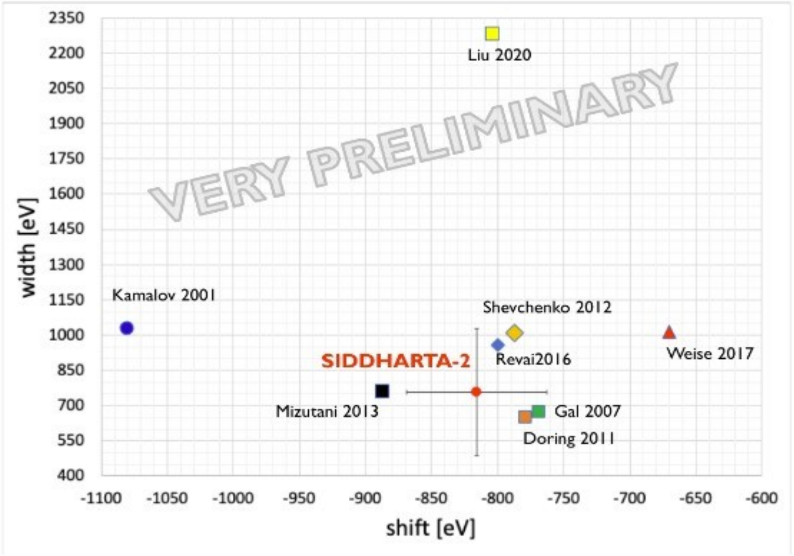
K^-d Femtoscopy with ALICE in Pb-Pb co



W. Resza @ Hadron 2023

Fit to K^-d correlation function:

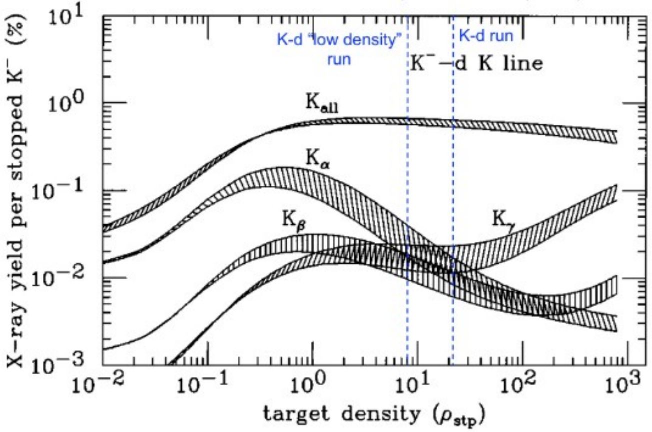
⇒ Real and imaginary part of K^-d scattering length via Lednicky model



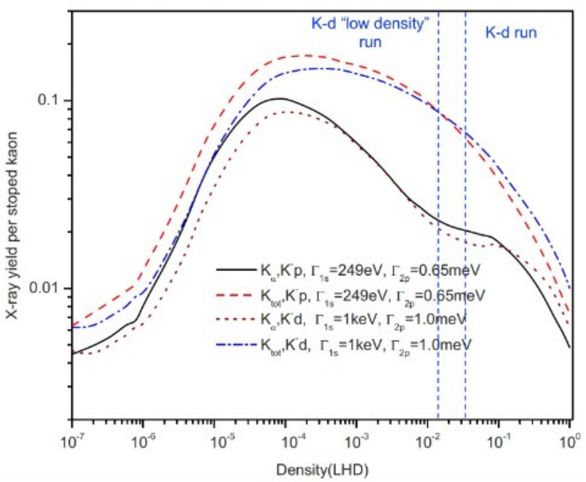
F. Sgaramella SIDDHARTA-2

Kd (2p->1s): the yield puzzle

T. Koike, T. Harada, Y. Akaishi, Phys.Rev.C 53 (1996), 79-87

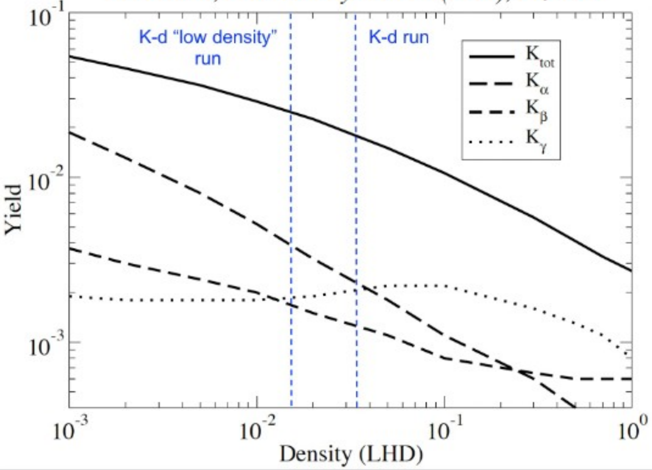


M Raeisi, S. Z. Kalantari, Phys.Rev.A 79, 012510 (2009)



Several cascade model predict **completely different kaonic deuterium X-ray yields** (absolute and relative) and different trends as function of the density

T.S. Jensen, Frascati Phys.Ser. 36 (2004), 349-354



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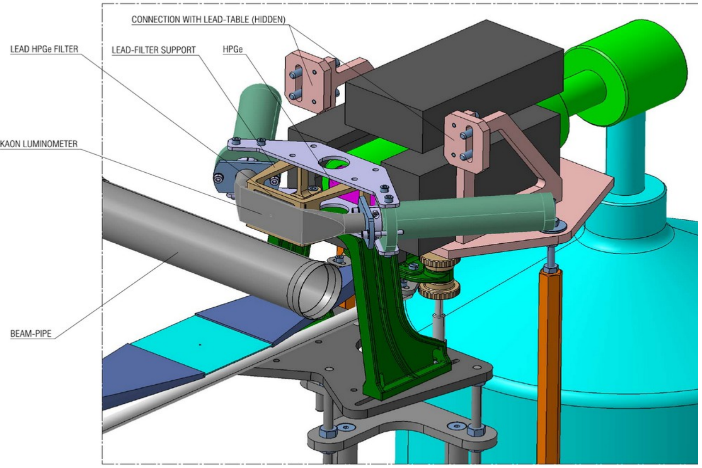
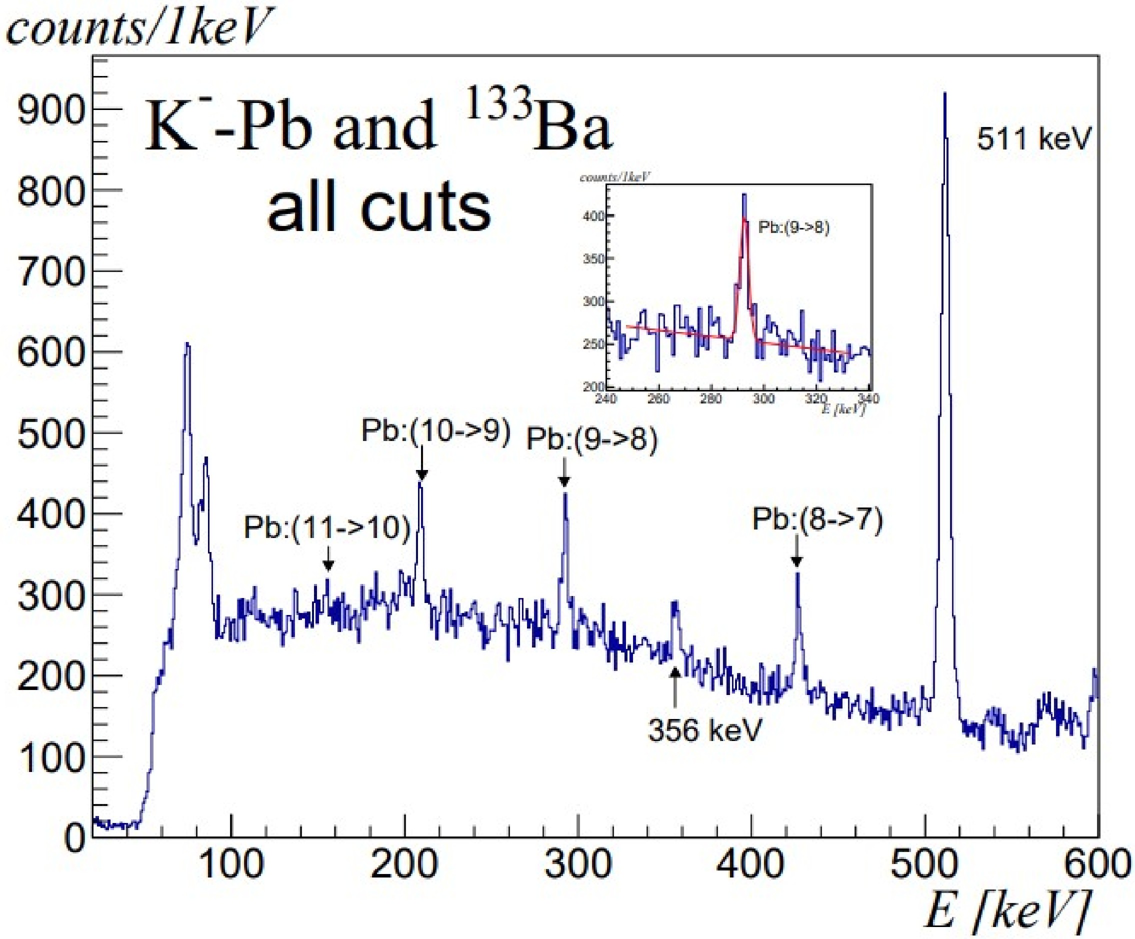
Laboratori Nazionali di Frascati

KPb measurement with HPGe detector

SIlicon **D**rift
Detectors for
HAdronic **A**tom
Research by
Timing **A**pplication





New test measurement of KPb transitions, including the GALL 88 one

Promising results obtained

First technical paper submitted

Double measurement of m_{K^-} with KNe

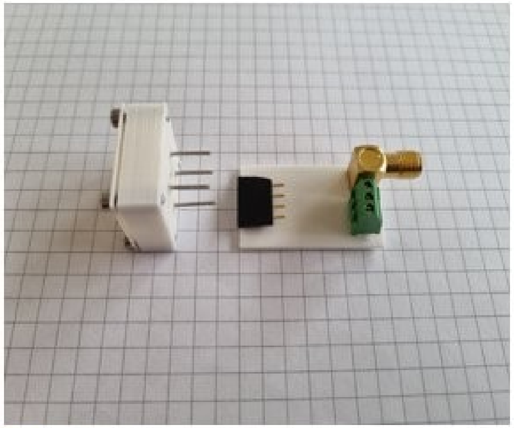
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

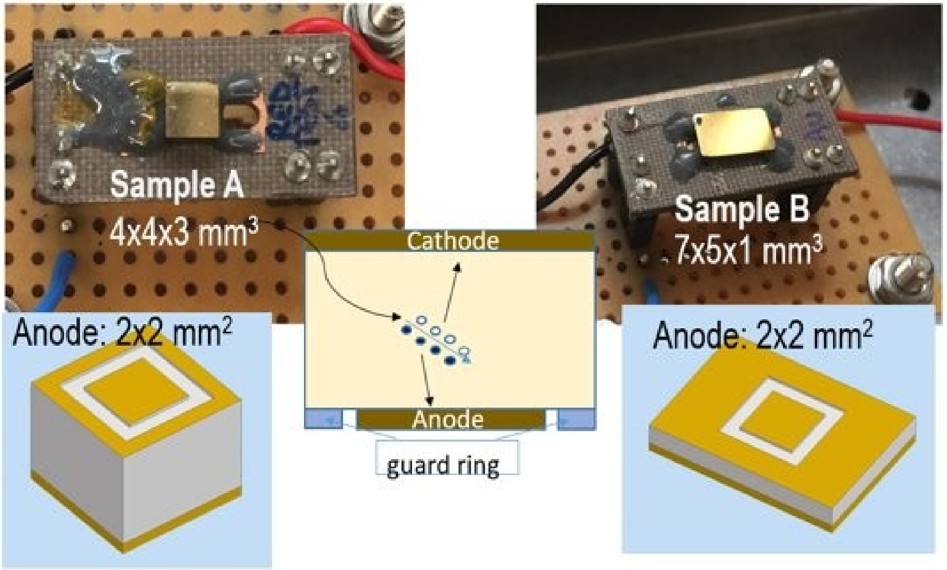
Intermediate mass Kaonic Atoms with CdZnTe

SIlicon **D**rift
Detectors for
HAdronic **A**tom
Research by
Timing **A**pplication

Work in collaboration between

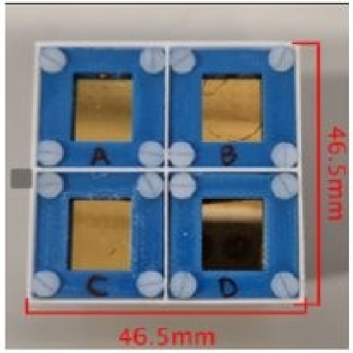
LNF: Setup Assembly and data analysis
IMEM-CNR: Detectors production
UniPa: Front-end and digital electronics
SMI: Mechanical supports and detectors' box

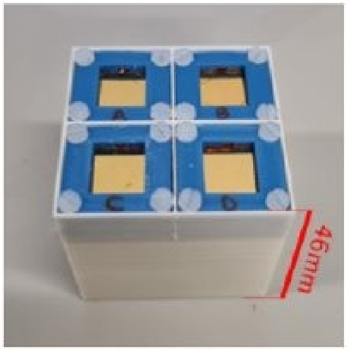




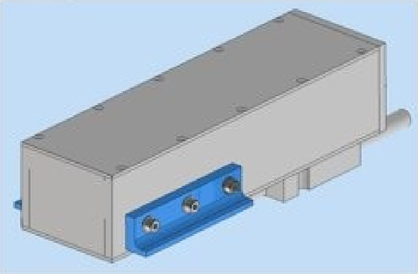
Intermediate mass Kaonic Atoms with CdZnTe

CdZnTe detectors have been never used in particle accelerators (?) or colliders





8 (4+4)
1,3x1,5x0,5 cm^3
CZT hemispherical
detectors



Intermediate mass Kaonic Atoms with CdZnTe

SIlicon **D**rift
Detectors for
HAdronic **A**tom
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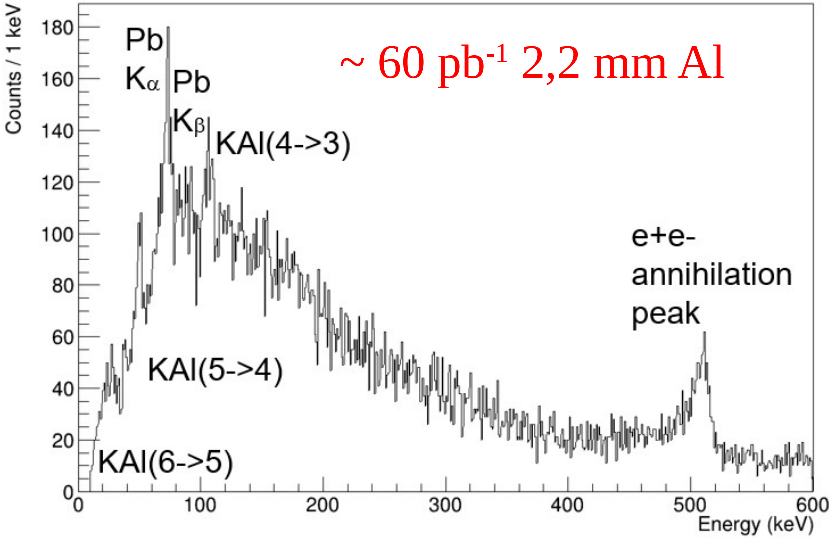
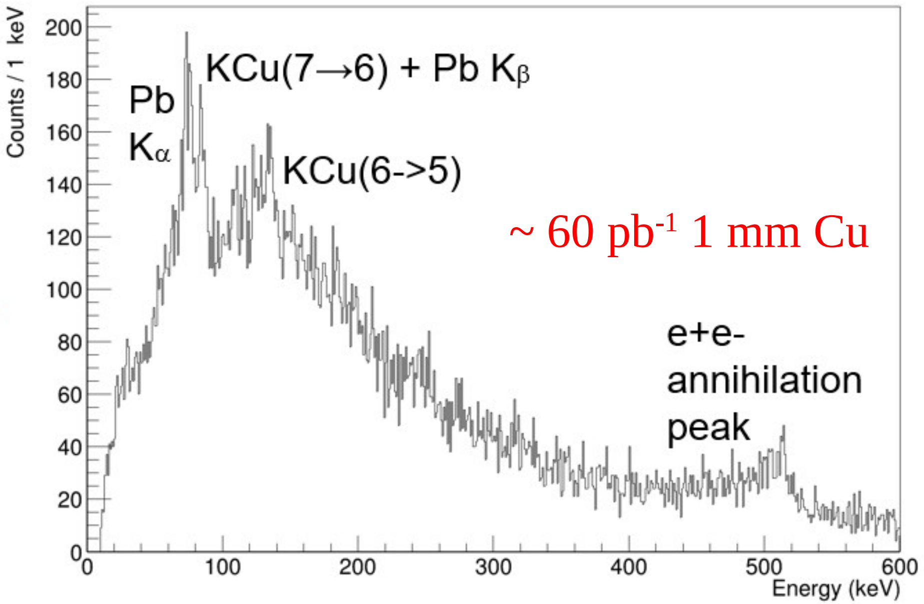
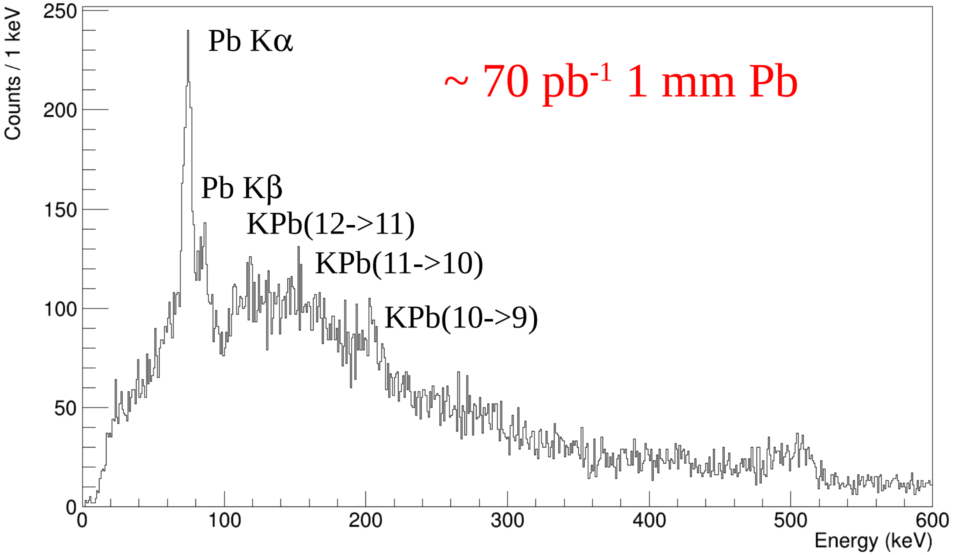






First kaonic atoms' spectra measured with CZT detectors

New perspectives opening

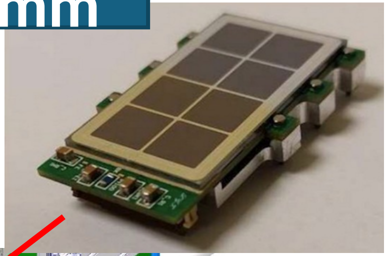
Proposal(s) for future measurements @ DAΦNE

Proposal for future extensive kaonic atoms measurements @ DAFNE to be performed exploiting:

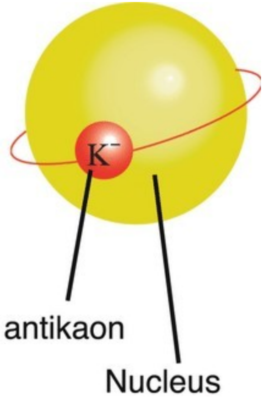
Kaonic atoms at DAΦNE collider: a strangeness adventure
C. Curceanu et al., doi.org/10.3389/fphy.2023.1240250

- 450 mm SDD (light KA, up to 15 keV)
- 1-2 mm SDD (light KA, up to 40 keV)
- CdZnTe detectors (Intermediate mass KA)
- HPGe detectors (Heavy KA)
- Crystal Spectrometer (High-Res light KA)

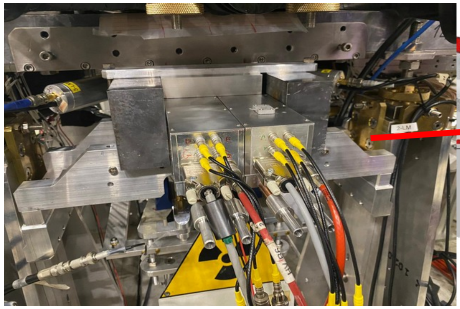
SDD 1mm

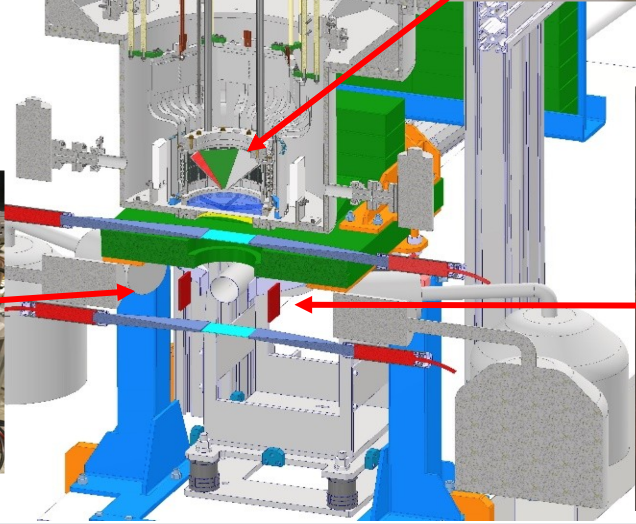


Extensive **K**aonic **A**toms research: from **LI**thium and **B**eryllium to **UR**anium



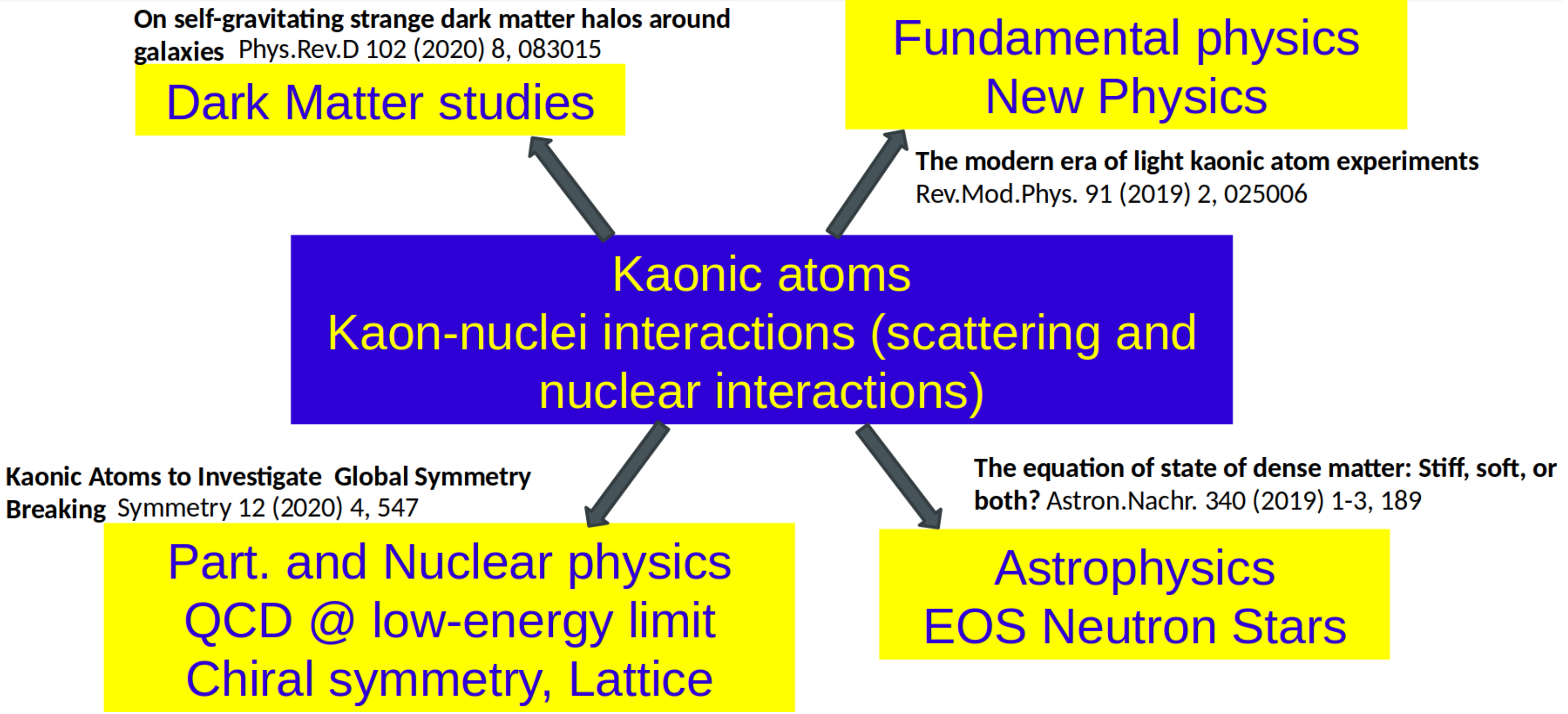
Cd(Zn)Te





HPGe

Proposal(s) for future measurements @ DAΦNE



On self-gravitating strange dark matter halos around galaxies Phys.Rev.D 102 (2020) 8, 083015

Dark Matter studies

Fundamental physics
New Physics

The modern era of light kaonic atom experiments Rev.Mod.Phys. 91 (2019) 2, 025006

Kaonic atoms
Kaon-nuclei interactions (scattering and nuclear interactions)

Kaonic Atoms to Investigate Global Symmetry Breaking Symmetry 12 (2020) 4, 547

The equation of state of dense matter: Stiff, soft, or both? Astron.Nachr. 340 (2019) 1-3, 189

Part. and Nuclear physics
QCD @ low-energy limit
Chiral symmetry, Lattice

Astrophysics
EOS Neutron Stars

Strong impacts on several fields

Modular concept for 1-3 years program depending on the availability and conditions of DAΦNE

Each module is individually under evaluation by LNF management

Conclusions (1)

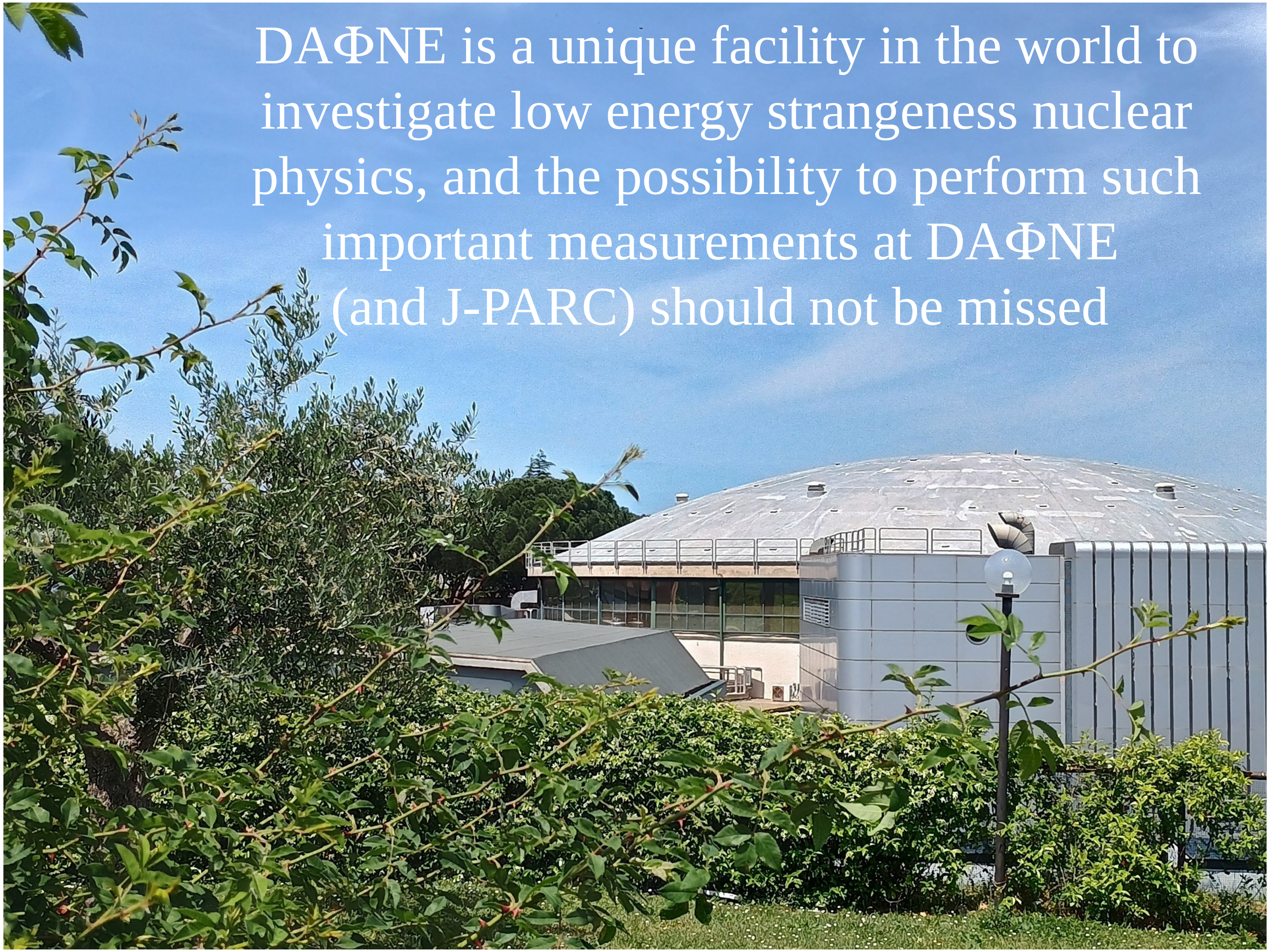
KHe L-transition measurement in gas : *J. Phys. G 49 (2022) 5, 055106*
Kaonic helium-4 yields L-lines in gas :
Nucl. Phys. A 1029 (2023) 122567
First measurement of intermediate mass kaonic atoms: *Eur. Phys. J. A 59(2023)3, 56*
First Measurement of KHe M-lines : *J. Phys. G (2024) 51 055103*
First Measurement of kaonic Neon (stat. precision < 1 eV) *Paper in preparation*
First measurement of Kaonic Deuterium: preliminary analysis

KPb pure E.M. transitions measurements with HPGe: *Paper in preparation*

Feasibility tests & exploratory measurements with CdZnTe detectors @ DAFNE:
Eur.Phys.J.ST 232 (2023) 10, 1487-1492
Sensors 23 (2023) 17, 7328
Nucl.Instrum.Meth.A 1060 (2024) 169060
Front.in Phys. 11 (2023) 1240250

EXKALIBUR: new X-ray detectors (SDDs – CZT - HPGe) have been developed/tested to perform kaonic atoms measurements along the periodic table providing new experimental data to probe the kaon-nucleus interaction

Conclusions (2)



DAΦNE is a unique facility in the world to investigate low energy strangeness nuclear physics, and the possibility to perform such important measurements at DAΦNE (and J-PARC) should not be missed

To Carlo

We dedicated our results to our dear colleague and friend Prof **Carlo Guaraldo**
you'll be very much missed!