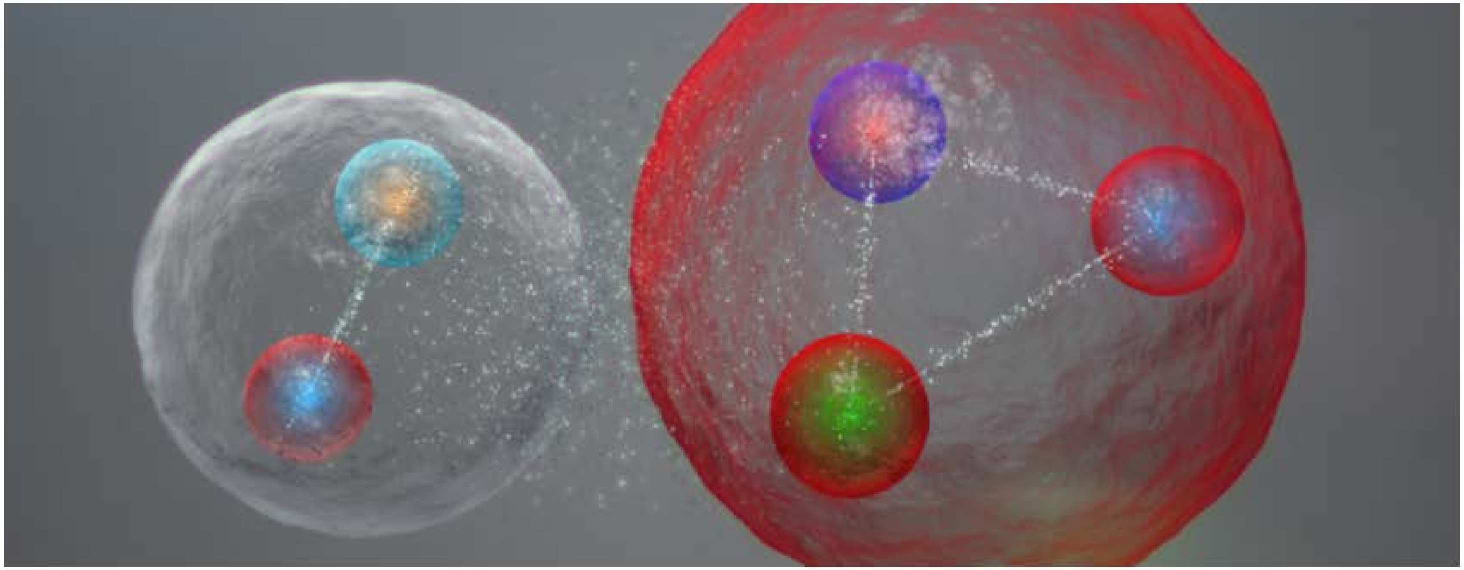
STRANU:

HOT TOPICS IN STRANGENESS NUCLEAR AND ATOMIC PHYSICS



Experimental studies of the kaon-nucleus interaction at low energy with X-ray spectroscopy of kaonic atoms: SIDDHARTA/SIDDHARTA-2 experiments and future perspectives

Diana Laura Sirghi

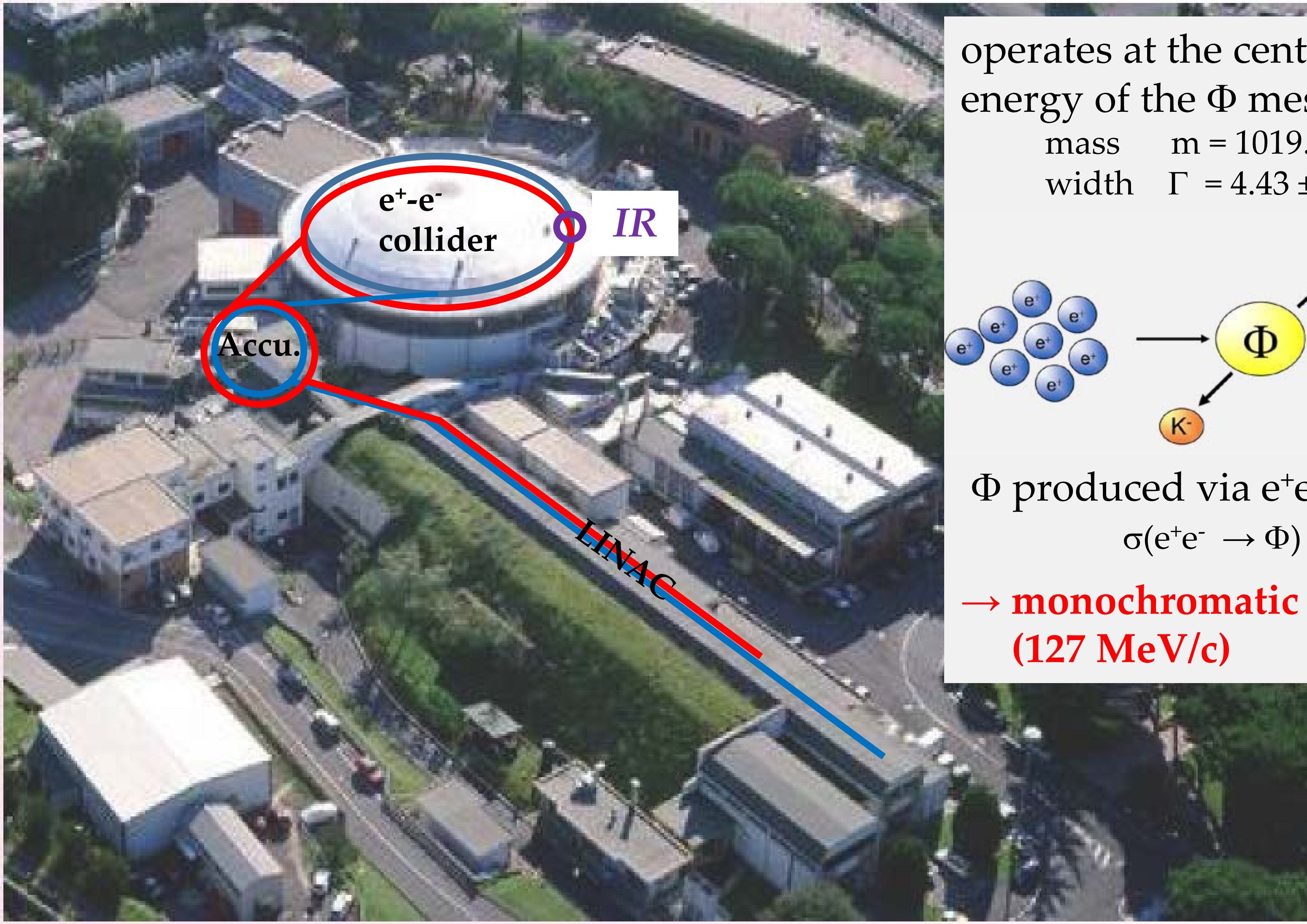
INFN-LNF

on behalf of SIDDHARTA-2 collaboration

24– 28 May 2021

DAΦNE accelerator, since 1998:

The Double Annular Φ factory for Nice Experiments



operates at the centre-of-mass energy of the Φ meson

mass $m = 1019.413 \pm .008$ MeV

width $\Gamma = 4.43 \pm 0.06$ MeV

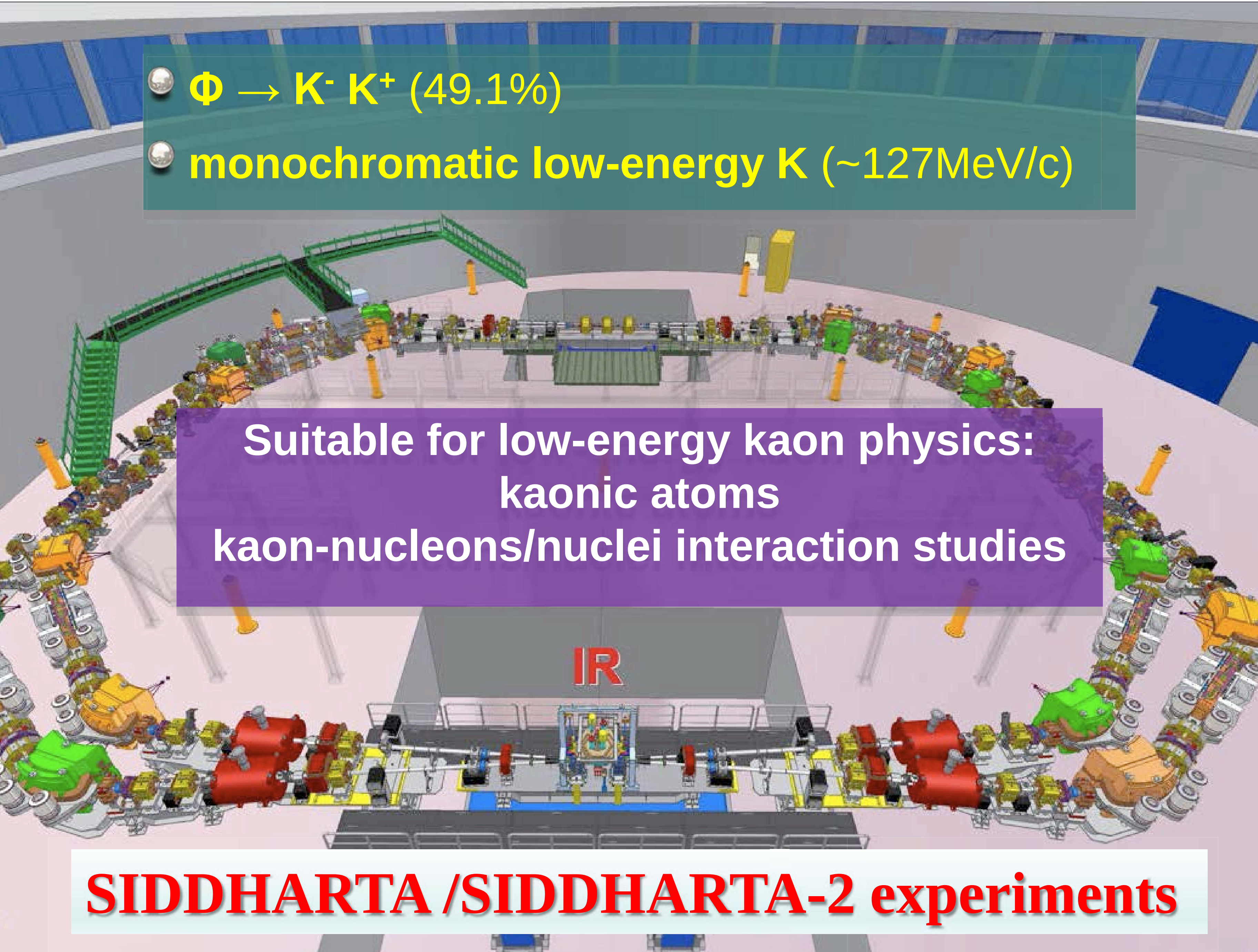
Φ produced via e^+e^- collision

$\sigma(e^+e^- \rightarrow \Phi) \sim 5\ \mu b$

→ monochromatic kaon beam (127 MeV/c)

- $\Phi \rightarrow K^- K^+$ (49.1%)
- **monochromatic low-energy K** (~127MeV/c)

Suitable for low-energy kaon physics:
kaonic atoms
kaon-nucleons/nuclei interaction studies



SIDDHARTA /SIDDHARTA-2 experiments

SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

LNF- INFN, Frascati, Italy
SMI- ÖAW, Vienna, Austria
Politecnico di Milano, Italy
IFIN – HH, Bucharest, Romania
TUM, Munich, Germany
RIKEN, Japan
Univ. Tokyo, Japan
Victoria Univ., Canada
Univ. Zagreb, Croatia
Univ. Jagiellonian Krakow, Poland
Research Center for Electron Photon Science (ELPH), Tohoku University

INFN LNF Istituto Nazionale di Fisica Nucleare

STRONG 2020

HadronPhysics I3 Study of Strongly Interacting Matter

HadronPhysics2 Study of Strongly Interacting Matter

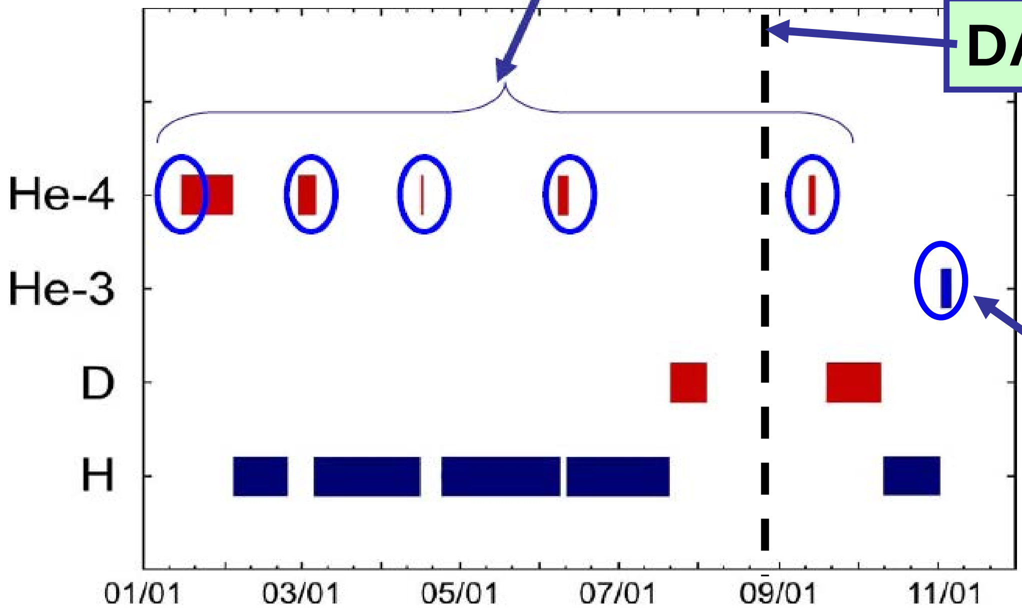
HrZZ Croatian Science Foundation

Farnesina Ministero degli Affari Esteri e della Cooperazione Internazionale

FWF Der Wissenschaftsfonds

SIDDHARTA data taking campaign: ended in November 2009

K-He4 data without Fe source



DAΦNE shutdown in Summer

New alignment of setup
→Improve S/N ratio

K-He3 data (~4days)

SIDDHARTA performed
kaonic atoms transitions measurements
on the upgraded DAΦNE collider

The scientific aim

SIDDHARTA measures the X-ray transitions occurring in the cascade processes of kaonic atoms

Fundamental study of **strong interaction** between anti-K & nucleus at low energy limit

The scientific aim

the determination of the

isospin dependent $\overline{KN}$ scattering lengths

through a

~ precision measurement of the shift

and *of the width*

of the K_{α} line of kaonic hydrogen

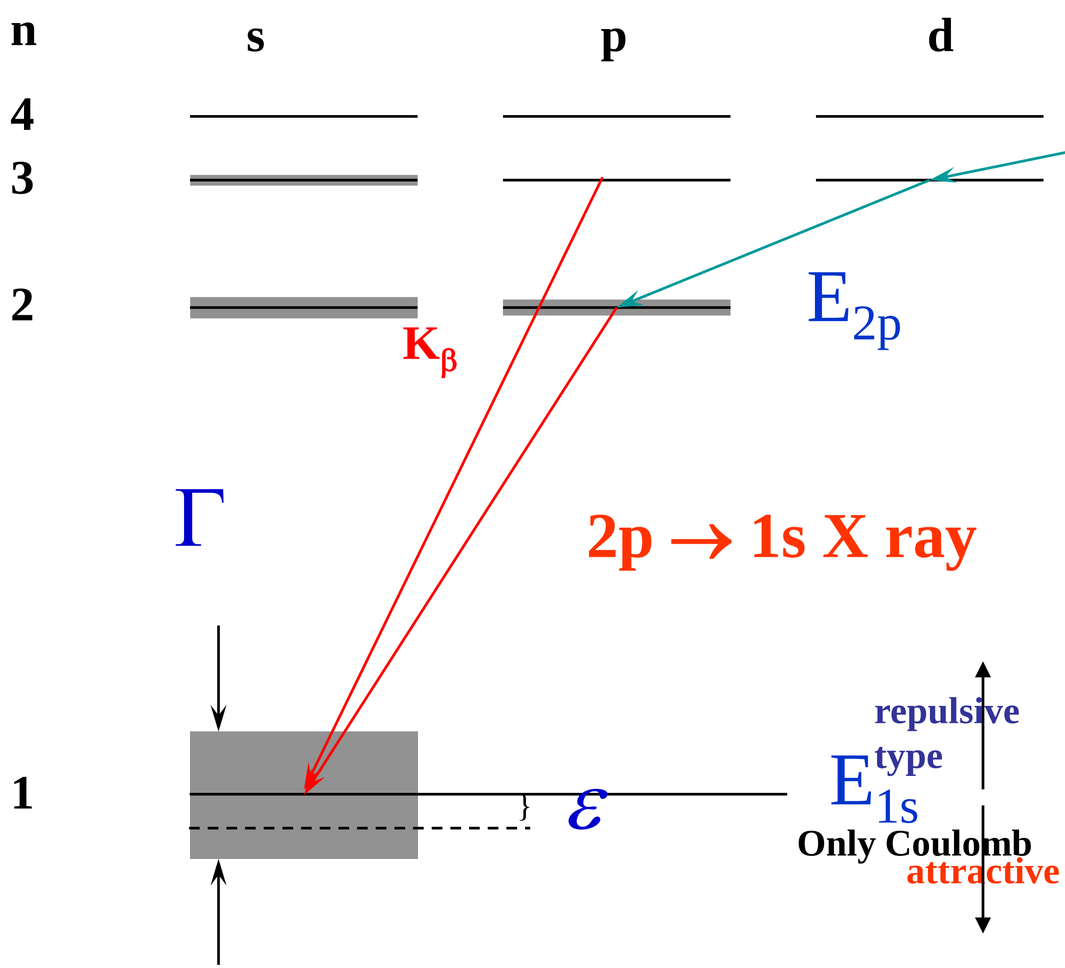
and

the *first measurement* of kaonic deuterium

Kaonic Hydrogen atoms

K- captured in excited orbit, replacing the e-

electromagnetic cascade



$$E(e.m.) \approx -\frac{1}{2}\mu c^2 (Z\alpha)^2 \cdot \left[\frac{1}{n_i^{\,2}} - \frac{1}{n_f^{\,2}}\right]$$

$$\varepsilon = E(\exp) - E(e.m.)$$
$$\varepsilon < 0 \text{ (repulsive)}$$
$$\varepsilon > 0 \text{ (attractive)}$$

Strong Interaction causes:

energy shift ε

of the last energy levels form their purely electromagnetic values

AND

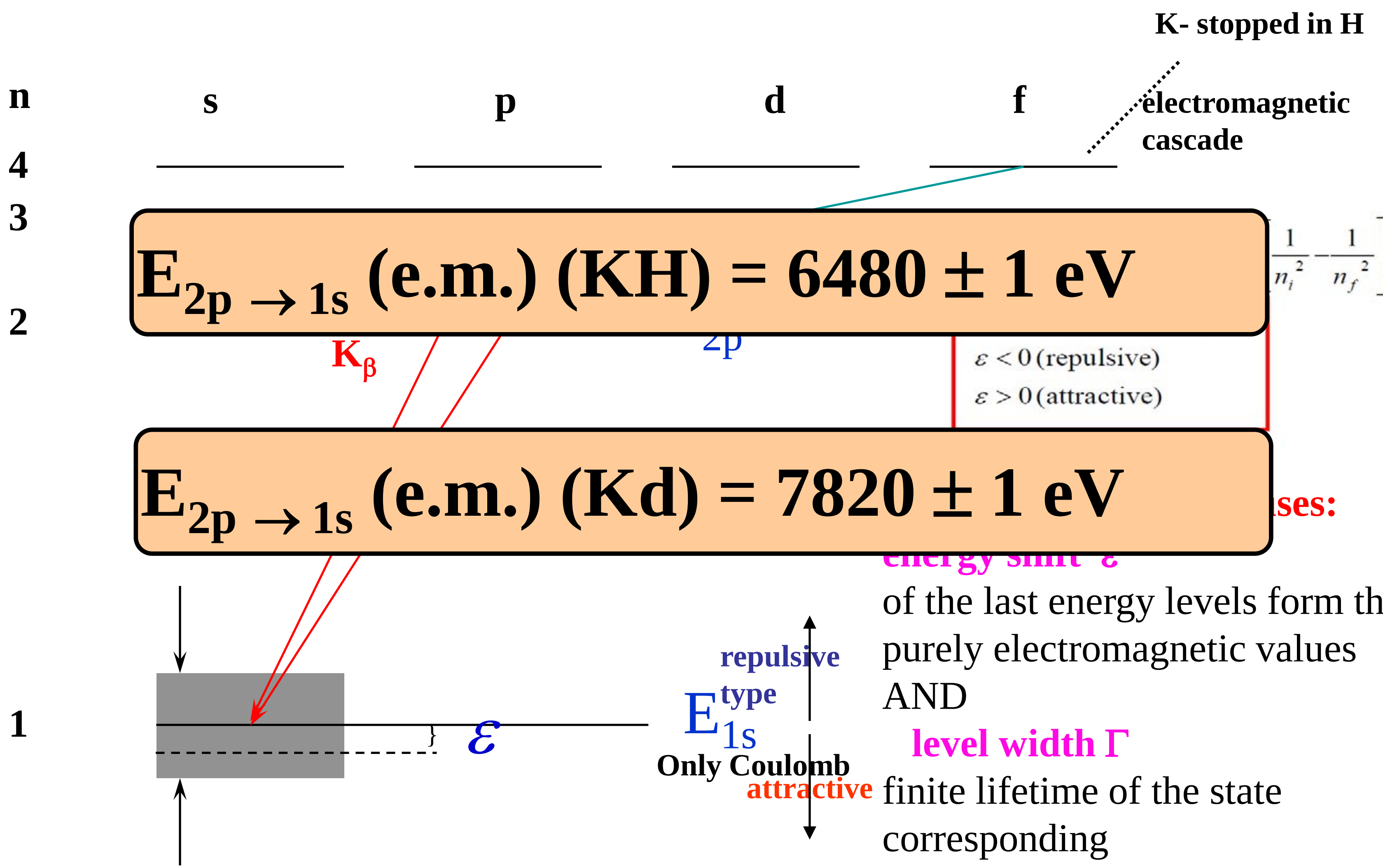
level width Γ

finite lifetime of the state corresponding

to an increase in the observed level width

$$\boldsymbol{\varepsilon = E_{2p \to 1s}(\exp) - E_{2p \to 1s}(e.m.)}$$

Kaonic Hydrogen atoms



$$E_{2p \to 1s}\ (\text{e.m.})\ (\text{KH}) = 6480 \pm 1\ \text{eV}$$

$$E_{2p \to 1s}\ (\text{e.m.})\ (\text{Kd}) = 7820 \pm 1\ \text{eV}$$

ses:

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

$$\varepsilon = E_{2p \to 1s}\ (\text{exp}) - E_{2p \to 1s}\ (\text{e.m.})$$

Importance of kaonic atoms studies

atomic binding energies of light systems the keV range →tens of MeV in the low-energy scattering experiments

	m (MeV/c^2)	μ (MeV/c^2)	B_{1s} (keV)	r_B (fm)	Accessible interaction
ep	0.511	0.511	13.6×10^{-3}	53 000	Electroweak
μp	105.7	95.0	2.53	279	Electroweak
πp	139.6	121.5	3.24	216	Electroweak + strong
Kp	493.7	323.9	8.61	81	Electroweak + strong
$\bar{p}p$	938.3	469.1	12.5	58	Electroweak + strong

Kaonic atoms: the unique opportunity to perform experiments equivalent to scattering at vanishing relative energies

determination of the antikaon-nucleon/nucleus interaction at "threshold", without the need of extrapolation to zero relative energy.

Determined isospin dependent KN scattering lengths are key ingredients for all models and theories dealing with low-energy QCD in systems with strangeness

- **Explicit and spontaneous chiral symmetry breaking (mass of nucleons)**
- **Dense baryonic matter structure**
- **Neutron (strange?) stars EOS**

SIDDHARTA results:

- **Kaonic Hydrogen**: 400pb^{-1}, most precise measurement ever,Phys. Lett. B 704 (2011) 113, Nucl. Phys. A881 (2012) 88; Ph D

- **Kaonic deuterium**: 100 pb^{-1}, as an exploratory first measurement ever, Nucl. Phys. A907 (2013) 69; Ph D

- **Kaonic helium 4** – first measurement ever in gaseous target; published in Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264 and Phys. Lett. B 697 (2011);; PhD

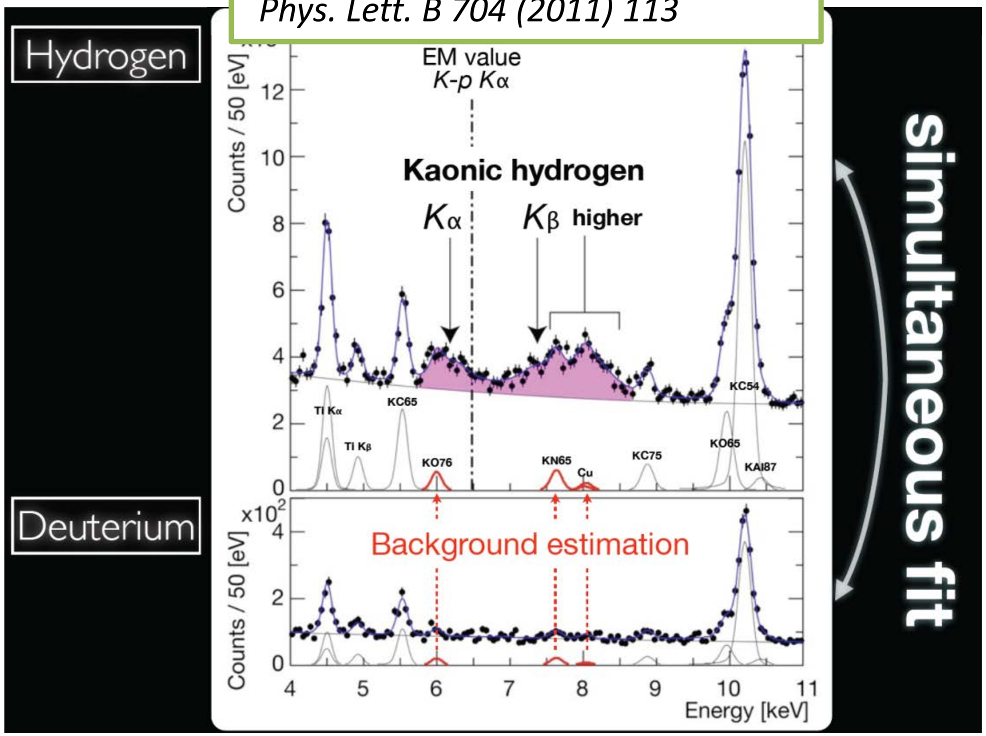
- **Kaonic helium 3** – 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D

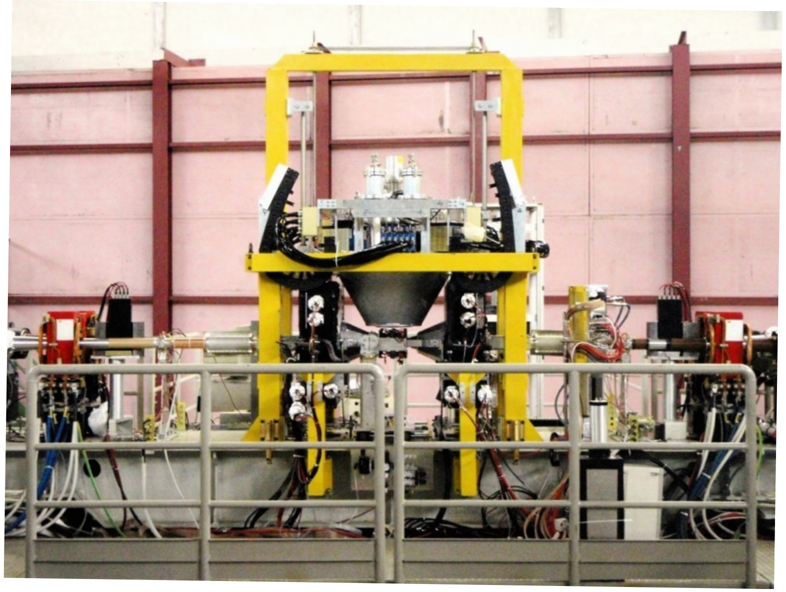
- **Widths and yields** of KHe3 and KHe4 - Phys. Lett. B714 (2012) 40; kaonic kapton yields – Nucl. Phys. A916 (2013) 30; yields of the KHe3 and KHe4 –EPJ A(2014) 50; KH yield – Nucl. Phys. A954 (2016) 7.

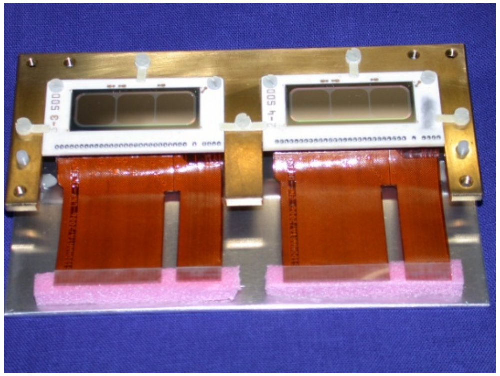
SIDDHARTA – important TRAINING for young researchers

SIDDHARTA results: KH (2009)

Phys. Lett. B 704 (2011) 113







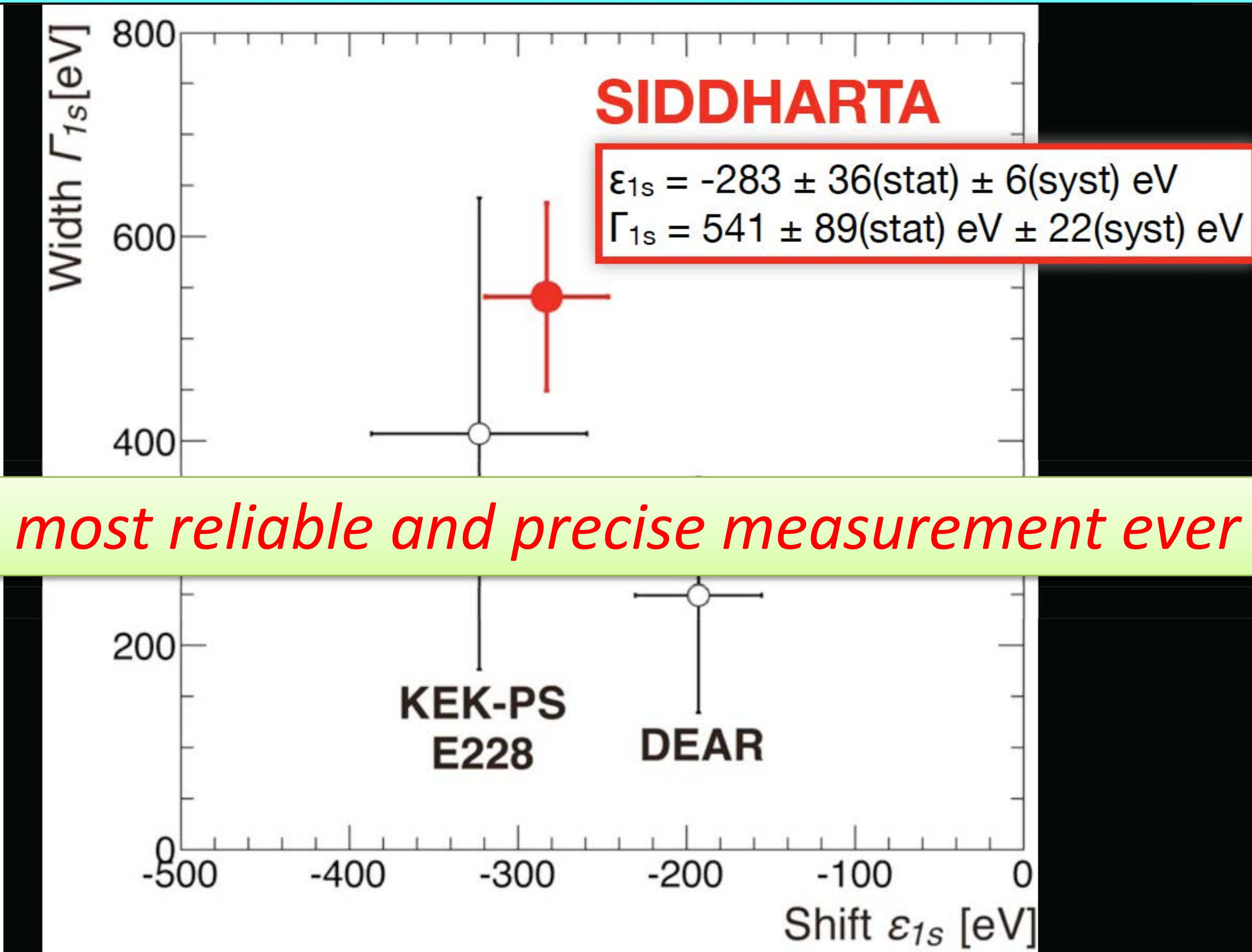
ε_{1S}= −283 ± 36(stat) ± 6(syst) eV

Γ_{1S}= 541 ± 89(stat) ± 22(syst) eV

Gas target (22 K, 2.5 bar)
144 SDD used as X-ray detector
Good energy resolution (140eV @ 6 keV)
Timing capability (huge background)

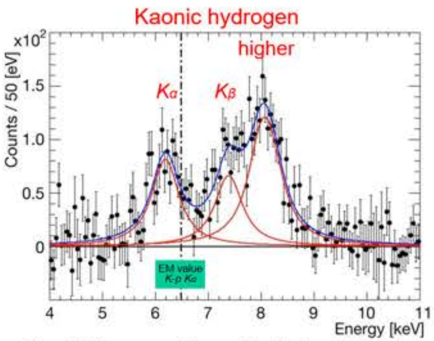
Drastically improved S/B ratio

SIDDHARTA results: KH (2009)



most reliable and precise measurement ever

SIDDHARTA results: KHe(2009)



1. Kaonic Hydrogen

Residuals of K-p x-ray spectrum after subtraction of fitted background

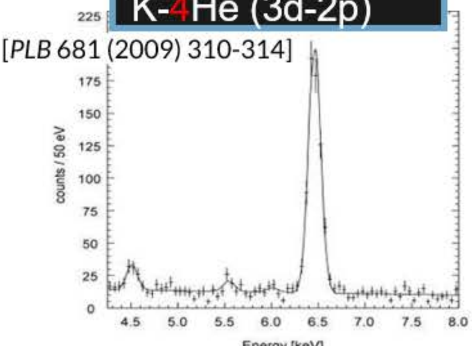
$\varepsilon_{1S}= -283 \pm 36(\mathrm{stat}) \pm 6(\mathrm{syst})$ eV
$\Gamma_{1S}= 541 \pm 89(\mathrm{stat}) \pm 22(\mathrm{syst})$ eV

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

2. Kaonic 4-Helium

K-4He (3d-2p)

[*PLB* 681 (2009) 310-314]

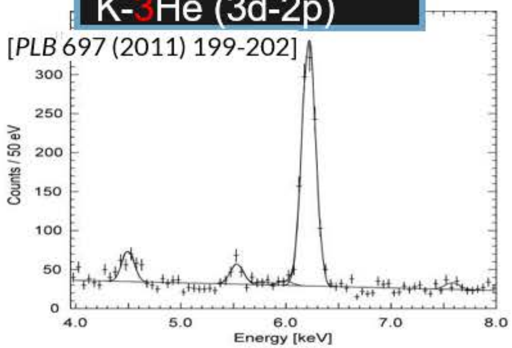


$$\Delta E_{2p} = +5 \pm 3(sta) \pm 4(sys) \text{ eV}$$

3. Kaonic 3-Helium

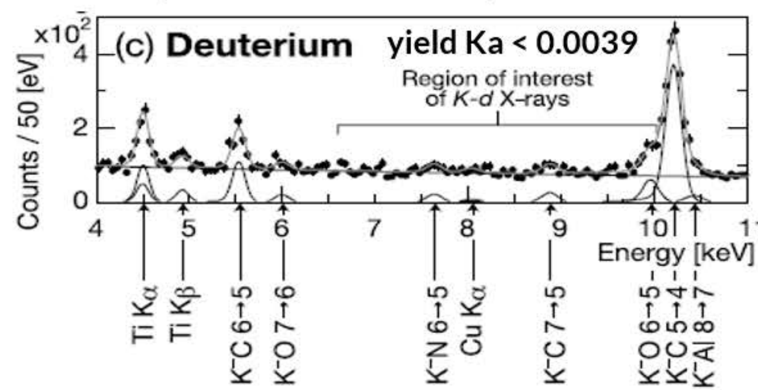
K-3He (3d-2p)

[*PLB* 697 (2011) 199-202]



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

4. Exploratory measurement for Kd, no measured ε, Γ values

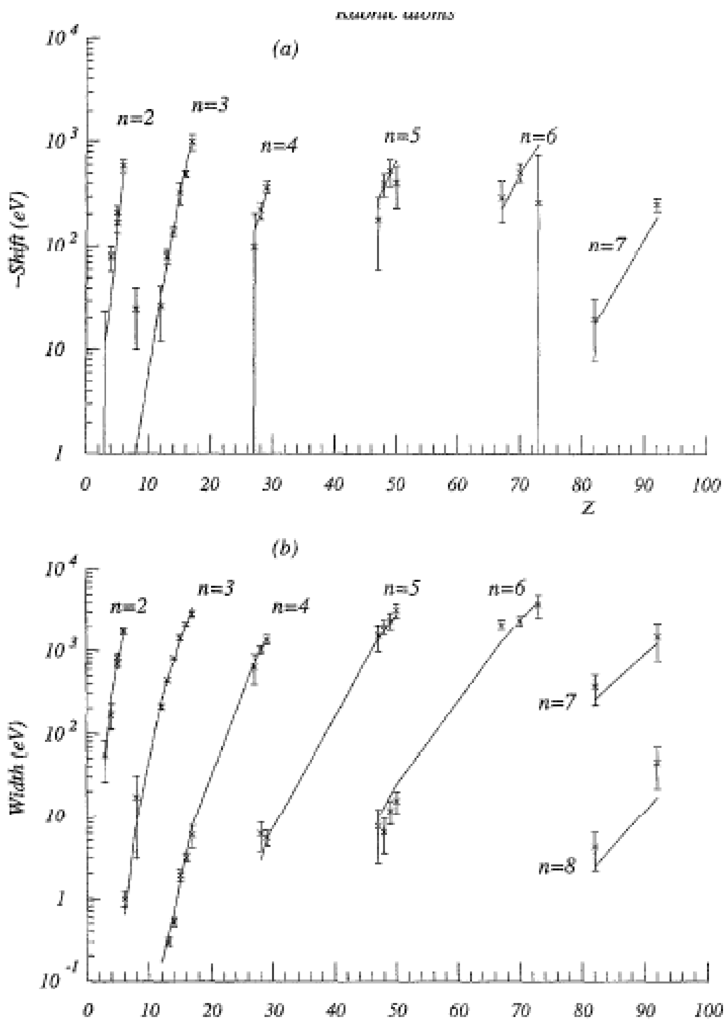


for first time in a gaseous target for ^{4}He

for the first time for ^{3}He

Kaonic atom 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

Kaonic atom data (Z≥3)
Used for studies of $K^{bar}N$ interaction

Optical model

$$2\mu V_{\rm opt}^{(2)}(r) = -4\pi\left(1+\frac{\mu}{m}\right)b_0\rho(r).$$

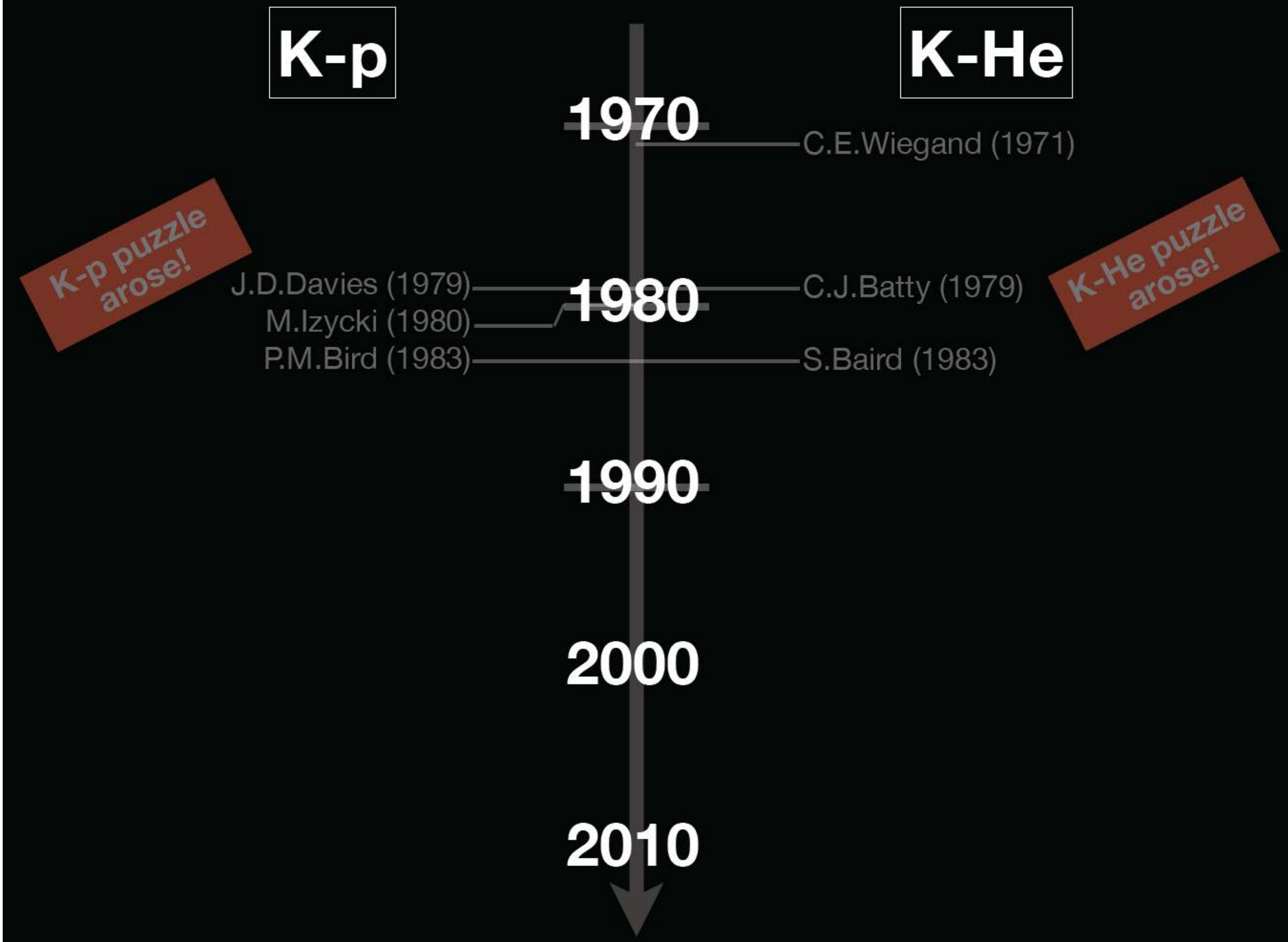
Experimental X-ray data of shift & width: Well fitted with optical potentials

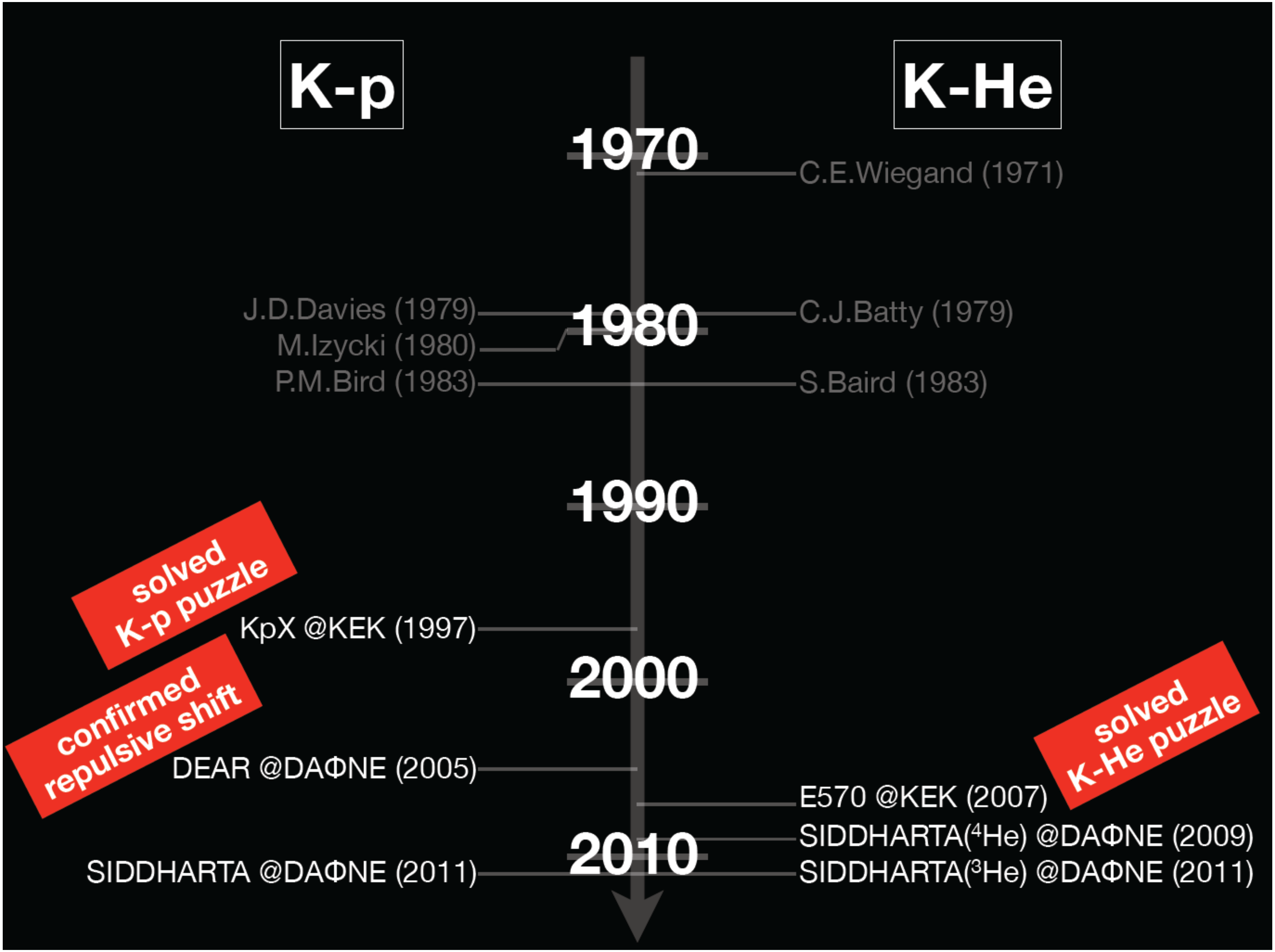
Expected shift of K-4He 2p state: ΔE ~ 0 eV

There are discrepancies for:

Kaonic Hydrogen (Z=1)

Kaonic Helium (Z=2)


K-p
K-He
1970
C.E.Wiegand (1971)
K-p puzzle arose!
K-He puzzle arose!
J.D.Davies (1979)
C.J.Batty (1979)
1980
M.Izycki (1980)
P.M.Bird (1983)
S.Baird (1983)
1990
2000
2010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1980
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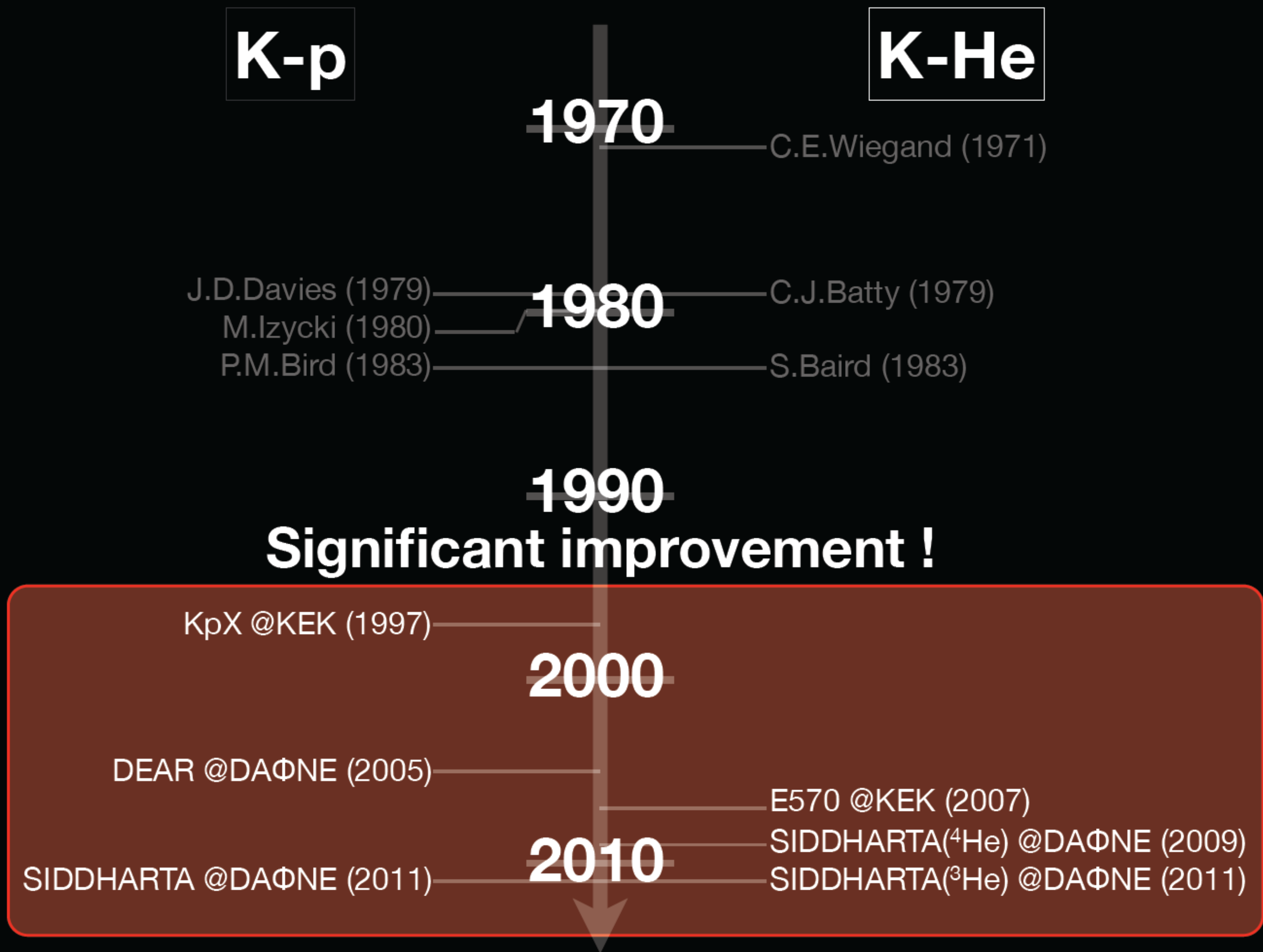
P.M.Bird (1983)
S.Baird (1983)
1990
solved K-p puzzle
KpX @KEK (1997)
2000
confirmed repulsive shift
DEAR @DAΦNE (2005)
solved K-He puzzle
E570 @KEK (2007)
SIDDHARTA(^{4}He) @DAΦNE (2009)
2010
SIDDHARTA @DAΦNE (2011)
SIDDHARTA(^{3}He) @DAΦNE (2011)


K-p
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J.D.Davies (1979)
C.J.Batty (1979)
1980
M.Izycki (1980)
P.M.Bird (1983)
S.Baird (1983)
1990
Significant improvement !
KpX @KEK (1997)
2000
DEAR @DAΦNE (2005)
E570 @KEK (2007)
SIDDHARTA(4He) @DAΦNE (2009)
2010
SIDDHARTA @DAΦNE (2011)
SIDDHARTA(3He) @DAΦNE (2011)

K-p

K-He

STILL MISSING!!!

the measurement of the kaonic deuterium

the most important experimental information missing in the field of the low-energy antikaon-nucleon interactions

SIDDHARTA-2 collaboration

starting from 2019 at DAFNE accelerator

DEAR @DAΦNE (2005)

E570 @KEK (2007)

SIDDHARTA(^{4}He) @DAΦNE (2009)

2010

SIDDHARTA @DAΦNE (2011)

SIDDHARTA(^{3}He) @DAΦNE (2011)

The scientific aim of SIDDHARTA-2

To perform precision measurements of kaonic atoms X-ray transitions

- unique information about QCD in the non -perturbative regime in the strangeness sector not obtainable otherwise

Starting with the precision measurement of ***shift*** and ***width*** of ***kaonic hydrogen***

- **NOW first measurement of kaonic deuterium**

To extract the antikaon-nucleon isospin dependent scattering lengths

- chiral symmetry breaking (mass problem), EOS for neutron stars

Deser Formula

Deser-type relation (including the isospin-breaking corrections) connects shift ε_{1s} and width Γ_{1s} to the real and imaginary part of $a_{K\text{-}p}$

$$\boxed{\varepsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K-p}[1 - 2\alpha\mu(ln\alpha - 1)a_{K-p} + \ldots]}$$

A similar formula holds for $a_{K\text{-}d}$

$$\boxed{\varepsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K-d}[1 - 2\alpha\mu(ln\alpha - 1)a_{K-d} + \ldots]}$$

The connection between the scattering lengths $a_{K\text{-}p}$ and $a_{K\text{-}d}$ and the s-wave $\bar{K}N$ isospin dependent (I=0,1) isoscalar a_0 and isovector a_1 scattering length:

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

$$a_{K-n} = a_1$$

$$a_{K-d} = \frac{4[m_N + m_K]}{[2m_N + m_K]}Q + C$$

$$Q = \frac{1}{2}[a_{K-p} + a_{K-n}] = \frac{1}{4}[a_0 + 3a_1]$$

C, includes all higher-order contributions, namely all other physics associated with the K^-d three-body interaction.

Fundamental inputs of low-energy QCD effective theories.

SIDDHARTA-2 improvements

SIDDHARTA-2 is a development

both on the detector side and on target side.

SIDDHARTA-2, consists in a series of improvements with respect to the SIDDHARTA setup aiming to dramatically:

increase the S/B ratio and also the signal rate:

- **by gaining in solid angle**
- **taking advantage of new SDDs**

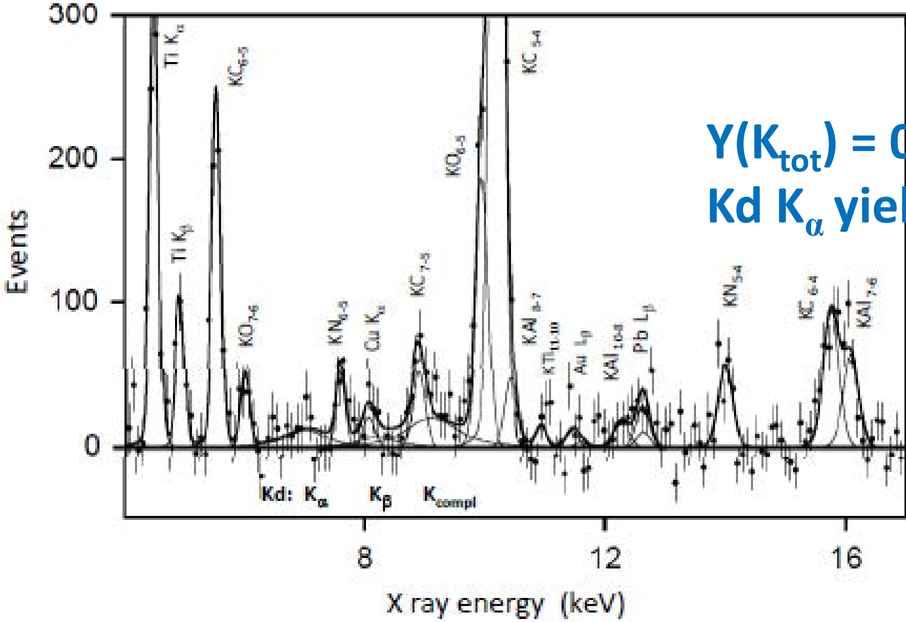
and

of the reduction of the background:

- **by improving the SDDs timing**
- **implementing of an additional veto system**

SIDDHARTA Kd exploratory measurement

First exploratory measurement for Kd



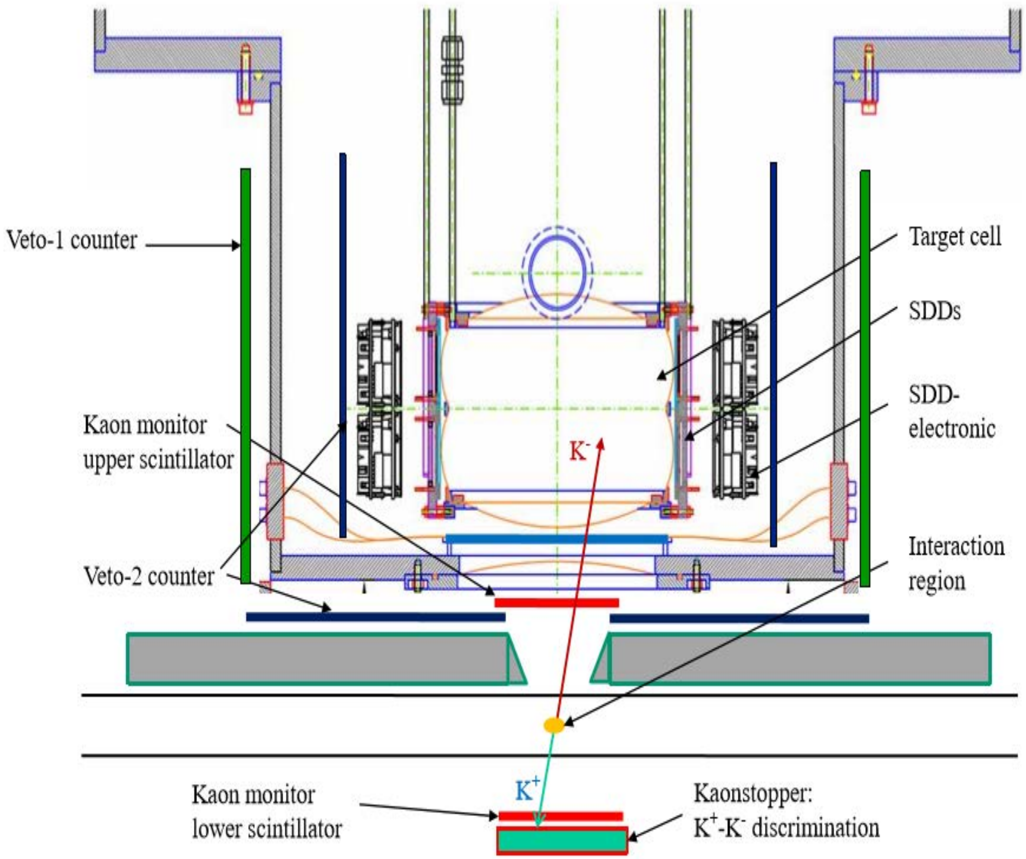
$Y(K_{tot}) = 0.0077 \pm 0.0051$

Kd K_α yield $Y(K_\alpha) = 0.0019 \pm\ 0.0012$

Yield of a factor about 10 smaller then the KH yield, estimated to be 1 to 2 % for K_α.

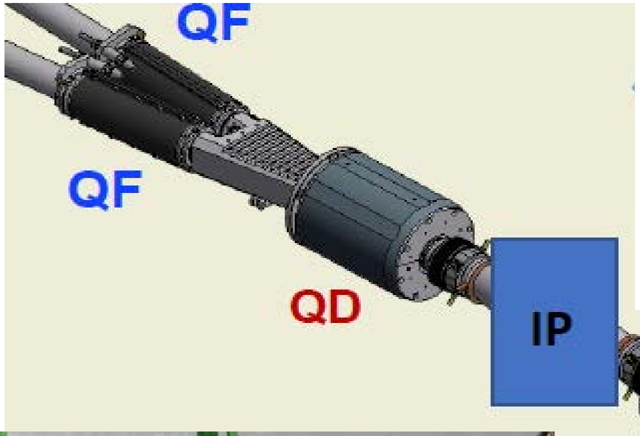
an enhancement by one order of magnitude of the signal-to background ratio is required for SIDDHARTA-2.

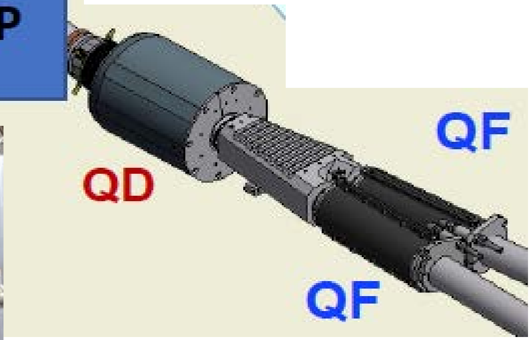
Important features of the SIDDHARTA-2 setup



- **New interaction region and beam pipe**
- **New vacuum chamber**
- **New cooling system**
- **Special designed shielding**
- **New Lightweight cryogenic target**
- **New Silicon Drift Detector**
- **Veto systems**
- **Luminosity monitor**

New interaction region



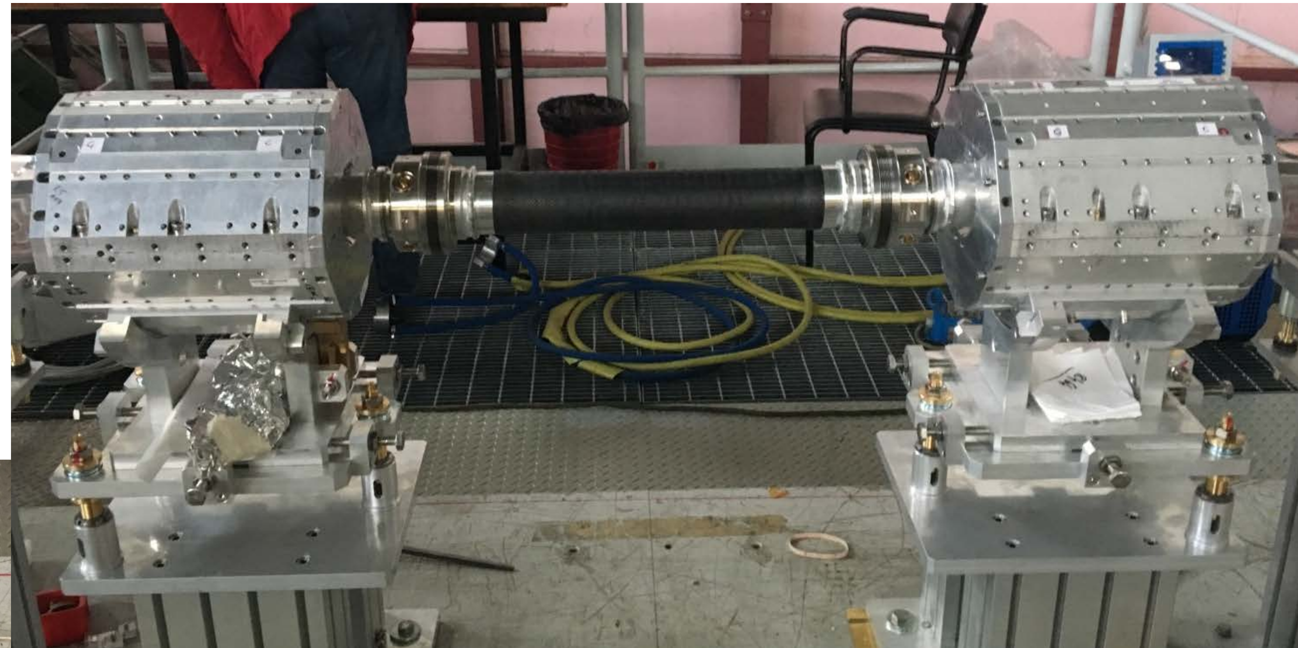


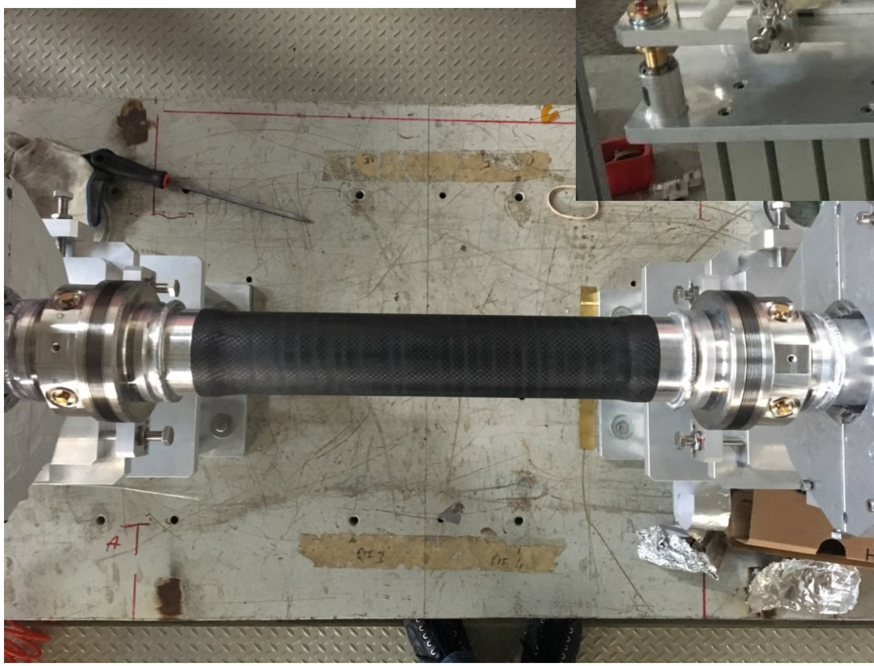
focusing quadrupole (QF)

quadrupole permanent magnet (QD)

New beam pipe

flanges removed
major source of
asynchronous
background



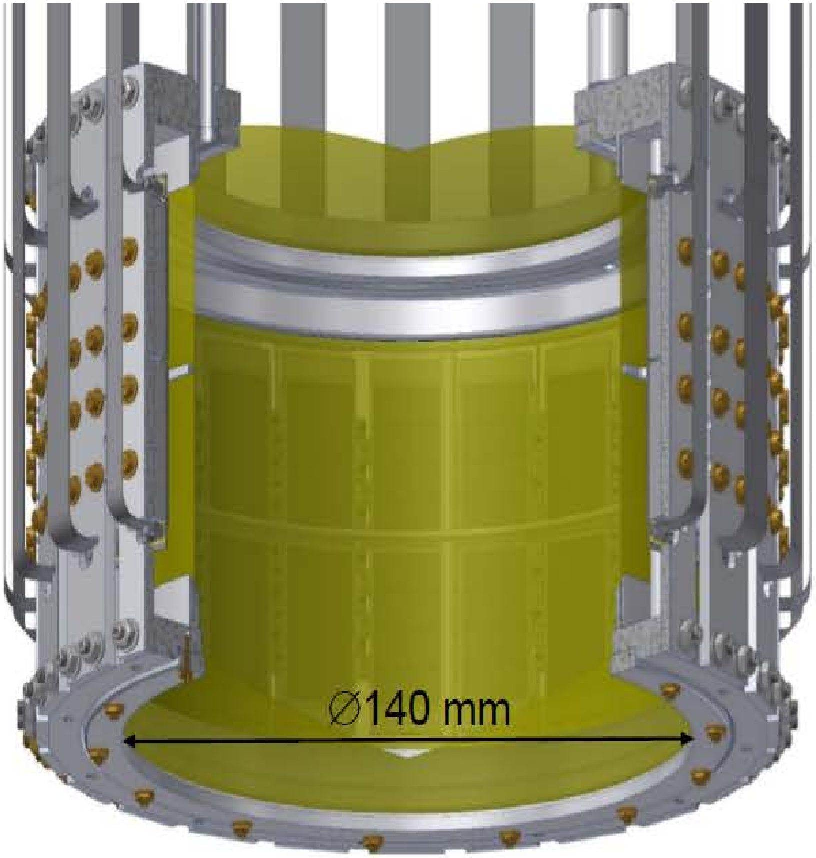


carbon fiber reinforcement
thickness ~ 500 micron
internal ultra pure aluminum
ø 55mm, thickness ~ 150 micron

DAΦNE luminosity monitor

SIDDHARTA-2 cryogenic target

Working temperature: 30 K
Working pressure : 0.3 MPa

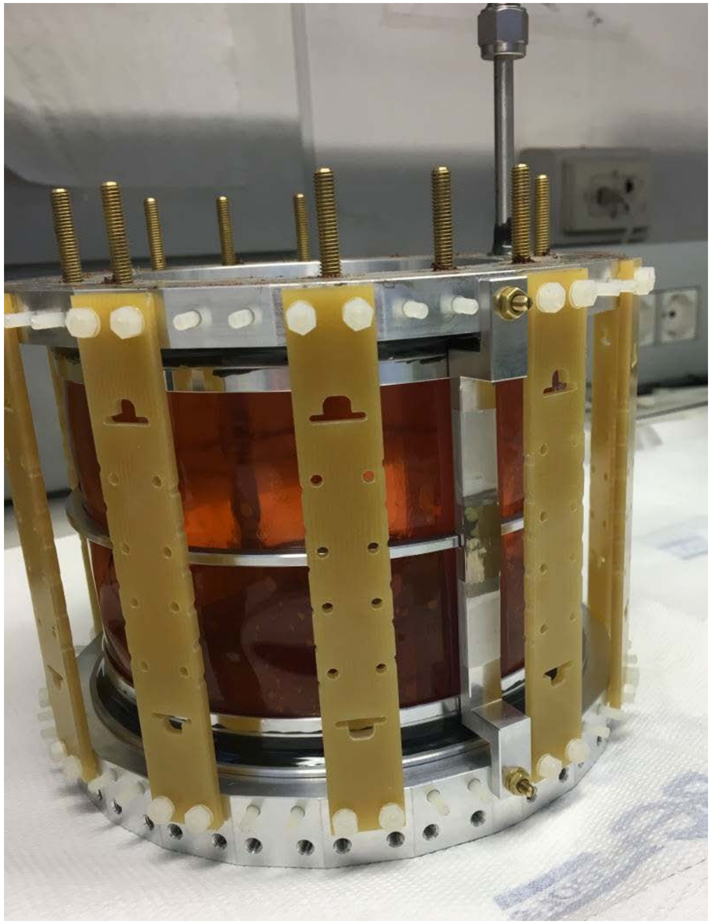


Final test during summer 2017:
Pressurised for 16 days
with P = 0.3 MPa (overP)

Cooling/pressure test
- 2.5 weeks 30 K / 0.19 MPa
- 3.5 days 30 K / 0.31 MPa

- Target cell wall is made of a 2-Kapton layer structure (25 μm + 25 μm + Araldit < 100 μm)
- **HP Deuterium generator**

Light target and Silicon Drift Detector assembly

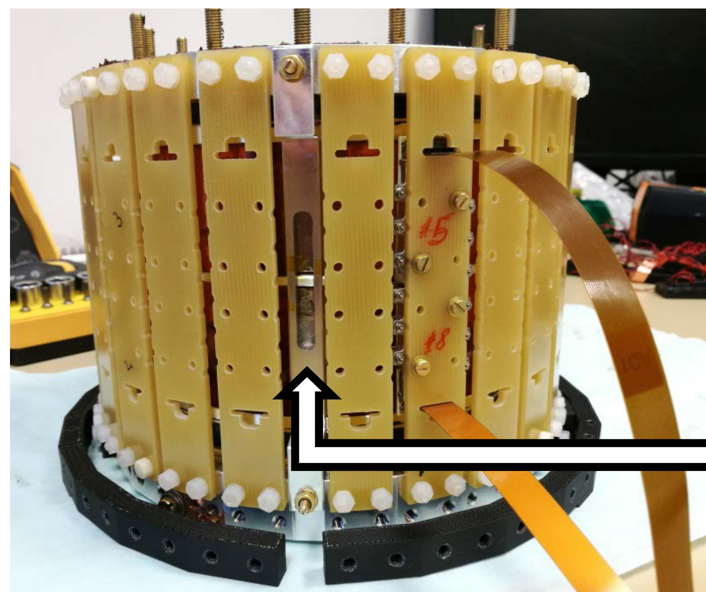


increase the target
stopping power

almost double gas
density with
respect to
SIDDHARTA (3% LHD)

SDDs placed 5 mm
from the target wall

Target cell wall is made of a
2-Kapton layer structure
(75 µm + 75 µm + Araldit)

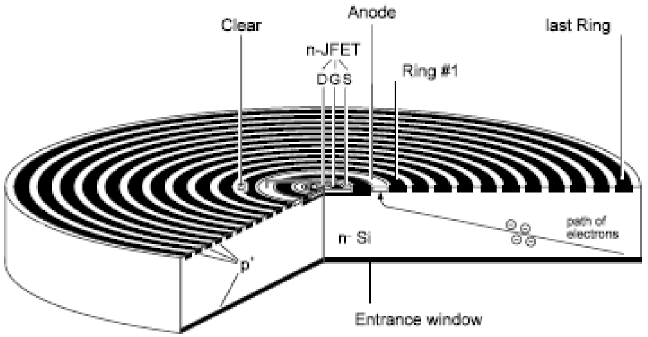


calibration foils inserted near to the SDD are activated by the X-ray tubes

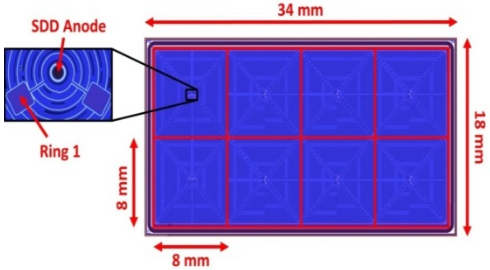
New SDD detectors

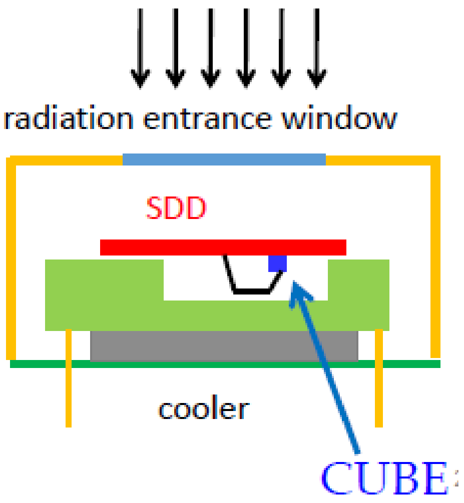
difference with respect to the SDDs in SIDDHARTA:

- the change of the preamplifier system from the JFET structure on the SDD chip to a complementary metal-oxide semiconductor integrated charge sensing amplifier CUBE), able to operate at very low temperatures (below 50 K) (standard SDD technology)
- reduction of the single element size (from 10 × 10 to 8 × 8 mm2)

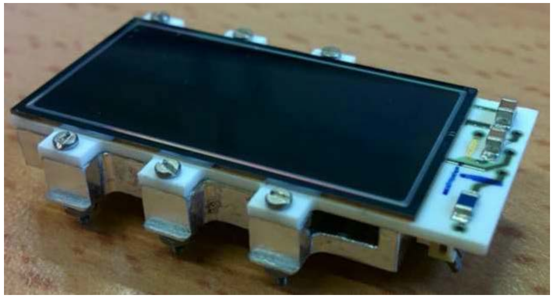


Better drift time of 300 ns compared to the SDDs in SIDDHARTA (~800 ns)





Monolitic 4x2 SDD array - single unit

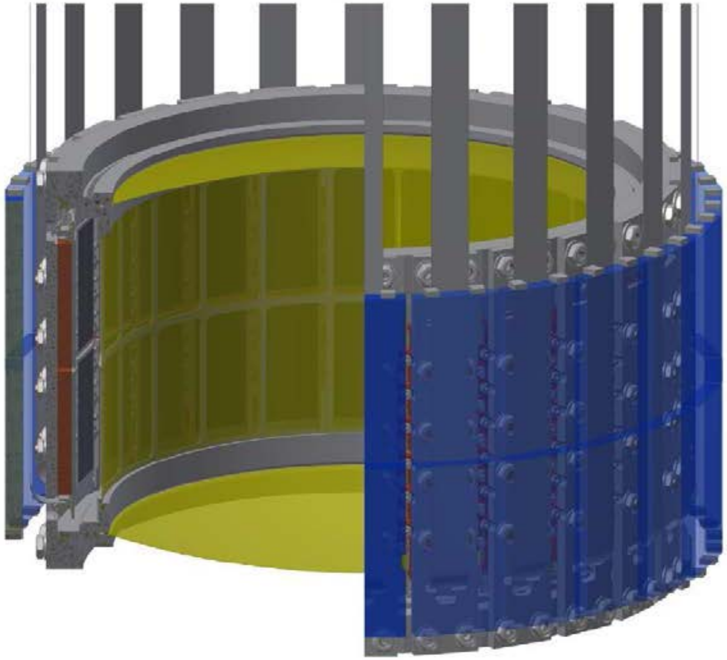


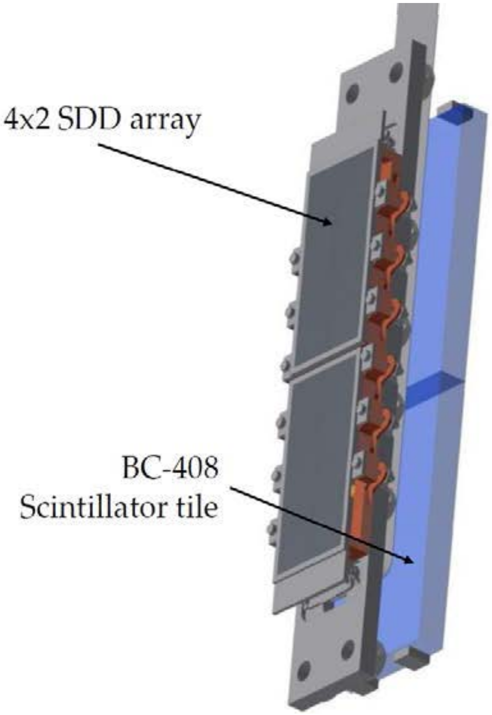
SDD characteristics:

- area/cell = 64 mm^2
- total area = 512 mm^2
- T = - 100°C
- drift time < 500 ns

More details:
see talk
F. Sgaramella

The 4 x2 SDD array around the target cell





The new advance technology will allow to setup a cryogenic target detector system with an efficient detector packing density,
covering a solid angle for stopped kaons in the gaseous target of ~ 2π.

48 monolithic SDD arrays will be around the target with a total area of about 246 cm^2

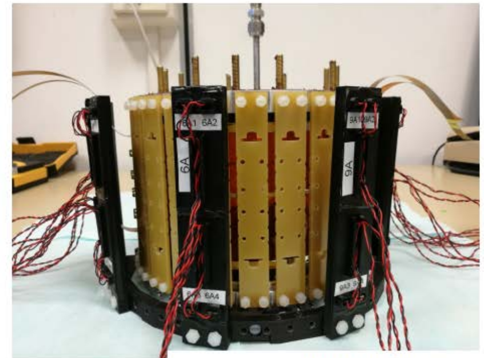
The Veto systems

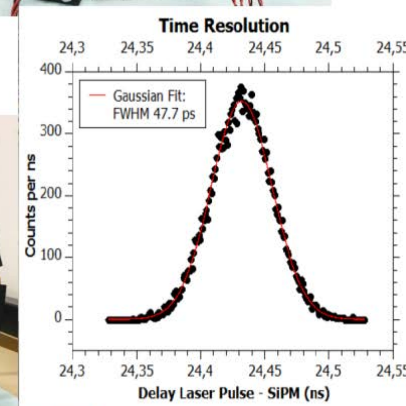
The veto-1 system:

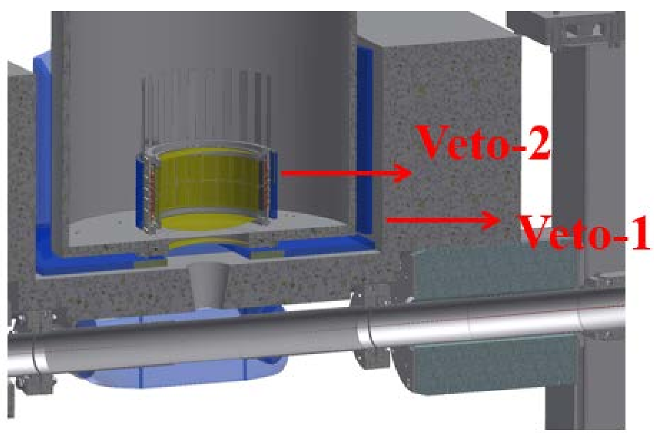
outer barrel of scintillators, acting as a gas stopping detector (and, possibly, as active shielding)- to identify the products of K- absorption on gas nuclei, characterized by a long moderation time (4-5 ns) (suppress the X-rays produce by the kaons stopped in gas from kaons stopped in setup material)

The veto-2 system:

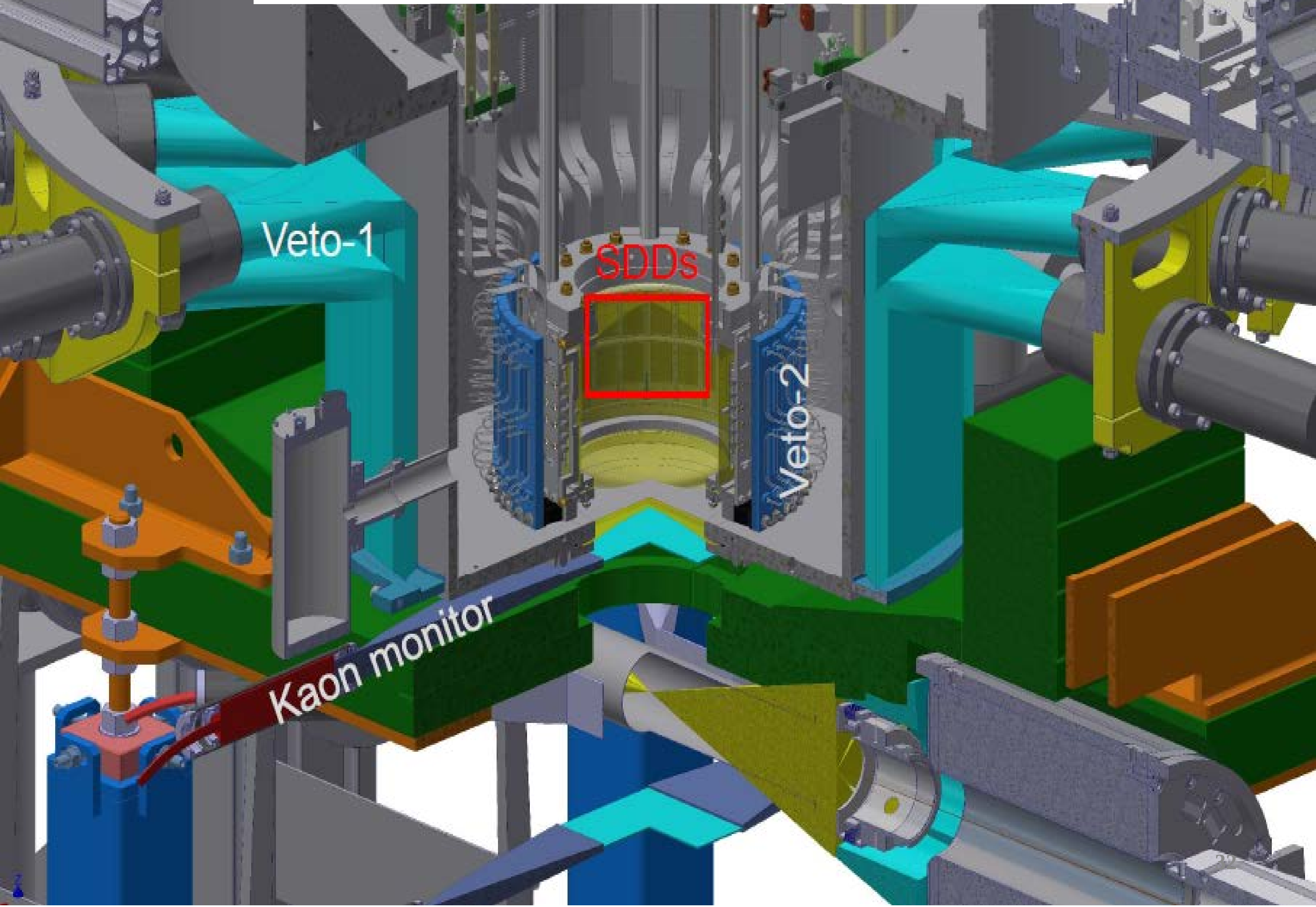
an inner ring of scintillator tiles (SciTiles) placed as close as possible behind the SDDs for charge particle tracking



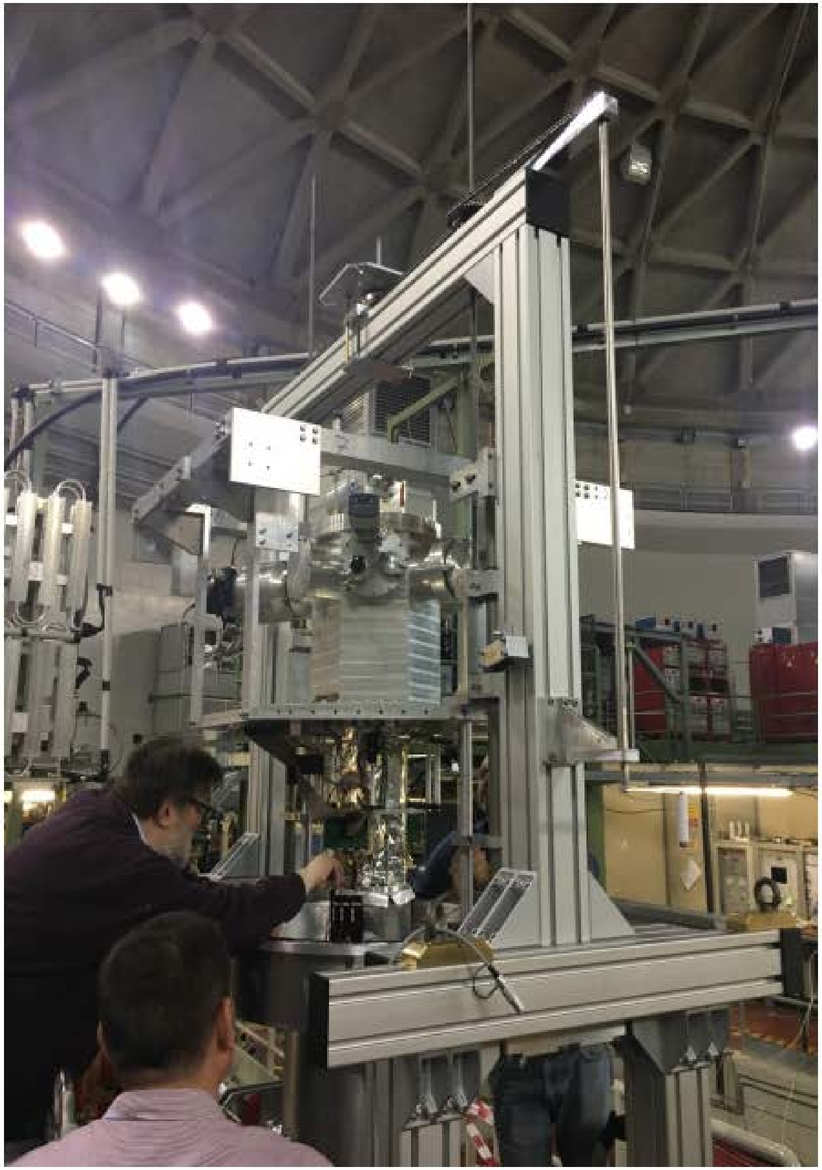




SIDDHARTA-2



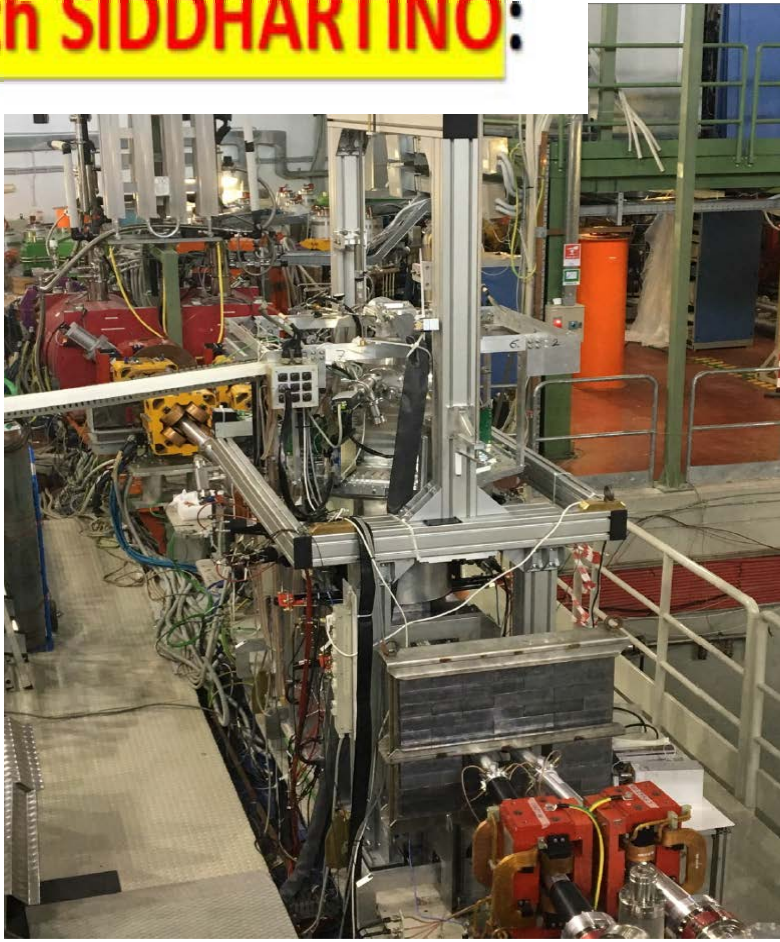
… precise adjustments …



… internal components

SIDDHARTA-2 PRESENT STATUS

We are presently in Phase 1 with SIDDHARTINO:



during the commissioning of DAΦNE

optimization with the SIDDHARTINO setup

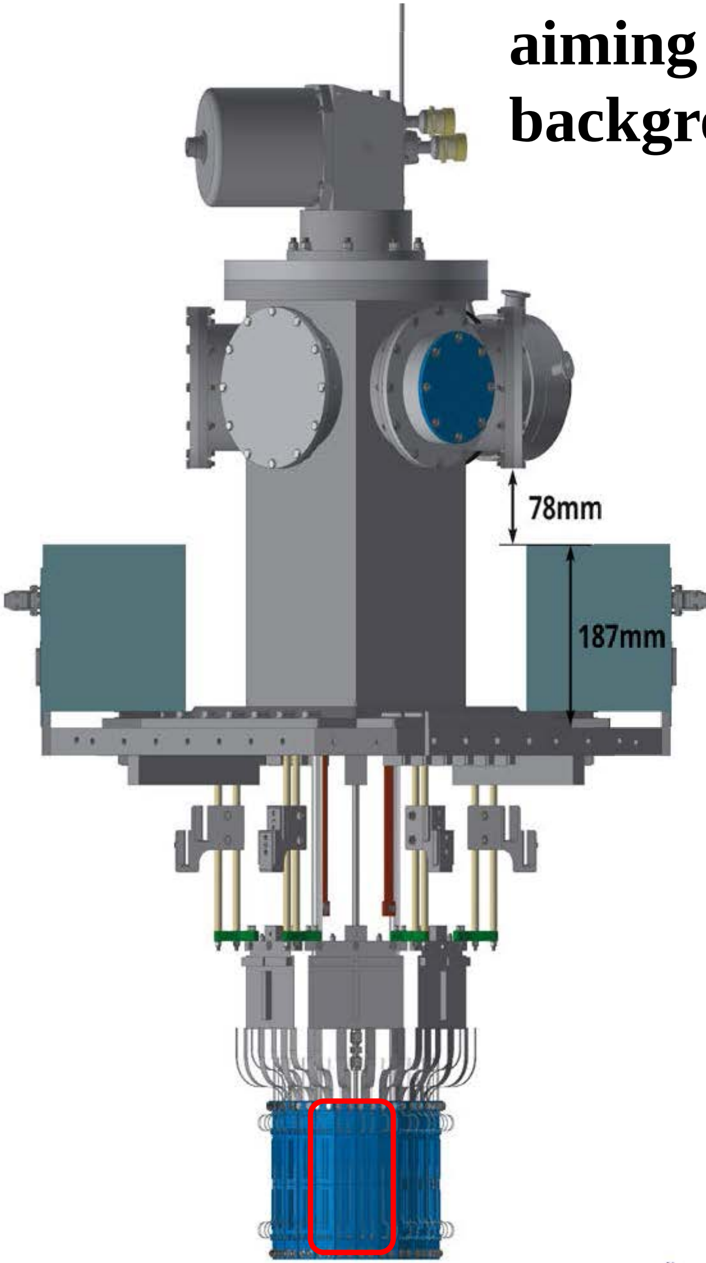
for the K^{-}-^{4}He measurement

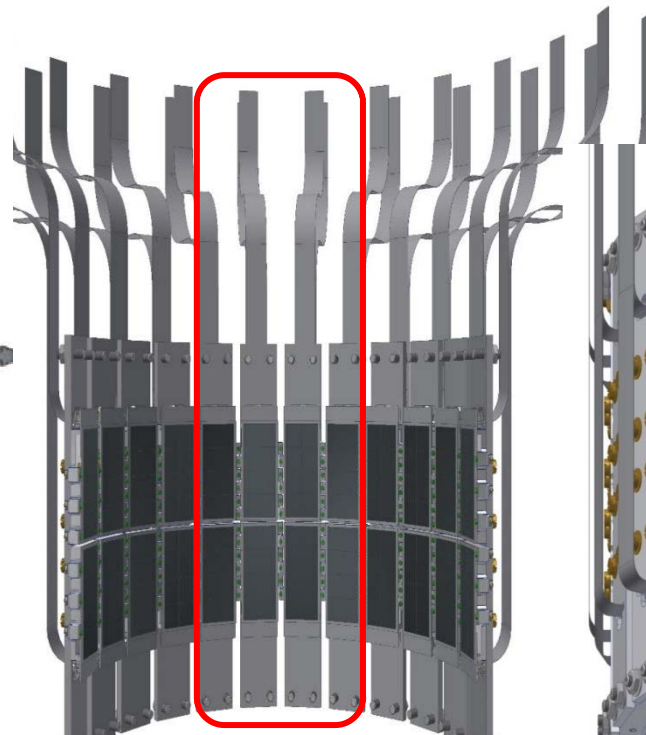
(with 8 SDD arrays)

Aim: confirm when DAΦNE background conditions are similar to those in SIDDHARTA 2009

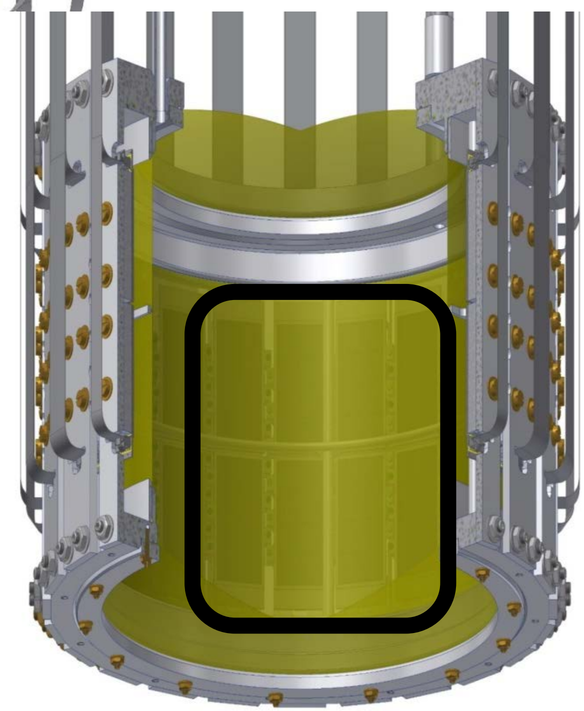
SIDDHARTINO = SIDDHARTA-2 with 8 SDDs arrays

aiming to measure kaonic helium to quantify the background in the new DAFNE configuration





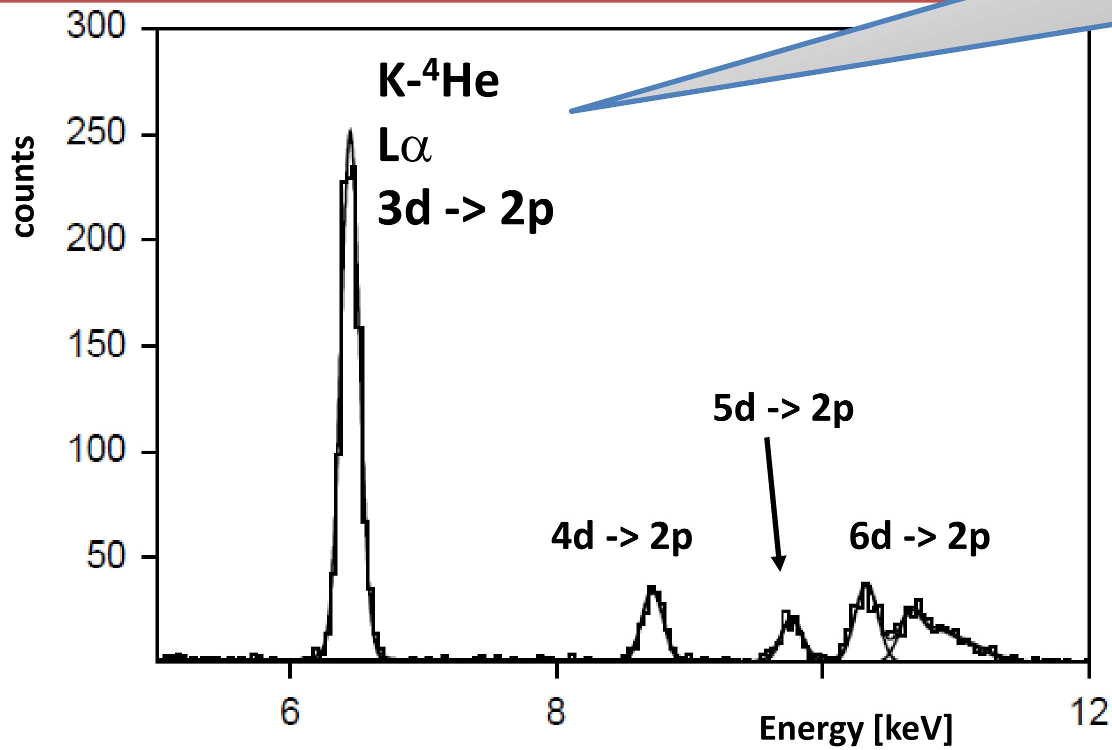
ONLY
8 SDD arrays
(out of 48)
1 BUS structure



More details:
see talk of M. Miliucci

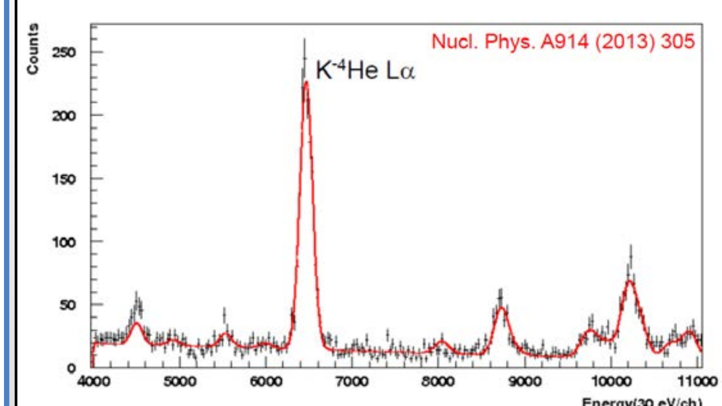
SIDDHARTINO – K-^{4}He test measurement

SIDDHARTINO expected spectrum for ~ 50 pb^{-1}
(one week of data taking in SIDDHARTA-like conditions)



About 1000 events in La peak, S/B > 100/1
(ideally should be 300/1)
Position precision :
6.452 +- 0.002 (stat) keV

SIDDHARTA measurement



S/B was 10/1 for the K-^{4}He measurement with ~ 30 pb^{-1}

Plan – Phase1:

- ***Work with SIDDHARTINO inside DAFNE: optimization SDD, trigger, DAQ, calib….***
  (see talks M. Miliucci, F. Sgaramella)
- ***Refine optimization of luminosity detector and cross check with DAFNE luminometer***
  (see talk F. Napolitano)
- ***Background reduction and optimization together with DAFNE for kaonic atoms measurements***
  (see talks M. Miliucci, F. Sgaramella)
- ***HPGe test run in parallel with SIDDHARTINO***

SIDDHARTINO in DAFNE
17 April 2019

SIDDHARTA-2 strategy

Phase 2
SIDDHARTA-2

Setup with all the SDDs (48 SDD arrays) all 2021 (22) and the *kaonic deuterium measurement* for a run of 800 pb^{-1}

Action plan for Kd measurement:

- **First run with SIDDHARTA-2 setup as planned (about 300 pb^{-1} integrated)**
- **Second run with optimized shielding, readout electronics and other necessary optimizations; (for other 500 pb^{-1} integrated)**

Test runs for other kaonic atoms measurements (HPGE…)

Phase-2: SIDDHARTA-2 K-d measurement

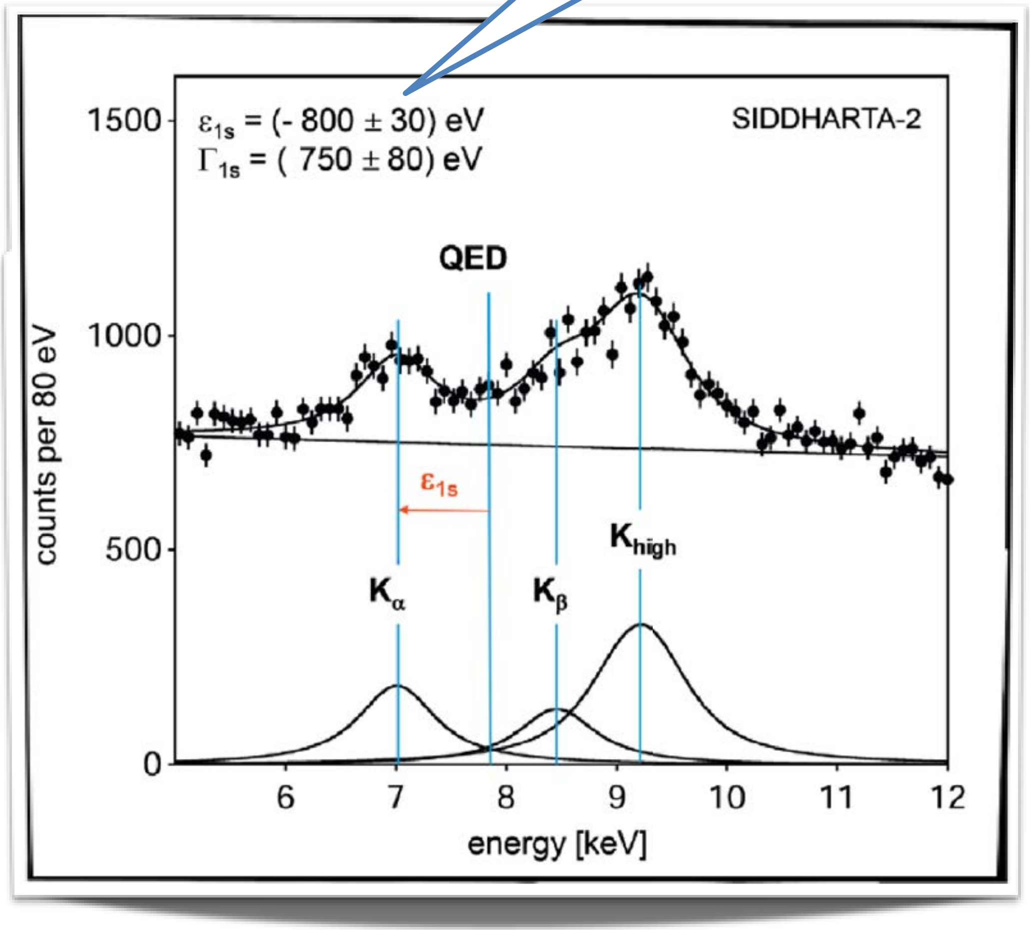
Kaonic deuterium run in (all) 2021

for S/B as 1/3:

for an integrated luminosity of 800 pb^{-1}

to perform the first measurement of the strong interaction induced energy shift and width of the kaonic deuterium ground state (similar precision as K^-p) !

achievable precision

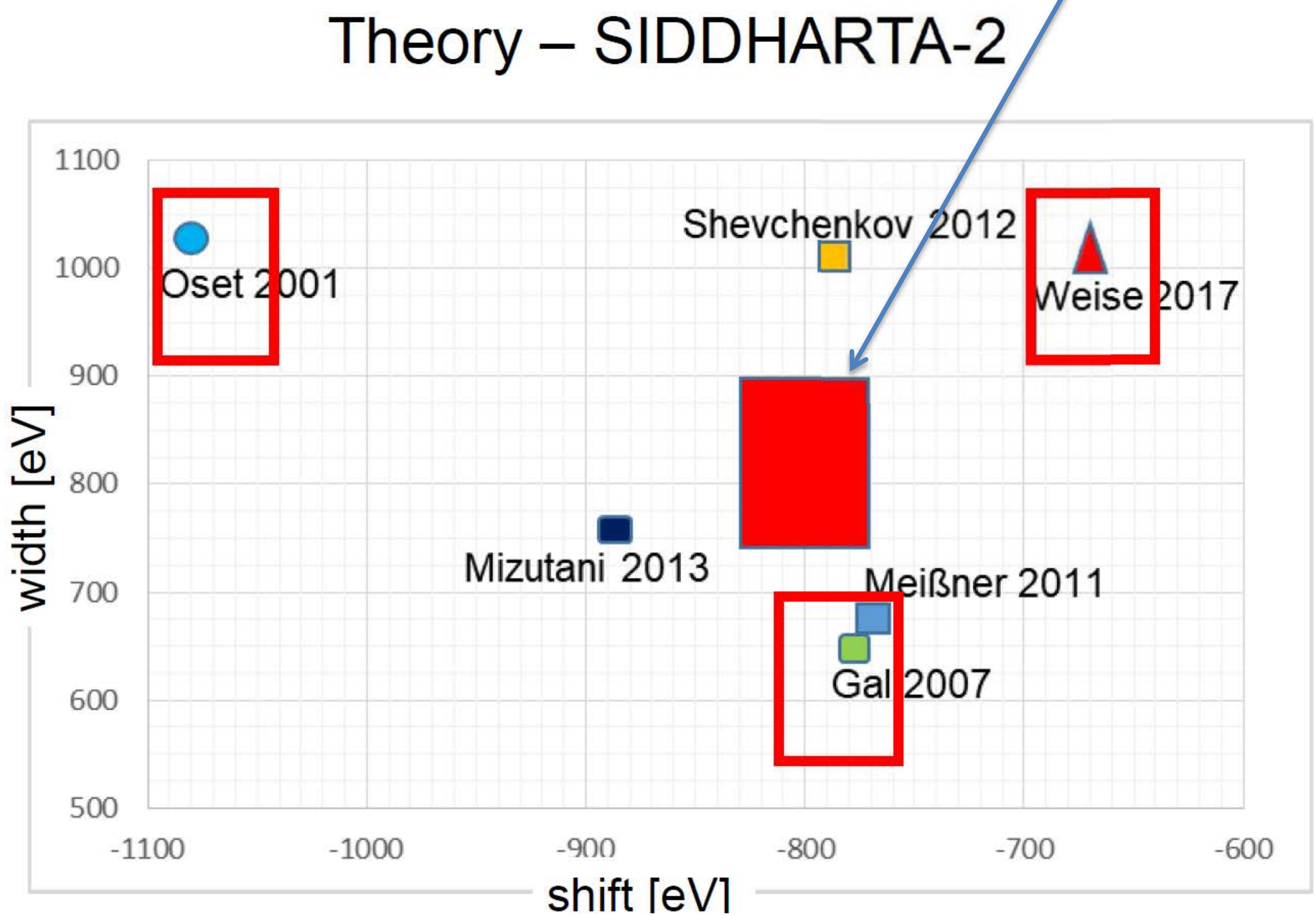


KH

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

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

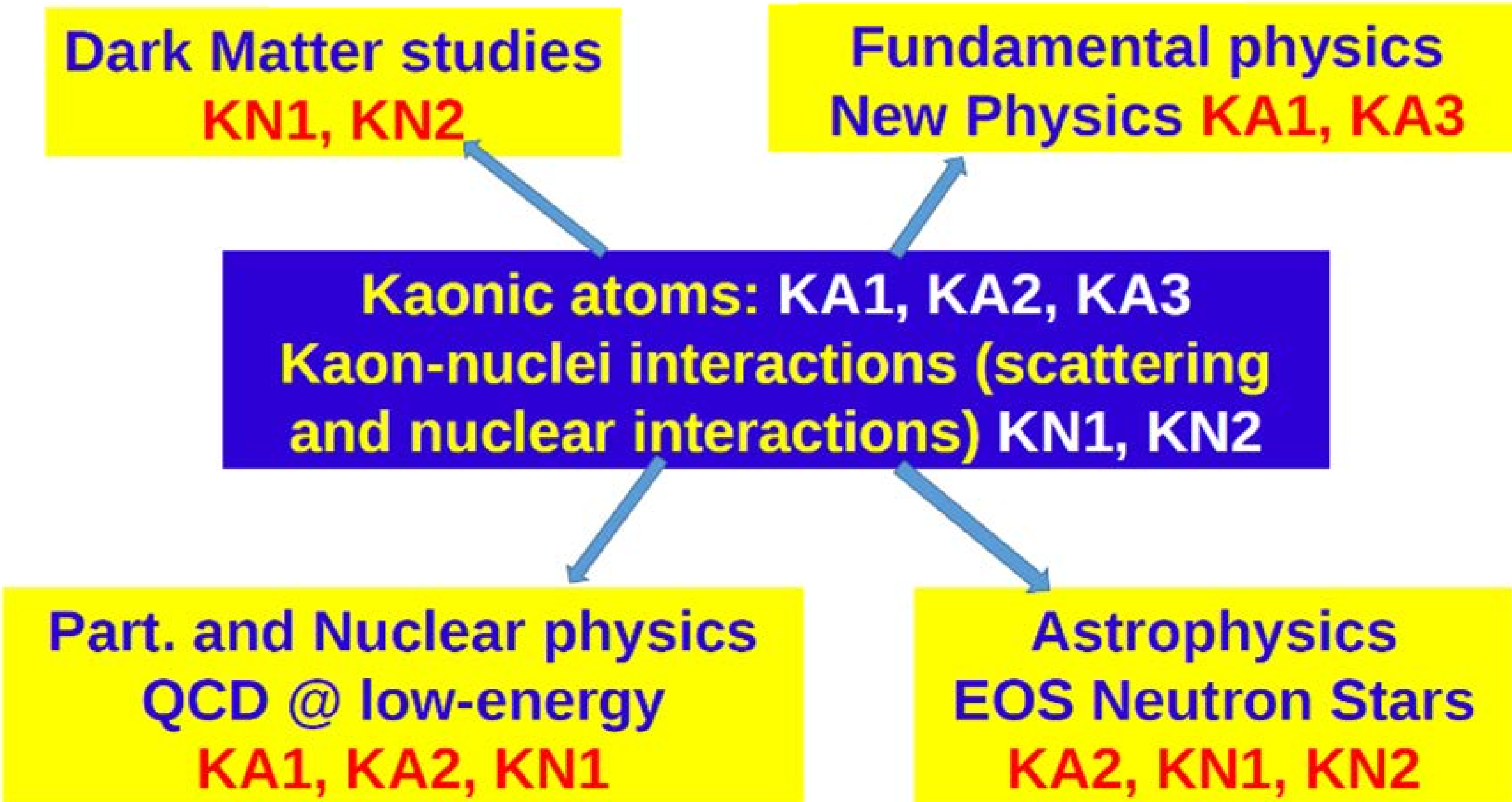
SIDDHARTA-2 targeted precision



The experimental result will set essential constraints for theories and will help to disentangle between different theoretical approaches

SIDDHARTA and SIDDHARTA-2 experiments on DAΦNE collider provide unique quality results for the understanding of the low-energy QCD in the strangeness sector.

FUTURE at DAΦNE



- **selected light and heavy kaonic atoms transitions (KA1, KA2, KA3)**
- **low-energy kaon-nucleon scattering processes (KN1)**
- **low-energy kaon-nuclei interactions (KN2)**

Priorities and readiness:

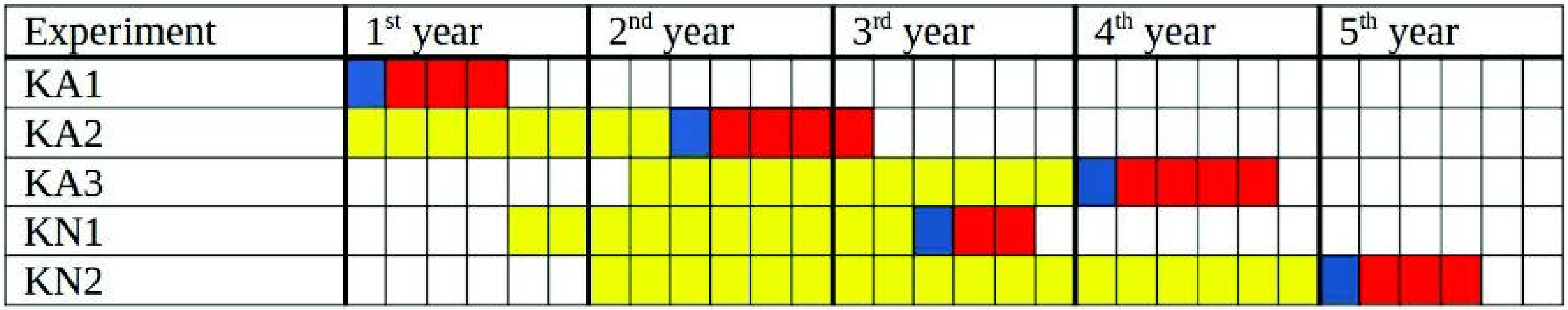


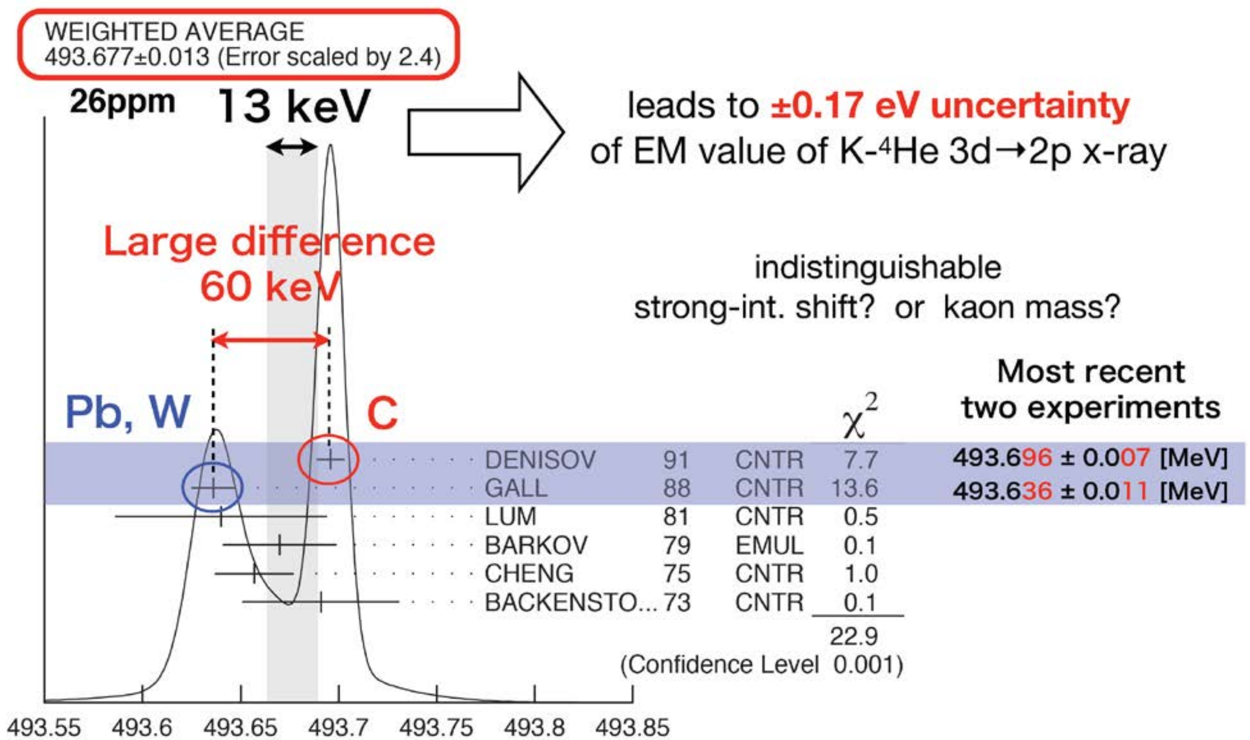
Fig. 1. Schematic Gantt Chart for Fundamental physics at the Strangeness Frontier at the DAΦNE Proposal: KA1 (see Sec. 2.1), KA2 (see Sec. 2.2), KA3 (see Sec. 2.3), KN1 (see Sec. 3.2), KN2 (see Sec. 3.3). Yellow: preparation phase. Blue: installation phase. Red: data taking.

Fundamental physics with kaonic atoms

Kaon mass discrepancy – impact on kaonic atoms; CPT, all physics where kaon mass is important such for charmed meson studies and searches beyond standard model

- a new measurement is strongly required – PDG…

The best D0 mass relies, and is limited by the K- mass (Claude Amsler; Simon Eydelman)



Uncertainty in electron screening. Gamma-ray contamination(Pb,W).

→ **new measurement with low-Z gas targets**

KA1: Kaon Mass and High Z kaonic atoms: HPGE

Possible kaonic transitions to be measured:

KC(2→1) : 340 keV
KC(3→1): 402 keV

KSe(4→3): 733 keV
KSe(5→4): 339 keV
KSe(5→3): 1073 keV
KSe(6→5) : 184 keV
KSe(6→4): 524 keV

KZr(4→3): 1015 keV
KZr(5→4): 470 keV
KZr(5→3): 1485 keV
KZr(6→5) : 255 keV
KZr(6→4): 725 keV

KTa(6→5): 853 keV
KTa(7→6): 514 keV
KTa(7→5) : 1367 keV
KTa(8→7): 334 keV
KTa(8→6): 848 keV

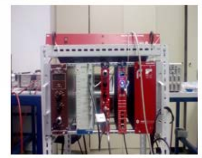
KPb(6→5) : 1076 keV
KPb(7→6): 649 keV
KPb(8→7): 421 keV
KPb(8→6): 1070 keV
KPb(9→8): 289 keV

Feasibility:

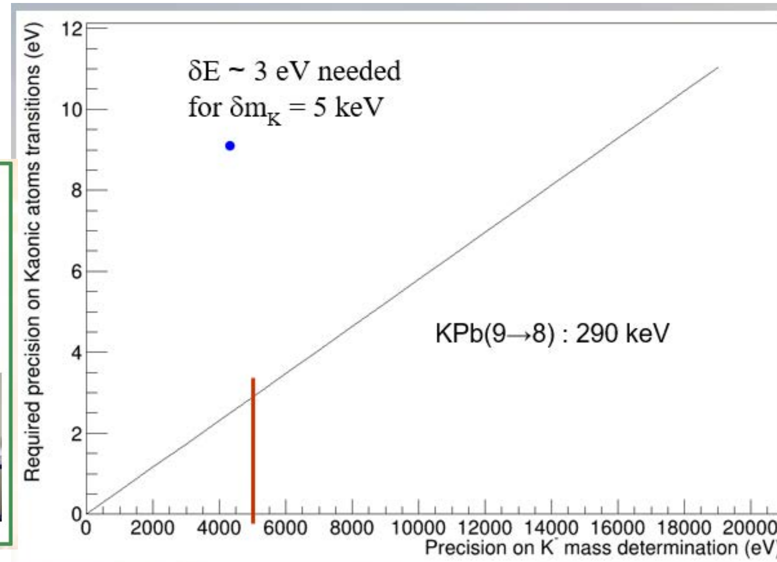
HPGe detector available,
Funded by University of Zagreb
Croatian Science Foundation project 8570

Resolutions (FWHM)
obtained with ^{60}Co, ^{133}Ba sources :

0.870 keV @ 81 keV
1.106 keV @ 302.9 keV
1.143 keV @ 356 keV
1.167 keV @ 1330 keV



Detector system ready for measurements!



$$\sigma m_K = \frac{m_K^2}{\mu_{KN}^2}\frac{1}{Z^2}\frac{10^6}{26,6}\frac{\sigma E^K_{X\to Y}}{\left(\frac{1}{Y^2}-\frac{1}{X^2}\right)}$$

Target just behind
the luminometer,
which is used as trigger

Detector Key Points:
- **Very large dynamic range**
- **Possibility to test High Z targets**
- **High resolution for precision measurements**
- **Rate capability up to 150 kHz**

Dedicated measurements:

- **Targets : Se, Zr, Ta, Pb (systematic errors minimisation, cascade processes in heavy kaonic atoms)**

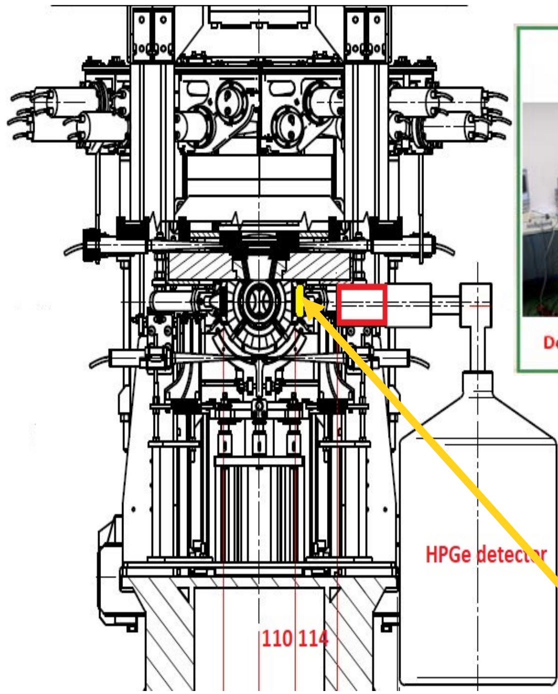
~ 360 pb-1 (~ 30 days) of beamtime requested

!!! Similar estimations for each target !!!

-

KA1: Kaon Mass and High Z kaonic atoms: HPGE

Feasibility test run during SIDDHARTA-2: KPb




Feasibility:

HPGe detector available,
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Resolutions (FWHM)
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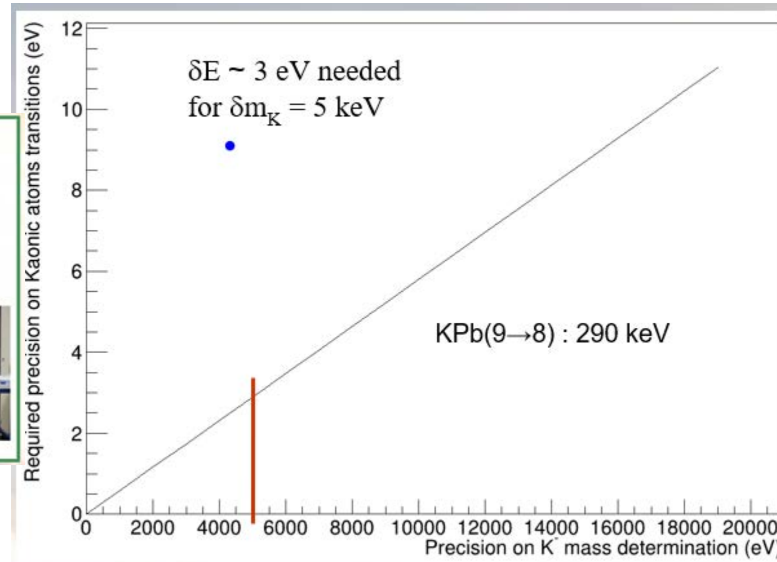
Detector system ready for measurements!



$$\sigma m_K = \frac{m_K^2}{\mu_{KN}^2}\,\frac{1}{Z^2}\,\frac{10^6}{26,6}\,\frac{\sigma E^K_{X\to Y}}{\left(\frac{1}{Y^2}-\frac{1}{X^2}\right)}$$

Detector Key Points:
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Target just behind
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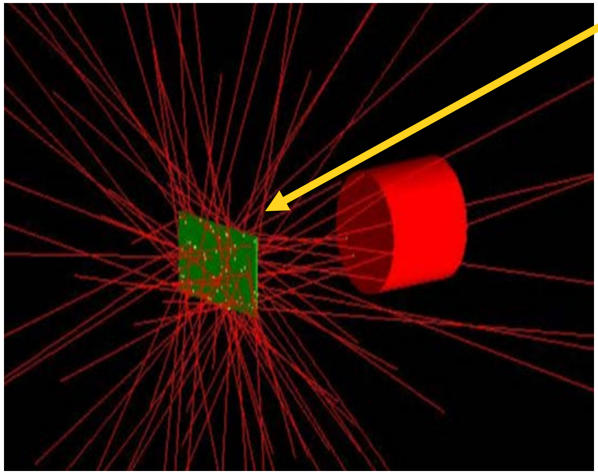


Dedicated measurements:

- **Targets : Se, Zr, Ta, Pb (systematic errors minimisation, cascade processes in heavy kaonic atoms)**

-

~ 360 pb-1 (~ 30 days) of beamtime requested

!!! Similar estimations for each target !!!

KA2: Light Kaonic Atoms Measurements

Expected impact:

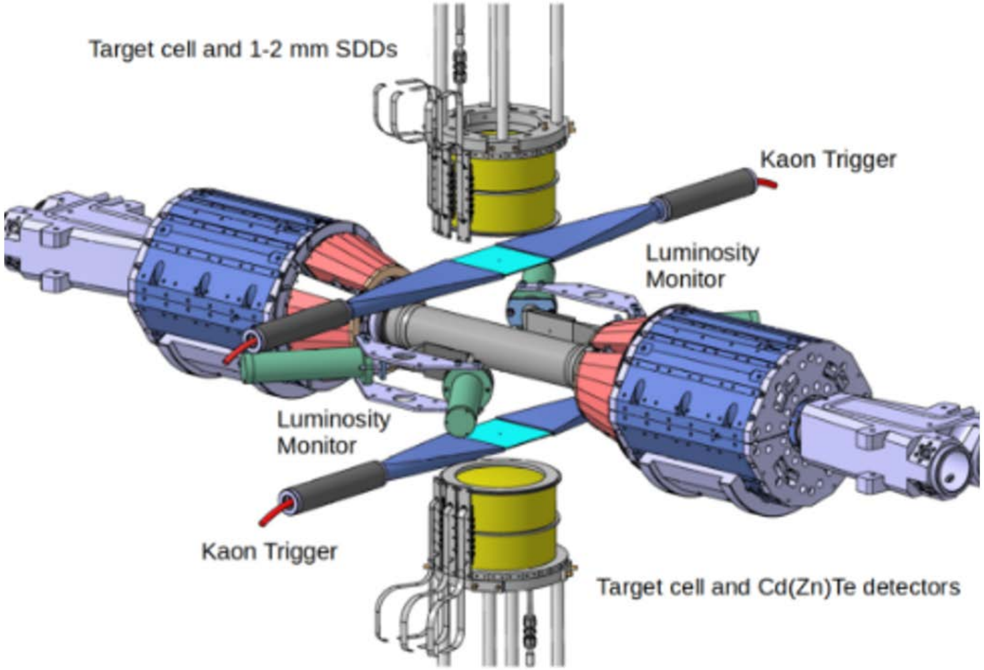
- **kaon-nuclei potential and chiral models below threshold and the nature of $\Lambda(1405)$.**
- **astrophysics: search for dark matter with strangeness and the equation of state for neutrons stars**
- **K3,4He(2p → 1s) transition: stronger constraints on the theoretical models describing the kaon-nucleon interaction in systems with more than two nucleons**
- **Information on the nature of the $\Lambda(1405)$ state can be obtained from the upper-level transitions of light kaonic atoms (different isotopes of KLi, KBe and KB[35])**

Proposed measurements:

- Targets : ^{3,4}He, ^{6,7}Li, ^{8,9}Be, ^{10,11}B
both low level and high level transitions with Δn = 1, 2, ...5, and energies in the range 10-100 keV

Second SIDDHARTA-2 like setup

Setup: SDD1mm & CdTe



SDD 1mm - FBK – FINANCED AND ORDERED

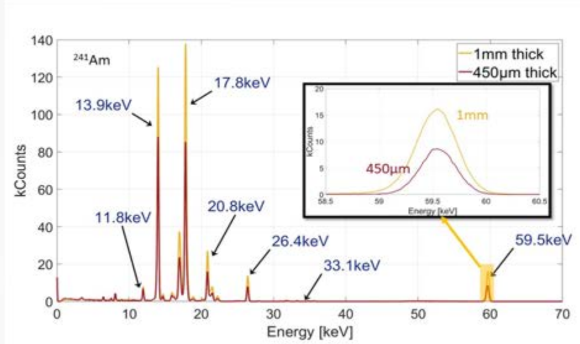
Possible kaonic transitions to be measured with 1-2 mm SDDs:

$K^3He(2\rightarrow1)$: 33 keV
$K^4He(2\rightarrow1)$: 35 keV

$K^{6,7}Li(3\rightarrow2)$: 15 keV
$K^{6,7}Li(4\rightarrow2)$: 20 keV

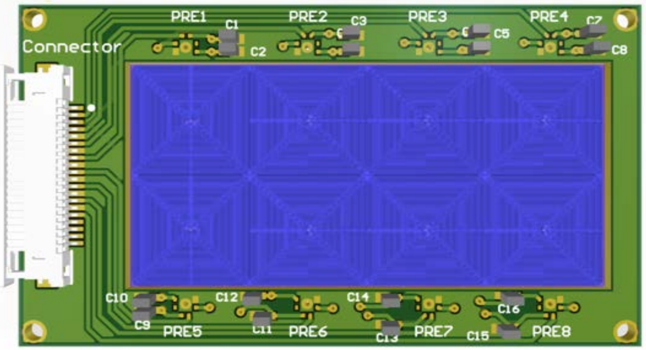
$K^{8,9}Be(3\rightarrow2)$: 27 keV
$K^{8,9}Be(4\rightarrow2)$: 37 keV
$K^{8,9}Be(5\rightarrow3)$: 14 keV

$K^{9,10,11}B(4\rightarrow3)$: 15 keV
$K^{9,10,11}B(5\rightarrow3)$: 22 keV
$K^{9,10,11}B(6\rightarrow4)$: 11 keV



First XRF tests with known targets show very pron
results

Prototypes of electronics boards are already available

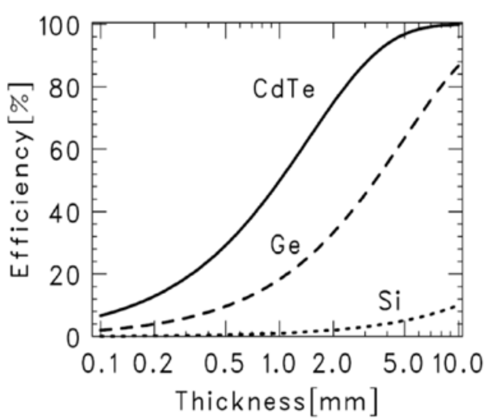


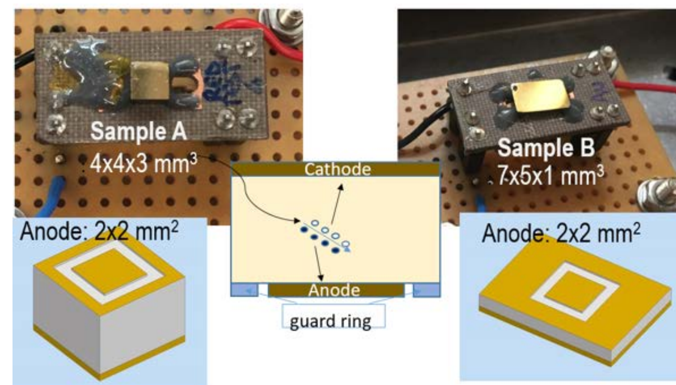
Cd(Zn)Te

Possible kaonic transitions to be measured with
CdTe detectors:

$K^6Li(2\rightarrow1)$: 81 keV
$K^6Li(3\rightarrow1)$: 97 keV
$K^7Li(2\rightarrow1)$: 82 keV
$K^7Li(3\rightarrow1)$: 98 keV
$K^{9,10}B(4\rightarrow2)$: 58 keV
$K^{9,10}B(5\rightarrow2)$: 65 keV
$K^{9,10}B(6\rightarrow2)$: 69 keV
$K^{9,10}B(7\rightarrow2)$: 71 keV
$K^{11}B(4\rightarrow2)$: 59 keV
$K^{11}B(5\rightarrow2)$: 66 keV
$K^{11}B(6\rightarrow2)$: 70 keV
$K^{11}B(7\rightarrow2)$: 72 keV

required 300 pb-1 for each target





CdTe (and also CdZnTe) detectors will be developed in the STRONG2020-ASTRA project

First prototypes will be available by mid ‘22

KA3: sub-eV precision Kaonic Atoms measurements: VOXES

Kaon-Nucleon interaction:
Chiral vs Phenomenological models

Possible kaonic transitions to be measured with HAPG crystal spectrometer:

$K^3He(3\to2)$: 6.2 keV
$K^3He(4\to2)$: 8.4 keV
$K^3He(5\to2)$: 9.4 keV
$K^3He(6\to2)$: 9.9 keV
$K^3He(7\to2)$: 10.2 keV

$K^4He(3\to2)$: 6.4 keV
$K^4He(4\to2)$: 8.7 keV
$K^4He(5\to2)$: 9.7 keV
$K^4He(6\to2)$: 10.3 keV
$K^4He(7\to2)$: 10.7 keV

$KN(6\to5)$: 7.6 keV
$KN(7\to5)$: 12.1 keV
$KN(8\to5)$: 15.1 keV
$KN(7\to6)$: 4.6 keV
$KN(8\to6)$: 7.5 keV
$KN(9\to6)$: 9.6 keV
$KN(10\to6)$: 11 keV
$KN(11\to6)$: 12.1 keV
$KN(10\to7)$: 6.5 keV
$KN(11\to7)$: 7.5 keV
$KN(12\to7)$: 8.3 keV

MORE DETAILS:
See talk of A. Scordo

Solve the kaonic helium isotopic shift problem

Precise determination of the K^- mass (2)

Stronger constraints for the EM cascade models for kaonic atoms

New Physics?

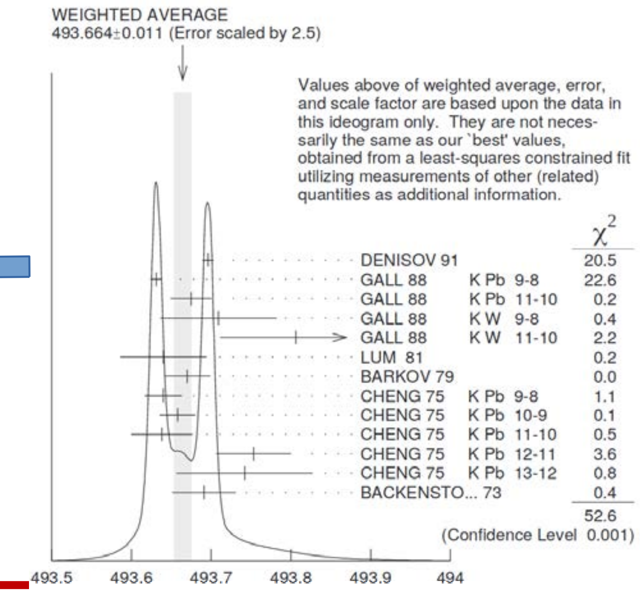
… ALL IN PARALLEL

But...EM calculated levels depend on the cascade processes...

There is only ONE possible solving measurment:
The $K^{3,4}He$ **isotopic shift measurement**

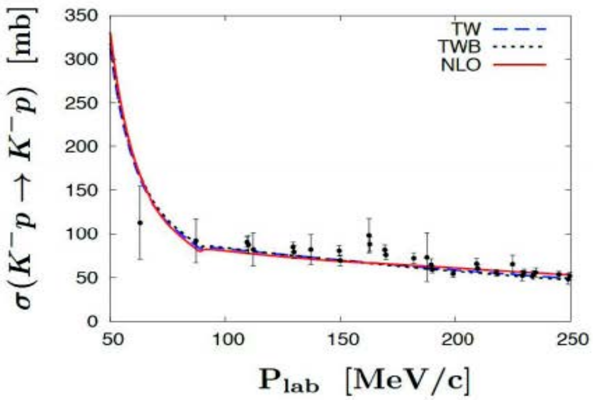
Calculated quantity [1]	Phenomenologica [2]	Chiral [3]
$\varepsilon(K^4He)$	-0,41 eV	-0,09 eV
$\varepsilon(K^3He)$	0,23 eV	-0,1 eV
$\varepsilon(K^4He) - \varepsilon(K^3He)$	-0,64 eV	0,01 eV

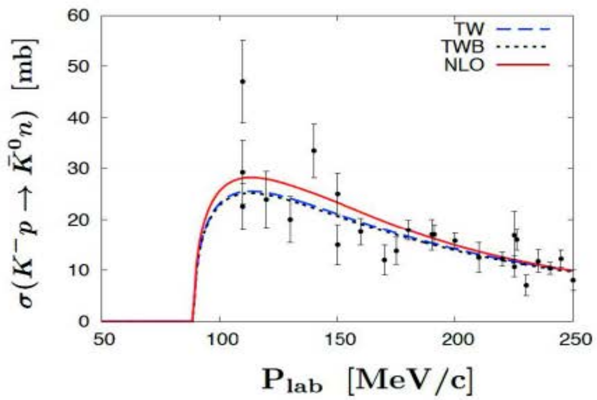
But...levels and calculated shifts depend on the K^- mass value...



Kaon-nuclei scattering and interaction: KN1, KN2

- The present knowledge of total and differential cross sections of low energy kaon-nucleon reactions is very limited.
- Below 150 MeV/c there is a “desert” - the experimental data are very scarce and with large errors and practically no data exist below 100 MeV/c.
- **Studies of Hyperon-nucleon, Hyeron-multinucleon (AMADEUS experience)**
- **Kaon-nucleon scattering/interaction data are fundamental to validate theories: chiral symmetries; lattice calculations; potential models etc.**





Measurement of the low-energy scattering process of kaons, and of the Λ(1405) kaon induced production, on various targets such as hydrogen, deuterium, helium-3 and helium-4

FUTURE at DAΦNE

Fundamental physics at the strangeness frontier at DAΦNE.
Outline of a proposal for future measurements.

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K. Piscicchia

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S. Eidelman

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H. Ohnishi, Y. Sada

Research Center for Electron Photon Science, Tohoku University, Sendai, Japan

arXiv:2104.06076v1 [nucl-ex] 13 Apr 2021

The DAΦNE collider at INFN-LNF is a unique source of low-energy kaons, which was used by the DEAR, SIDDHARTA and AMADEUS collaborations for unique measurements of kaonic atoms and kaon-nuclei interactions. Presently, the SIDDHARTA-2 collaboration is underway to measure the kaonic deuterium exotic atom. With this document we outline a proposal for fundamental physics at the strangeness frontier for future measurements of kaonic atoms and kaon-nuclei interactions at DAΦNE, which is intended to stimulate discussions within the broad scientific community performing research directly or indirectly related to this field.

PACS numbers: 13.75.Jz, 36.10.-k, 36.10.Gv, 14.40.-n, 25.80.Nv, 29.30.-h, 29.90.+r, 87.64.Gb, 07.85.Fv, 29.40.-n, 29.40.Gx, 29.40.Wk

https://arxiv.org/pdf/2104.06076.pdf

Towards a LOI

(authors: Editorial Board only)

FUTURE at DAΦNE

Support:

STRONG-2020, EU

THEIA Network

Theoreticians who provided input:

- Ignazio Bombaci
- Alessandro Drago
- Isaac Vidana
- Wolfram Weise, TU Munich
- Avraham Gal, Jerusalem
- Eli Friedman, Jerusalem
- Jiri Mares. Prague
- Oset & Ramos, Spain
- Laura Tolos, Spain
- Ulf Meissner, Bonn & China
- Tony Thomas, Adelaide
- Tetsuo Hyodo, Japan
- Shota Ohnishi, Japan
- Maxim Pospelov, Randolf Pohl -> new physics

Contacted and consider signing LOI (groups of)

- ***Theoreticians from list shown + others***
- **Laura Fabbietti, TUM, Germany**
- **Paul Indelicato, CNRS, France**
- **Hiroyuki Noumi, Osaka Univ. Japan**
- **Shinji Okada, Chubu Univ., Japan**
- **Fuminori Sakuma, RIKEN, Japan**
- **Kiyoshi Tanida, JPARC, Japan**
- **Hiroaki Ohnishi, Sendai and Tohoku, Japan**
- **Simon Eidelman, Novosibirsk, Russia**
- **Moskov Amaryan, Old Dominion University, USA**
- **Pawel Moskal, Jagiellonian Univ, Poland**
- **Josef Pochodzalla, Mainz Univ, Germany**
- **Mario Bragadireanu, IFIN-HH, Romania**
- **Damir Bosnar, Univ. Zagreb, Croatia**
- **Igor Strakovsky, SAID INS The George Washington University, USA**
- **INFN (LNF + more), Italy**
- **SMI, Vienna, Austria**

11 countries

LOI/Technical Design Report in preparation

We strongly believe that this is an opportunity which cannot be missed, since we propose to measure fundamental interaction processes which could not be measured till now, and which will have <u>a huge and concrete impact, “now and here”, in particle and nuclear physics, astrophysics, cosmology and foundational Issues, supported by a strong international collaboration.</u>

Our proposed measurements have a huge potential of producing a consistent number of high-impact publications in high-impact factor journals, which will guide the developments of physics at strangeness frontier in the next 10-20 years, setting DAΦNE and LNF on the forefront of fundamental physics studies.