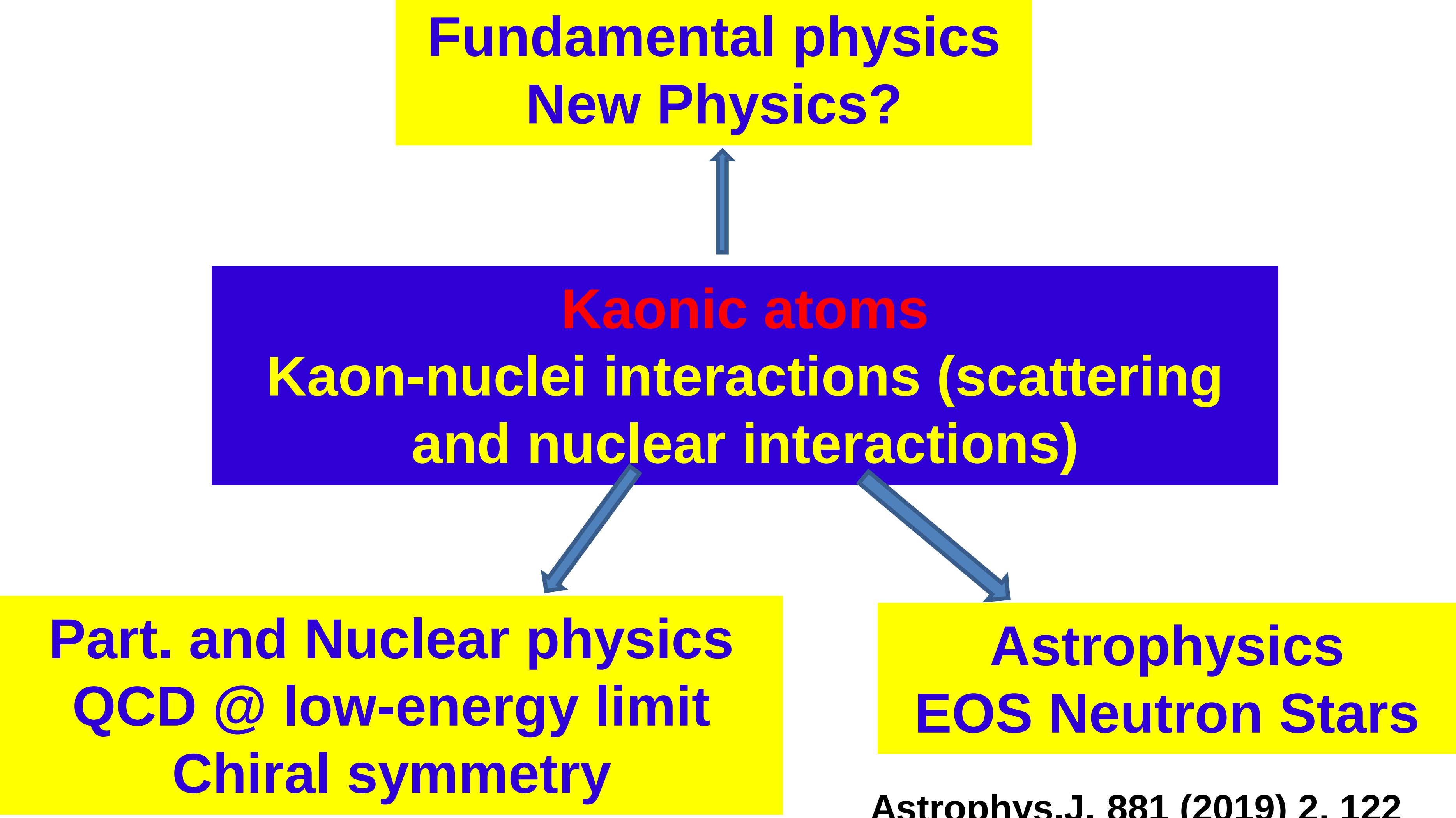
Kaonic atoms spectroscopy at DAFN
overview and perspectives

Catalina Curceanu, LNF-INFN (Italy)
on behalf of the SIDDHARTA-2 collaboration

THEIA – STRONG-2020
9th Dec. 2020 (online)

Rev.Mod.Phys. 91 (2019) 2, 025006

The modern era of light kaonic atom experiments



Fundamental physics
New Physics?

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

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

Astrophysics
EOS Neutron Stars

Kaonic Atoms to Investigate Global Symmetry Breaking

Symmetry 12 (2020) 4, 547

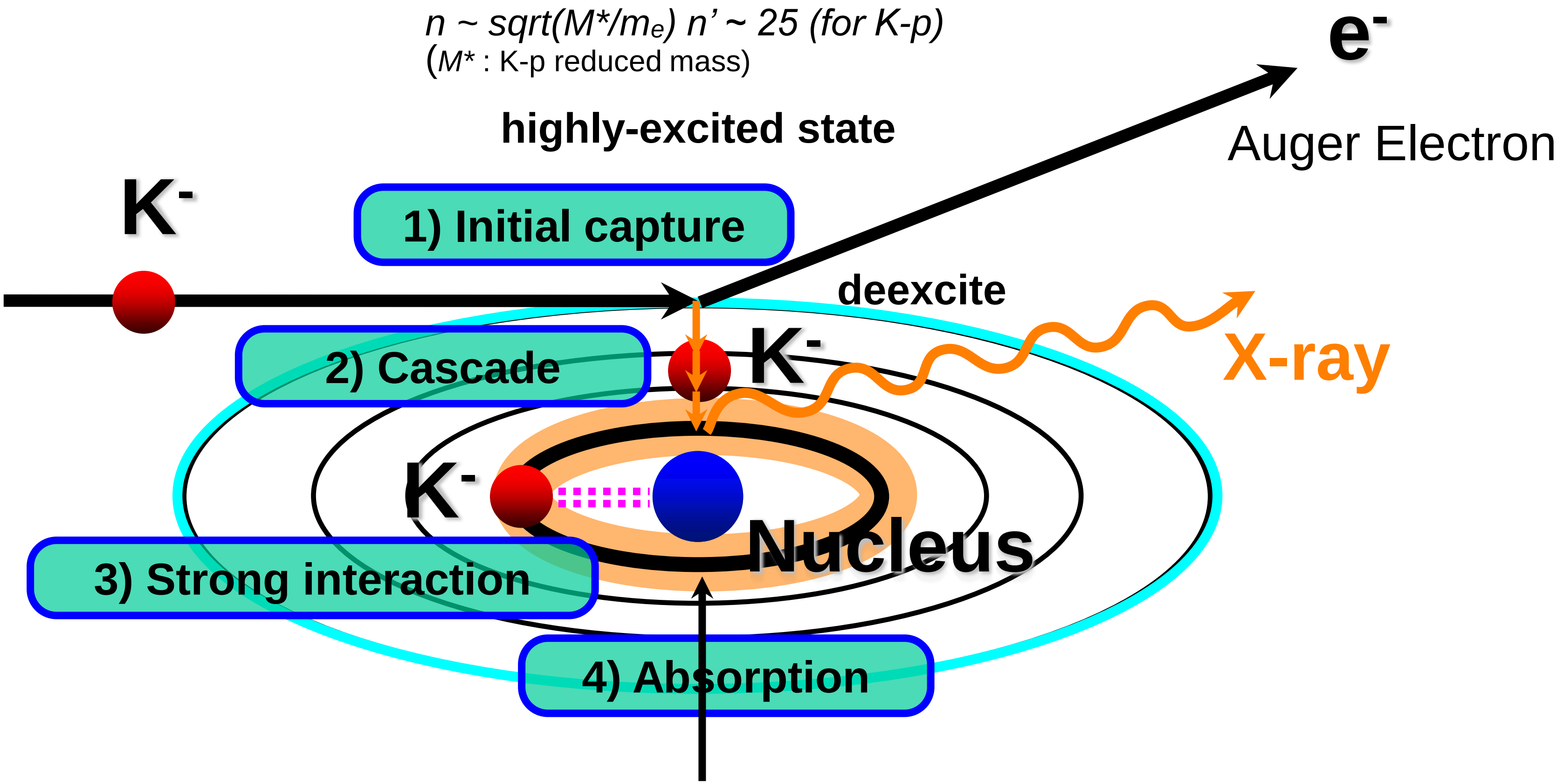
Astrophys.J. 881 (2019) 2, 122

Merger of compact stars in the two-families scenario

Kaonic atoms spectroscopy: at DAFNE

Kaonis atoms: brief introduction

Kaonic atom formation



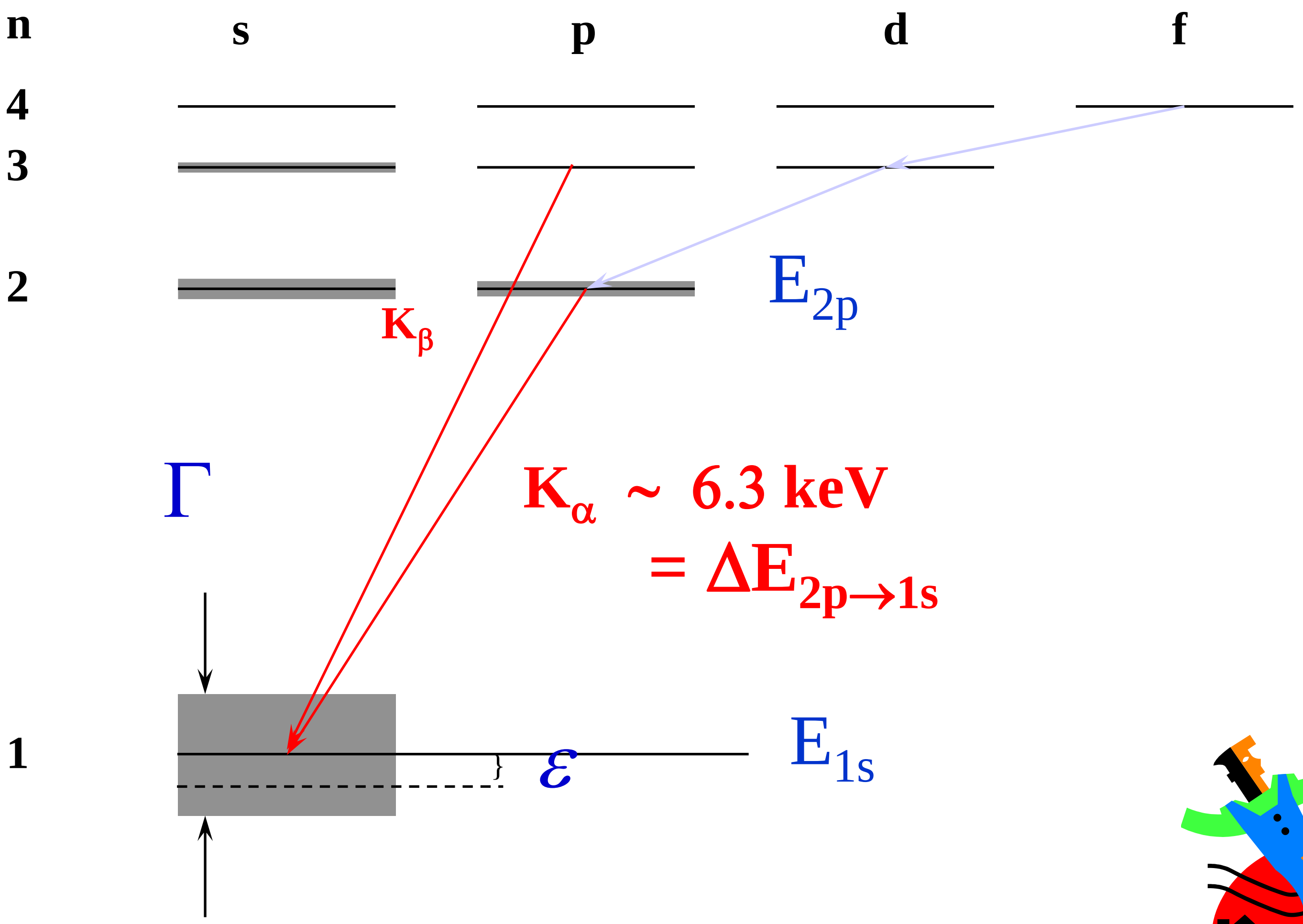
stopped in a target medium

Shift and Width of last orbit

The strong int. width > Radiative width

- **1s** for K-p, K-d
- **2p** for K-He

Kaonic cascade and the strong interaction



$K_\alpha \sim$ **6.3 keV**

$= \Delta E_{2p\rightarrow 1s}$

The (main) scientific aim

the determination of the ***isospin dependent***
KN scattering lengths through a

–

~ precision measurement of the shift
and *of the width*

of the K_α line of **kaonic hydrogen**

and

of **kaonic deuterium**

Measurements of kaonic Helium 3 and 4 as well (2p level)
And other types of exotic atoms

Antikaon-nucleon scattering lengths

Once the shift and width of the 1s level for kaonic hydrogen and deuterium are measured -) scattering lengths

(isospin breaking corrections):

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-p}\ \mathrm{eV\ fm}^{-1}$$

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-d}\ \mathrm{eV\ fm}^{-1}$$

one can obtain the isospin dependent antikaon-nucleon scattering lengths

$$a_{K^-p} = (a_0 + a_1)/2$$

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

SCATTERING LENGTHS

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

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

(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

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

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

⇐

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

$$k = \frac{4[m_n + m_K]}{[2m_n + m_K]}$$

Importance of the kaonic atoms studies

Measuring the $\bar{K}N$ scattering lengths with the precision of a few percent will drastically change the present status of low-energy $\bar{K}N$ phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

↓

1. **Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;**
2. **Threshold amplitude in QCD**
3. **Information on Λ(1405)**
4. **Contribute to the determination of the *KN sigma terms*, which give the degree of chiral symmetry breaking;**
5. **4 related alaso with the determination of the *strangeness content of the nucleon* from the KN sigma terms**

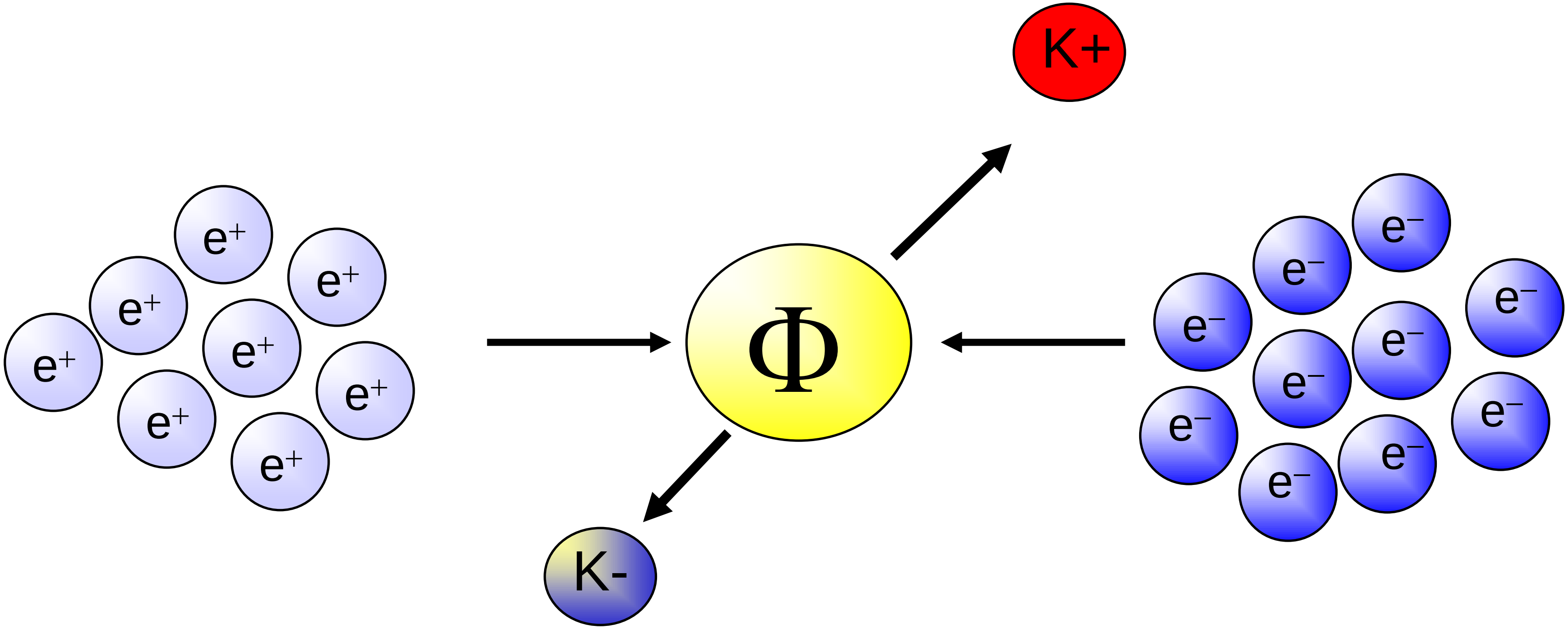
Kaonis atoms are fundamental tools for understanding QCD in non-perturbative regime:

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

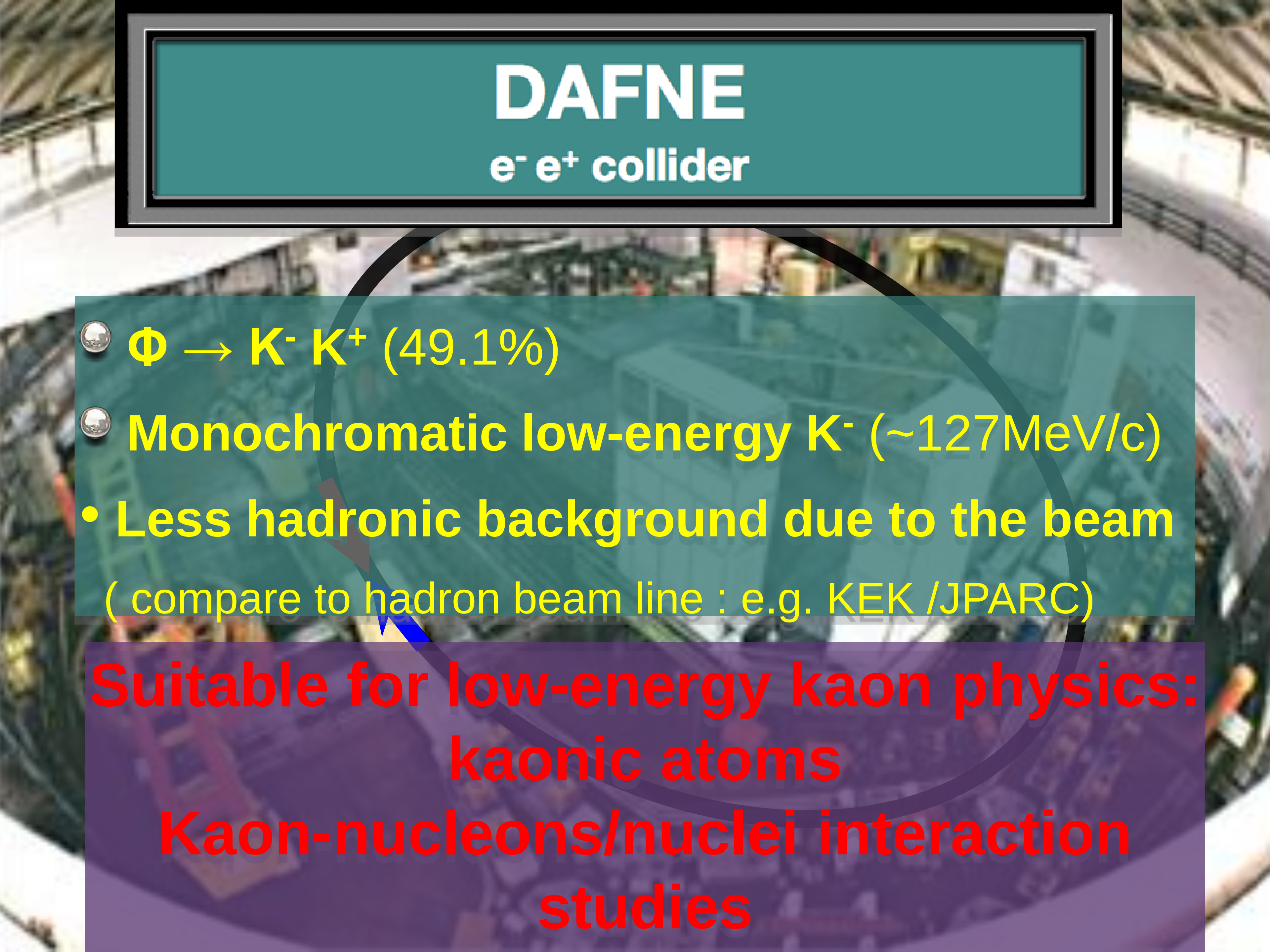
Role of Strangeness in the Universe from particle and nuclear physics to astrophysics

DAΦNE

The DAFNE principle



Flux of produced kaons: about 1000/second



DAFNE

$e^- e^+$ collider

- $\Phi \rightarrow K^- K^+$ (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **Less hadronic background due to the beam**

(compare to hadron beam line : e.g. KEK /JPARC)

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

SIDDHARTA

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

HadronPhysics I3

Study of Strongly Interacting Matter

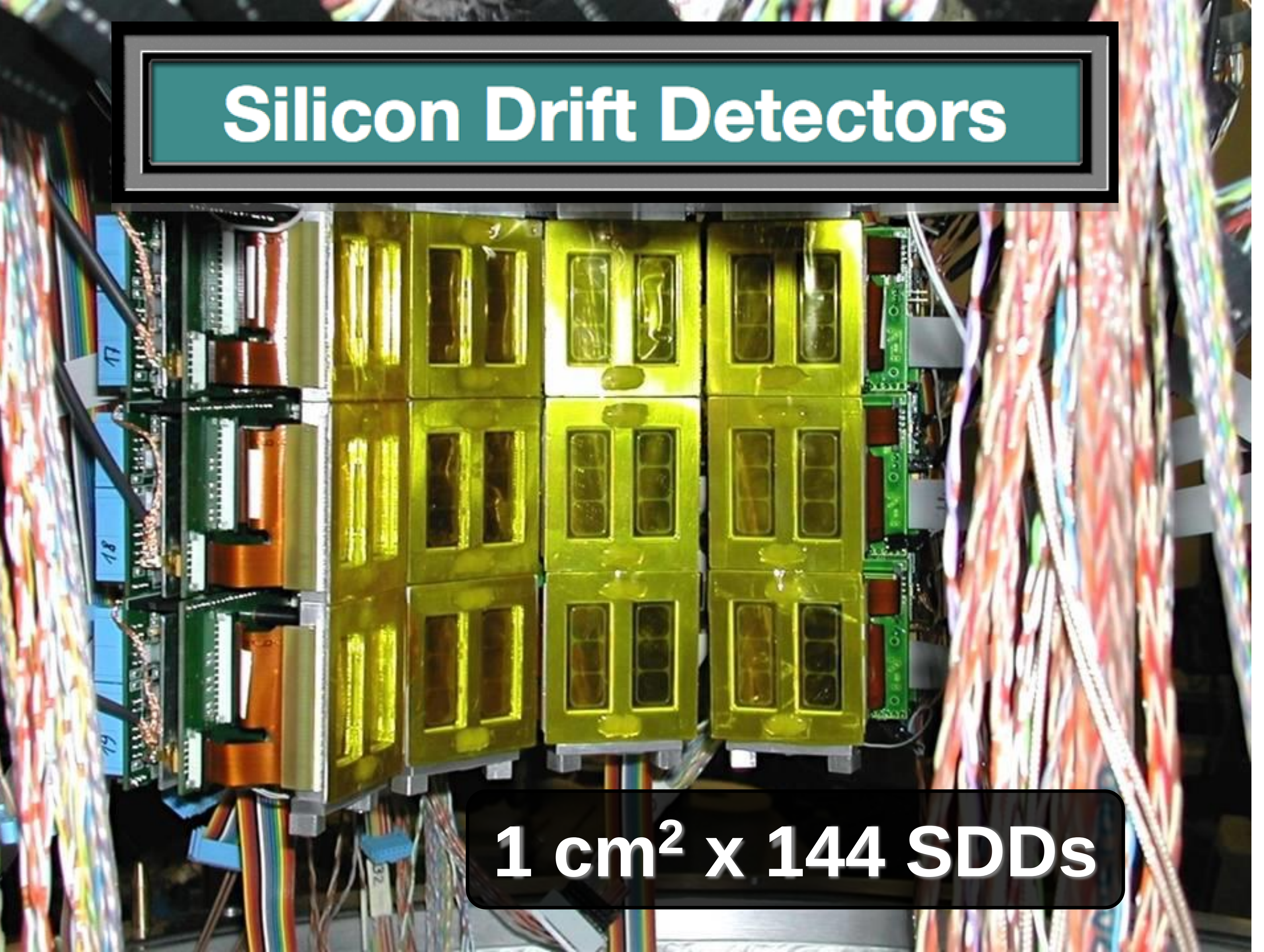
- **LNF- INFN, Frascati, Italy**
- **SMI- ÖAW, Vienna, Austria**
- **IFIN – HH, Bucharest, Romania**
- **Politecnico, Milano, Italy**
- **MPE, Garching, Germany**
- **PNSensors, Munich, Germany**
- **RIKEN, Japan**
- **Univ. Tokyo, Japan**
- **Victoria Univ., Canada**

HadronPhysics2

Study of Strongly Interacting Matter

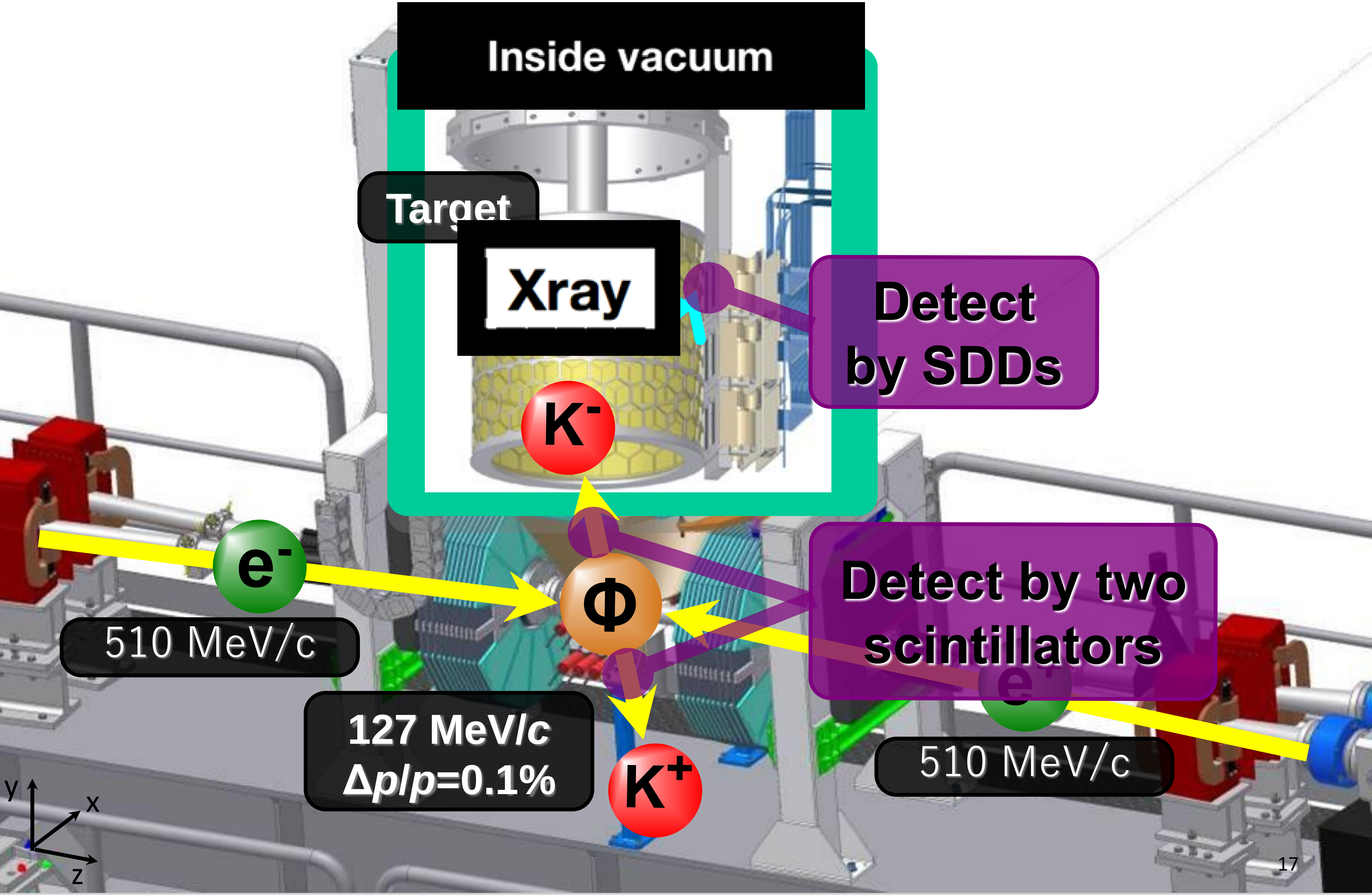
EU Fundings: JRA10 – FP6 - I3H
FP7- I3HP2

Silicon Drift Detectors



1 cm^2 x 144 SDDs

SIDDHARTA overview



Inside vacuum

Target

Xray

Detect by SDDs

Detect by two scintillators

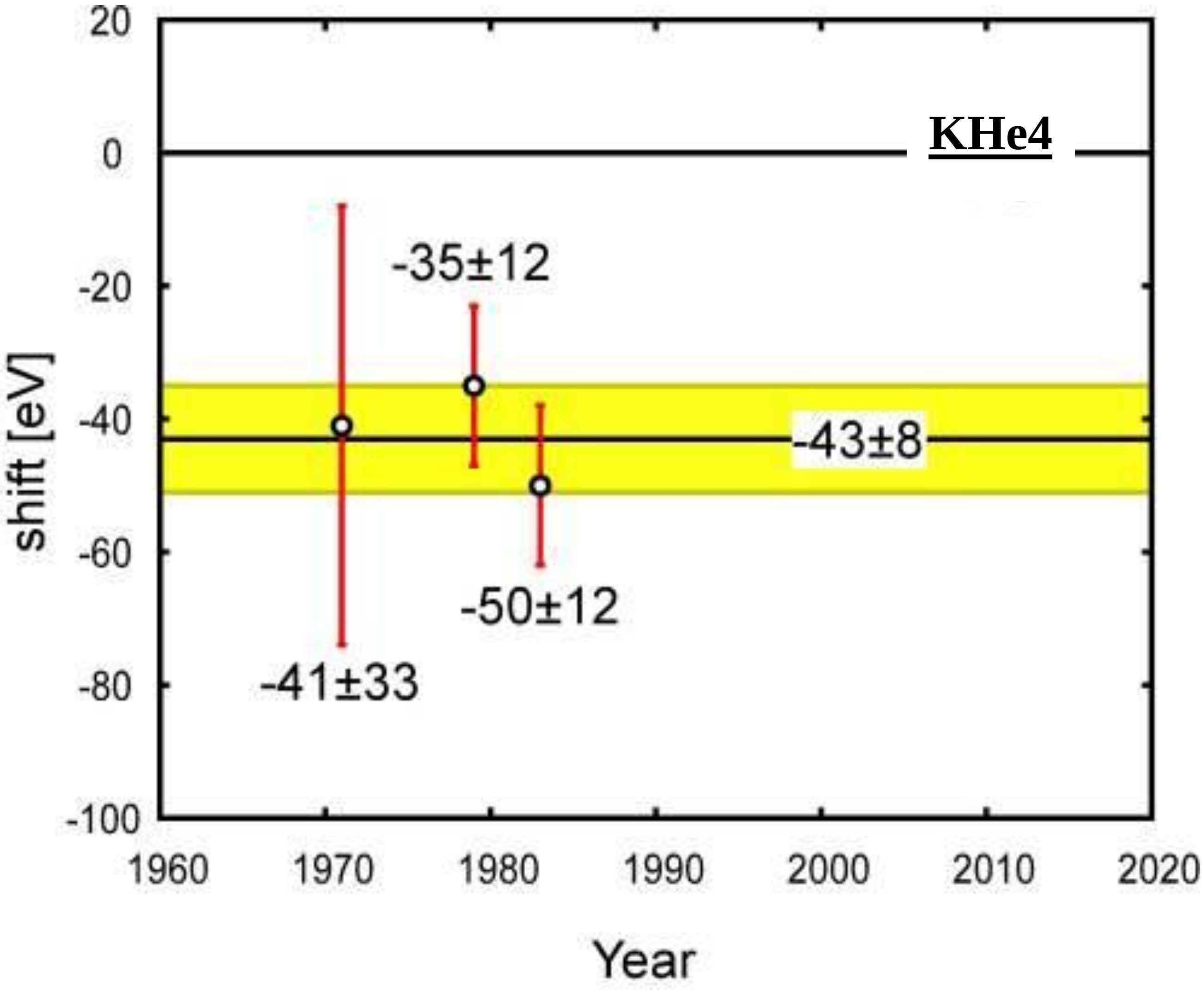
510 MeV/c

127 MeV/c
$\Delta p/p=0.1\%$

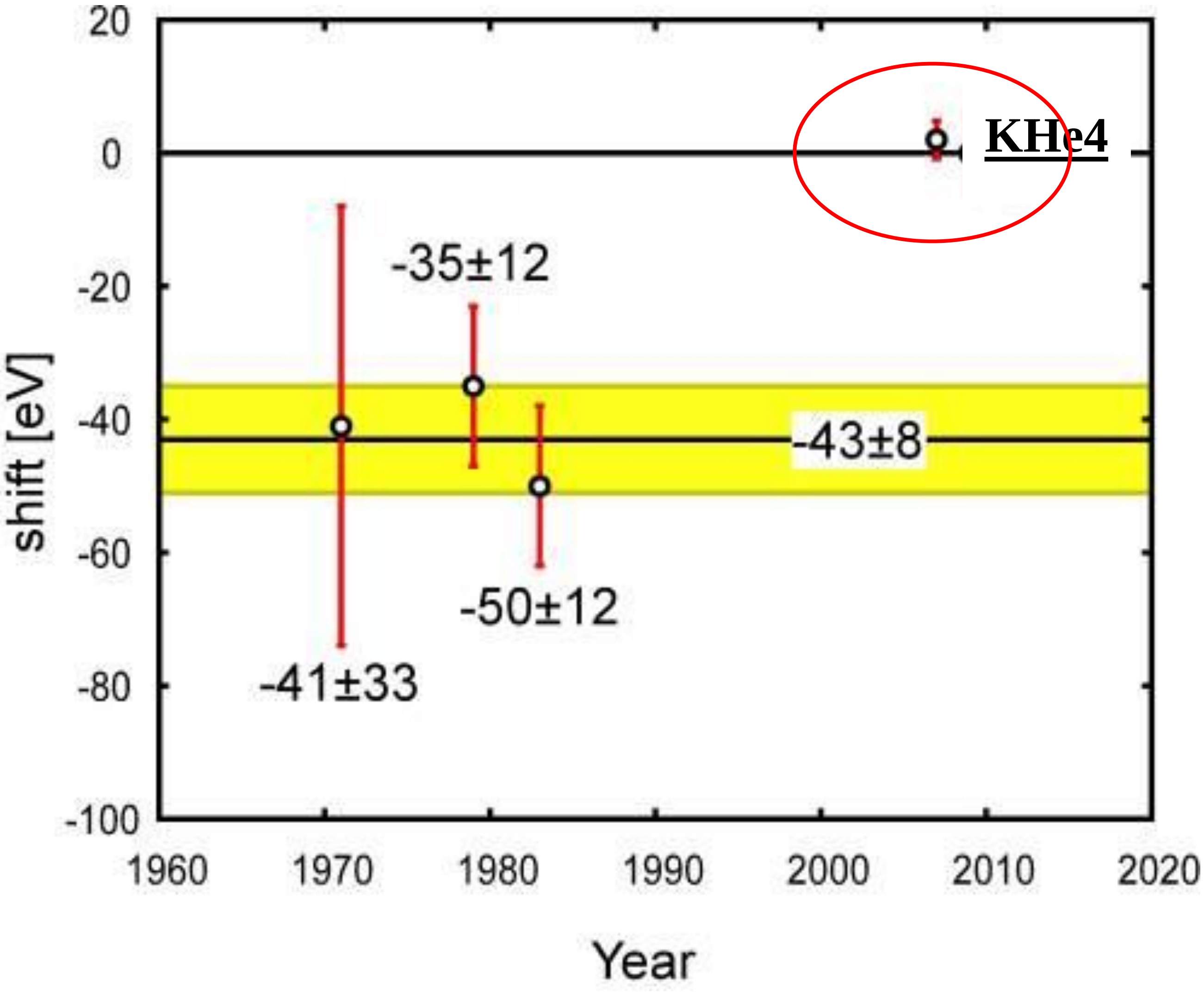
510 MeV/c

Kaonic helium (puzzle)

Kaonic 4 old data

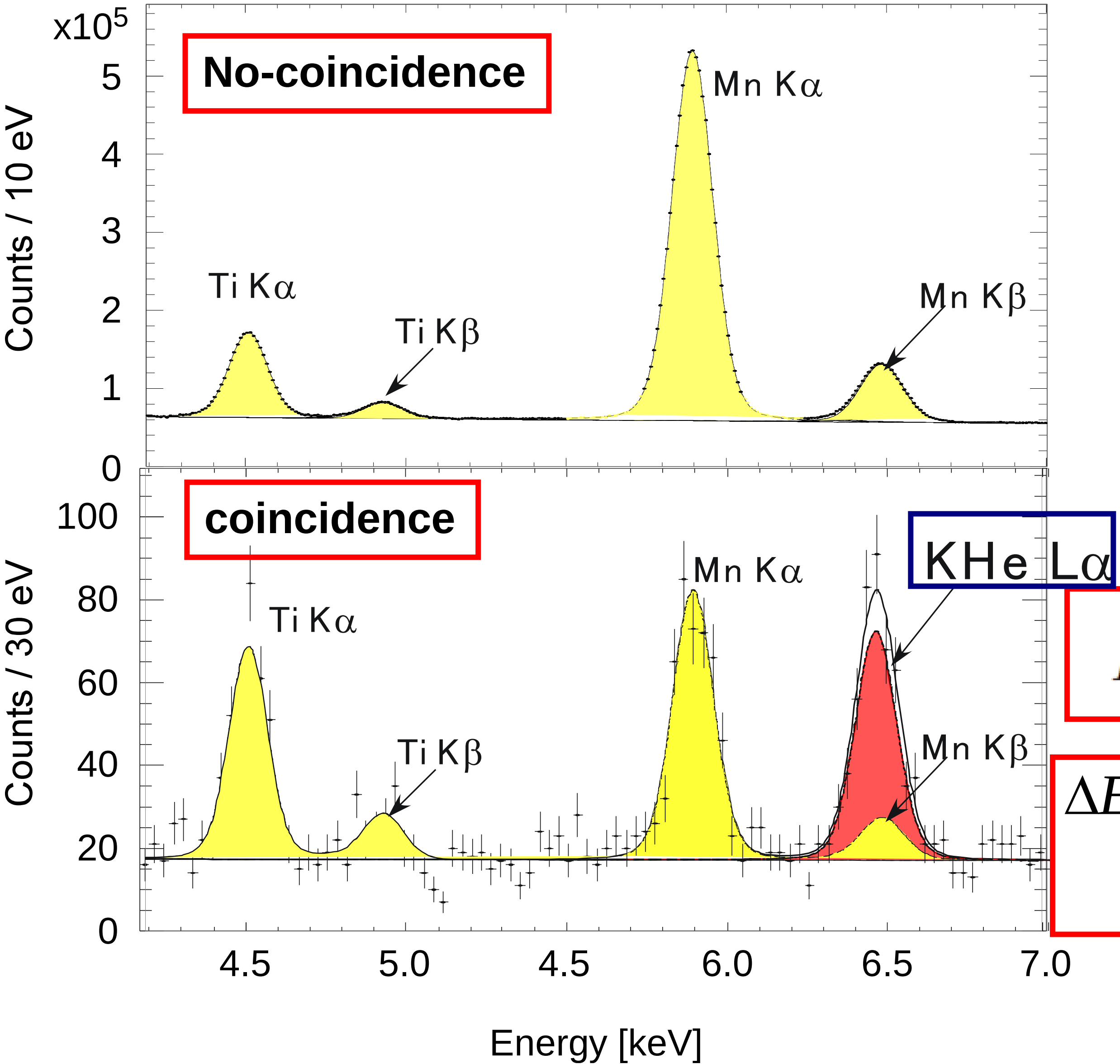


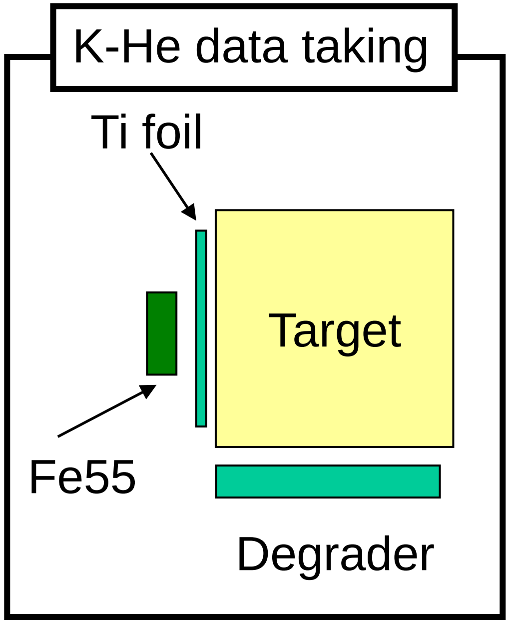
E570 solved the kaonic hydrogen puzzle



KHe-4 energy spectrum at SIDDHARTA

PLB681(2009)310; NIM A 628(2011)264

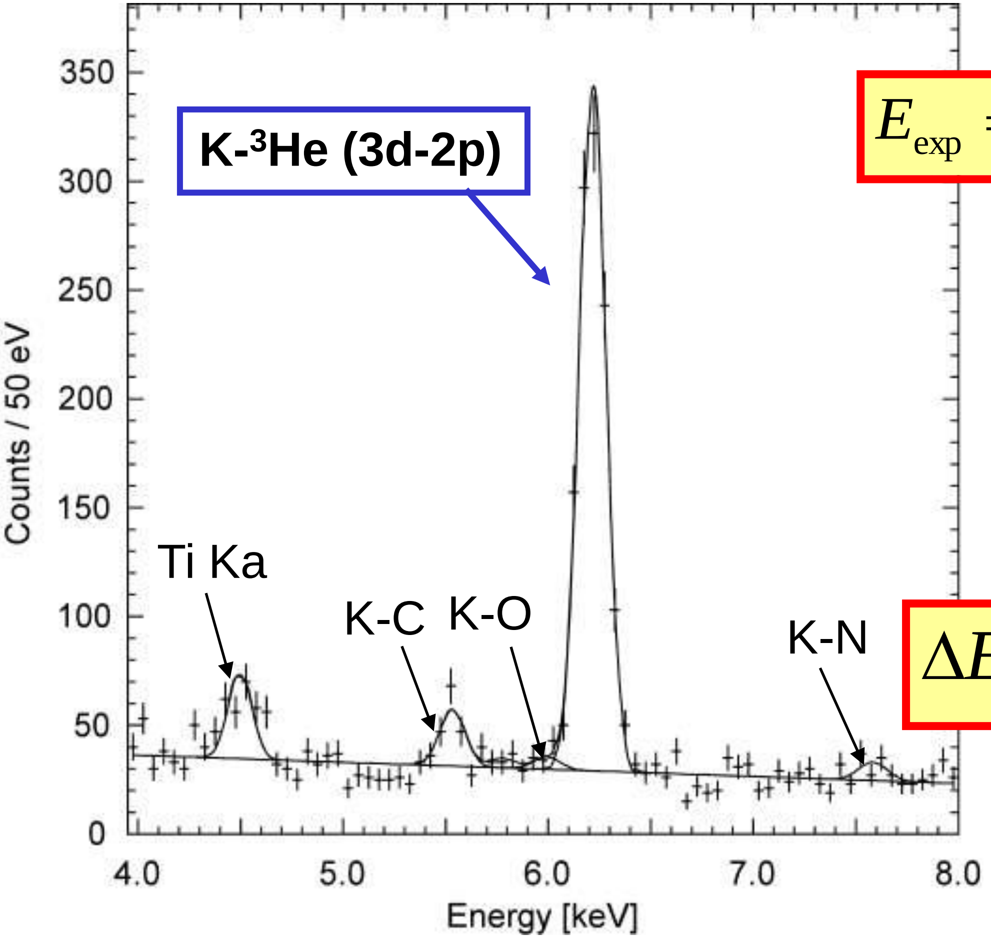




$$E_{\mathrm{exp}} = 6463.6 \pm 5.8 \text{ eV},$$

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

Kaonic Helium-3 energy spectrum



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

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

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

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

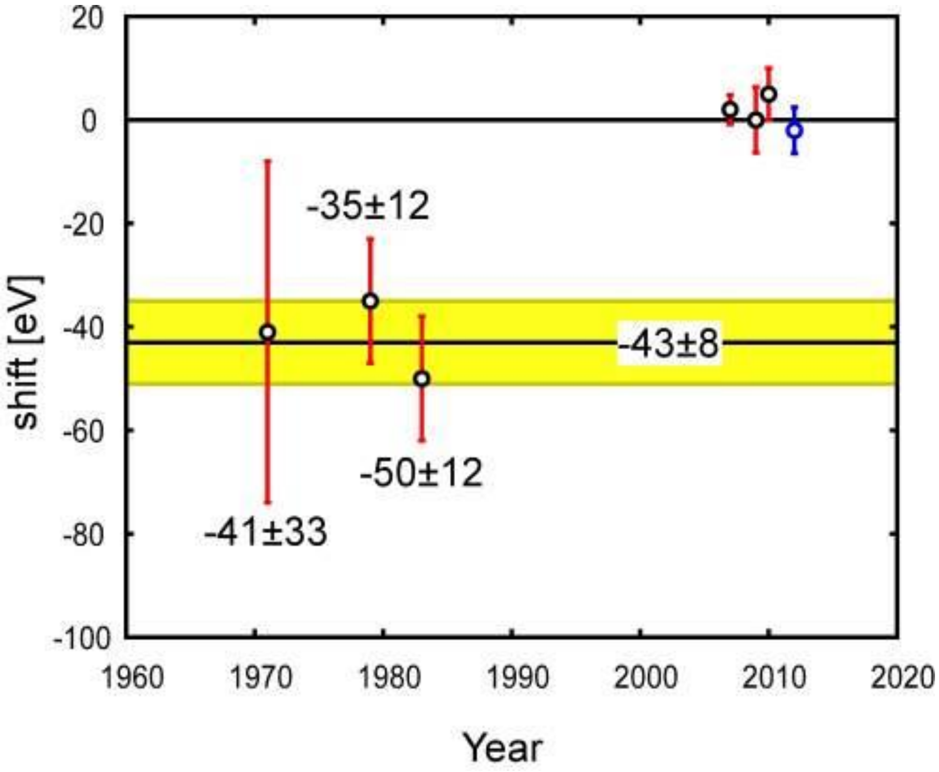
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \mathrm{eV}$$

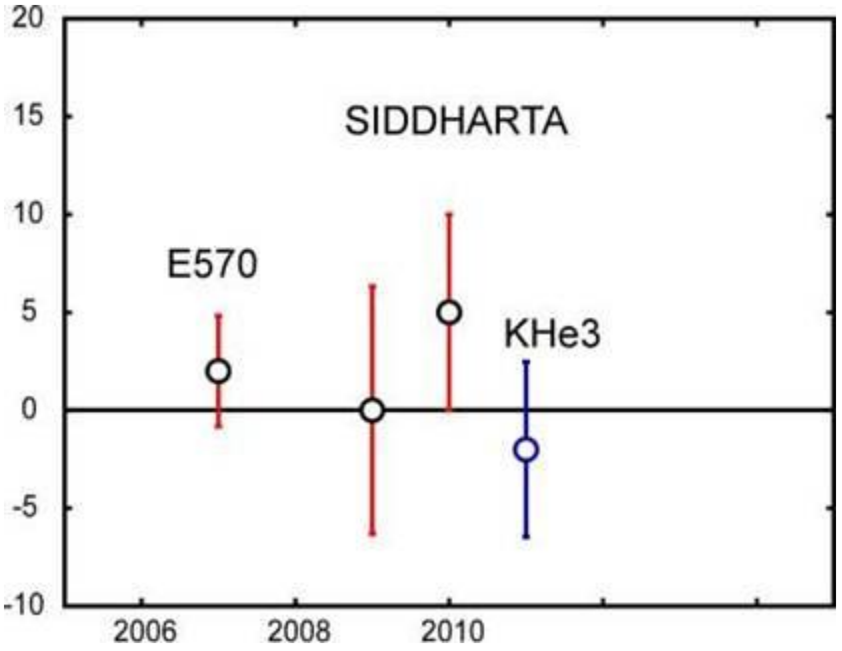
arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199

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

Comparison of results

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

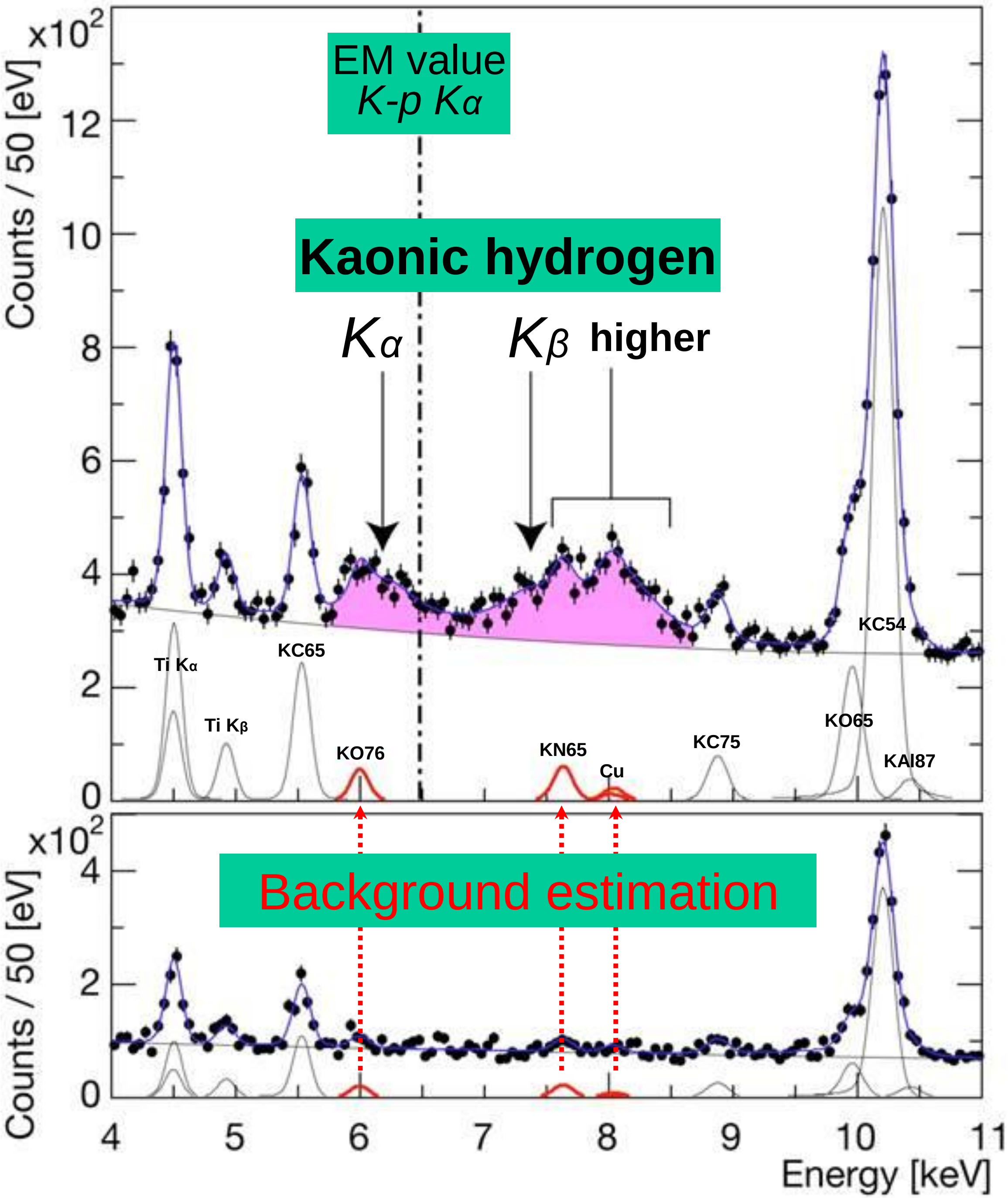




***error bar** $=\pm\sqrt{(stat)^2+(syst)^2}$

Hydrogen spectrum

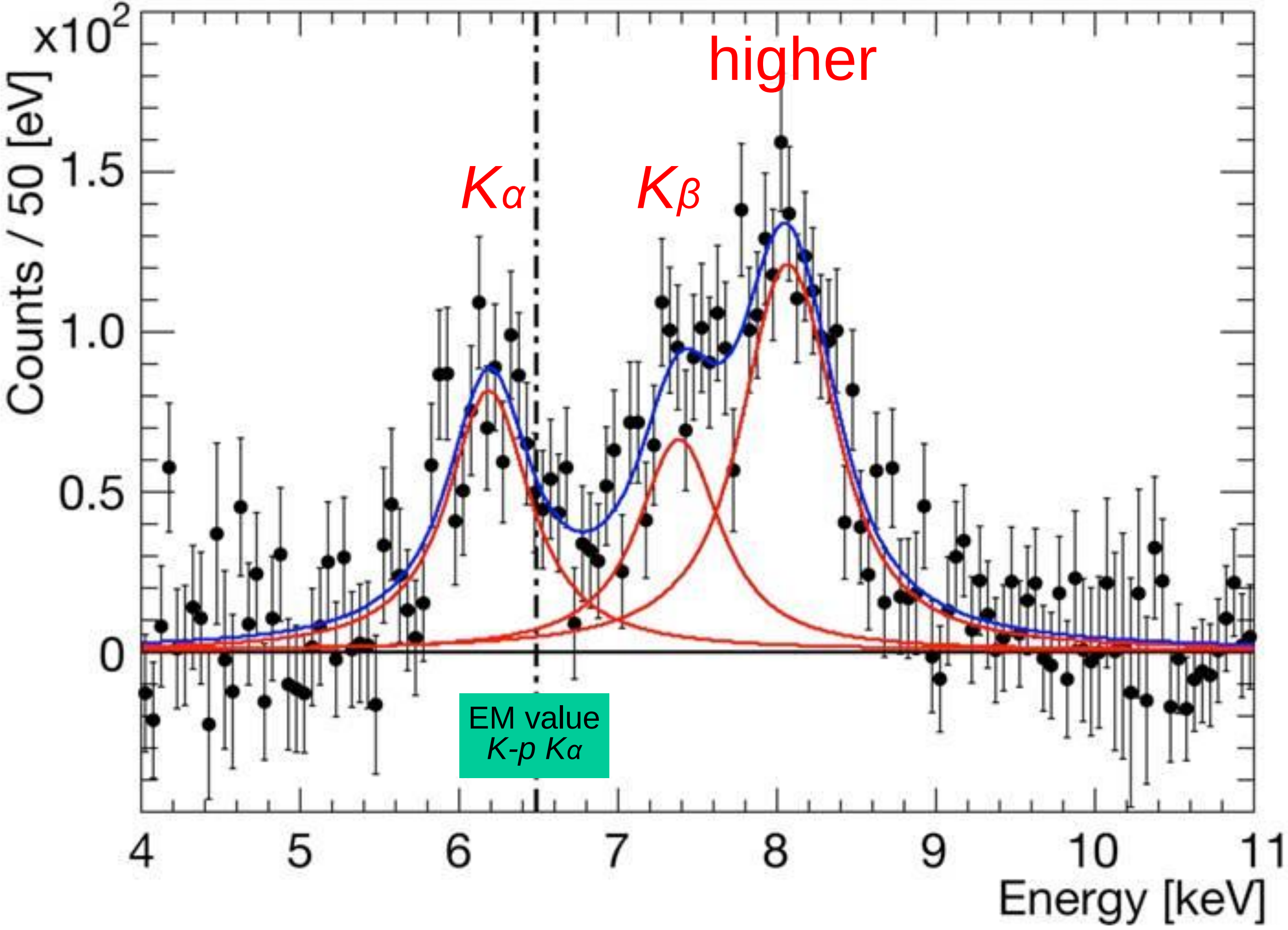
Deuterium spectrum



simultaneous fit

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

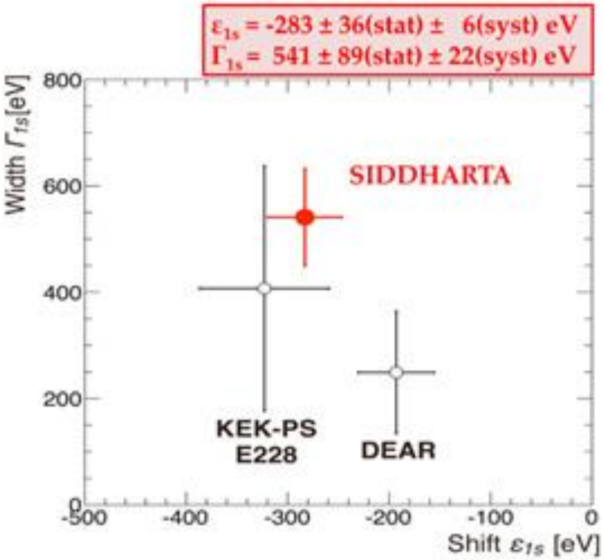
Kaonic hydrogen



KAONIC HYDROGEN results

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

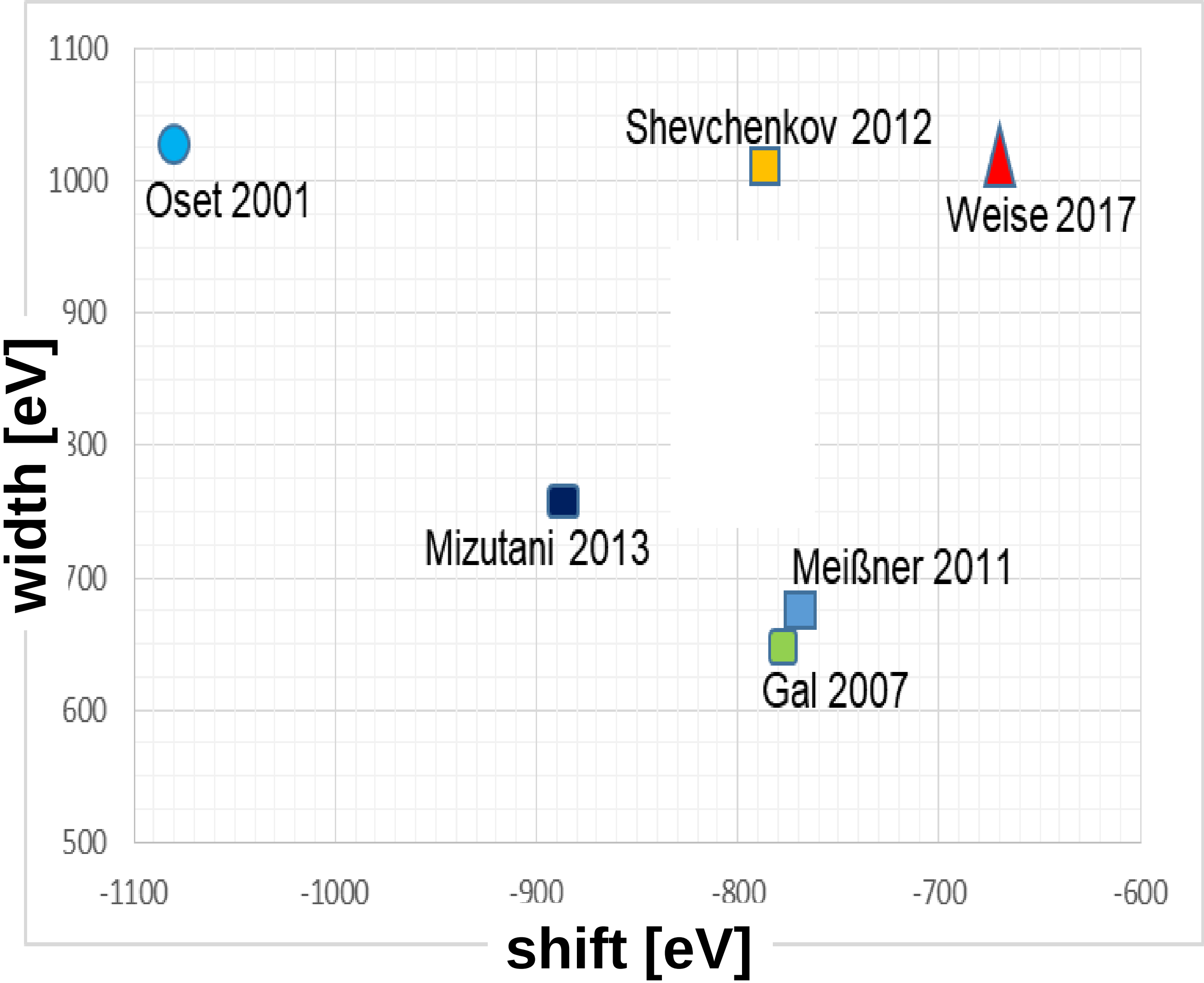
$$\Gamma_{1S} = 541 \pm 89(\mathrm{stat}) \pm 22(\mathrm{syst})\ \mathrm{eV}$$



Phys. Lett. B 704 (2011) 113

SIDDHARTA-2
Kaonic Deuterium

Theory for kaonic deuterium



SIDDHARTA-2

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
Helmholtz Inst. Mainz, Germany
Univ. Jagiellonian Krakow, Poland
Research Center for Electron Photon Science (ELPH), Tohoku University
CERN, Switzerland

HadronPhysics2
Study of Strongly Interacting Matter

HadronPhysics I3
Study of Strongly Interacting Matter

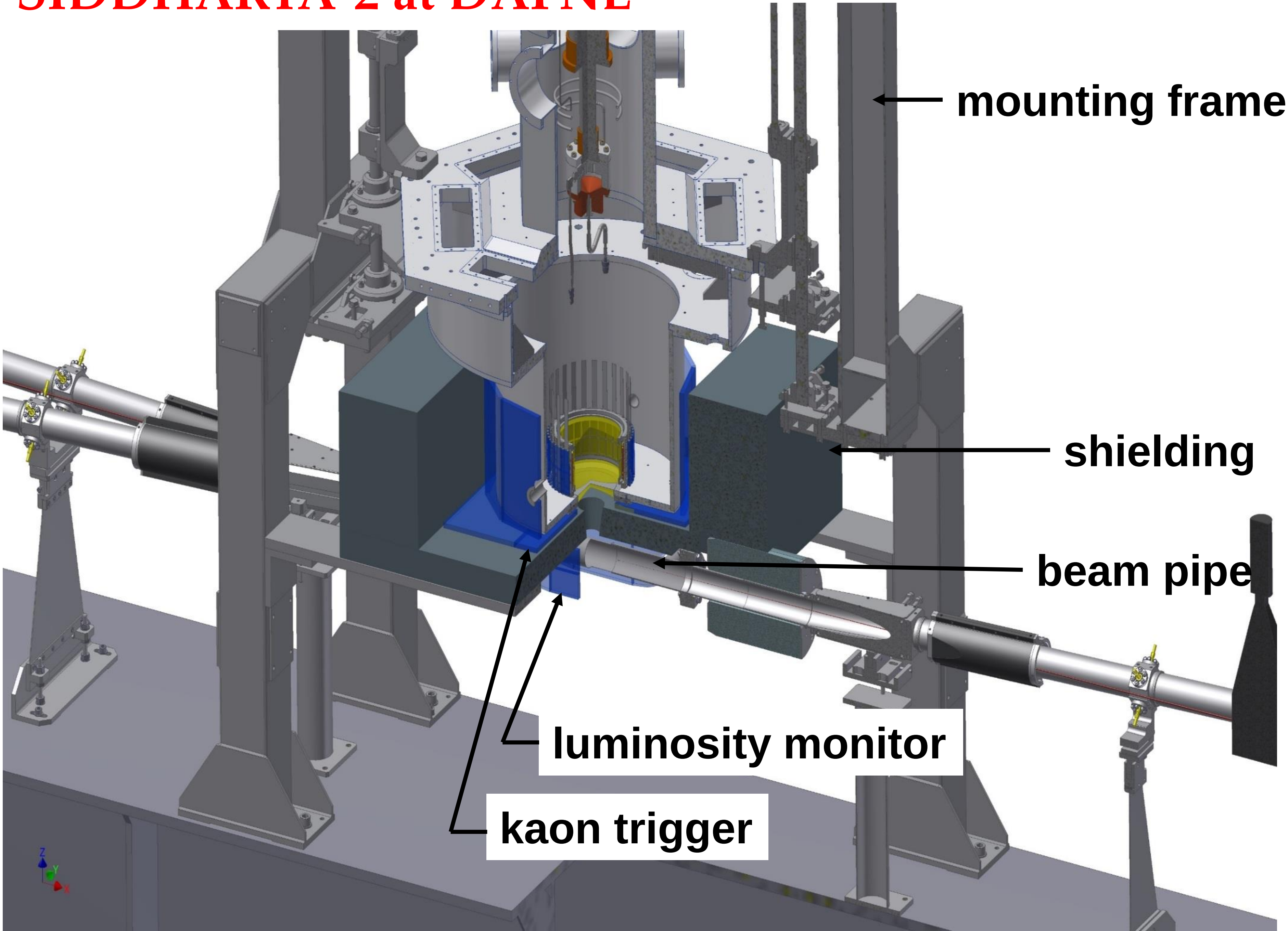
FWF Der Wissenschaftsfonds.

Farnesina
Ministero degli Affari Esteri
e della Cooperazione Internazionale

STRONG-2020

Croatian Science Foundation,
research project 8570

SIDDHARTA-2 at DAFNE



mounting frame

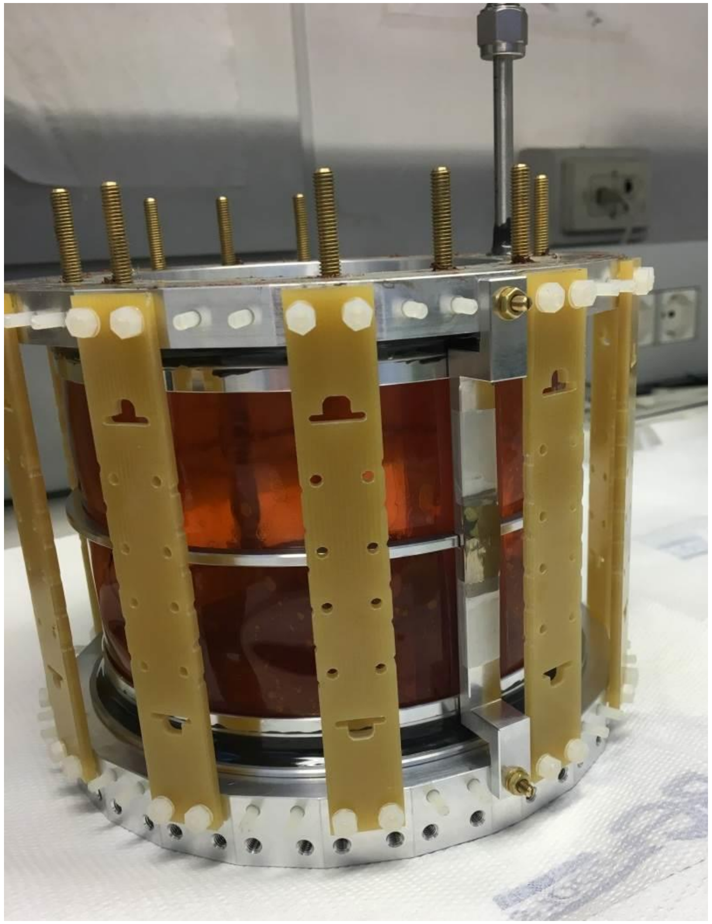
shielding

beam pipe

luminosity monitor

kaon trigger

Light target and Silicon Drift Detector assembly

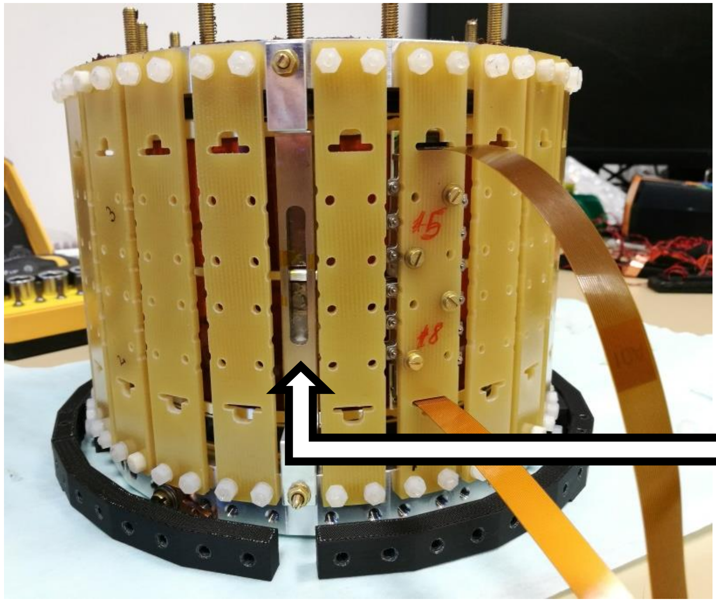


Target cell wall is made of a 2-Kapton layer structure (75 µm + 75 µm + Araldit)

increase the target stopping power

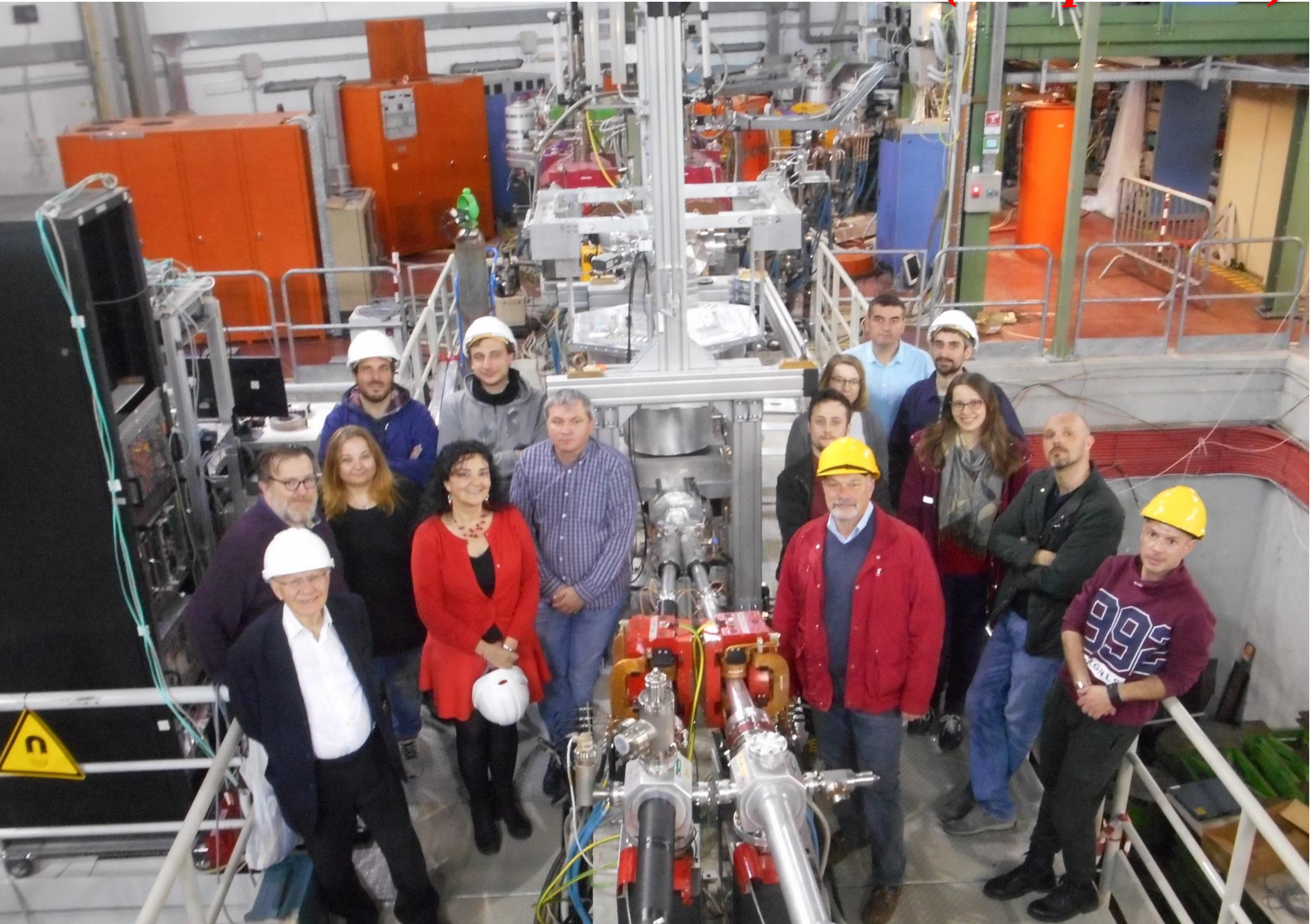
almost double gas density with respect to SIDDHARTA (3% LHD)

SDDs placed 5 mm from the target wall



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

SIDDHARTINO installed on DAFNE (17 April 2019)



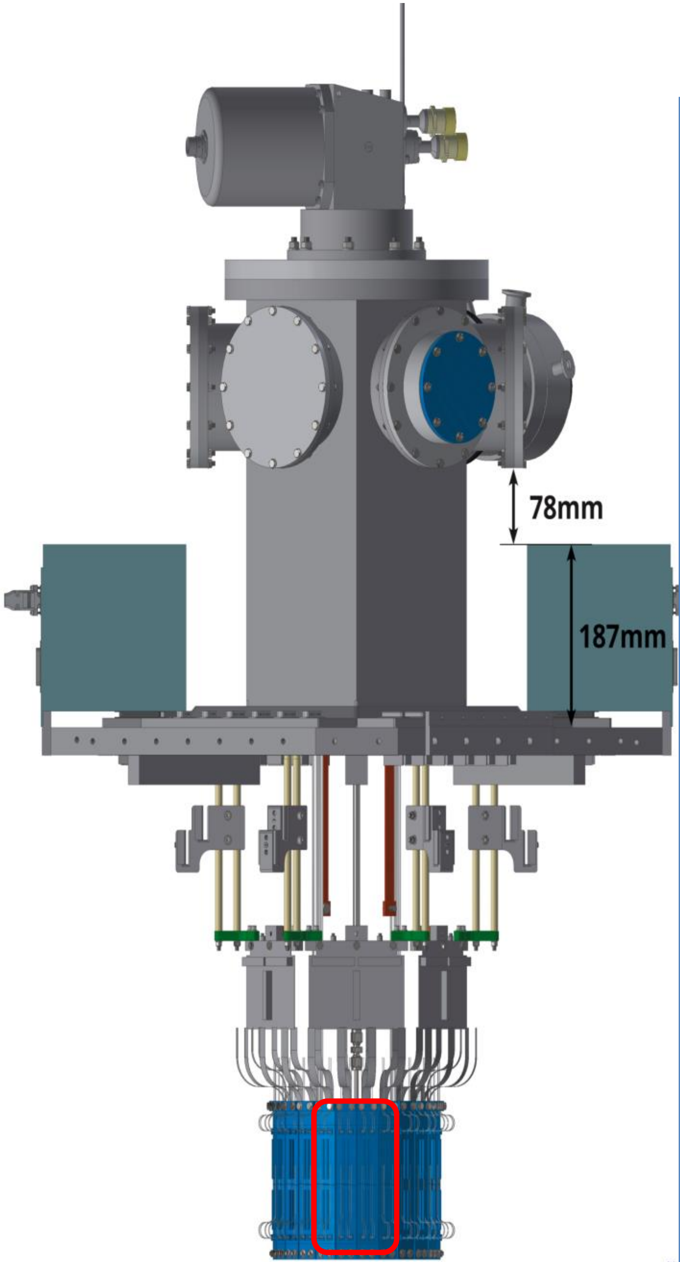
SIDDHARTA-2 - present status

We are presently in Phase 1 with SIDDHARTINO:

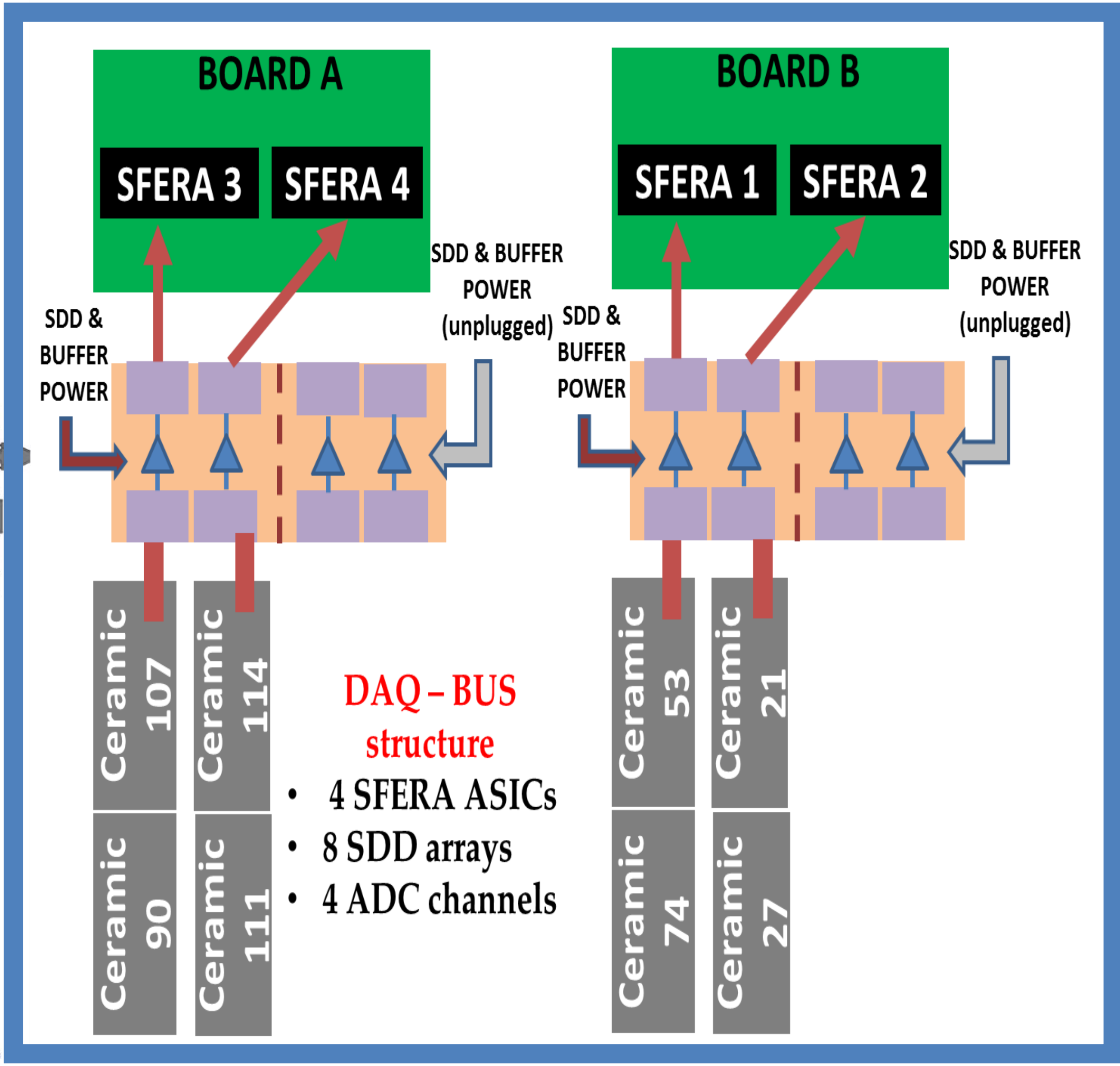
during the commissioning of DAΦNE
optimization with the SIDDHARTINO setup
for the K-^{4}He measurement
(with 8 SDD arrays)

(Phase 2: Kd measurement)

SIDDHARTINO = SIDDHARTA-2 with 8 SDD's



DAQ BUS configuration



BOARD A

SFERA 3

SFERA 4

SDD & BUFFER POWER

SDD & BUFFER POWER (unplugged)

Ceramic 107

Ceramic 114

Ceramic 90

Ceramic 111

BOARD B

SFERA 1

SFERA 2

SDD & BUFFER POWER

SDD & BUFFER POWER (unplugged)

Ceramic 53

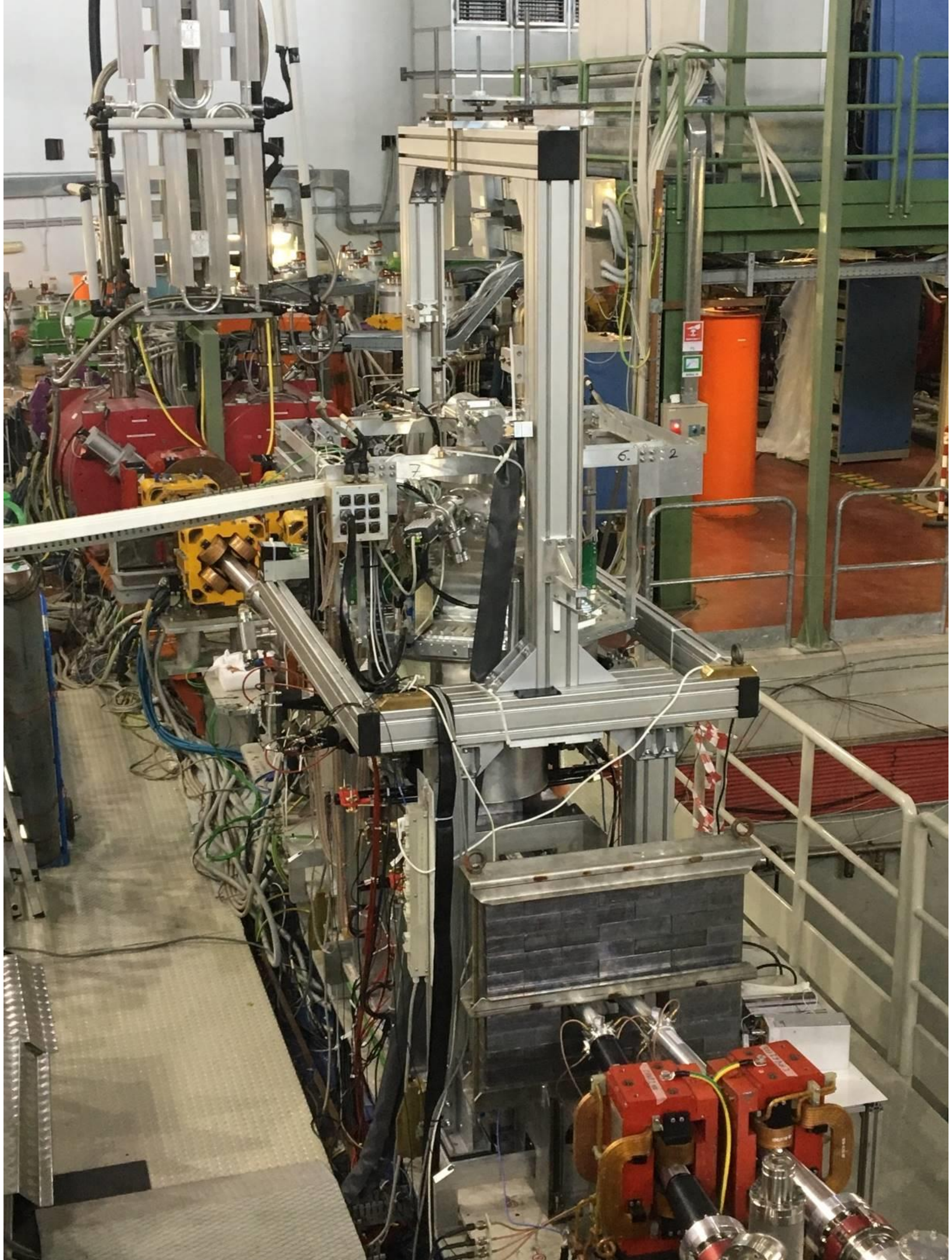
Ceramic 21

Ceramic 74

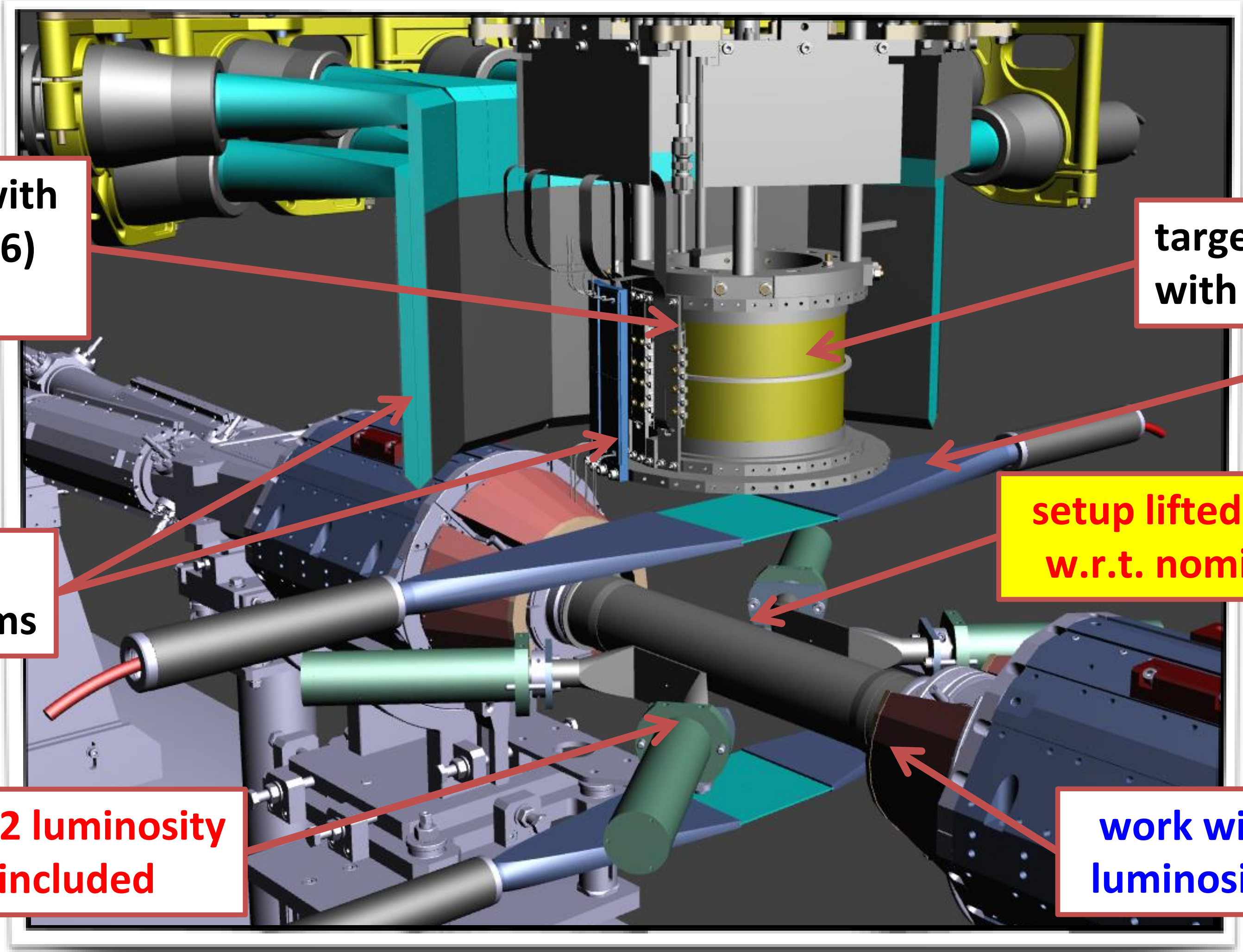
Ceramic 27

DAQ – BUS structure

- 4 SFERA ASICs
- 8 SDD arrays
- 4 ADC channels


7
6. 2

SIDDHARTINO apparatus and constraints



equipped with
8 SDD (1/6)
arrays

target filled
with He-4 gas

trigger

complete
Veto systems

setup lifted by ~100 mm
w.r.t. nominal position

SIDDHARTA-2 luminosity
monitor included

work with DAΦNE
luminosity monitor

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

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *August 12, 2020*
ACCEPTED: *September 22, 2020*
PUBLISHED: *October 14, 2020*

Characterization of the SIDDHARTA-2 luminosity monitor

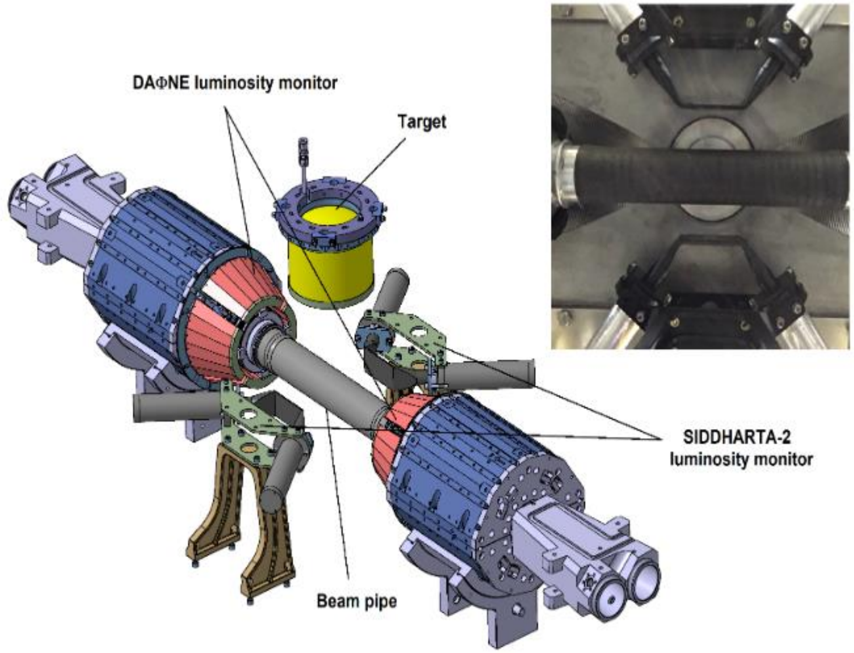


Figure 2. Schematic representation of the SIDDHARTA-2 setup with implemented luminosity monitor and the top view picture of the two installed modules (right upper corner).

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *August 12, 2020*
ACCEPTED: *September 22, 2020*
PUBLISHED: *October 14, 2020*

Characterization of the SIDDHARTA-2 luminosity monitor

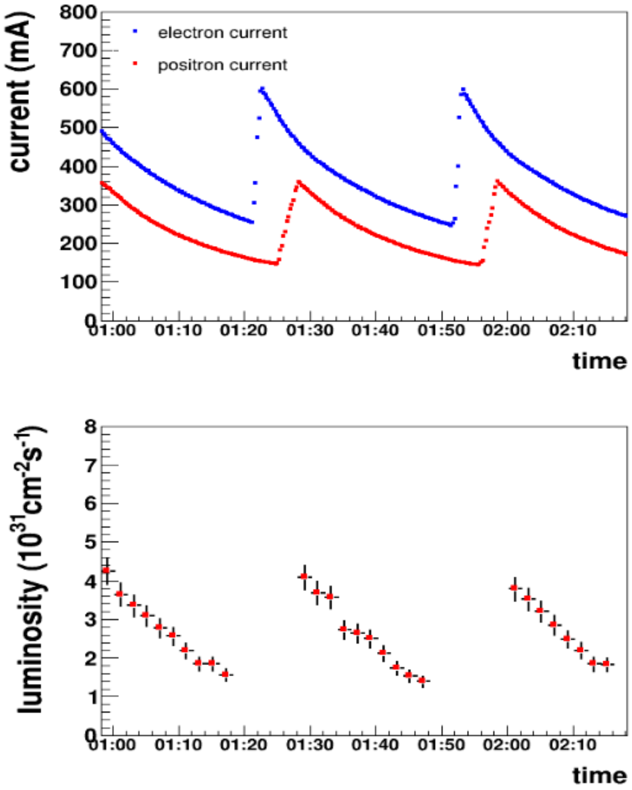


Figure 10. (upper) DAΦNE currents: electron (blue) and positron (red); (lower) measured luminosity — each point corresponds to 2 min of data taking.

Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy

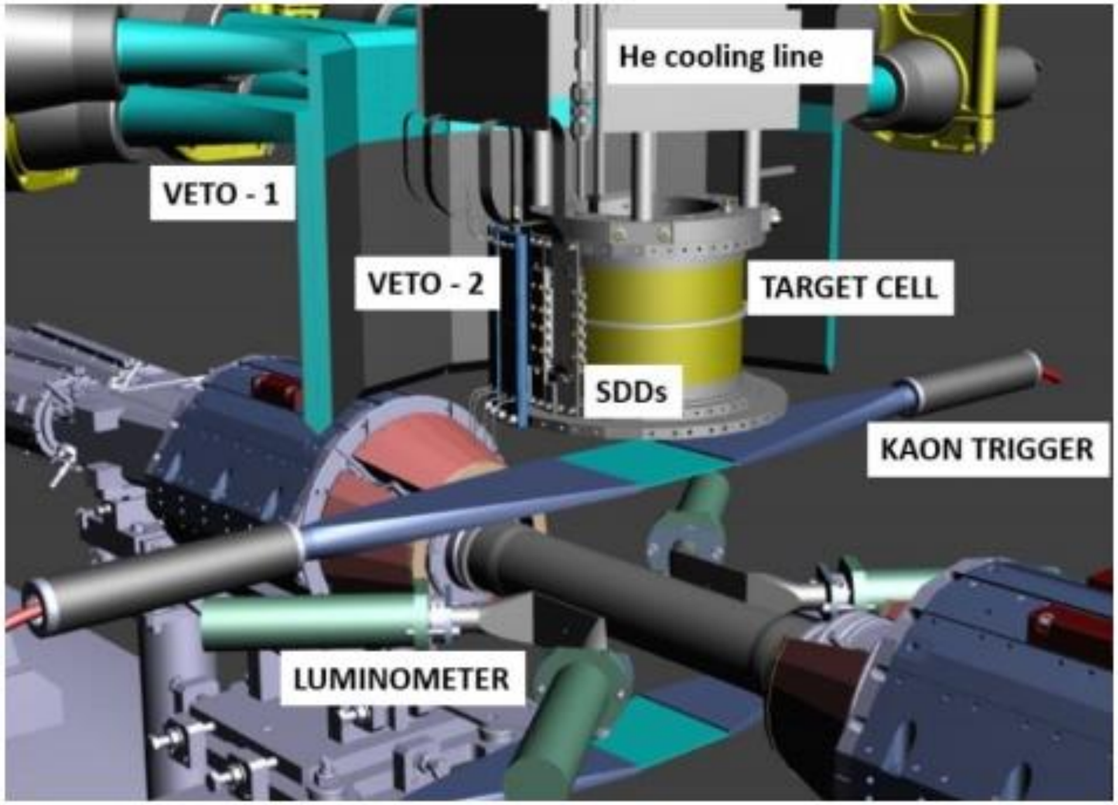
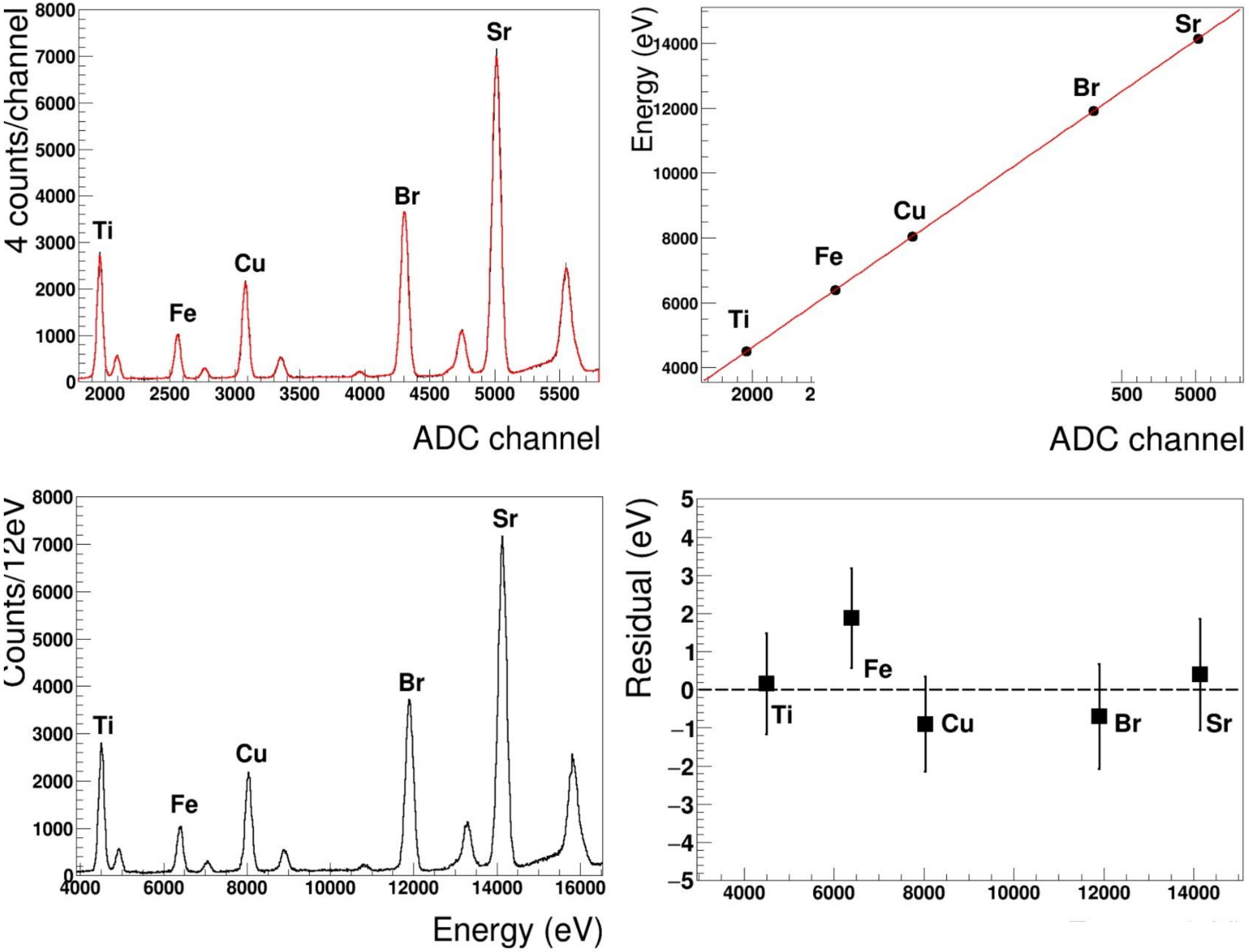


Figure 1: Schematic drawing of the SIDDHARTA-2 experiment.

Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy



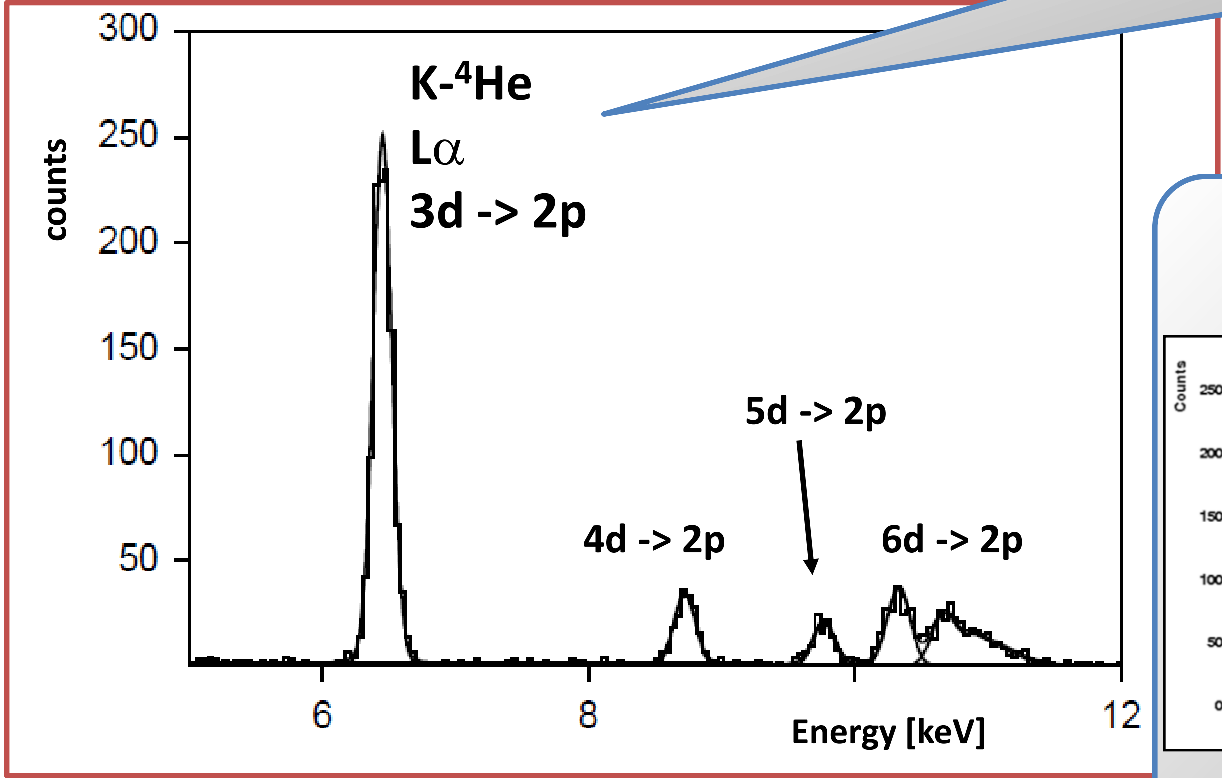
Paper draft ready (Marco Miliucci, Diana Sirghi, Alessandro Scordo)

Plan – Phase1:

1) ***Work with SIDDHARTINO inside DAFNE: optimization SDD, trigger, DAQ, calib….***
2) ***Refine optimization of luminosity detector and cross check with DAFNE luminometer***
3) ***Background reduction and optimization together with DAFNE for kaonic atoms measurements***
4) ***Kaonic Helium measurement with SIDDHARTINO -> background w.r.t. SIDDHARTA and SIDDHARTA-2 for Kd goal***
   depending on DAFNE's plans (early 2021)
5) ***HPGe test run in parallel with SIDDHARTINO***

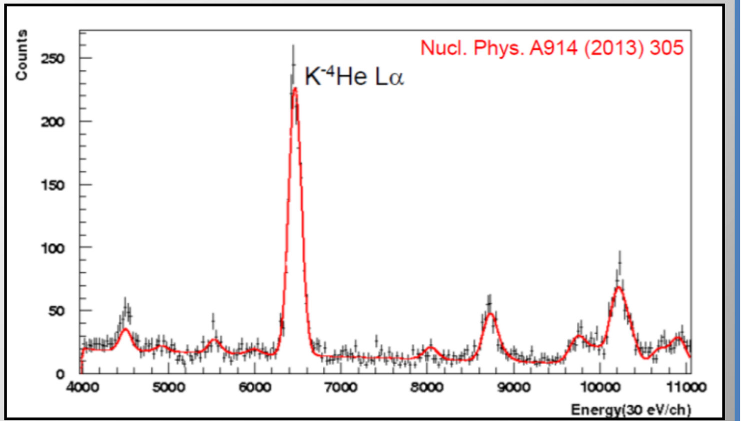
SIDDHARTINO – K-^{4}He test measurement

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



Nucl. Phys. A914 (2013) 305

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

SIDDHARTA-2 strategy and requests

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:

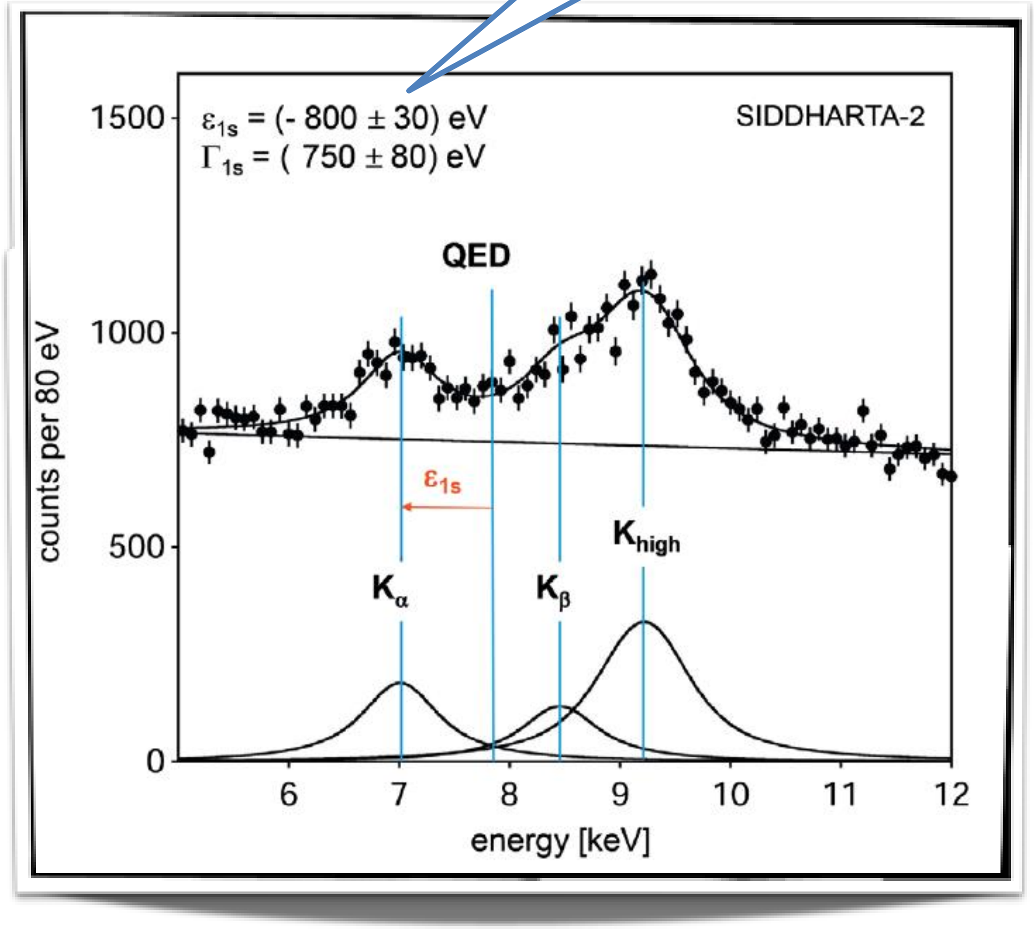
for an integrated luminosity of 800 pb^{-1}

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) !

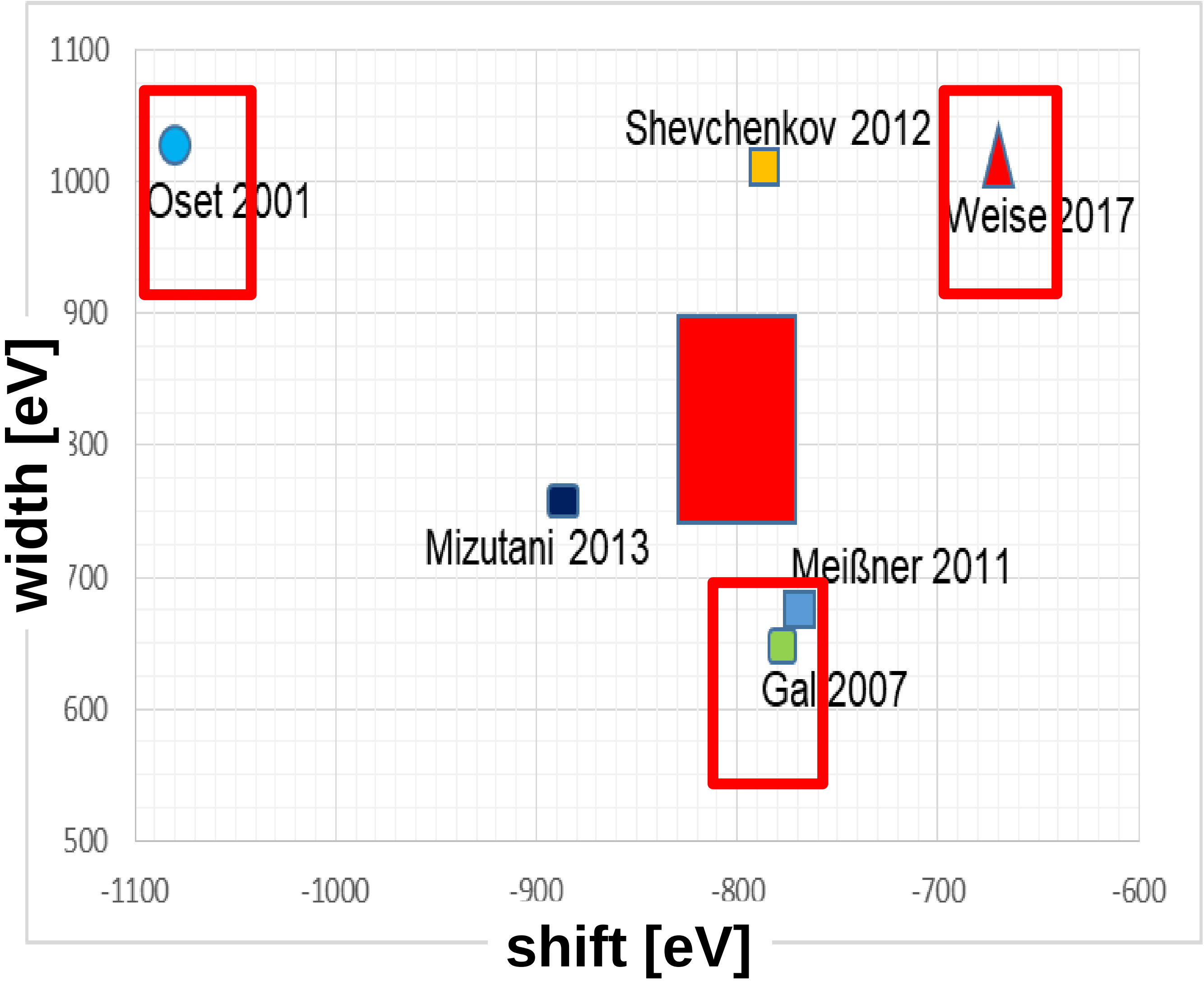
Includes:

- **veto-2 second layer**
- **Optimizations SDD, veto1**
- **Shielding, trigger….**

achievable precision



SIDDHARTA-2 kaonic deuterium at DAFNE



On the width of the K^-D atom ground state

N. Barnea[a], E. Friedman[a], A. Gal[a,*]

[a] *Racah Institute of Physics, The Hebrew University, 91904 Jerusalem, Israel*

Table 2: K^-d scattering lengths $a^{\rm full}_{K^-d}$ (in fm) calculated in three methods: (i) summing up a fixed-scatterer multiple-scattering (MS) series (10) with $a^{\rm sub}_{K^-N}$ input values [14]; (ii) solving exact $\bar{K}NN$ Faddeev equations without introducing additional subthreshold dependence [18]; and (iii) solving the K^-d two-body problem using V_{K^-} from a global fit to kaonic atoms data, taken here at $\delta\sqrt{s} = -7$ MeV. Single-scattering contributions $a^{\rm SS}_{K^-d}$ (11), using $a^{\rm th}_{K^-N}$ and $a^{\rm sub}_{K^-N}$ input amplitudes, are also listed.

Method	Ref.	$a^{\rm SS}_{K^-d}$(th)	$a^{\rm SS}_{K^-d}$(sub)	$a^{\rm full}_{K^-d}$
MS	[14]	$-0.58+{\rm i}\,1.59$	$-0.06+{\rm i}\,2.55$	$-0.59+{\rm i}\,2.70$
Faddeev	[18]	$-0.37+{\rm i}\,1.65$	$-0.16+{\rm i}\,2.44$	$-1.47+{\rm i}\,1.08$
V_{K^-}	present	$-0.08+{\rm i}\,1.86$	$+0.18+{\rm i}\,2.49$	$-1.26+{\rm i}\,1.41$

Future programme and perspectives:

- Feasibility studies in parallel with Siddharta-2 (Ge and VOXES crystal spectrometer)

- 1mm SDDs

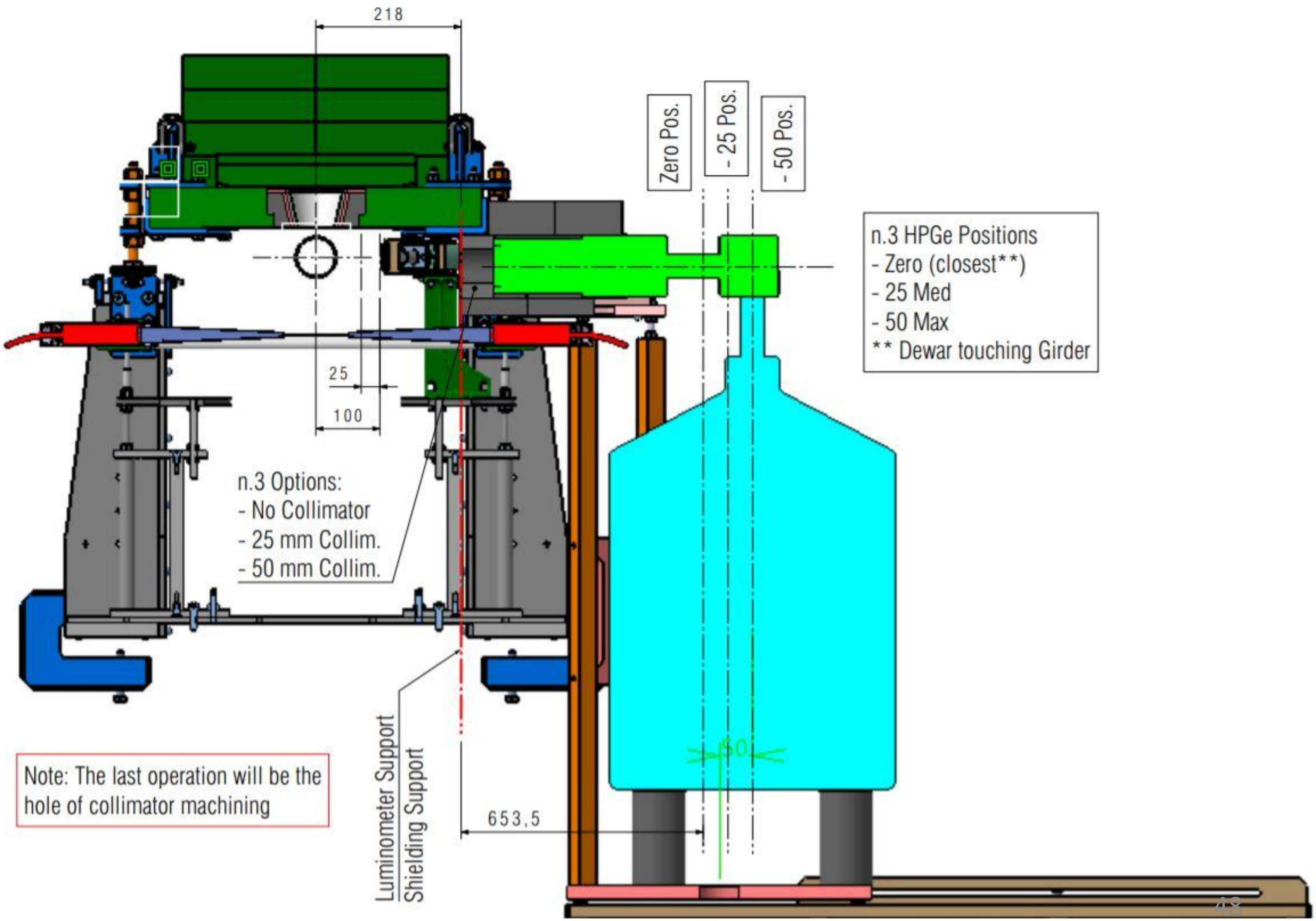
- Proposal for Extension of the Scientific Program at DAFNE – WE NEED THEIA SUPPORT

- Kaon mass - precision measurement at a level < 7 keV
- Kaonic helium transitions to the 1s level

- Other light kaonic atoms (K^-Bi, Li, B,, K^-C,…)
- Heavier kaonic atoms (K^-Si, K^-Pb…)

- Radiative kaon capture – Λ(1405) study
- Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)

HPGe: kaonic lead for kaon mass – ready Univ. Zagreb



n.3 HPGe Positions
- Zero (closest**)
- 25 Med
- 50 Max

** Dewar touching Girder

n.3 Options:
- No Collimator
- 25 mm Collim.
- 50 mm Collim.

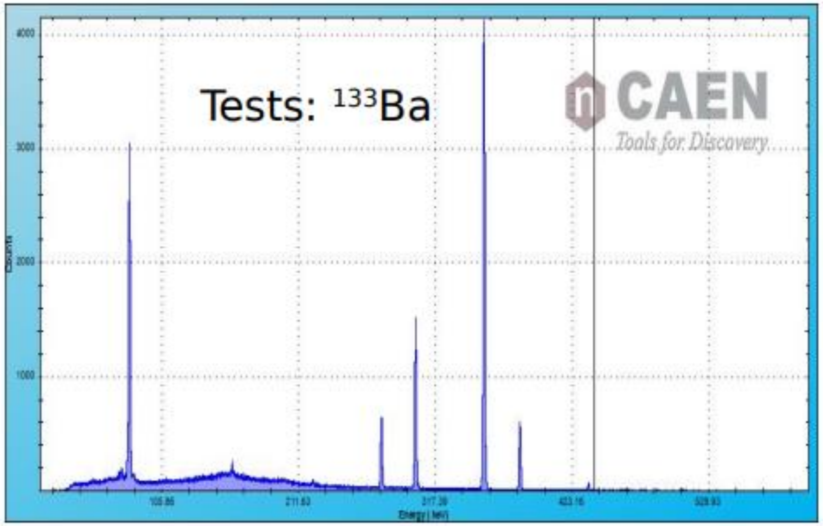
Note: The last operation will be the hole of collimator machining

HPGe test run during SIDDHARTA-2

Signal from spectroscopy amplifier ~20 μs (shaping time 6 μs), restriction on the rate.

- **Digital Pulse Processing** for Pulse Height Analysis firmware , based on V.T. Jordanov et al. Nucl. Instr. Meth. A 353 (1994) 337

- **Coincidences with luminometer**



Possible rates up to 150 kHz

^{60}Co, ^{133}Ba spectra,
resolutions: 0.870 keV at 81 keV
1.106 keV at 302.9 keV
1.143 keV at 356 keV
1.167 keV at 1330 keV

Detector system ready for measurements!

HPGe test run during SIDDHARTA-2

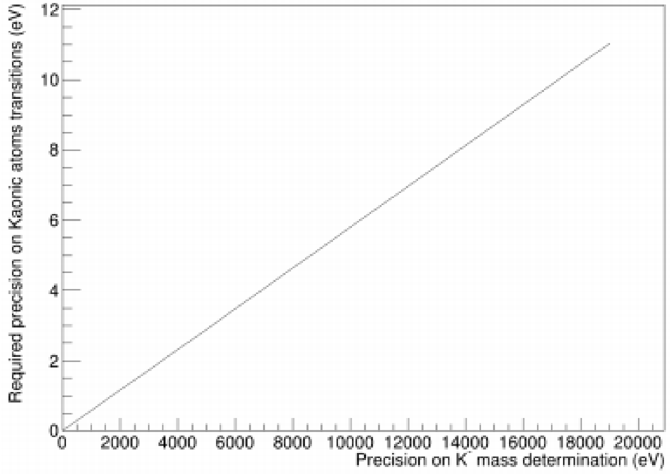
In a pure gaussian and background free spectrum, the achievable precision is

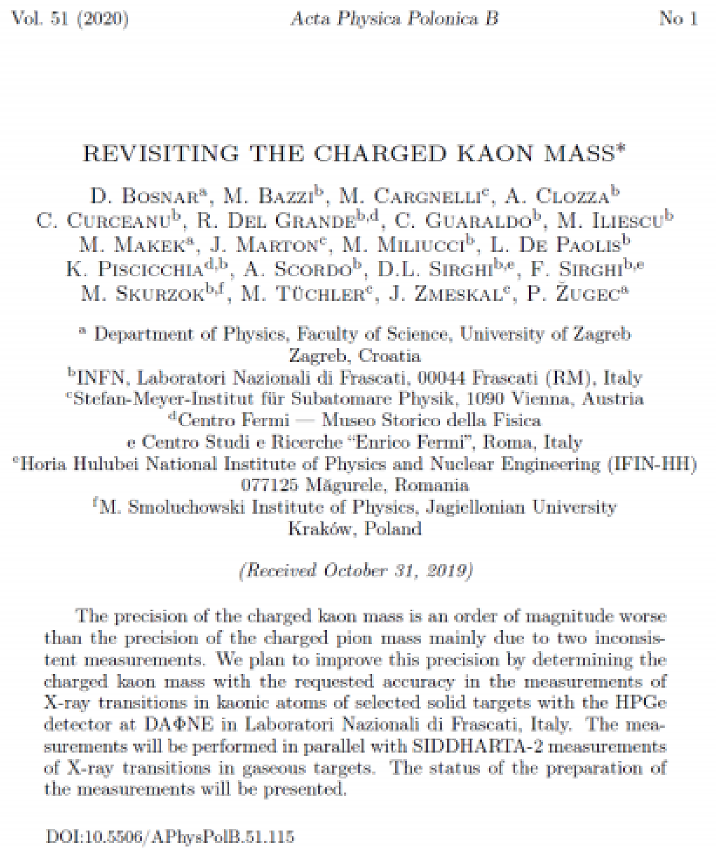
$$\text{precision(trans.)} = \frac{\sigma}{\sqrt{N}}$$

For a FWHM(302.9 keV) of 1.106 keV
N ≈ 30000 is needed for a 3 eV precision
($\delta m_K = 5$ keV)

Considering MC
simulated (hadronic) background

N≈50.000 X-rays in the peak (291.6 kEV)
to reach the 3 eV required precision




Vol. 51 (2020) *Acta Physica Polonica B* No 1

REVISITING THE CHARGED KAON MASS*

D. Bosnar[a], M. Bazzi[b], M. Cargnelli[c], A. Clozza[b]
C. Curceanu[b], R. Del Grande[b,d], C. Guaraldo[b], M. Iliescu[b]
M. Makek[a], J. Marton[c], M. Miliucci[b], L. De Paolis[b]
K. Piscicchia[d,b], A. Scordo[b], D.L. Sirghi[b,e], F. Sirghi[b,e]
M. Skurzok[b,f], M. Tüchler[c], J. Zmeskal[c], P. Žugec[a]

[a] Department of Physics, Faculty of Science, University of Zagreb
Zagreb, Croatia
[b]INFN, Laboratori Nazionali di Frascati, 00044 Frascati (RM), Italy
[c]Stefan-Meyer-Institut für Subatomare Physik, 1090 Vienna, Austria
[d]Centro Fermi — Museo Storico della Fisica
e Centro Studi e Ricerche "Enrico Fermi", Roma, Italy
[e]Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH)
077125 Măgurele, Romania
[f]M. Smoluchowski Institute of Physics, Jagiellonian University
Kraków, Poland

(Received October 31, 2019)

The precision of the charged kaon mass is an order of magnitude worse than the precision of the charged pion mass mainly due to two inconsistent measurements. We plan to improve this precision by determining the charged kaon mass with the requested accuracy in the measurements of X-ray transitions in kaonic atoms of selected solid targets with the HPGe detector at DAΦNE in Laboratori Nazionali di Frascati, Italy. The measurements will be performed in parallel with SIDDHARTA-2 measurements of X-ray transitions in gaseous targets. The status of the preparation of the measurements will be presented.

DOI:10.5506/APhysPolB.51.115

For the 291.6 keV transition,
with target distance from the HPGe of 115 mm, a 1,21% efficiency is expected resulting in ~4000 events / day

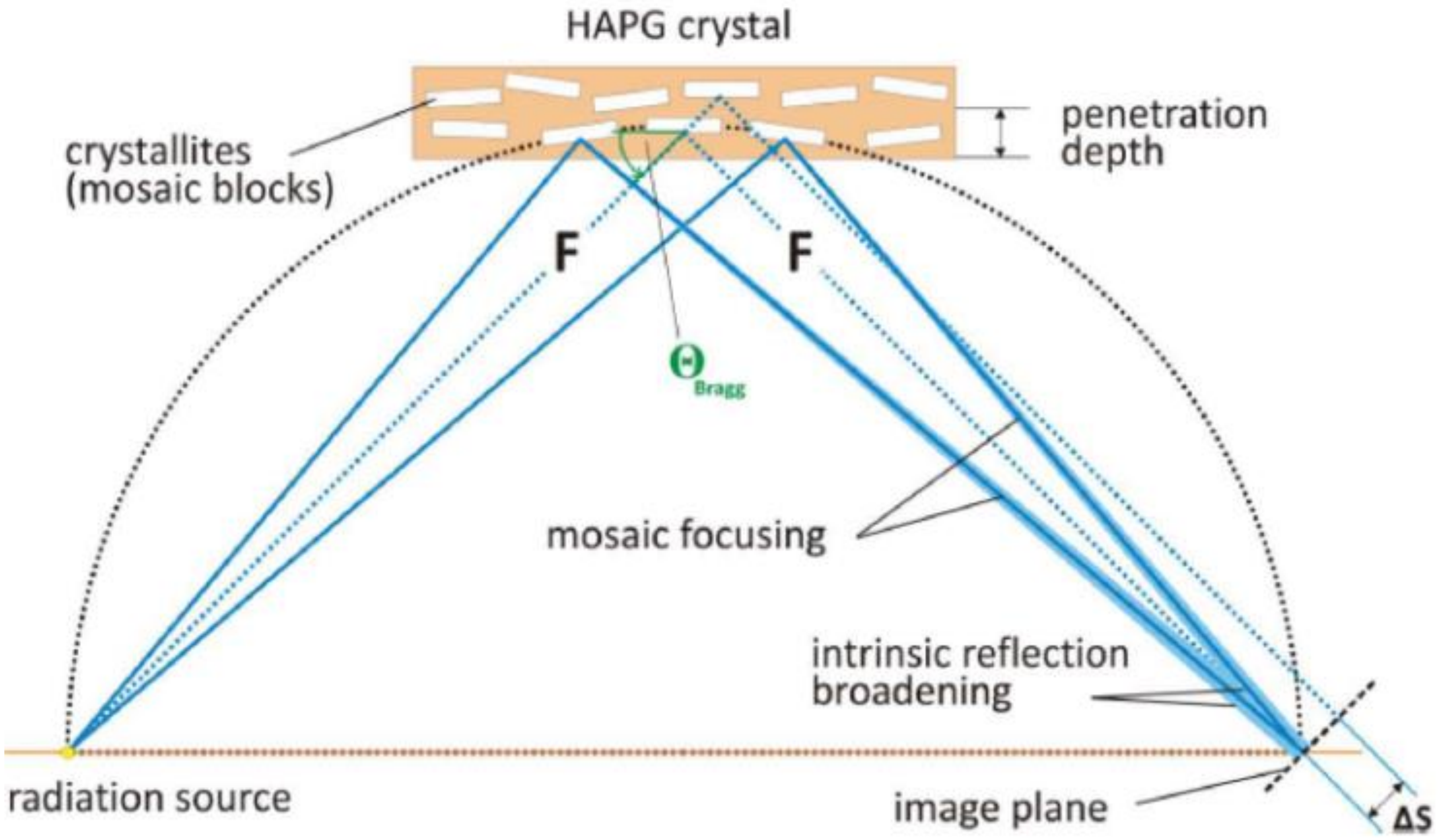
VOn hamos X-ray spectrometer for Extended Sources: VOXES

INFN-CSN5

Young Researcher Grant 2015, n. 17367/2015.

Alessandro Scordo (PI)
Laboratori Nazionali di Frascati, INFN

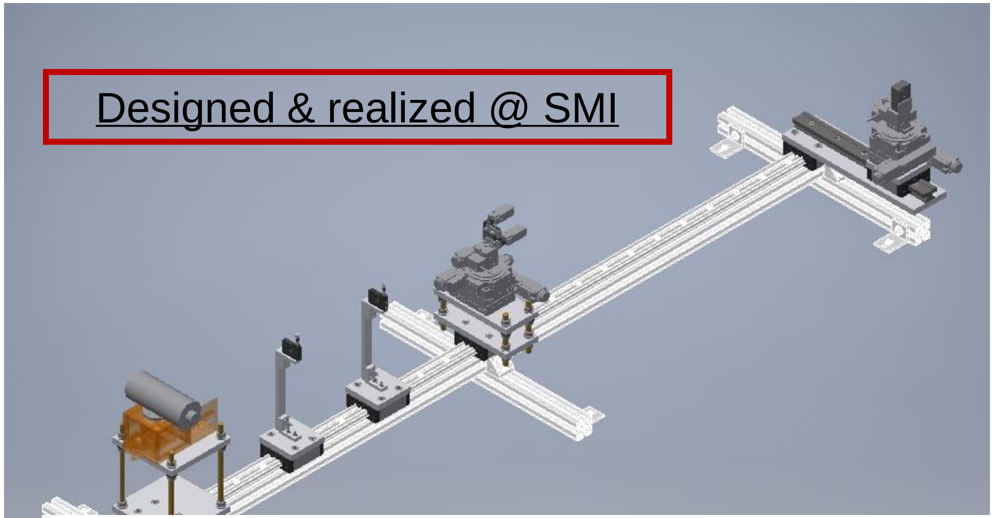
VOXES (Scordo @ LNF)

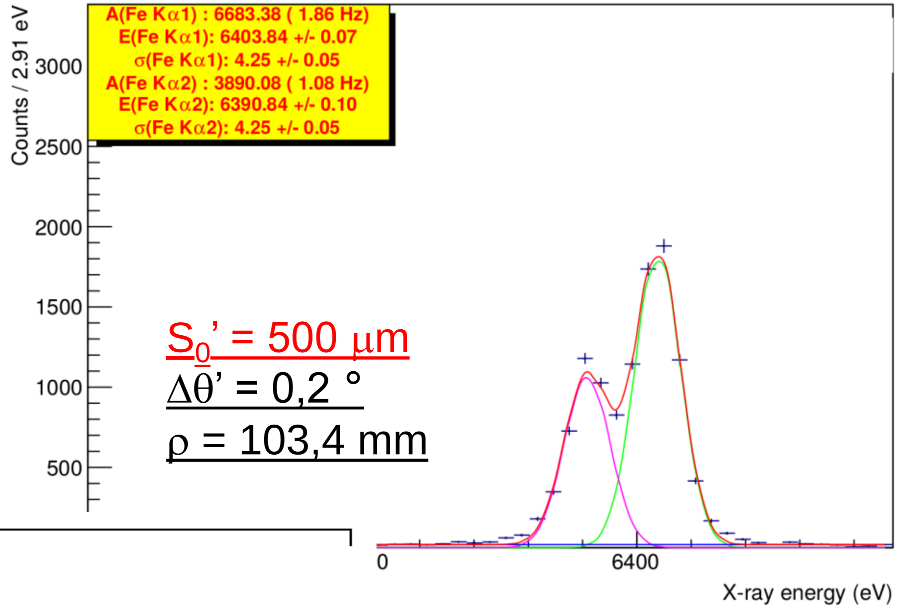


Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Multi line setup and complete characterization

Designed & realized @ SMI

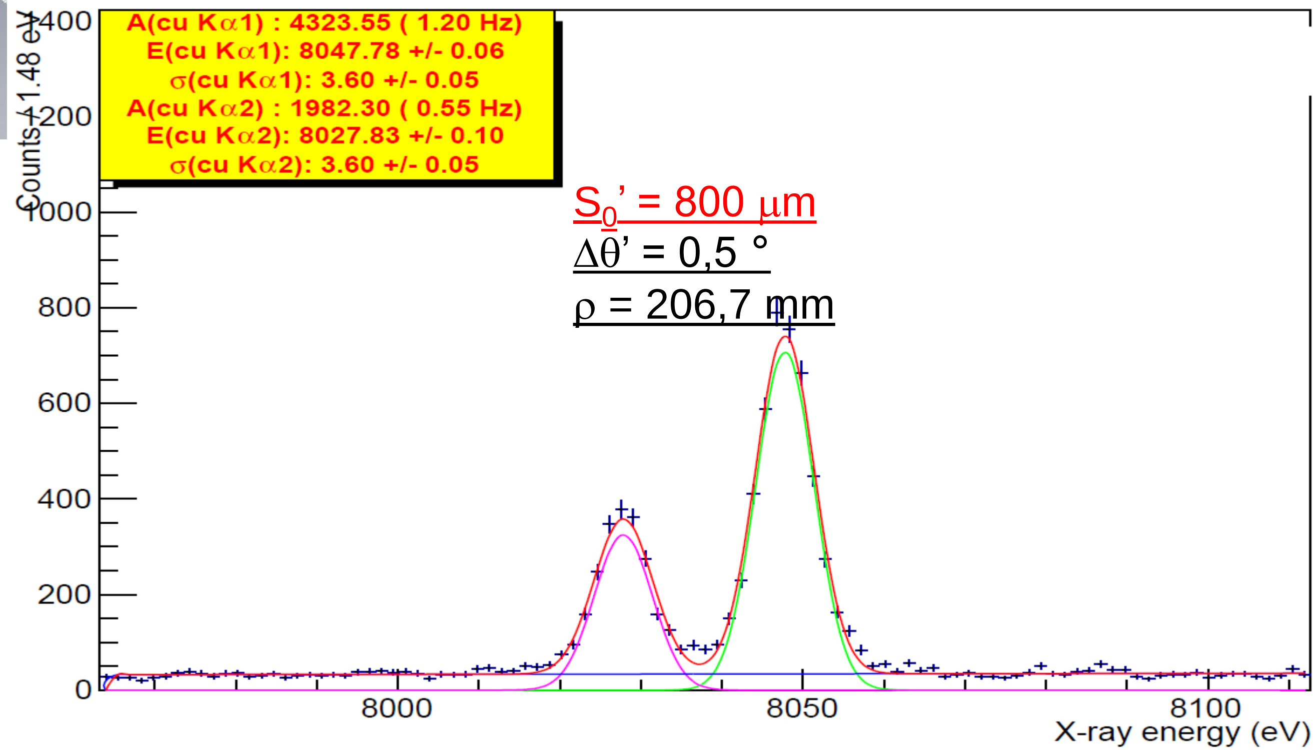




$S_0' = 500\ \mu m$

$\Delta\theta' = 0{,}2$ °

$\rho = 103{,}4$ mm



$S_0' = 800\ \mu m$

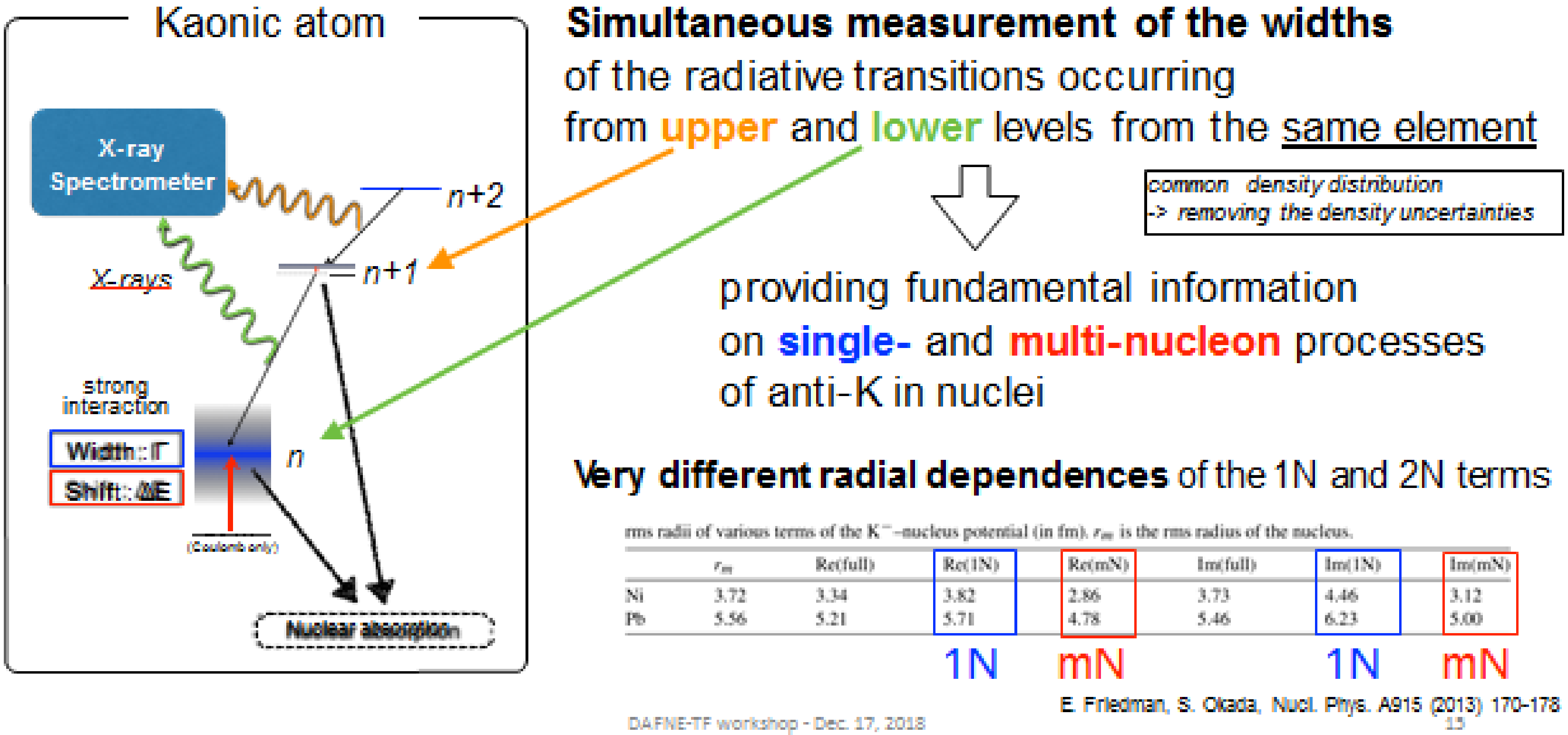
$\Delta\theta' = 0{,}5$ °

$\rho = 206{,}7$ mm

Feasibility tests for future measurements – (II)

WIKAMP proposal presented at DAFNE as ICFA, LNF December 17, 2018

Investigation of single-and multi-nucleon processes of antikaons in nuclei by simultaneous measurements of upper and lower levels transition widths of selected kaonic atoms with ultra-high energy resolution detectors



Simultaneous measurement of the widths
of the radiative transitions occurring
from upper and lower levels from the same element

common density distribution
-> removing the density uncertainties

providing fundamental information
on **single-** and **multi-nucleon** processes
of anti-K in nuclei

Very different radial dependences of the 1N and 2N terms

rms radii of various terms of the K^-–nucleus potential (in fm). r_m is the rms radius of the nucleus.

	r_m	Re(full)	Re(1N)	Re(mN)	Im(full)	Im(1N)	Im(mN)
Ni	3.72	3.34	3.82	2.86	3.73	4.46	3.12
Pb	5.56	5.21	5.71	4.78	5.46	6.23	5.00
			1N	mN		1N	mN

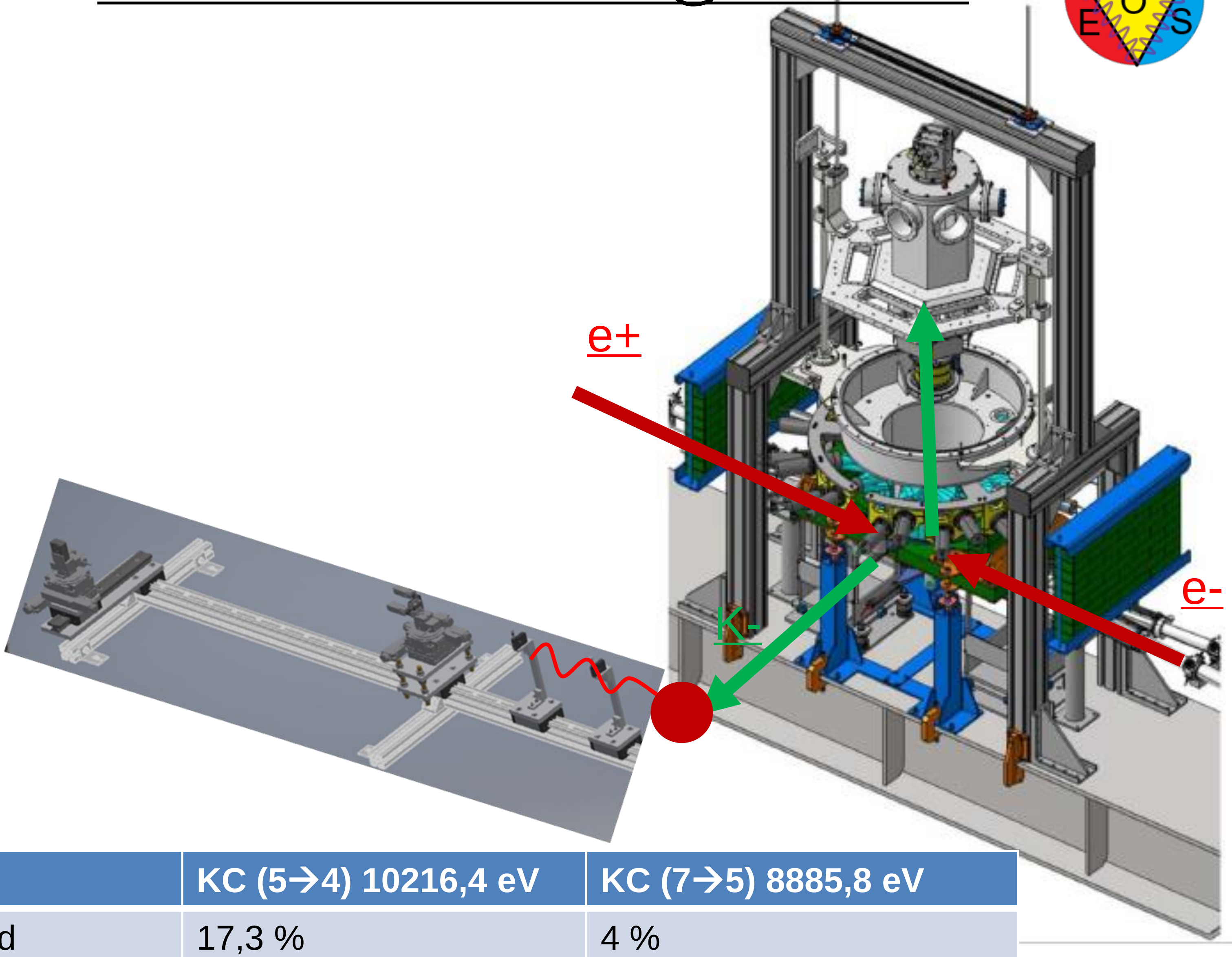
E. Friedman, S. Okada, Nucl. Phys. A915 (2013) 170-178

DAFNE-TF workshop - Dec. 17, 2018

15

- ❖kaon single-and multi-nucleon processes **using VOXES / TES**
- ❖determination of the charged kaon mass (K-) **using VOXES / TES**

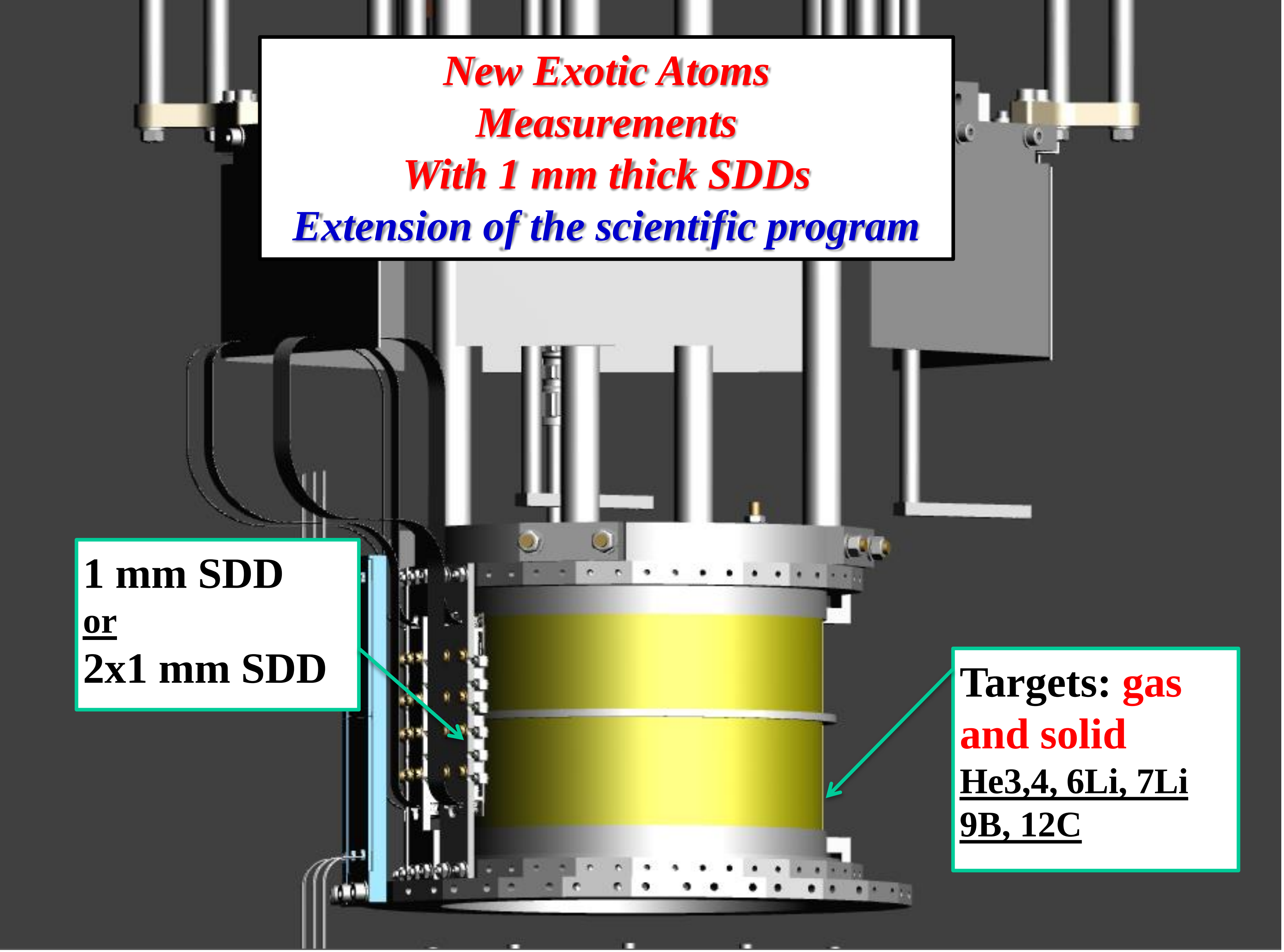
Test measurements @ DAΦNE



	KC (5→4) 10216,4 eV	KC (7→5) 8885,8 eV
Yield	17,3 %	4 %
ev / 200 gg	95	16
δE (200 gg)	(<=) 0,7 eV	(≈) 1,6 eV

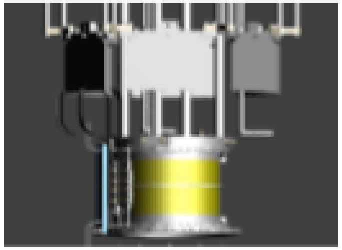
New Exotic Atoms Measurements With 1 mm thick SDDs

Extension of the scientific program



1 mm SDD
or
2x1 mm SDD

Targets: gas and solid
He3,4, 6Li, 7Li
9B, 12C



Light Kaonic Atoms Measurements with 1mm SDDs

August 2020

The SIDDHARTA-2 Collaboration

Kaonic Helium 3 and 4 transitions to 1s level to check models (potential, chiral,…..) resulting from SKH and Kd

An advantage of "upper levels"*

Sławomir Wycech

In analogy to antiprotons the scenario under the $\overline{K}N$ threshold is determined by a resonant state $\Lambda(1405)$ with a pole close to E_{cm} 1410 MeV that is in the ^{3}He region. On the other side one has $\Sigma(1385)$ state which exerts maximum repulsive effect in the ^{4}He region. Apparently these two main agents yield attractive shift in ^{3}He and repulsive in ^{4}He. Now, in order to go above the errors one has to magnify the shifts and enhance the atomic-nuclear overlaps. The proper targets would be ^{8}Be and ^{6,7}Li. These offer similar values of E_{cm} as ^{4}He and ^{3}He . A simple re-scaling of overlaps generates the level shifts of about 100 eV. One should perhaps consider also studies of $3D$ levels in these atoms. One interesting outcome might be the estimate where the isospin 0 Re $T(\overline{K}N \rightarrow \overline{K}N)$ amplitude crosses zero. That will help to settle the controversy as to where is the $\Lambda(1405)$ pole in the complex plane located.

9th August 2020

Features of K^-NN interaction in light kaonic atoms

E. Friedman, A Gal

Generally speaking, studies of 'beyond single nucleon interactions' in kaonic atoms are at present necessary and feasible theoretically, and are feasible experimentally. Several chiral models of K^- nucleon interactions near threshold have been successful in reproducing K^- nucleon data. These models form a solid basis for global optical potentials that reproduce very well strong interaction observables in kaonic atoms throughout the Periodic Table, when supplemented by a phenomenological term representing interaction of K^- with two or several nucleons. Current projects (e.g. in Prague and in Barcelona) are tackling this topic in medium weight and heavy nuclei.

We have been engaged recently in a more phenomenological approach to interaction of K^- with two nucleons in kaonic atoms. We get a clear picture showing that features of K^-NN interaction are evident already in very light nuclei. In particular, from 12C upwards features of K^-2N interaction in the nuclear medium are already fully developed. Similar analyses of pionic atoms where the experimental results are more extensive and are of much higher quality show great similarity with kaonic atoms. Moreover, gradual build-up of in-medium features is clearly observed over the sequence of 3He, 6Li, 7Li, 9Be, 10B and 11B. We believe these species are amenable to few-body approaches using present-day methods.

Returning to kaonic atoms, only for 9Be, 10B and 11B the experimental results are of sufficient quality and indeed gradual build-up of in-medium features in parallel with pionic atoms is evident. We believe that good quality data, particularly values of strong interaction widths of the 2p level in kaonic atoms of 3He, 6Li, 7Li and 9Be will be a significant contribution to few-body studies of the onset of K^-NN interaction in the nuclear medium.

Therefore we propose that these four species of kaonic atoms will be part of the near future experimental program.

Before giving some examples related to this, we also wish to mention that the measurement of kaonic atoms, such as kaonic carbon, are fundamental to extract the charged kaon mass; presently, exactly based on these type of measurements (kaonic carbon and kaonic lead) there is a puzzle badly affecting the kaon mass value – as easily can be seen in PDG (https://pdg.lbl.gov/2019/reviews/rpp2018-rev-charged-kaon-mass.pdf) the two most precise measurements are about 6-8 sigmas far away:

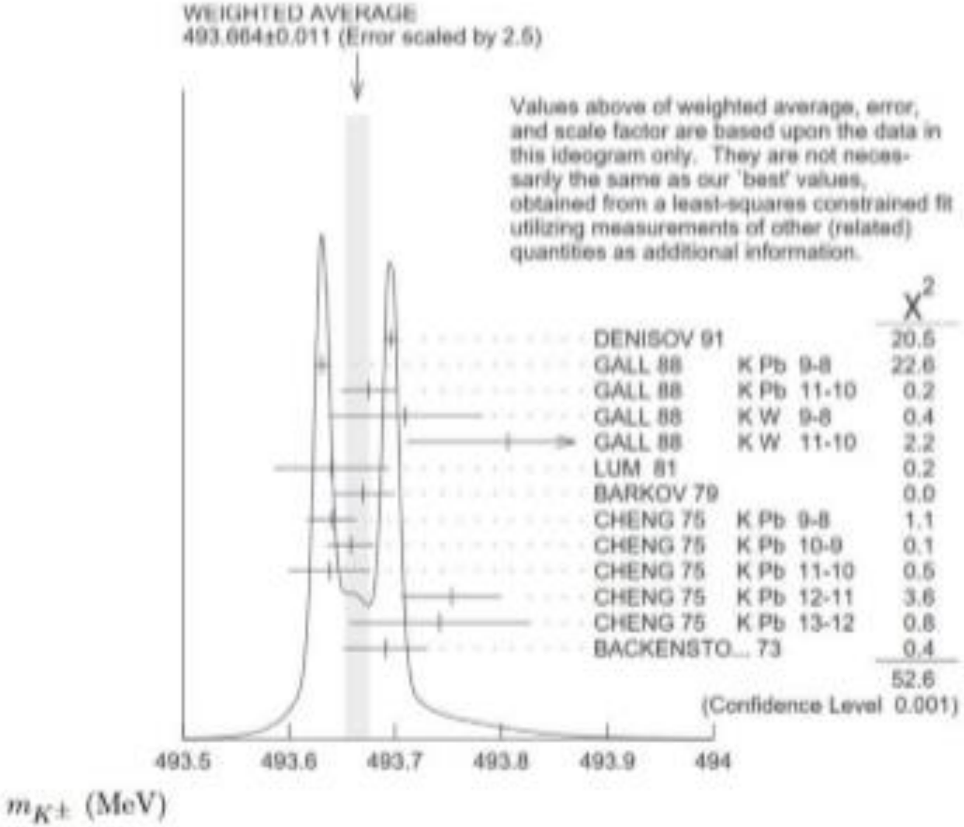


Figure 73.1: Ideogram of $m_{K\pm}$ mass measurements. GALL 88 and CHENG 75 measurements are shown separately for each transition they measured.

For test of QCD antikaon-nucleon scattering lengths from KH and Kd: kaonic Helium-3 2-->1 transition = 33 keV kaonic Helium-4 2-->1 transition = 35 keV

For kaon mass: kaonic Carbon 4-->3 transition = 22 keV

QCD (Lambda(1405), multi-nucleon…):

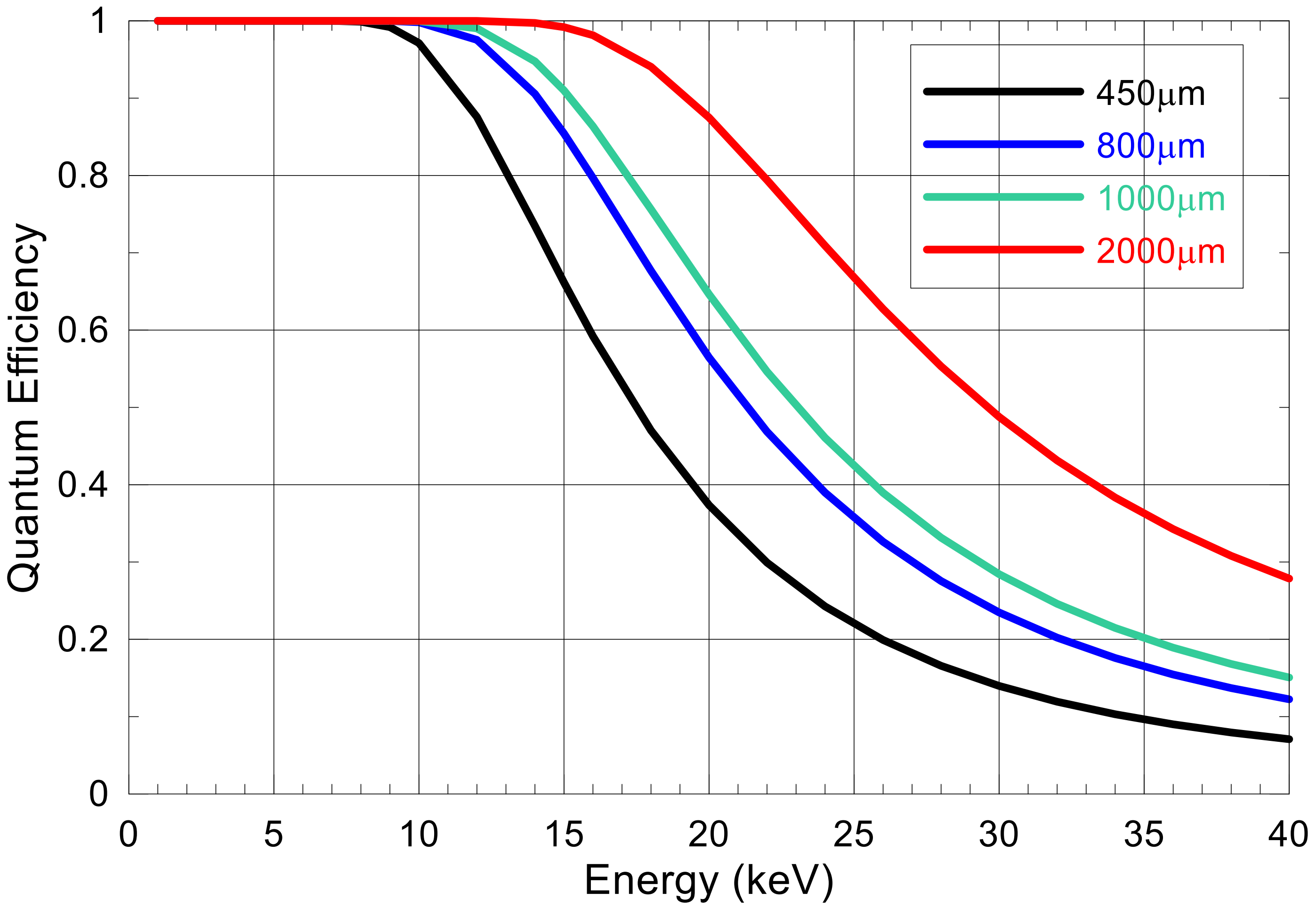
Kaonic Lithium-6 3-->2 transition = 15.08 keV kaonic Lithium-6 4-->3 transition = 5.28 keV

Kaonic Lithium-7 3-->2 transition = 15.3 keV kaonic Lithium-7 4-->3 transition = 5.34 keV

Kaonic Boron-9 3-->2 transition = 43.04 keV kaonic Boron-9 4-->3 transition = 15.07 keV

Kaonic Beryllium-9 is similar to kaonic Boron 9.

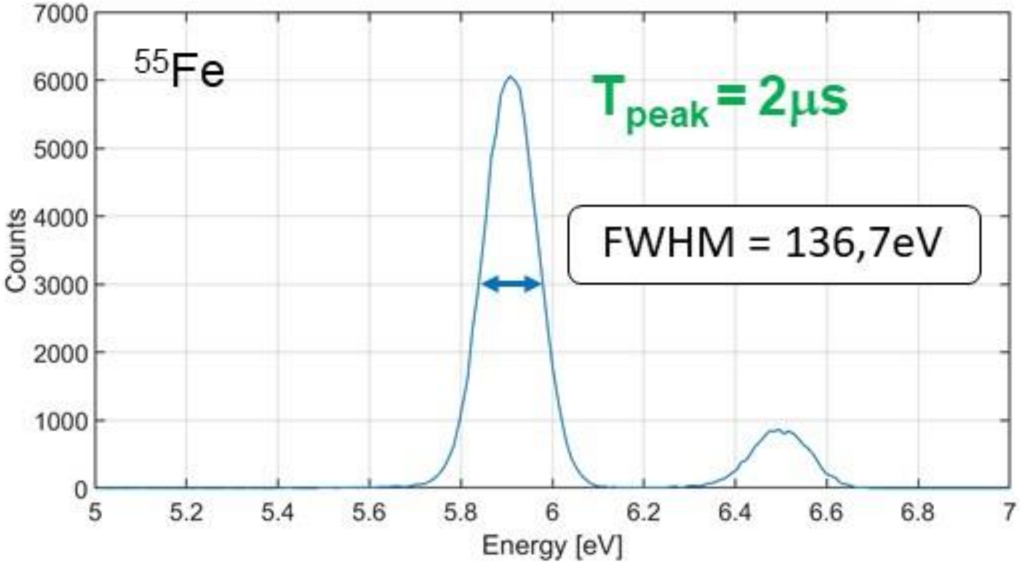
Thicker SDDs for larger efficiency at E>10keV

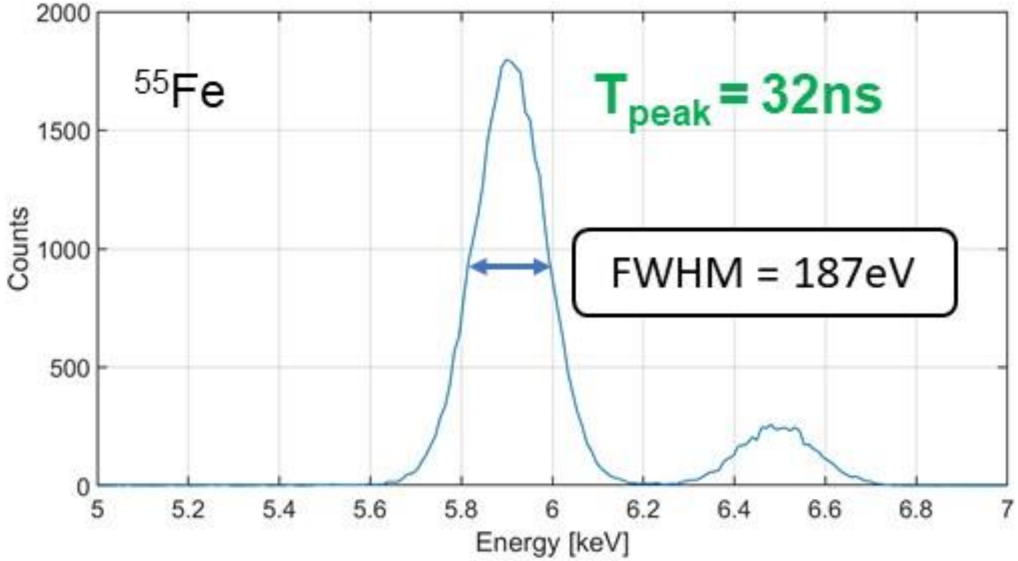


- 1-2 mm SDDs may increase x2-x4 the efficiency @30keV vs. present 450um SDDs
- 800um and 1mm SDDs prototypes already produced by FBK for ARDESIA (INFN)

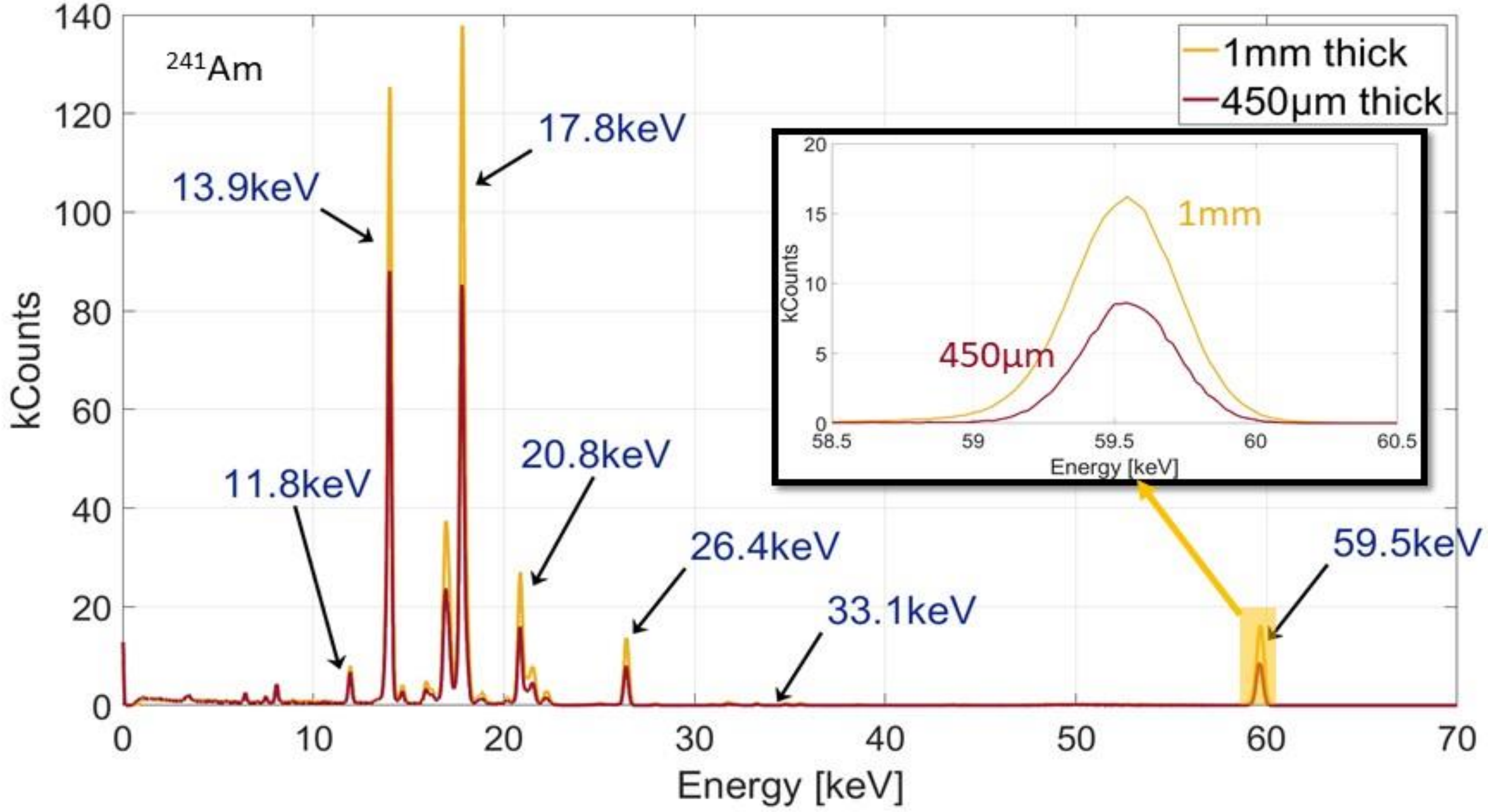
Preliminary tests on 1mm thick SDD (1)

single SDD
5x5mm^2 square
T=-40°C

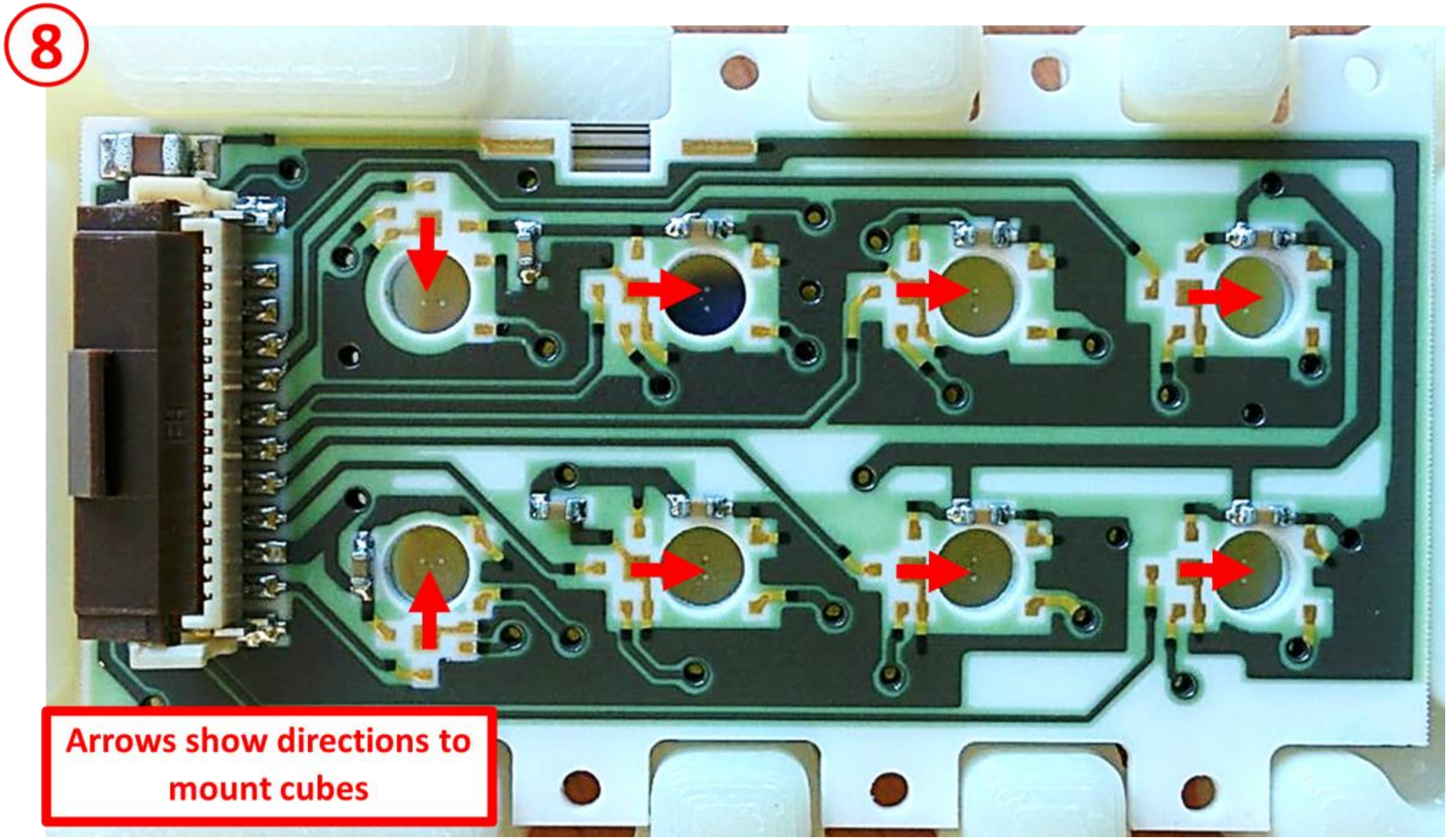




Preliminary tests on 1mm thick SDD (2)



OLD assembly/bonding strategy

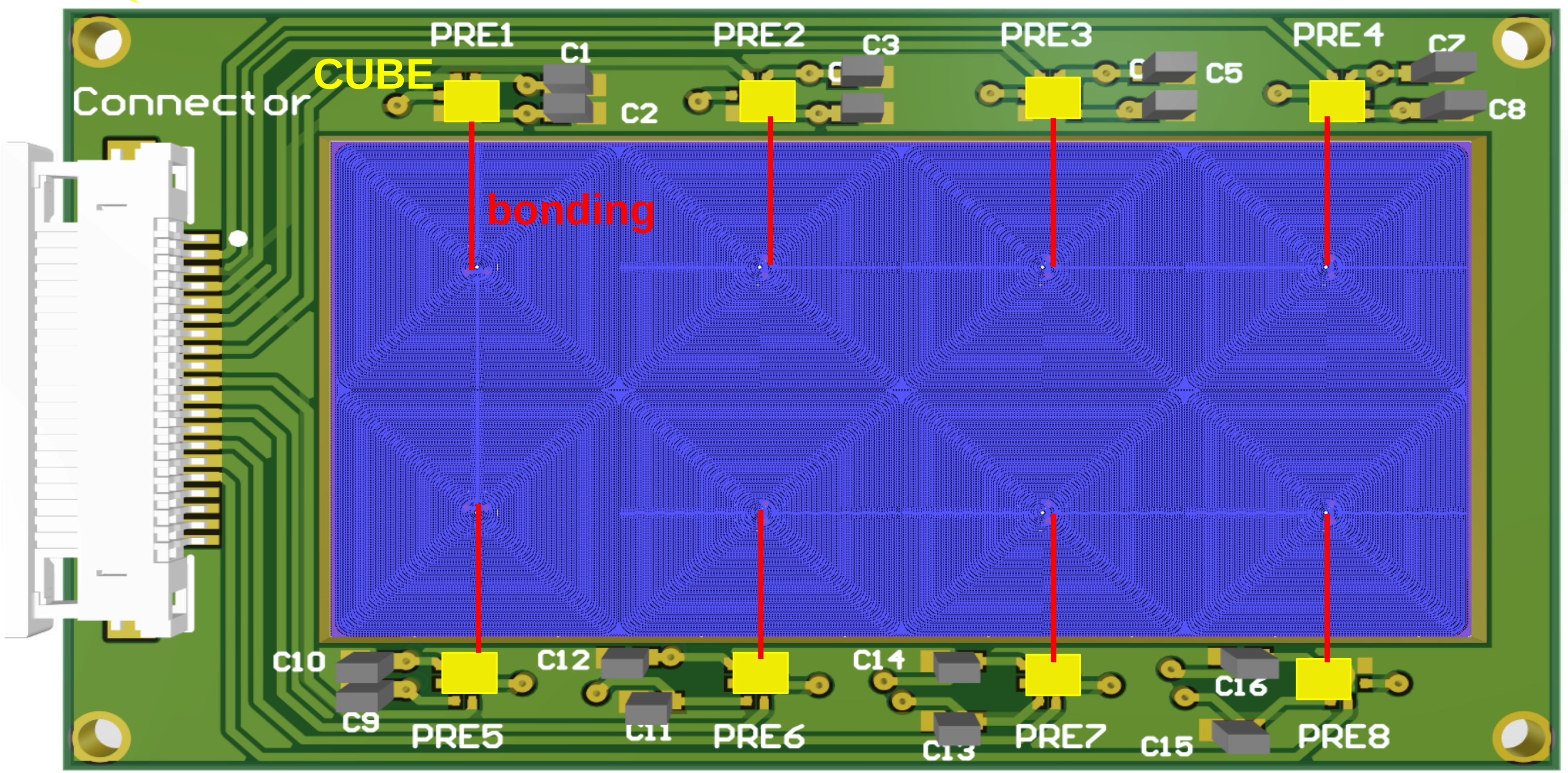


⑧

Arrows show directions to mount cubes

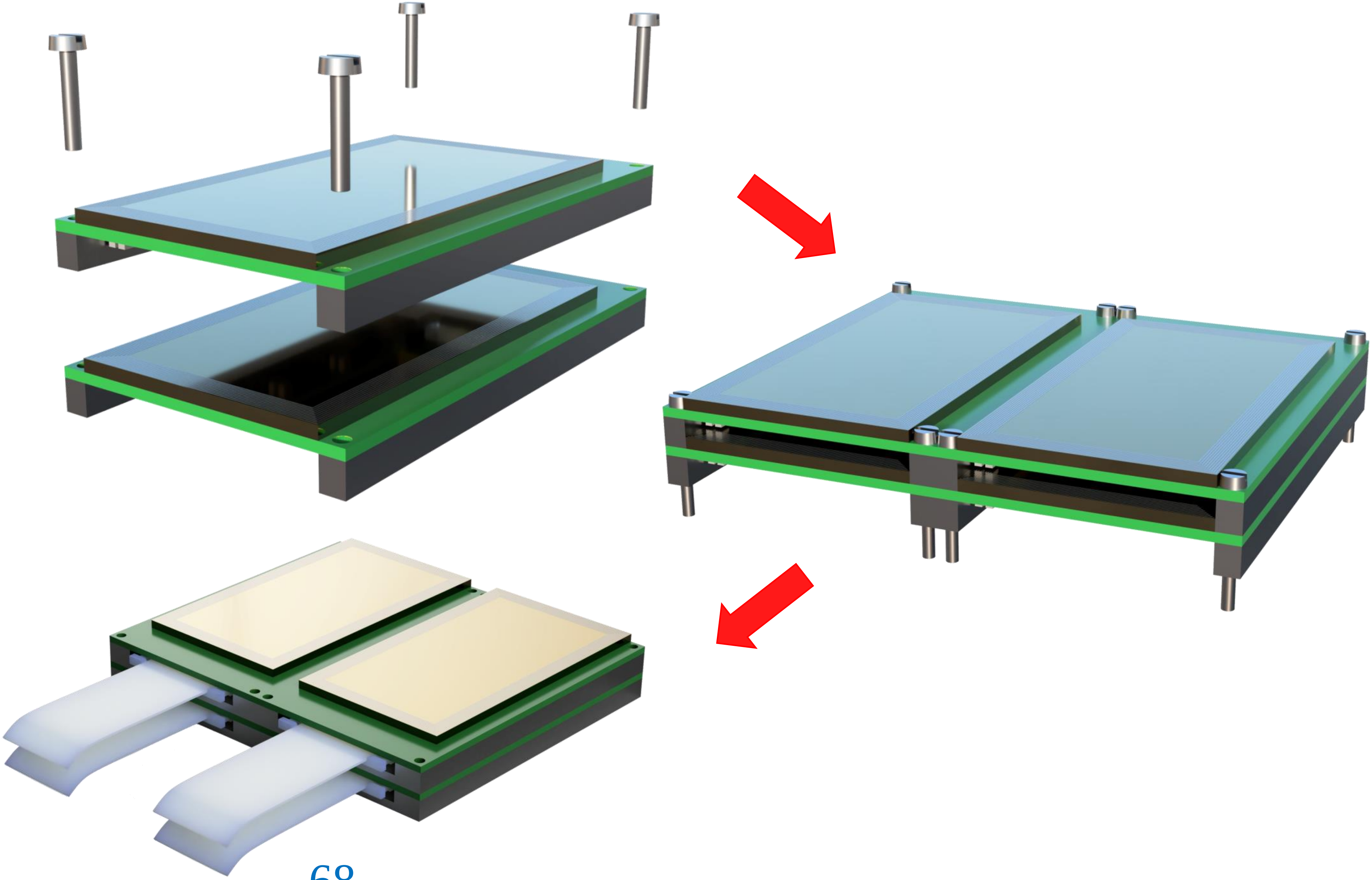
1) substrate board OVERLAPPED to the main area of the SDD array
2) bonding from SDDs to CUBEs in the CENTRAL area of the module

NEW assembly/bonding strategy

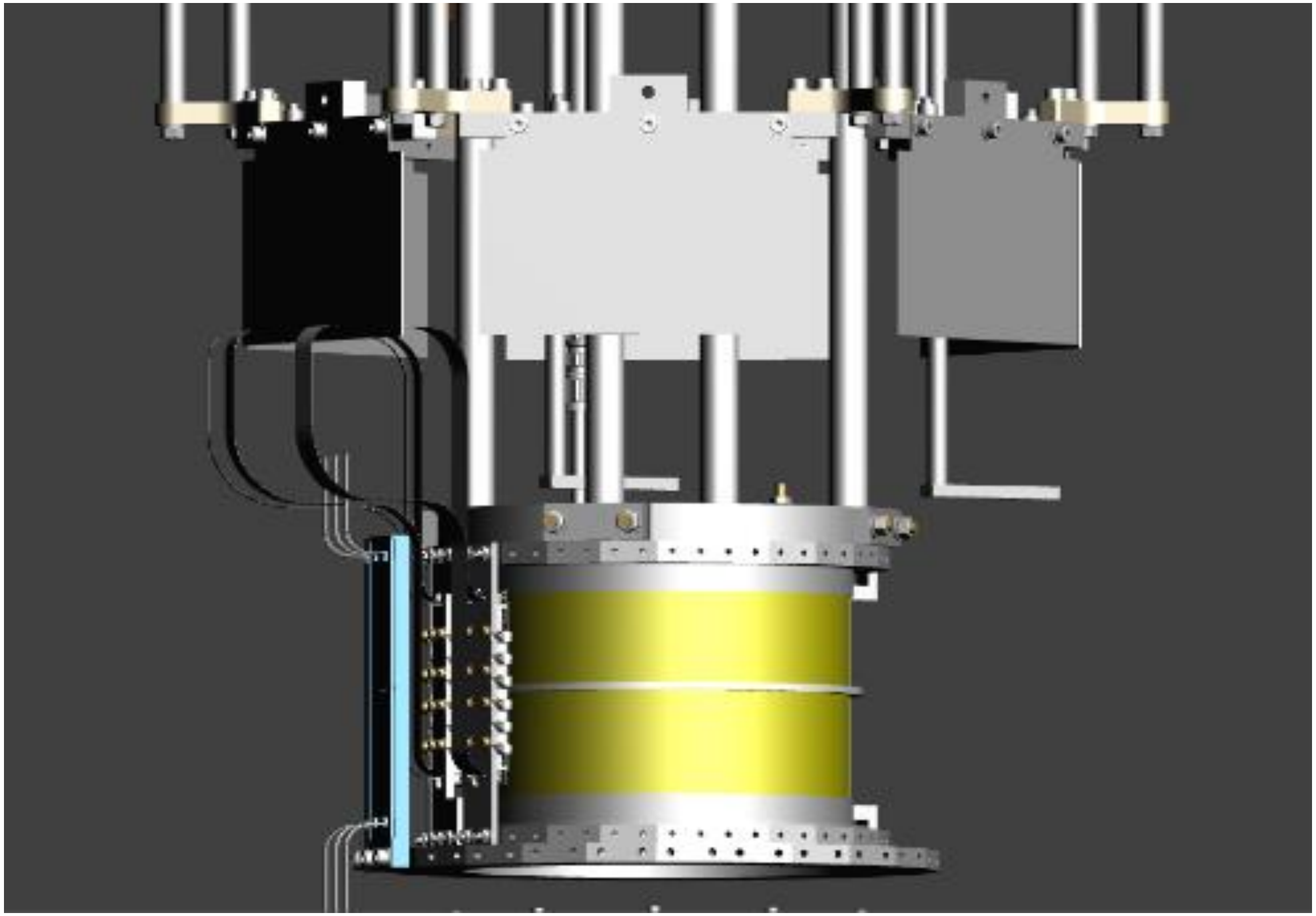


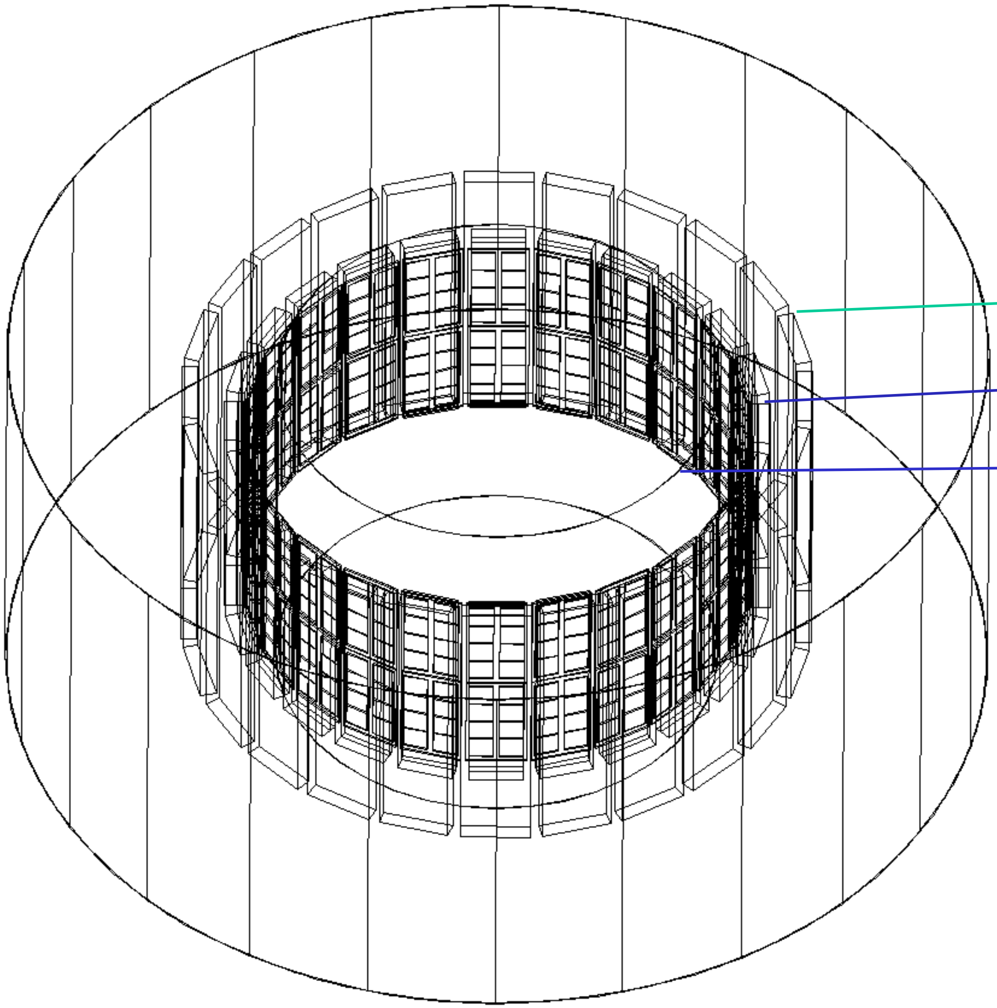
1) substrate board glued on the EXTERNAL frame of the SDD array
2) CUBEs placed and bonded in the EXTERNAL area of the substrate

Assembly of more SDD layers



Monte Carlo simulations





MIPS VETO

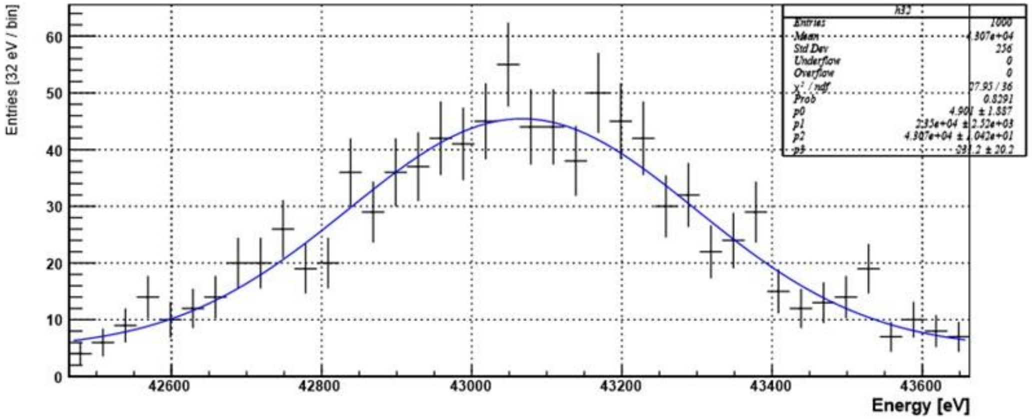
SDD

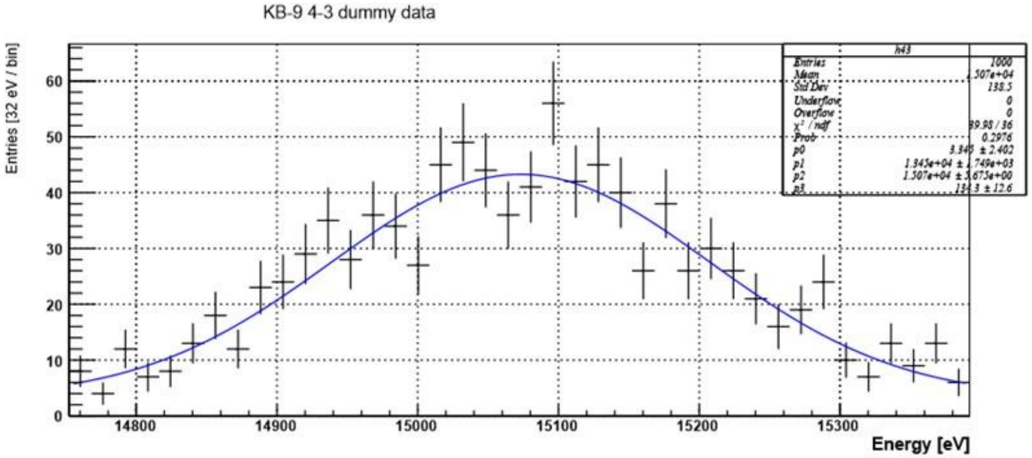
TARGET

The outcome of the preliminary Monte Carlo simulation is that the number of events for example for kaonic Boron is (for yields of 100%):

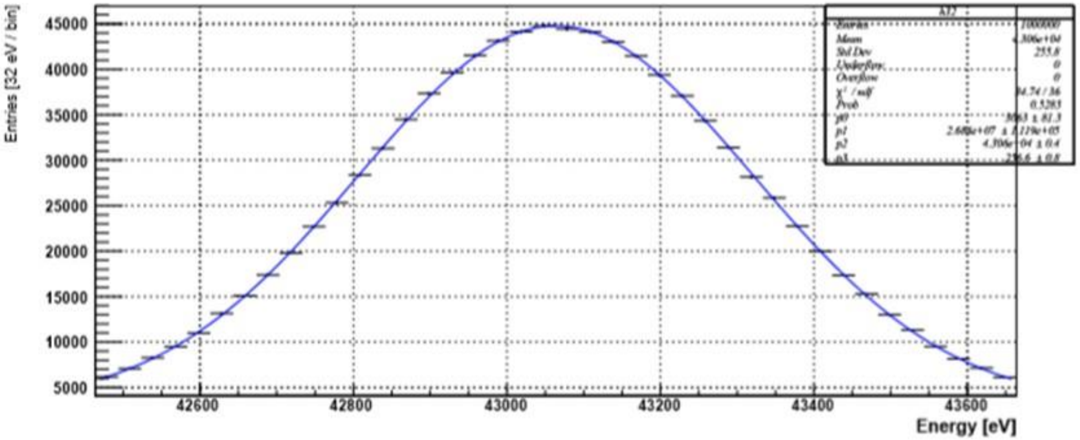
kaonic Boron-9 3-->2 transition = 43.04 keV: 180 events/pb-1/48 SDDs (5.12 cm**2 each SDD) for 1mm SDDs; 360 events/pb**-1/48 SDDs for 1mm SDDs**
kaonic Boron-9 4-->3 transition = 15.07 keV: 1200 events/pb-1/48 SDDs (5.12 cm**2 each SDD)**

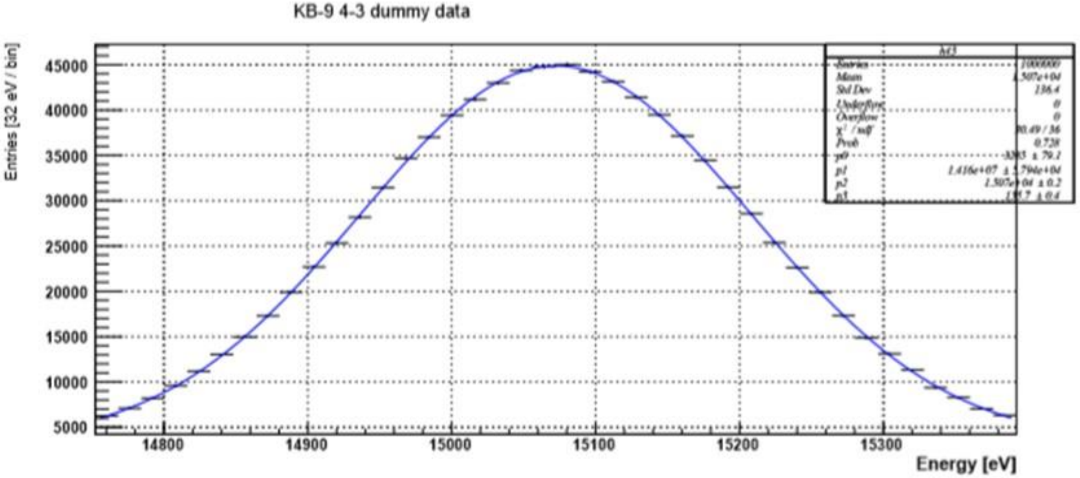
As example of simulated spectra we give two limiting cases – one with a statistics of 1000 events:



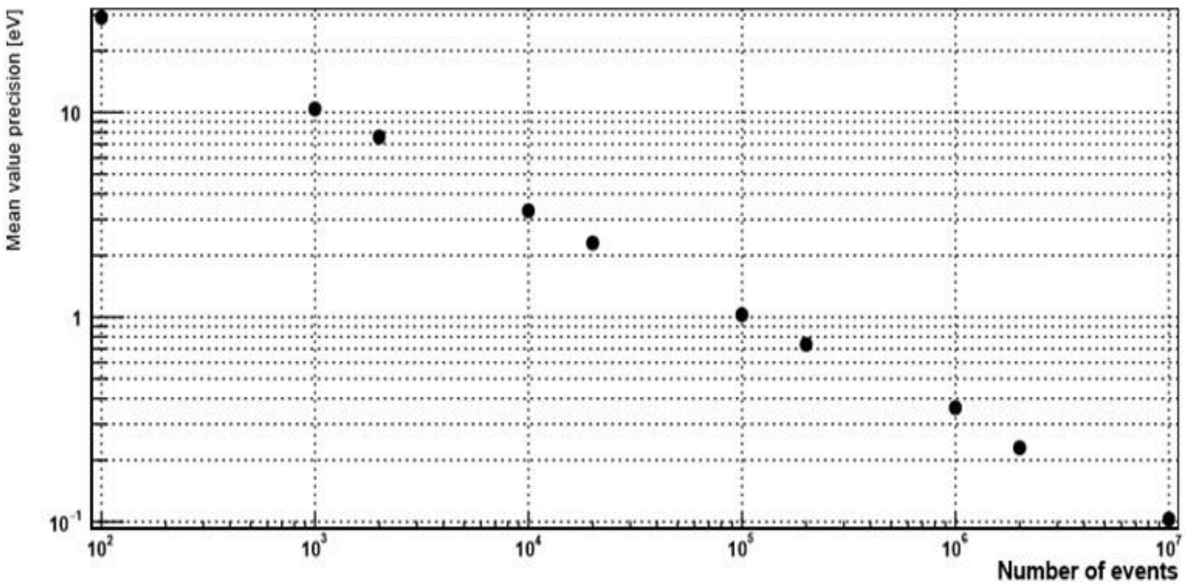


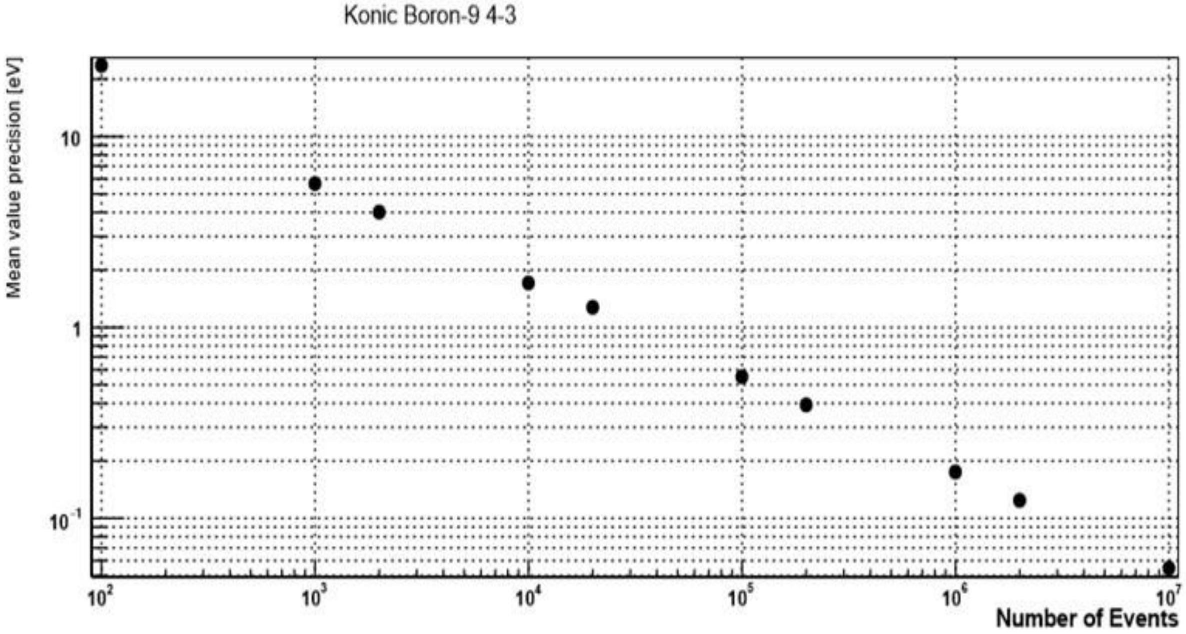
And one with a statistics of 1000000 events:





the precision of the measurement as function of statistics in the peak, obtaining the following outcome:

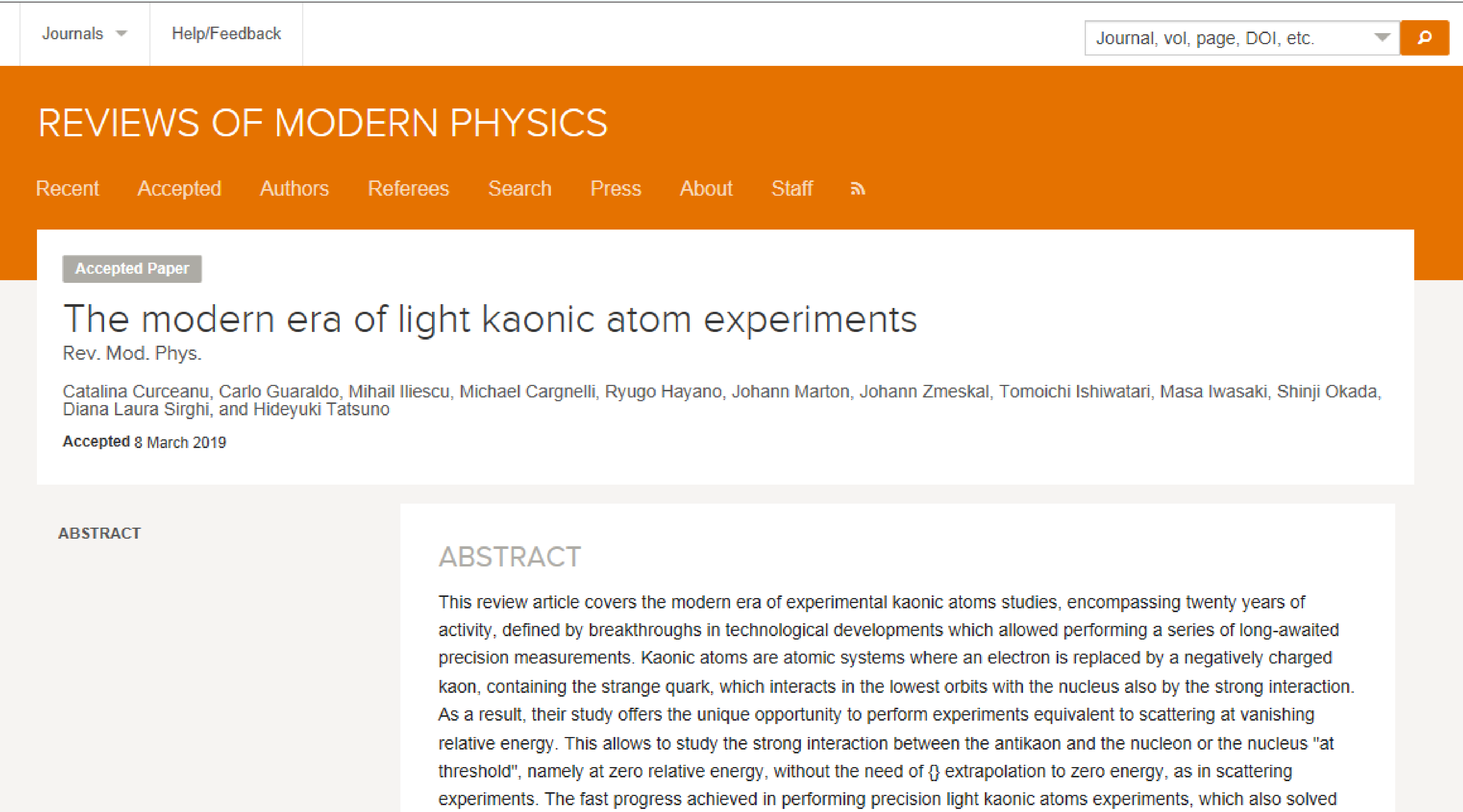




Taking into account the rate of events, and also considering that yield is not 100% but more likely around 20% we expect to obtain 10.000 events as follows:

- For the 15 keV transition with 240 events per pb-1 we need about 40 pb**-1 to obtain a precision of about 2 eV**
- For the 43 keV transition with 1mm SDDs we need about 270 pb-1 and about 135 pb**-1 to obtain a precision of about 2-3 eV (for about 100 pb**-1 the precision in both cases remains very good – at level of better than 3-4 eV).**
All other proposed measurements are similar.
In Conclusion: with about 100-200 pb-1 per target and with 4-5 different types of targets we can do precision measurements of a series of kaonic atoms strongly impacting in the QCD studies (including chiral symmetry).**

For more infos:



REVIEWS OF MODERN PHYSICS

The modern era of light kaonic atom experiments

Rev. Mod. Phys.

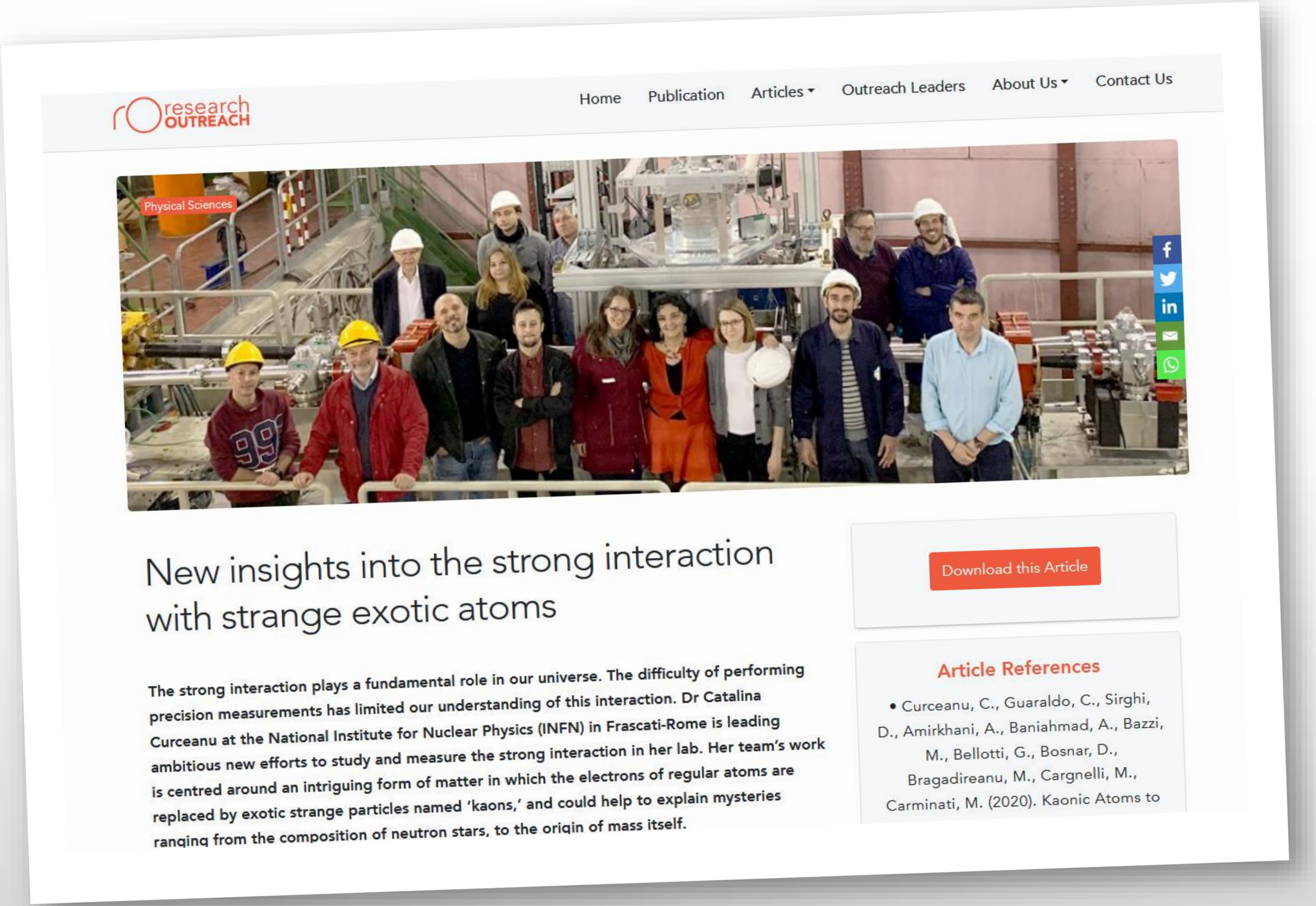
Catalina Curceanu, Carlo Guaraldo, Mihail Iliescu, Michael Cargnelli, Ryugo Hayano, Johann Marton, Johann Zmeskal, Tomoichi Ishiwatari, Masa Iwasaki, Shinji Okada, Diana Laura Sirghi, and Hideyuki Tatsuno

Accepted 8 March 2019

ABSTRACT

This review article covers the modern era of experimental kaonic atoms studies, encompassing twenty years of activity, defined by breakthroughs in technological developments which allowed performing a series of long-awaited precision measurements. Kaonic atoms are atomic systems where an electron is replaced by a negatively charged kaon, containing the strange quark, which interacts in the lowest orbits with the nucleus also by the strong interaction. As a result, their study offers the unique opportunity to perform experiments equivalent to scattering at vanishing relative energy. This allows to study the strong interaction between the antikaon and the nucleon or the nucleus "at threshold", namely at zero relative energy, without the need of {} extrapolation to zero energy, as in scattering experiments. The fast progress achieved in performing precision light kaonic atoms experiments, which also solved

Published 20th June 2019 Rev. Mod. Phys. 91, 025006



New insights into the strong interaction with strange exotic atoms

The strong interaction plays a fundamental role in our universe. The difficulty of performing precision measurements has limited our understanding of this interaction. Dr Catalina Curceanu at the National Institute for Nuclear Physics (INFN) in Frascati-Rome is leading ambitious new efforts to study and measure the strong interaction in her lab. Her team's work is centred around an intriguing form of matter in which the electrons of regular atoms are replaced by exotic strange particles named 'kaons,' and could help to explain mysteries ranging from the composition of neutron stars, to the origin of mass itself.

Article References

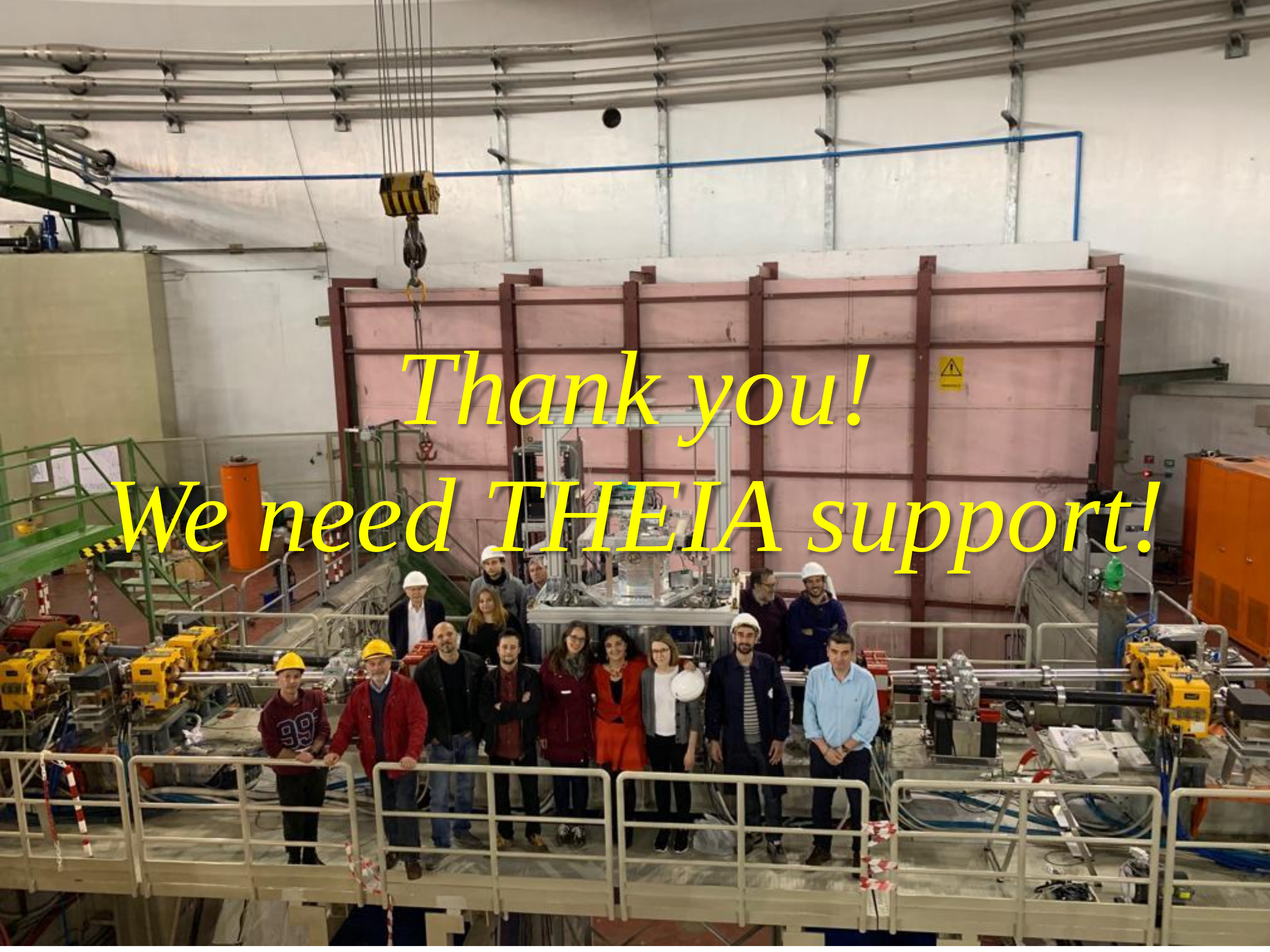
- Curceanu, C., Guaraldo, C., Sirghi, D., Amirkhani, A., Baniahmad, A., Bazzi, M., Bellotti, G., Bosnar, D., Bragadireanu, M., Cargnelli, M., Carminati, M. (2020). Kaonic Atoms to

Future measurements planned at DAFNEpromise to boost even farther our comprehension in “strangeness physics” and help having a better understanding of the role of strangeness in the Universe and of how Nature works.

There is no exquisite beauty without some STRANGENESS in the proportion.

Edgar Allan Poe

www.janeandcompanydesign.etsy.com

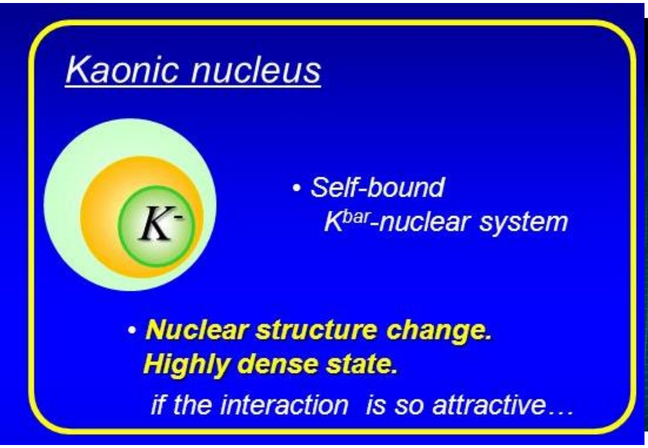


Thank you!

We need THEIA support!

The Modern Era of precision measurements of hadronic (kaonic) atoms fosters a deeper understanding of the antikaon-nuclei interactions at threshold, which is fundamental to unveil the mechanisms at work on non-perturbative strangeness QCD.

Implications going from particle and nuclear physics to astrophysics.



Kaonic nucleus

- Self-bound
  K^{bar}-nuclear system

- ***Nuclear structure change.***
  Highly dense state.
  if the interaction is so attractive…