Experimental studies of the kaonic atoms at DAΦNE collider: from SIDDHARTA to SIDDHARTA-2

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on behalf of SIDDHARTA/SIDDHARTA-2 collaboration

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SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

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

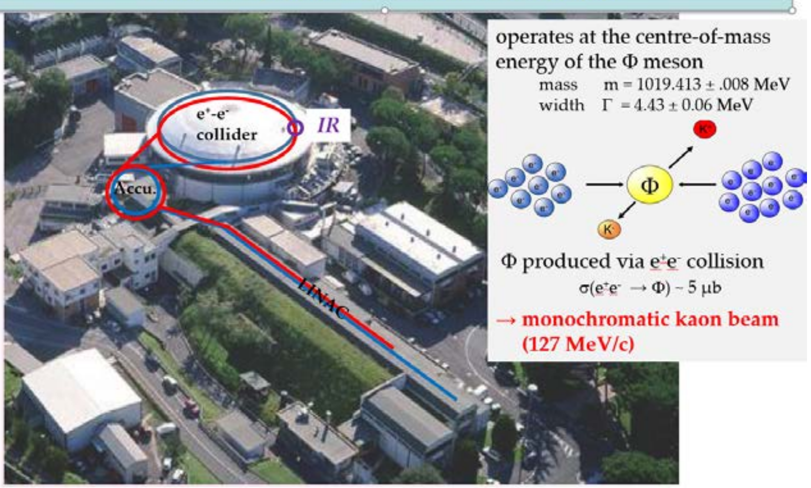
STRONG-2020

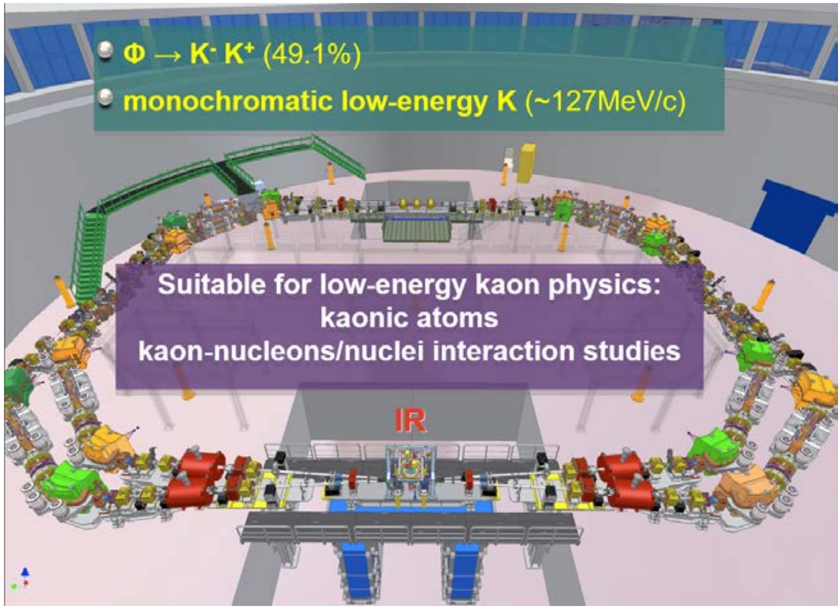
Croatian Science Foundation, research project 8570

- 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

DAΦNE accelerator, since 1998:

The Double Annular Φ factory for Nice Experiments





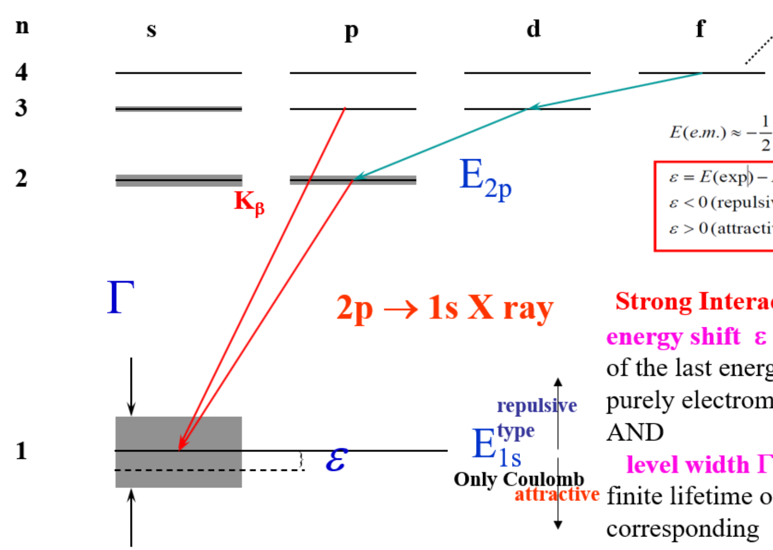
The scientific aim

the determination of the
isospin dependent $\overline{K}N$ 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



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

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

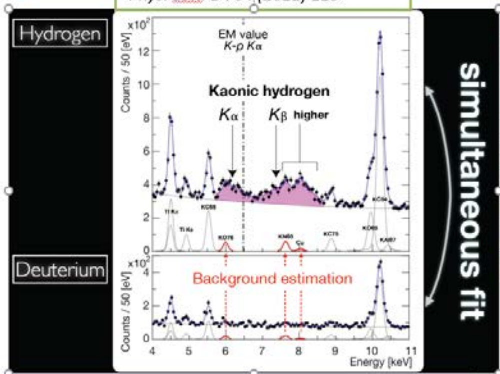
$$\varepsilon = E_{2p\rightarrow 1s}(\exp) - E_{2p\rightarrow 1s}(e.m.)$$

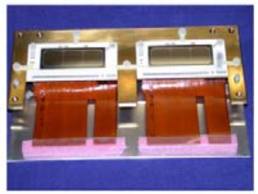
SIDDHARTA/SIDDHARTA-2 measure the
X-ray transitions
occurring in the cascade processes
of kaonic atoms

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

SIDDHARTA results: KH (2009)

Phys. Lett. B 704 (2011) 113





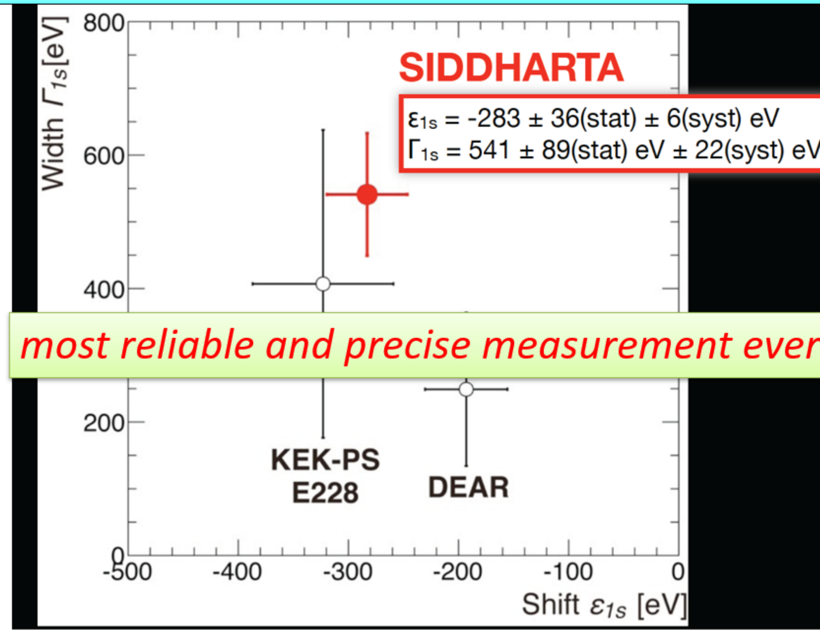
ε_{1S} = −283 ± 36(stat) ± 6(syst) eV

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:

- **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*

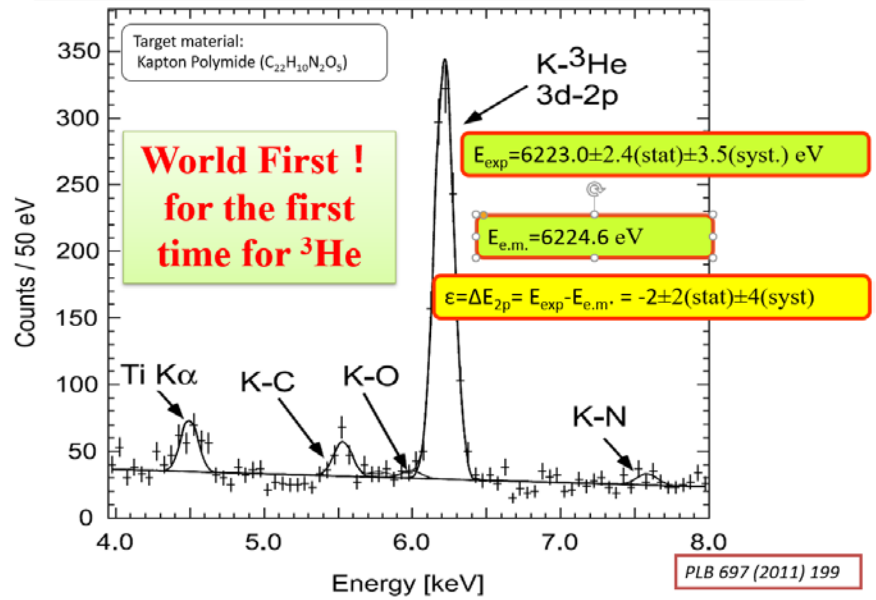
- **Kaonic helium 4** *– first measurement ever in gaseous target; published in Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264 and Phys. Lett. B 697 (2011);; PhD*

- **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: K-^{3}He



PLB 697 (2011) 199

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 $a_{K\text{-}p}$

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

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

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

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:

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

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

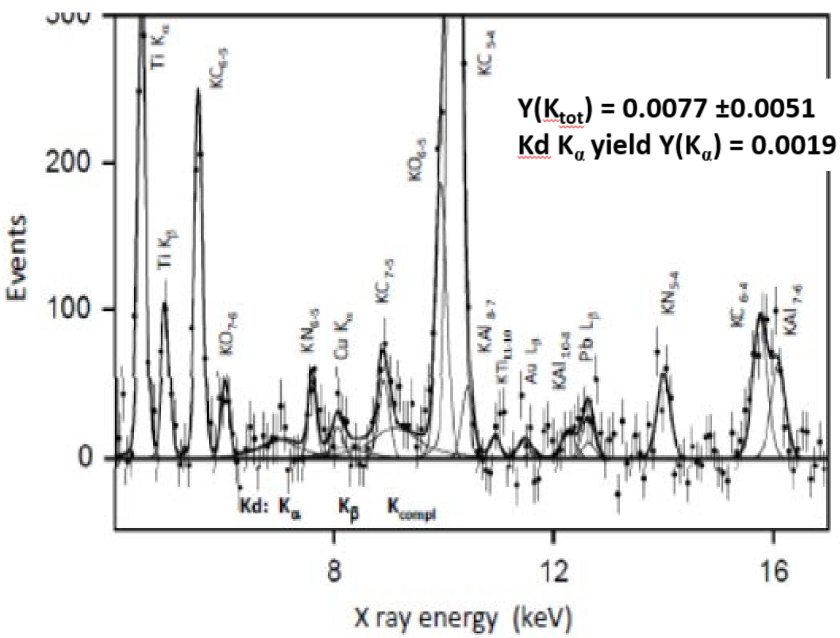
$$a_{K-d} = \frac{4[m_N + m_K]}{[2m_N + m_K]}Q + C$$

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

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: First Kd exploratory measurement



Experimental challenges towards K^-d

- X-ray yield: K^-p ~ 1 %
  K^-d ~ 0.1 %
- 1s state width: K^-p ~ 540 eV
  K^-d ~ 800 – 1000 eV

BG sources: asynchronous BG → timing
synchronous BG → spatial correlation

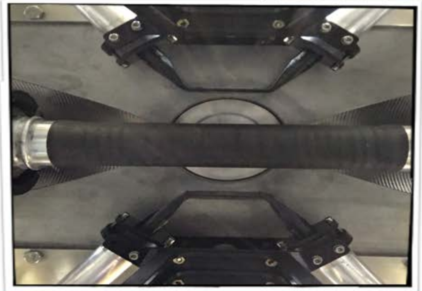
an enhancement by one order of magnitude of the signal-to background ratio is required for SIDDHARTA-2.

Important features of the SIDDHARTA-2 setup

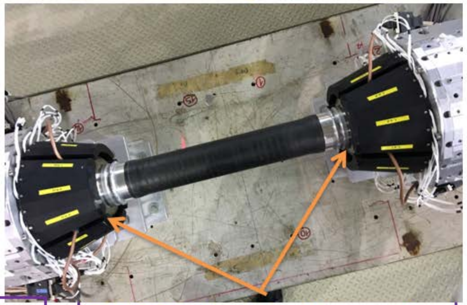
- New interaction region and beam pipe
- Special designed shielding
- Lightweight cryogenic target
- Silicon Drift Detector
- Veto-2 system
- Luminosity monitor

New beam pipe

flanges removed
major source of
asynchronous
background

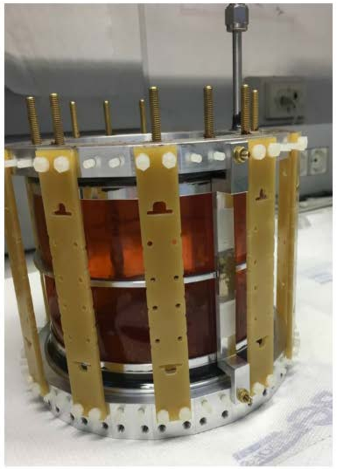


SIDDHARTA-2 luminosity monitor



DAΦNE luminosity monitor

Light target and Silicon Drift Detector assembly

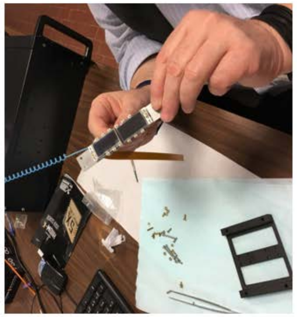


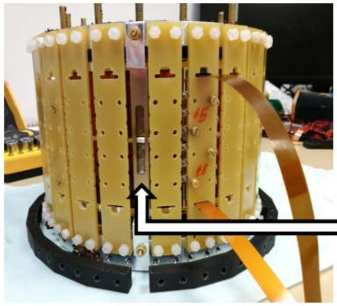
Target cell wall is made of a 2-Kapton layer structure (75 μm + 75 μm + Araldit)

increase the target stopping power

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

SDDs placed 5 mm from the target wall

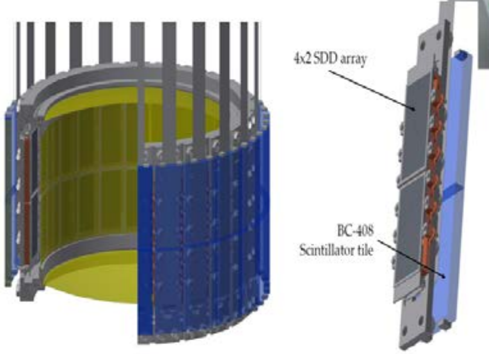


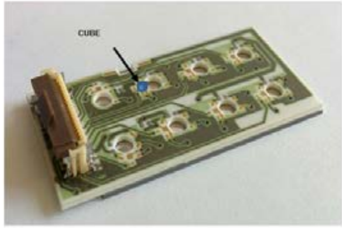


calibration foils inserted near to the SDD are activated by the X-ray tubes

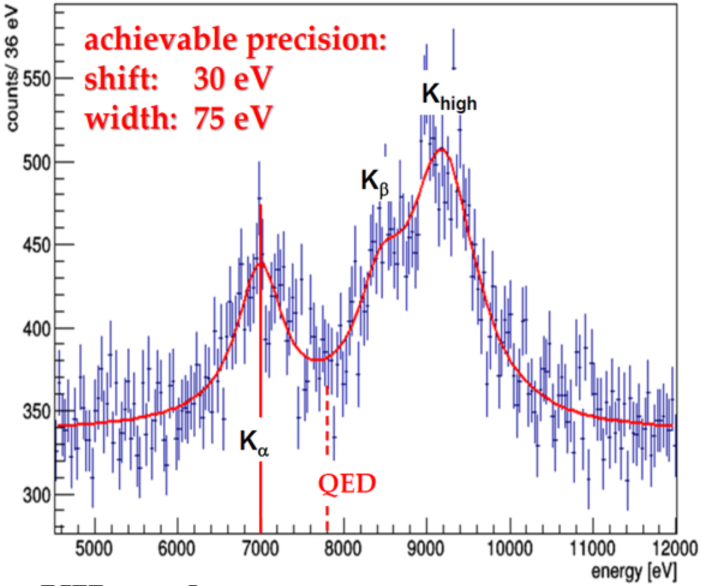
SIDDHART-2 new X-ray detector

New SDD technology with CUBE preamplifier





Geant4 simulated $K^{-}d$ X-ray spectrum for 800 pb^{-1}



KH results:

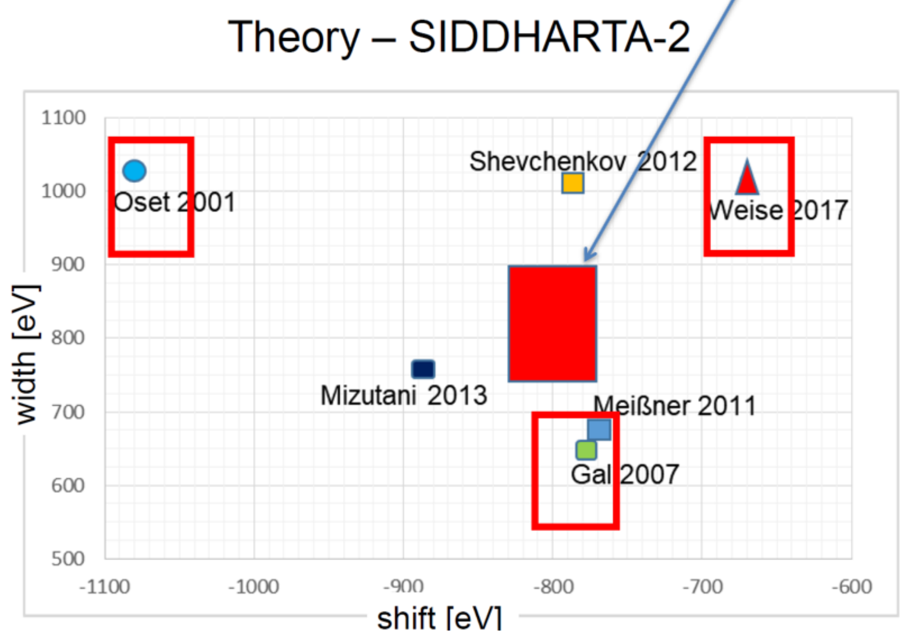
$\varepsilon_{1S} = -283 \pm 36(\text{stat}) \pm 6(\text{syst})$ eV
$\Gamma_{1S} = 541 \pm 89(\text{stat}) \pm 22(\text{syst})$ eV

signal: shift - 800 eV
width 800 eV
density: 3% (LHD)
detector area: 246 cm^2

Kα yield: 0.1 %
yield ratio as in $K^{-}p$
S/B ~ 1 : 3

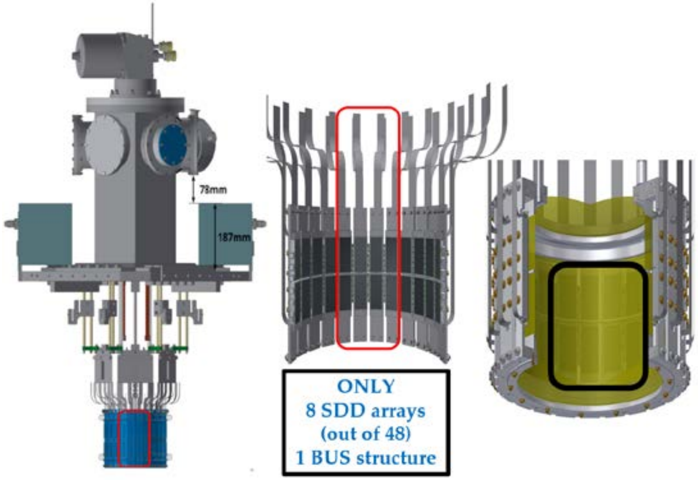
- charged particle veto
- asynchronous BG

SIDDHARTA-2 kaonic deuterium at DAFNE



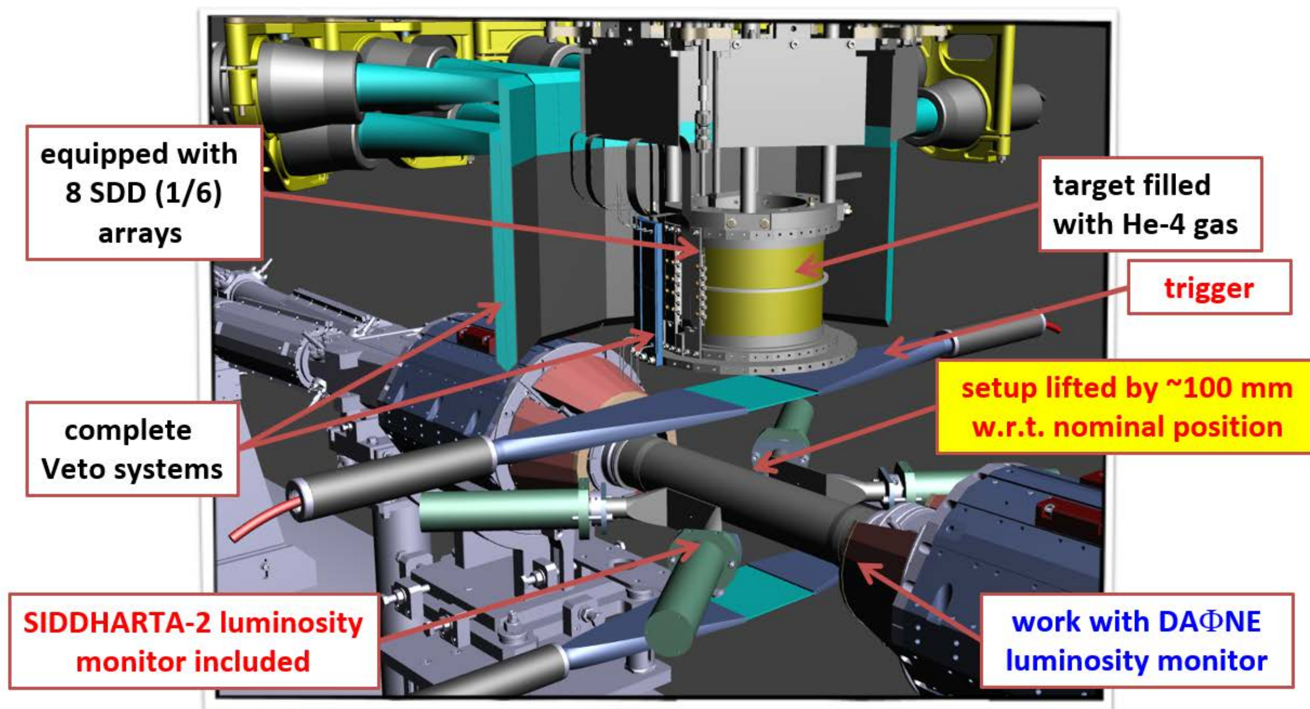
The experimental result will set essential constraints for theories and will help to disentangle between different theoretical approaches

SIDDHARTINO = SIDDHARTA-2 with 8 SDDs



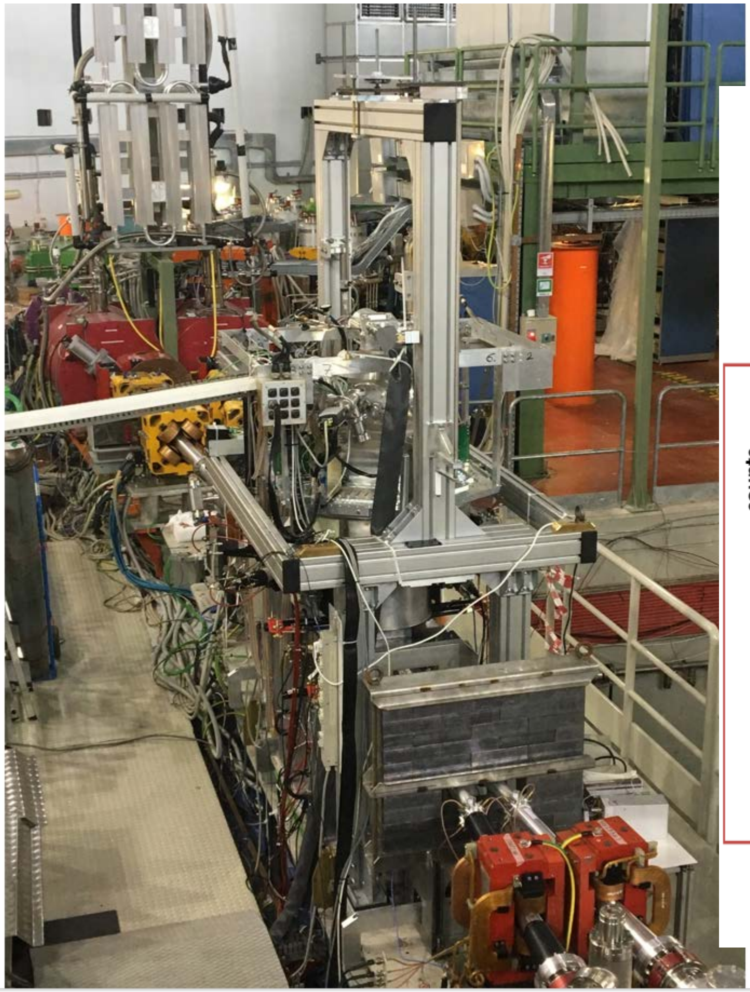
- **aiming to measure kaonic helium to quantify the background in the new DAFNE configuration**

SIDDHARTINO apparatus and constraints



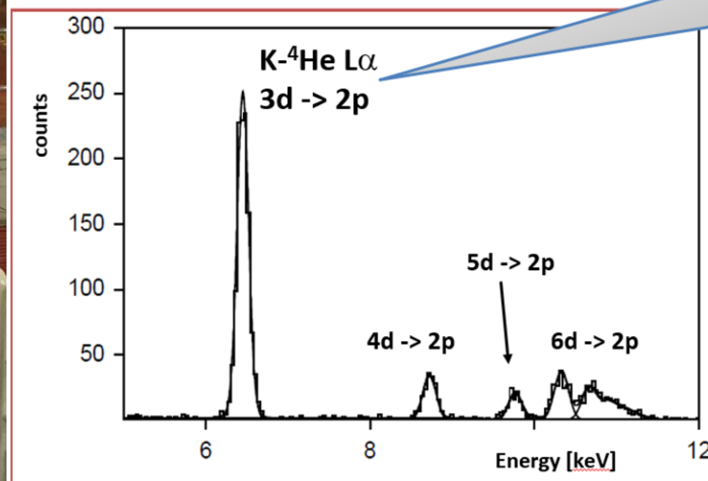
Aim: confirm when DAΦNE background conditions are similar to those in SIDDHARTA 2009

SIDDHARTINO apparatus in DAFNE



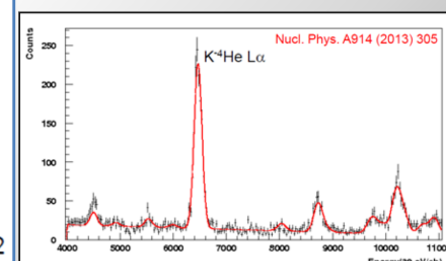
SIDDHARTINO – K-^{4}He test measurement

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}

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

Many thanks to the DAFNE team and LNF Management and to gr 3!