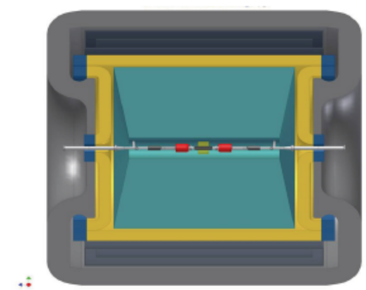
7th Workshop of the APS Topical Group on Hadronic Physics

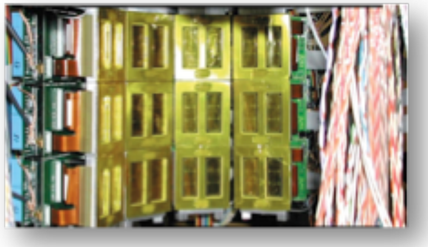
Strong interaction with strangeness in the low energy regime: strange atoms, resonances, nuclei

J. Marton
for SIDDHARTA2 and AMADEUS
SMI Vienna, Austria

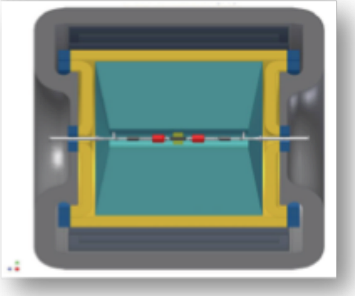


Motivation

- Hadronic Physics according to the mass scale
  – Light quarks up, down
  – (Semi-) light quark - strange quark
  – Heavy quarks charm, bottom, top

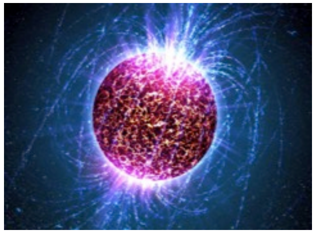


- Strong interaction with strangeness - regime of spontaneous and explicit chiral symmetry breaking

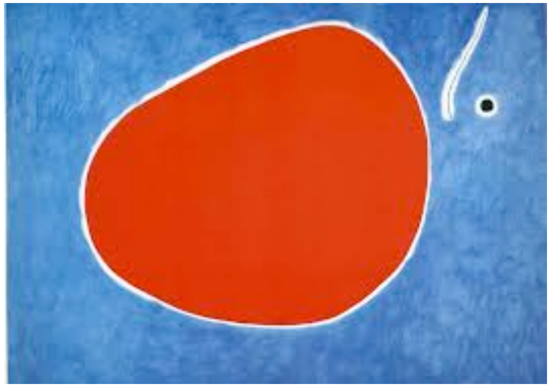


- Scattering and spectroscopic (e.g. kaonic atoms) investigations - some key data still missing

- Bound states: Hyperons, resonances and hypernuclei - production mechanism, properties



- Role of strangeness in the universe (compact stars, relation to GW in binaries)? "Hyperon puzzle", hyperons in medium

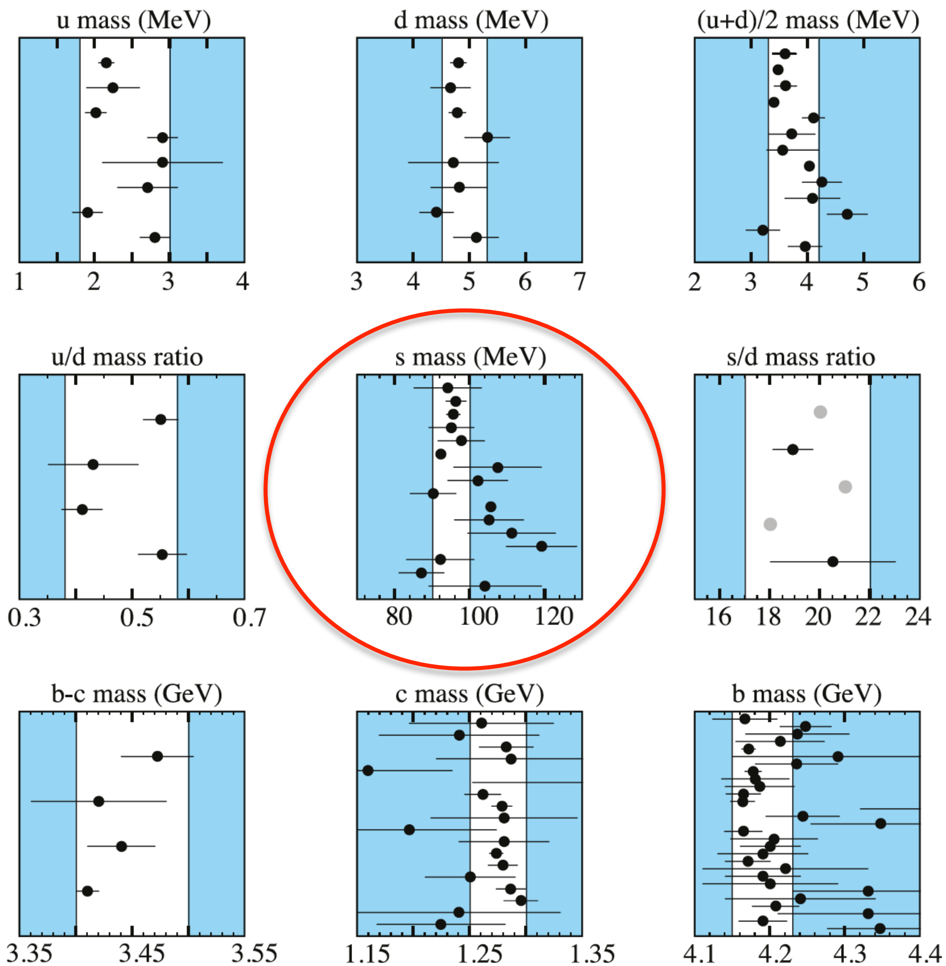


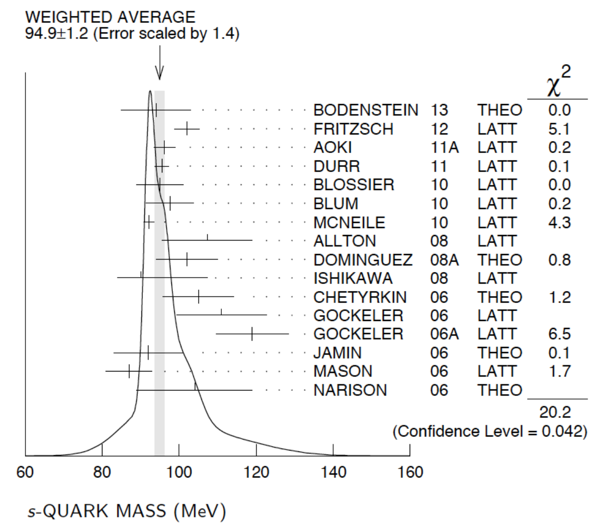
Outline

- Hadronic atoms as probes for strong interaction at threshold
- Results of experiments at DAFNE/LNF-INFN
  - SIDDHARTA: Antikaon-nucleon interaction
  - AMADEUS: Antikaon interaction with nuclei
- SIDDHARTA2 Kaonic deuterium experiment
  - Experimental challenges (yield, background)
  - Target and Instrumentation
- Summary and Outlook

Strangeness

- Strange quark – not *light* but not *heavy*





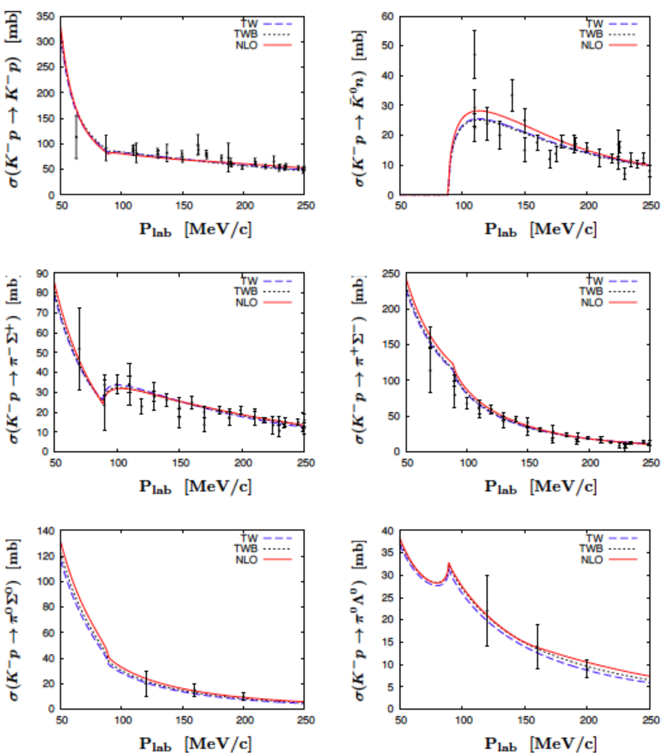
Kaonic atoms →

Spontaneous and explicit Chiral symmetry breaking in low-energy QCD

K.A. Olive *et al.* (Particle Data Group), Chin. Phys. C38, 090001 (2014) (URL: http://pdg.lbl.gov)

Sources of experimental information on $K_{bar}N$ interaction

K-p scattering data
for threshold data extrapolation necessary



Threshold branching ratios

threshold branching ratios

$$\frac{\Gamma(K^- p \to \pi^+ \Sigma^-)}{\Gamma(K^- p \to \pi^- \Sigma^+)}$$

$$\frac{\Gamma(K^- p \to \pi^+ \Sigma^-, \pi^- \Sigma^+)}{\Gamma(K^- p \to \text{all inelastic channels})}$$

$$\frac{\Gamma(K^- p \to \pi^0 \Lambda)}{\Gamma(K^- p \to \text{neutral states})}$$

Kaonic atom data

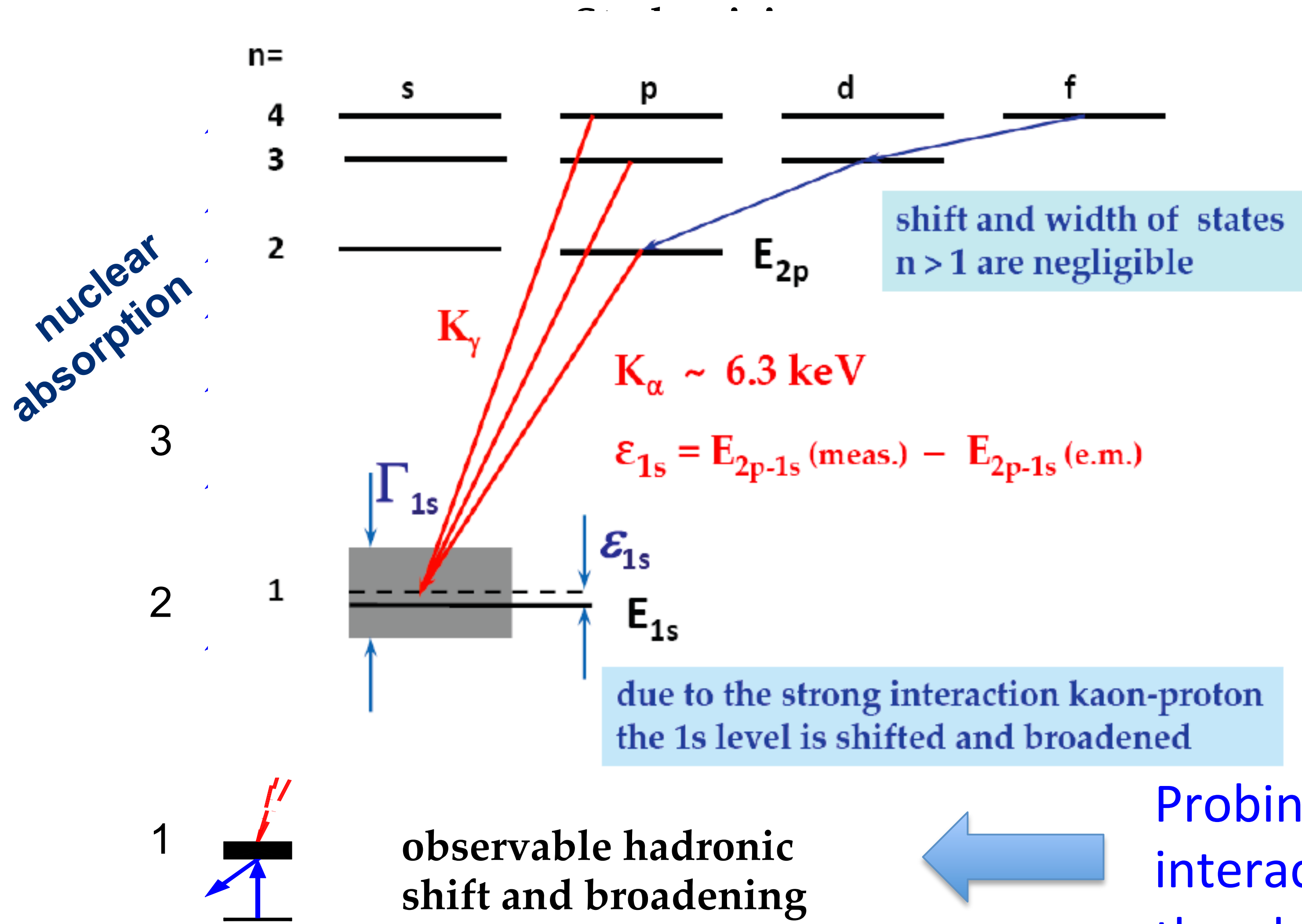
Kaonic hydrogen
Kaonic Deuterium

1s state shift
1s state width

→ x-ray spectroscopy

Constraints from precise kaonic hydrogen measurements → sub-threshold extrapolations of the KbarN amplitude with strongly reduced uncertainties

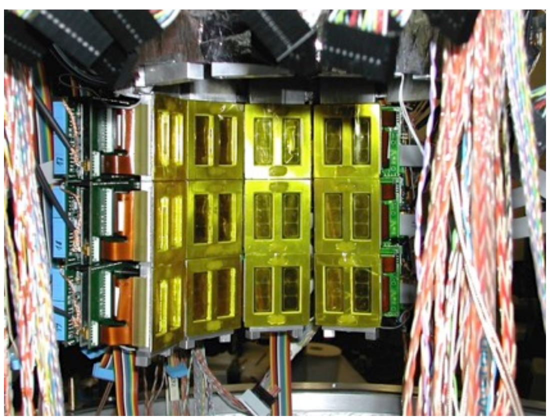
Cascade in hadronic atoms (KH,KD)



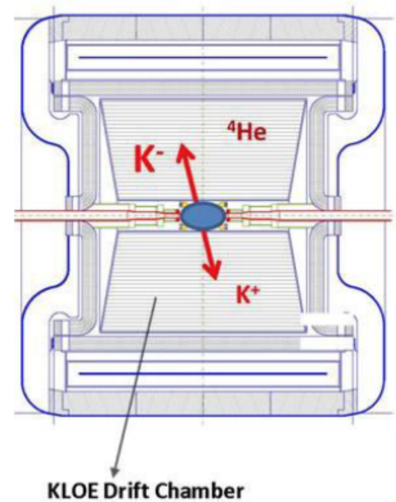
Probing strong interaction at threshold

Hadron physics with strangeness at DAFNE/LNF-INFN

SIDDHARTA



AMADEUS



SIDDHARTA collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

LNF- INFN, Frascati, Italy

SMI - ÖAW, Vienna, Austria

IFIN – HH, Bucharest, Romania

Politecnico, Milano, Italy

MPE, Garching, Germany

PNSensors, Munich, Germany

RIKEN, Japan

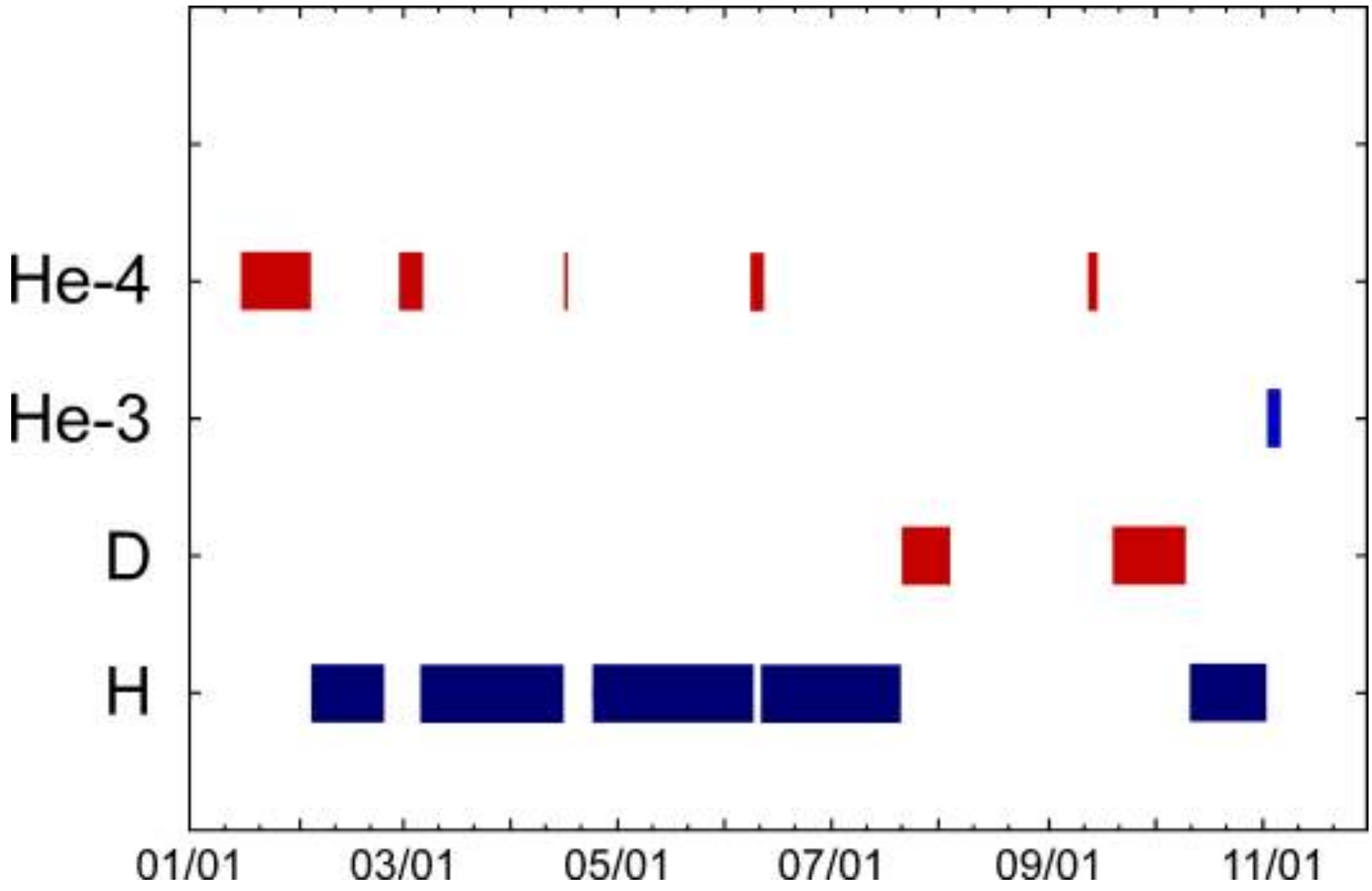
Univ. Tokyo, Japan

Victoria Univ., Canada

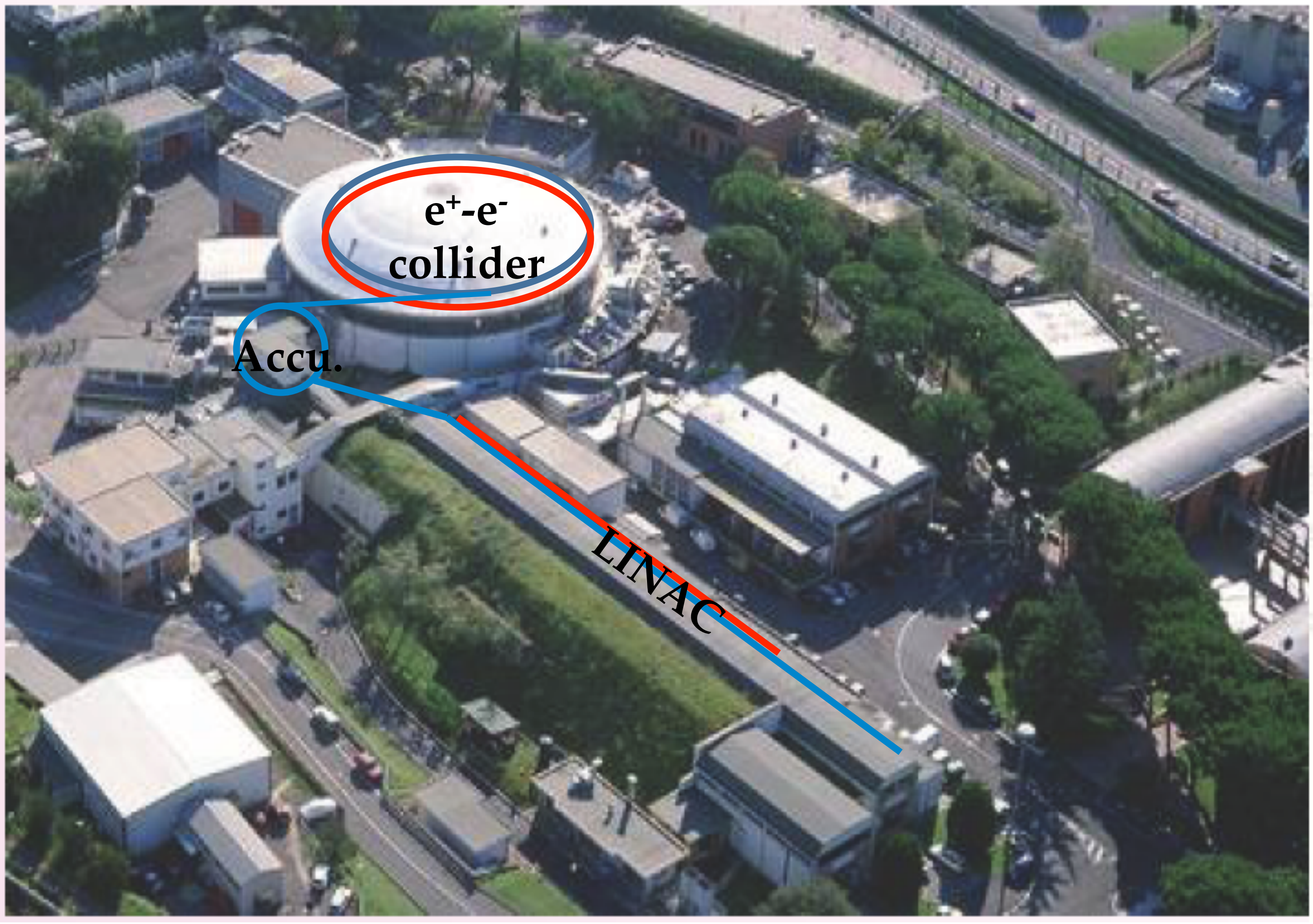
EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2
Austrian Science Fund

Austrian Science Fund (FWF):
[P24756-N20]

SIDDHARTA data overview



Kaonic atoms at DAΦNE/Frascati



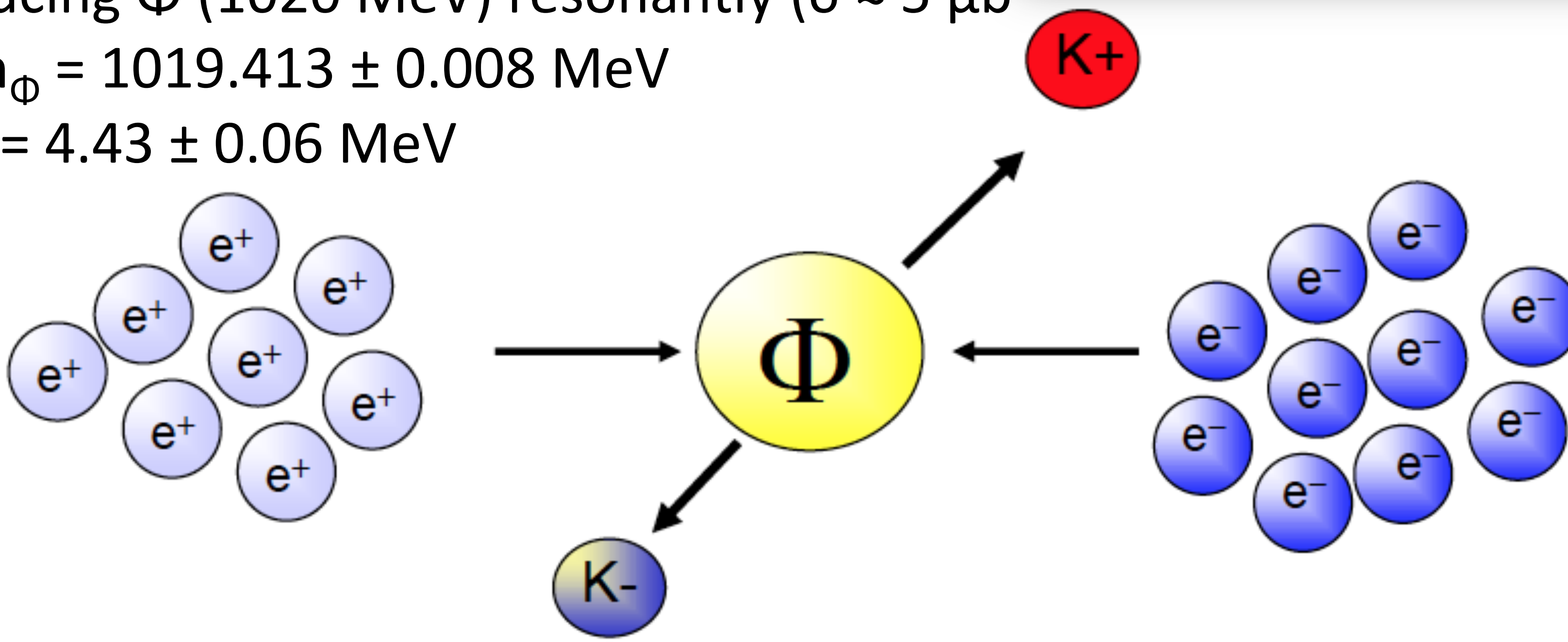
DAΦNE:

Φ Factory of LNF-INFN

Double anular electron-positron collider producing Φ (1020 MeV) resonantly ($\sigma \approx 5\ \mu b$

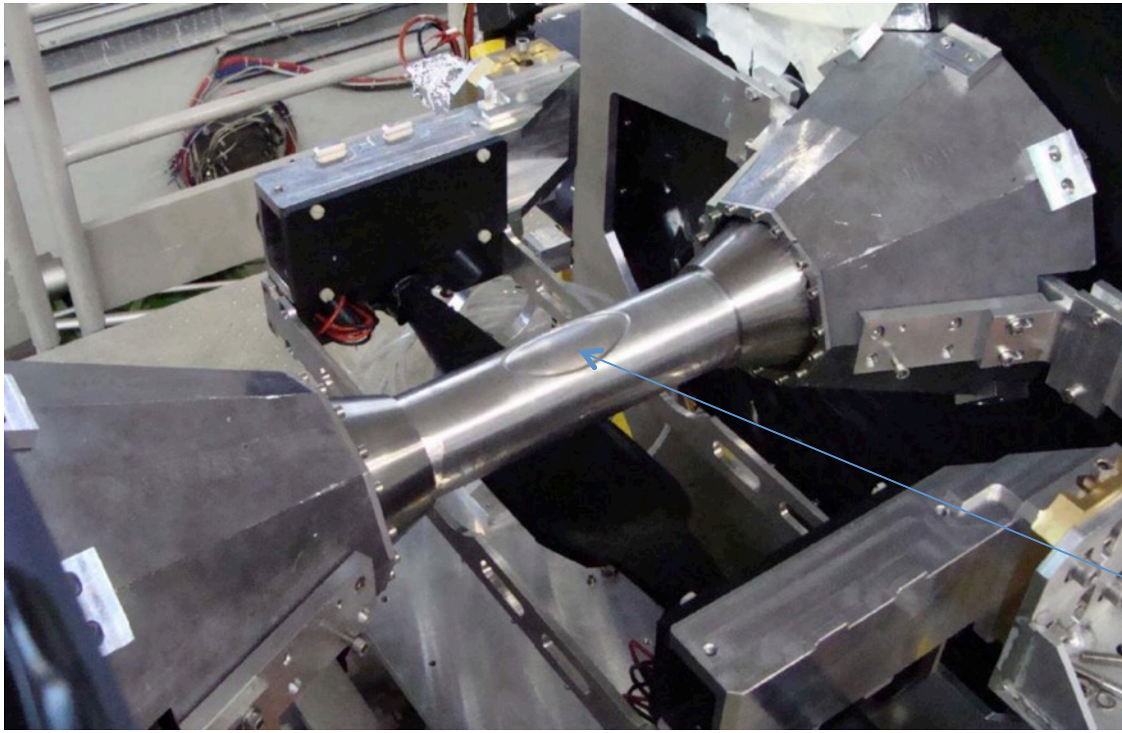
$m_{\Phi} = 1019.413 \pm 0.008$ MeV

$\Gamma = 4.43 \pm 0.06$ MeV



Flux of produced kaons: about 1000/second

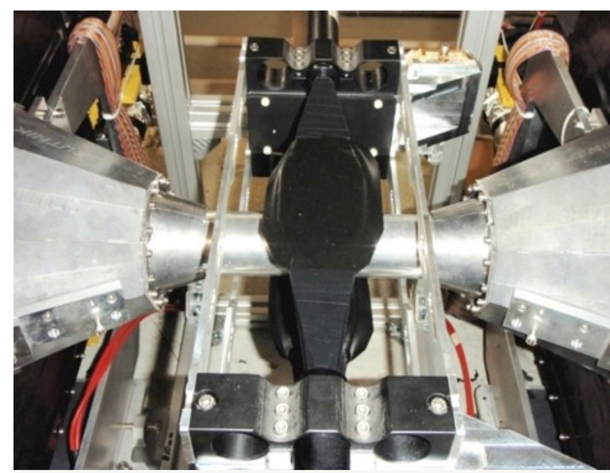
Beam pipe in e^+e^- intersection of SIDDHARTA



SIDDHARTA used the KLOE intersection of DAFNE

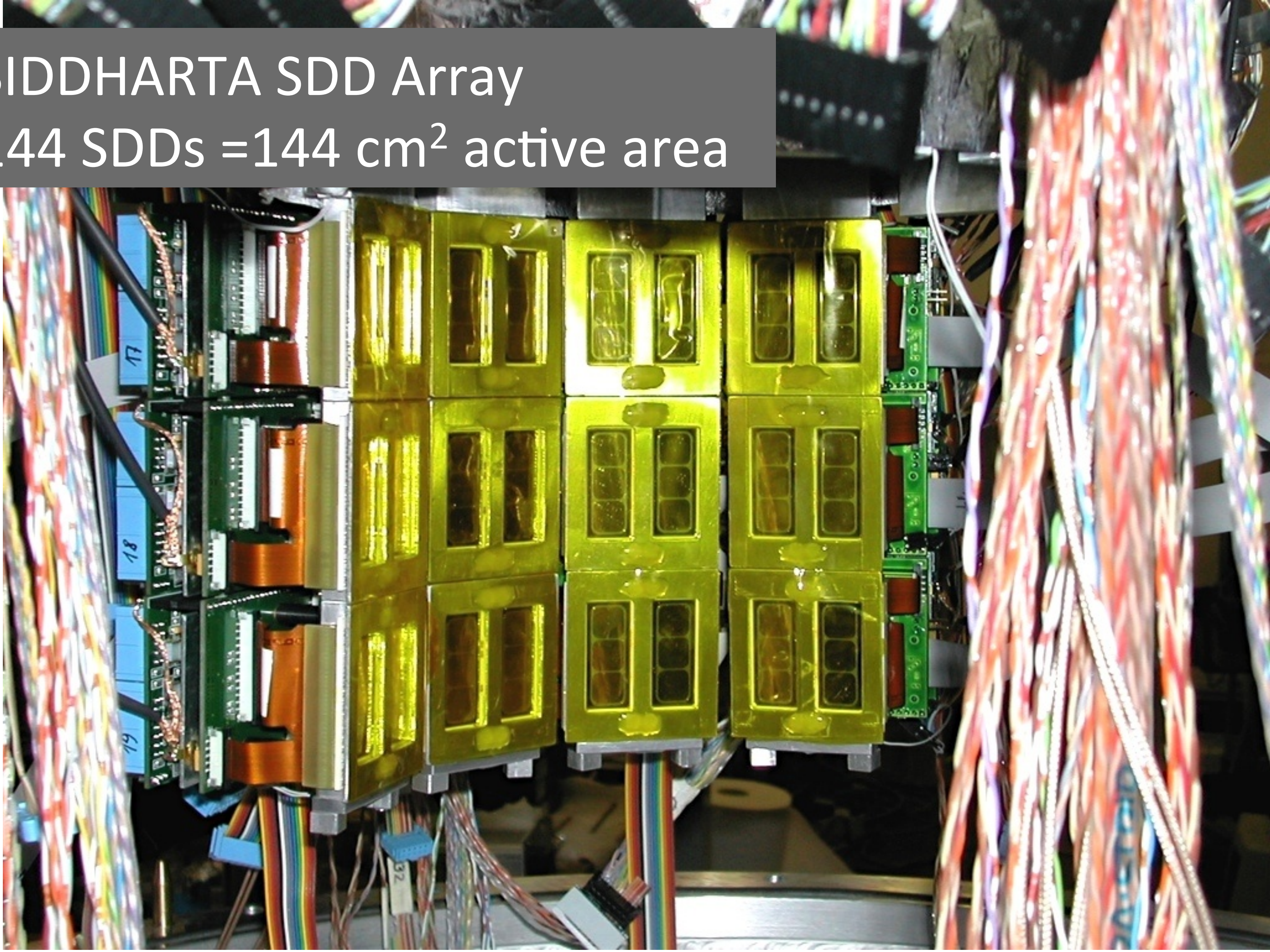
Luminosity increased with new system providing a large crossing angle (crab waist system)

Kaon window

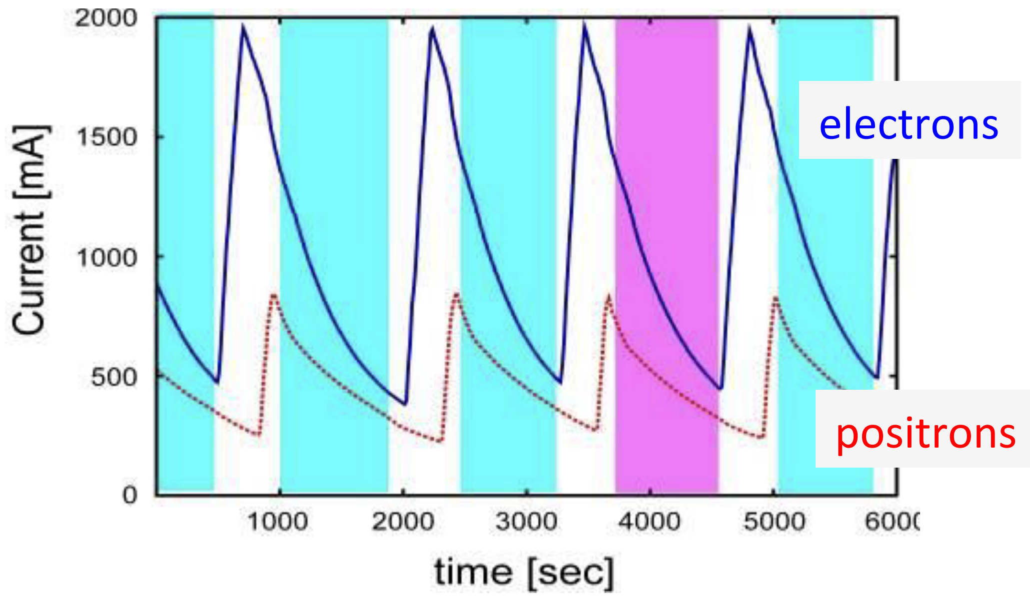


Kaon detectors sitting below and above the intersection

SIDDHARTA SDD Array
144 SDDs =144 cm^2 active area



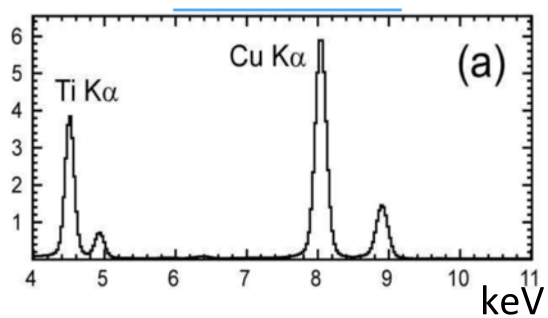
SIDDHARTA data taking



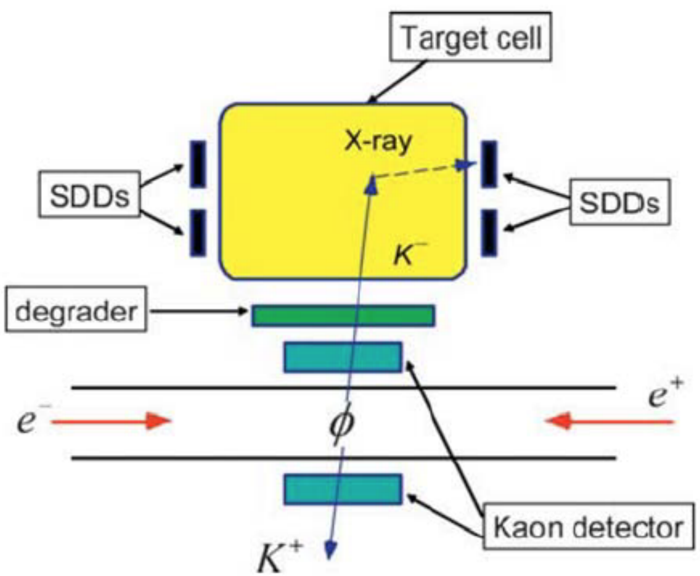
Charged kaons from Φ decay

Φ → K^+ + K^- (BR ≈ 50%)

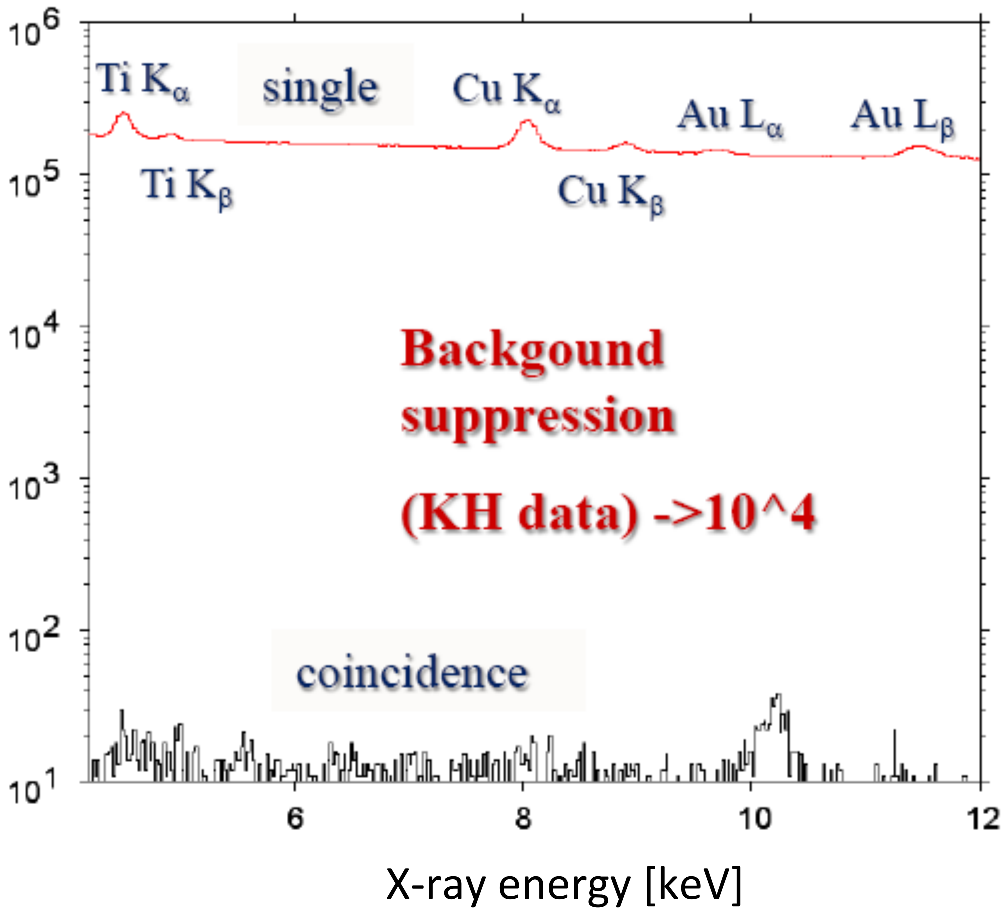
Calibration with X-ray tube and Ti/CU foils



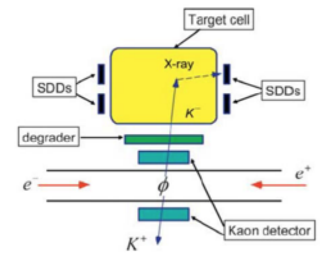
Syst. error ≈ 3-4 eV

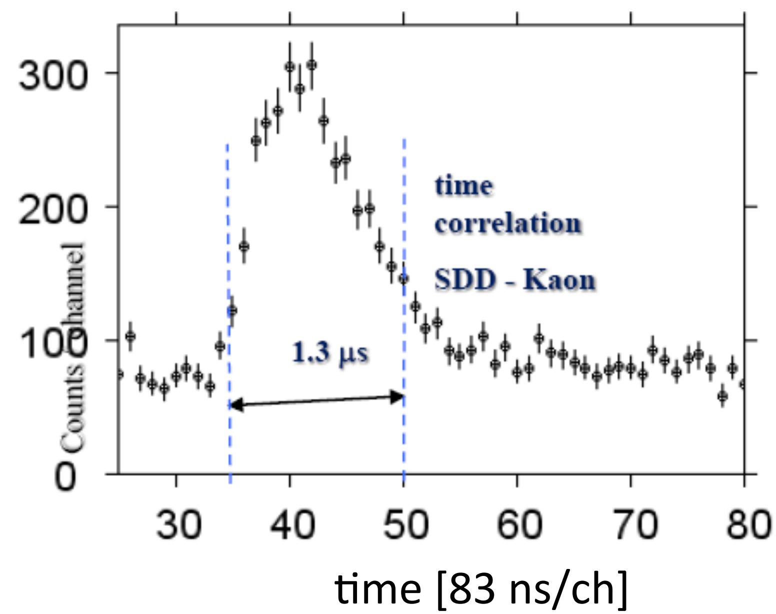


Background suppression in SIDDHARTA

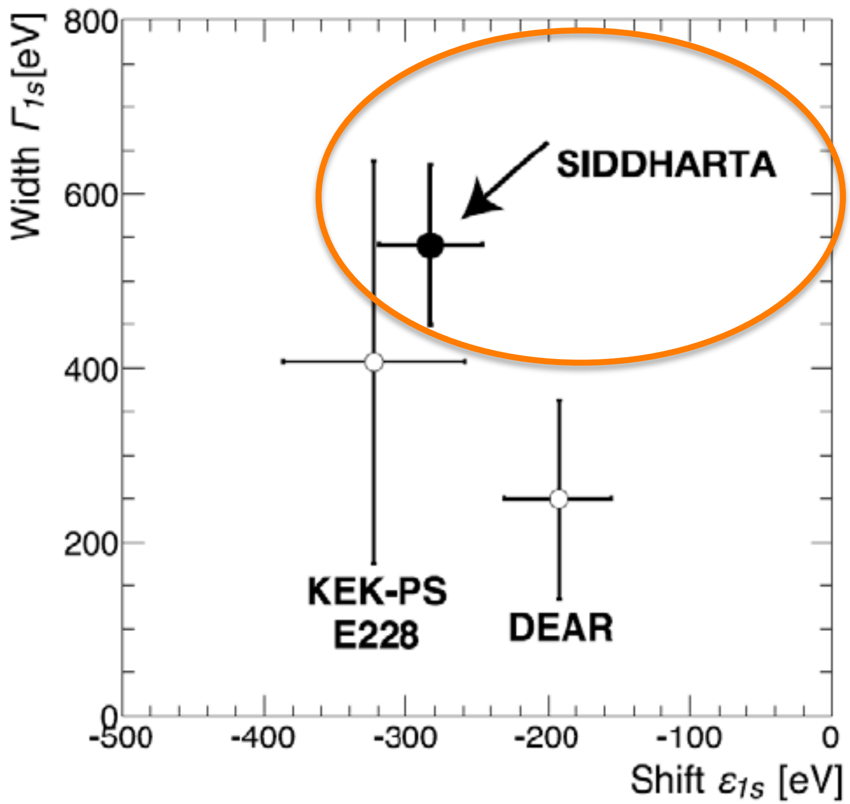


Efficient background suppression by using the kaon - x-ray correlation

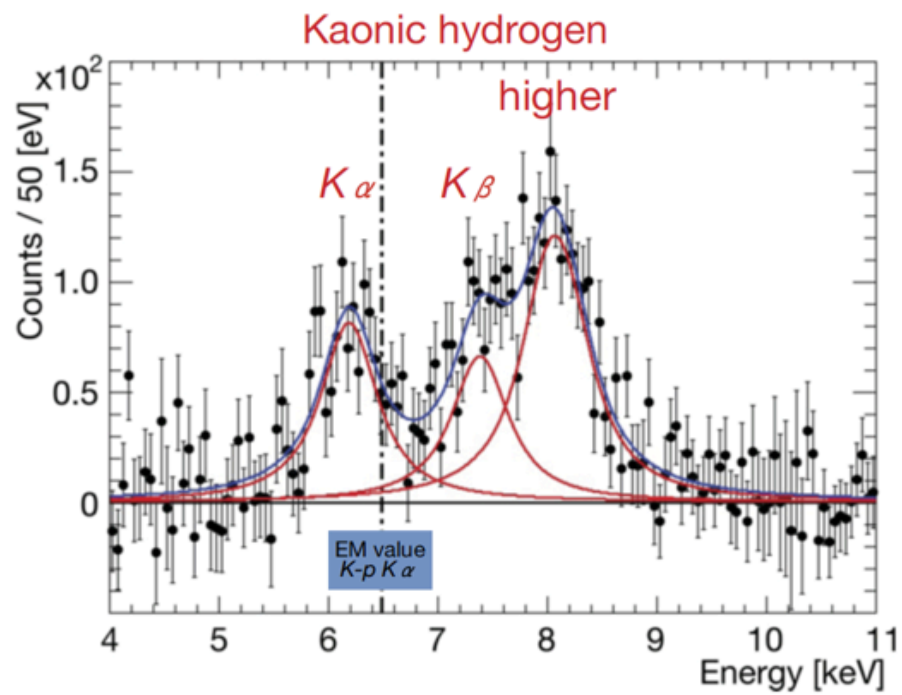




$K^{-}p$ result SIDDHARTA



X-ray spectrum with background subtracted



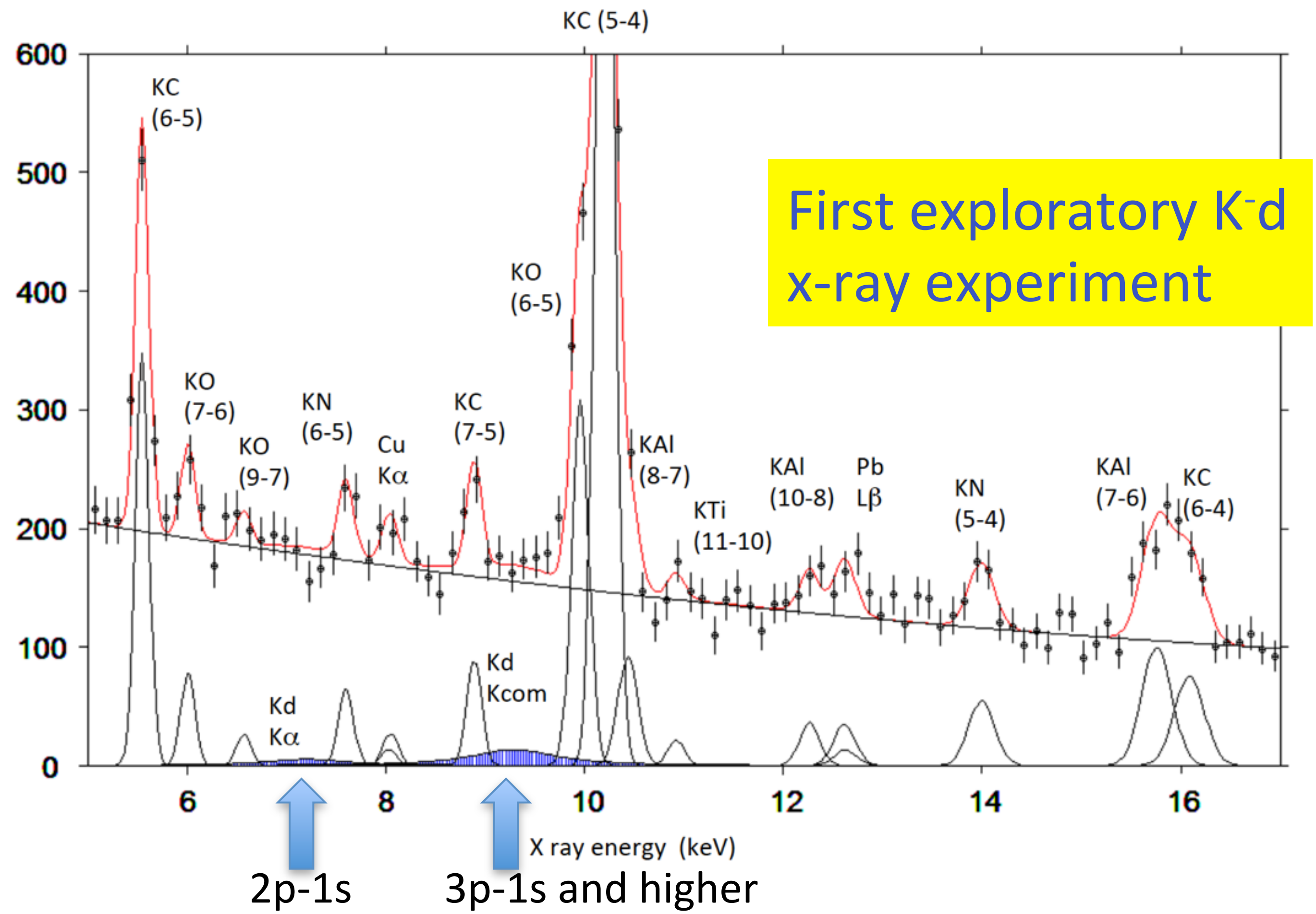
ε_{1S}= −283 ± 36(stat) ± 6(syst) eV

Γ_{1S}= 541 ± 89(stat) ± 22(syst) eV

Physics Letters B704 (2011) 113

Kaonic atoms with deuterium gas (SIDDHARTA)

fit for shift about 500 eV, width about 1000eV, Kα / Kcomplex = 0.4



Yield of K-series in KD

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Available online at www.sciencedirect.com

SciVerse ScienceDirect

Nuclear Physics A 907 (2013) 69–77

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Preliminary study of kaonic deuterium X-rays by the SIDDHARTA experiment at DAΦNE

M. Bazzi [a], G. Beer [b], C. Berucci [c,a], L. Bombelli [d], A.M. Bragadireanu [a,e], M. Cargnelli [c,*], C. Curceanu (Petrascu) [a] A. d'Uffizi [a], C. Fiorini [d], T. Frizzi [d], F. Ghio [f], C. Guaraldo [a], R. Hayano [g], M. Iliescu [a], T. Ishiwatari [c], M. Iwasaki [h], P. Kienle [c,i,1], P. Levi Sandri [a], A. Longoni [d], J. Marton [c], S. Okada [h], D. Pietreanu [a,e], T. Ponta [e], A. Romero Vidal [j], E. Sbardella [a], A. Scordo [a], H. Shi [g], D.L. Sirghi [a,e], F. Sirghi [a,e], H. Tatsuno [a], A. Tudorache [e], V. Tudorache [e], O. Vazquez Doce [i], E. Widmann [c], J. Zmeskal [c]

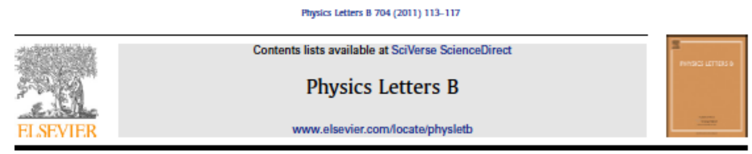
Upper limits (90 C.L.) for the x-ray yield (SIDDHARTA)

$$Y(K_{tot}) < 0.0143$$

$$Y(K_{\alpha}) < 0.0039$$

Results of SIDDHARTA

Kaonic Hydrogen: 400pb^{-1}, most precise measurement, Physics Letters B704 (2011) 113


Physics Letters B 704 (2011) 113–117
Contents lists available at SciVerse ScienceDirect
Physics Letters B
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A new measurement of kaonic hydrogen X-rays

SIDDHARTA Collaboration

M. Bazzi[a], G. Beer[b], L. Bombelli[c], A.M. Bragadireanu[a,d], M. Cargnelli[e,*], G. Corradi[a], C. Curceanu (Petrascu)[a], A. d'Uffizi[a], C. Fiorini[c], T. Frizzi[c], F. Ghio[f], B. Girolami[f], C. Guaraldo[a], R.S. Hayano[g], M. Iliescu[a,d], T. Ishiwatari[e], M. Iwasaki[h], P. Kienle[e,i], P. Levi Sandri[a], A. Longoni[c], V. Lucherini[a], J. Marton[e], S. Okada[a,*], D. Pietreanu[a,d], T. Ponta[d], A. Rizzo[a], A. Romero Vidal[a], A. Scordo[a], H. Shi[g], D.L. Sirghi[a,d], F. Sirghi[a,d], H. Tatsuno[g,1], A. Tudorache[d], V. Tudorache[d], O. Vazquez Doce[a], E. Widmann[e], J. Zmeskal[e]

Kaonic deuterium: 100 pb^{-1}, exploratory first measurement ever, Nucl. Phys.A907 (2013)69

- 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)

- Kaonic helium 3: 10 pb^{-1}, first measurement, published in Phys. Lett. B 697 (2011) 199


Kaonic hydrogen casts new light on strong dynamics – CERN Courier 26.10.11 17:10

CERN Courier

CERN COURIER

Oct 25, 2011

Kaonic hydrogen casts new light on strong dynamics

(http://images.iop.org/objects/ccr/cern/51/9/6/CCnew3_09_11.jpg)

SIDDHARTA (http://images.iop.org/objects/ccr/cern/51/9/6/CCnew3_09_11.jpg)

Chiral SU(3) theory of antikaon-nucleon interactions with improved threshold constraints
Y. Ikeda, T. Hyodo and W. Weise, Nucl. Phys. A881 (2012) 98-114.

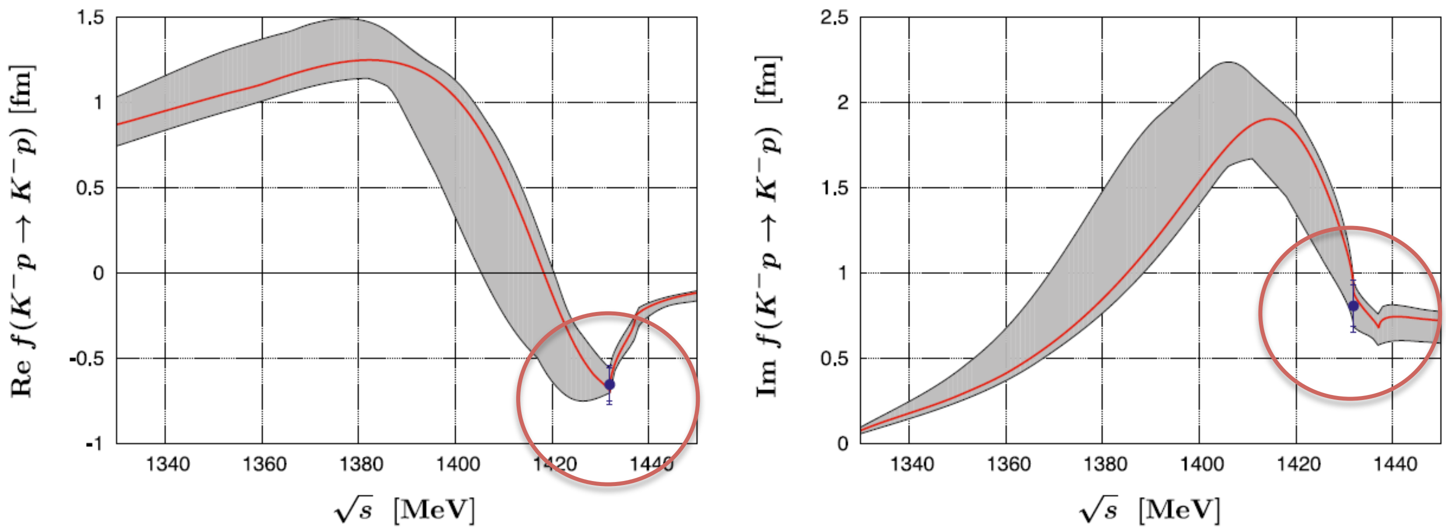


Fig. 4. Real part (left) and imaginary part (right) of the $K^- p \to K^- p$ forward scattering amplitude obtained from the NLO calculation and extrapolated to the subthreshold region. The empirical real and imaginary parts of the $K^- p$ scattering length deduced from the recent kaonic hydrogen measurement (SIDDHARTA [15]) are indicated by the dots including statistical and systematic errors. The shaded uncertainty bands are explained in the text.

Motivation for new experiments

- SIDDHARTA – K-p strong interaction observables
- SIDDHARTA – First exploratory experiment on $K^{-}D$

But: No data on hadronic shift and width of 1s state of kaonic deuterium

→ still to be measured

- ➢ Study of K-n interaction: Isospin-dependent scattering lengths from KH and KD → $K^{-}p$ interaction at low energy is well understood, but the case of $K^{-}d$ represents the most important missing information
- ➢ High resolution studies of kaonic atoms (e.g. K-He, heavier kaonic atoms)

Expected shift and width

a_d [fm]	ε_{1s} [eV]	Γ_{1s} [eV]	Reference
-1.58 + *i* 1.37	- 887	757	Mizutani 2013 [4]
-1.48 + *i* 1.22	- 787	1011	Shevchenko 2012 [5]
-1.46 + *i* 1.08	- 779	650	Meißner 2011 [1]
-1.42 + *i* 1.09	- 769	674	Gal 2007 [6]
-1.66 + *i* 1.28	- 884	665	Meißner 2006 [7]

=>
shift = -800 eV
width = 800 eV
used in simulation

Modified Deser formula next-to-leading order in isospin breaking (Meißner, Raha, Rusetsky 2004 [3])
(μ_c reduced mass of K^-d, α finestructure constant)

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_d \left(1 - 2\alpha\mu_c\left(\ln\alpha - 1\right)a_d\right) \qquad (1)$$

[1] M. Döring, U.-G. Meißner, Phys. Lett. B 704 (2011) 663.
[3] U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349.
[4] T. Mizutani, C. Fayard, B. Saghai, K. Tsushima, arXiv:1211.5824[hep-ph] (2013).
[5] N.V. Shevchenko, Nucl. Phys. A 890-891 (2012) 50-61.
[6] A. Gal, Int. J. Mod. Phys. A22 (2007) 226
[7] U.-G. Meißner, U. Raha, A. Rusetsky, Eur. phys. J. C47 (2006) 473

Isospin scattering lengths

- The isospin scattering lengths a_0 and a_1 for I=0,1 cannot be determined from ε_{1s} and Γ_{1s} from kaonic hydrogen.
- The (modified) Deser-type formula
U.G.Meißner,U.Raha,A.Rusetsky,Eur.Phys.J.C35(2004)349,arXiv:hep-ph/0402261.

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_p\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_p\right)$$

$a_p = ½(a_0+a_1)$

- Kaonic deuterium provides the lacking information

$a_n = a_1$

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$
$$a_{K^-n} = a_1$$
$$a_{K^-d} = [a_0 + 3a_1]Q + C$$
$$Q = \frac{[m_N + m_K]}{[2m_N + m_K]}$$

AMADEUS

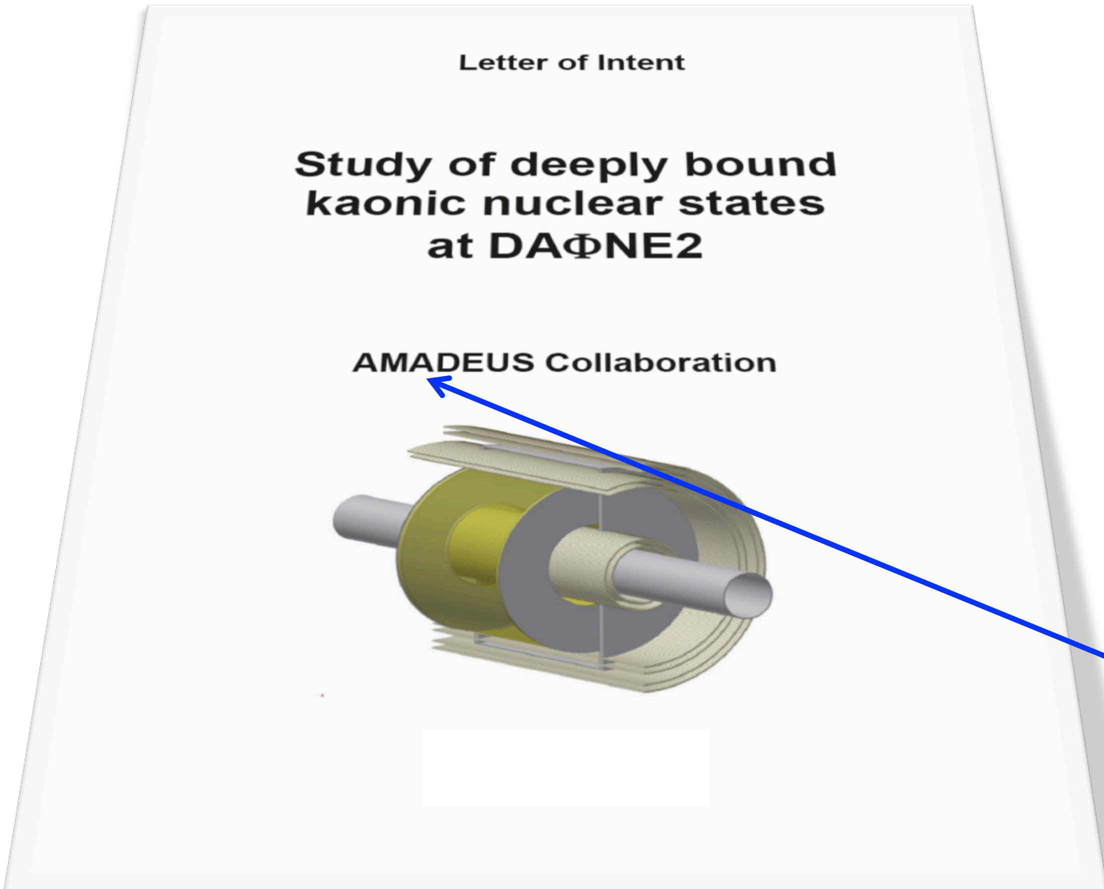
Antikaon Matter At DAΦNE: Experiments with Unraveling Spectroscopy

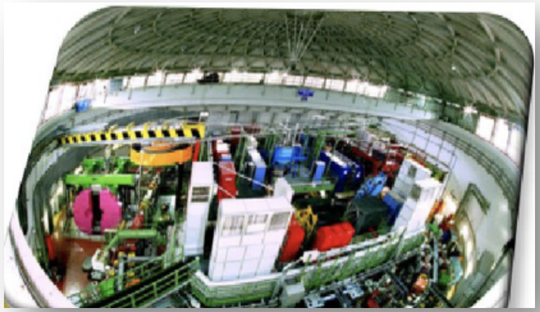
AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

lnf.infn.it/esperimenti/siddharta
and
LNF-07/24(IR) Report on lnf.infn.it web-page (Library)

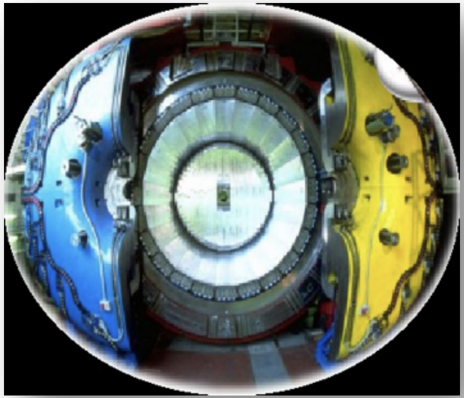
AMADEUS started in 2005 and
was presented and discussed in all the LNF Scientific Committees

EU Fundings FP7 – HP2 and HP3:
Network WP9 – LEANNIS;
WP24 (SiPM JRA);
WP28 (GEM JRA)





DAΦNE kaon source + KLOE

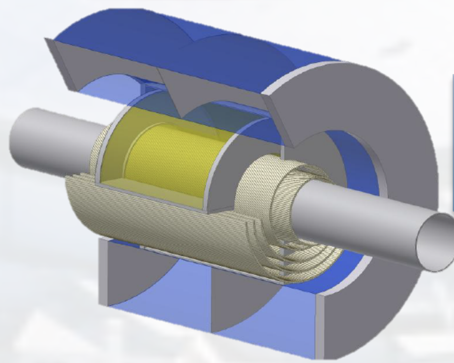


Powerful combination of DAFNE with the detector system of KLOE (96% acceptance)
Very good performance for the detection of **charged and neutral** particle in the relevant energy range

Kaon scattering

Subthreshold resonances

Antikaon nuclear absorption



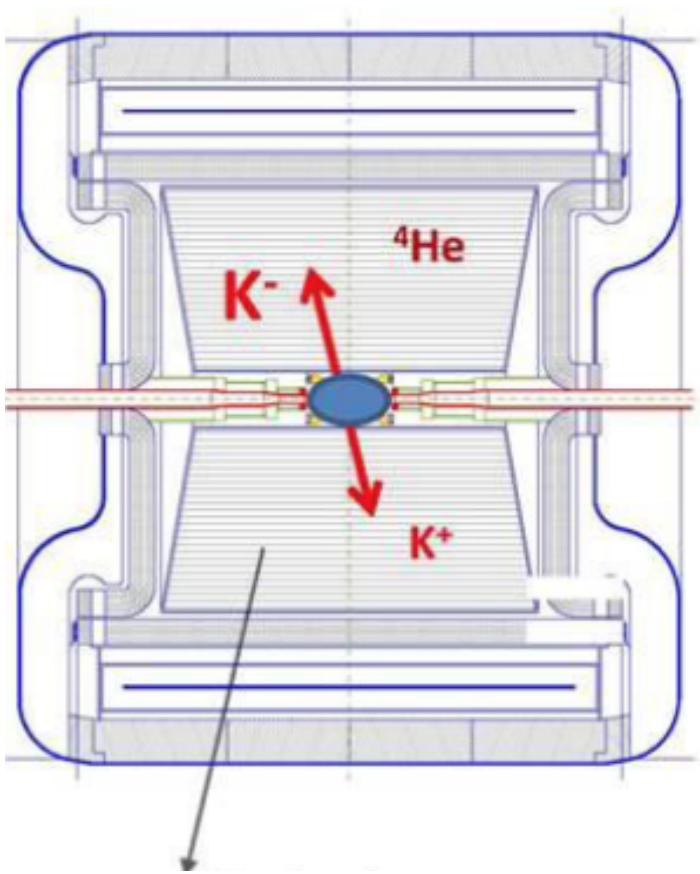
AMADEUS- a laboratory
for low-energy kaon physics

Antikaon bound states

Hypernuclear physics

Consequences of strangeness
for dense baryonic matter
(neutron stars)?

Pre-AMADEUS studies with KLOE data



KLOE Drift Chamber (DC)

- Study of antikaon interaction in nuclear matter following K^- absorption in the DC gas (or structure materials)
- KLOE drift chamber (DC) gas: mainly ^4He (90% ^4He, 10% isobutane C_4H_{10})
- 0.1% K^- stop in the DC gas (Monte Carlo, data analysis)
- Enables the study of K^- absorption and searches for bound states (e.g. with 2 fb^{-1} hundreds of kaonic clusters) – analysis of Λ/Σ – p,d, t correlations
- However: Analysis complicated due to material mix

Antikaon absorption in nuclei

1) $Y\pi$ CORRELATION

'p' , 'n' BOUND nucleons

- K^- 'n' → $\Lambda\pi^-$ (direct formation) → $\Sigma(1385)$ I=1
- K^- 'p' → $\Sigma^0\pi^0$ → $\Lambda(1405)$ I=0
- K^- 'p' → $\Sigma^+\pi^-$ → $\Lambda^* + \Sigma^*$

To measure the amount of resonant capture → position of the resonance

2) Y N CORRELATION

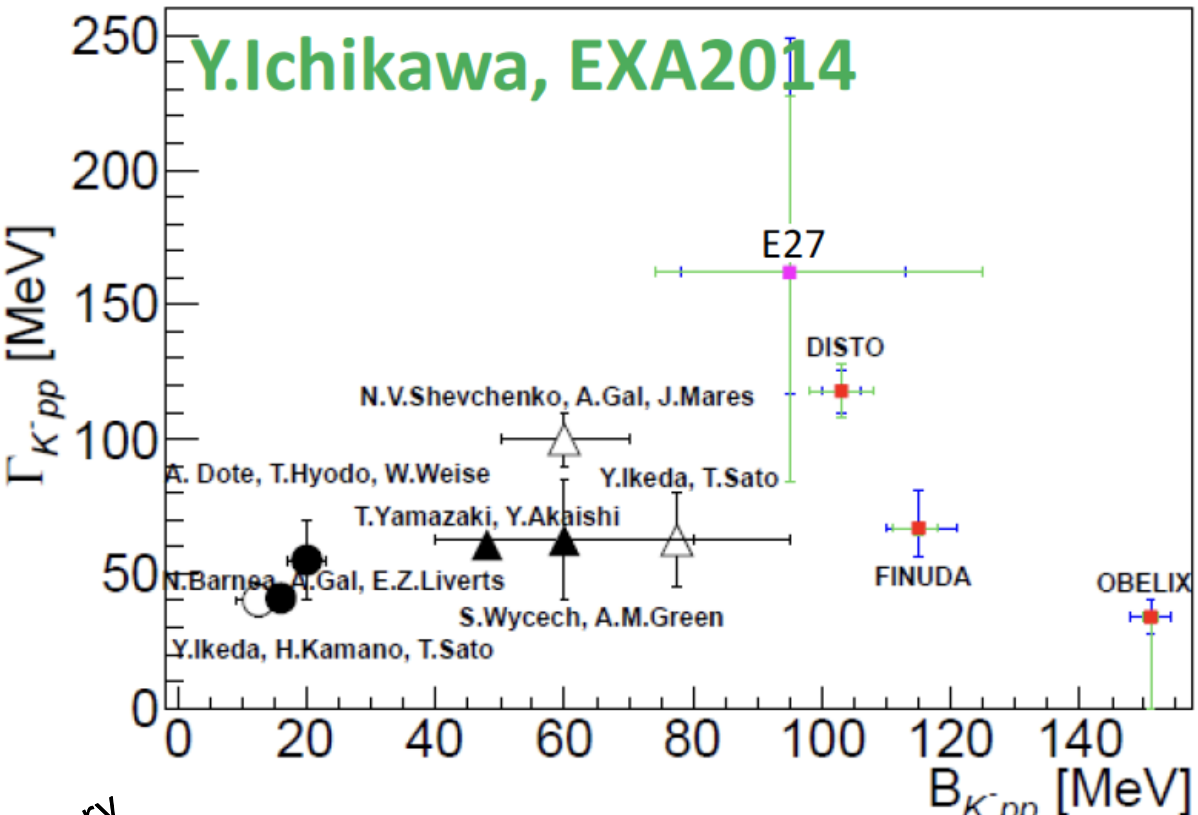
- K^- 'pp' → Λ/Σ^0 p (without YN scattering) → $(K^-$ 'pp'$)^{B.S.}$
- K^- 'ppn' → Λ d (without YN scattering) → $(K^-$ 'ppn'$)^{B.S.}$
- K^- 'ppnn' → Λ t → rare 4NA

search for possible bound states

- with YN scattering → to get information on U_{YN}

Quasi-bound kaonic nuclei ?

Decay widths and binding energies from experiment and theory:



Theory

	Dote,Hyodo, Weise	Akaishi, Yamazaki	Barnea, Gal, Liverts	Ikeda, Sato	Ikeda, Kamano,Sato	Schevchenko ,Gal, Mares	Revai, Schevchenko	Maeda, Akaishi, Yamazaki
B (MeV)	17-23	48	16	60-95	9-16	50-70	32	51.5
Γ(MeV)	40-70	61	41	45-80	34-46	90-110	49	61

The present knowledge from experiment and theory is still insufficient to make a clear statement about quasi-bound kaonic nuclear systems

- Experiments so far:

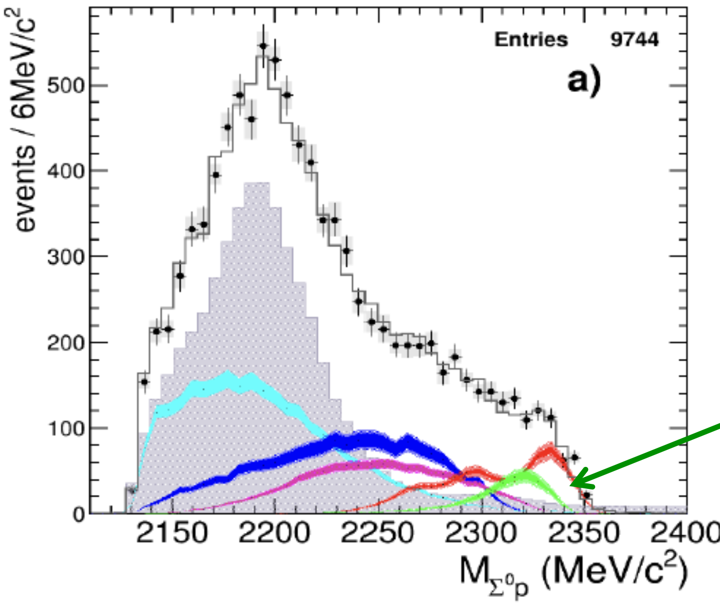
FINUDA
KEK
DISTO
FOPI
HADES
OBELIX
J-PARC E15, E27

- Future: AMADEUS

Recent results from Pre-AMADEUS

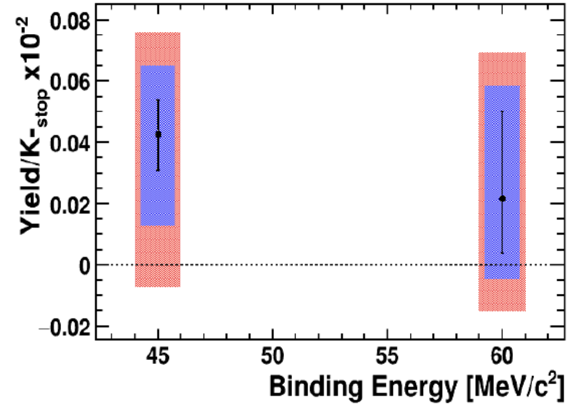
K^- absorption on two nucleons and ppK^- bound state search in the $\Sigma^0 p$ final stat

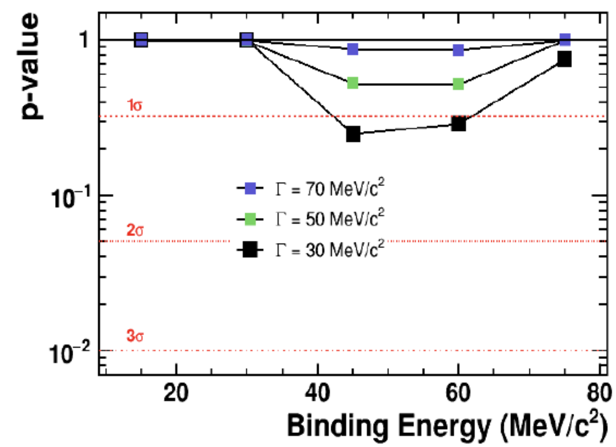
O. Vázquez Doce[1,2], L. Fabbietti[1,2], M. Cargnelli[3], C. Curceanu[4], J. Marton[3], K. Piscicchia[4,5], A. Scordo[4], D. Sirghi[4], I. Tucakovic[4], S. Wycech[6], J. Zmeskal[3], A. Anastasi[4,7], F. Curciarello[7,8,9], E. Czerwinski[10], W. Krzemien[6], G. Mandaglio[7,11], M. Martini[4,12], P. Moskal[10], V. Patera[13,14], E. Pérez del Rio[4] and M. Silarsk



L_{int}= 1.74 fb^{-1}
K^-_{stop} = 3.25 10^8

K-pp ?



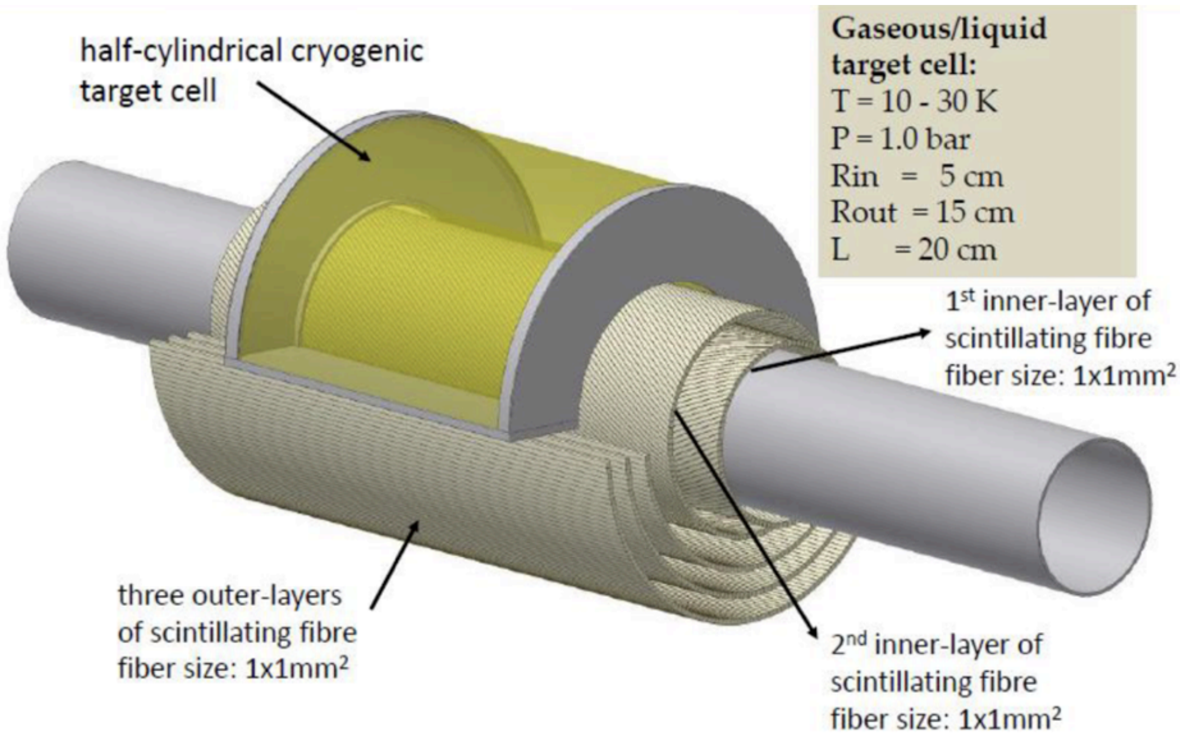


$ppK^-/K^-stop=(0.044\pm0.009stat+0.004-0.005syst)\cdot10^{-2}$

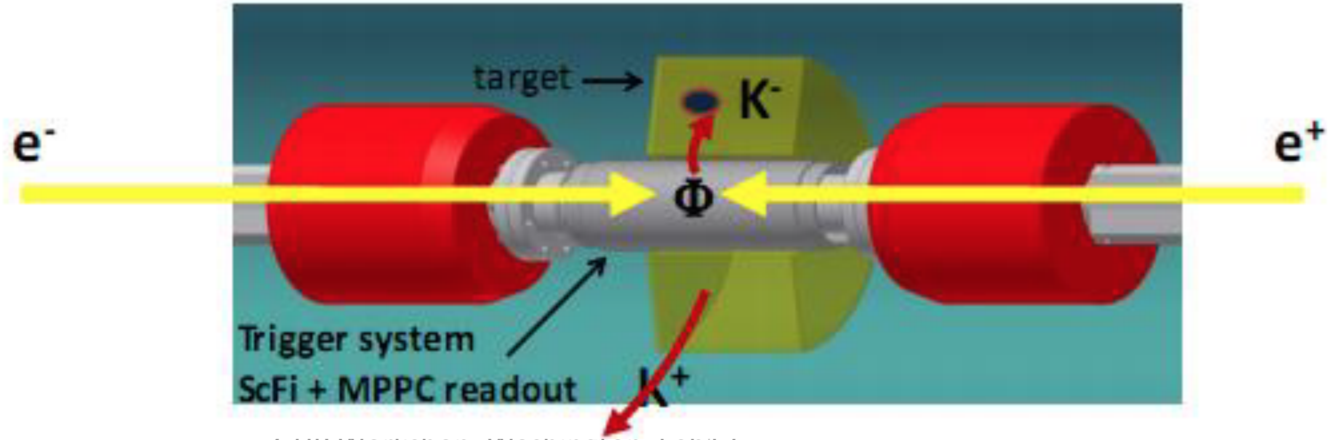
Physics Letters B, Volume 758, 10 July 2016, Pages 134-139

Significance 1σ – not sufficient to claim ppK^- observation

Possible AMADEUS Setup



Axial magnetic field: 0.5T

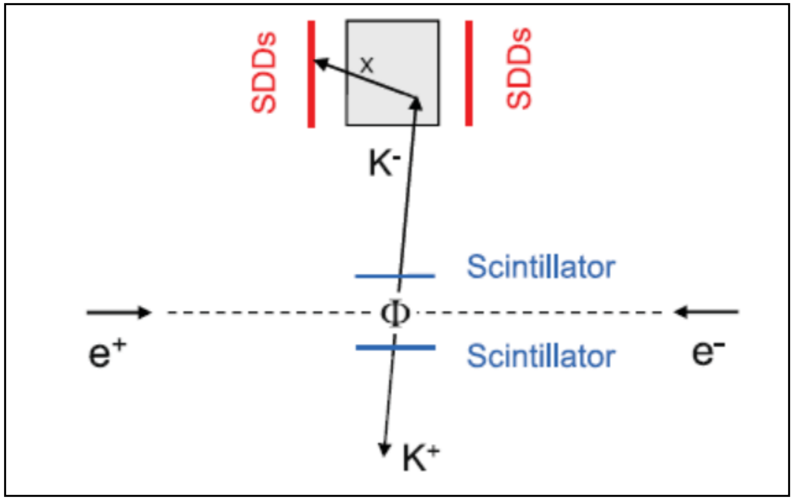


Kaonic deuterium Experiment: new instrumentation

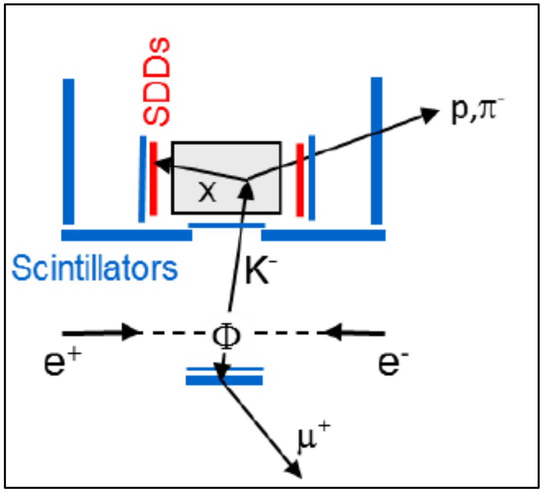
From SIDDHARTA to SIDDHARTA2

- New SDDs with CUBE preamp
- Factor 2 in density of deuterium gas
- Kaon trigger geometry and arrangement
- Discrimination K^+/K^- by lifetime detector
- Active shielding of apparatus
- Better timing resolution of SDDs by cooling

SIDDHARTA



SIDDHARTA2



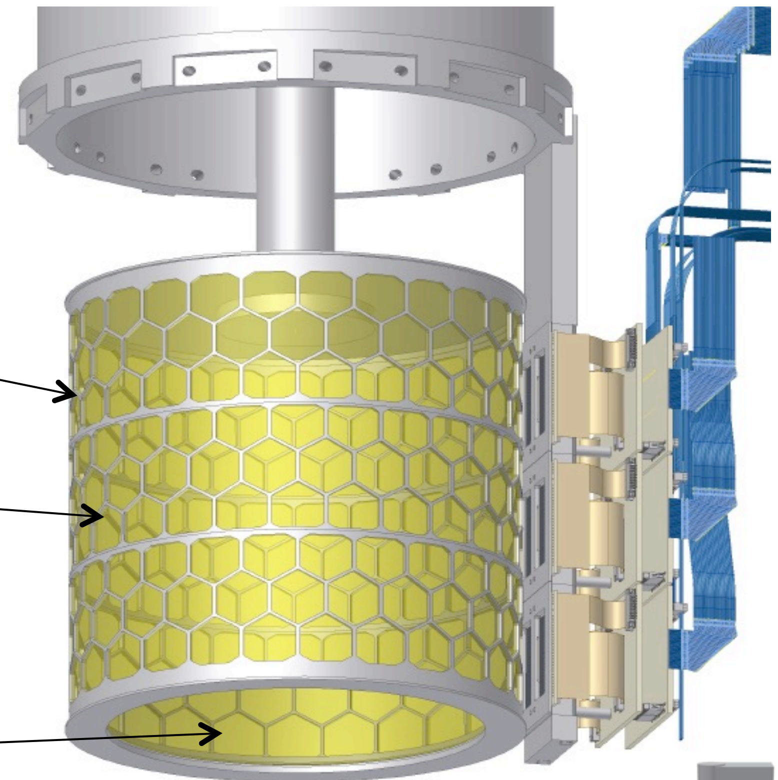
Lightweight cryogenic target (used for KH)

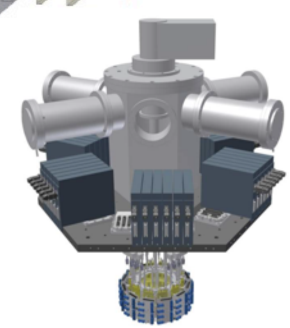
working T 22 K
working P 1.5 bar

Alu-grid

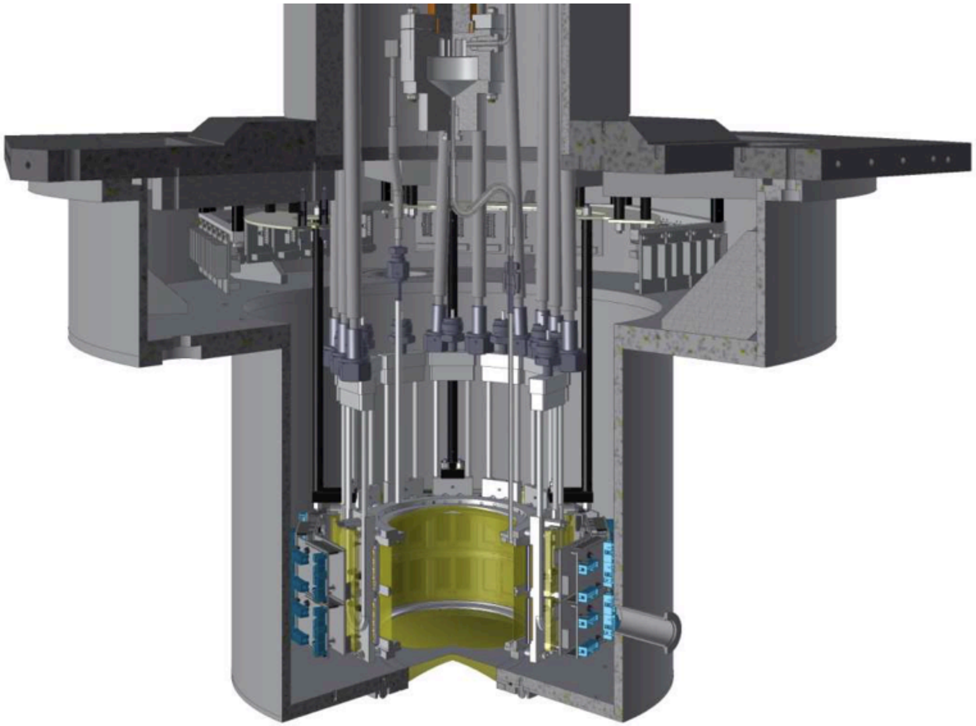
Side wall:
Kapton 50 μm

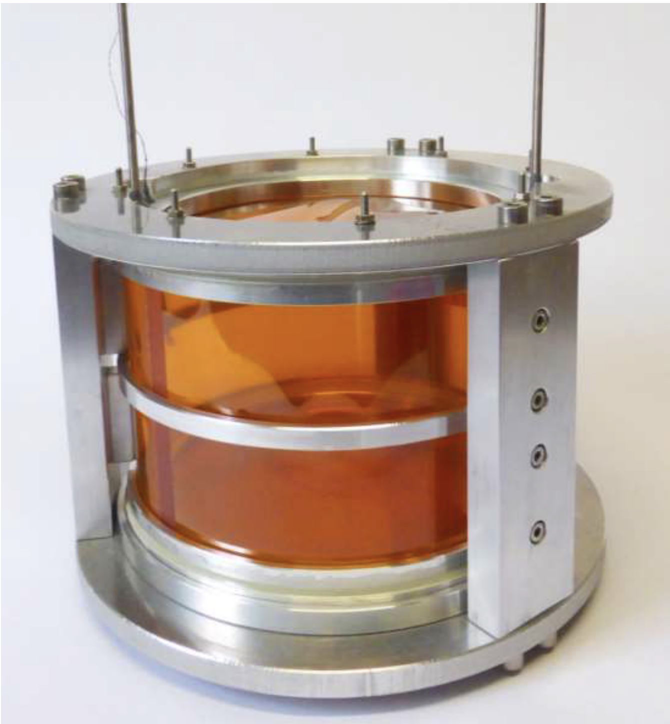
Kaon entrance
Window:
Kapton 75 μm





Prototypes





New SDDs for SIDDHARTA2

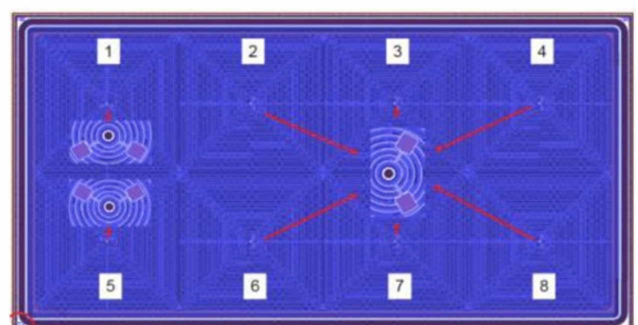
SIDDHARTA

- JFET integrated on SDD
- lowest total anode capacitance
- limited JFET performance
- sophisticated SDD+JFET technology

3x1 matrix

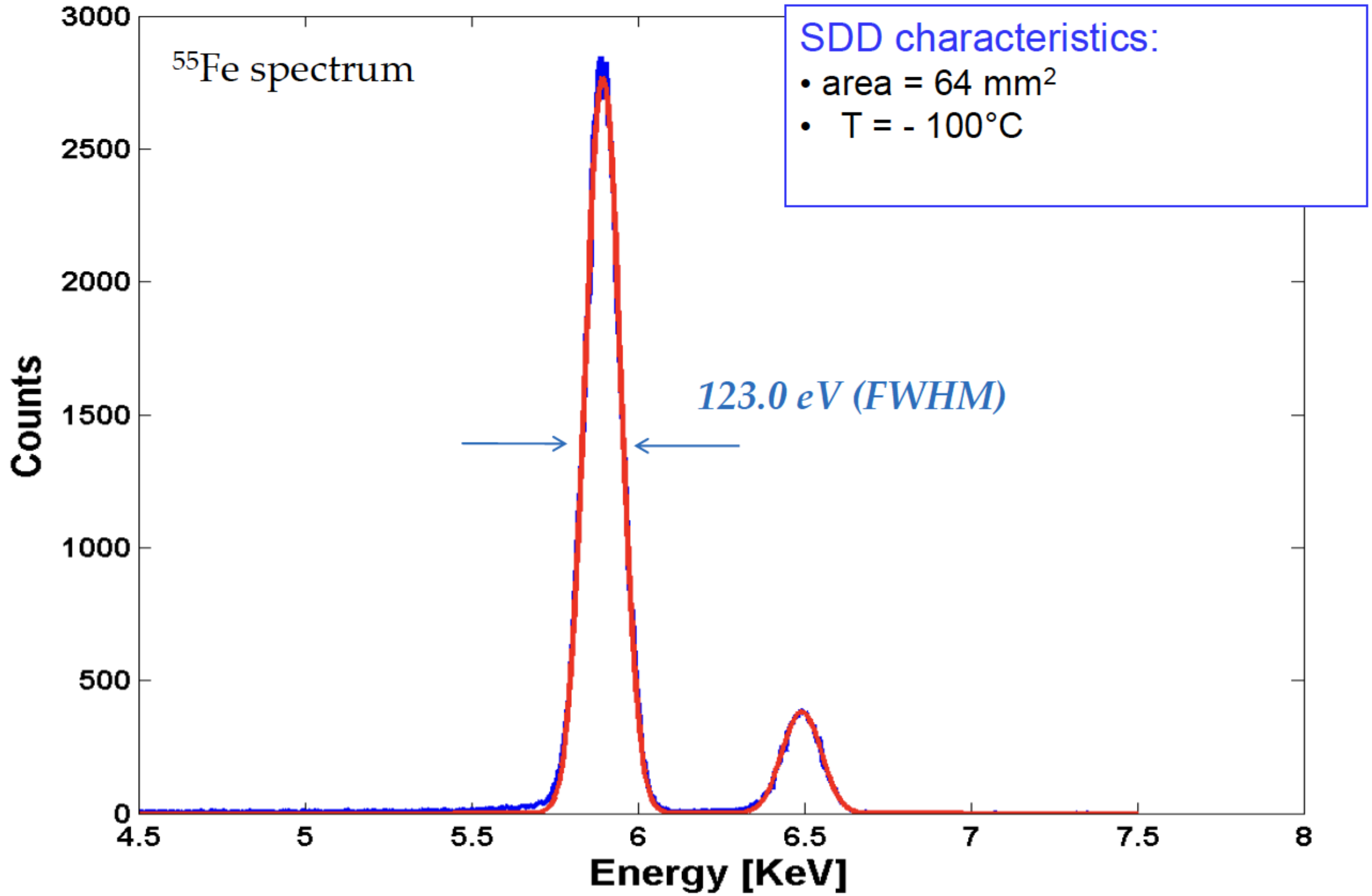
SIDDHARTA2

- external CUBE preamplifier (MOSFET input transistor)
- larger total anode capacitance
- better FET performances
- standard SDD technology

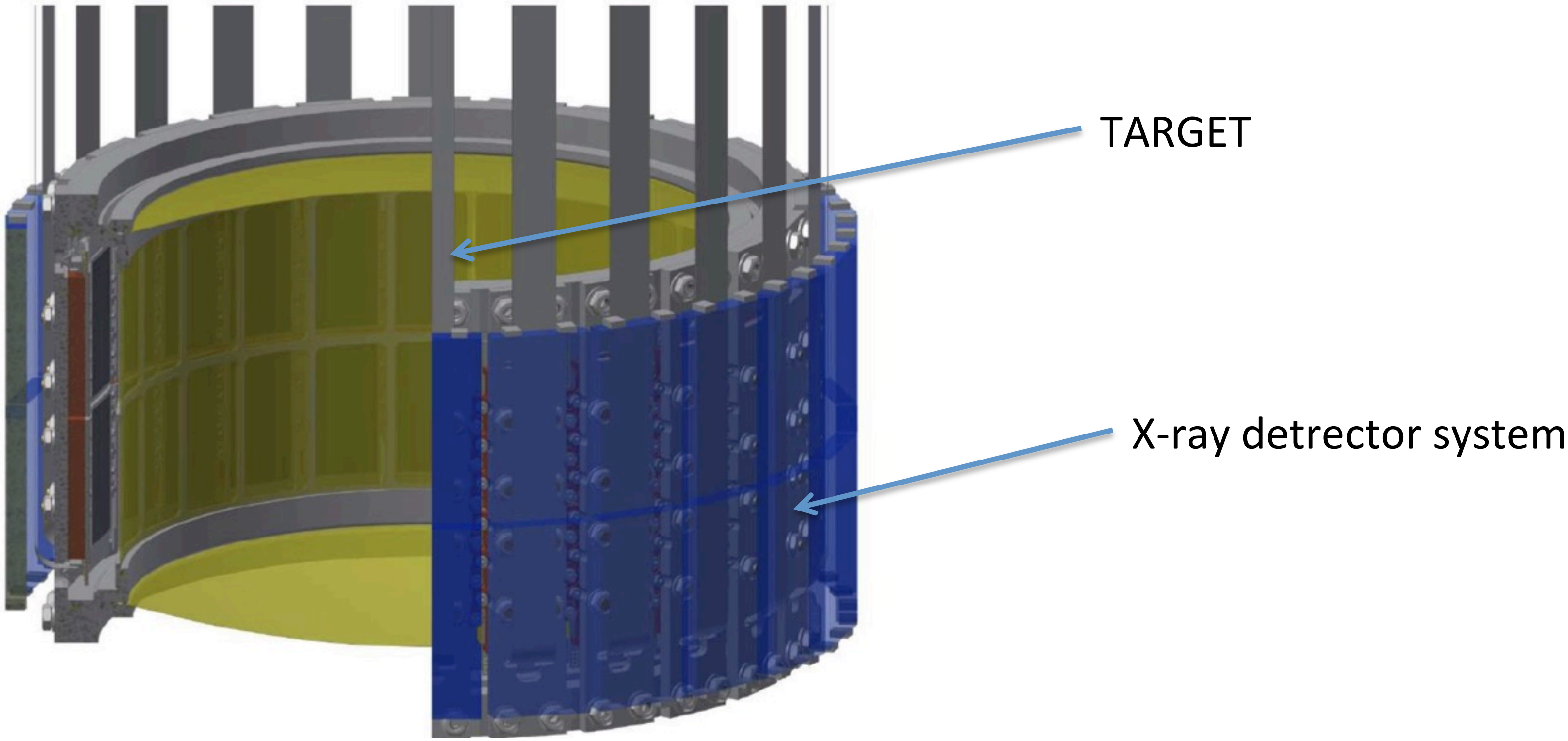


4x2 matrix

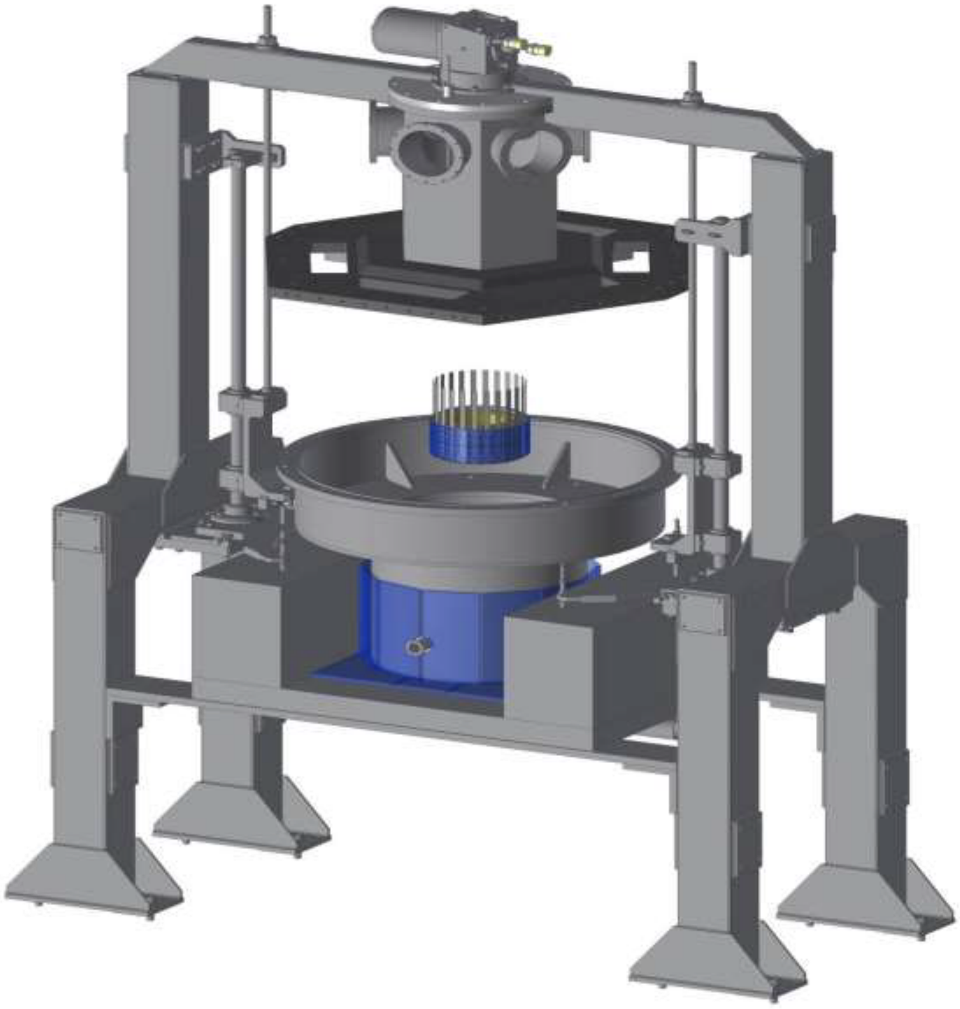
Energy resolution of new SDD



Target – SDD geometry



SIDDHARTA2 Setup at DAFNE



- new target design
- new SDD arrangement
- vacuum chamber
- more cooling power
- improved trigger scheme
- shielding and anti-coincidence (veto)

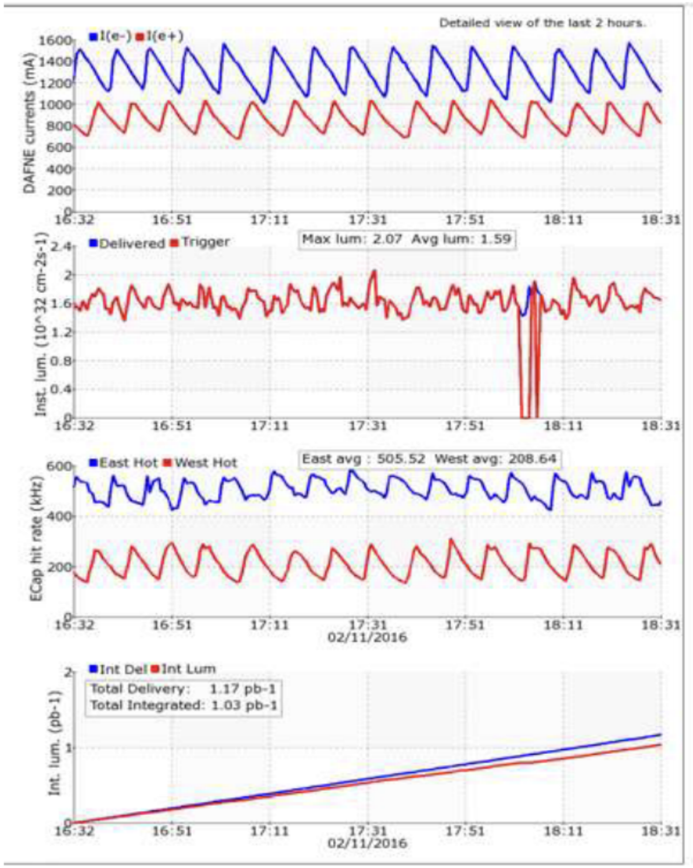
SDD Characterization

- Extremely important for precision x-ray spectroscopy
  - Stability
    - Long term monitoring gain and offset
    - Stability under small temperature variations
    - Gain stability at different x-ray rates
  - Linearity
  - SDD time response at various temperatures
  - SDD operation at low temperatures
  - Radiation hardness

	Signal to background	Kα events
SIDDHARTA	1:100	1280
from SIDDHARTA to SIDDHARTA-2		
Improved setup: Cryogenic target new SDDs	1:18	5210
Trigger 1	1:12	3865
Veto-1	1:8.5	3074
Veto-2	1:4.4	2686
K+ discrimination	1:3.1	2664
Drift time 400 ns	1:3.0	2664
SIDDHARTA-2 final Monte Carlo results		
SIDDHARTA-2	1:3.0	2664

Running SIDDHARTA2

DAΦNE two hours luminosity plot



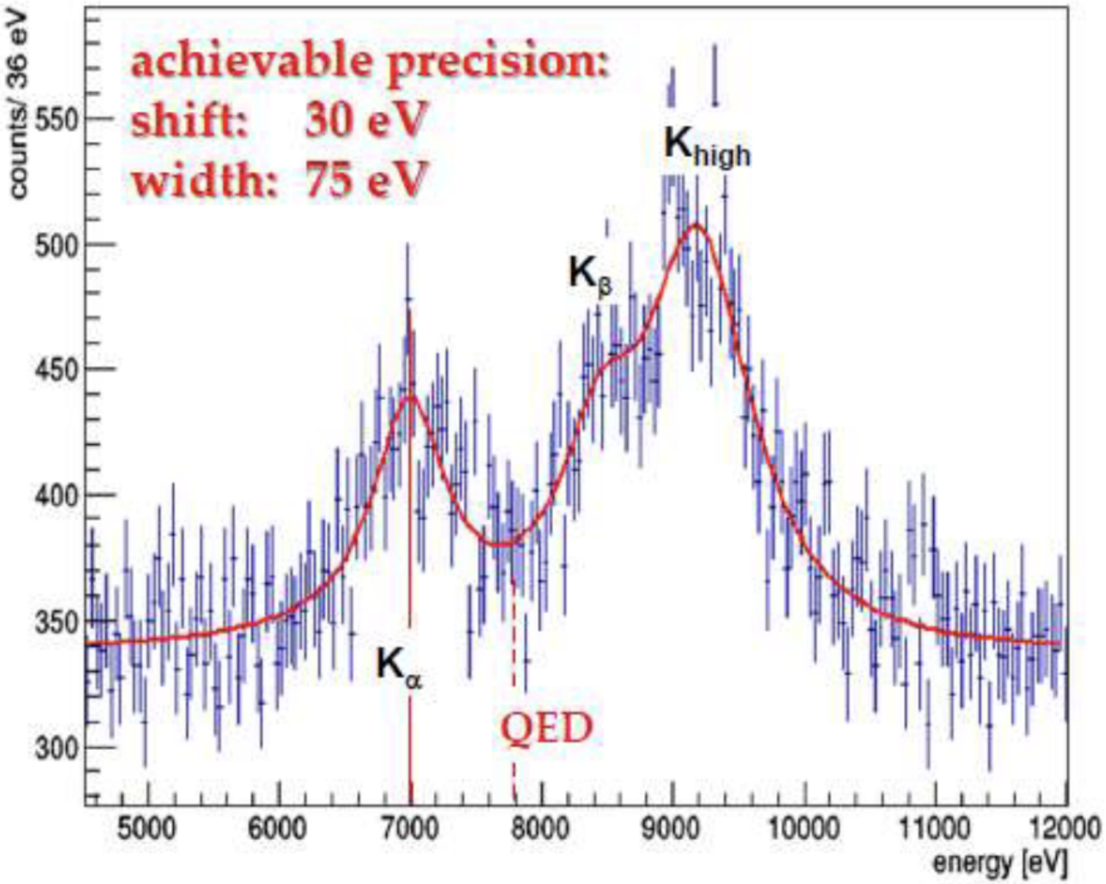
The new SDDs will allow to run in "topping up" mode (*)

- due to cube preamplifier technology

➢ **80% duty cycle**

(*) if background conditions are similar to the SIDDHARTA ones

Kaonic deuterium with SIDDHARTA2 at DAFNE



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

We expect to measure shift and width of kaonic deuterium with a similar relative precision like kaonic hydrogen

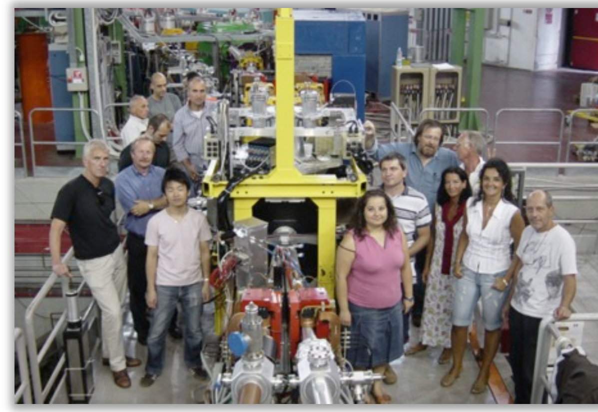
Time-line SIDDHARTA2

- Setup ready 2017
- Installation at DAFNE 2018
- Beam time after optimization 800 pb^{-1}

First determination of the hadronic shift and width of the 1s ground state of kaonic deuterium leading to the extraction of the isospin-dependent scattering lengths

Summary

- SIDDHARTA – important results on light kaonic atoms, AMADEUS studies on K_{bar} interaction on nuclei
- Strong impact for $K_{bar}N$ theory
- SIDDHARTA – first exploratory experiment on $K^{-}d$ − important for the planning of SIDDHARTA2
- SIDDHARTA2 with strongly improved apparatus aiming at a first extraction of 1s state shift and width in kaonic deuterium
- SIDDHARTA2 at DAFNE − beamtime in 2018/2019



FWF
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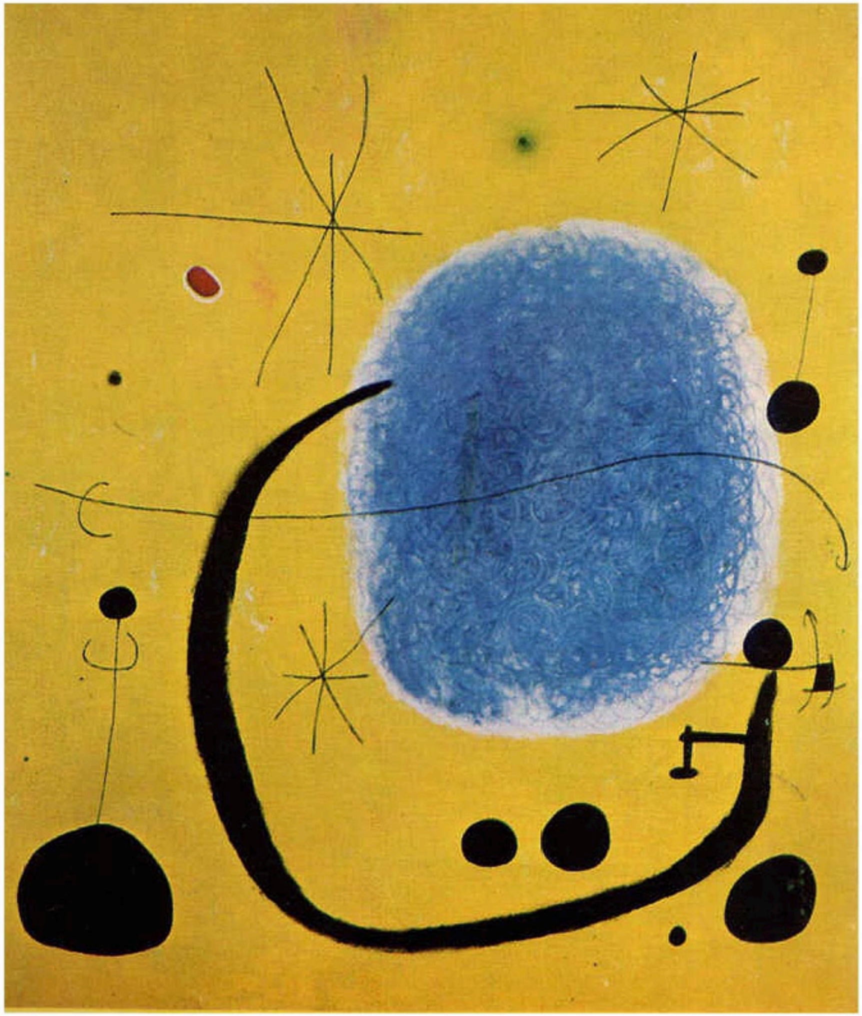

Thank you for your attention