Istituto Nazionale Fisica Nucleare - Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare

EXCITED QCD

2020

Krynica Zdrój, 2-8 / 02/ 2020

Low-energy kaon-nucleon/nuclei studies at DAΦNE: SIDDHARTA-2 and AMADEUS

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On behalf of SIDDHARTA-2 collaboration

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Scientific goals

SIDDHARTA-2:

K^-n interaction at threshold

- isospin dependence of the scattering amplitude

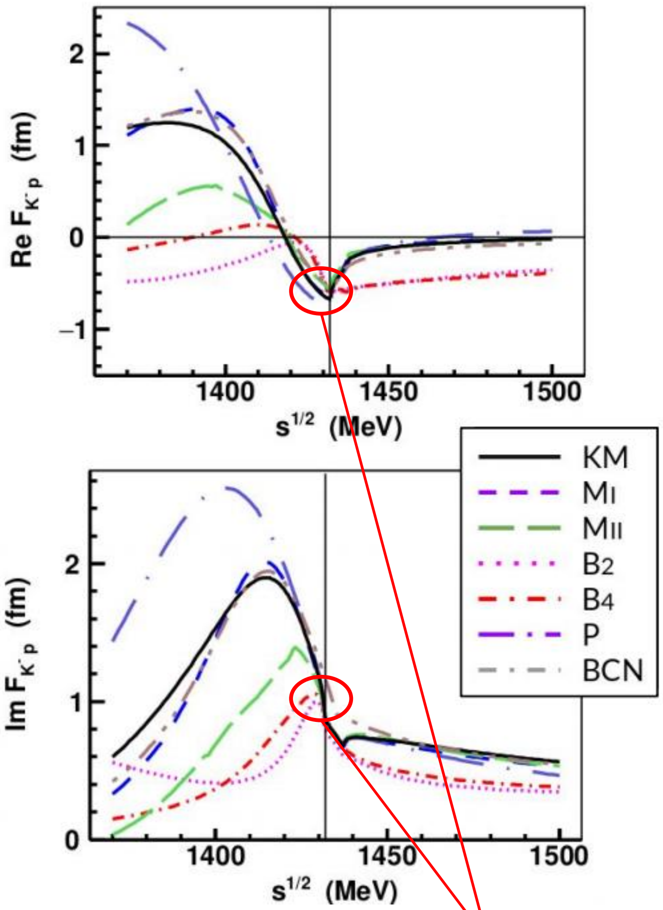
→The first precise measurement of K-transitions in Kaonic Deuterium

AMADEUS:

K^- absorption in nuclei

- K^-N interaction above or below threshold (Λ(1405), kaonic bound states)
- K^-2N, K^-3N, K^-4N (multi-nucleon) interactions

K⁻p scattering lengths



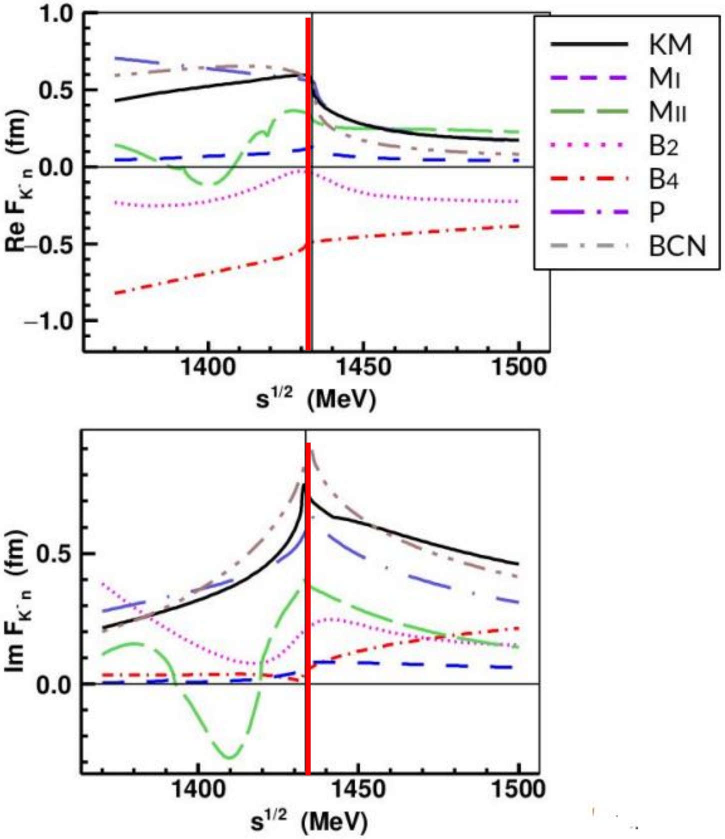
K^-p scattering amplitude in Chiral calculations

- **Kyoto-Munich (KM)**
  Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A 881 (2012) 98
- **Murcia (MI , MII)**
  Z. H. Guo, J. A. Oller, Phys. Rev. C 87 (2013) 035202
- **Bonn (B2 , B4)**
  M. Mai, U.-G. Meißner - Eur. Phys. J. A 51 (2015) 30
- **Prague (P)**
  A. C., J. Smejkal, Nucl. Phys. A 881 (2012) 115
- **Barcelona (BCN)**
  A. Feijoo, V. Magas, À. Ramos, Phys. Rev. C 99 (2019) 035211

SIDDHARTA: first experimental constraint at threshold!

Discrepancies in the region above/below threshold → **AMADEUS**

K⁻n scattering lengths



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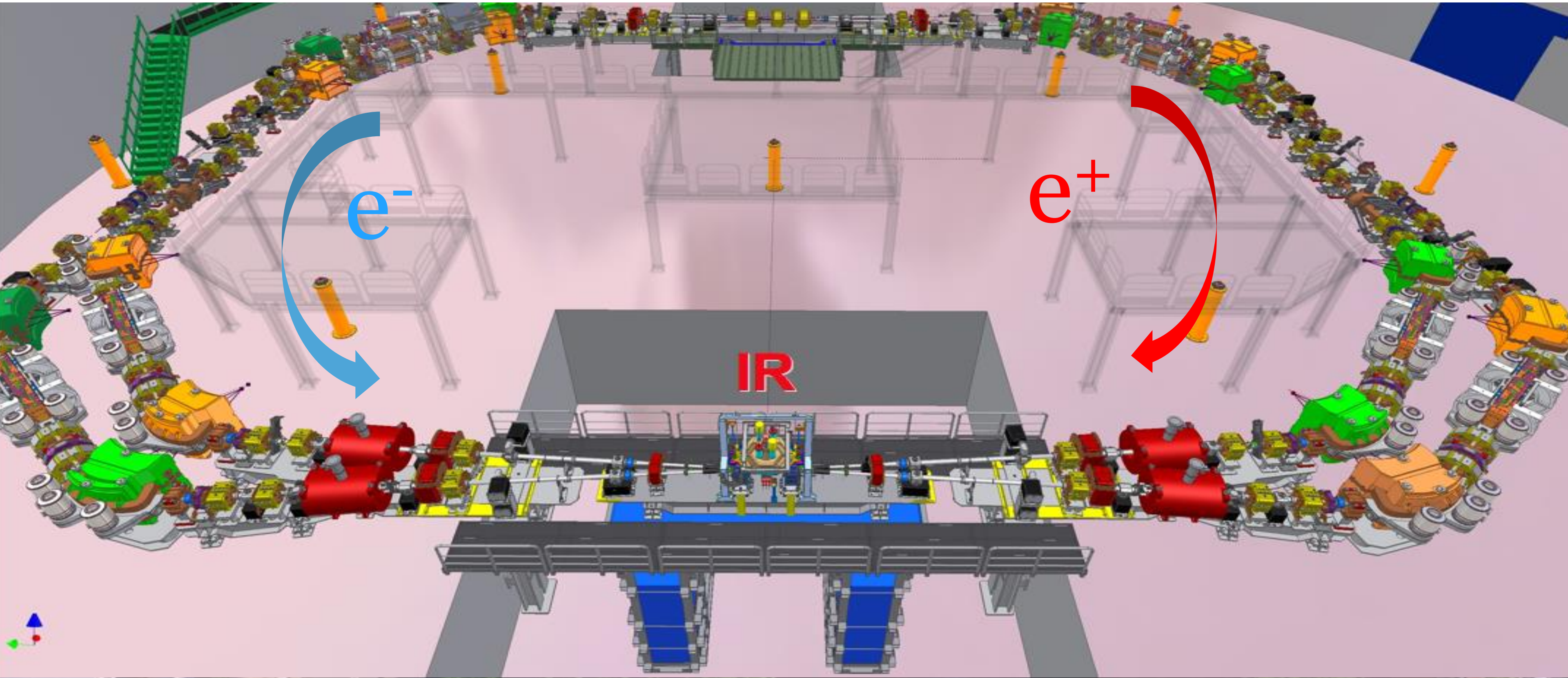
SIDDHARTA-2: first experimental constraint at threshold

AMADEUS: first experimental constraint below threshold

DAΦNE Collider

I.N.F.N.- Laboratori Nazionali di Frascati

- $\Phi \rightarrow K^- K^+$ (49.1%)
- Monochromatic low-energy K^- (~127 MeV/c ; $\Delta p/p = 0.1\%$)
- Electromagnetic (**asynchronous**) bkg
- Hadronic (syncronous) bkg



SIDDHARTA – 2 Collaboration

Silicon **D**rift **D**etectors for **H**adronic **A**tom **R**esearch by **T**iming **A**pplication

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

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
ELPH, Tohoku University

STRONG-2020

Croatian Science Foundation, research project 8570

SIDDHARTA (-2) project

Scientific Goal

To perform precise measurements of kaonic atoms X-ray transitions unique information about QCD in the non-perturbative regime in the strangeness sector not obtainable otherwise

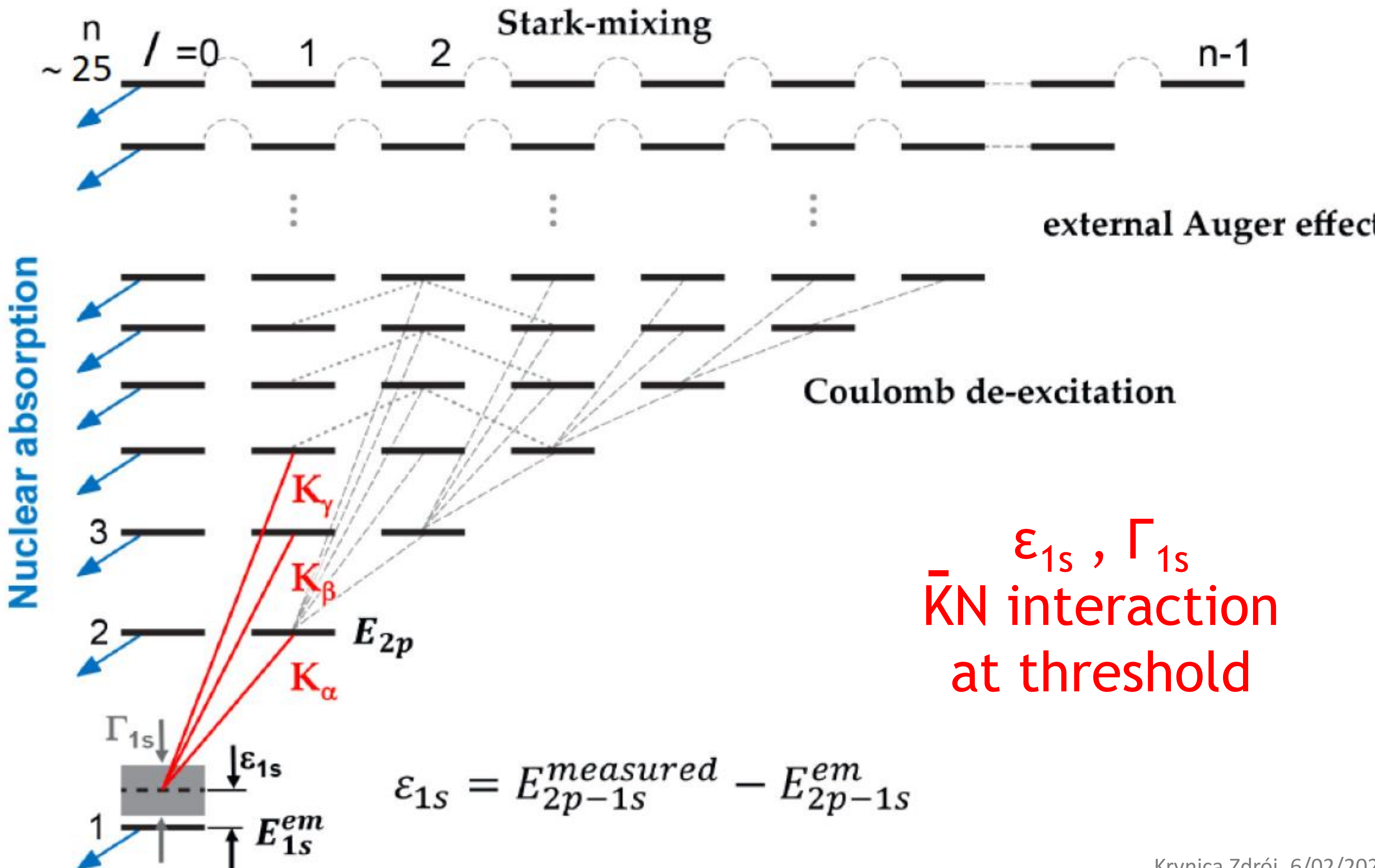
SIDDHARTA 2 aim..

to perform a precise measurement of **kaonic deuterium** to determine X-ray transitions to the ground state (1s-level), such as **to determine its shift and width induced by the presence of the strong interaction**.

↓

The analysis of the combined measurements of kaonic deuterium and kaonic hydrogen (already measured by SIDDHARTA) will allow, **the extraction of the isospin-dependent antikaon-nucleon scattering lengths which are fundamental inputs of low-energy QCD effective theories.**

Cascade process → strong interaction



ε_{1s} , Γ_{1s}

$\bar{K}N$ interaction at threshold

Deser-type relations

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

KH (SIDDHARTA,2009)

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

KD (SIDDHARTA-2,2019)

a_{K-p} and a_{K-d} : S-wave scattering lengths.

isoscalar a_0 and isovector a_1 scattering lengths

very important quantities for understanding the low energy QCD with strangeness

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

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

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

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

Horiuchi et al., EPJ Web Conf. Series 199, 03003 (2019)

SIDDHARTA results:

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

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

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

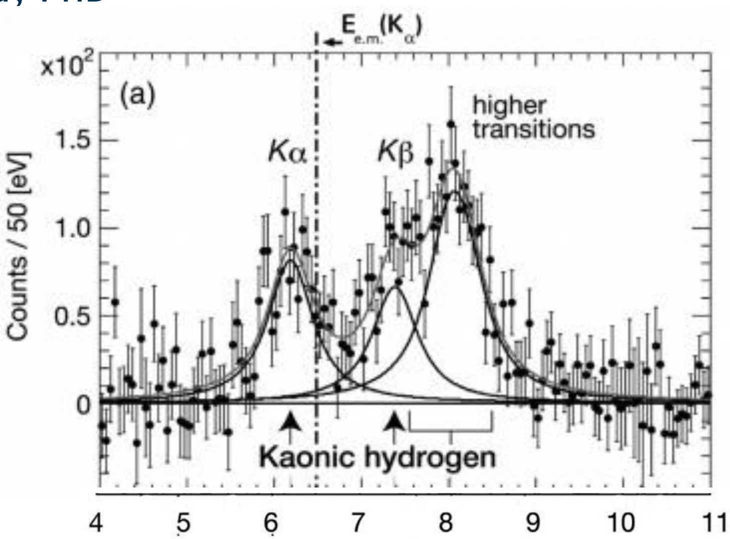
- **Kaonic helium 3 - 10 pb^{-1}**, first measurement in the world, PhD
  Phys. Lett. B 697 (2011) 199

- **Widths and yields of KHe3 and KHe4**
  Phys. Lett. B714 (2012) 40;

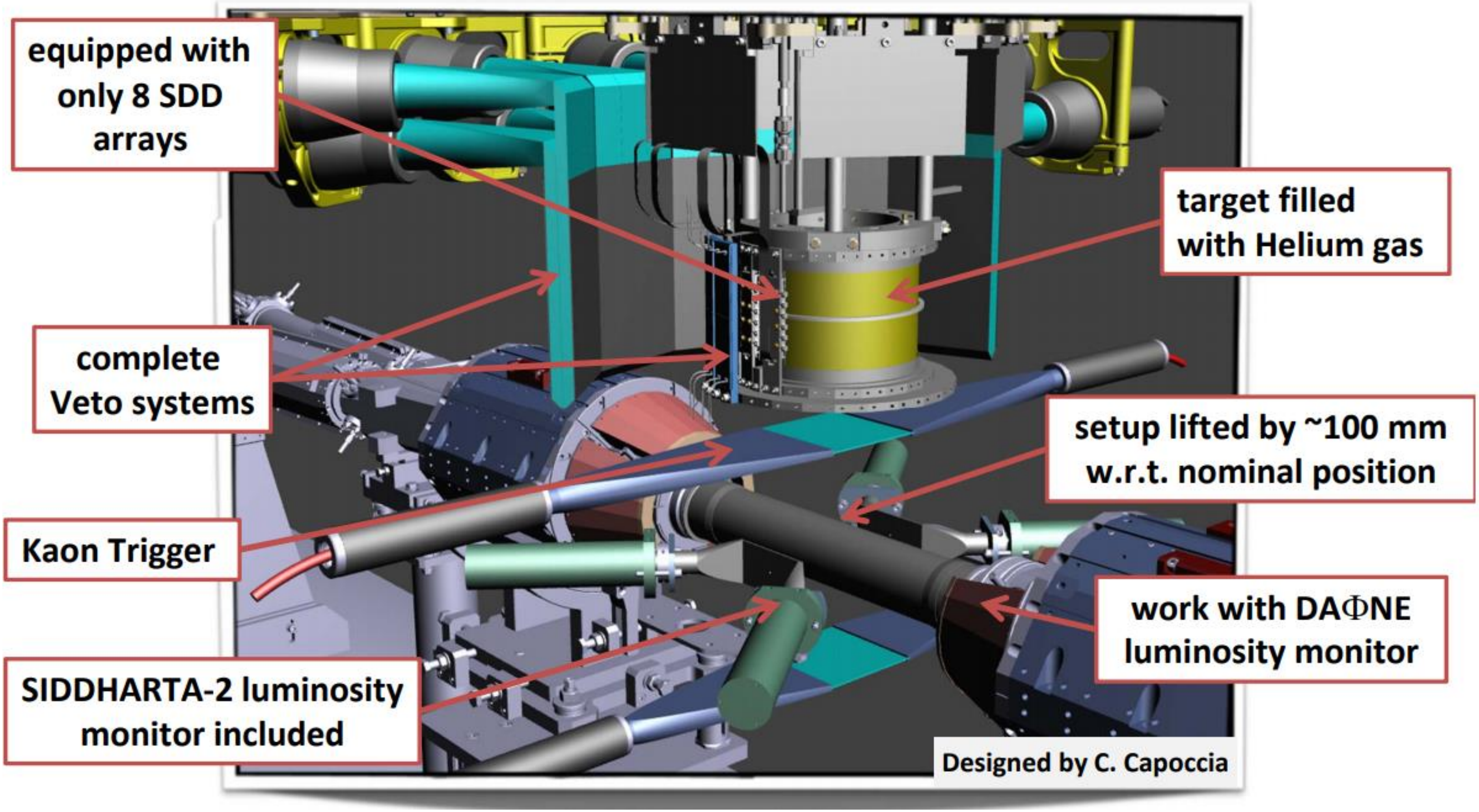
-**Kaonic kapton yields**
Nucl. Phys. A916 (2013) 30;

-**Yields of the KHe3 and KHe4**
EPJ A(2014) 50;

-**KH yield**
Nucl. Phys. A954 (2016) 7.

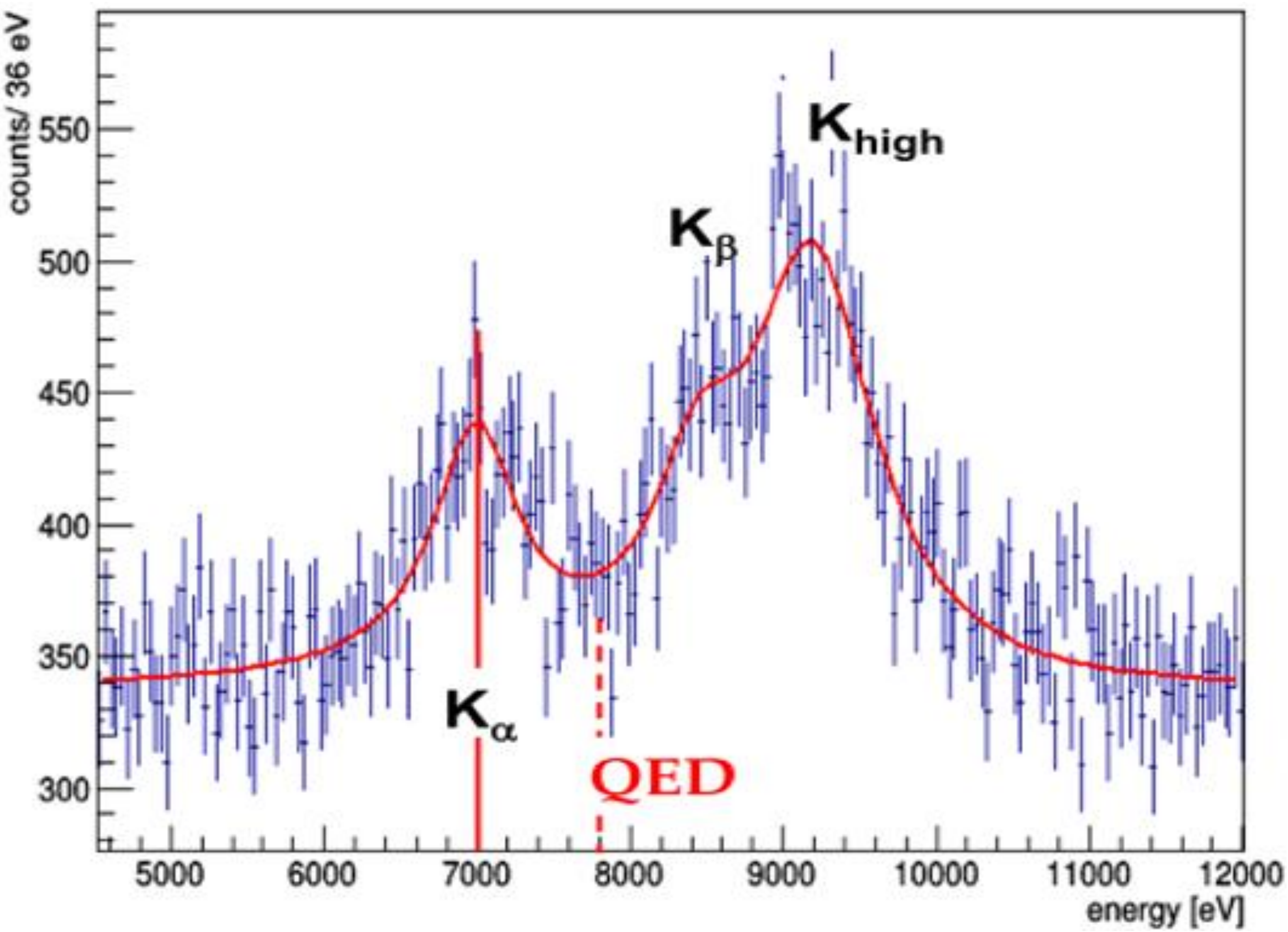


Sharp & Succesfull SIDDHARTINO installation (April 2019)



MC Kaonic deuterium

KD yield < 0.1 %



$$\int L = 800 pb^{-1}$$

density: 3% (LHD)

detector area: 246 cm^2

↓

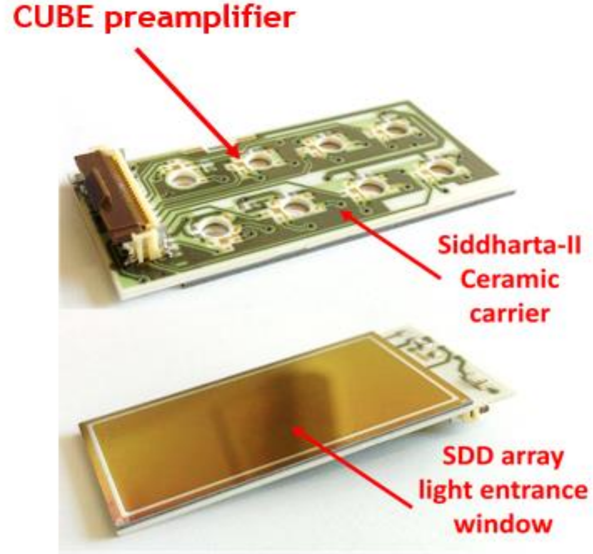
$$\varepsilon = -800 \pm \mathbf{30}\ \text{eV}$$

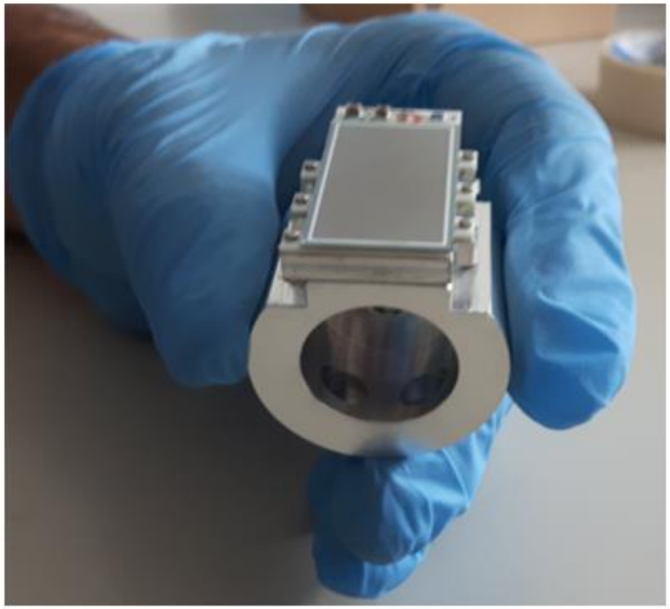
$$\Gamma = 750 \pm \mathbf{75}\ \text{eV}$$

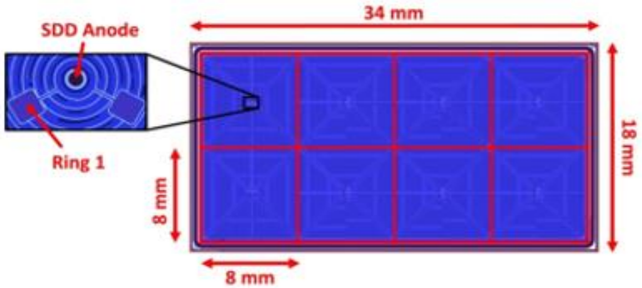
↓

Same precision as SIDDHARTA, which gave the most precise measurement of KH so far

New dedicated technology SDD (FBK + PoliMi + LNF)



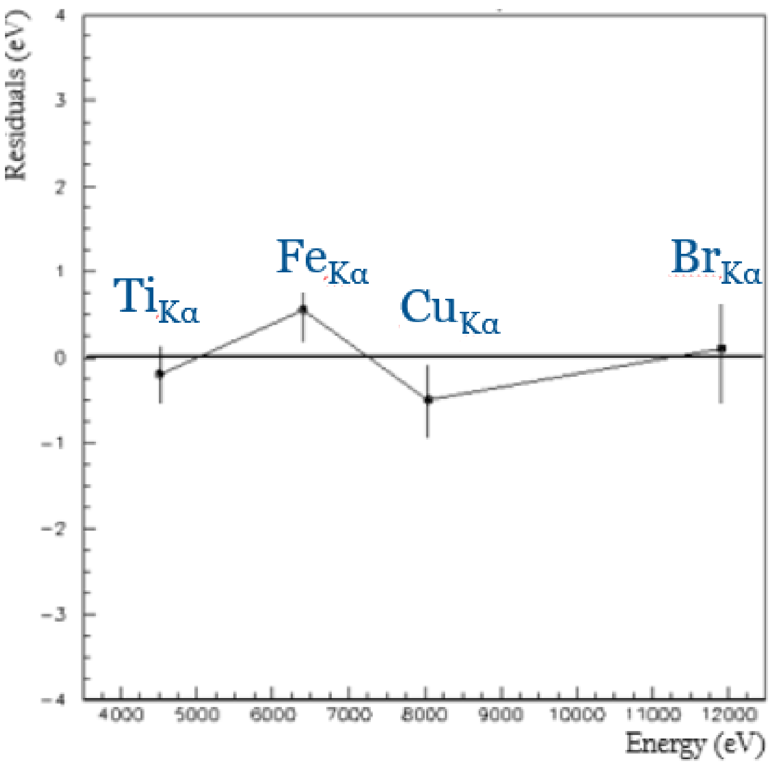




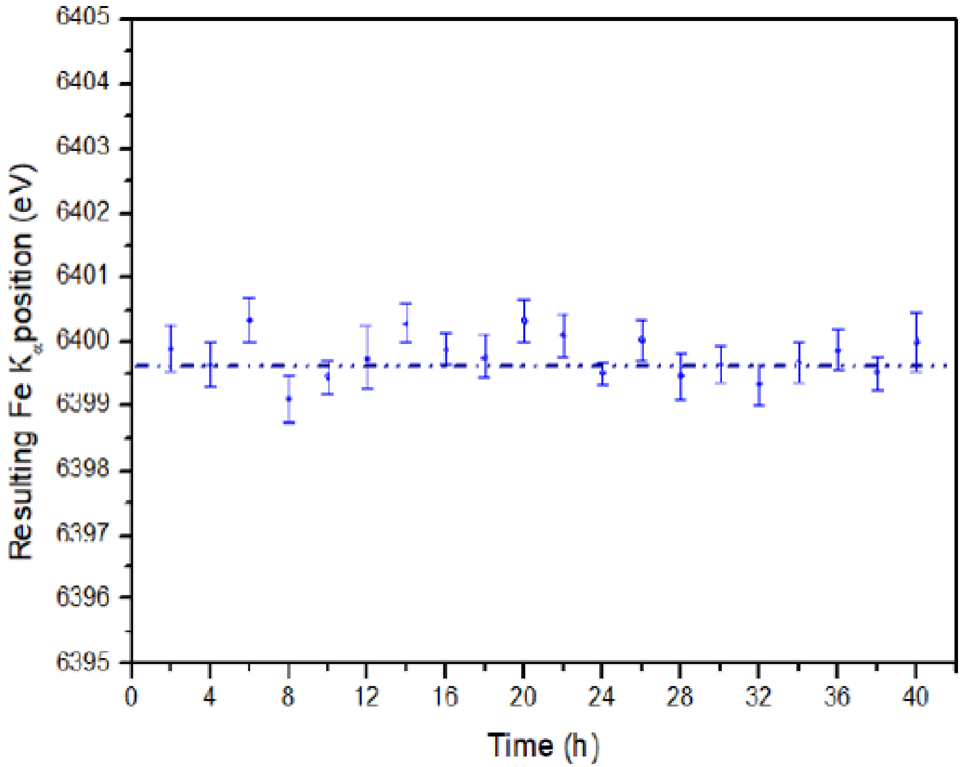
New technology SDD arrays for SIDDHARTA 2
common polarization for all the 8 units

New dedicated technology SDD

Linearity

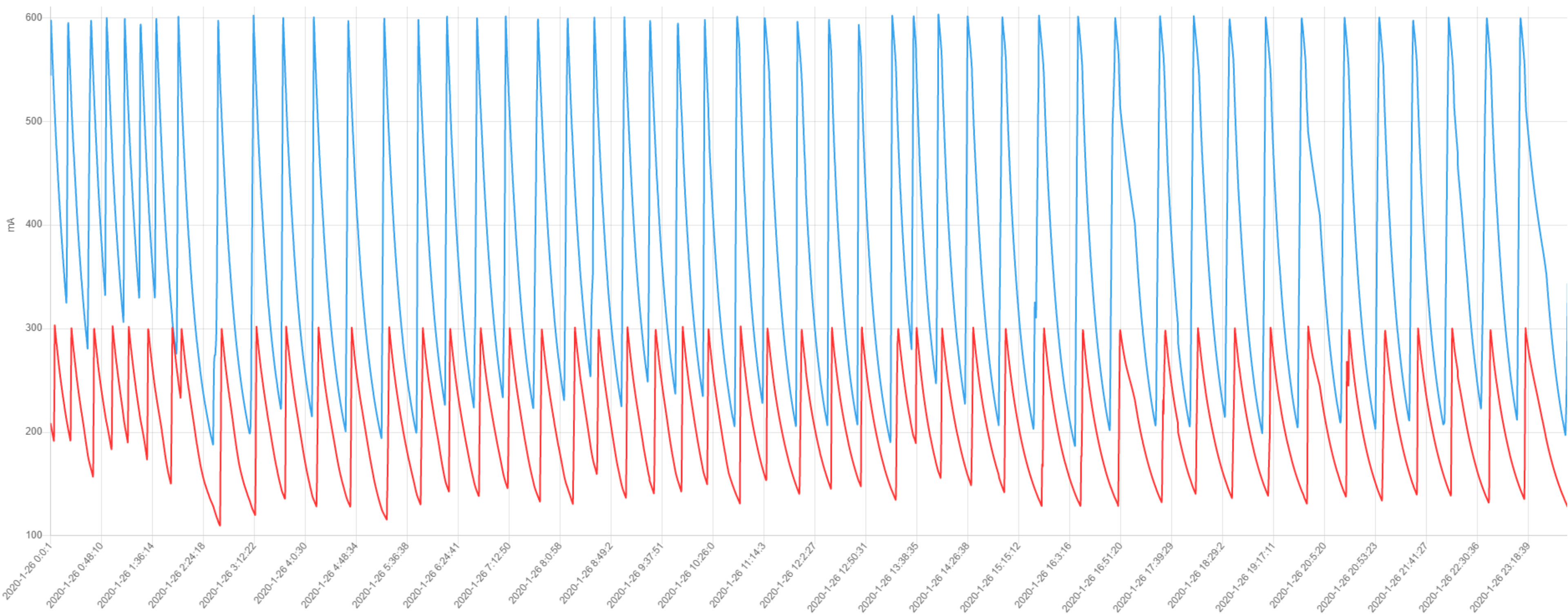


Stability



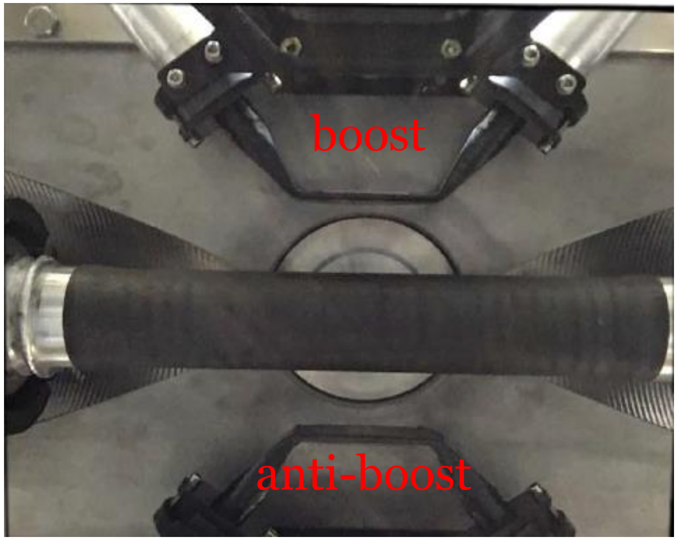
Miliucci et al., Condens. Matter, 4(2) (2019)

DAΦNE status

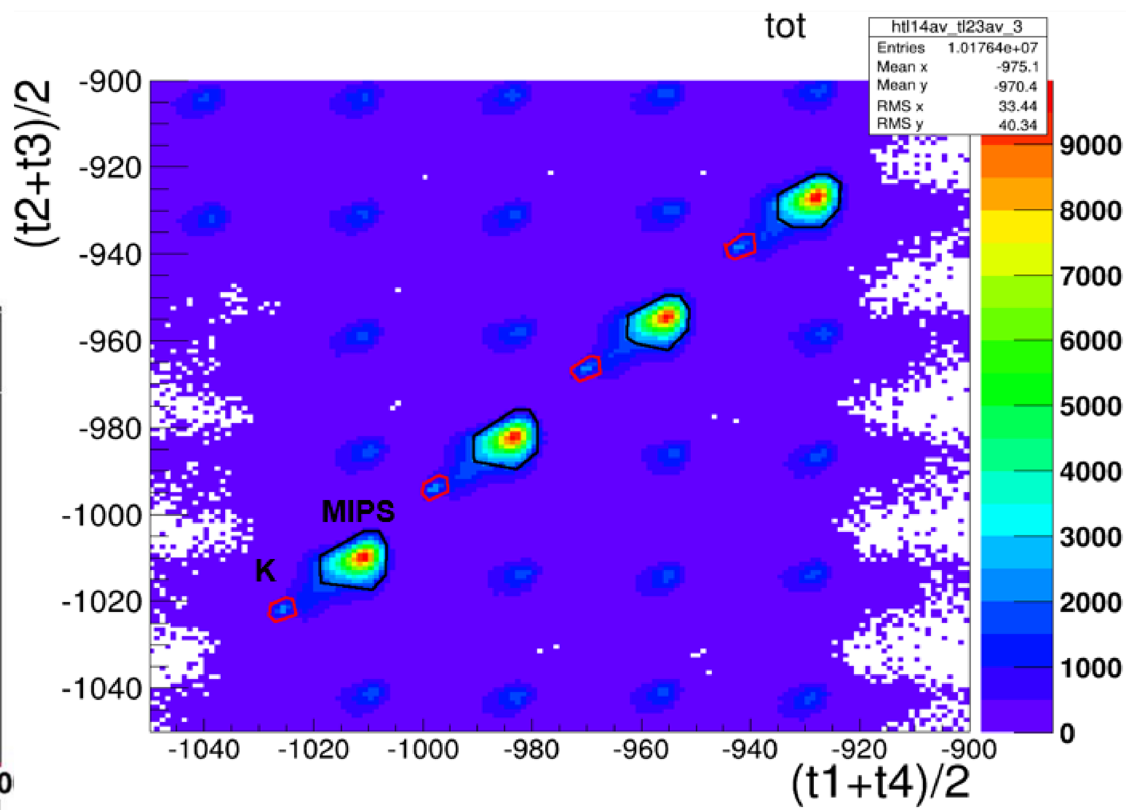


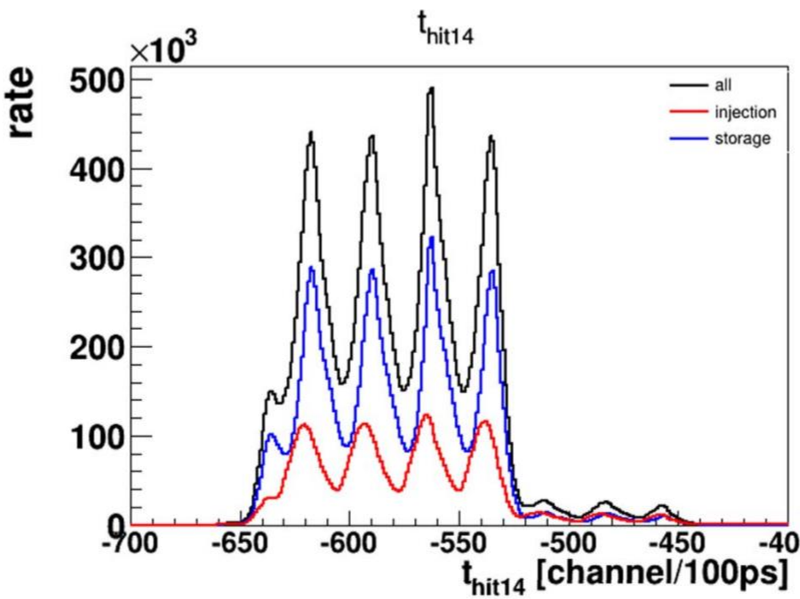
e+ / e- beams

LUMINOSITY MONITOR



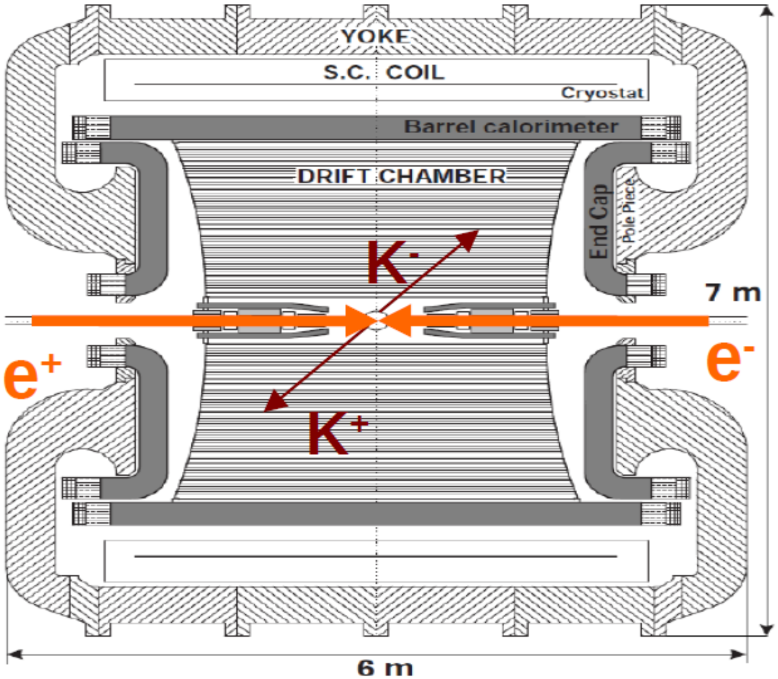
Habemus K!!!





Timing resolution = 500 ps

AMADEUS



The KLOE detector

- Cylindrical drift chamber with a 4π geometry and electromagnetic calorimeter
- 96% acceptance
- Optimized in the energy range of all charged particles involved
- Good performance in detecting photons and neutrons

KLOE used as active target: Carbon, Helium, Hydrogen

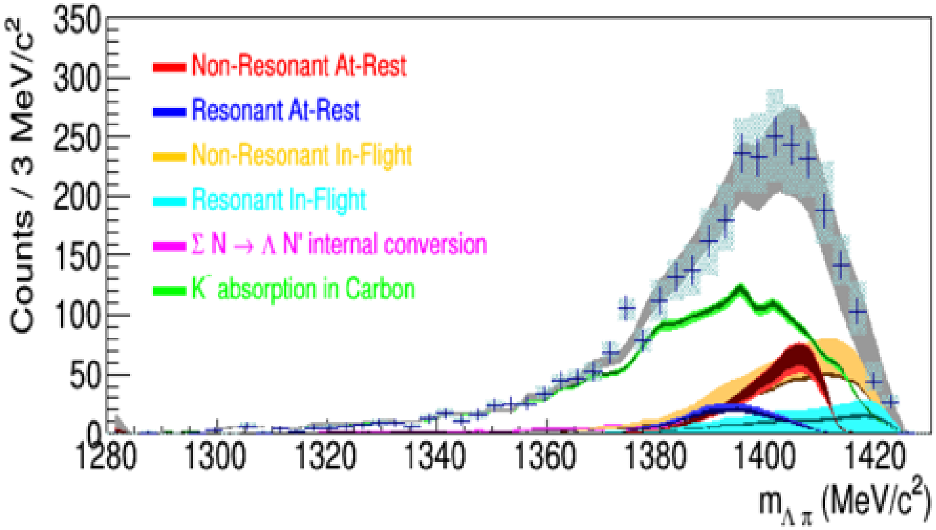
Nuclear absorption:

- AT REST → $P_K = 0$ MeV/c
- IN FLIGHT → $P_K \sim 100$ MeV/c

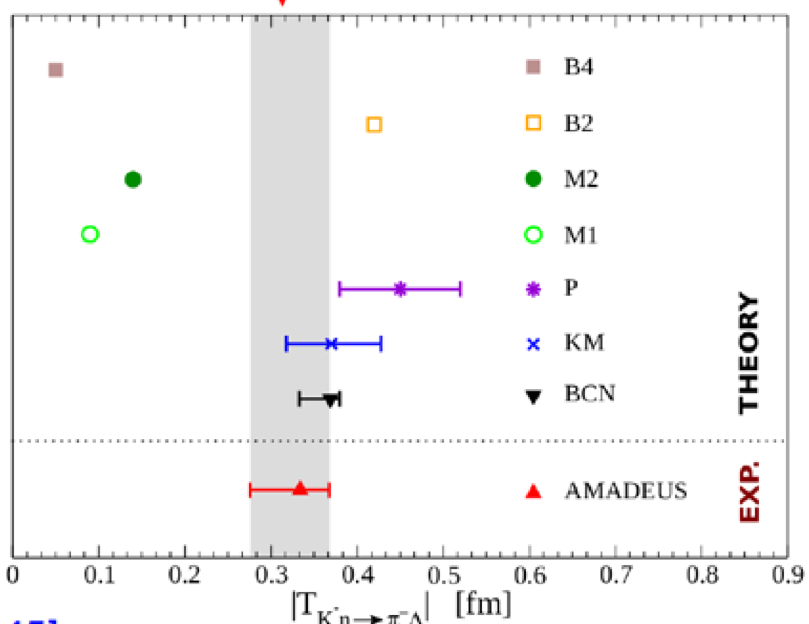
K^- n amplitude below the threshold

Bound neutron in Helium:

K^- "n" $^3He \rightarrow \Lambda \pi^-$ ^3He



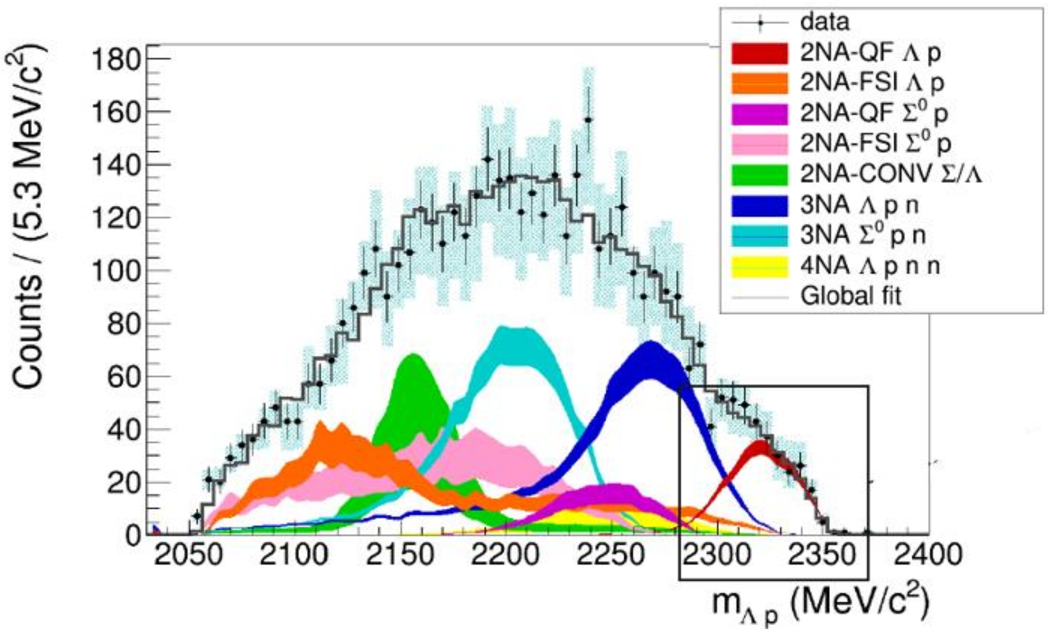
$$|f^s_{ar}| = (0.334 \pm 0.018\,\mathrm{stat}^{+0.034}_{-0.058}\mathrm{syst})\,\mathrm{fm}\,.$$



[K. P., S. Wycech, L. Fabbietti et al. Phys.Lett. B782 (2018) 339-345]

[K. P., S. Wycech, C. Curceanu, Nucl. Phys. A 954 (2016) 75-93]

Multi-N absorption



No K-pp bound state emerges from the fitted data

R. Del Grande, K. Piscicchia, O. Vazquez Doce et al., Eur.Phys.J. C79 (2019) no.3, 190

Process	Branching Ratio (%)	σ (mb)	@	p_K (MeV/c)
2NA-QF Λp	0.25 ± 0.02 (stat.) $^{+0.01}_{-0.02}$(syst.)	2.8 ± 0.3 (stat.) $^{+0.1}_{-0.2}$ (syst.)	@	128 ± 29
2NA-FSI Λp	6.2 ± 1.4(stat.) $^{+0.5}_{-0.6}$(syst.)	69 ± 15 (stat.) ± 6 (syst.)	@	128 ± 29
2NA-QF Σ^0p	0.35 ± 0.09(stat.) $^{+0.13}_{-0.06}$(syst.)	3.9 ± 1.0 (stat.) $^{+1.4}_{-0.7}$ (syst.)	@	128 ± 29
2NA-FSI Σ^0p	7.2 ± 2.2(stat.) $^{+4.2}_{-5.4}$(syst.)	80 ± 25 (stat.) $^{+46}_{-60}$ (syst.)	@	128 ± 29
2NA-CONV Σ/Λ	2.1 ± 1.2(stat.) $^{+0.9}_{-0.5}$(syst.)	-		
3NA Λpn	1.4 ± 0.2(stat.) $^{+0.1}_{-0.2}$(syst.)	15 ± 2 (stat.) ± 2 (syst.)	@	117 ± 23
3NA Σ^0pn	3.7 ± 0.4(stat.) $^{+0.2}_{-0.4}$(syst.)	41 ± 4 (stat.) $^{+2}_{-5}$ (syst.)	@	117 ± 23
4NA Λpnn	0.13 ± 0.09(stat.) $^{+0.08}_{-0.07}$(syst.)	-		
Global $\Lambda(\Sigma^0)$p	21 ± 3(stat.) $^{+5}_{-6}$(syst.)	-		

Future perspectives

- Kaonic helium
  2p->1s transitions

- Other Kaonic atoms
  Pioneering technology of **1 mm** thick SDDs

- Kaon mass:
  High precision X-ray spectrometer with HAPG crystals (**VOXES**)
  High purity Germanium Detectors (**GEKA**)

Stay tuned…

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