EXOTICO: EXOTIC ATOMS MEET NUCLEAR COLLISIONS FOR A NEW FRONTIER PRECISION ERA IN LOW-ENERGY STRANGENESS NUCLEAR PHYSICS

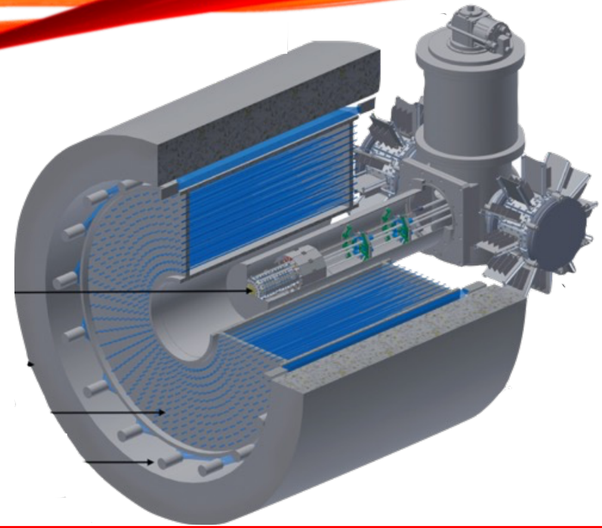
Trento 17 – 21 October 2022

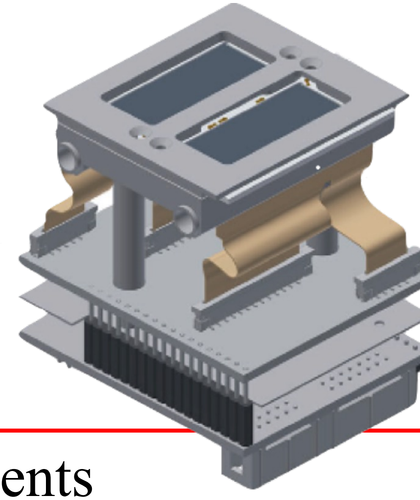
Kaonic Atoms X-ray spectroscopy: the SIDDHARTA-2 experiment

Francesco Sgaramella
on behalf of the SIDDHARTA-2 Collaboration

STRONG-2020

INFN Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI



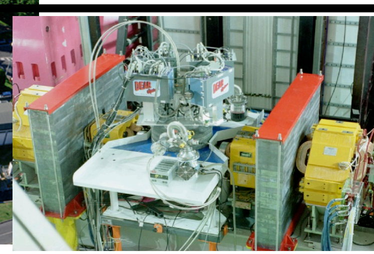


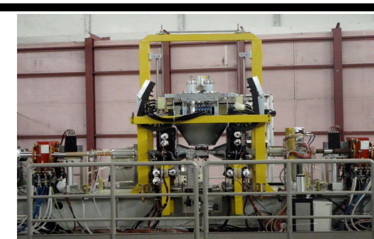
The modern era of light kaonic atom experiments

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

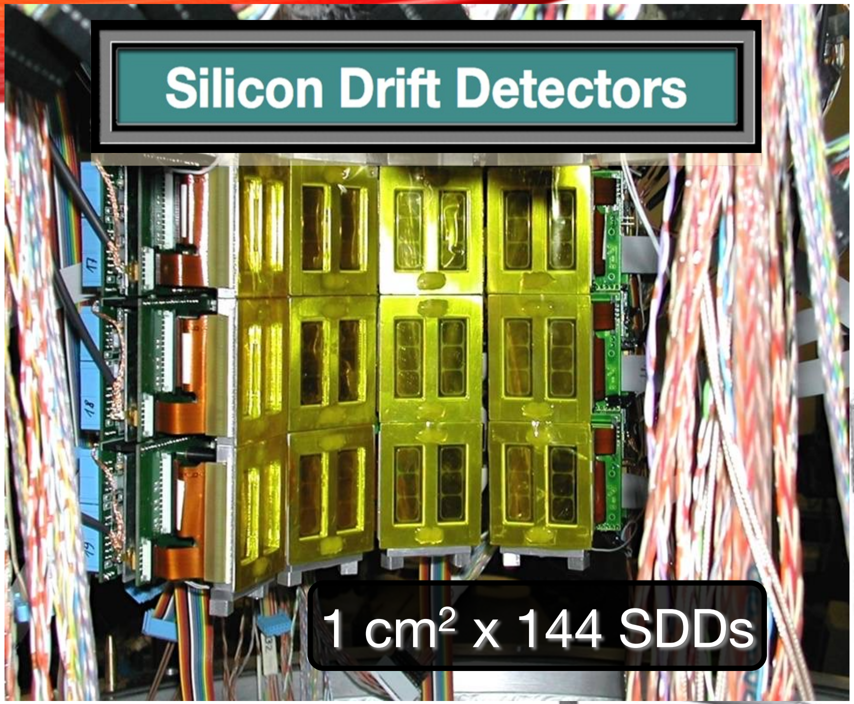
Rev. Mod. Phys. **91**, 025006 – Published 20 June 2019

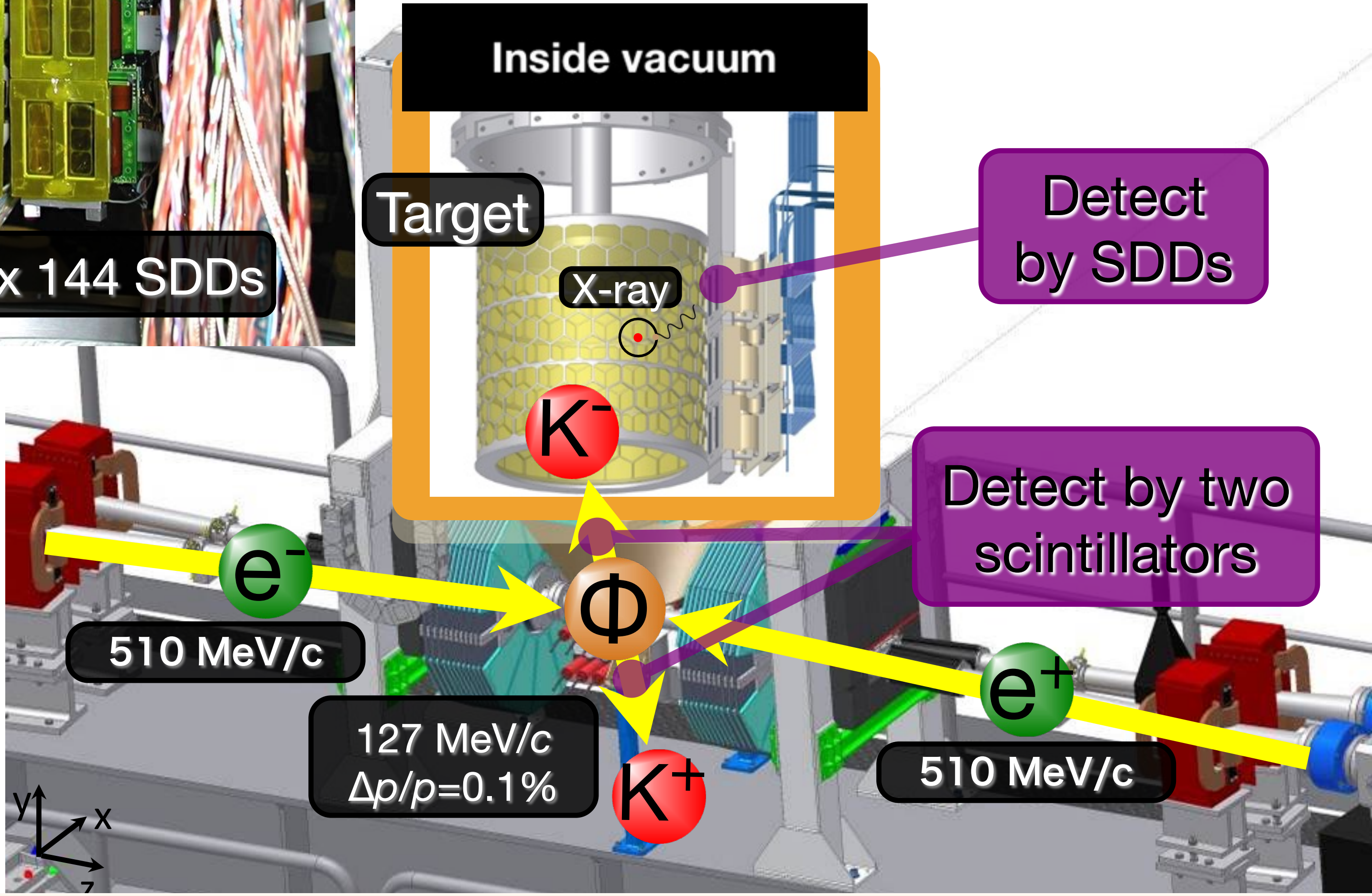
DEAR 2002 | **SIDDHARTA 2009** | **SIDDHARTA-2 2022**



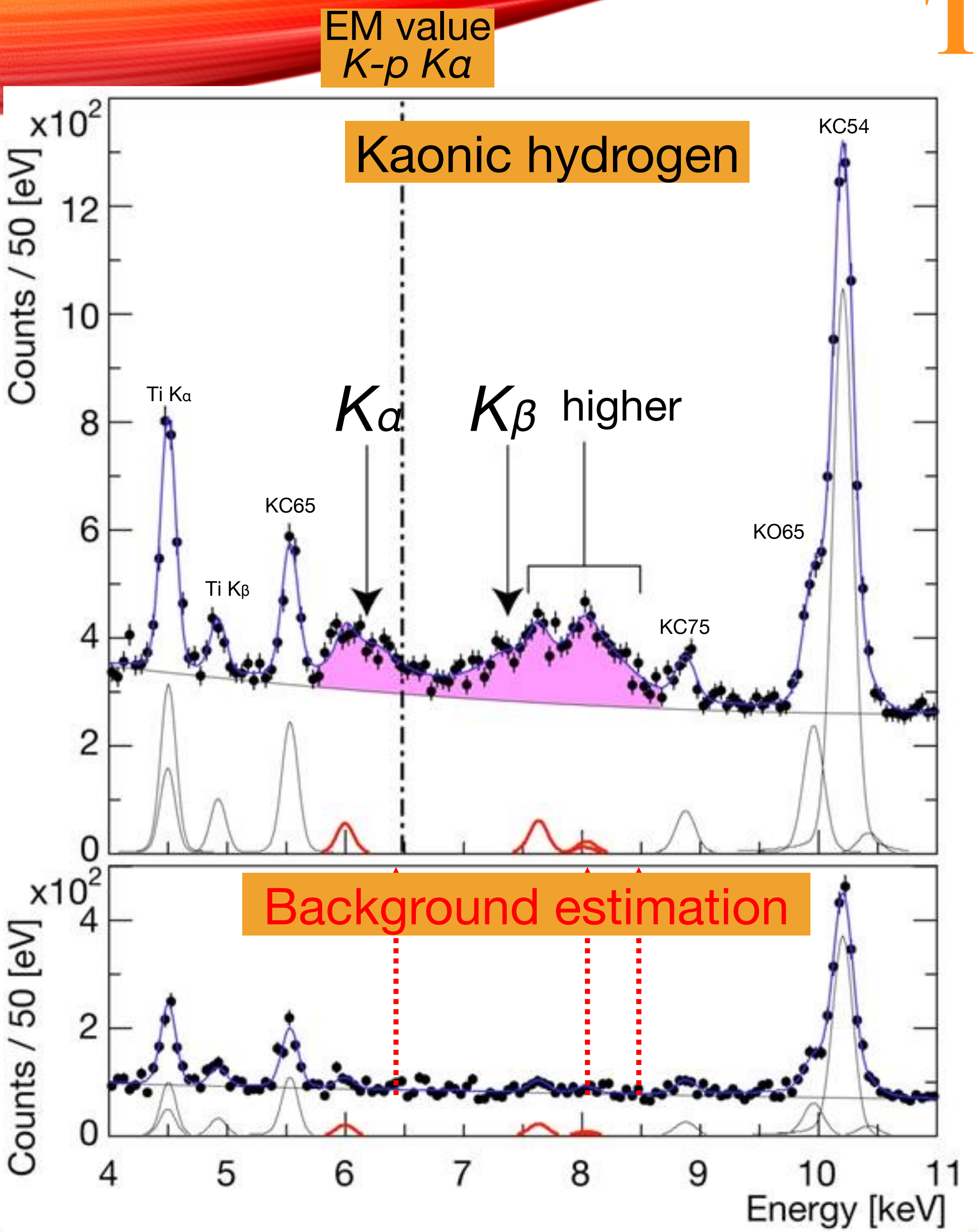


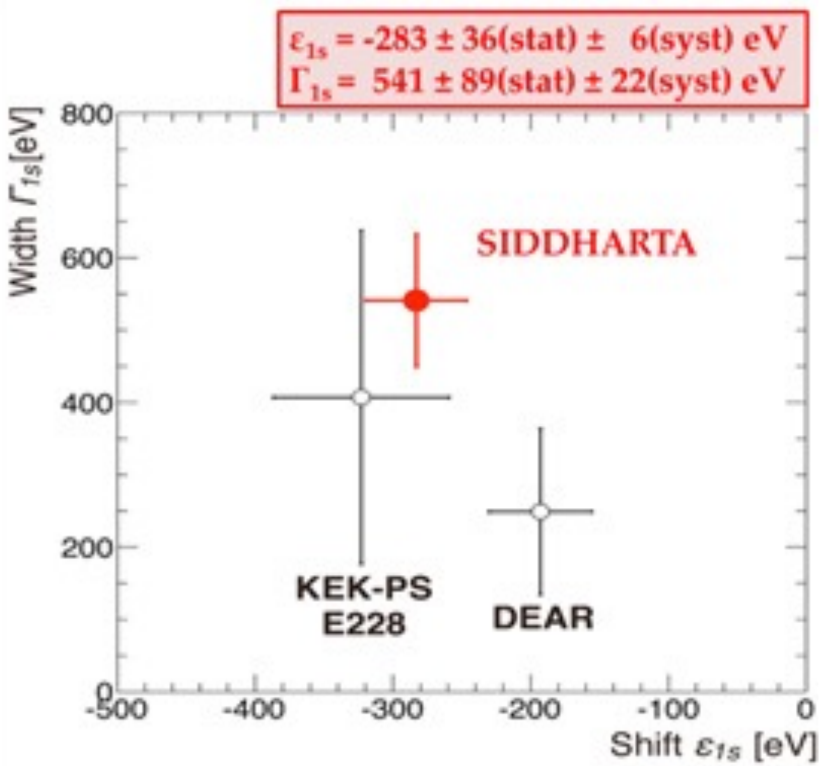
The SIDDHARTA Experiment





The SIDDHARTA Experiment





Phys. Lett. B 704 (2011) 113

SIDDHARTA-2 COLLABORATION

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

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

INFN LNF
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

HadronPhysics2
Study of Strongly Interacting Matter

STRONG-2020

HadronPhysics I3
Study of Strongly Interacting Matter

HRZZ
Croatian Science Foundation

FWF Der Wissenschaftsfonds.

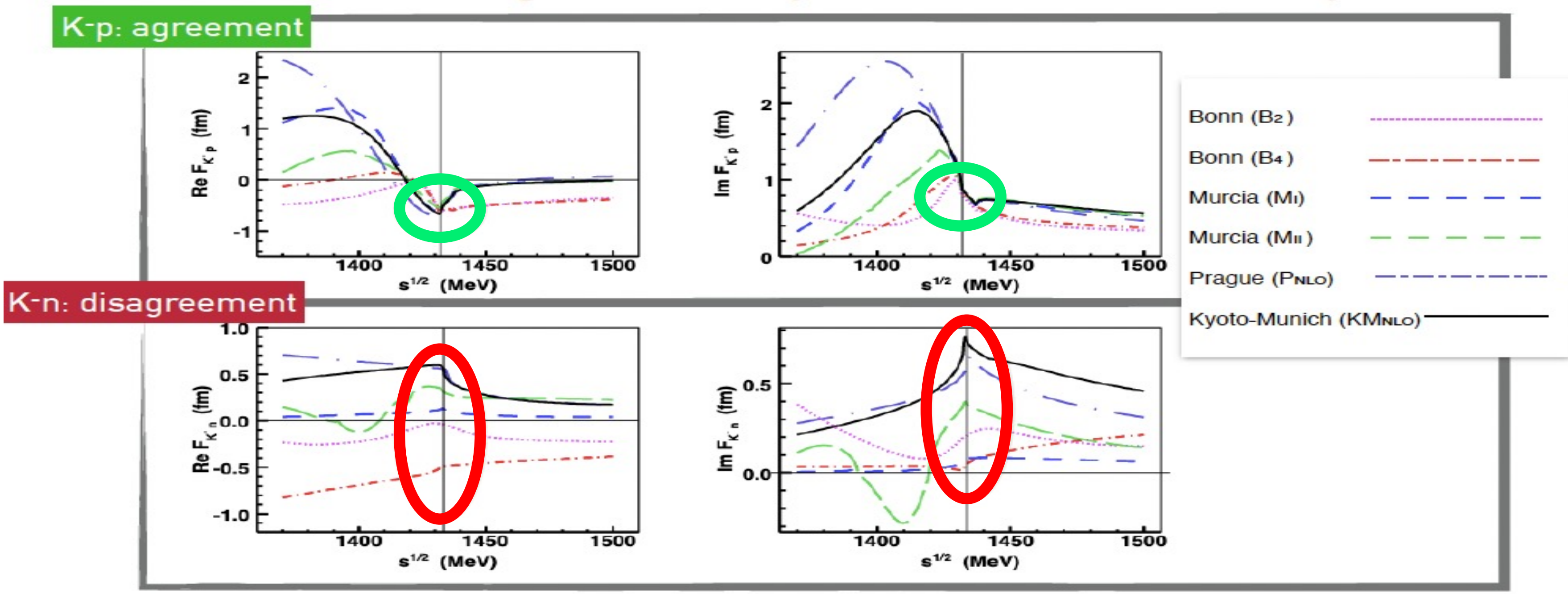
Farnesina
Ministero degli Affari Esteri e della Cooperazione Internazionale

Scientific Goal

To perform the *first measurement ever of kaonic deuterium X-ray* transition to the ground state (1s-level) such as to determine its shift and width induced by the presence of the strong interaction.

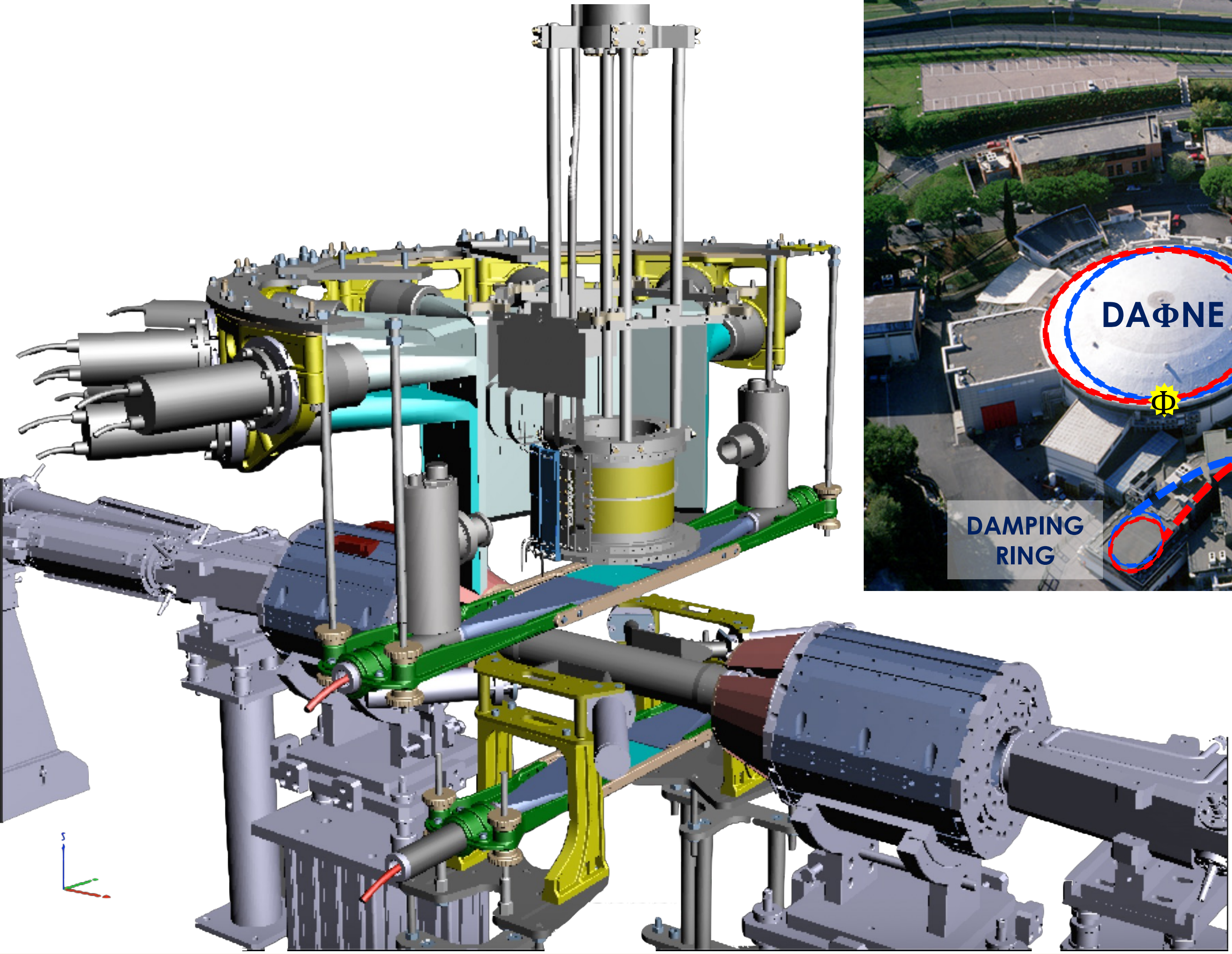
Analysis of the combined measurements of kaonic deuterium and kaonic hydrogen

completely solve Isospin-dependent K-N scattering length

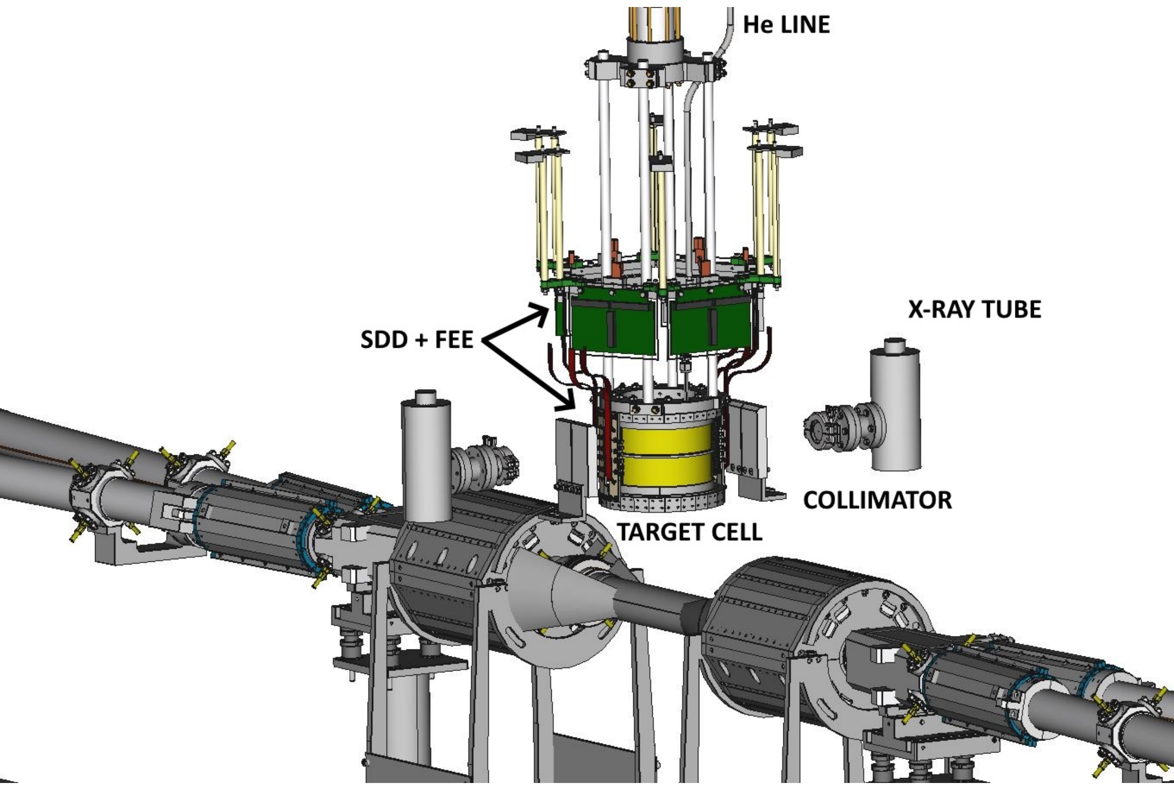


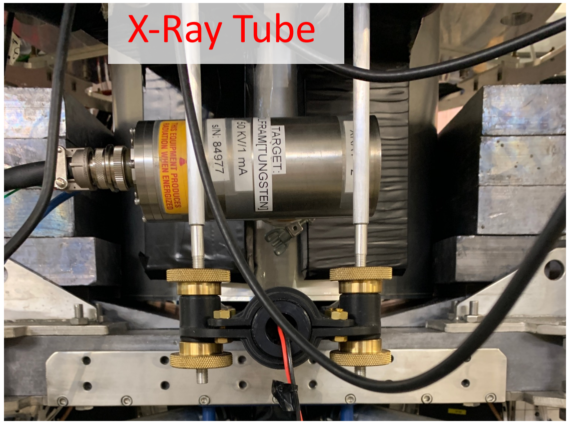
A. Ciepl$\acute{y}$, M. Mai, Ulf-G. Meißner, J. Smejkal, https://arxiv.org/abs/1603.02531v2

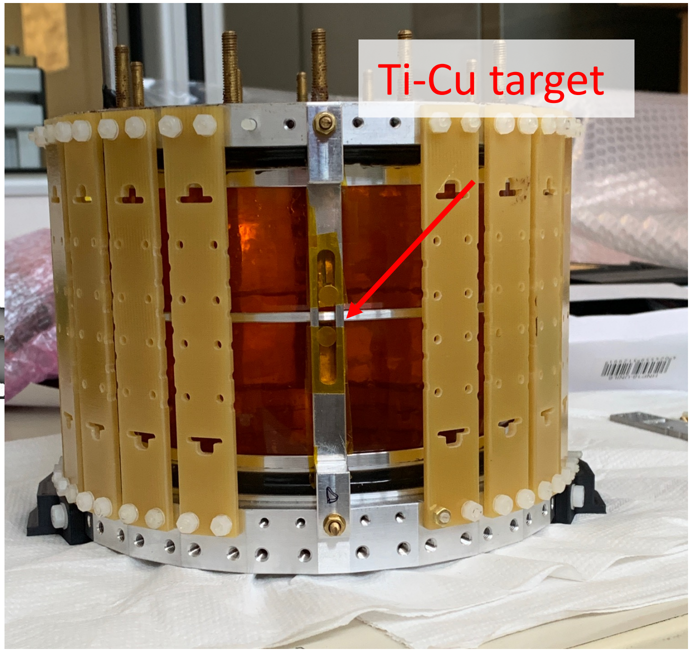
SIDDHARTA-2 setup



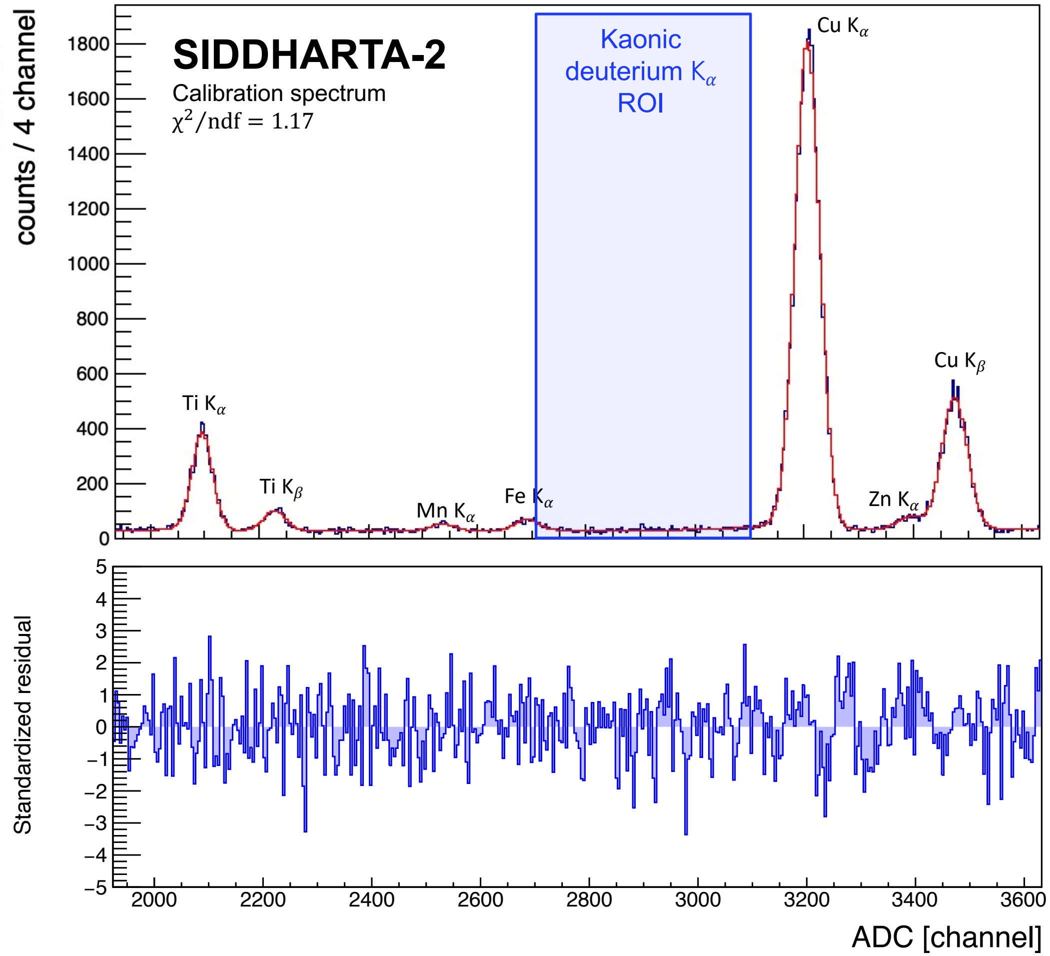
SDDs Calibration Procedure

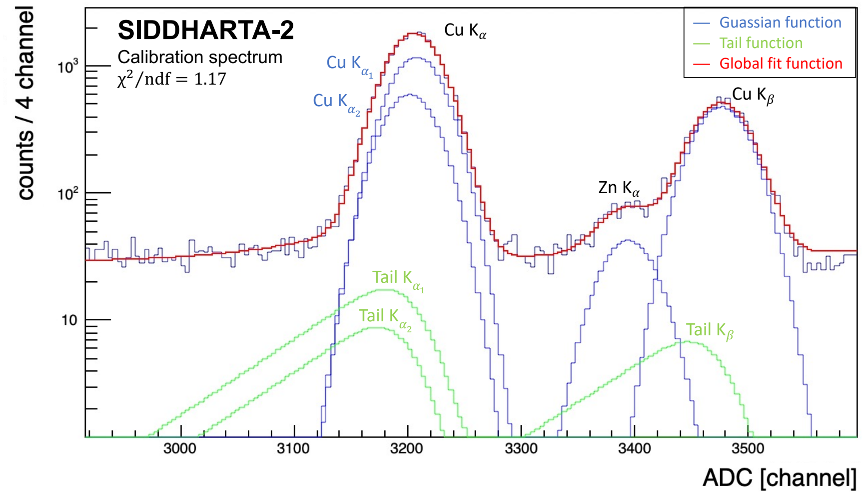






SDDs Calibration Procedure





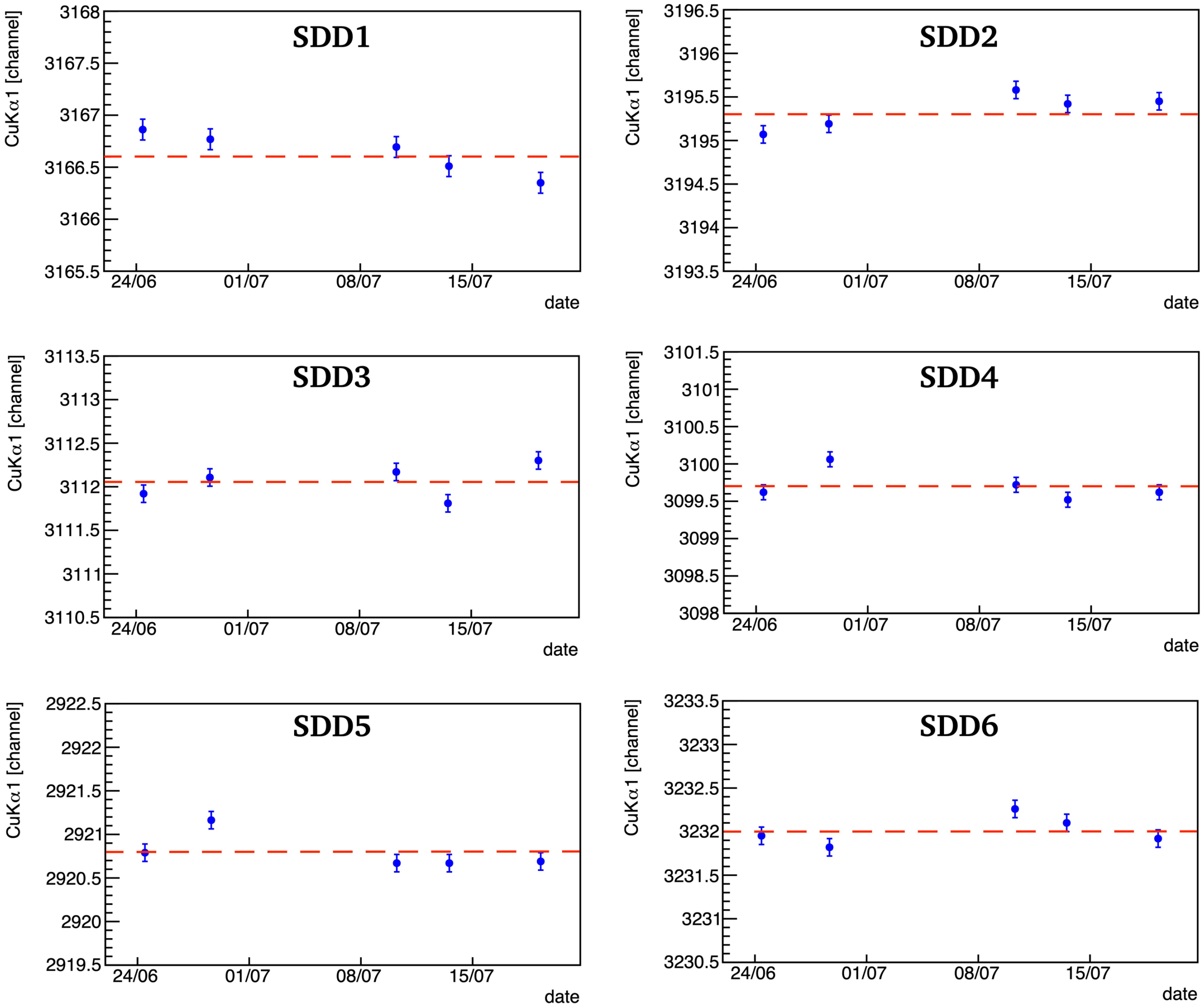
$$Gauss\ func.:\ H_G \cdot e^{\frac{-(x-x_0)^2}{2\sigma^2}}$$

$$\sigma = \sqrt{FF \cdot E \cdot \epsilon + \frac{noise^2}{2.35^2}}$$

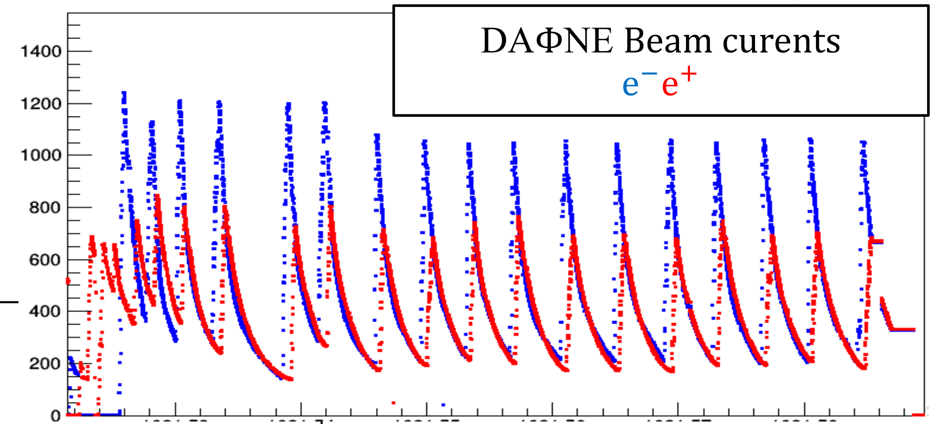
$$Tail\ func.:\ H_T \cdot e^{\frac{x-x_0}{\beta\sigma}+\frac{1}{2\beta^2}} \cdot erfc\left(\frac{x-x_0}{\sqrt{2}\sigma}+\frac{1}{\sqrt{2}\beta}\right)$$

Energy calibration precision $\Delta E/E < 10^{-3}$

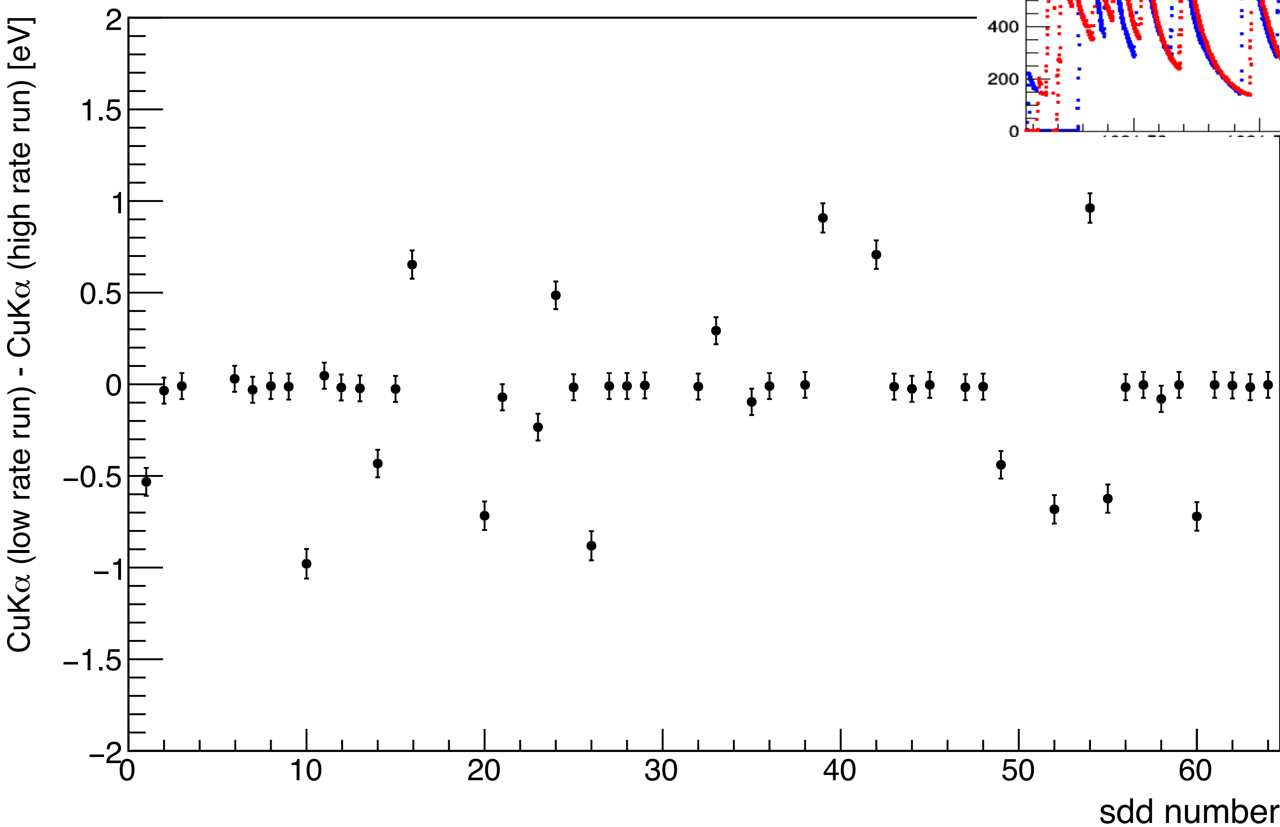
SDDs Calibration Procedure - Stability



SDDs Calibration Procedure - Stability



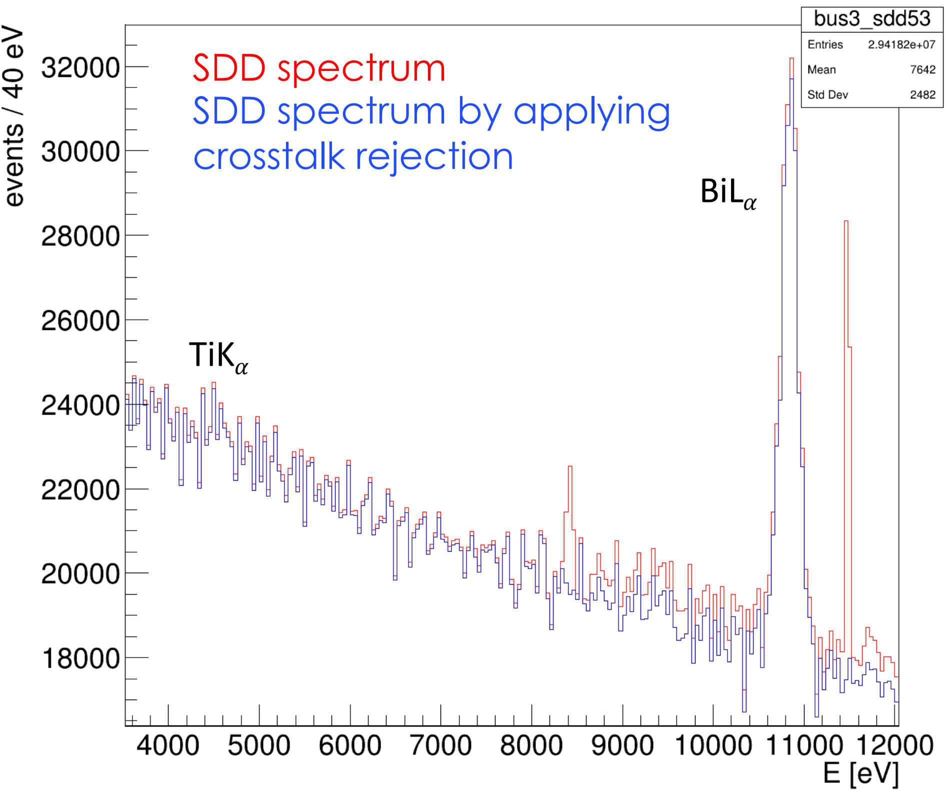
Difference between CuKα peak position at low (60 Hz) and high (600 Hz) counting rate

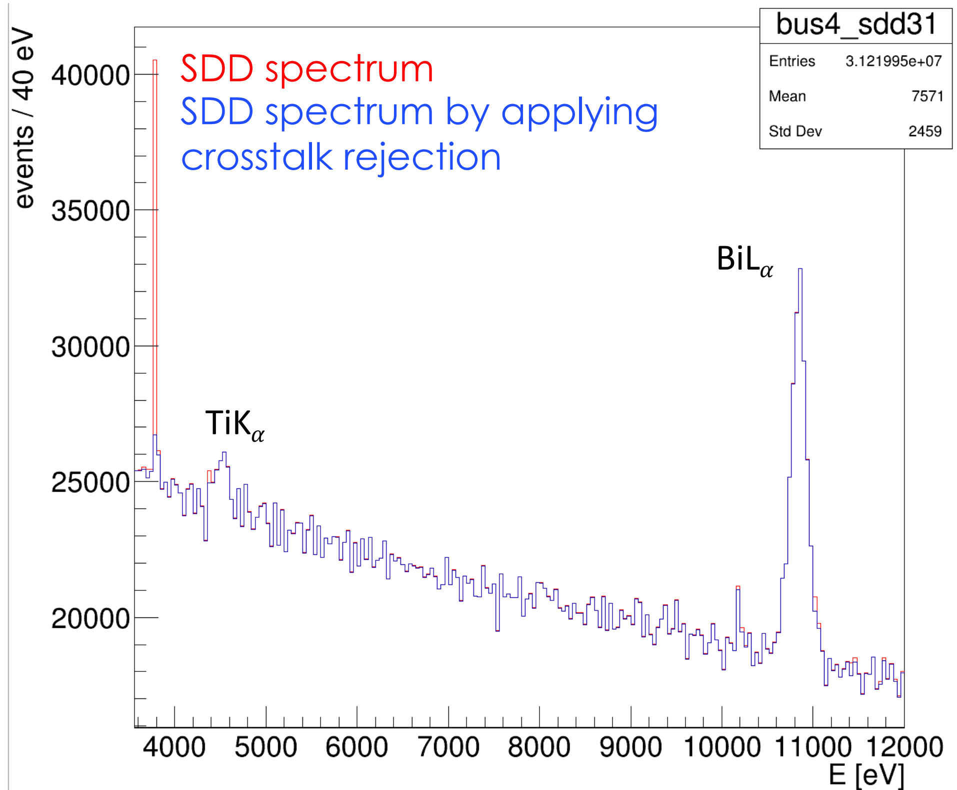


SDDs - crosstalk rejection

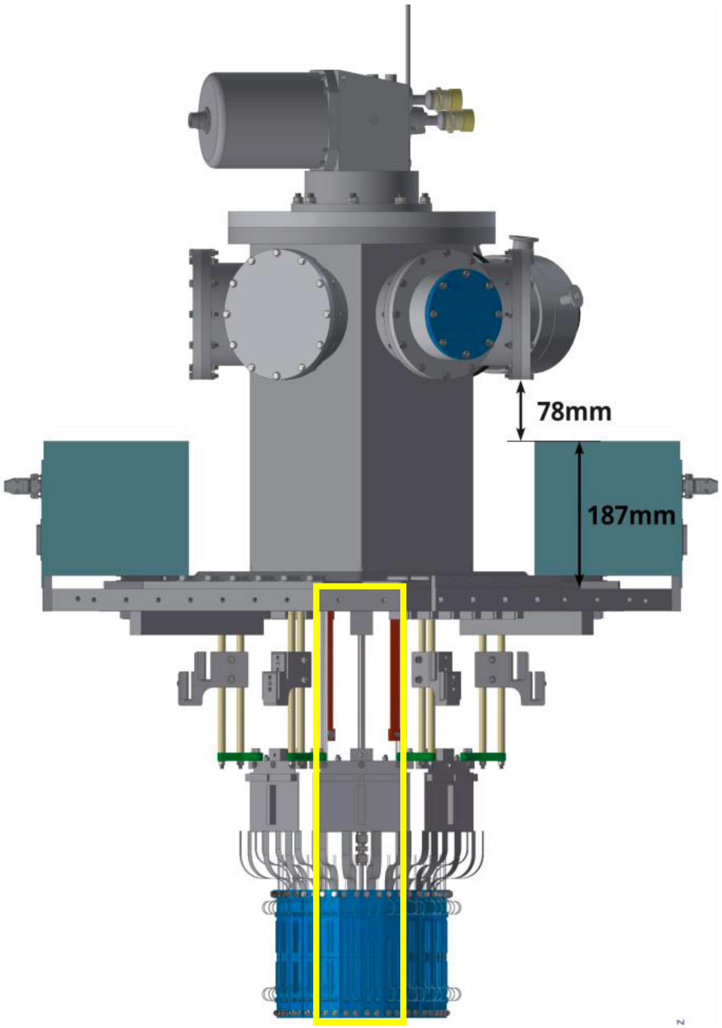
<u>CrossTalk rejection based on spatial and time correlation between hit and previous hit</u>

- **Time Correlation:** two events within 5 μs
- **Spatial Correlation:** different signals from nearby channels, at any level of the electronic chain (SFERA, cables, buffer board, ceramic)





SIDDHARTINO



SIDDHARTINO: phase 1 of SIDDHARTA-2
1/6 of SIDDHARTA-2

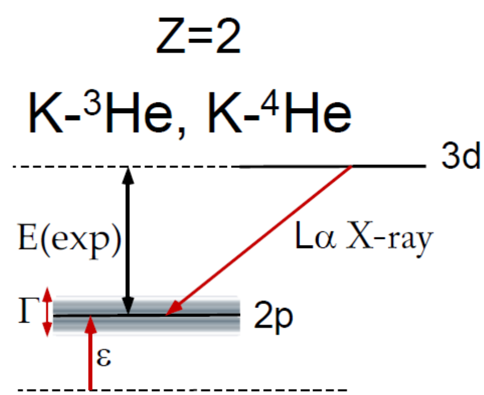
Optimization of the machine background during the DAΦNE beams commissioning phase in preparation for the K-d run through the **measurement of K-^{4}He 3d->2p transition**

- **Detector tuning for SIDDHARTA-2:**
  - **SDDs**
  - **Kaon Trigger**
  - **Degrader Optimization**
- **Concluded in 2021**

Kaonic Helium

$$\varepsilon = E_{3d \rightarrow 2p}(\text{exp}) - E_{3d \rightarrow 2p}(\text{e.m.})$$

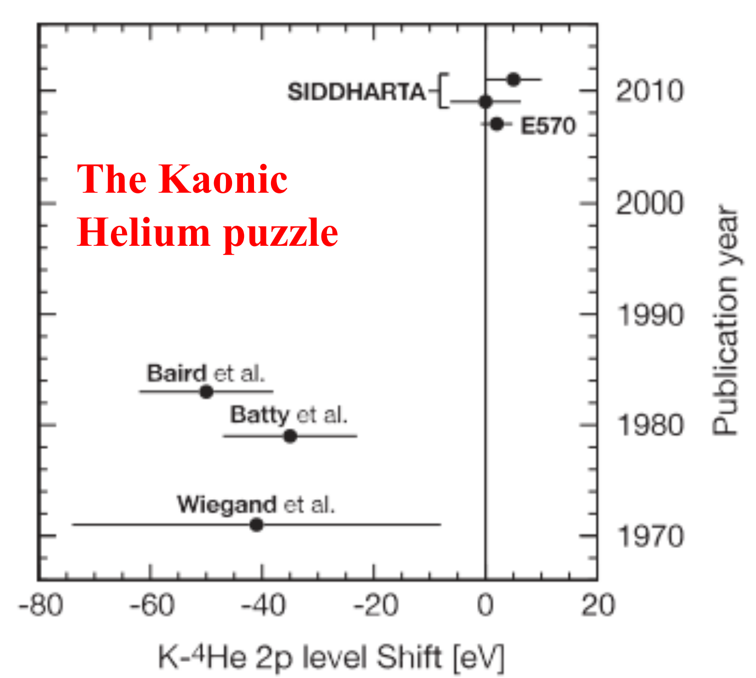
The most suitable transition to observe the strong interaction effects



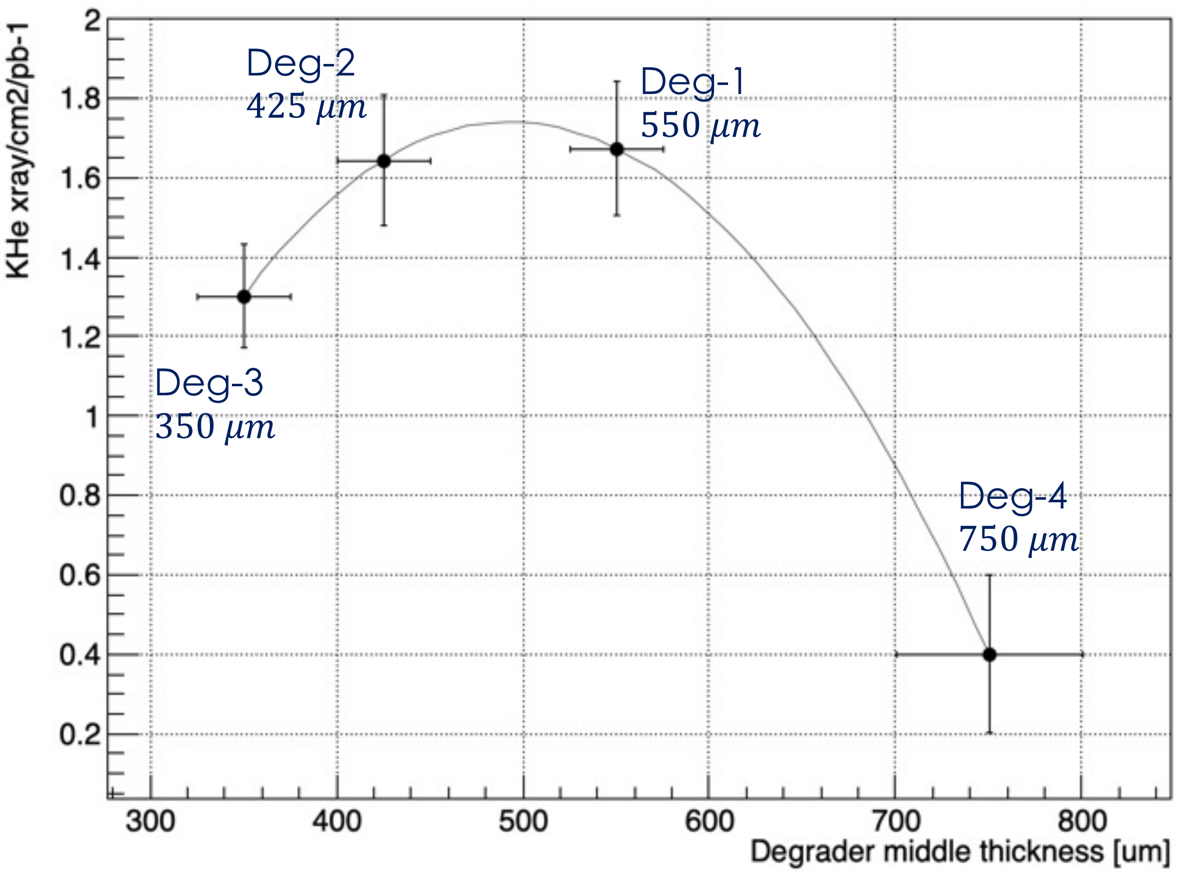
Most kaons are absorbed without radiative transition to *1s* state.

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

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



SIDDHARTINO
The kaonic ^{4}He measurement



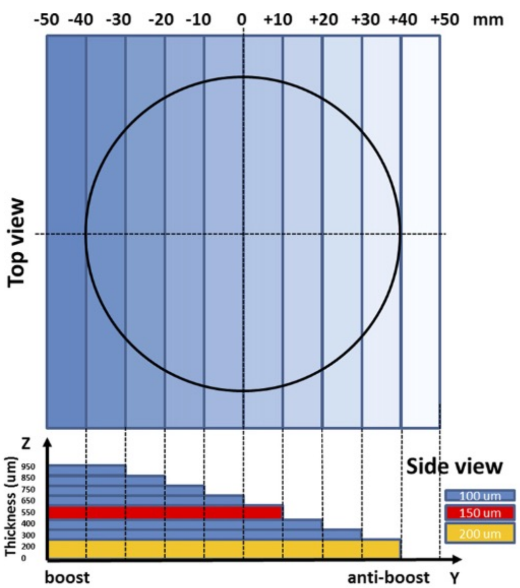
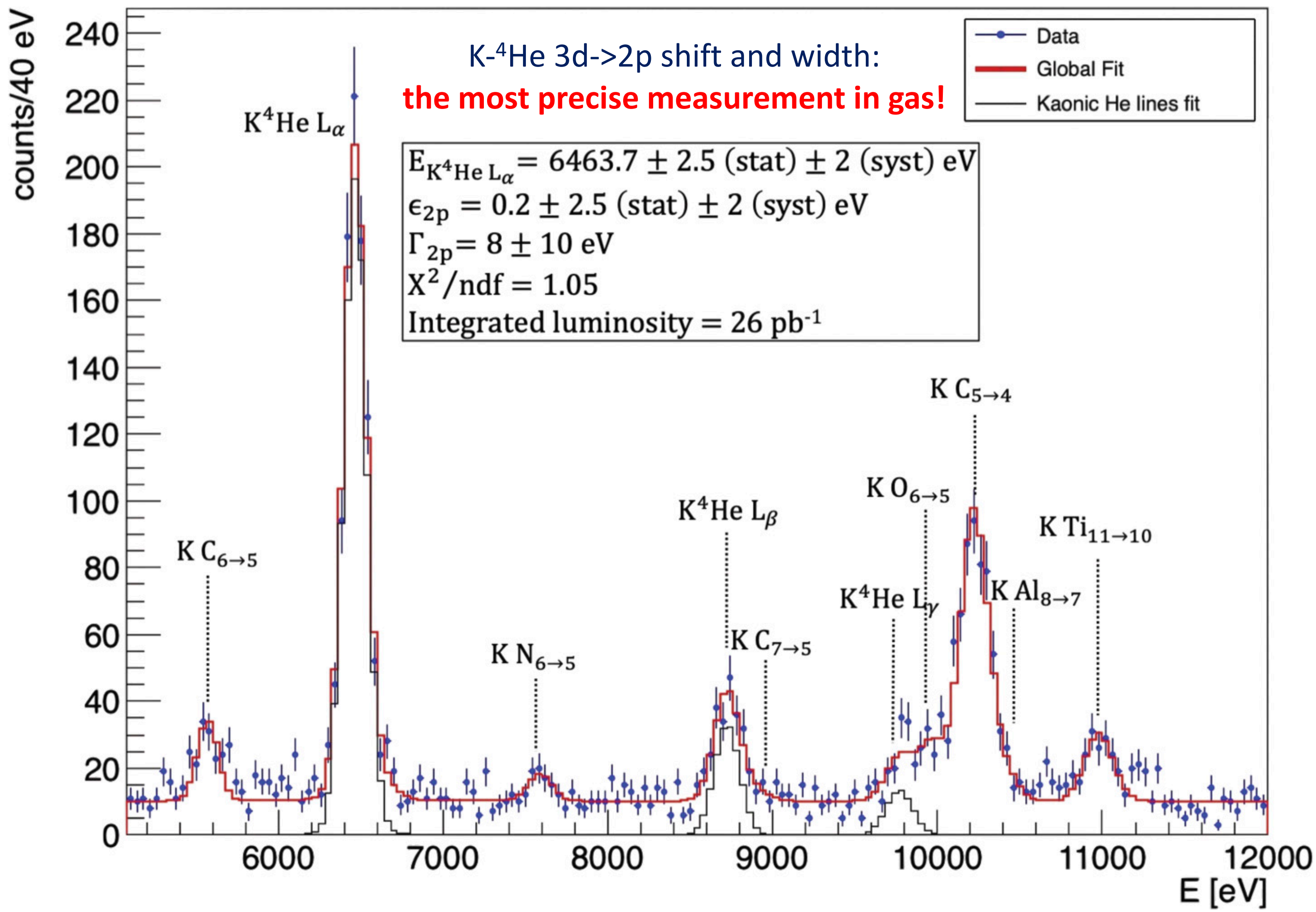


Figure 6. Nearest to optimal configuration of the Mylar degrader: the circle represents the size of the entrance window of the vacuum chamber; direction '*Y*' points to the outer side of the DAΦNE ring, corresponding to the anti-boost side for kaons. The degrader has eight steps to compensate for the boost effect, with thicknesses shown in the lower part of the figure.

OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **49** (2022) 055106 (14pp)
https://doi.org/10.1088/1361-6471/ac5dac

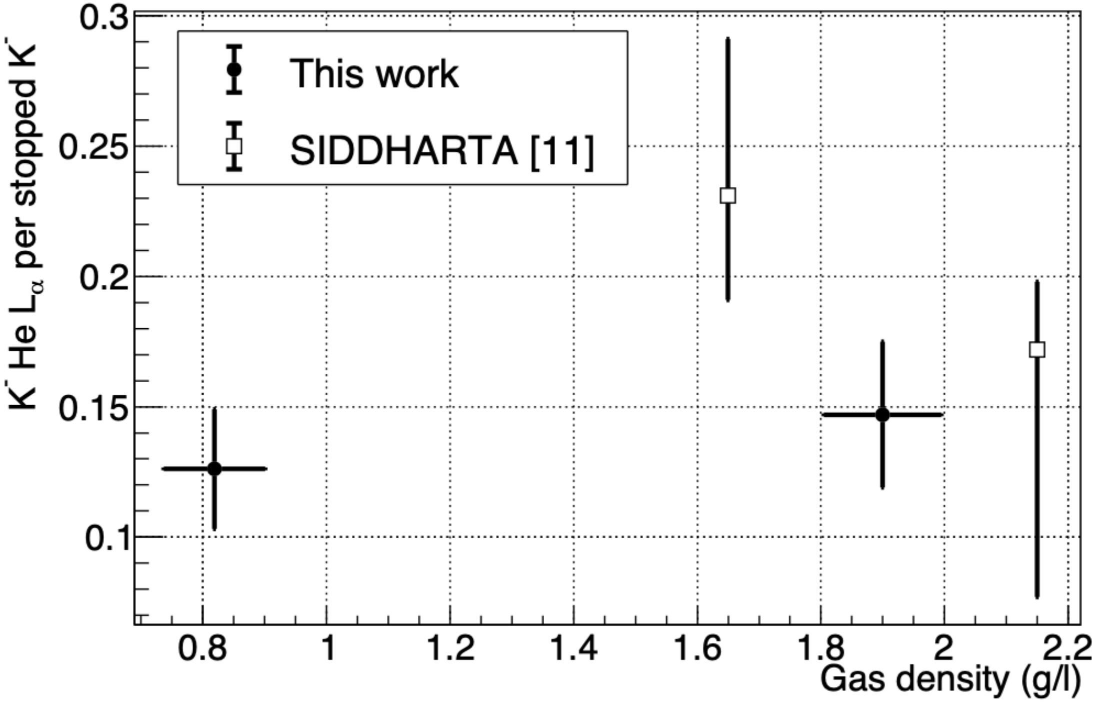
A new kaonic helium measurement in gas by SIDDHARTINO at the DAΦNE collider*

SIDDHARTINO
The kaonic ^{4}He measurement



D Sirghi *et al* 2022 *J. Phys. G: Nucl. Part. Phys.* **49** 055106

SIDDHARTINO
The kaonic ^{4}He measurement



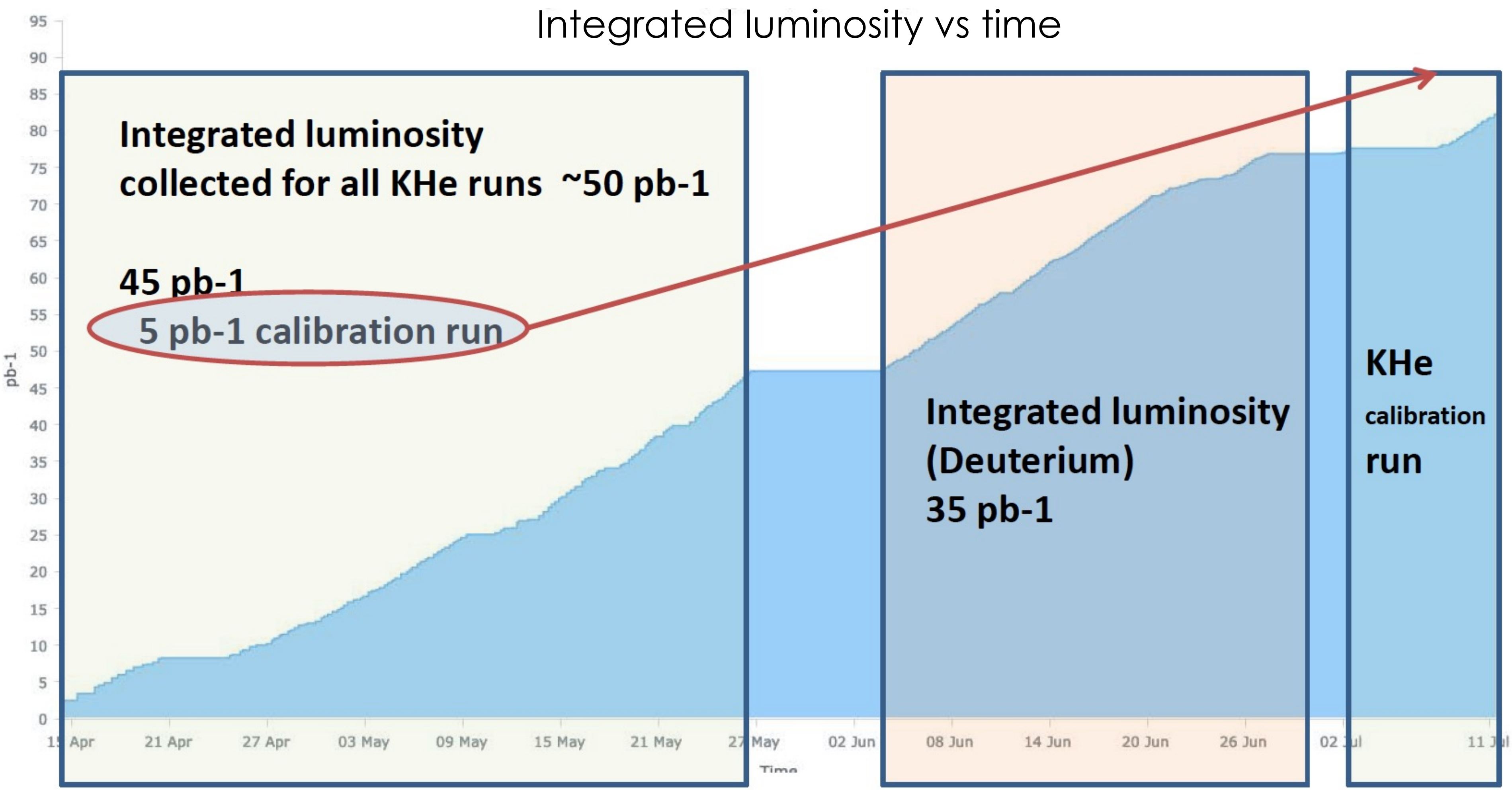
K-^{4}HE LOW DENSITY RUN: 0.75% LIQUID HELIUM DENSITY -> **YIELDS AT LOWEST MEASURED DENSITY**

Density	1.90 g/l	0.82 g/l
L_α yield	0.148 ± 0.027	0.126 ± 0.023
L_β/L_α	0.193 ± 0.042	0.133 ± 0.037
L_γ/L_α	0.035 ± 0.015	not detected

Submitted to Nuclear Physics A

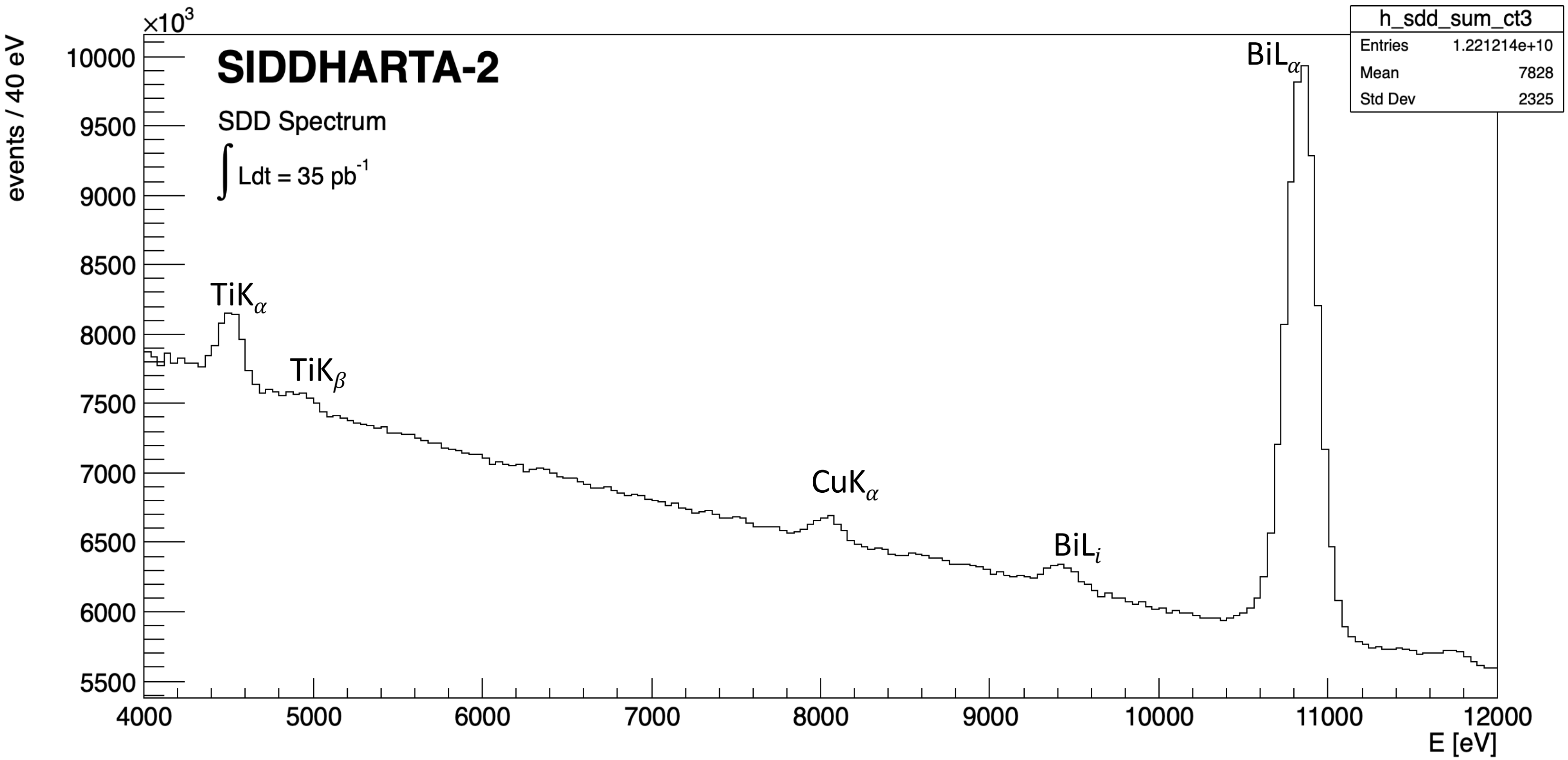
SIDDHARTA-2

SIDDHARTA 2 - First Run



SIDDHARTA 2 - First Run

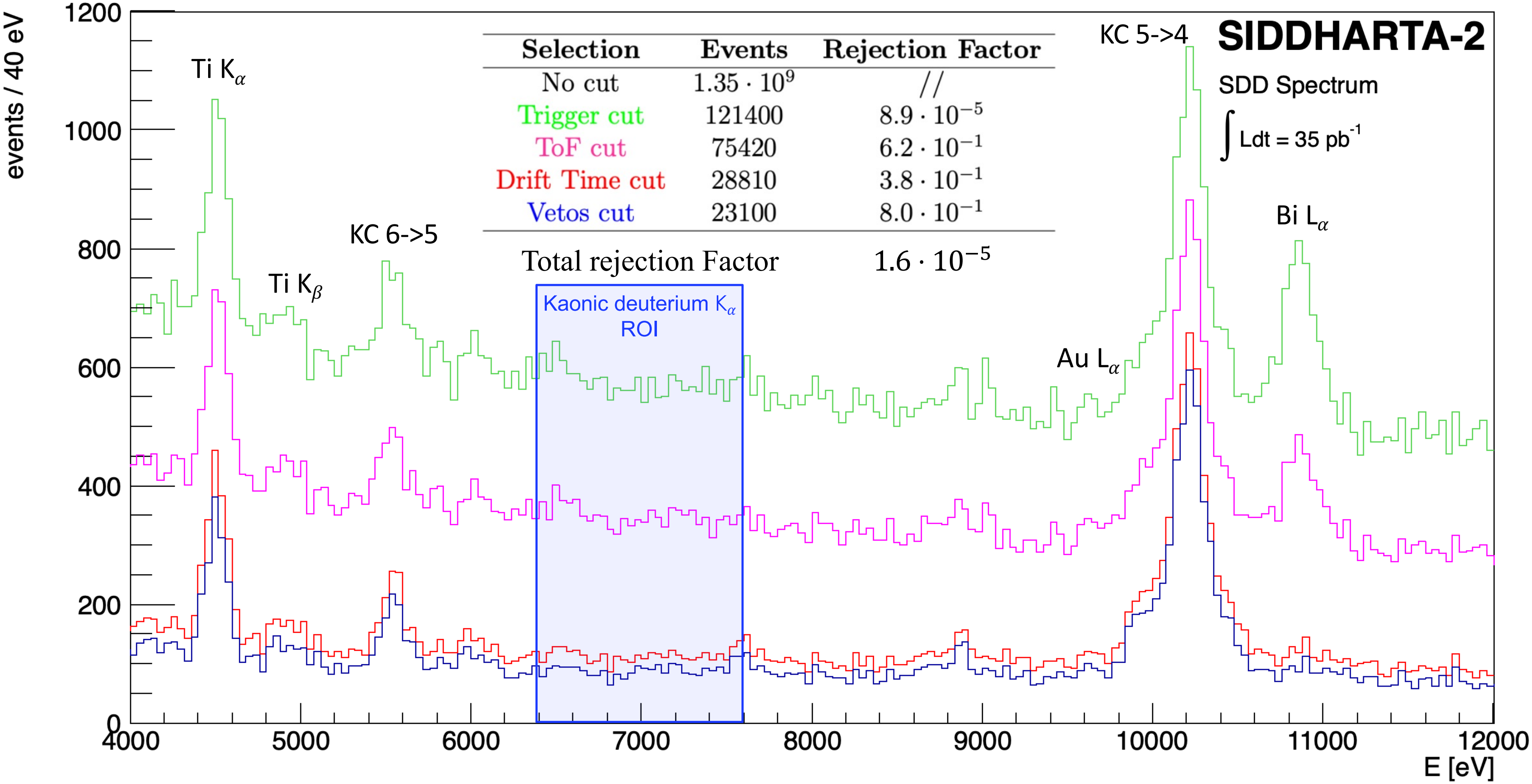
Kaonic deuterium test run



SIDDHARTA 2 - First Run

Work in progress

Kaonic deuterium test run

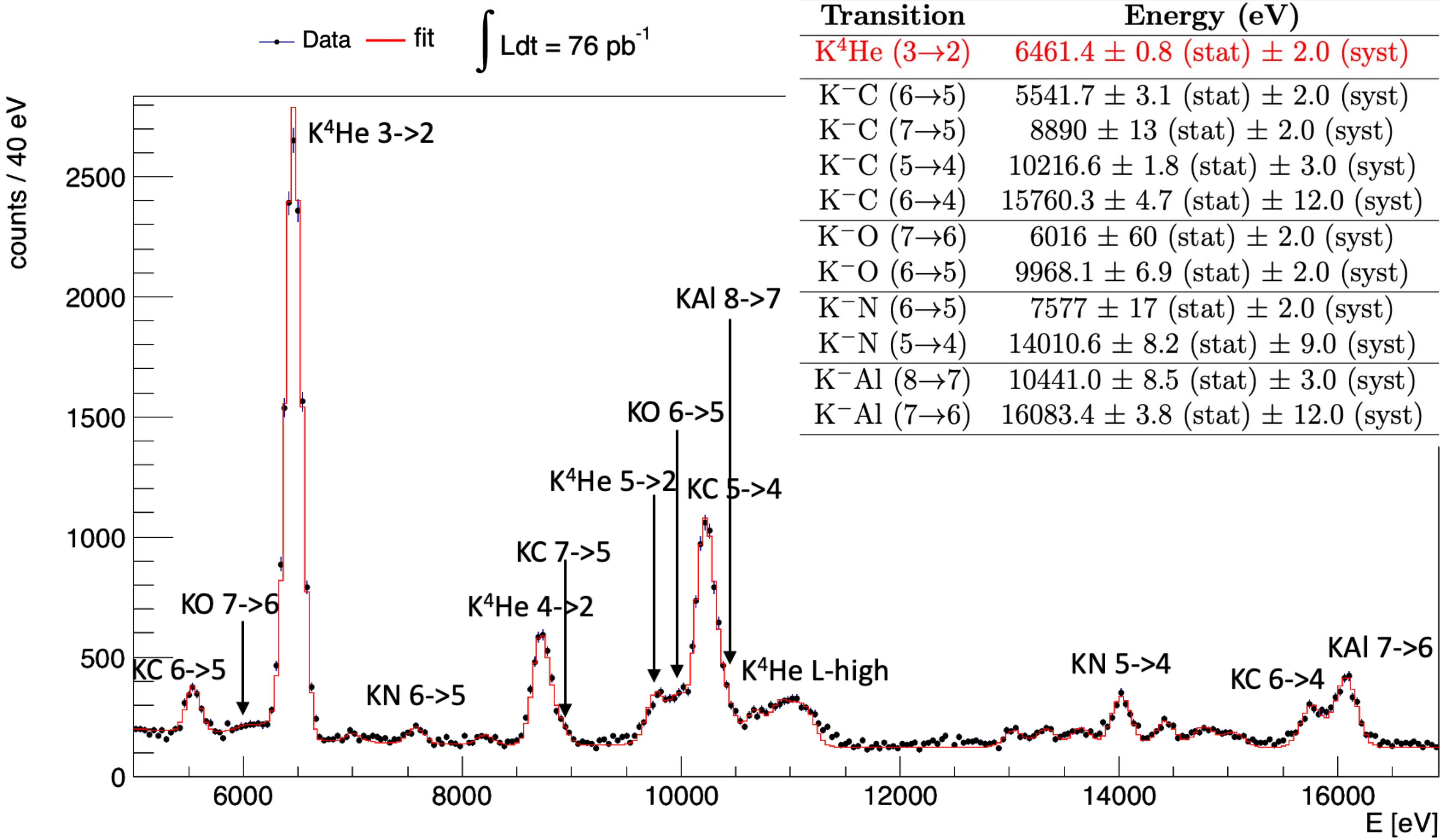


Selection	Events	Rejection Factor
No cut	$1.35 \cdot 10^9$	//
Trigger cut	121400	$8.9 \cdot 10^{-5}$
ToF cut	75420	$6.2 \cdot 10^{-1}$
Drift Time cut	28810	$3.8 \cdot 10^{-1}$
Vetos cut	23100	$8.0 \cdot 10^{-1}$
Total rejection Factor		$1.6 \cdot 10^{-5}$

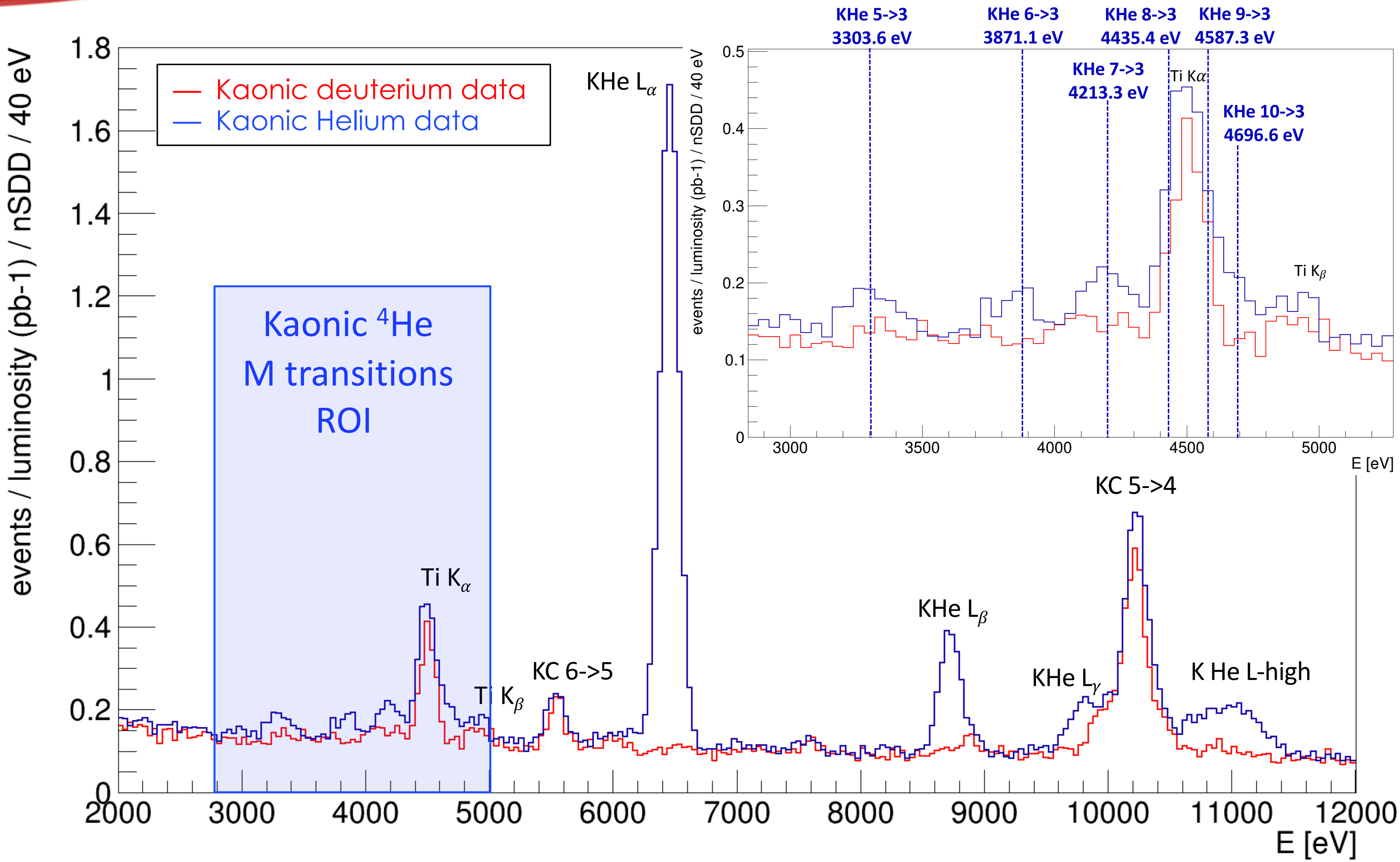
SIDDHARTA 2 – kaonic ^{4}He Run

Combined analysis of SIDDHARTA-2 and SIDDHARTINO data

Transition	Energy (eV)
K^4He (3→2)	6461.4 ± 0.8 (stat) ± 2.0 (syst)
K^-C (6→5)	5541.7 ± 3.1 (stat) ± 2.0 (syst)
K^-C (7→5)	8890 ± 13 (stat) ± 2.0 (syst)
K^-C (5→4)	10216.6 ± 1.8 (stat) ± 3.0 (syst)
K^-C (6→4)	15760.3 ± 4.7 (stat) ± 12.0 (syst)
K^-O (7→6)	6016 ± 60 (stat) ± 2.0 (syst)
K^-O (6→5)	9968.1 ± 6.9 (stat) ± 2.0 (syst)
K^-N (6→5)	7577 ± 17 (stat) ± 2.0 (syst)
K^-N (5→4)	14010.6 ± 8.2 (stat) ± 9.0 (syst)
K^-Al (8→7)	10441.0 ± 8.5 (stat) ± 3.0 (syst)
K^-Al (7→6)	16083.4 ± 3.8 (stat) ± 12.0 (syst)

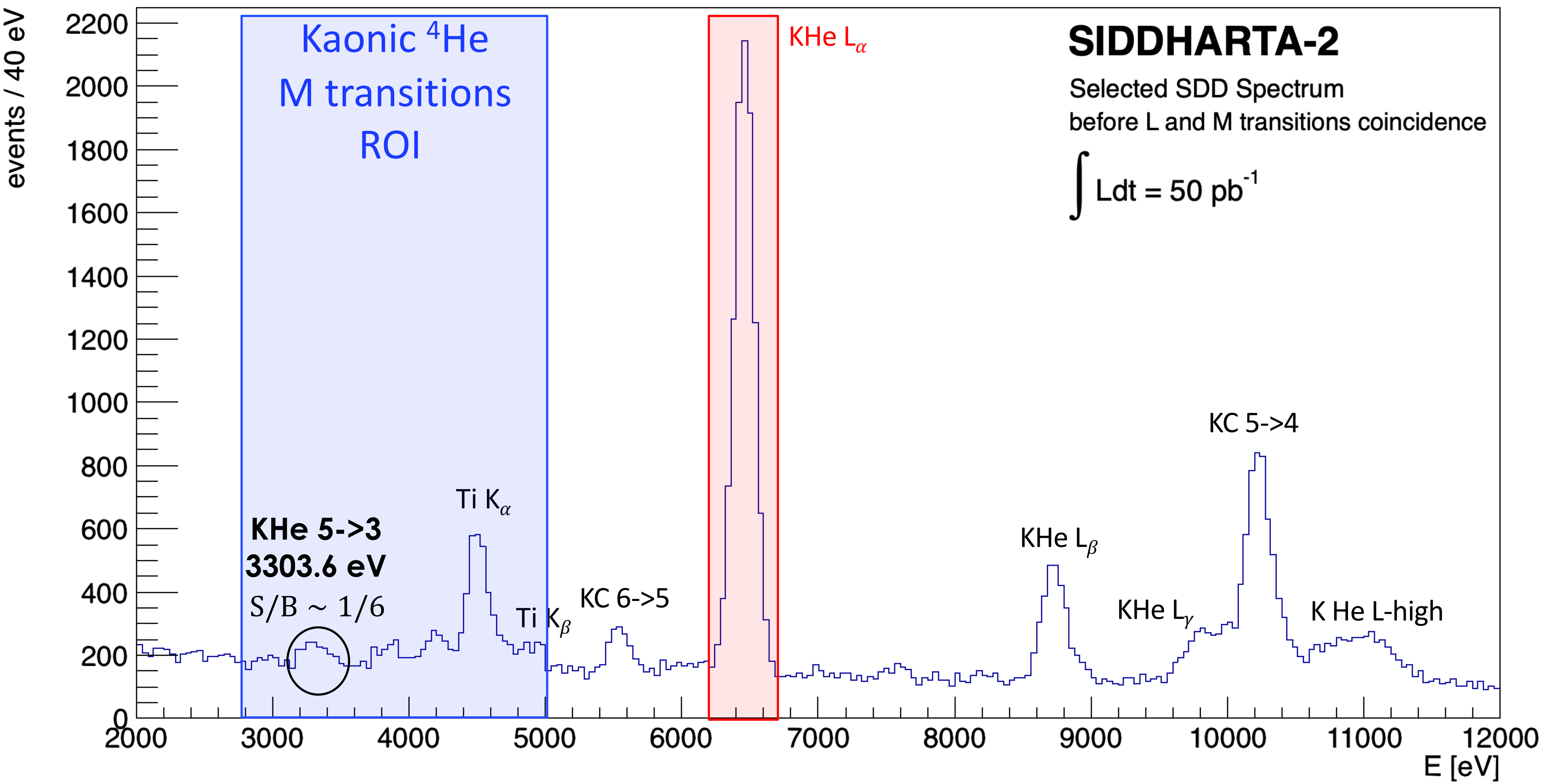


SIDDHARTA 2 – kaonic ^{4}He Run



SIDDHARTA 2 – kaonic ^{4}He Run

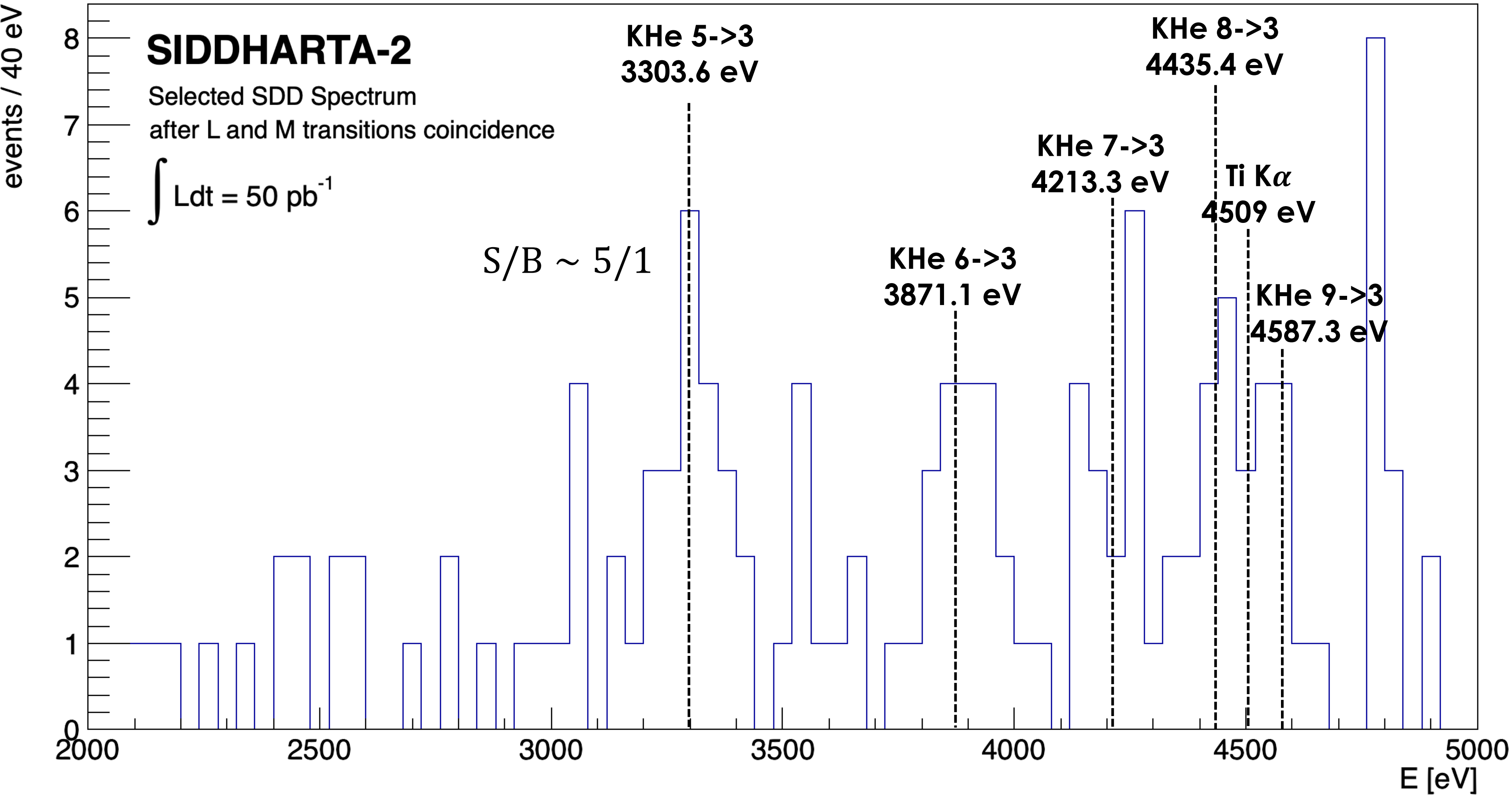
Coincidence between L (n=2) and M (n=3) transitions



SIDDHARTA 2 – kaonic ^{4}He Run

Coincidence between L (n=2) and M (n=3) transitions

Feasibility test for future kaonic atom measurements (kaonic ^{4}He fundamental level)



Future Perspective

SIDDHARTA-2

SIDDHARTA-2 strategy after the test run in 2022:

- **Optimize the SIDDHARTA-2 setup**: target entrance window, pressure measurement, shielding (Sept. 2022 – February 2023)
- **Kaonic deuterium run with SIDDHARTA-2** optimized setup for about 300 pb^{-1} integrated luminosity (from February to July 2023)
- **Second Kaonic deuterium run** with optimized shielding, readout, veto, add 1mm SDD bus and other necessary optimizations; (for remaining integrated luminosity, 400-500 pb-1) (end 2023 - 2024)
- **Calibration runs**: KHe; Neon; solid targets

K-d measurement

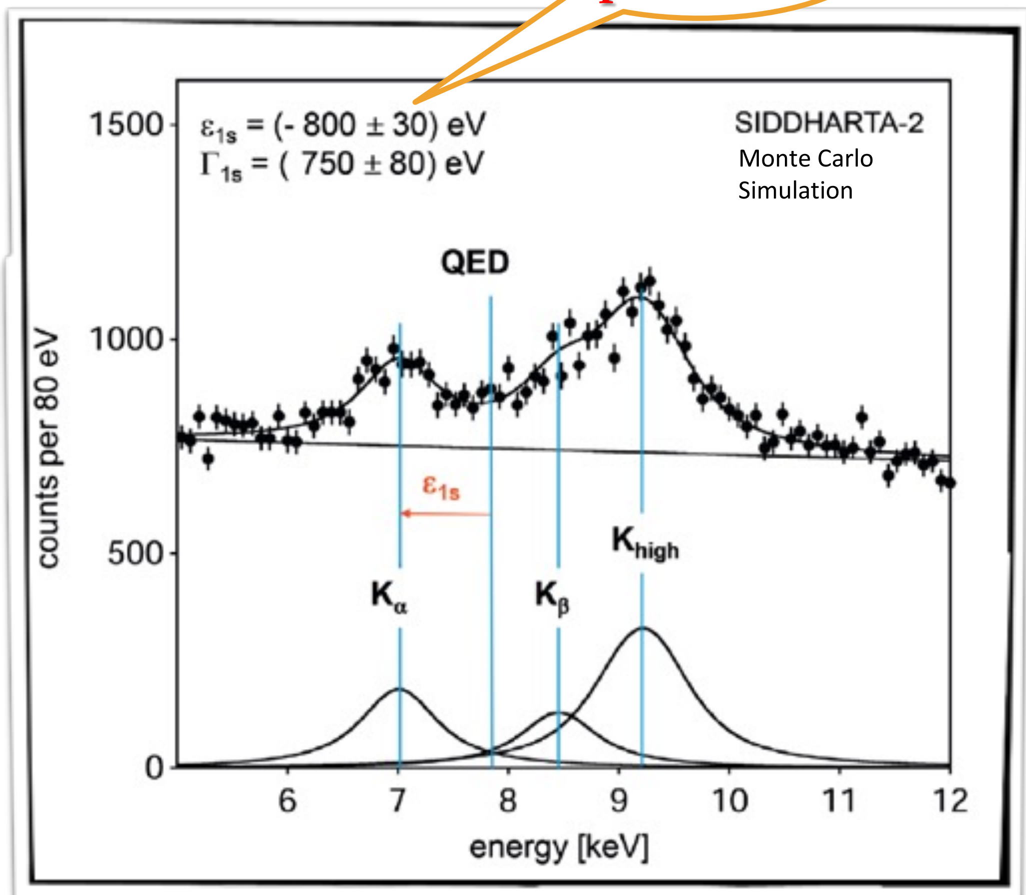
Kaonic deuterium run in (all)

2023/24

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

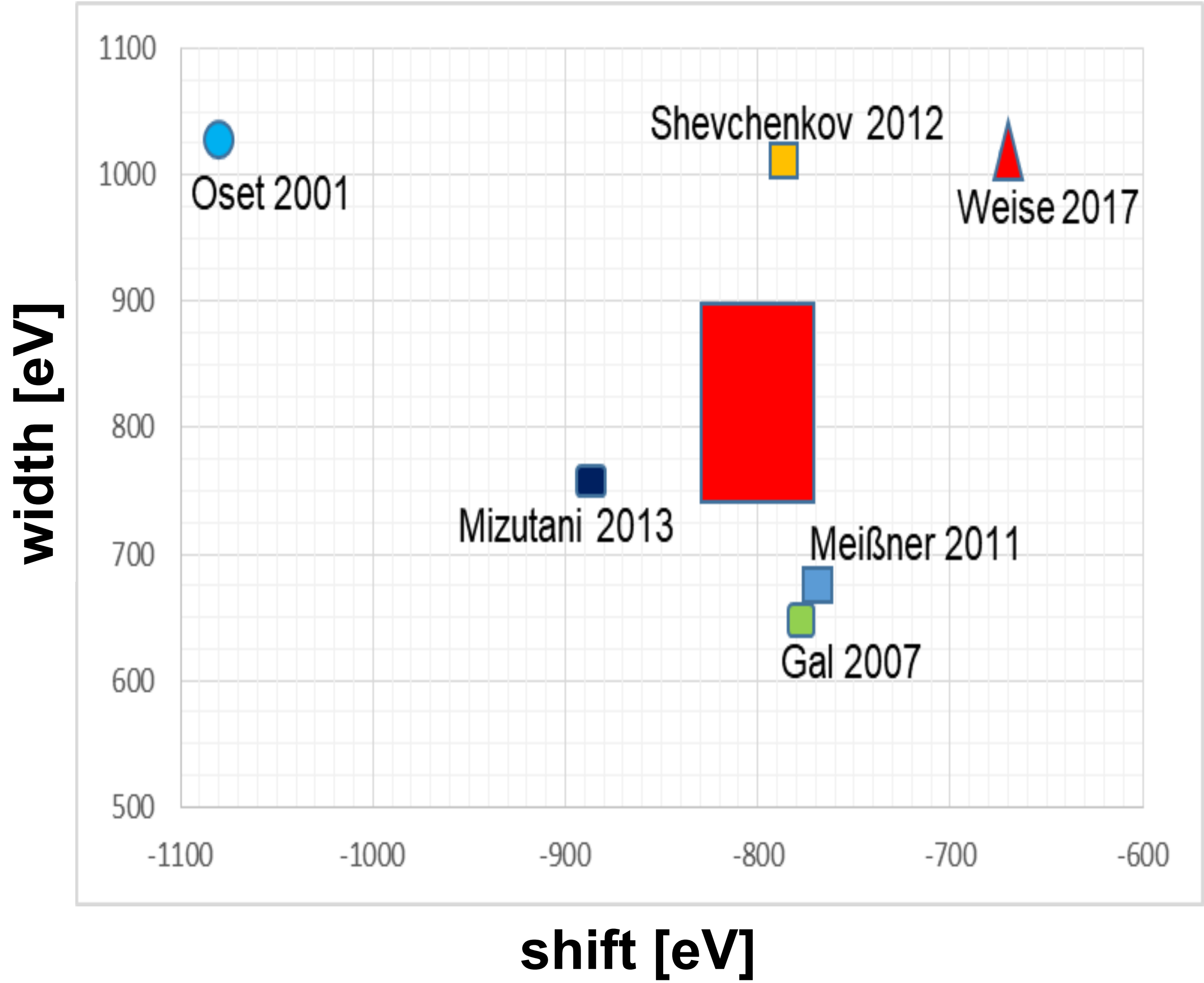
to perform the first measurement of the strong interaction induced energy shift and width of the kaonic deuterium ground state (similar precision as K-p) !

achievable precision



Significant impact in the theory of strong interaction with strangeness

K-d measurement



Outcomes

- **Kaonic Atoms bring great insights in kaon-nucleon interaction**
  - Tool to directly probe low energy QCD
  - Rich of implications from nuclear to astrophysics and cosmology

- **Measurement of Kaonic-Deuterium key to fully disentangle isospin dependence on KN scattering lengths**

- **Phase1 SIDDHARTINO concluded**
  - ✓ SDDs and Kaon Trigger tuning
  - ✓ Optimization of the machine background
  - ✓ **Performed the most precise K-^{4}He $3d \rightarrow 2p$ measurement in gas**
    - Energy shift and width
    - Yield at two different density 1.9 g/l and 0.82 g/l

- **SIDDHARTA-2 at DAFNE**
  - ✓ **Several solid target high-n transition energies measured for the first time**
  - ✓ **Kaonic ^{4}He $3d \rightarrow 2p$ sub eV (stat) precision measurement**
  - ✓ **First measurement of kaonic ^{4}He M (n=3) transitions**
  - ✓ **First kaonic deuterium test run**

SIDDHARTA-2
ready for
Kaonic Deuterium Run


Thank You