Kaonic Atoms with SIDDHARTA-2 at the DAFNE Collider

Francesco Sgaramella
on behalf of the SIDDHARTA-2 Collaboration

STRONG-2020

INFN Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

Kaonic Atoms to Investigate Global Symmetry Breaking Symmetry 12 (2020) 4, 547

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

The modern era of light kaonic atom experiments Rev.Mod.Phys. 91 (2019) 2, 025006

Fundamental physics New Physics

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

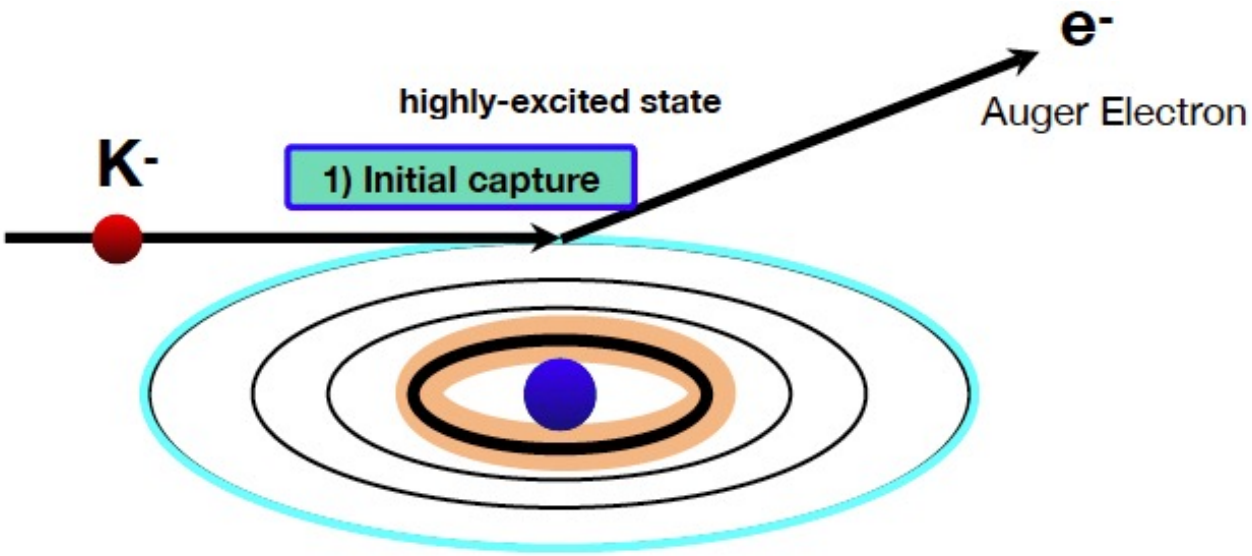
On self-gravitating strange dark matter halos around galaxies Phys.Rev.D 102 (2020) 8, 083015

Dark Matter studies

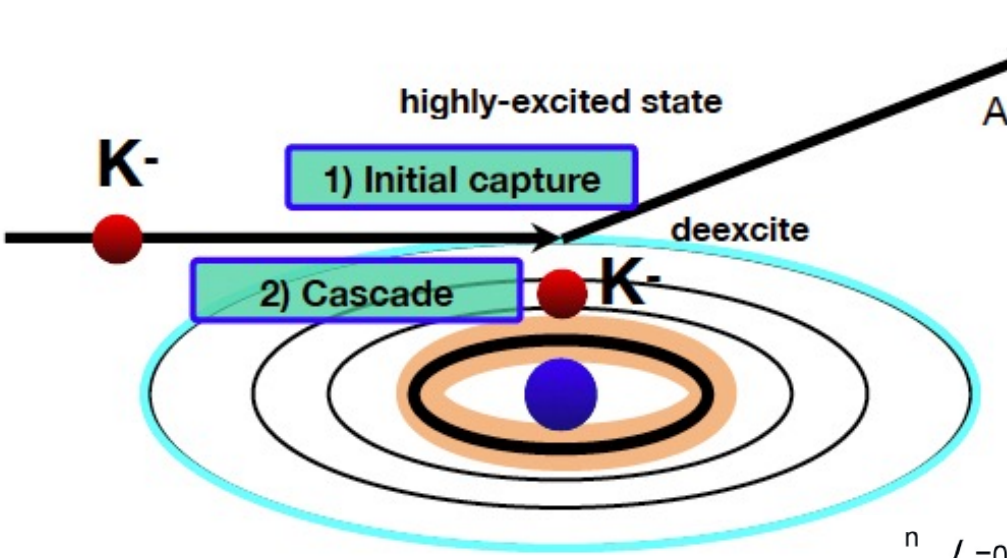
The equation of state of dense matter: Stiff, soft, or both? Astron.Nachr. 340 (2019) 1-3, 189

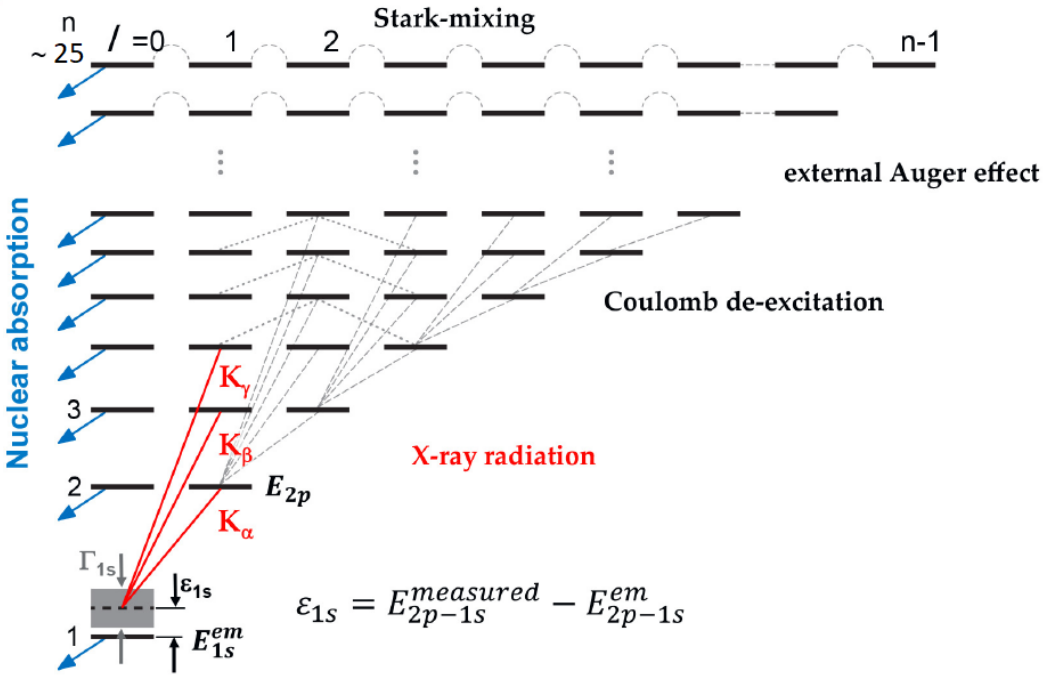
Astrophysics
EOS Neutron Stars

Kaonic atom Formation

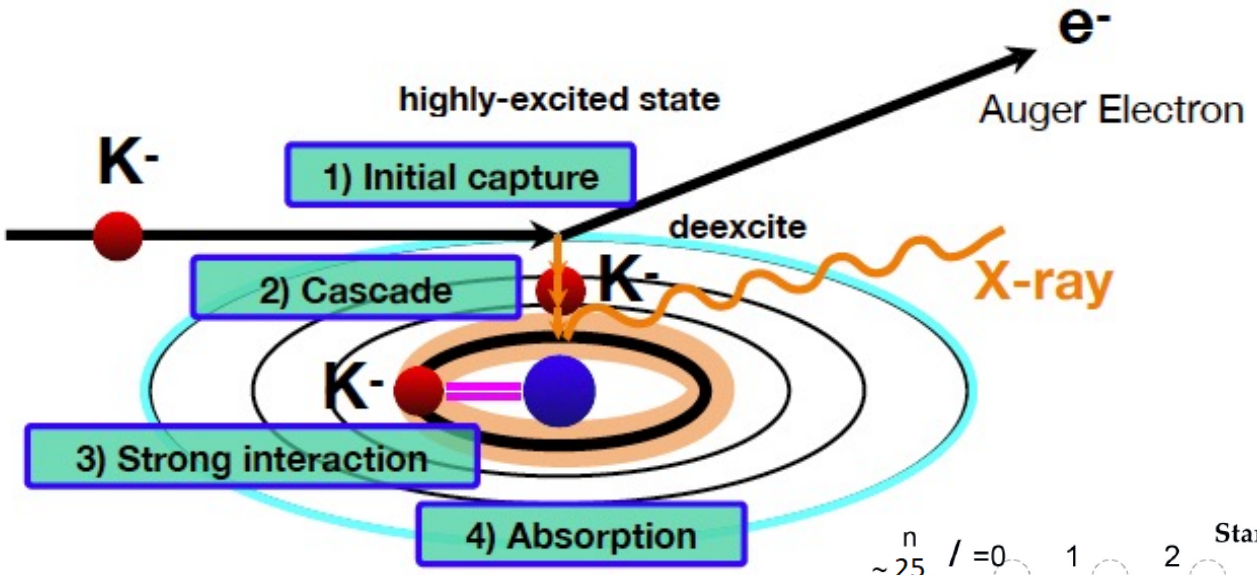


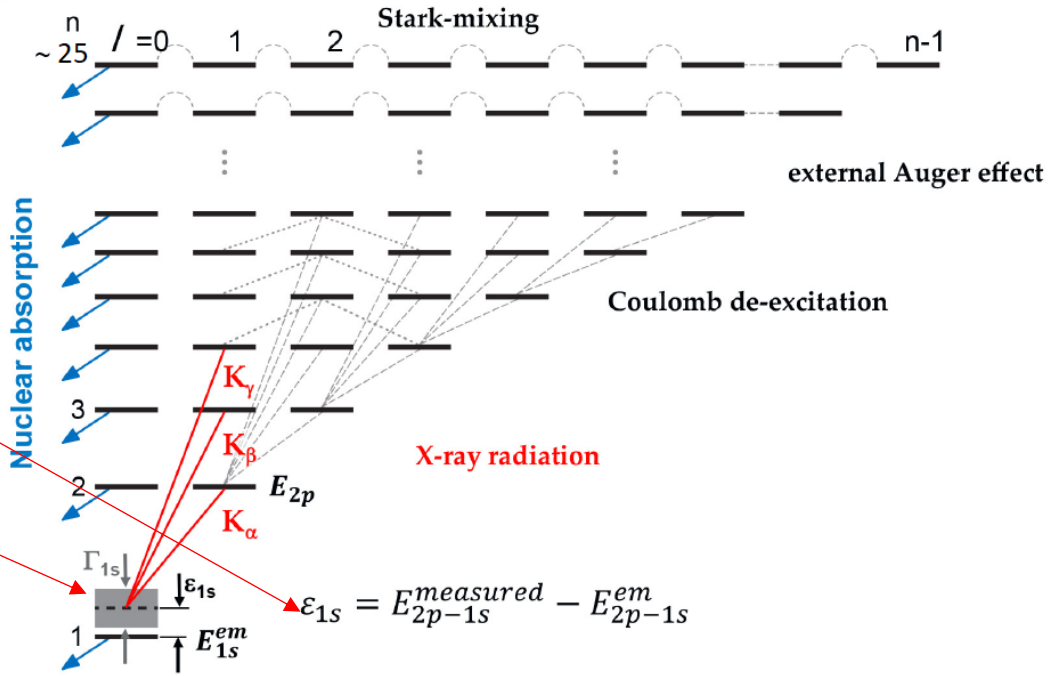
Kaonic atom Formation





Kaonic atom Formation





Width Γ and shift ε obtained by measuring the X-rays emitted

SIDDHARTA-2

SIlicon **D**rift **D**etector for **H**adronic **A**tom **R**esearch by **T**iming **A**pplications

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
ELPH, Tohoku University
CERN, Switzerland

SIDDHARTA-2 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.

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Analysis of the combined measurements of kaonic deuterium and kaonic hydrogen

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

(μ_c reduced mass of the K^-p system, α fine-structure constant)

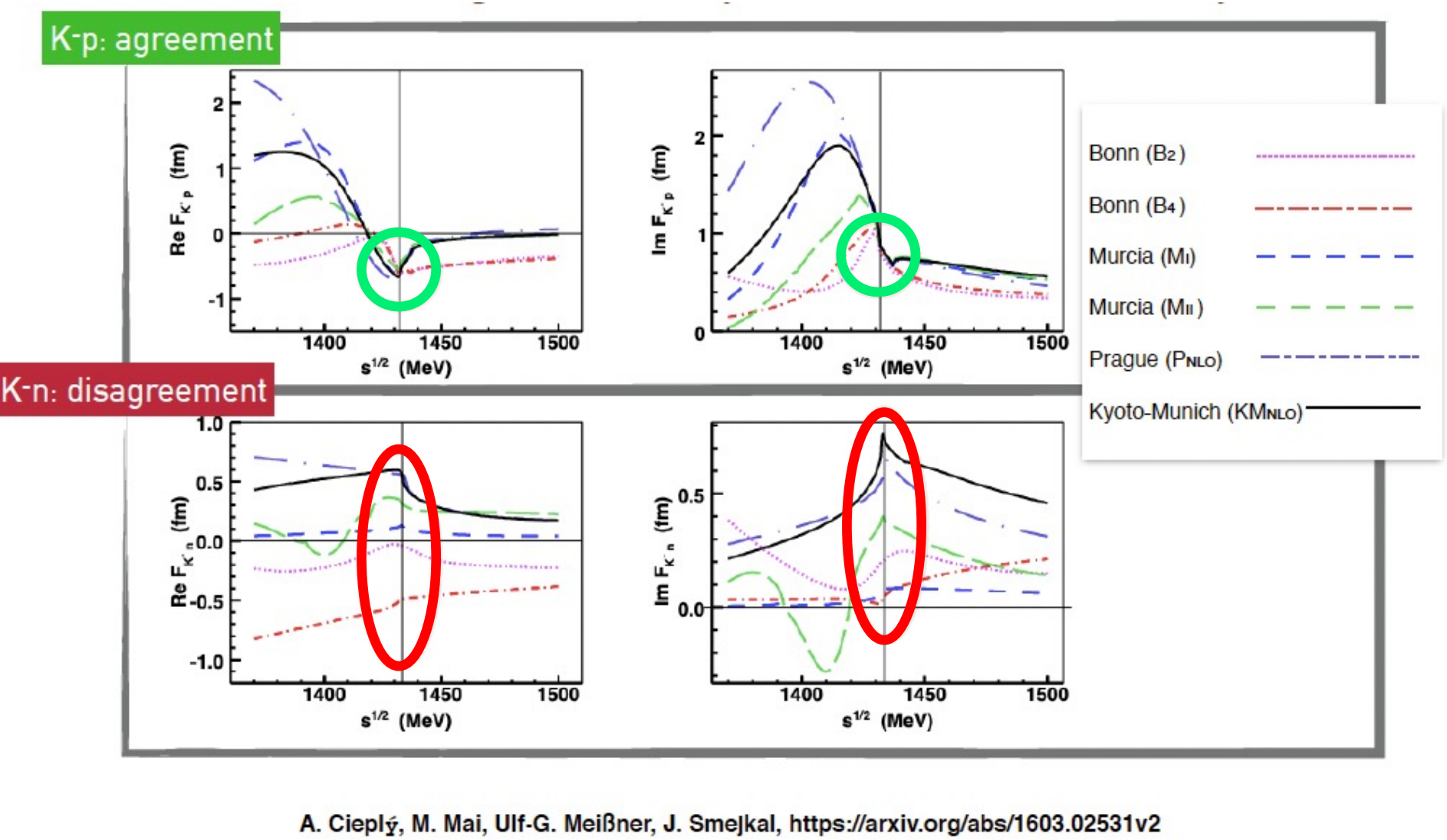
U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

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

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

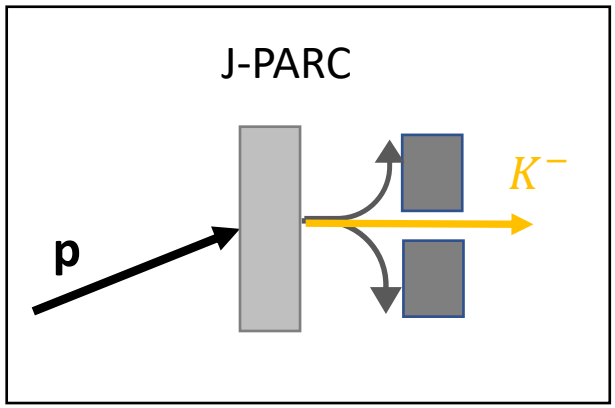
completely solve Isospin-dependent K-N scattering length

Kaonic atoms – scattering amplitudes



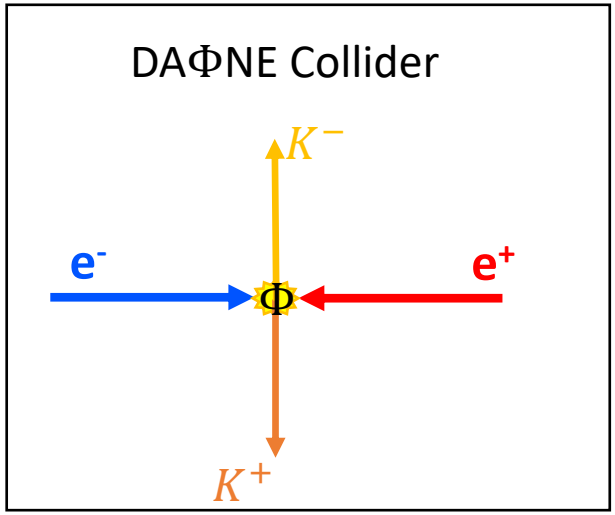
A. Cieplý, M. Mai, Ulf-G. Meißner, J. Smejkal, https://arxiv.org/abs/1603.02531v2

Kaon Beam Source



High intensity

High background

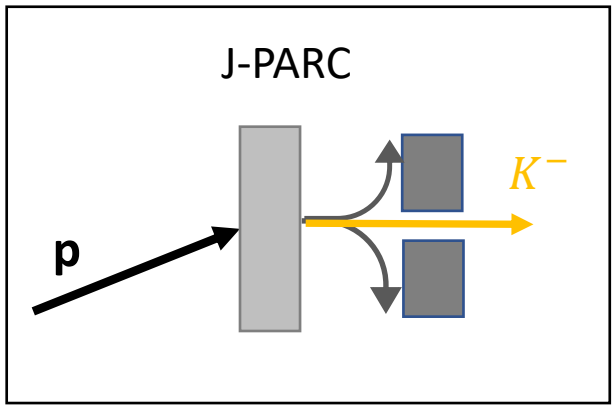


Monochromatic

Low energy kaons

Solid angle

Experimental Principle



High intensity

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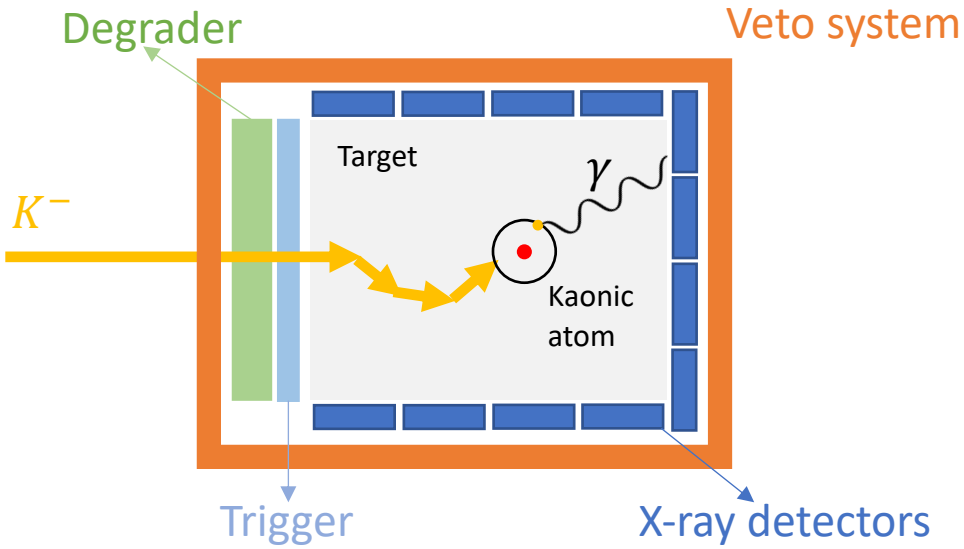
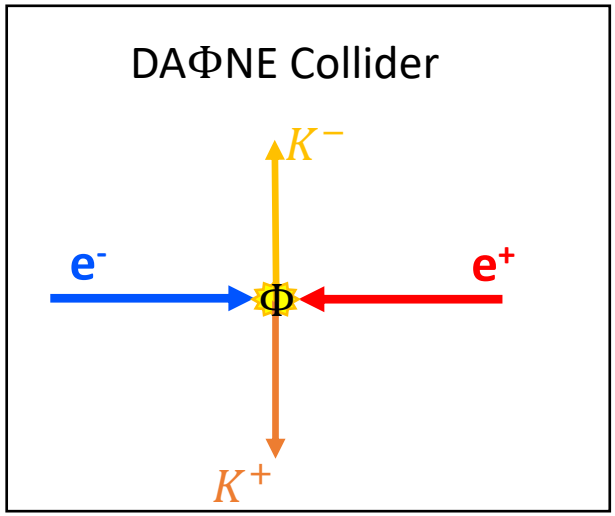


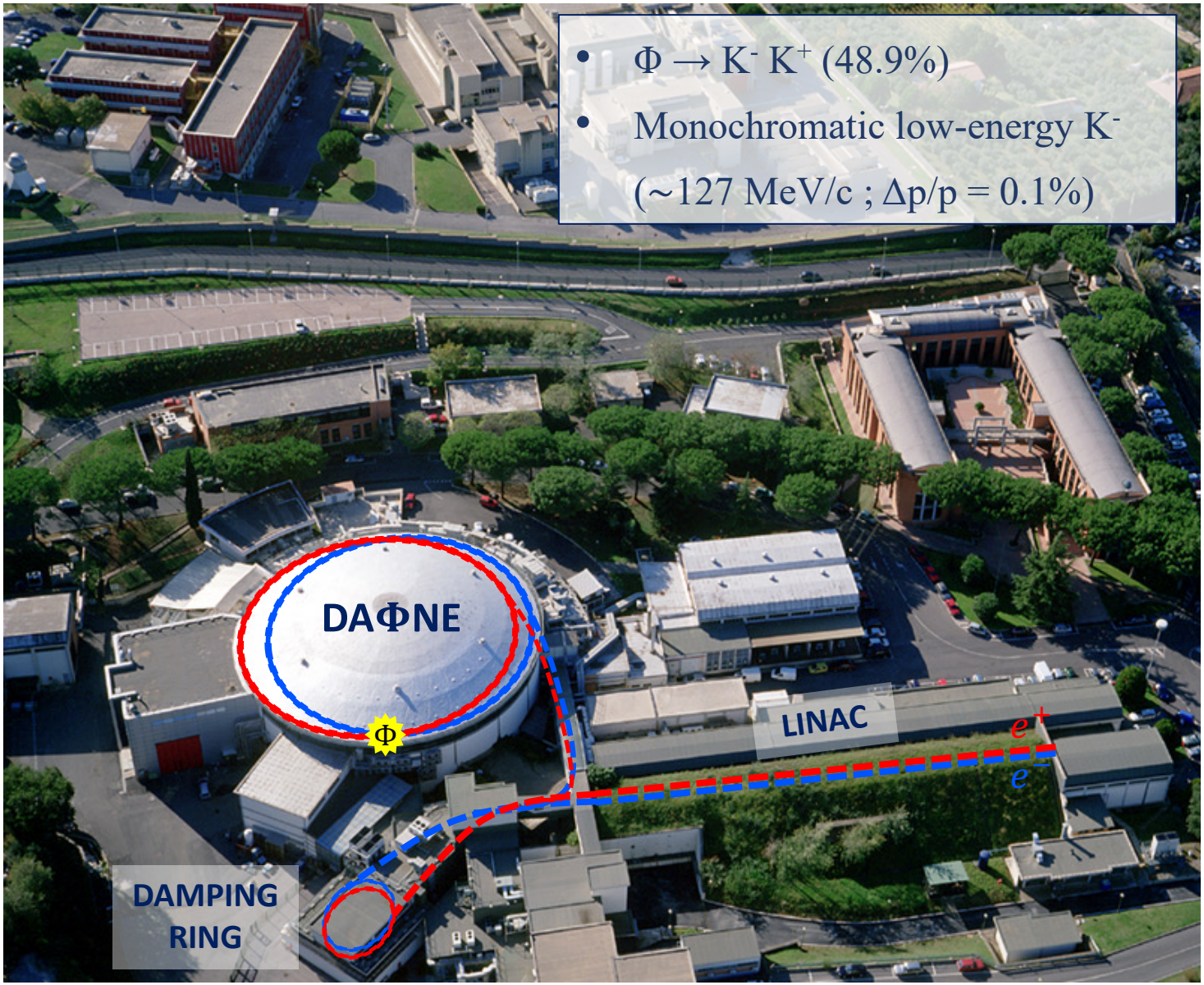


Monochromatic

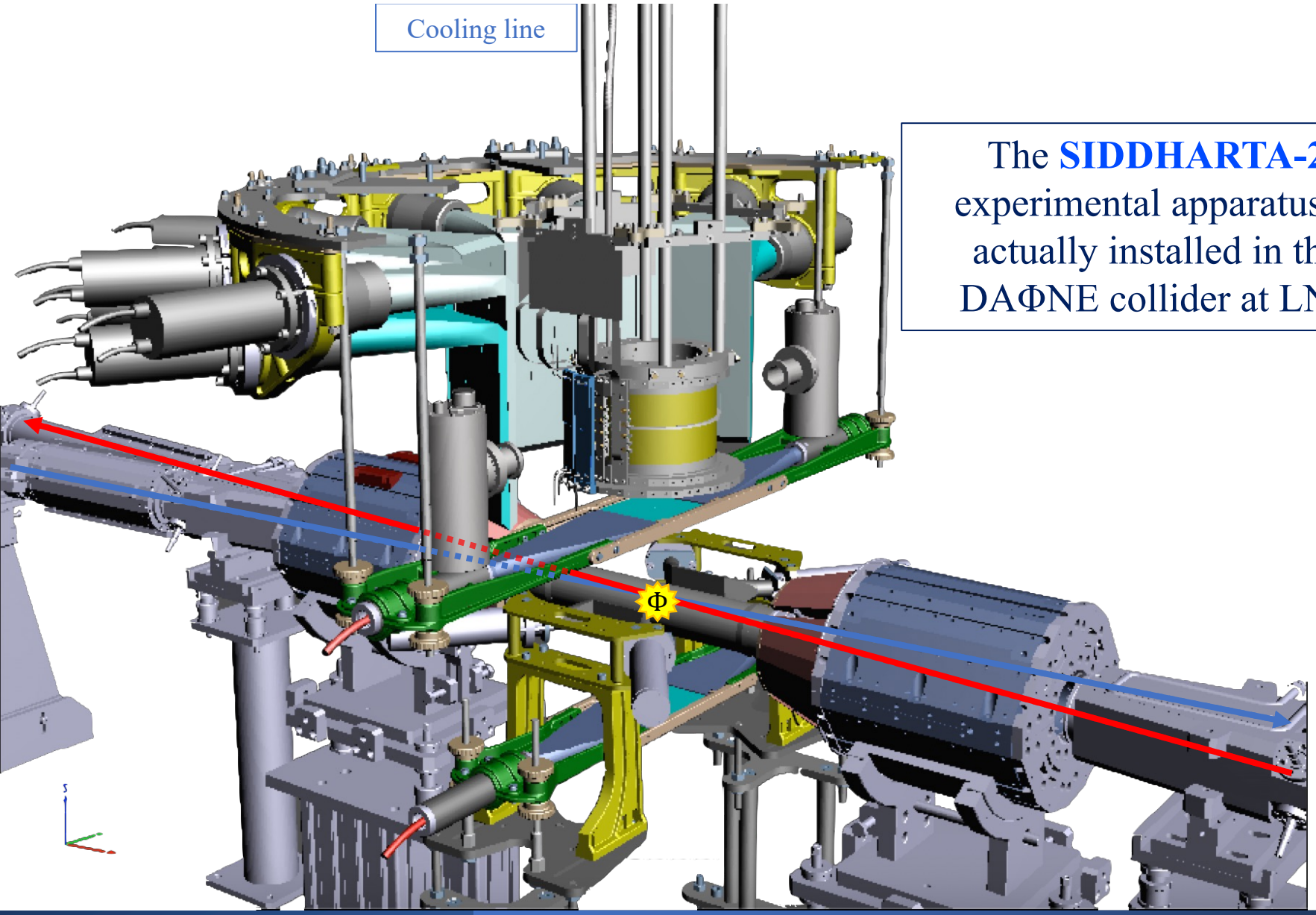
Low energy kaons

Solid angle

LNF - e^+e^- Accelerator Complex

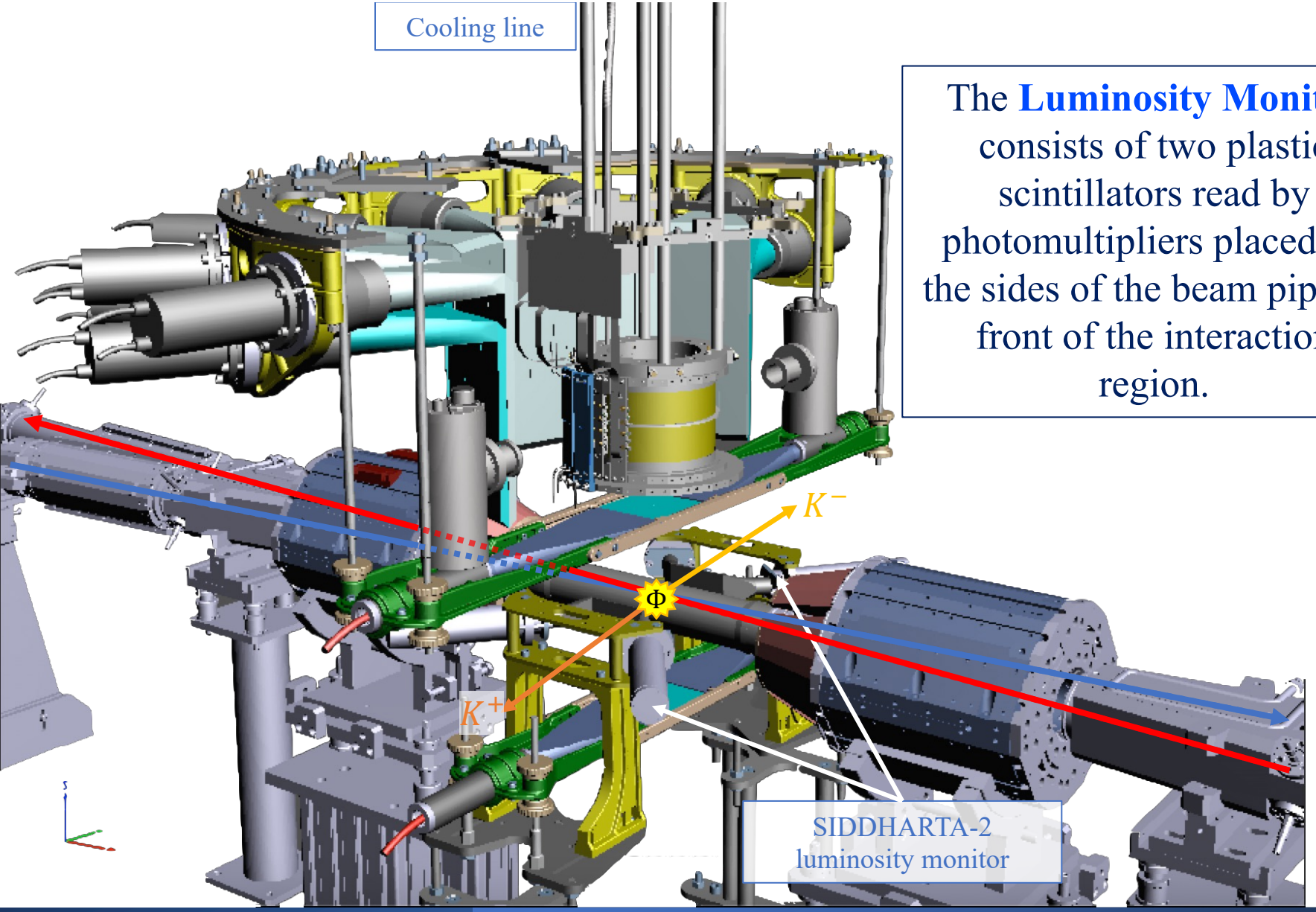


SIDDHARTA-2 setup



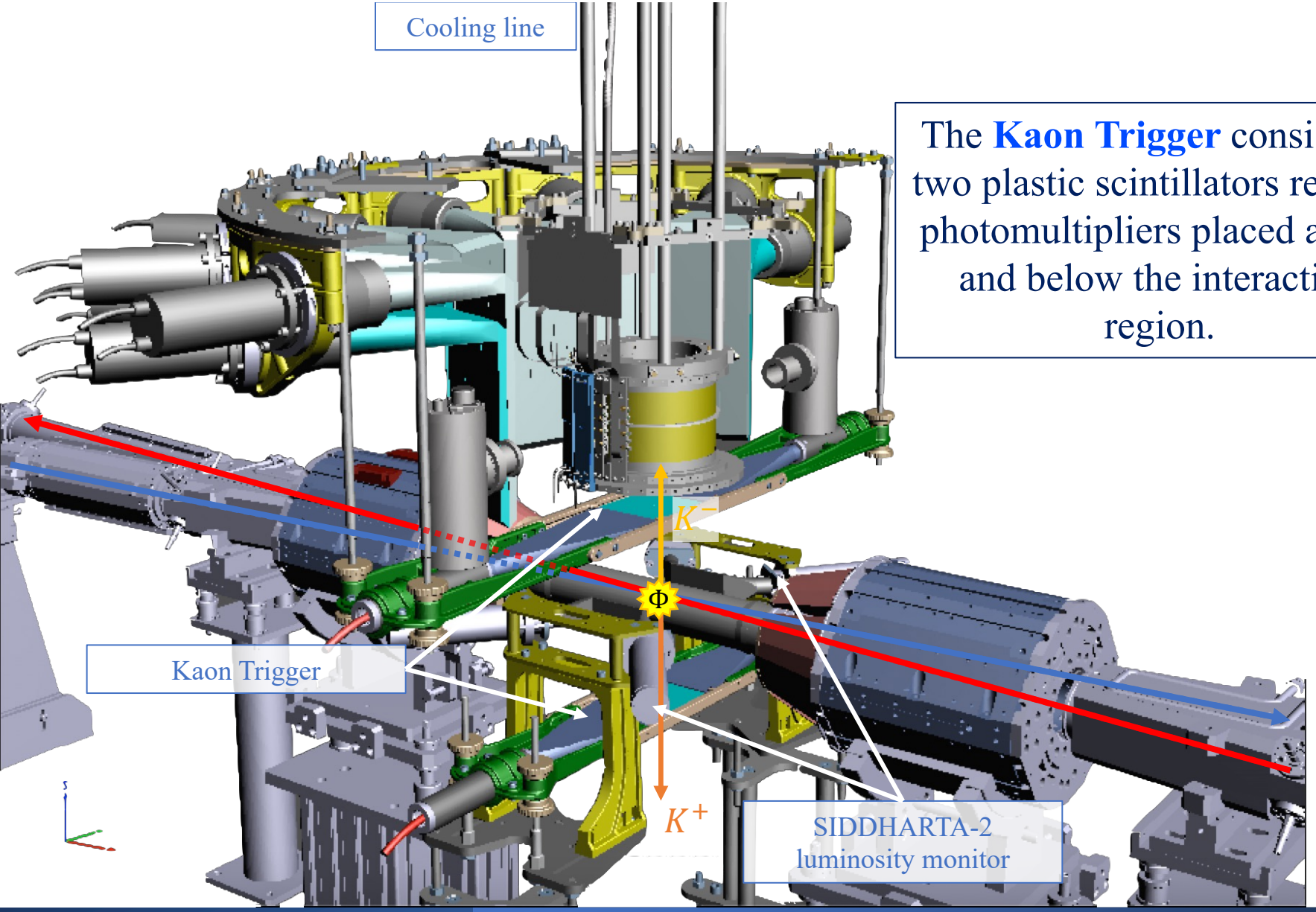
The **SIDDHARTA-2** experimental apparatus is actually installed in the DAΦNE collider at LNF

SIDDHARTA-2 setup



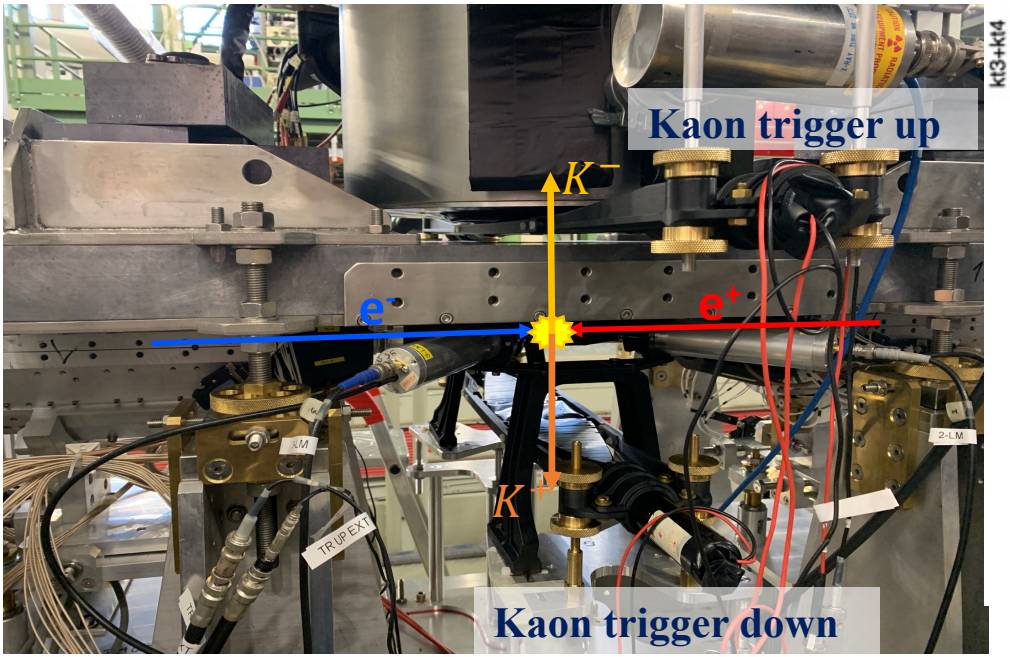
The **Luminosity Monitor** consists of two plastic scintillators read by photomultipliers placed on the sides of the beam pipe, in front of the interaction region.

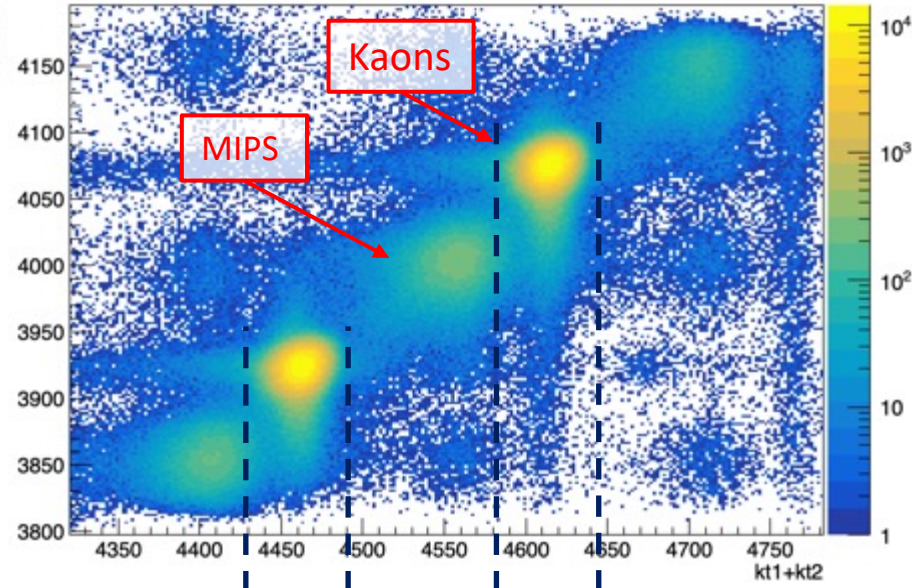
SIDDHARTA-2 setup

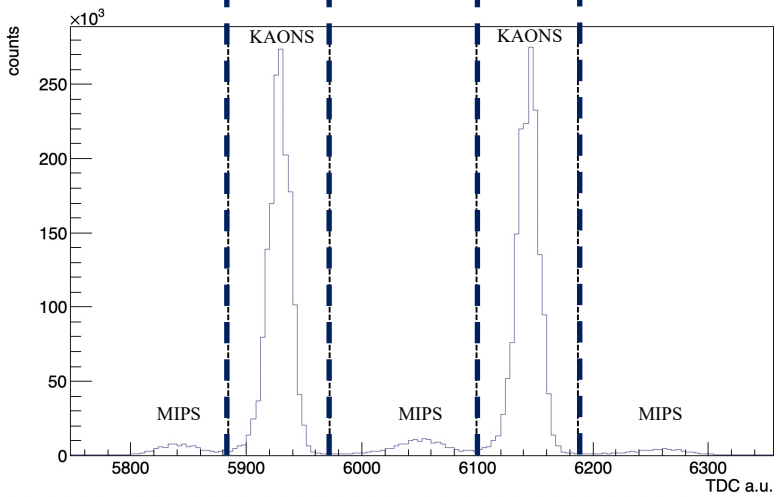


The **Kaon Trigger** consists of two plastic scintillators read by photomultipliers placed above and below the interaction region.

Kaon Trigger

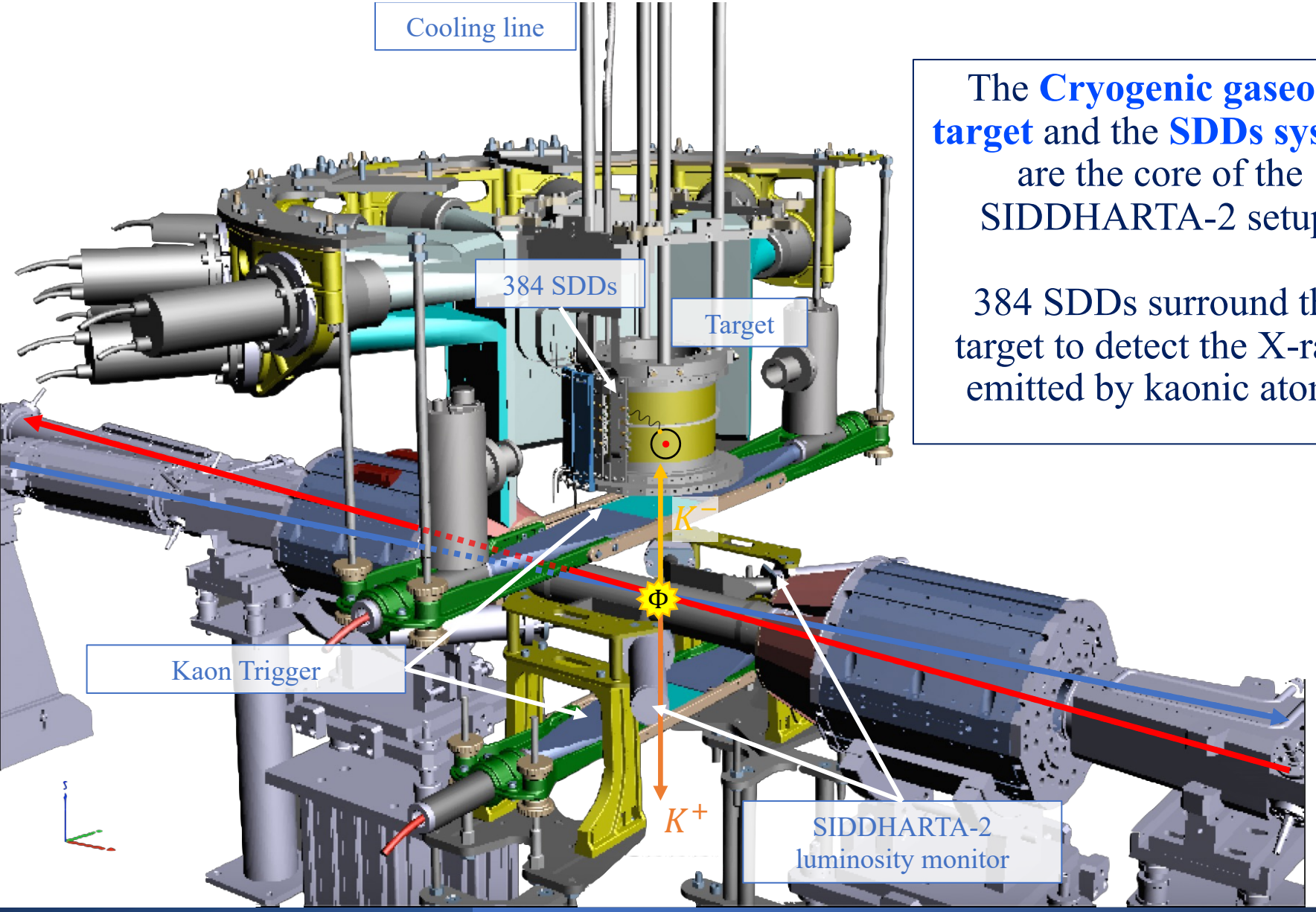






The ToF is different for Kaons, m(K)~ 500 MeV/c^2 and light particles originating from beam-beam and beam-environment interaction (MIPs).
Can efficiently discriminate by ToF Kaons and MIPs!

SIDDHARTA-2 setup

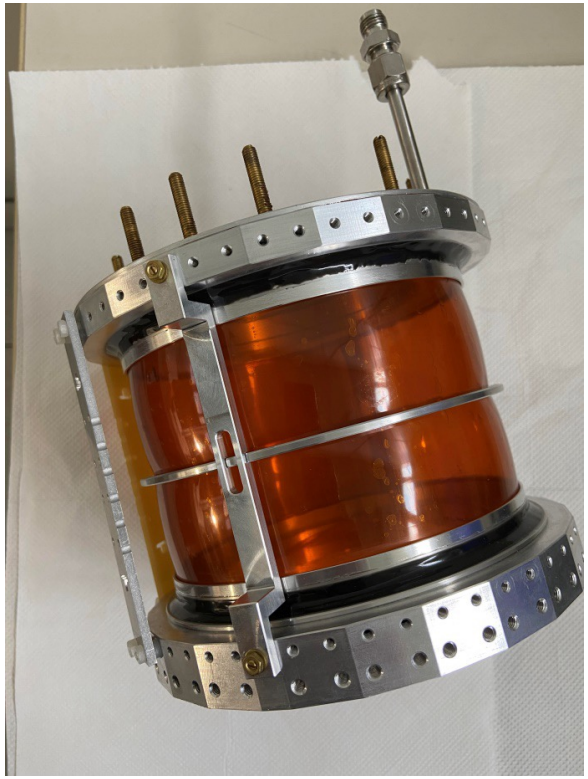


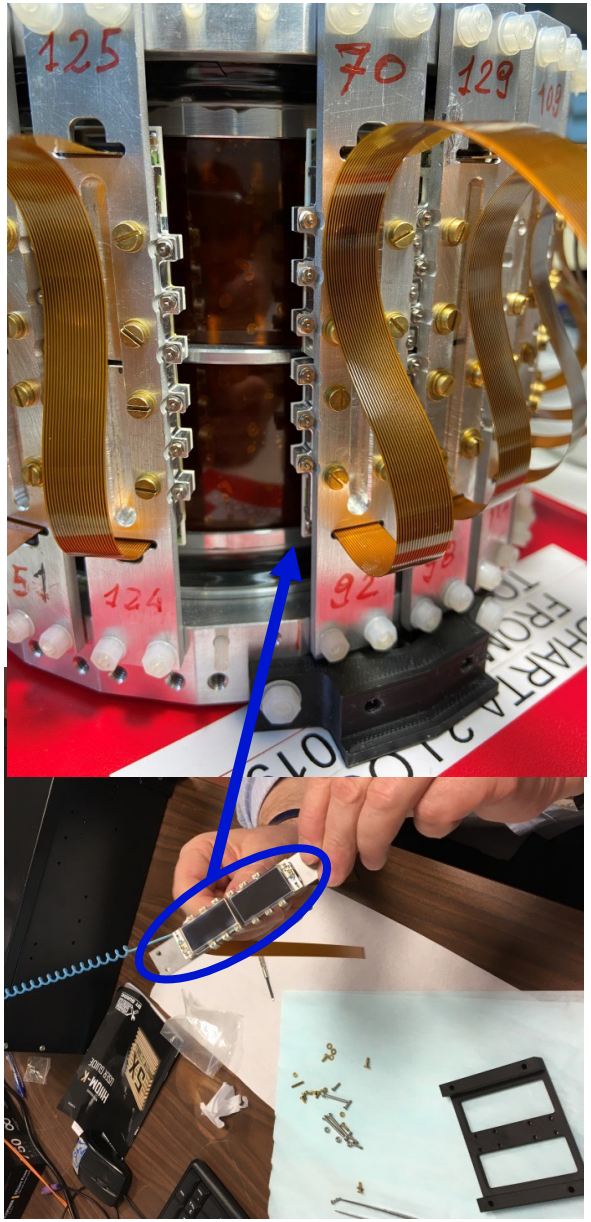
The **Cryogenic gaseous target** and the **SDDs system** are the core of the SIDDHARTA-2 setup.

384 SDDs surround the target to detect the X-rays emitted by kaonic atoms

The SIDDHARTA-2 target

Cryogenic Cylindrical target cell made of high purity aluminium frame and
150 thick Kapton walls





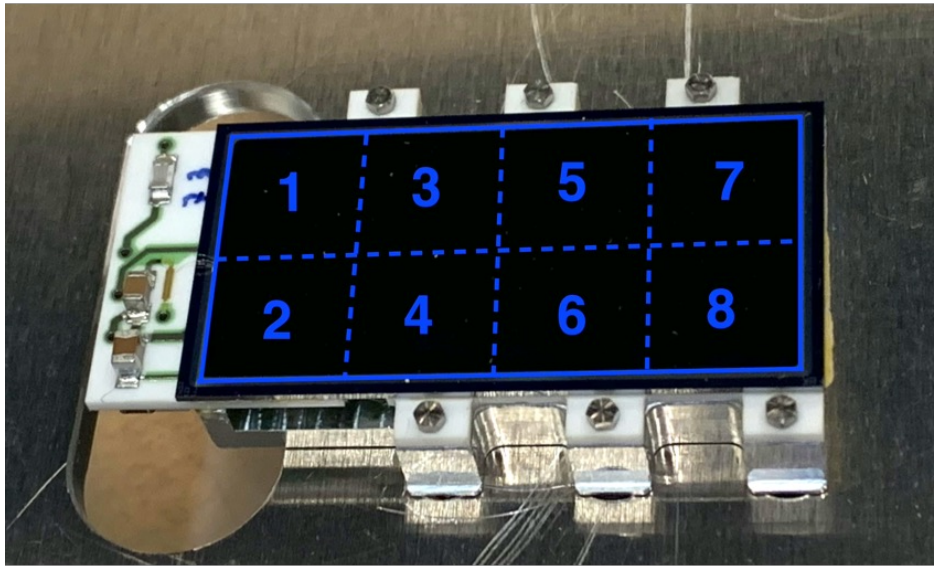
384 Silicon Drift Detectors (SDDs) are mounted on aluminium finger support for cooling (-150°C)

Silicon Drift Detectors

FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

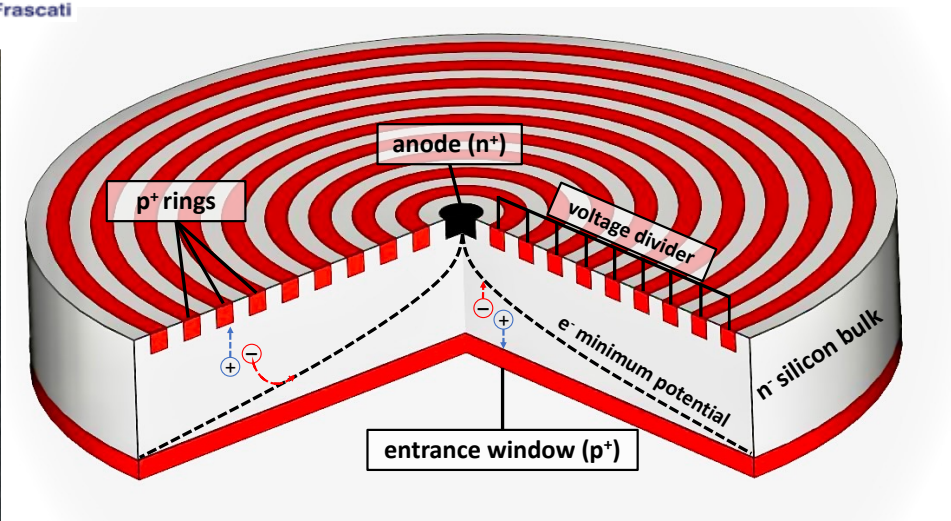
POLITECNICO MILANO 1863

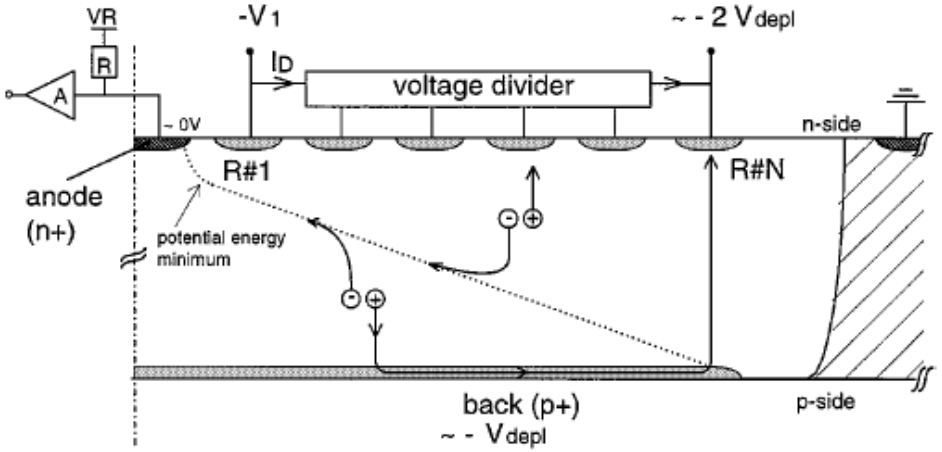
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati



8 SDD units (0.64 cm²)
for a total active area of 5.12 cm²
Thickness of 450 µm ensures a high collection efficiency for X-rays of energy between 5 keV and 12 keV

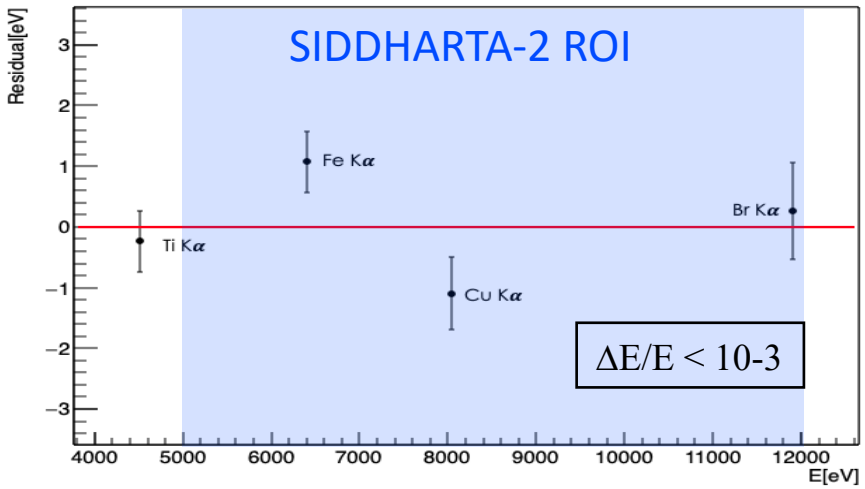
SDD cross section



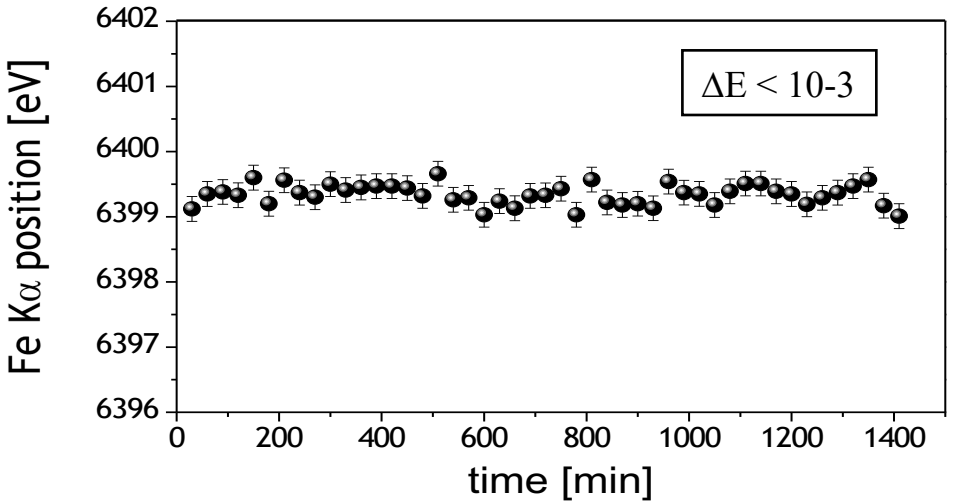


Silicon Drift Detectors

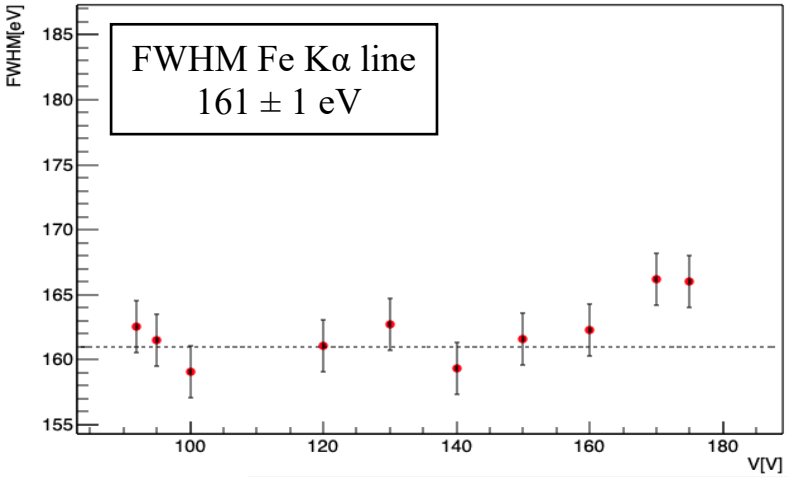
Linearity



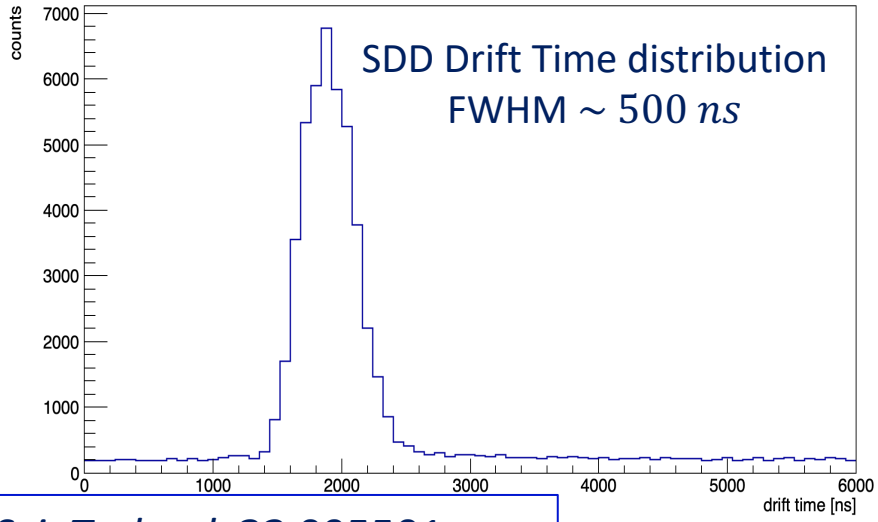
Stability



Energy Resolution

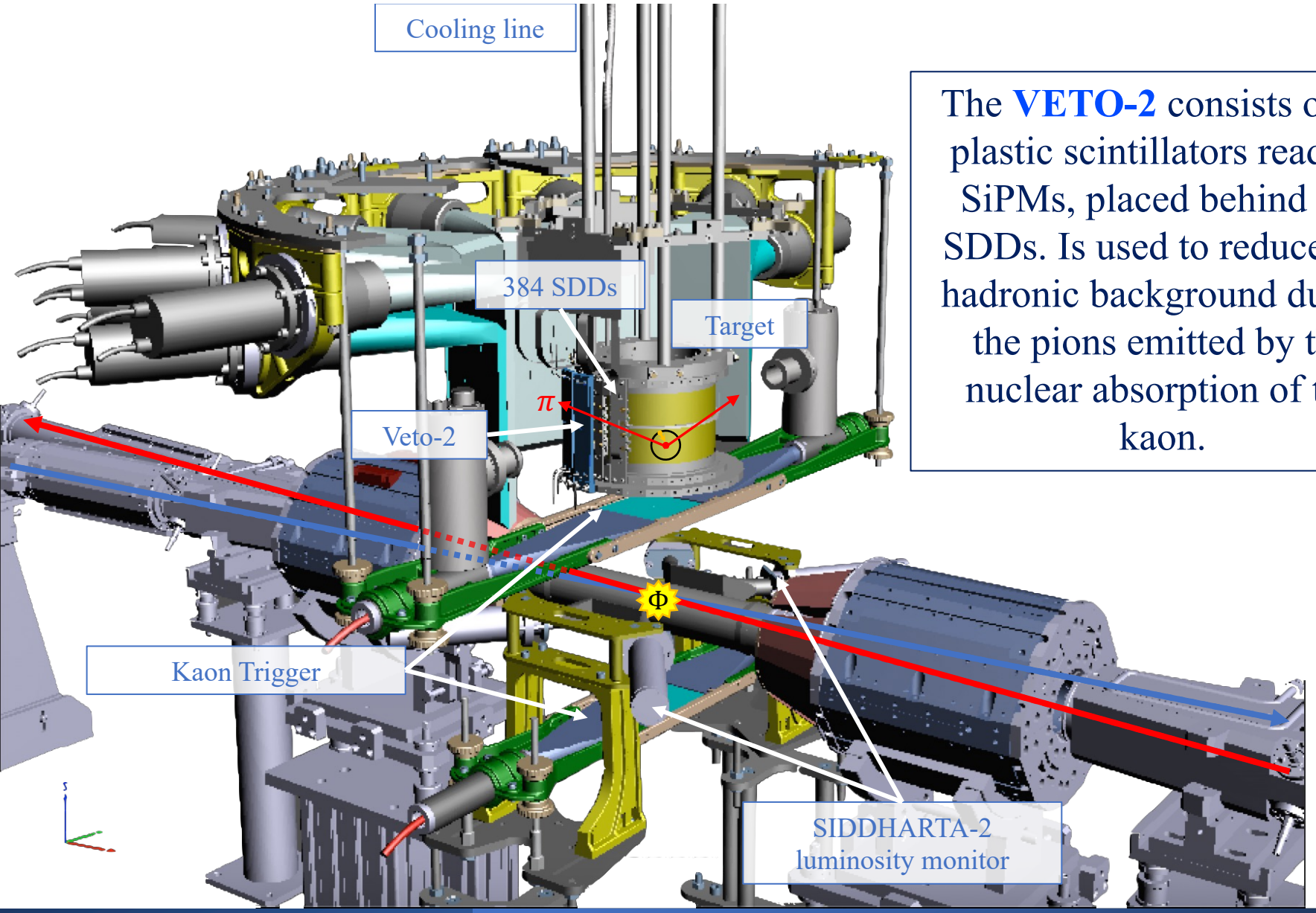


Timing Resolution



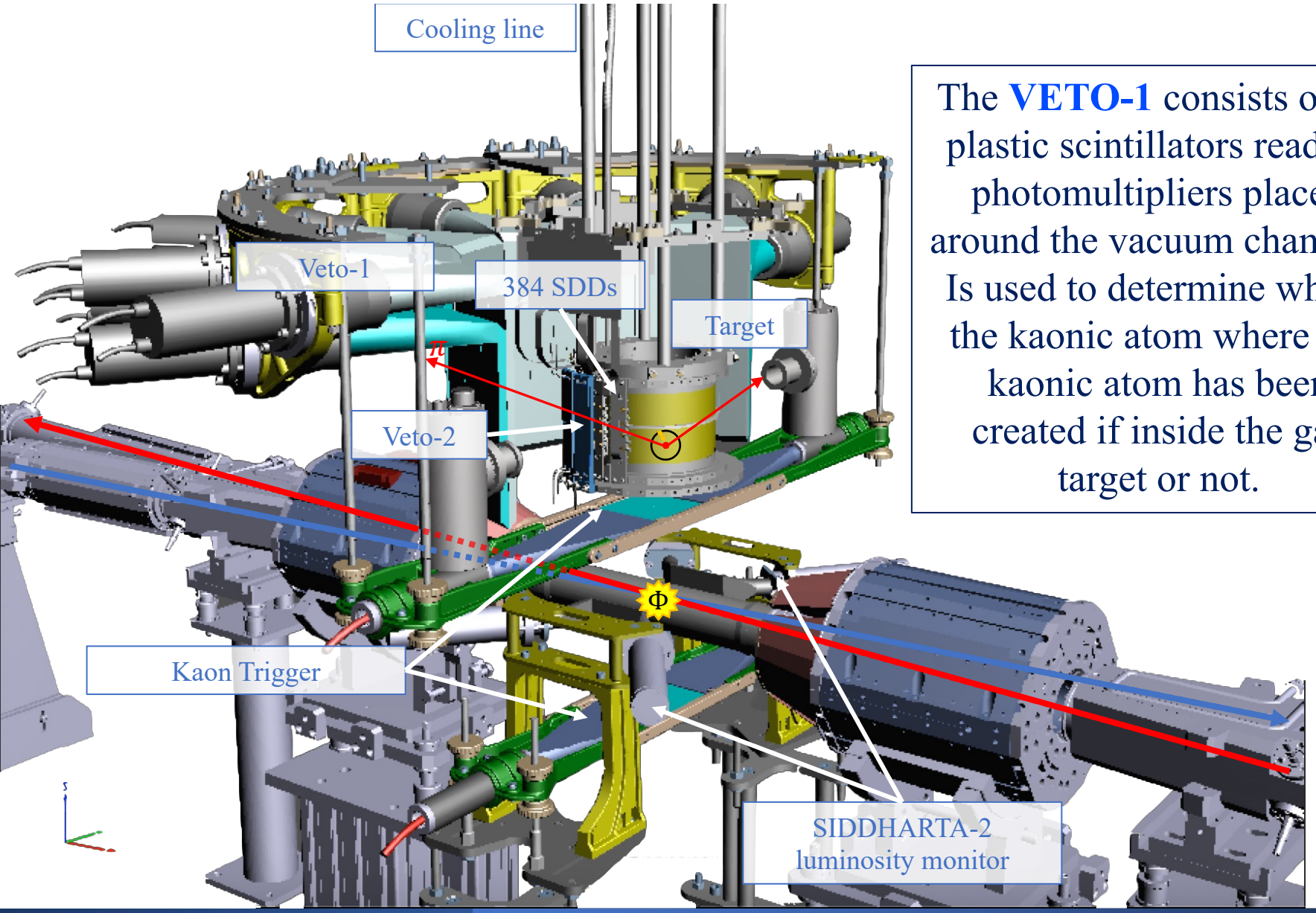
M Miliucci *et al* 2021 *Meas. Sci. Technol.* **32** 095501

SIDDHARTA-2 setup



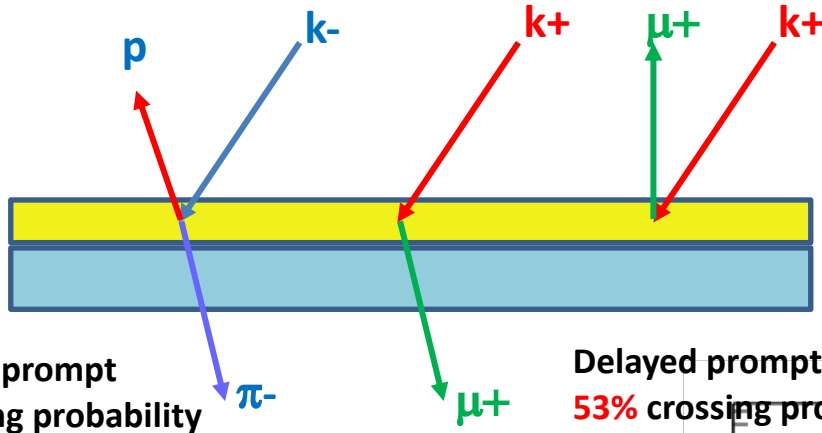
The **VETO-2** consists of 96 plastic scintillators read by SiPMs, placed behind the SDDs. Is used to reduce the hadronic background due to the pions emitted by the nuclear absorption of the kaon.

SIDDHARTA-2 setup



The **VETO-1** consists of 12 plastic scintillators read by photomultipliers placed around the vacuum chamber. Is used to determine where the kaonic atom where the kaonic atom has been created if inside the gas target or not.

Kaon Charge Detector



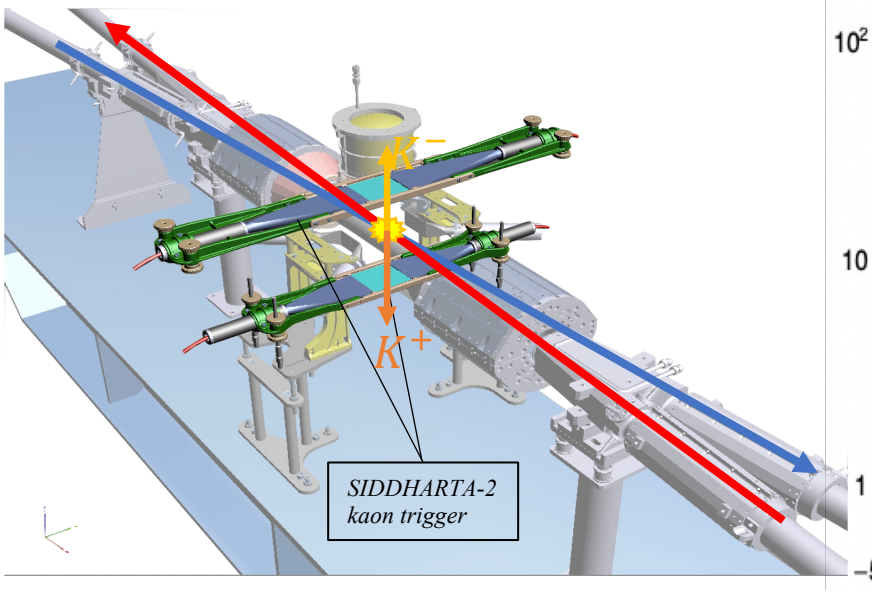
Stop both K^+ and K^- in a passive layer (Teflon) and detect secondaries in a scintillator

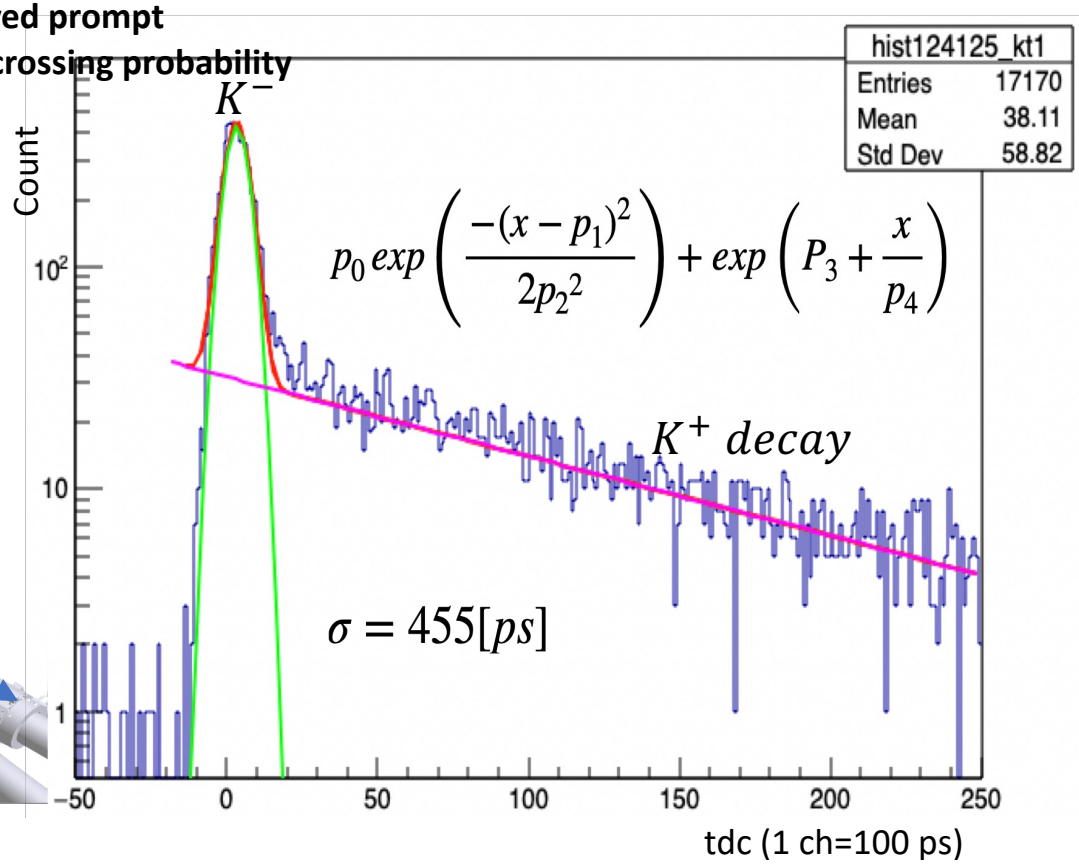
2 mm teflon or 5 mm thick scintillator

5-10 mm thick scintillator

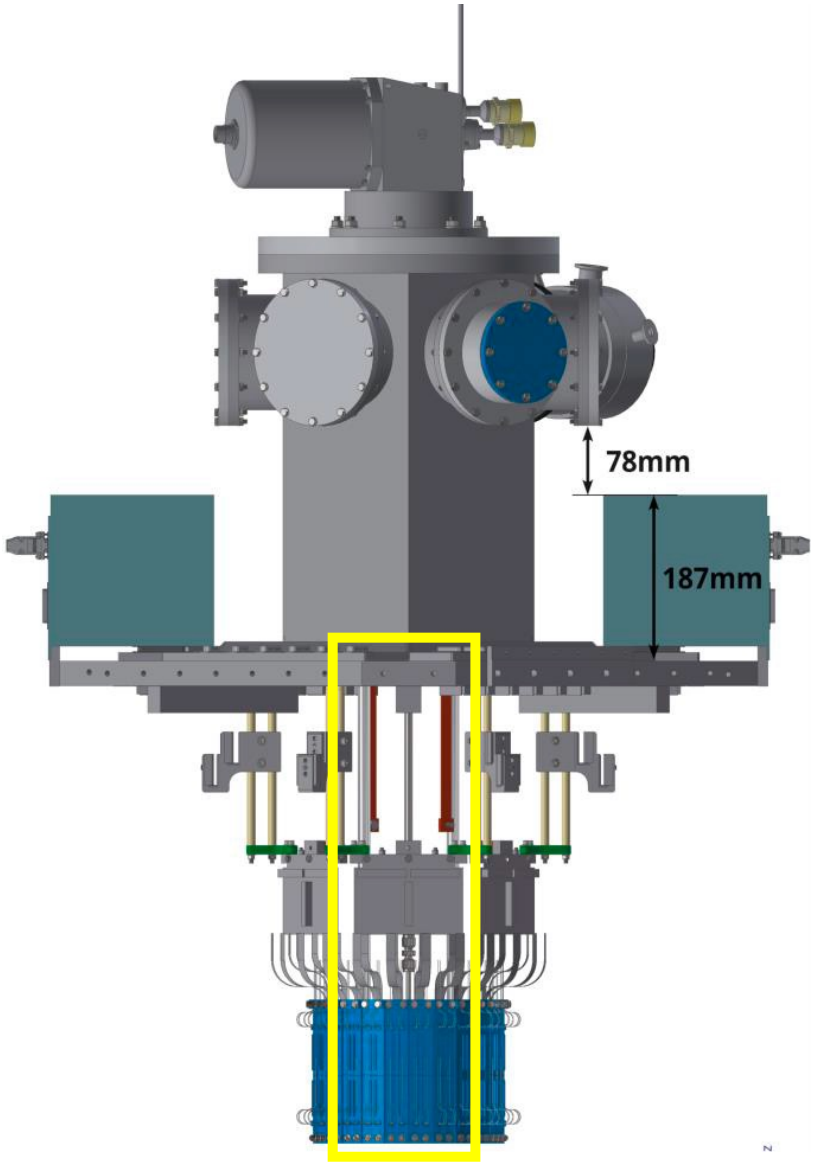
Immediate prompt
83% crossing probability

Delayed prompt
53% crossing probability





SIDDHARTINO

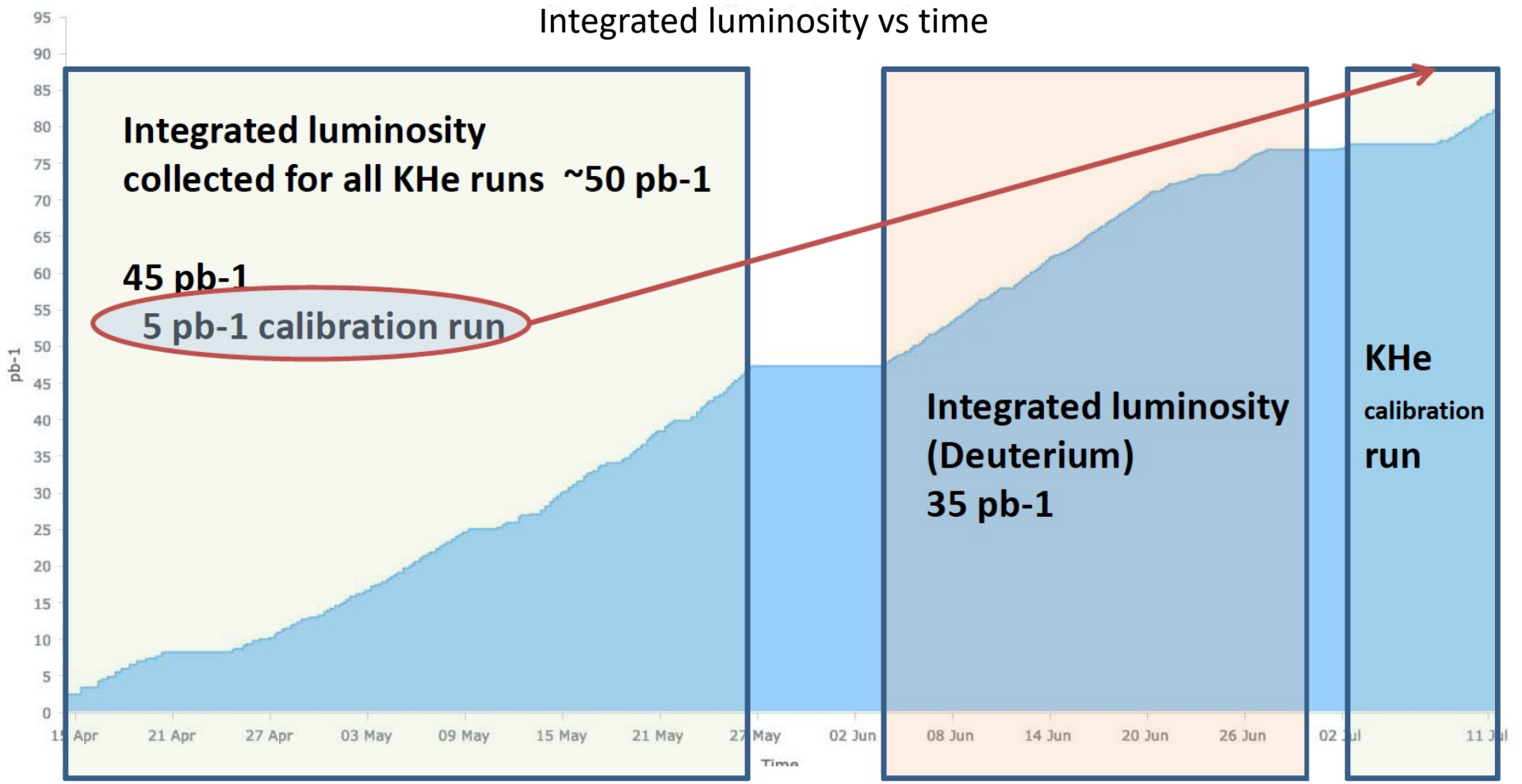


SIDDHARTINO: phase 1 of SIDDHARTA-2
1/6 of SIDDHARTA-2

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**
- **Concluded in 2021**

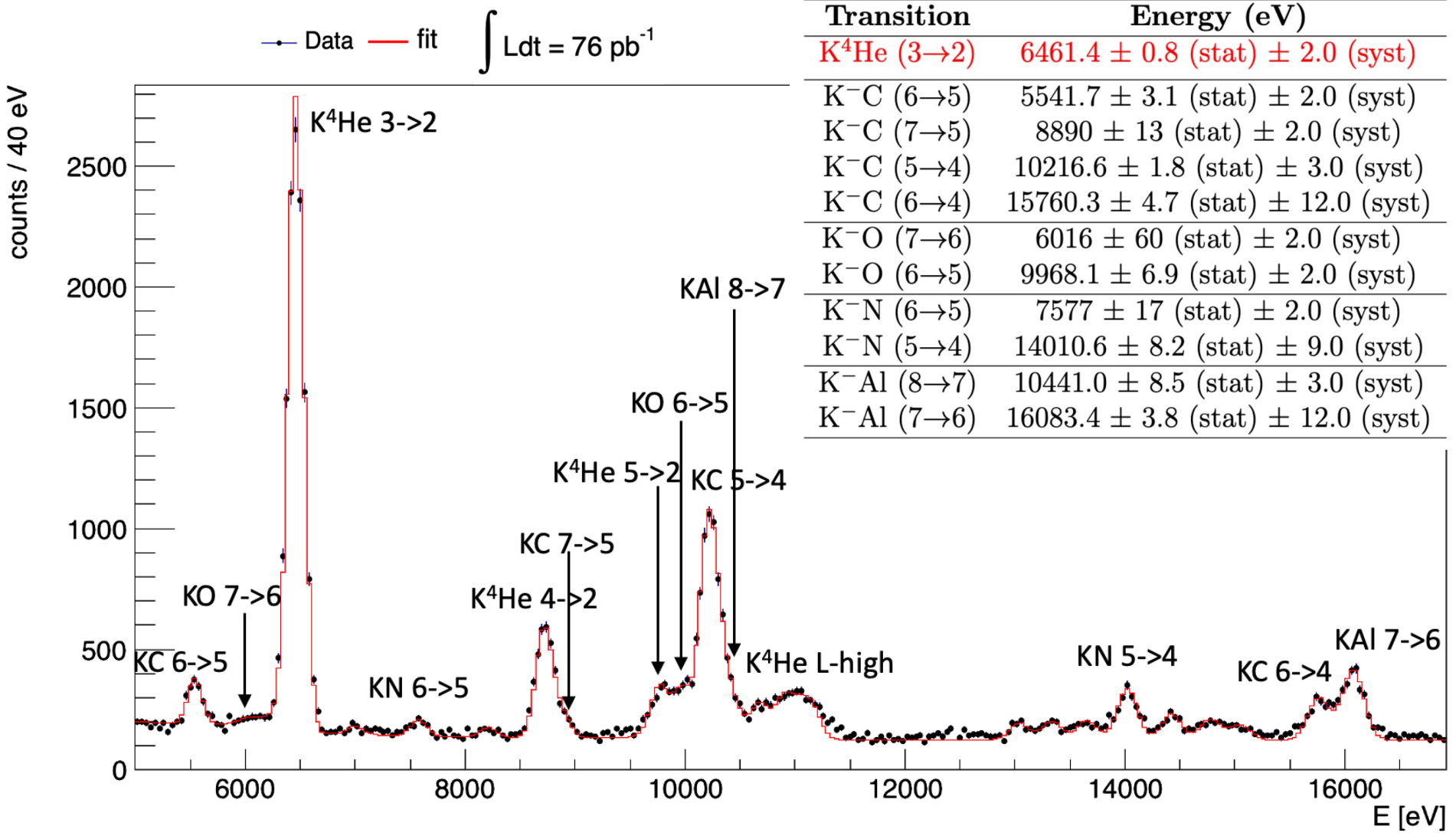
SIDDHARTA-2 First Run



SIDDHARTA-2 Kaonic ^{4}He

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 K-d measurement

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

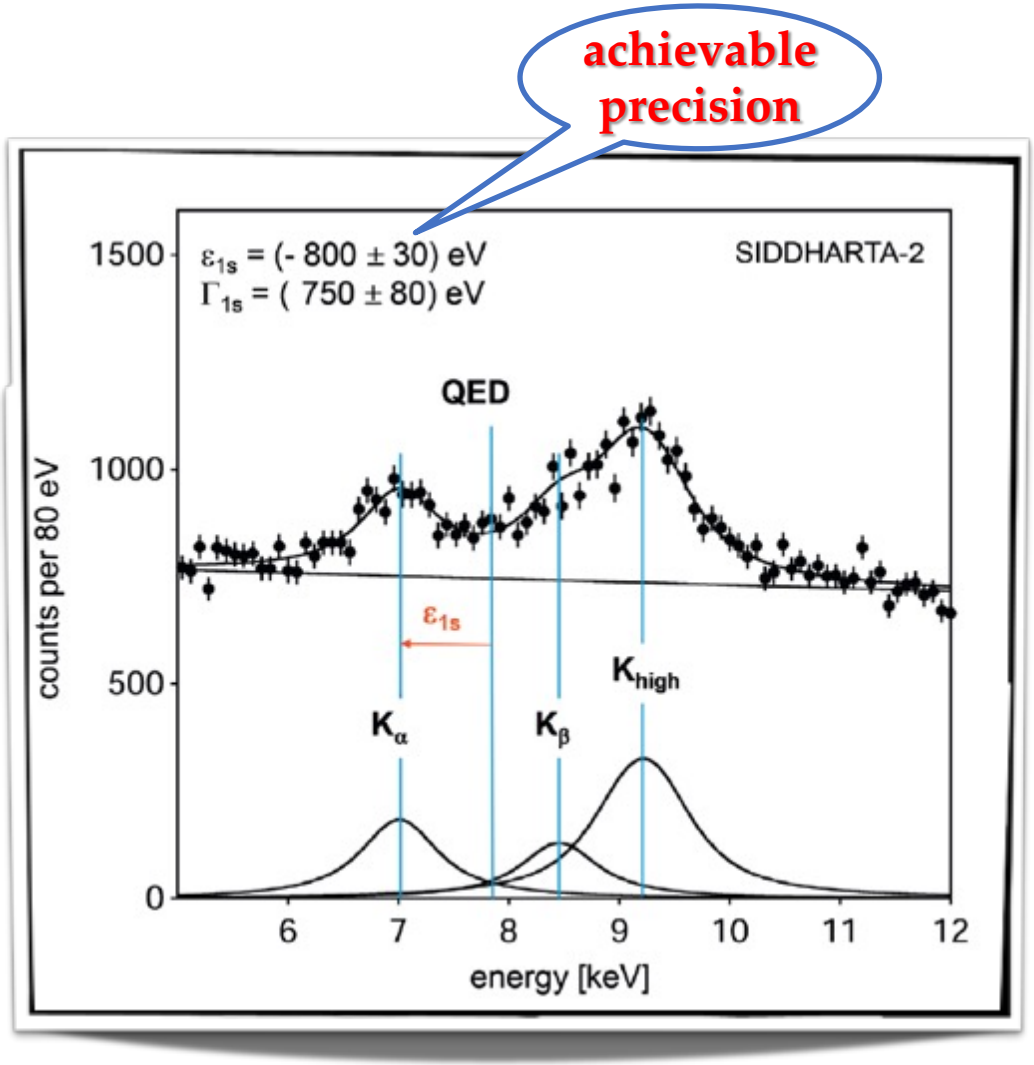
SIDDHARTA-2 K-d measurement

Kaonic deuterium run in (all)

2023

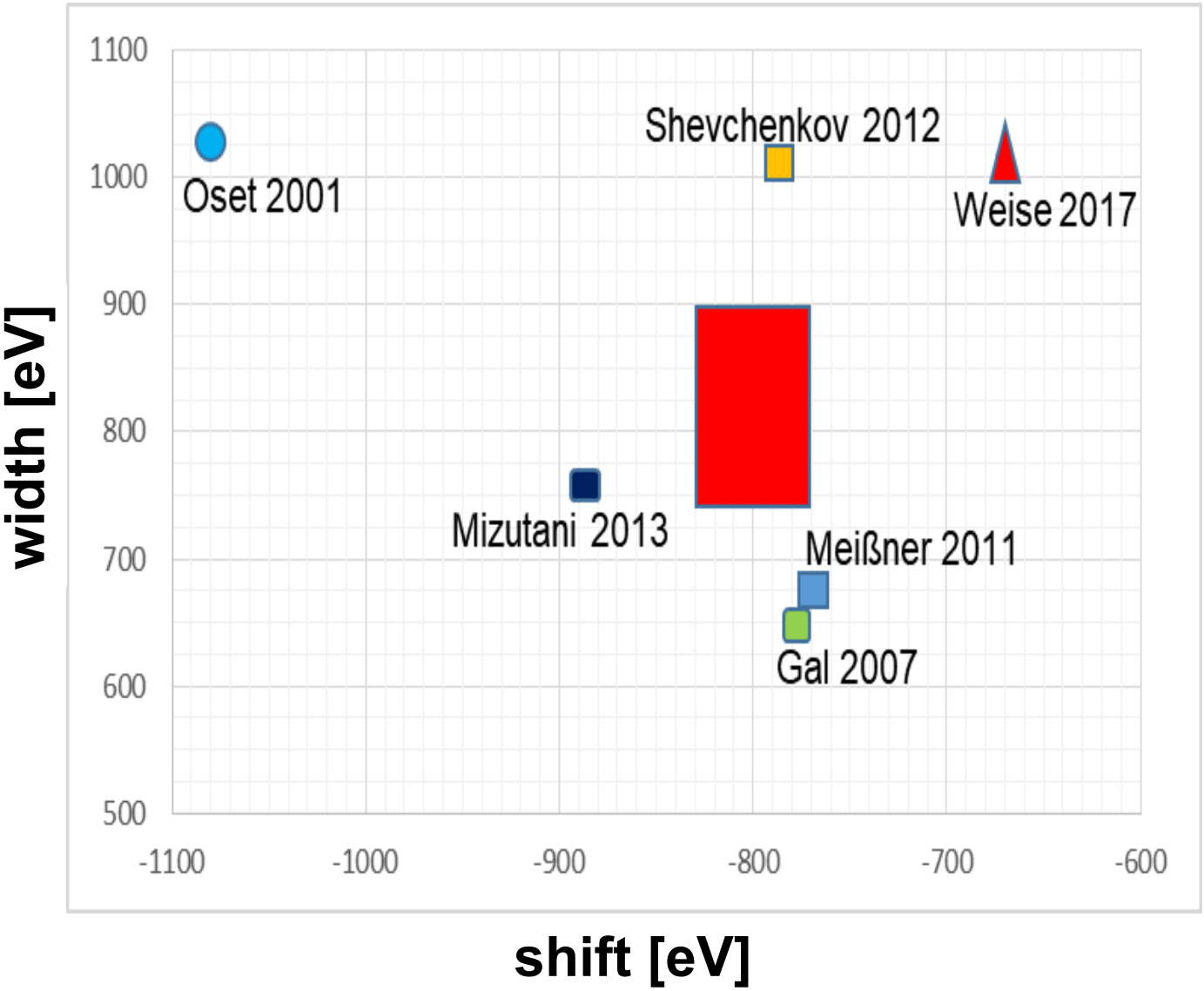
Monte Carlo for an integrated luminosity of 800 pb^{-1}

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) !



Significant impact in the theory of strong interaction with strangeness

SIDDHARTA-2 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

- **SIDDHARTA-2 at DAFNE**
  - Installation of the full SIDDHARTA-2 setup
  - Kaonic ^{4}He test run concluded in July 2022
  - **Performed the most precise K-^{4}He 3d → 2p measurement in gas**
  - **Several solid target high-n transition energies measured for the first time**
  - **First kaonic deuterium test run**


SIDDHARTA-2 setup
ready for
Kaonic Deuterium Run


Thank You