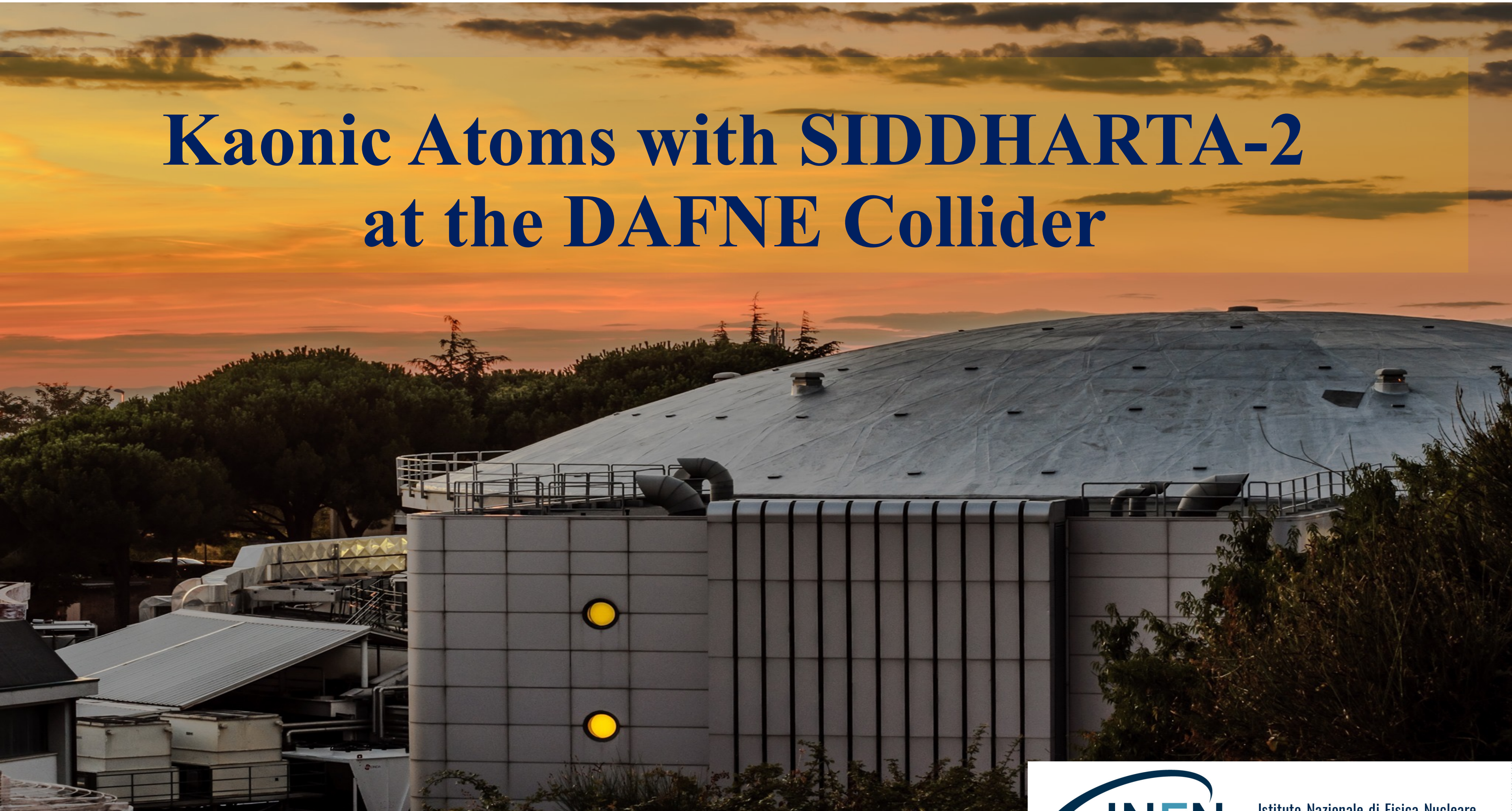
Quinto Incontro Nazionale di Fisica Nucleare INFN 2022

Kaonic Atoms with SIDDHARTA-2 at the DAFNE Collider



Francesco Sgaramella
on behalf of the SIDDHARTA-2 Collaboration

INFN Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

STRONG-2020

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)

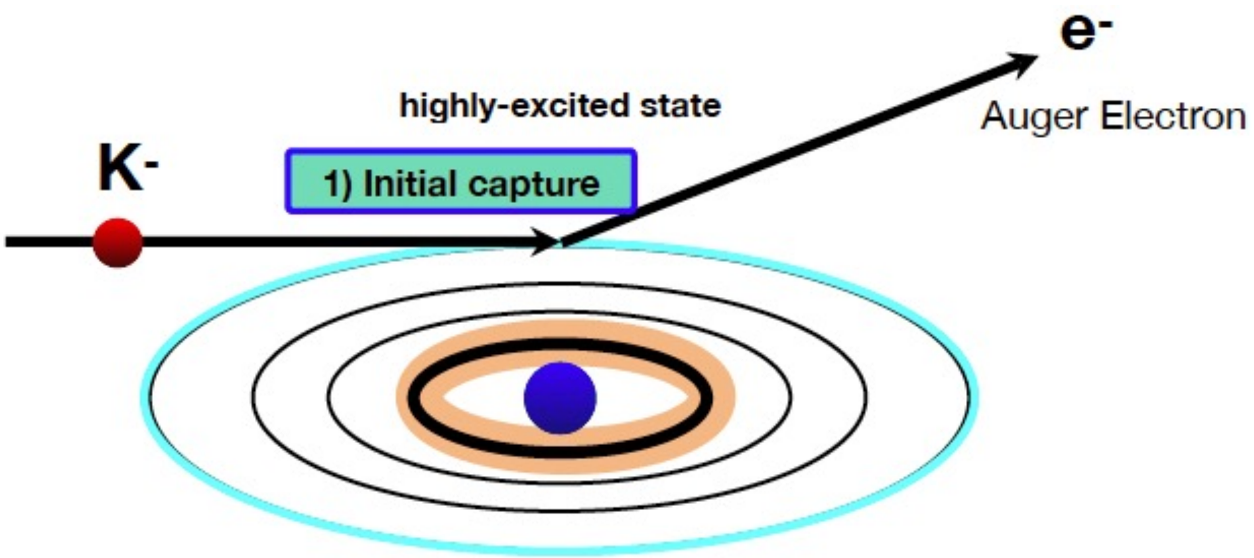
On self-gravitating strange dark matter halos around galaxies Phys.Rev.D 102 (2020) 8, 083015

Dark Matter studies

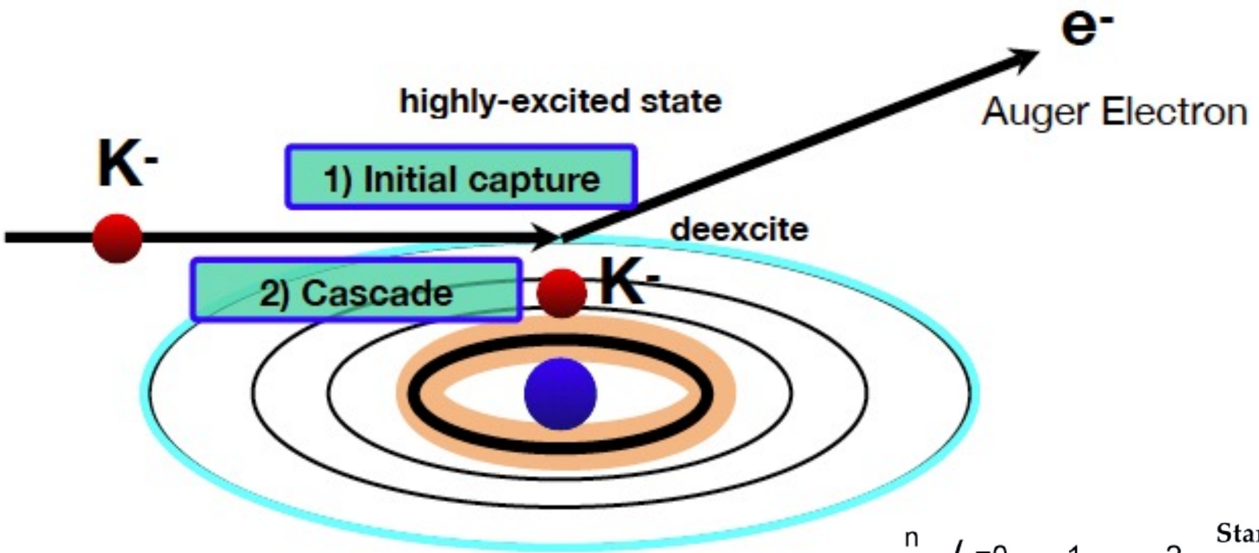
The equation of state of dense matter: Stiff, soft, or both? Astron.Nachr. 340 (2019) 1-3, 189

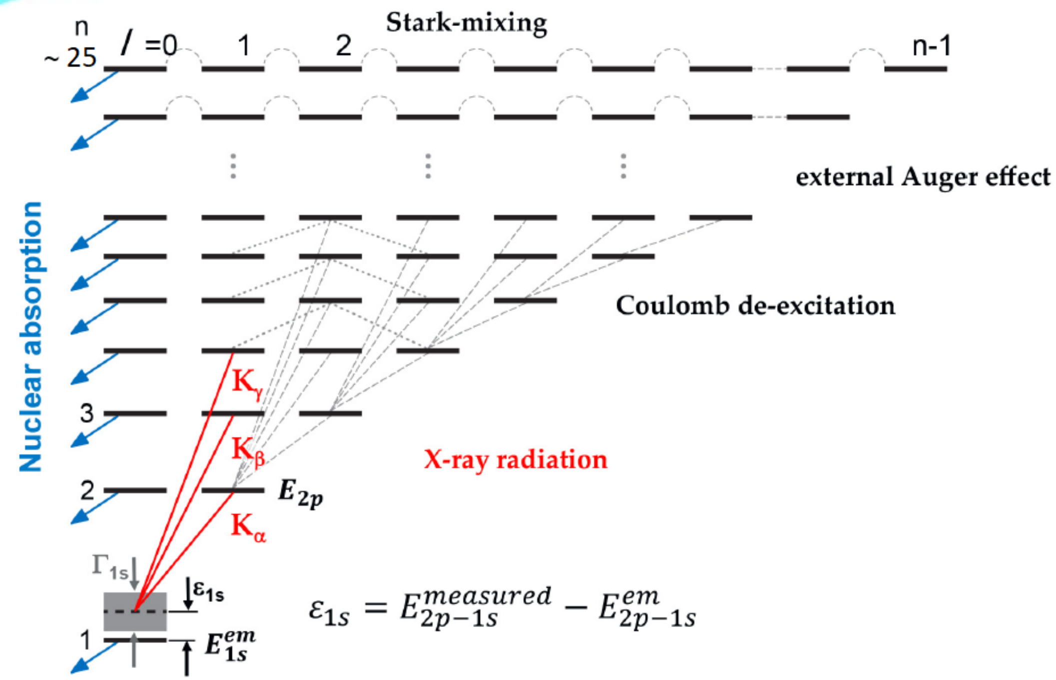
Astrophysics
EOS Neutron Stars

Kaonic atom Formation

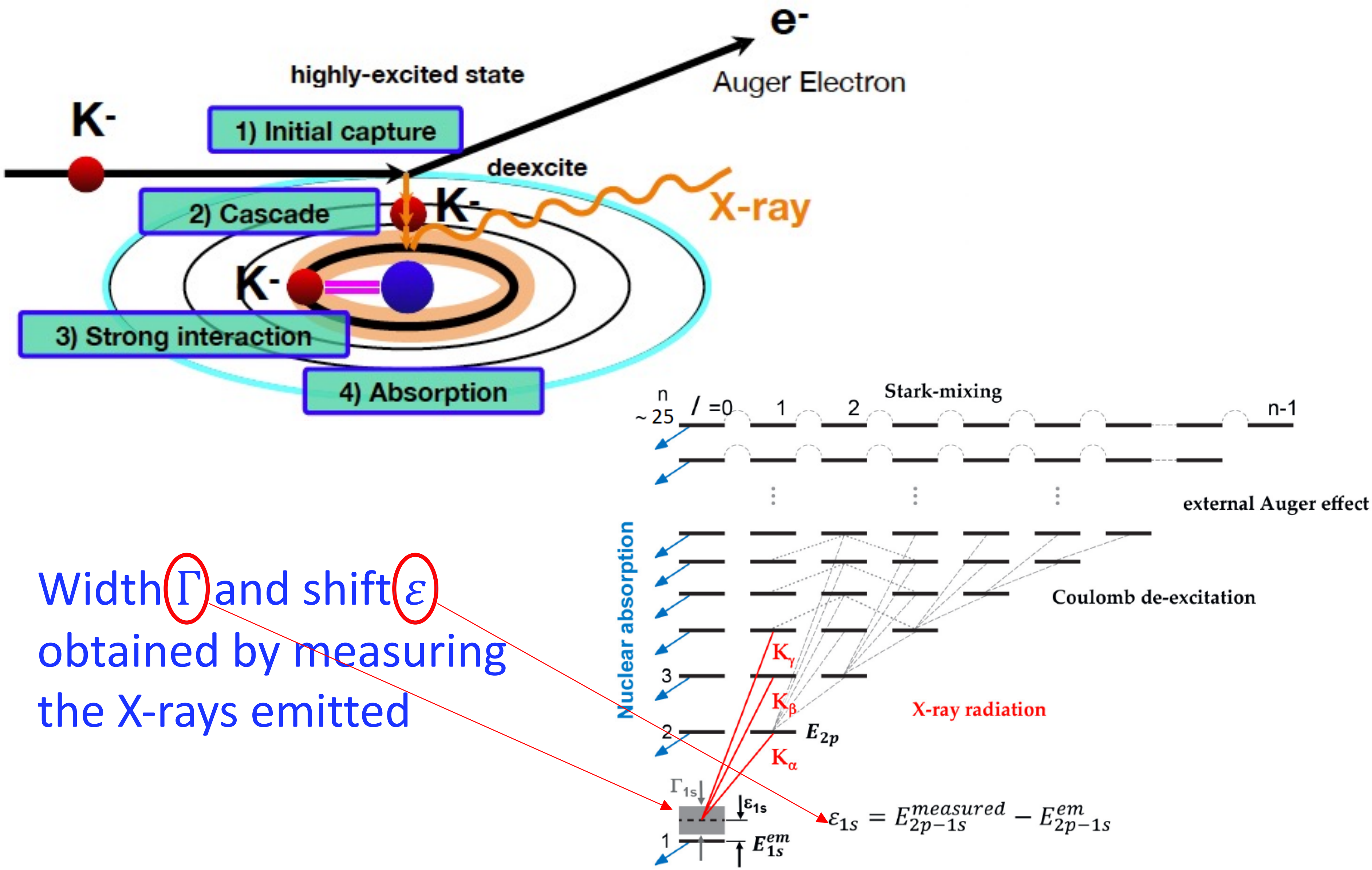


Kaonic atom Formation





Kaonic atom Formation



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

$$\varepsilon_{1s} = E^{measured}_{2p-1s} - E^{em}_{2p-1s}$$

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)

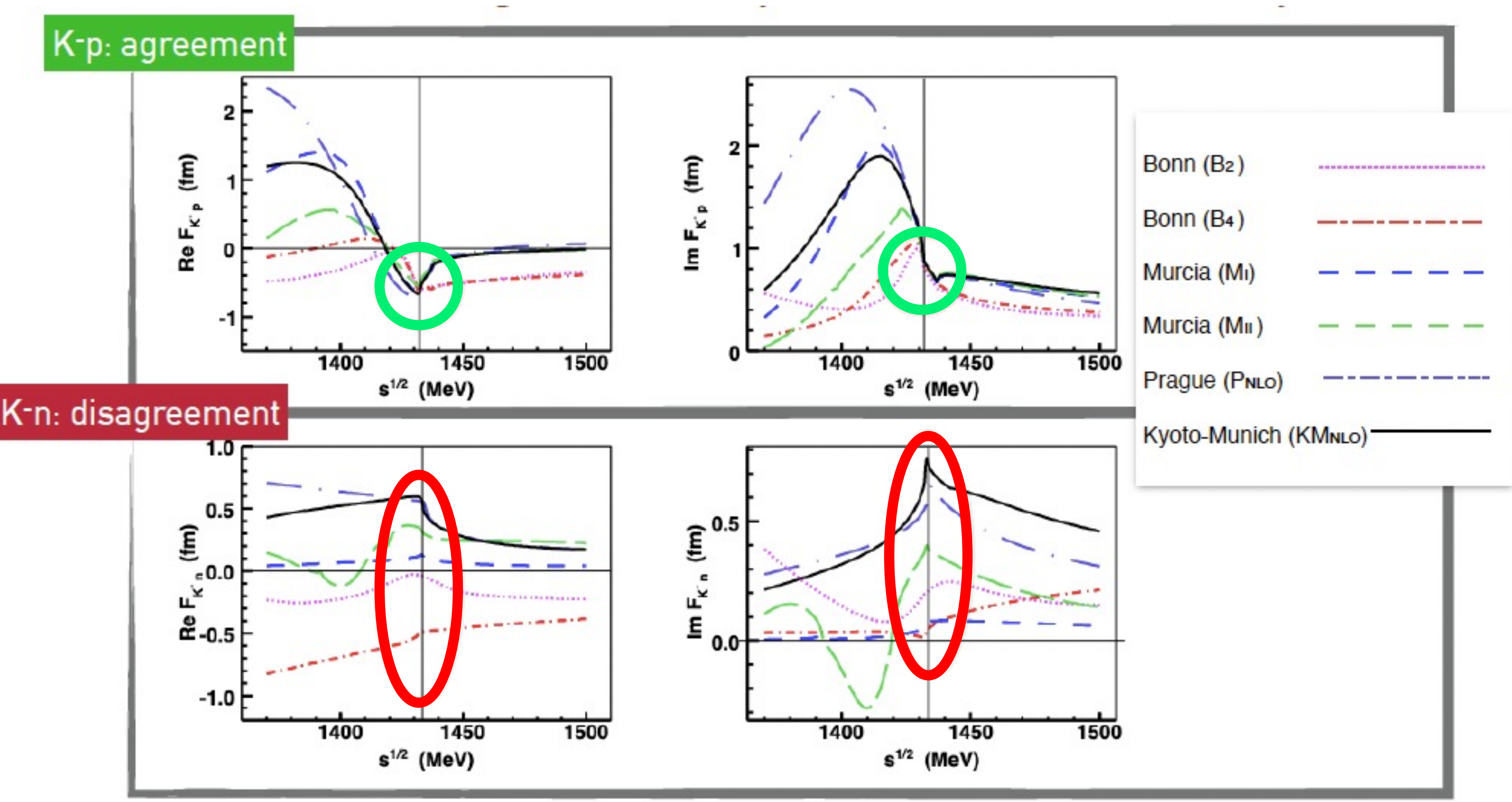
U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

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

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

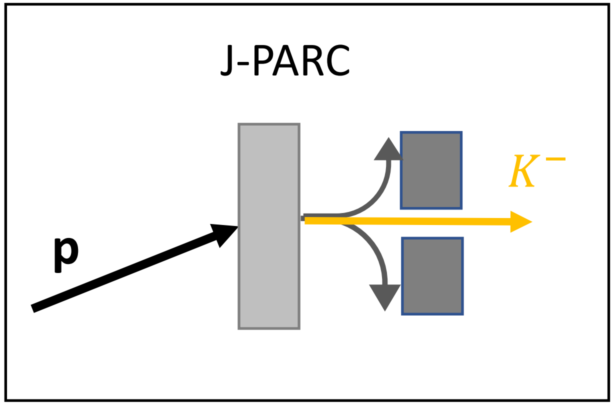
completely solve Isospin-dependent K-N scattering length

Kaonic atoms – scattering amplitudes



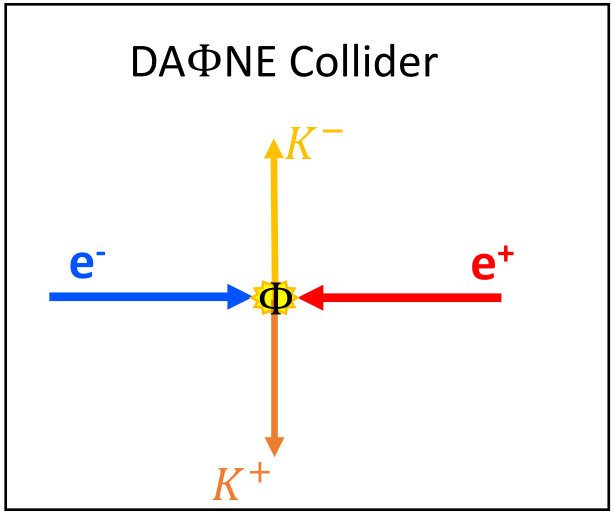
A. Ciepl$\acute{y}$, M. Mai, Ulf-G. Meißner, J. Smejkal, https://arxiv.org/abs/1603.02531v2

Kaon Beam Source



High intensity

High background

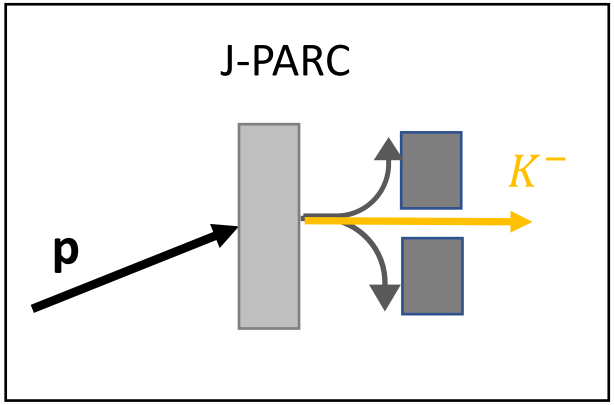


Monochromatic

Low energy kaons

Solid angle

Experimental Principle



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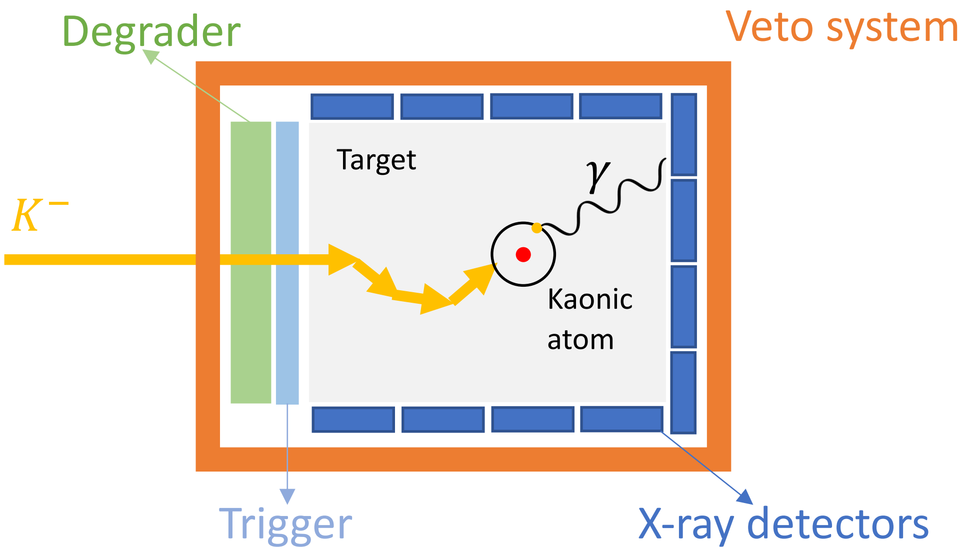
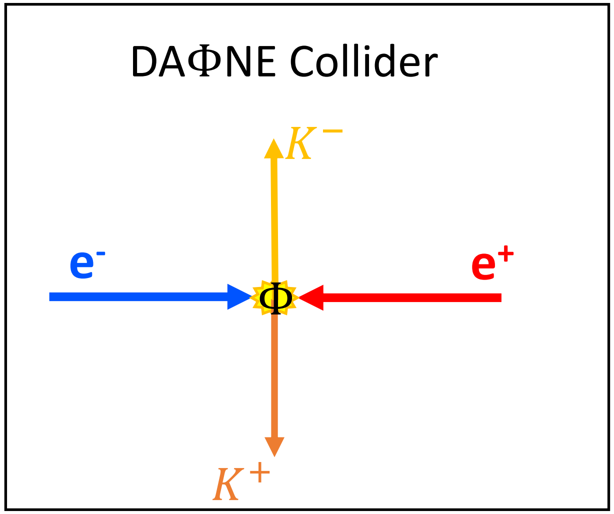




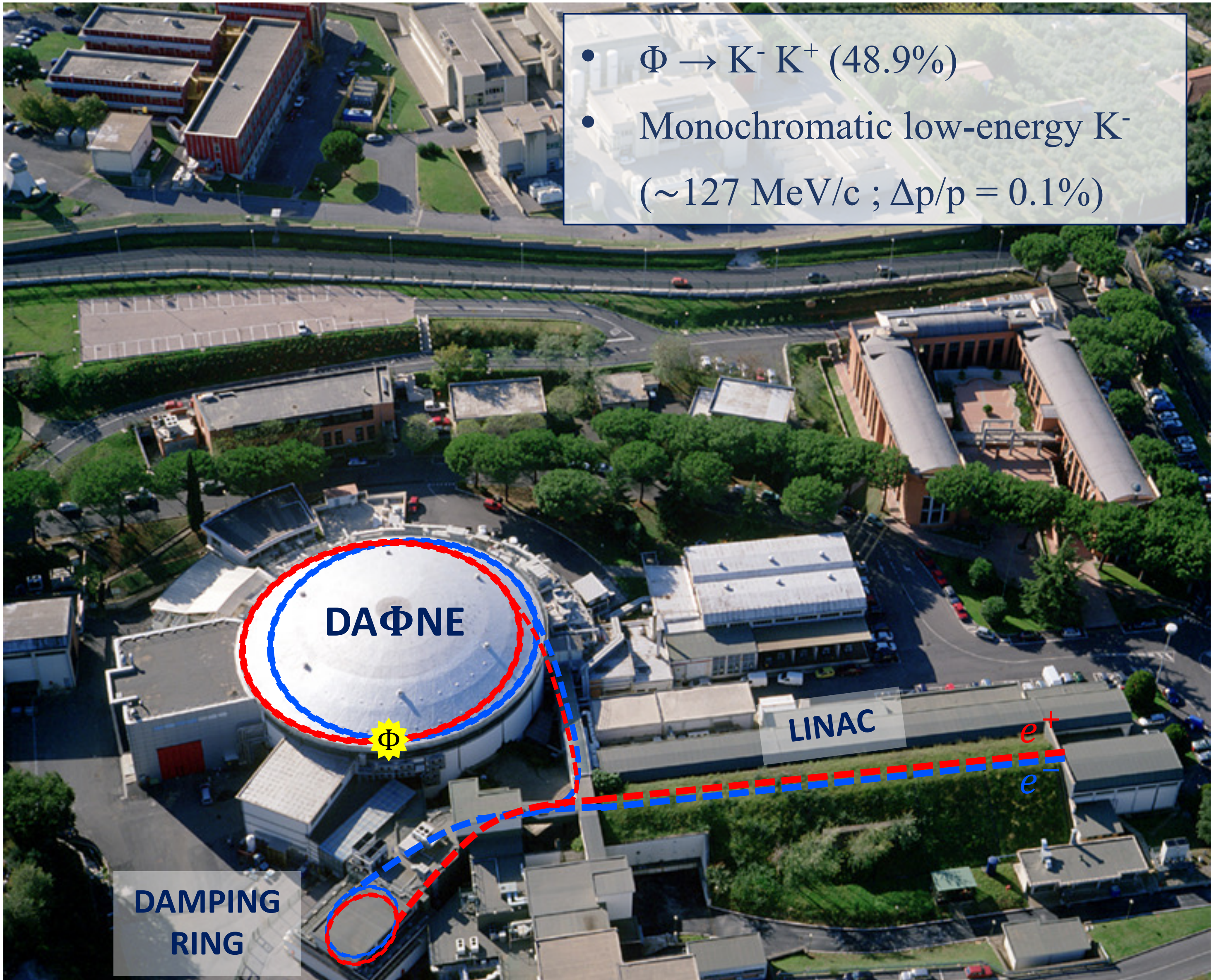
Monochromatic

Low energy kaons

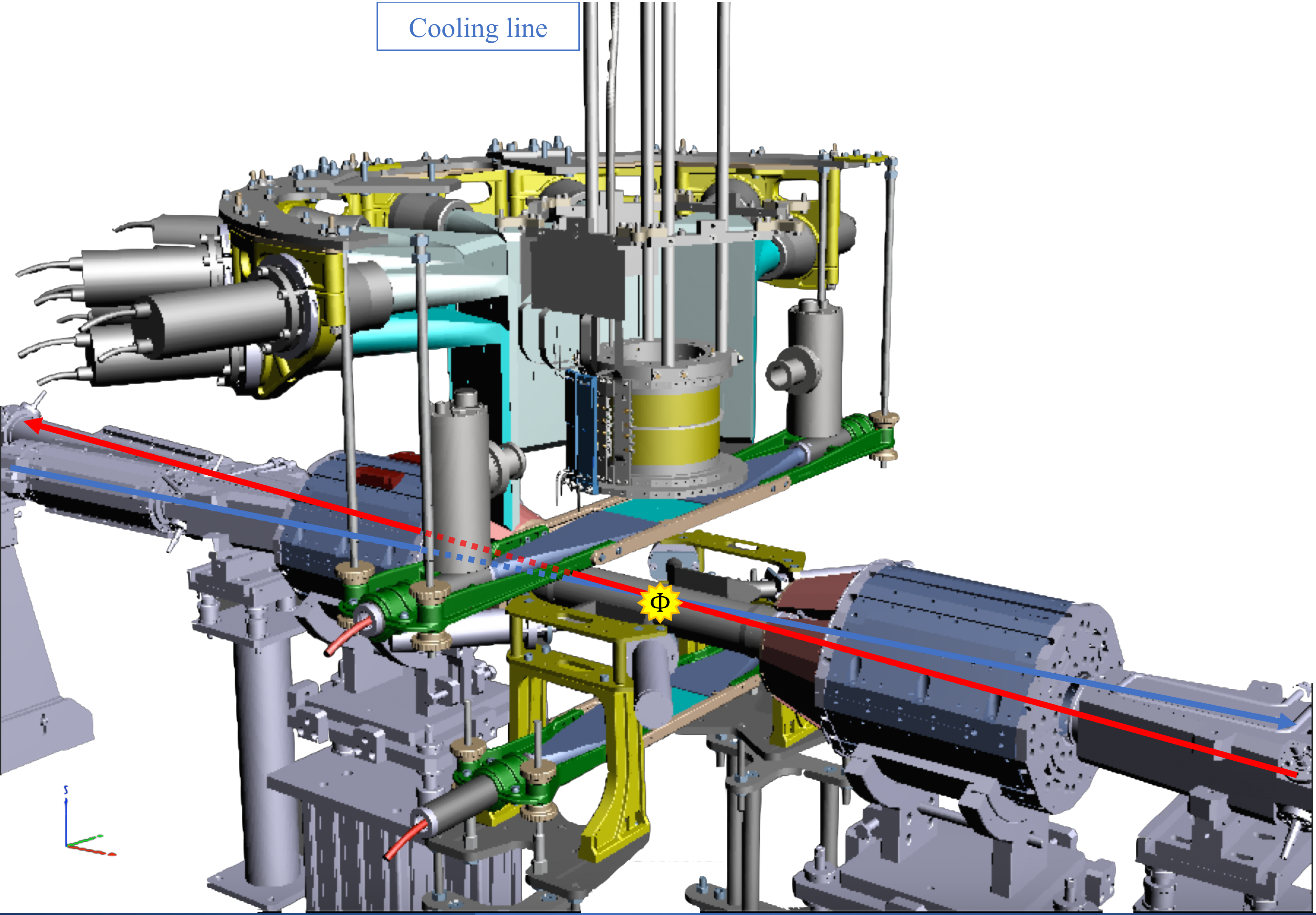
Solid angle

LNF - e^+e^- Accelerator Complex

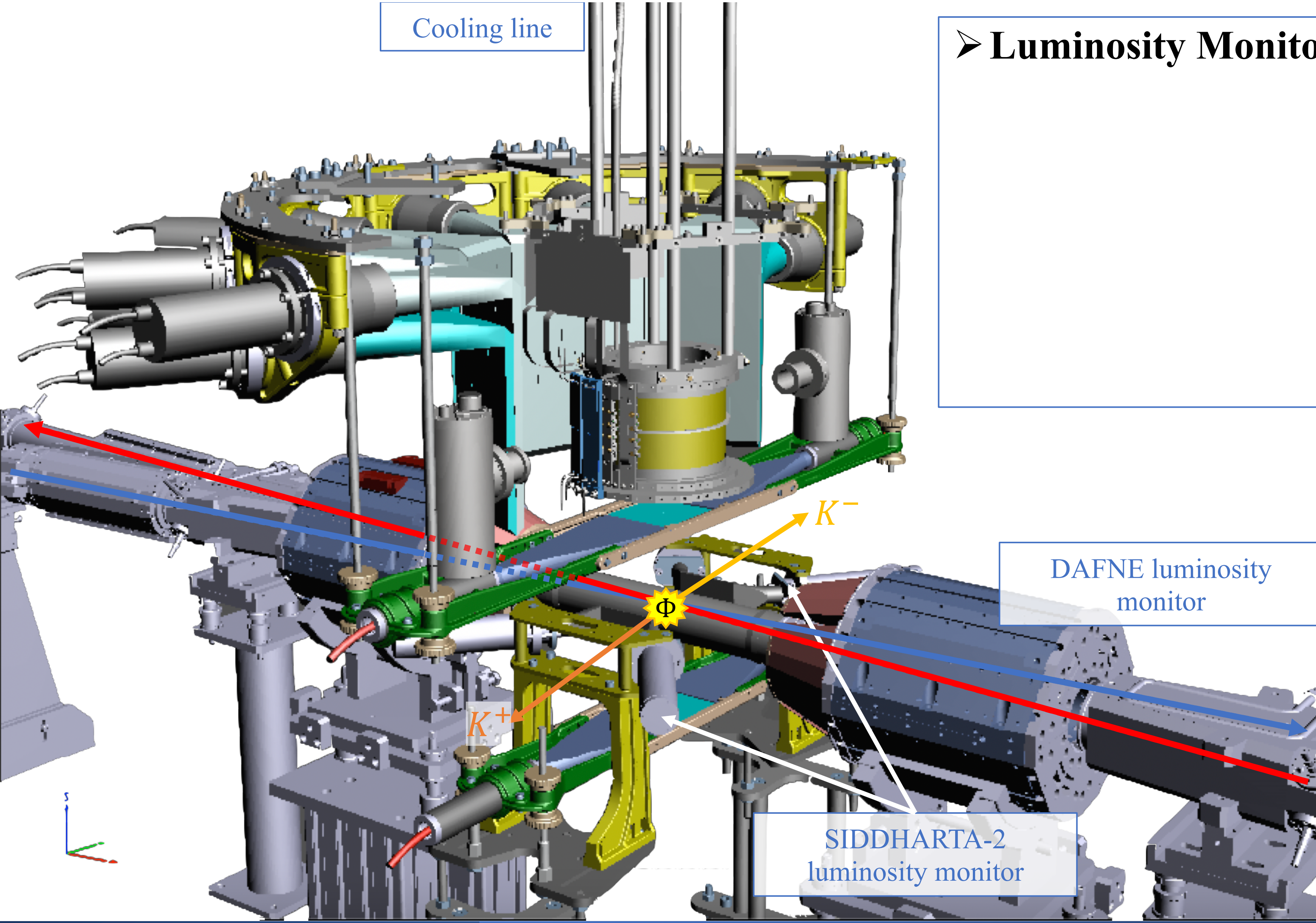
- $\Phi \rightarrow K^- K^+$ (48.9%)
- Monochromatic low-energy K^- (~127 MeV/c ; $\Delta p/p = 0.1\%$)



SIDDHARTA-2 setup



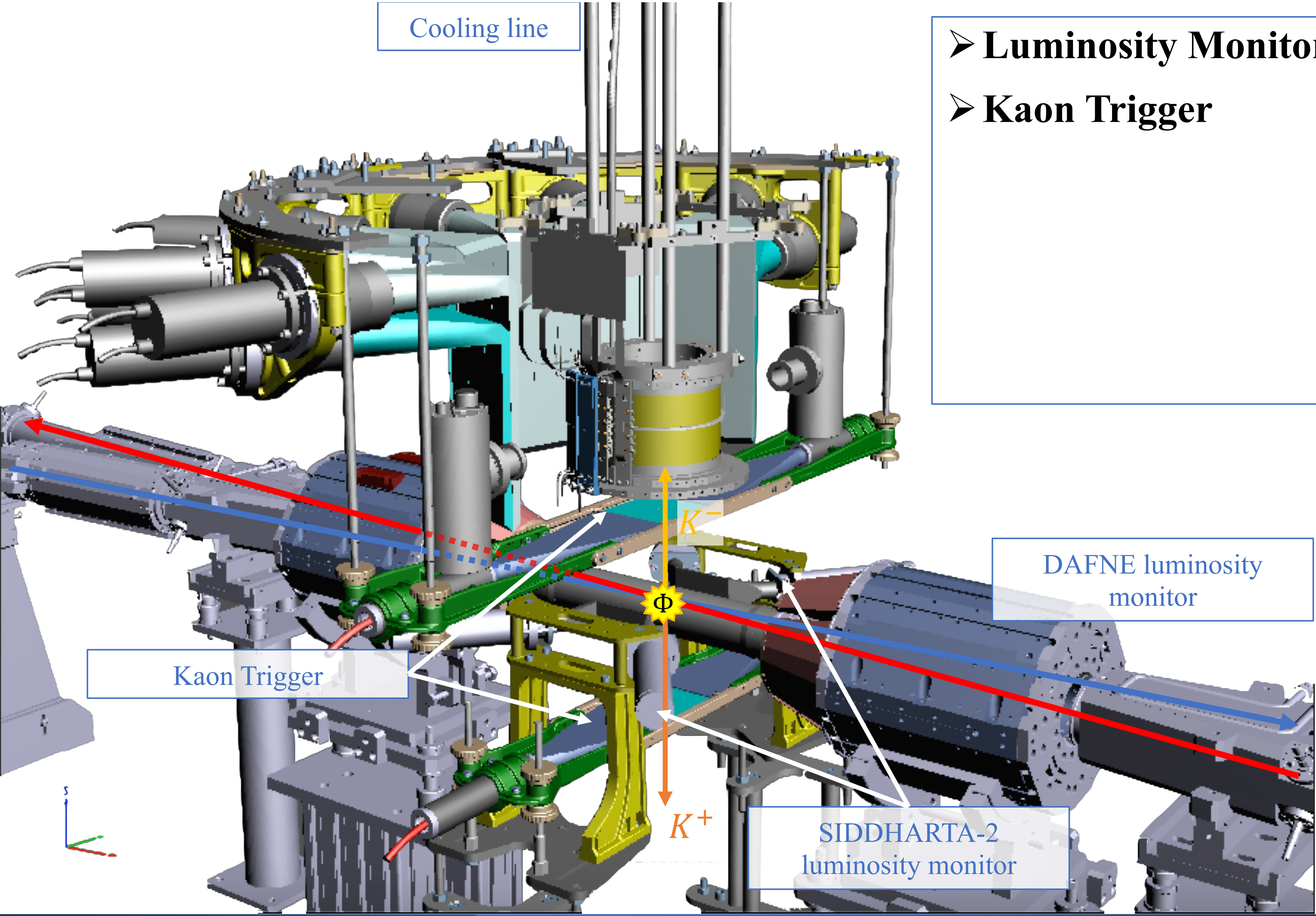
SIDDHARTA-2 setup



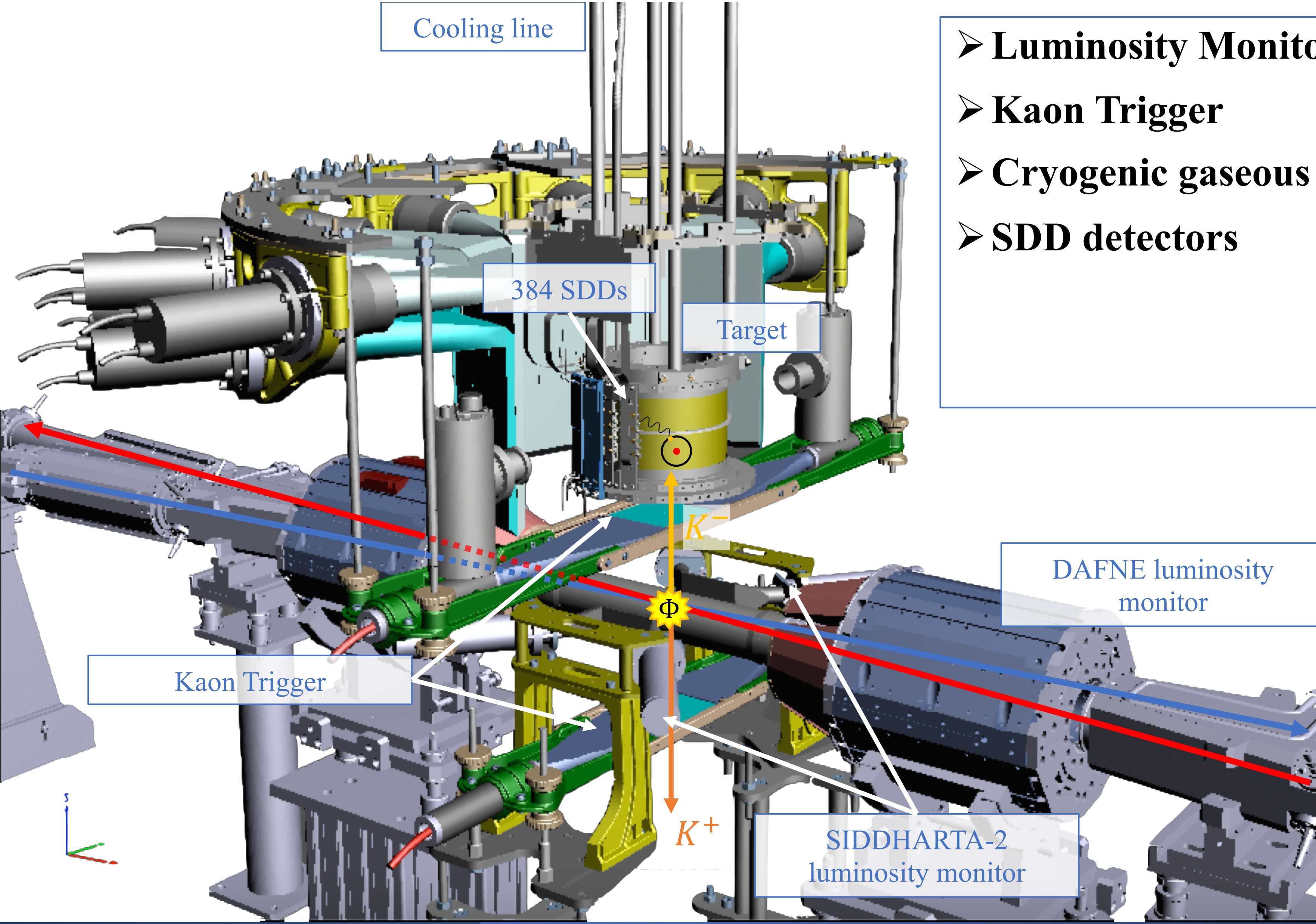
- **Luminosity Monitor**

SIDDHARTA-2 setup

- **Luminosity Monitor**
- **Kaon Trigger**

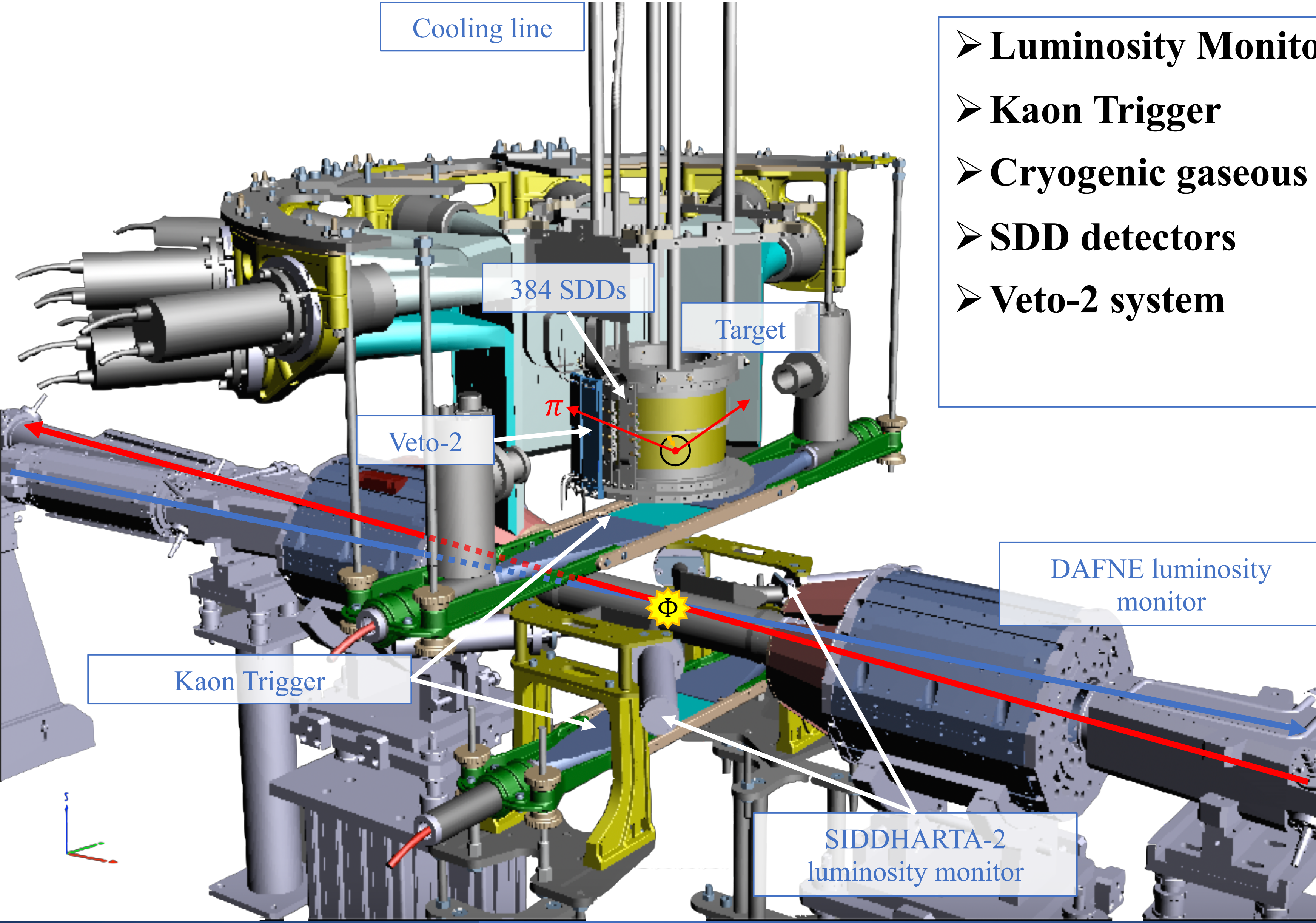


SIDDHARTA-2 setup



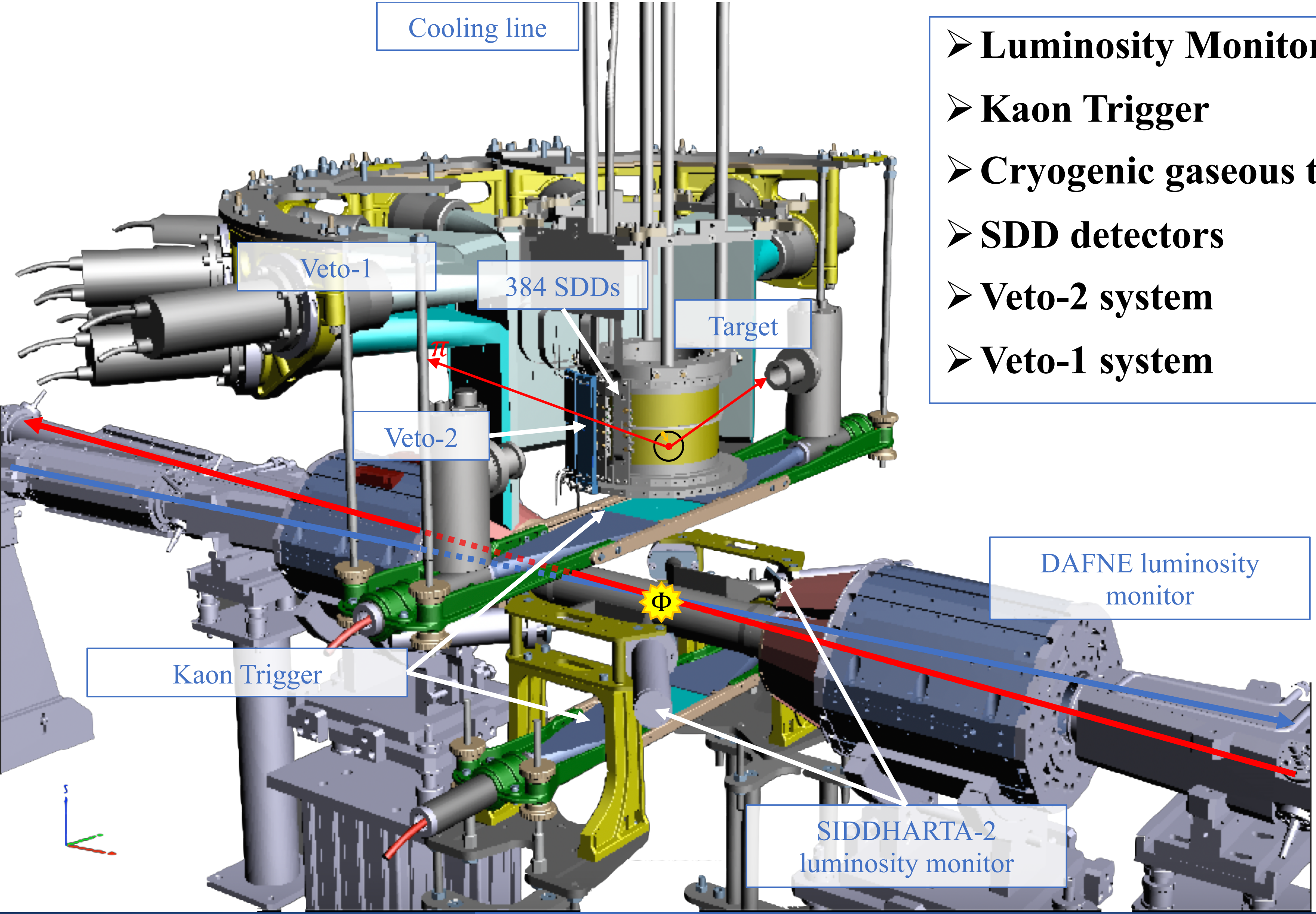
- **Luminosity Monitor**
- **Kaon Trigger**
- **Cryogenic gaseous target**
- **SDD detectors**

SIDDHARTA-2 setup



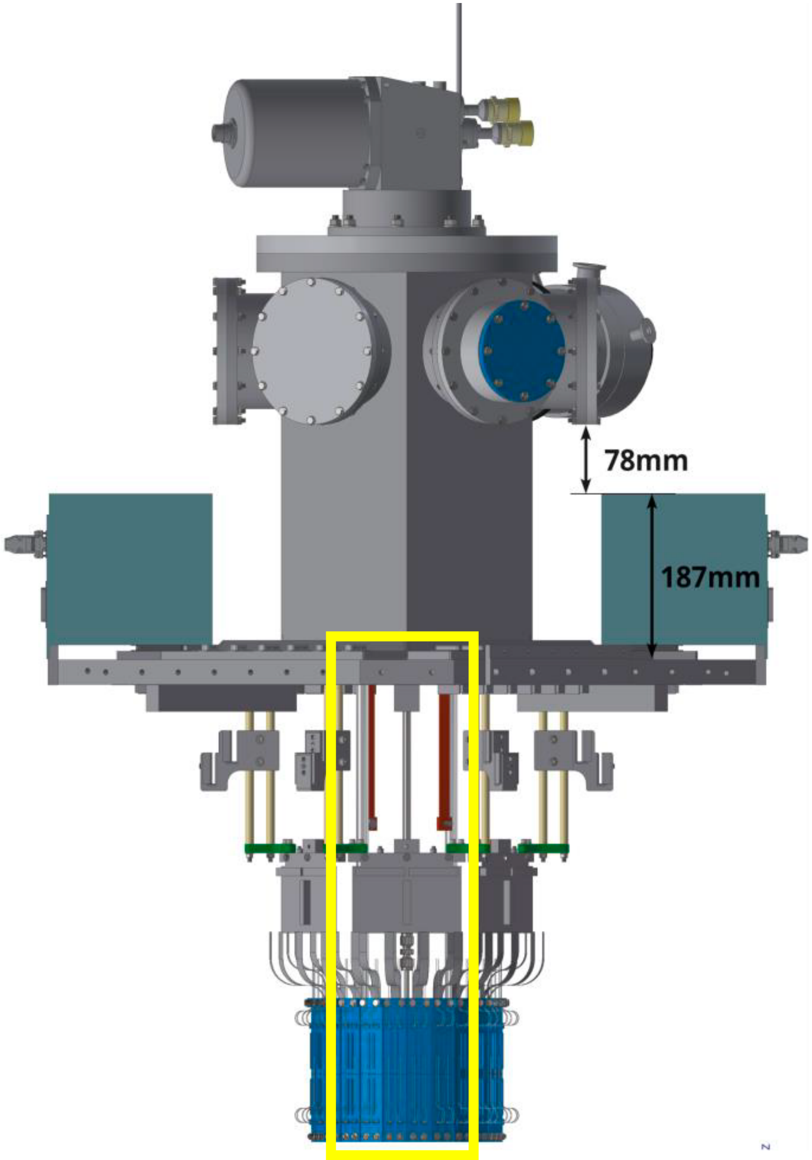
- **Luminosity Monitor**
- **Kaon Trigger**
- **Cryogenic gaseous target**
- **SDD detectors**
- **Veto-2 system**

SIDDHARTA-2 setup



- **Luminosity Monitor**
- **Kaon Trigger**
- **Cryogenic gaseous target**
- **SDD detectors**
- **Veto-2 system**
- **Veto-1 system**

SIDDHARTINO

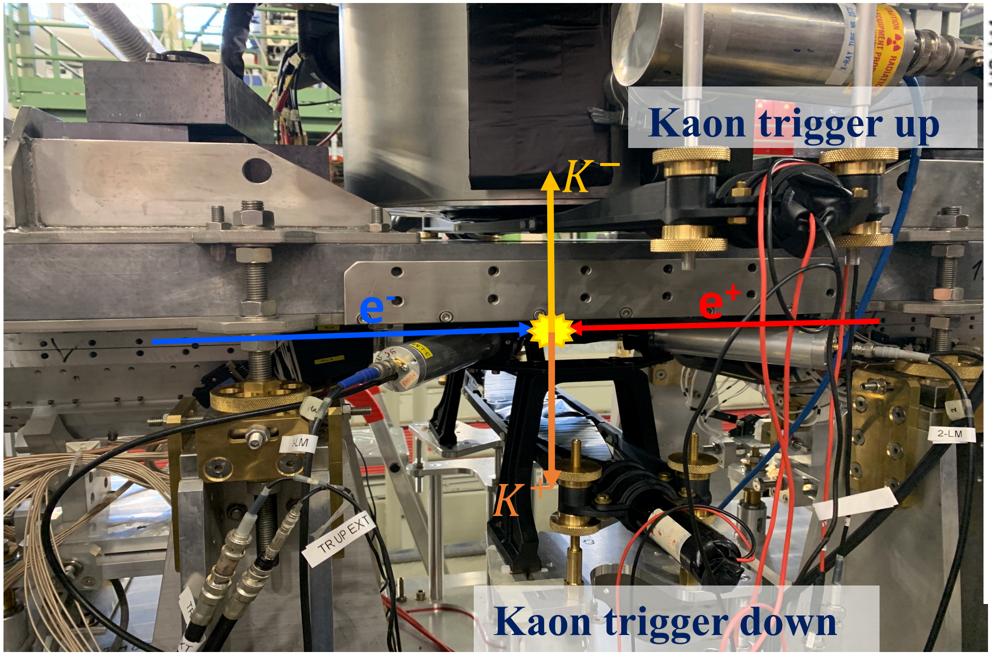


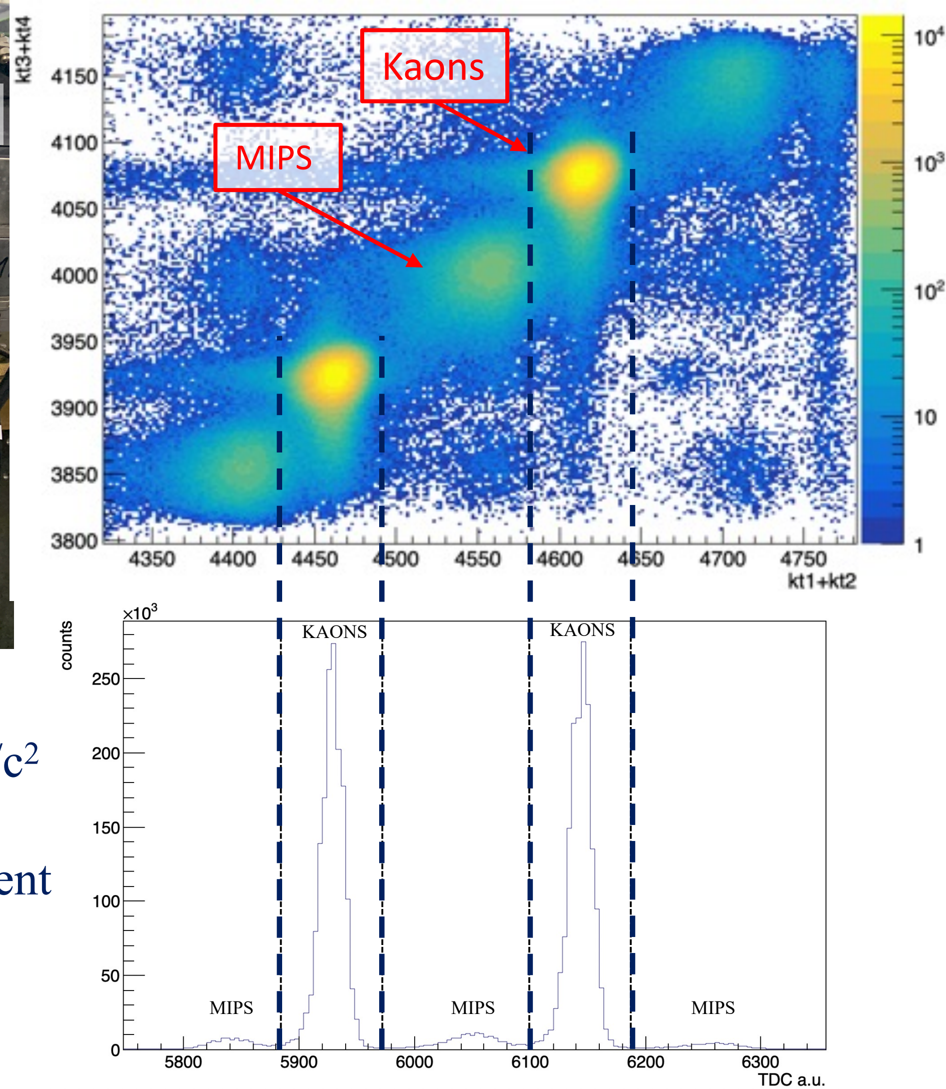
SIDDHARTINO: phase 1 of SIDDHARTA-2
1/6 of SIDDHARTA-2

Evaluation 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**

Kaon Trigger

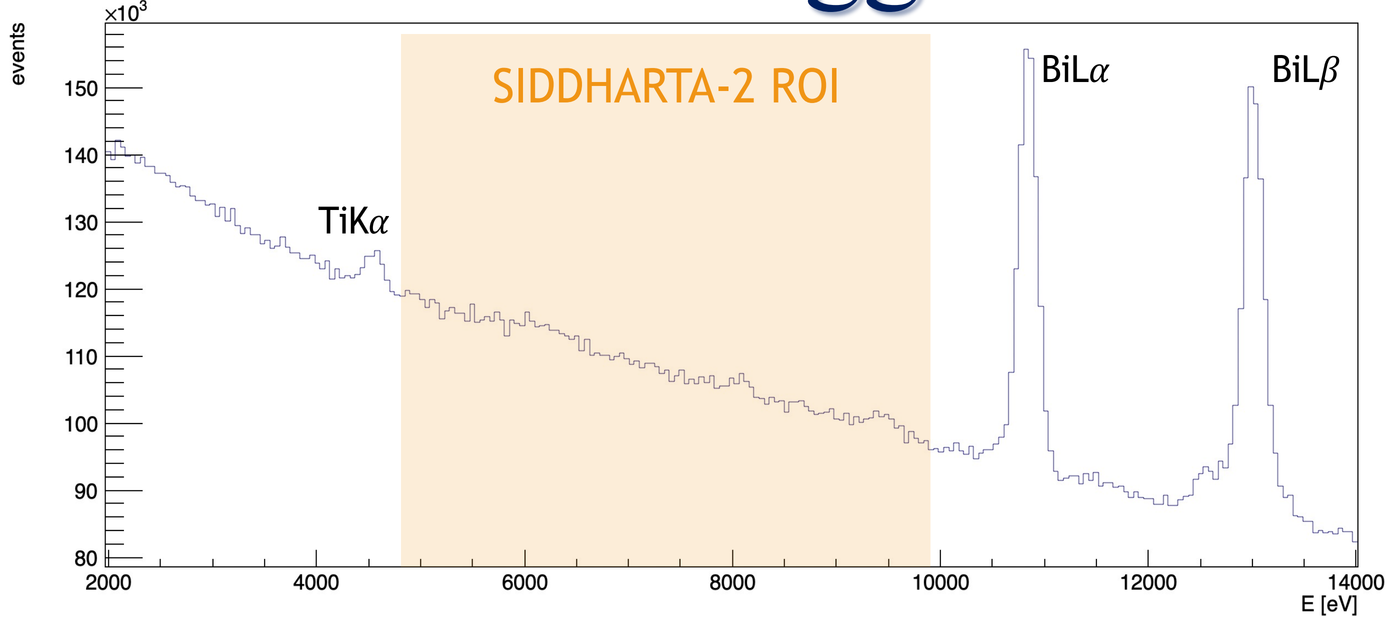




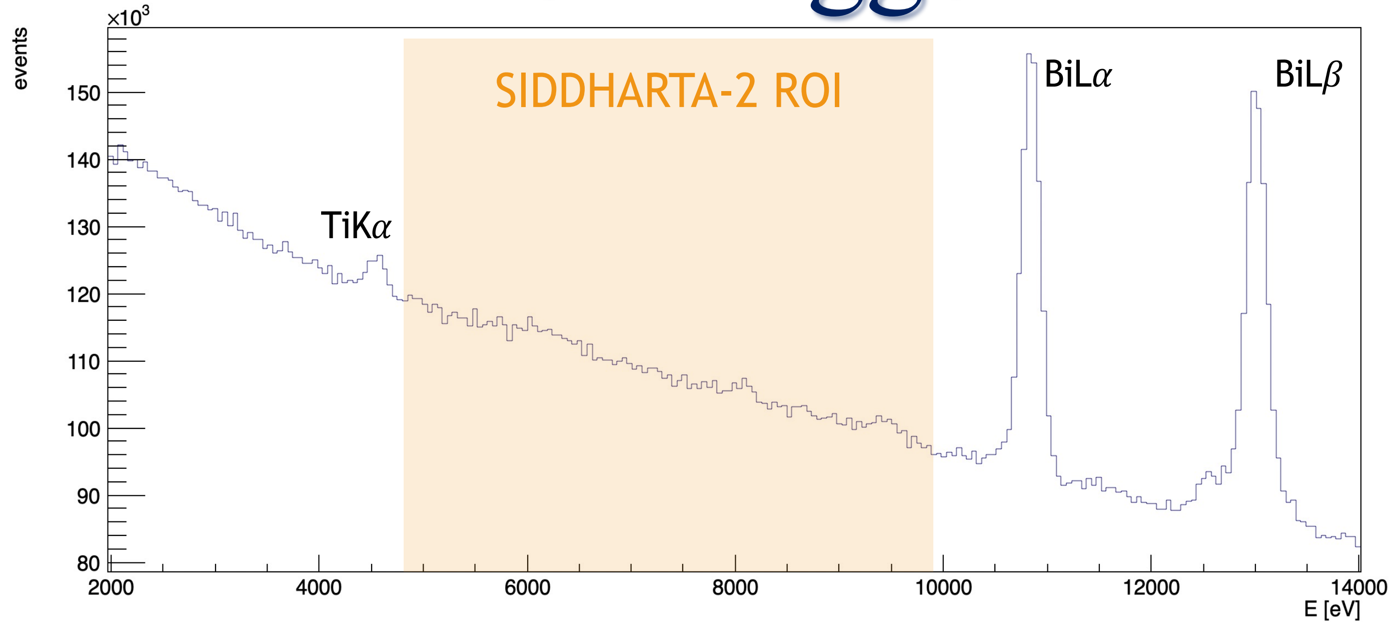
The ToF is different for Kaons, m(K)~ 500 MeV/c^2 and light particles originating from beam-beam and beam-environment interaction (MIPs).

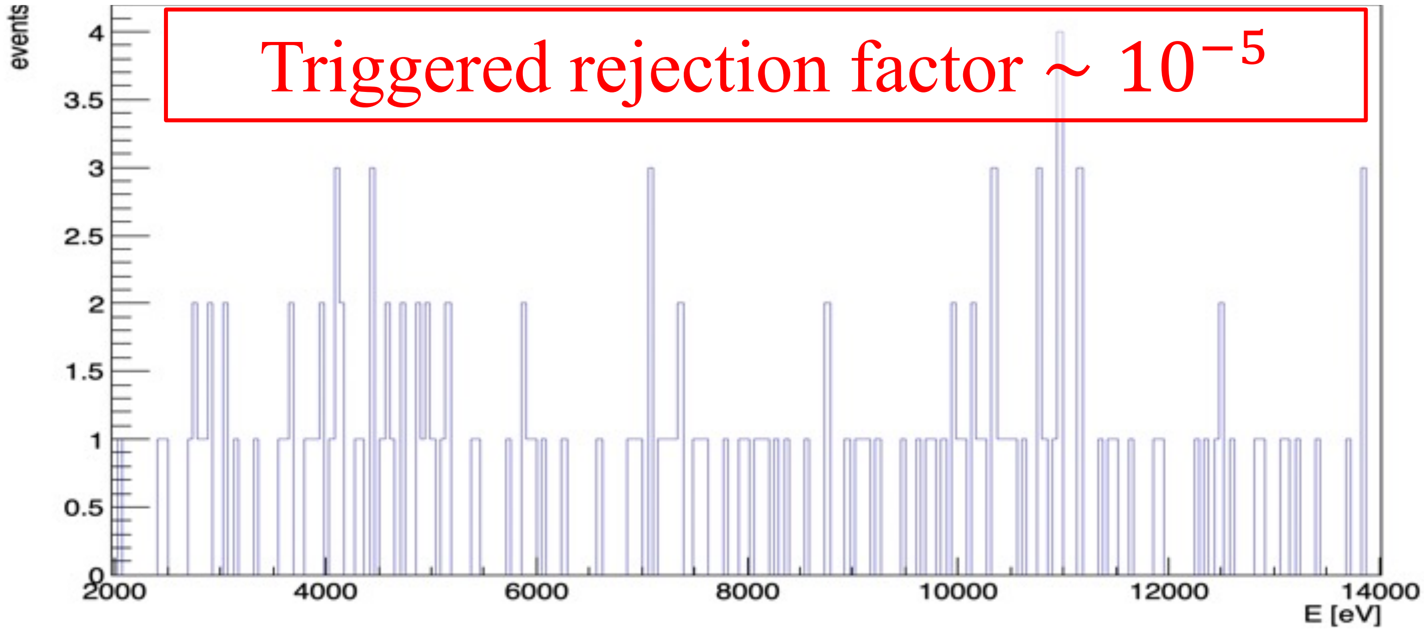
Can efficiently discriminate by ToF Kaons and MIPs!

Kaon Trigger



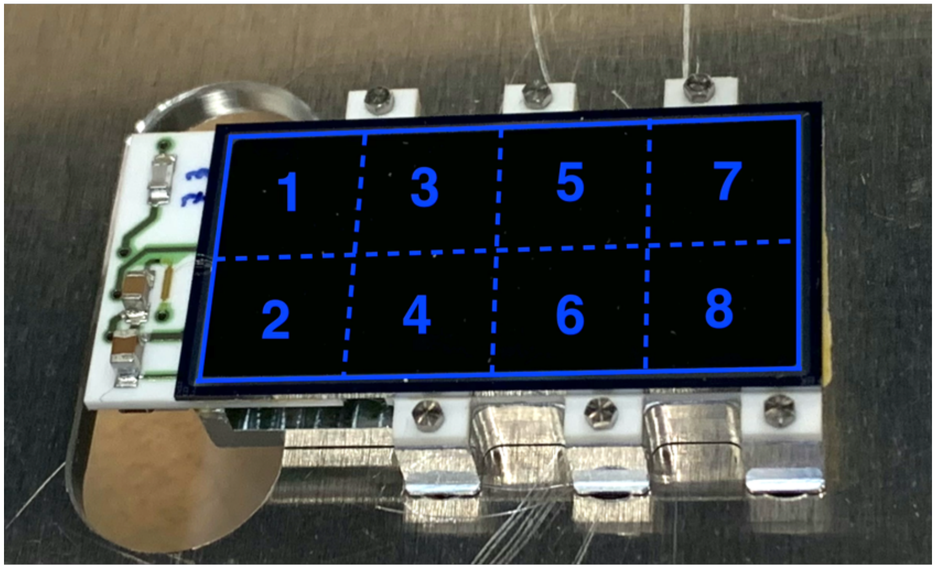
Kaon Trigger



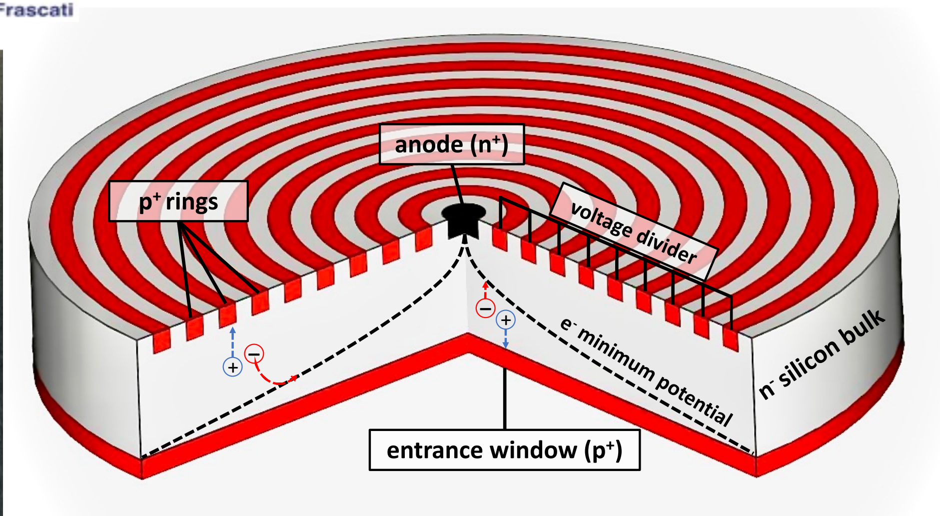


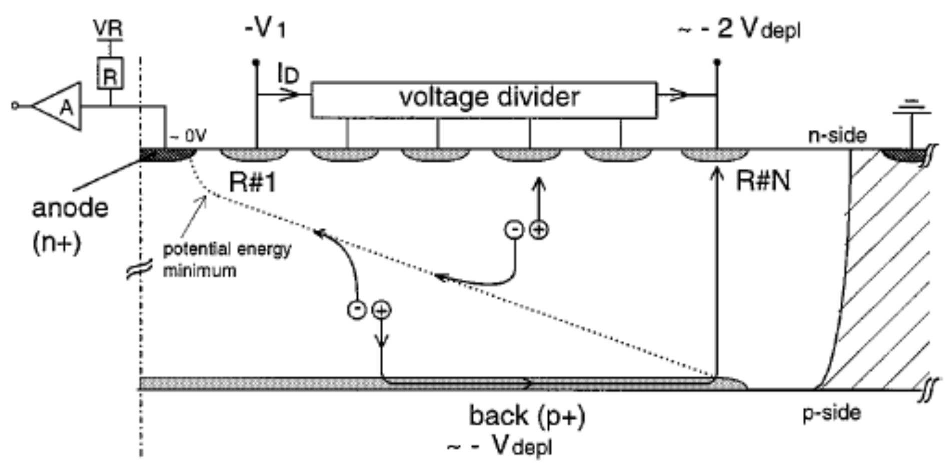
Silicon Drift Detectors

FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE
POLITECNICO MILANO 1863
INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati



SDD cross section

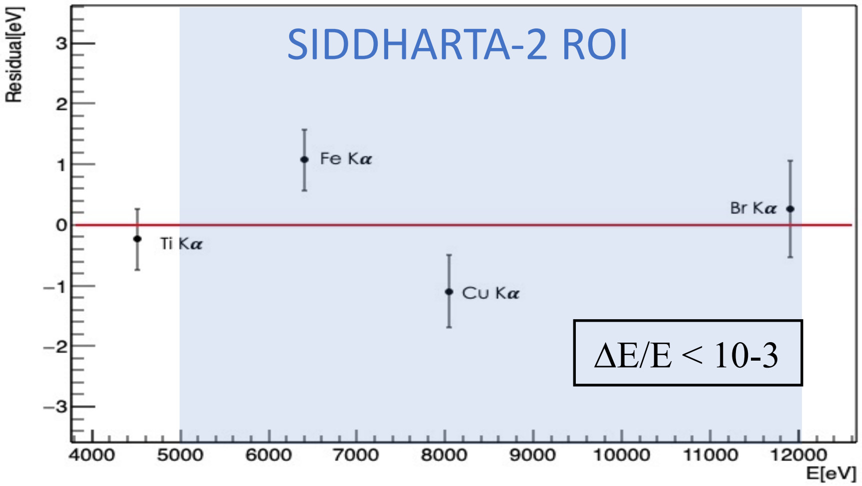




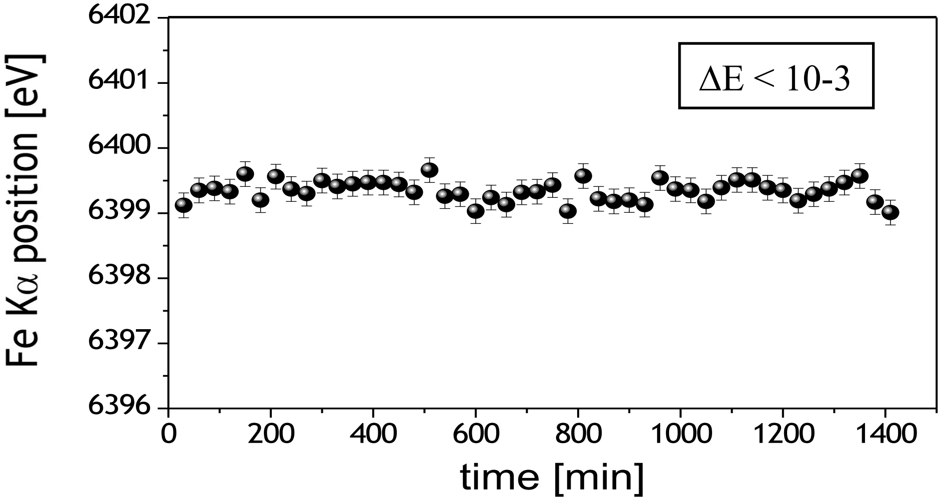
8 SDD units (0.64 cm^2)
for a total active area of 5.12 cm^2
Thickness of 450 µm which ensures a high collection efficiency for X-rays of energy between 5 keV and 12 keV

Silicon Drift Detectors

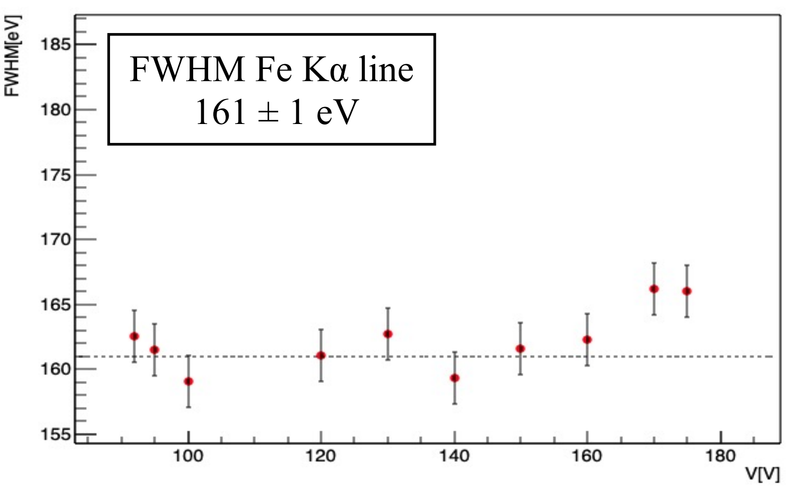
Linearity



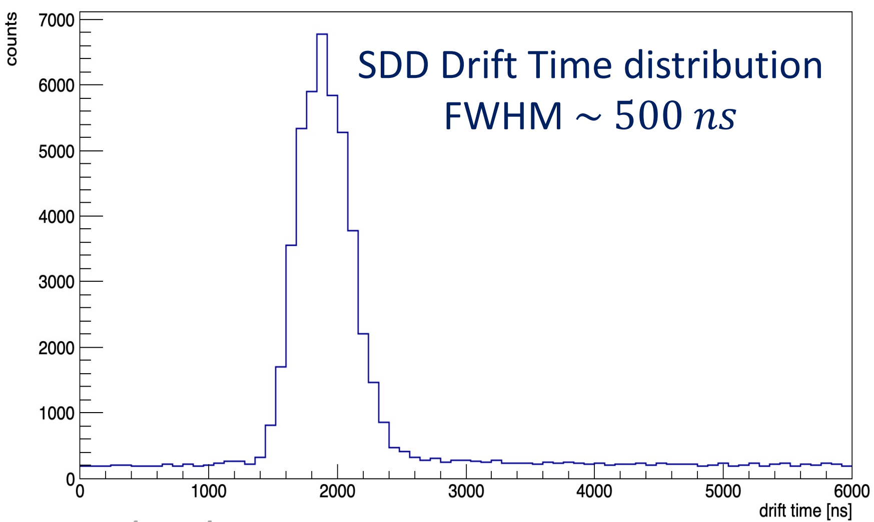
Stability



Energy Resolution



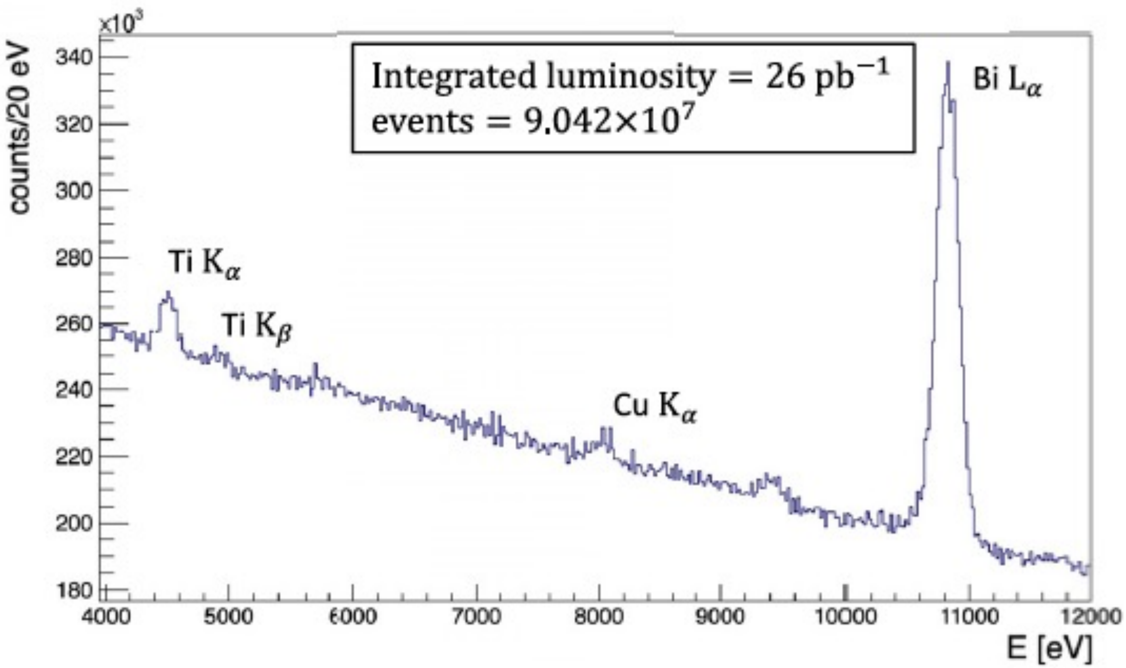
Timing Resolution



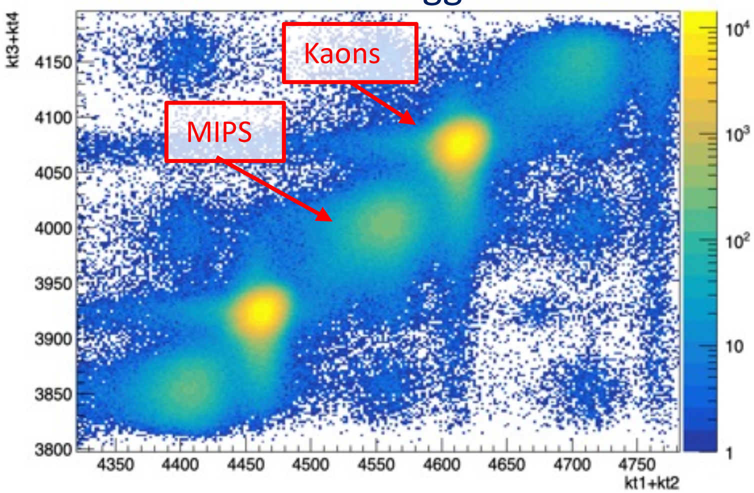
M Miliucci *et al* 2021 *Meas. Sci. Technol.* **32** 095501

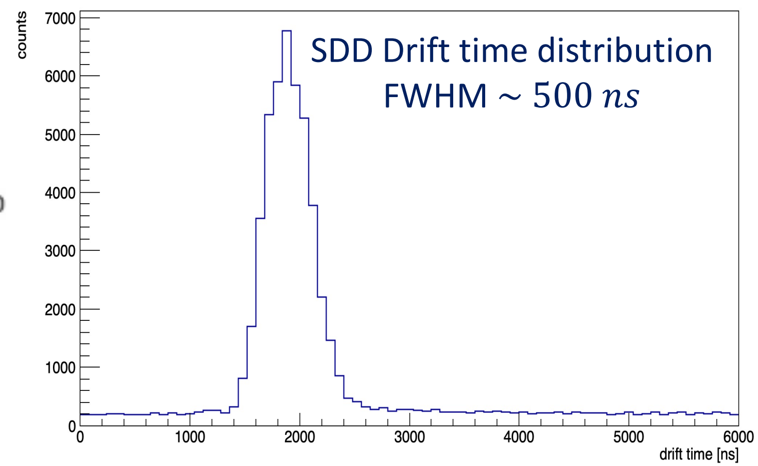
Kaonic ^{4}He 3d → 2p measurement

SIDDHARTINO spectrum before applying the **kaon trigger** and the **drift time rejection**

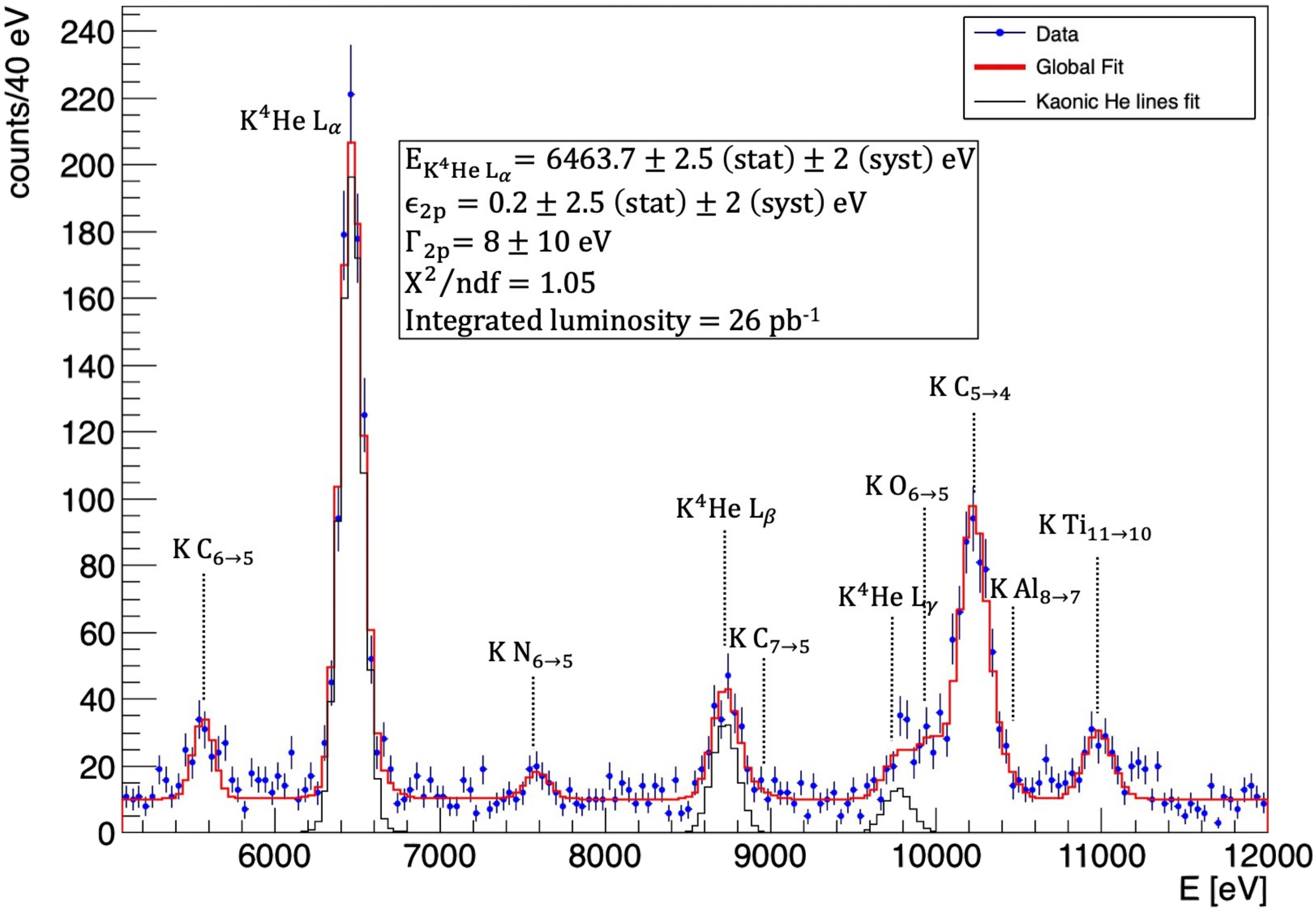


Kaon Trigger





Kaonic ^{4}He 3d → 2p measurement



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

SIDDHARTA-2 setup
Ready for Run

SIDDHARTA-2 K-d measurement

SIDDHARTA-2

Setup with all the SDDs (48 SDD arrays) **2022/3** and the *kaonic deuterium measurement* for a run of 800 pb^{-1}

Action plan for Kd measurement:

- First run with SIDDHARTA-2 setup as planned (about 300 pb^{-1} integrated)
- Second run with optimized shielding, readout electronics and other necessary optimizations; (for other 500 pb^{-1} integrated)

SIDDHARTA-2 K-d measurement

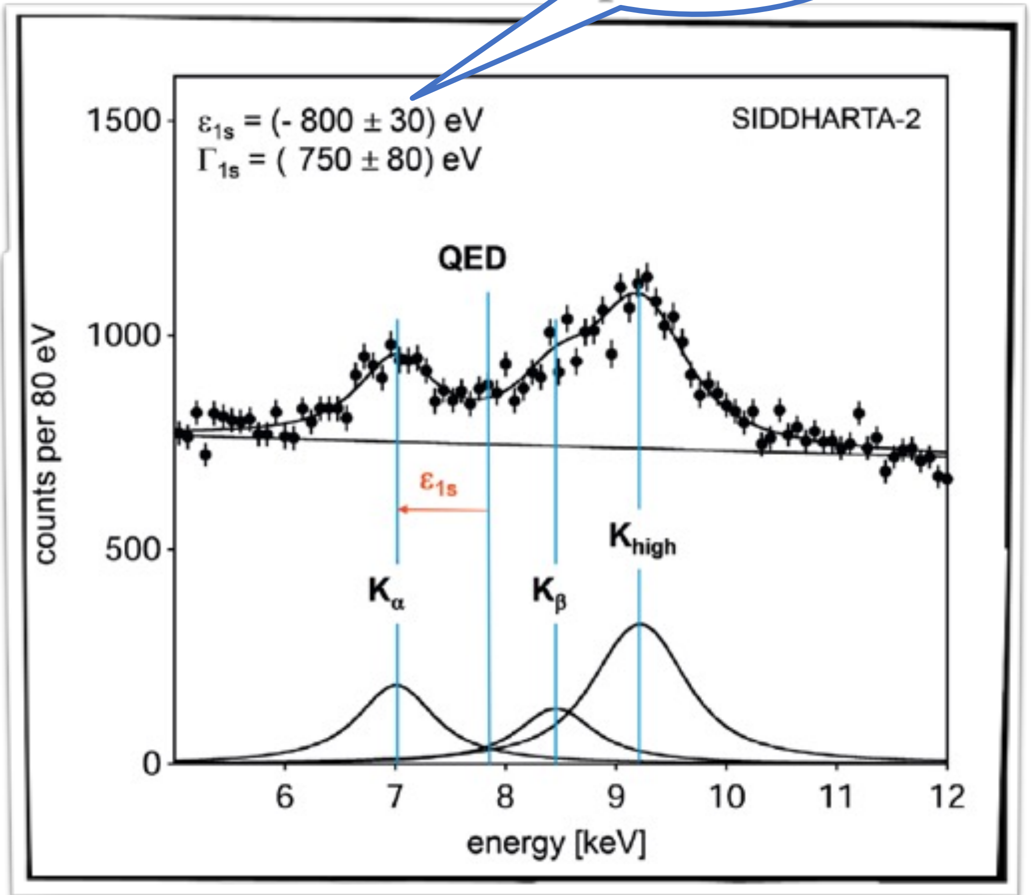
achievable precision

Kaonic deuterium run in (all)

2022

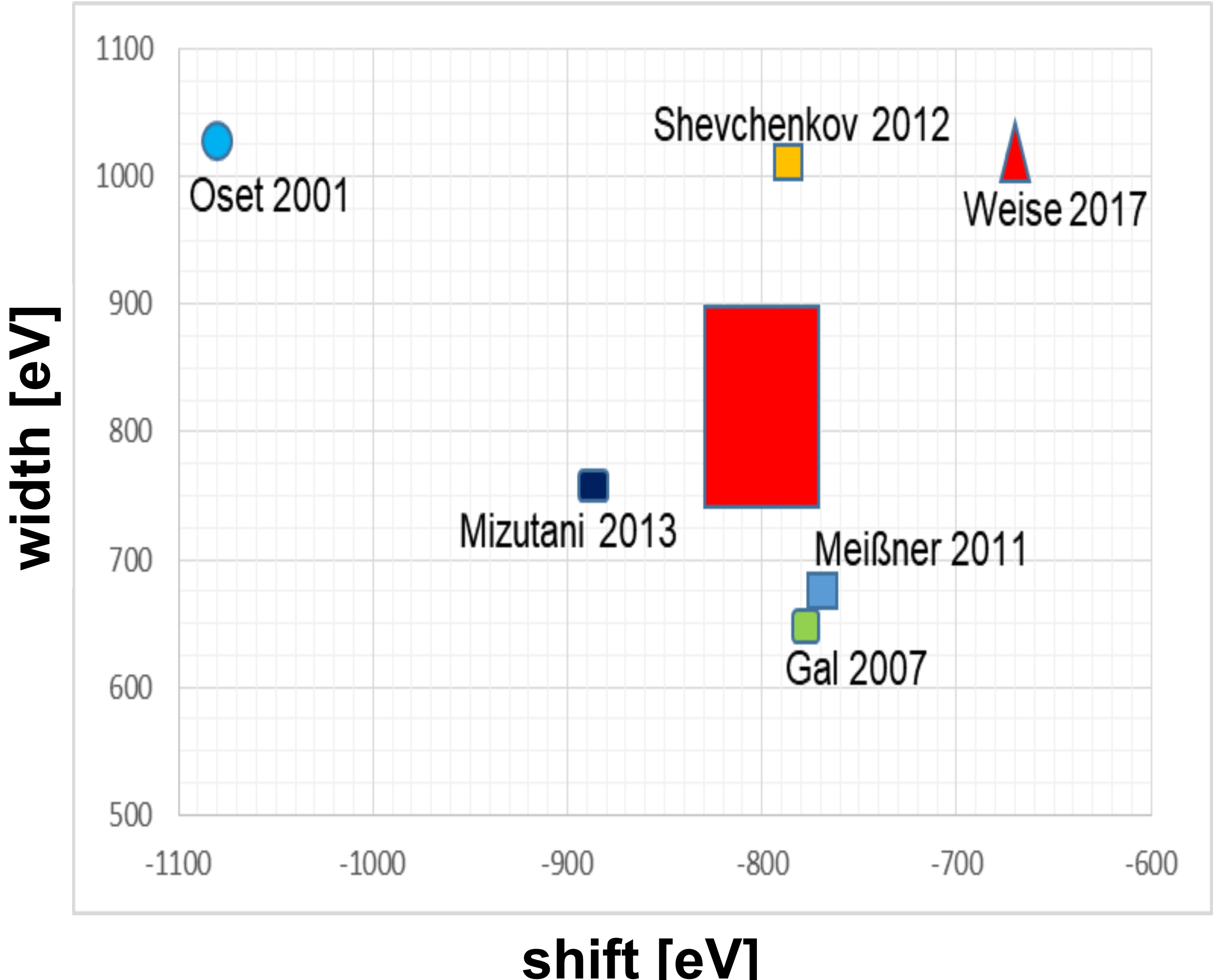
Monte Carlo for an integrated luminosity
of 800 pb^{-1}

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



Conclusions

- **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*
  - *Evaluation of the machine background*
  - ***Performed the most precise K-^4He $3d \rightarrow 2p$ measurement in gas***

- **SIDDHARTA-2 at DAFNE**
  - *Installation of the full SIDDHARTA-2 setup*
  - *Start of the kaonic deuterium run up to an integrated luminosity of 800 pb^{-1}*

Beyond SIDDHARTA-2

Future programme and perspectives

- **Feasibility studies in parallel with Siddharta-2**

- **Various setups in preparation:**
  - *HPGe*
  - *Crystal spectrometers (VOXES)*
  - *CdZnTe detectors*
  - *SDD 1mm for kaonic atoms measurement*

- **Proposal for Extension of the Scientific Program at DAFNE:**
  - *Kaon mass - precision measurement at a level < 7 keV*
  - *Kaonic helium transitions to the 1s level*
  - *Other light kaonic atoms (K^-Bi, Li, B,, K^-C,…)*
  - *Heavier kaonic atoms (K^-Si, K^-Pb…)*
  - *Radiative kaon capture – Λ(1405) study*
  - *Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen)*

Beyond SIDDHARTA-2

Future programme and perspectives

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  - *CdZnTe detectors*
  - *SDD 1mm for kaonic atoms mea*

Next Talk:
Kaonic atoms beyond SIDDHARTA-2: future measurements and perspectives at the DAFNE collider, A. Scordo

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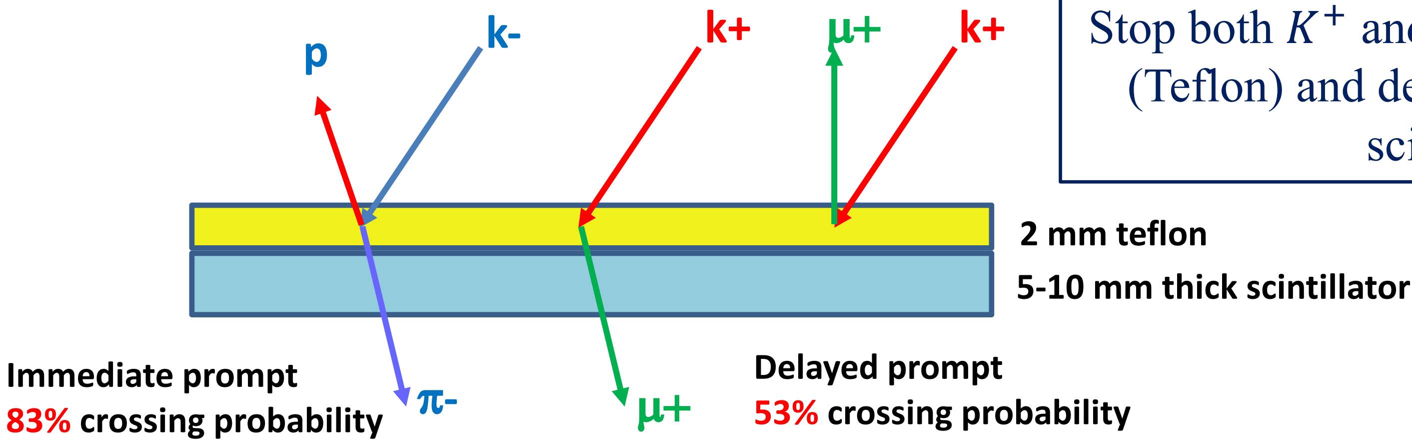
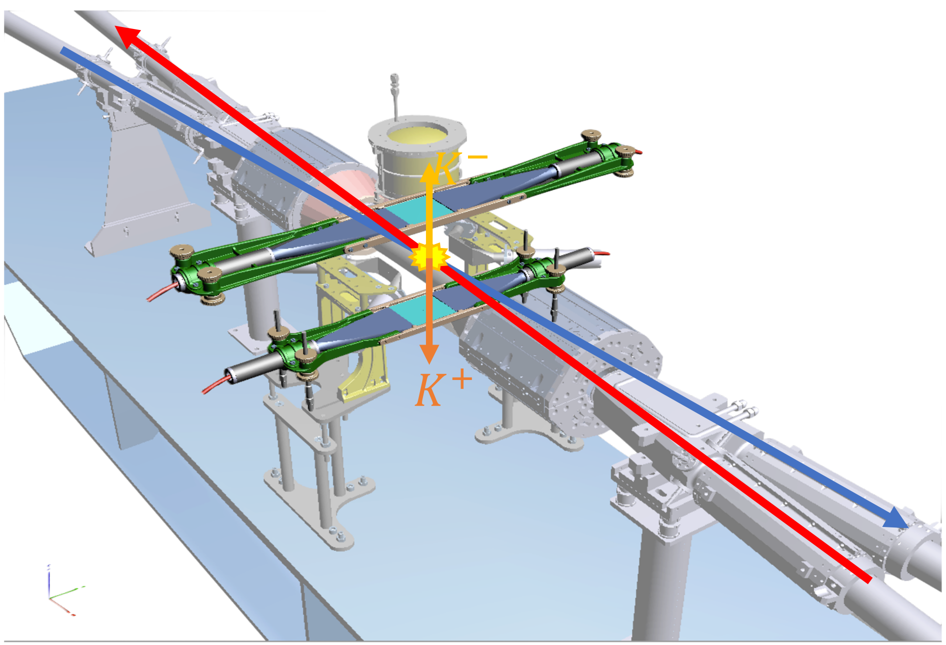
Thank You

SPARE

Kaon Charge Discriminator



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



Interaction	Channel	Branching ratio
K^-p	$\Sigma^-\pi^+ \to (n\pi^-)\pi^+$	15.92%
K^-p	$\Sigma^+\pi^- \to (p\pi^0)\pi^-$	18.56%
K^-p	$\Sigma^+\pi^- \to (n\pi^+)\pi^-$	17.12%
K^-p	$\Sigma^0\pi^0 \to (\Lambda\gamma)\pi^0 \to ((p\pi^-)\gamma)\pi^0$	15.52%
K^-p	$\Sigma^0\pi^0 \to (\Lambda\gamma)\pi^0 \to ((n\pi^0)\gamma)\pi^0$	8.72% *
K^-p	$\Lambda\pi^0 \to (p\pi^-)\pi^0$	2.66%
K^-p	$\Lambda\pi^0 \to (n\pi^0)\pi^0$	1.54% *
K^-n	$\Sigma^-\pi^0 \to (n\pi^-)\pi^0$	4.32%
K^-n	$\Sigma^0\pi^- \to (\Lambda\gamma)\pi^- \to ((p\pi^-)\gamma)\pi^-$	2.76%
K^-n	$\Sigma^0\pi^- \to (\Lambda\gamma)\pi^- \to ((n\pi^0)\gamma)\pi^-$	1.56%
K^-n	$\Lambda\pi^- \to (p\pi^-)\pi^-$	7.27%
K^-n	$\Lambda\pi^- \to (n\pi^0)\pi^-$	4.09%