The SIDDHARTA-2 experiment: present status and future perspectives

Florin Sirghi o behalf of SIDDHARTA-2 Collaboration

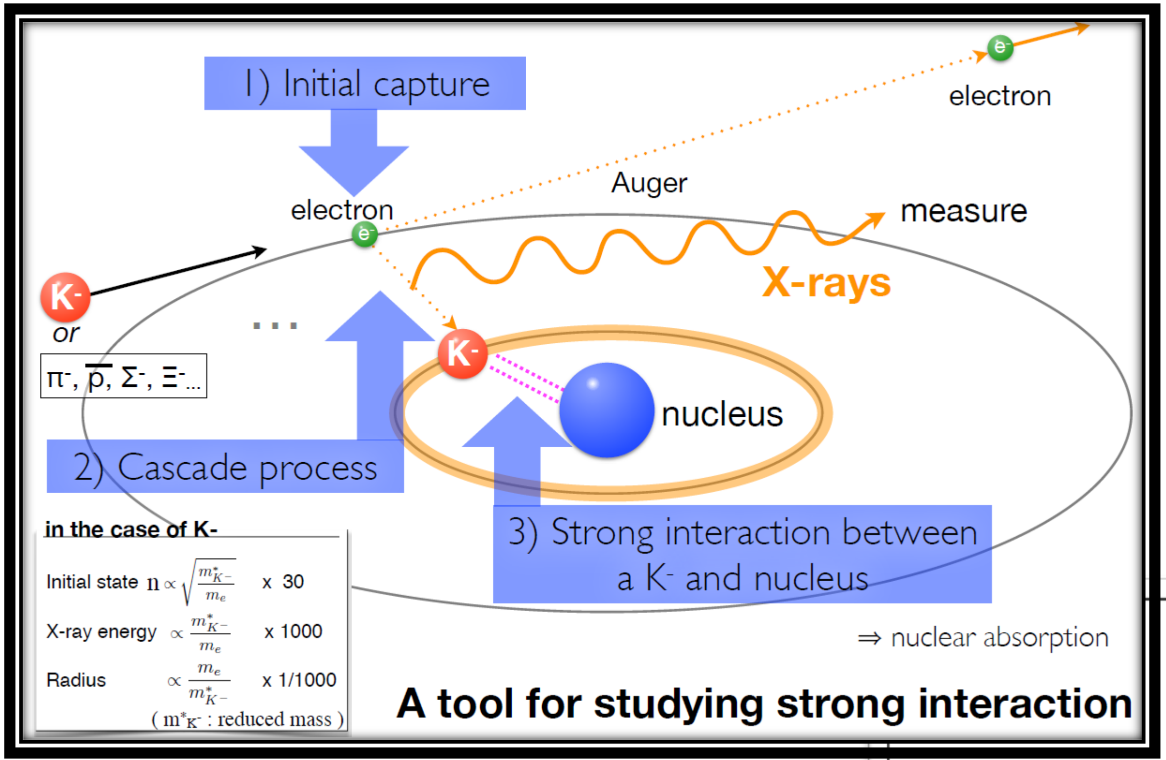
FONDAZIONE BRUNO KESSLER

ECT* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

ROCKSTAR: Towards a ROadmap of the Crucial measurements of Key observables in Strangeness reactions for neutron sTARs equation of state

Trento, 9-13 October 2023

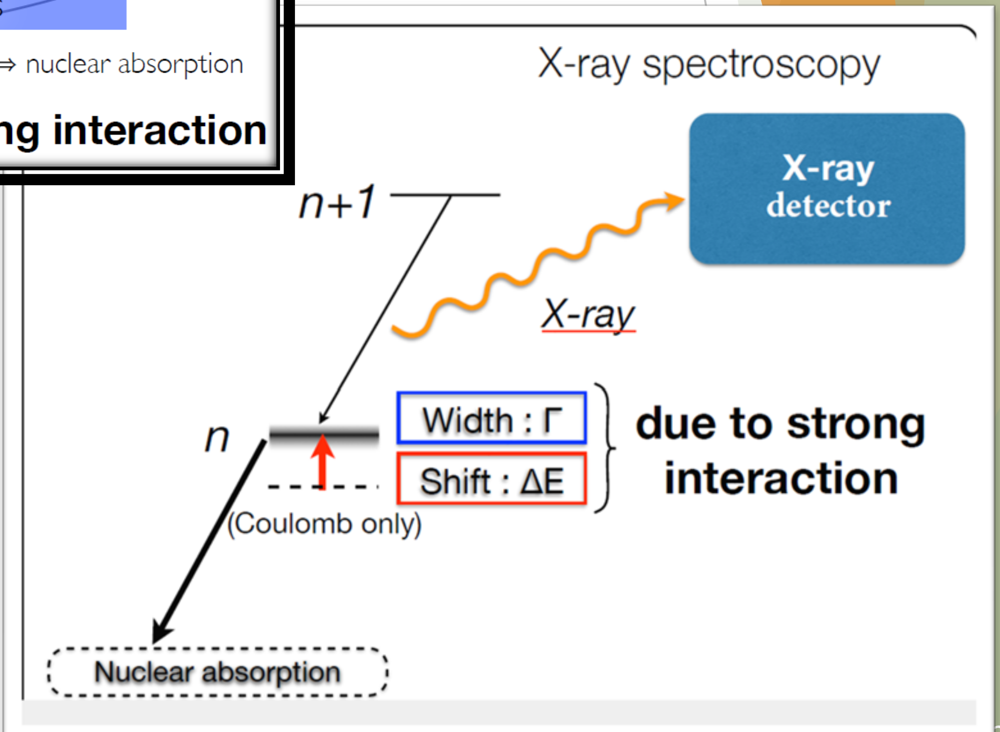
KAONIC ATOMS RESEARCH



Kaonic atoms are formed by stopping a *negatively charged kaon* in a target medium

H, He, D, N, …

Li, Be, C, Al, …



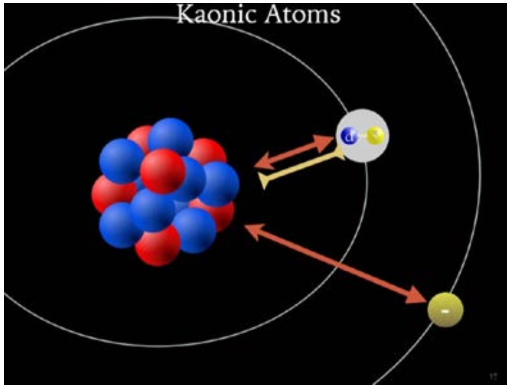
Strong interaction induced width Γ and shift ε obtained by measuring the X-rays emitted

KAONIC ATOMS RESEARCH

SUCCES

Quality kaon beam

- $\Phi \rightarrow K^- K^+$ (48.9%)
- Monochromatic low-energy K^- (~127 MeV/c ; $\Delta p/p$ = 0.1%)
- Less hadronic background compared to hadron beam line

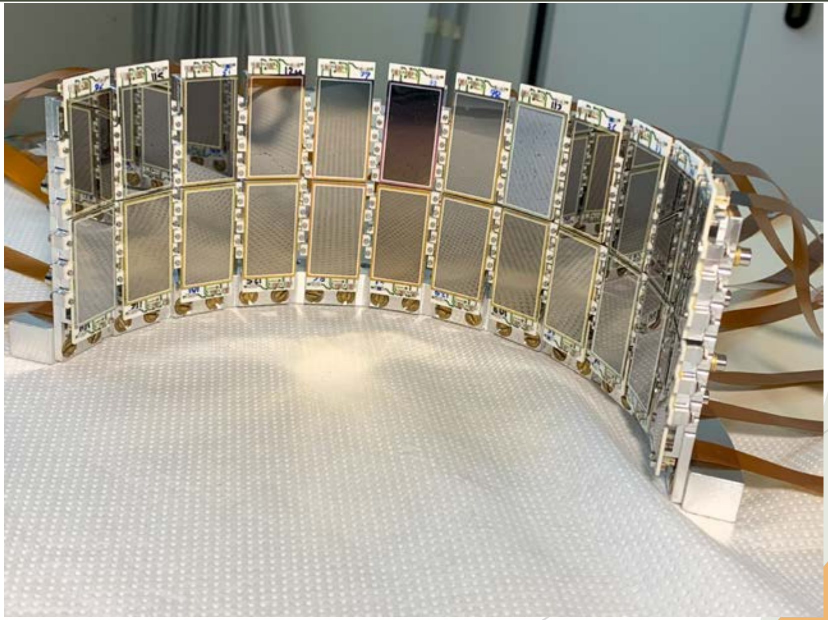


KAONIC ATOMS RESEARCH

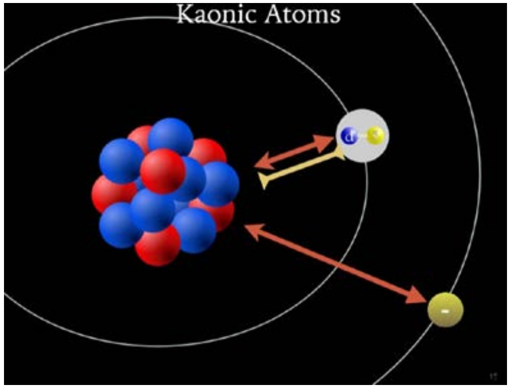
SUCCES

Quality kaon beam

Efficient x-ray detector system



Silicon Drift Detectors



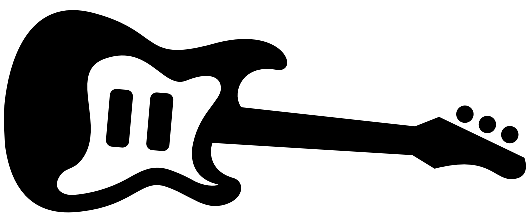
KAONIC ATOMS RESEARCH

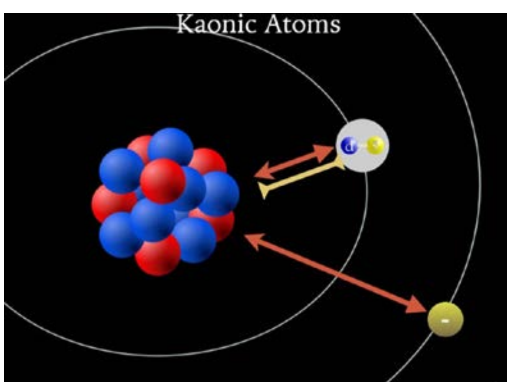
SUCCES

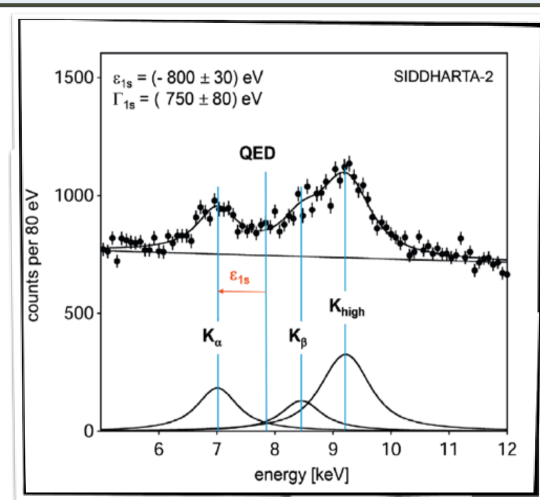
Quality kaon beam

Efficient x-ray detector system

Powerful analysis tools







Monte Carlo simulations

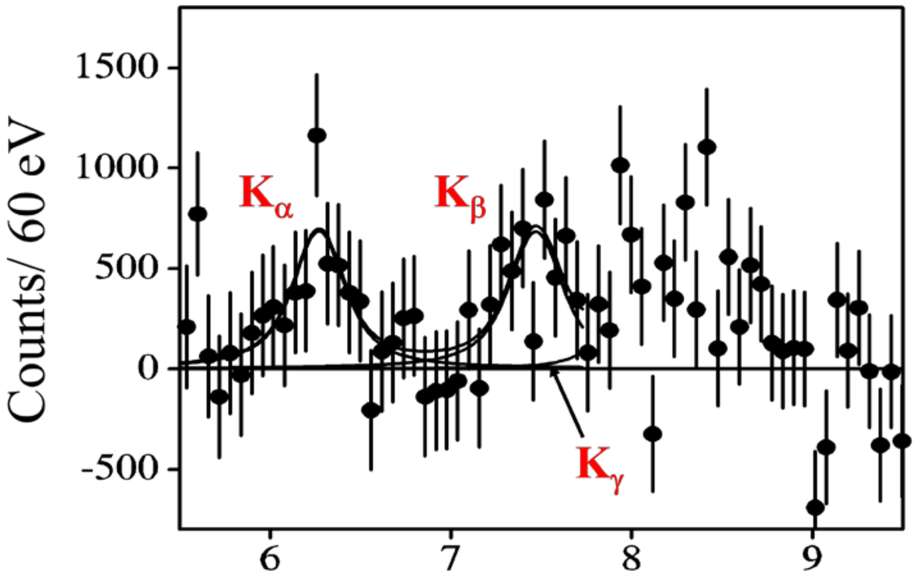
Optimization of the setup and detectors response (trigger, SDDs, veto, ...)

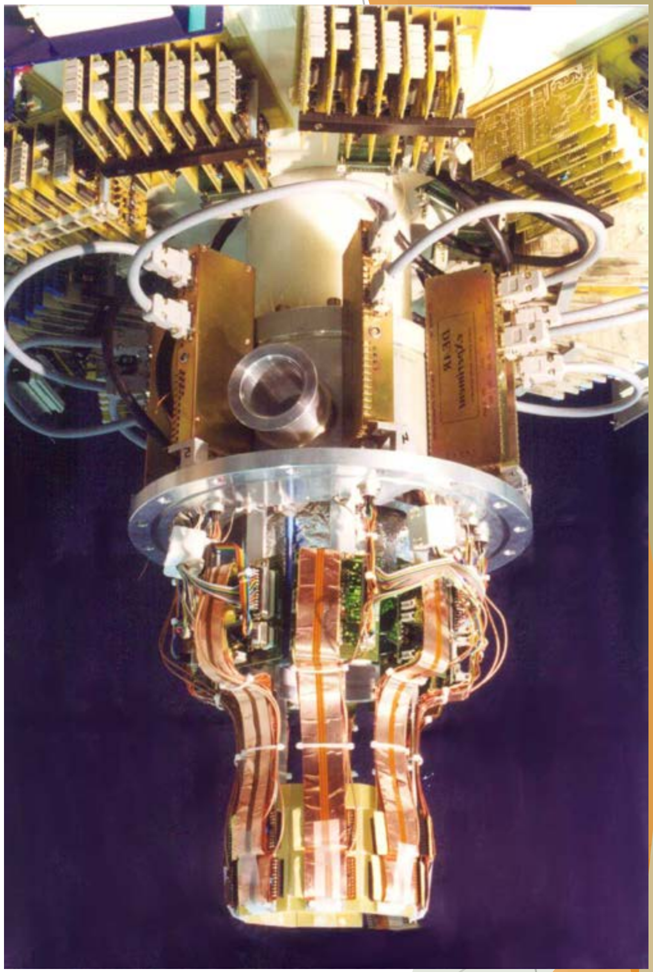
Kaonic deuterium expectation


EXKALIBUR
SIDDHARTA-2
SIDDHARTA
DEAR
KAONIC
ATOMS
RESEARCH

KAONIC HYDROGEN
KAONIC Nitrogen

G. Beer et al., PRL 94 (2005) 212302





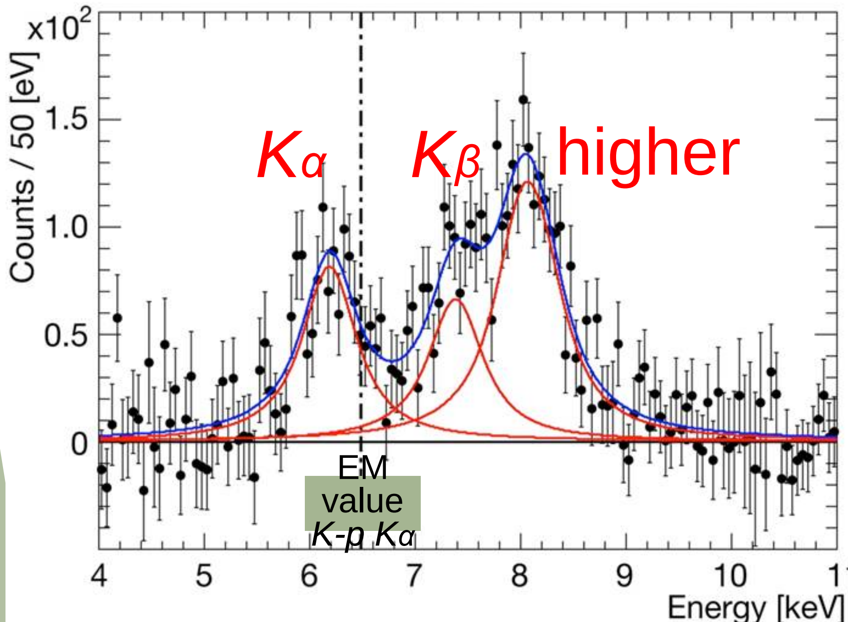
A new method to obtain a precise value of the mass of the charged kaon"
Phys. Lett. B535 (2002) 52.

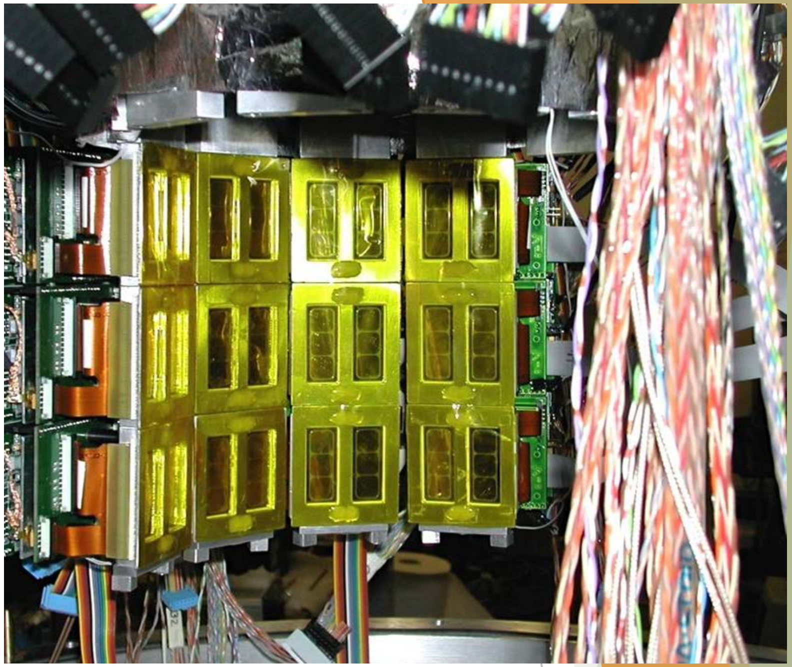
Kaonic nitrogen X-ray transition yields in a gaseous target
Phys. Lett. B593 (2004) 48.

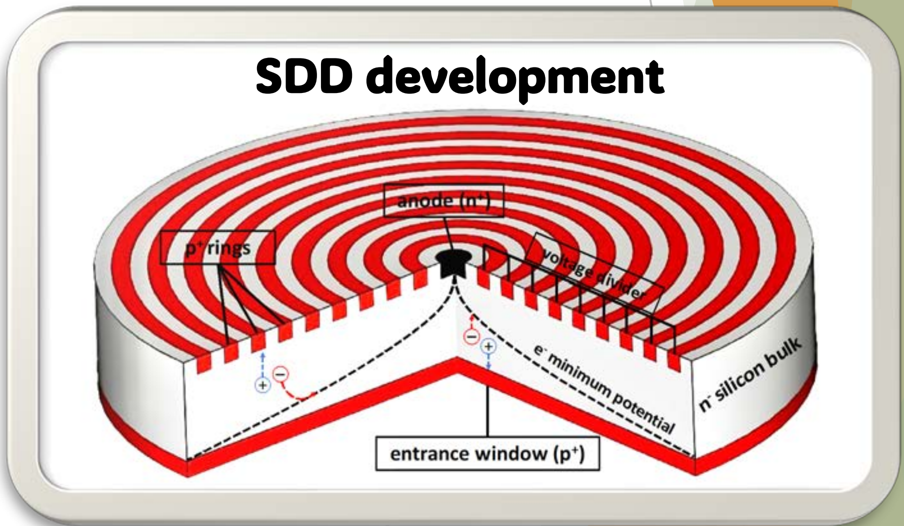
KAONIC HYDROGEN

KAONIC Helium

C. Curceanu et al., *Phys. Lett. B* 704 (2011) 113







Kaonic helium 4 - Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264, Phys. Lett. B 697 (2011)

Kaonic helium 3 – Phys. Lett. B 697 (2011) 199

Yields - Phys. Lett. B714 (2012) 40; Nucl. Phys. A916 (2013) 30; EPJ A(2014) 50; Nucl. Phys. A954 (2016) 7

SIDDHARTA-2

KAONIC
ATOMS
RESEARCH

Scientific Goal of SIDDHARTA-2

The first measurement of *kaonic deuterium* transitions to the fundamental 1s level
to extract the antikaon-nucleon isospin dependent scattering lengths (using also the measurement of kaonic hydrogen performed by SIDDHARTA)

e.g., Kaonic hydrogen

U.-G. Meißner et al, Eur Phys J C35 (2004) 349
(Deser-Type relation with isospin-braking correction)

$$\epsilon_{1s} + i\Gamma_{1s}/2 = 2\alpha^3 \mu_r^2 a_{K^-p} [1 + 2\alpha \mu_r (1 - \ln\alpha) a_{K^-p}]$$

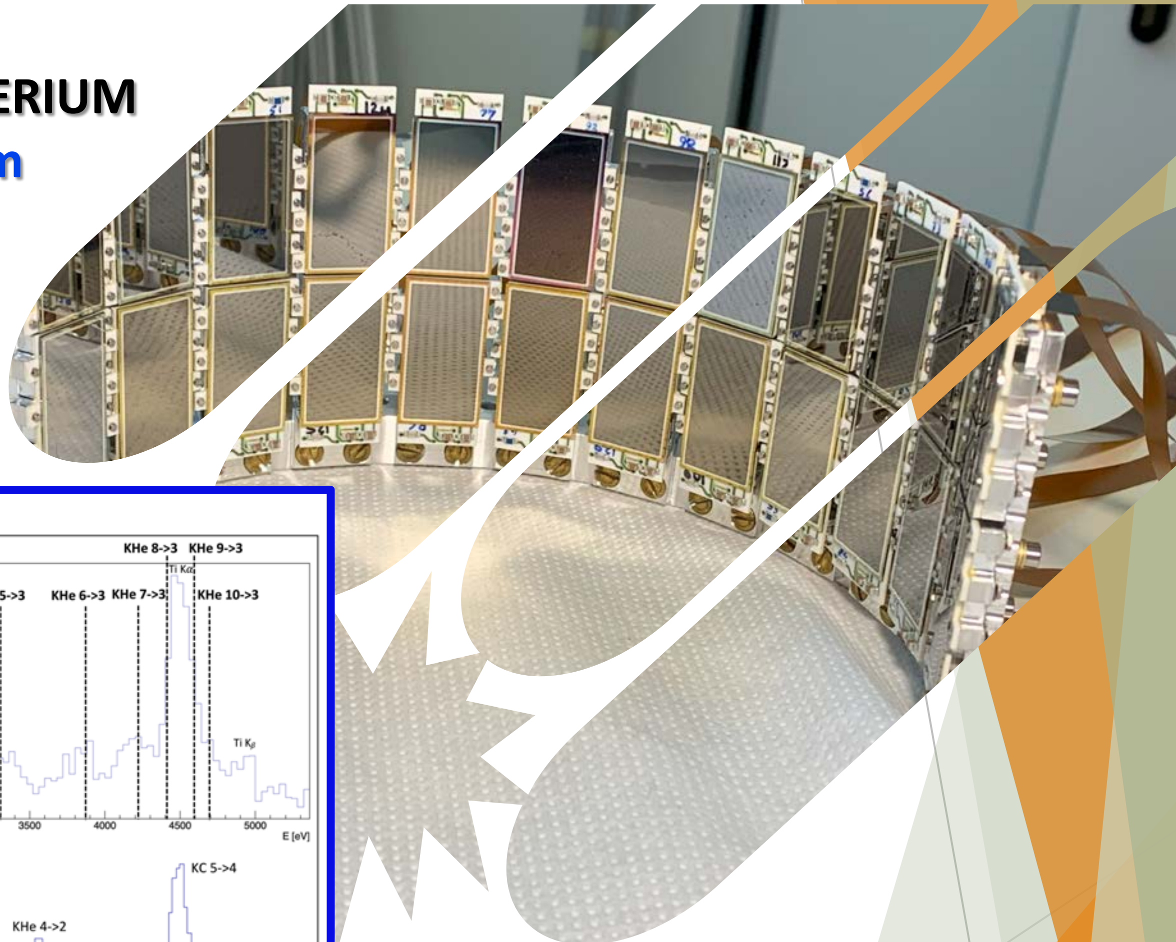
Shift **Width**

K-p Kα x-ray

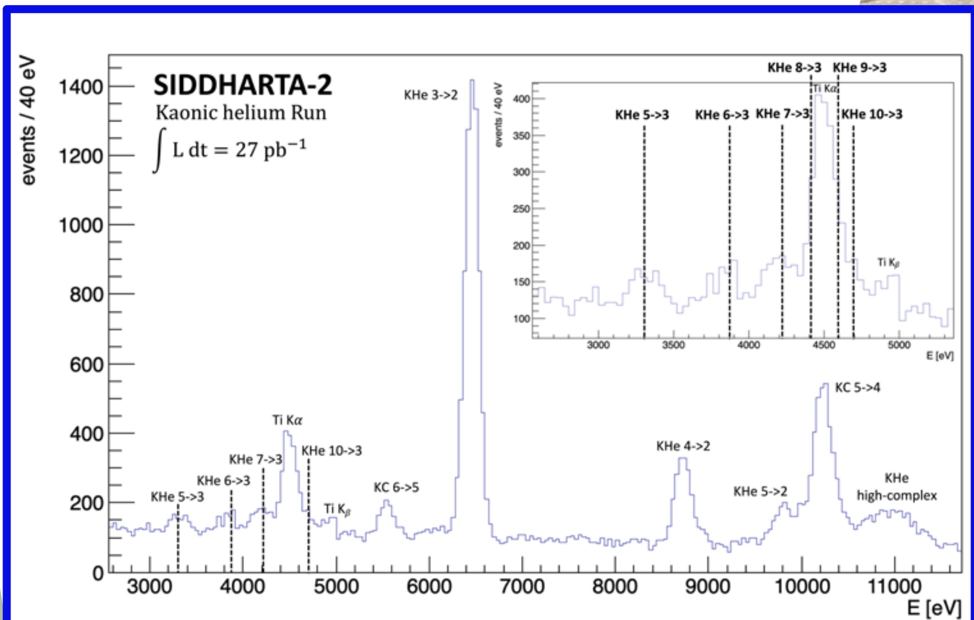
K-p scattering length
(= K-p scattering amplitude at threshold)

Experimental determination of the isospin-dependent K-N scattering length

KAONIC DEUTERIUM
KAONIC Helium
KAONIC Neon

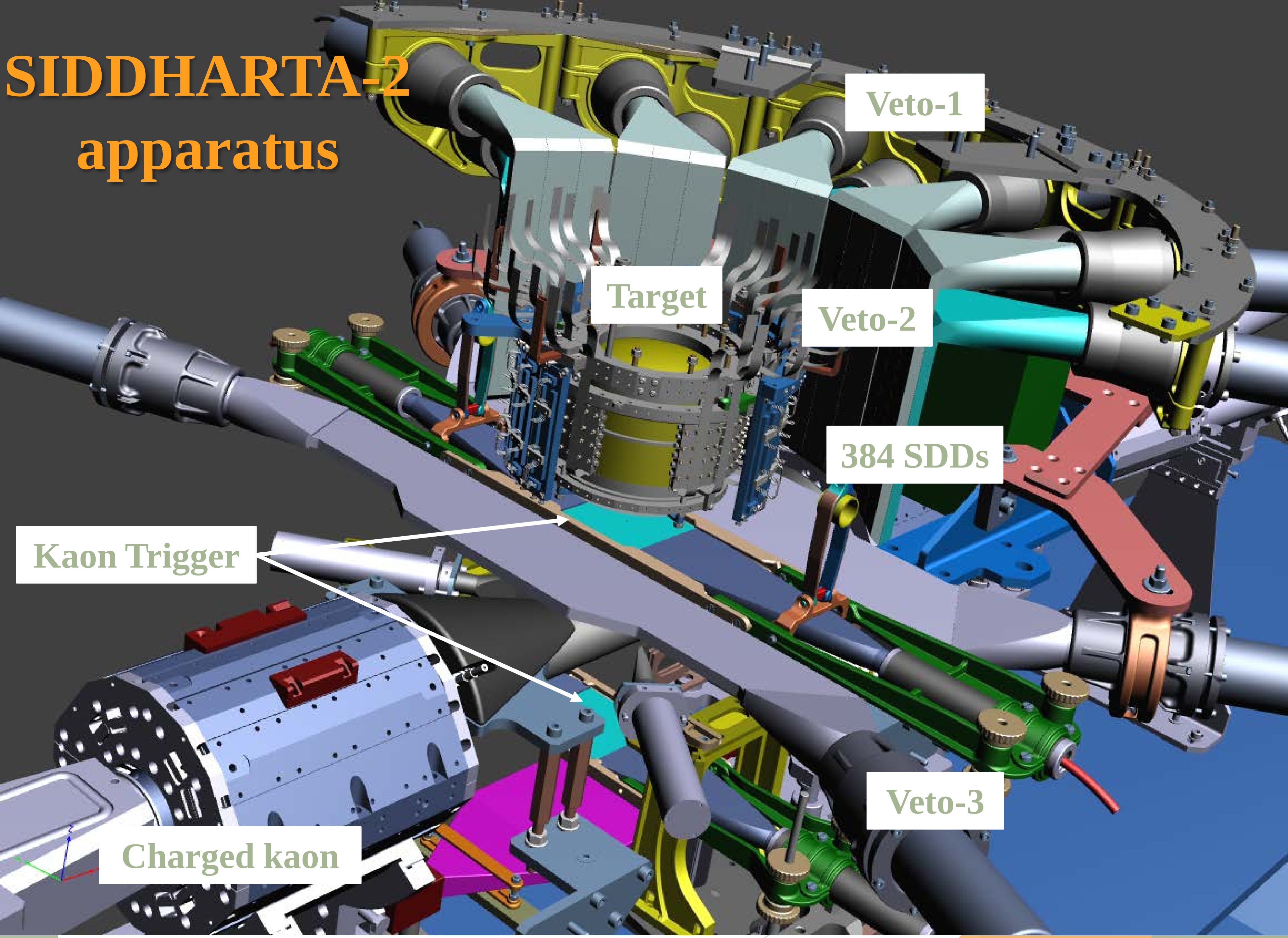


KAONIC Helium



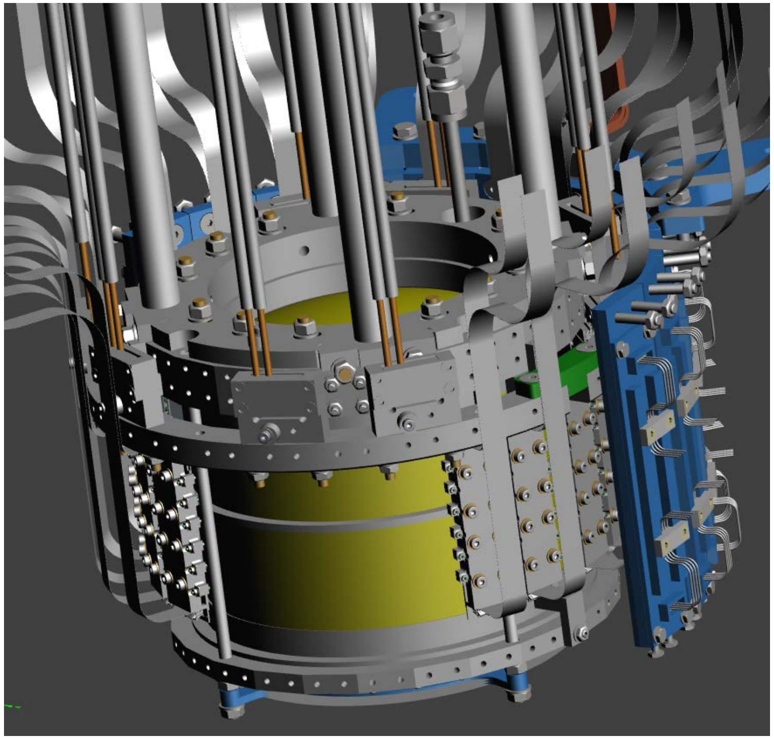
Kaonic Helium - D Sirghi et al., J. Phys. G: Nucl. Part. Phys. 49 (2022) 055106
F. Sgaramella et al., Eur. Phys. J. A 59, 56 (2023)
Yields - D.L. Sirghi et al., Nuclear Physics A 1029 (2023) 122567

SIDDHARTA-2 apparatus



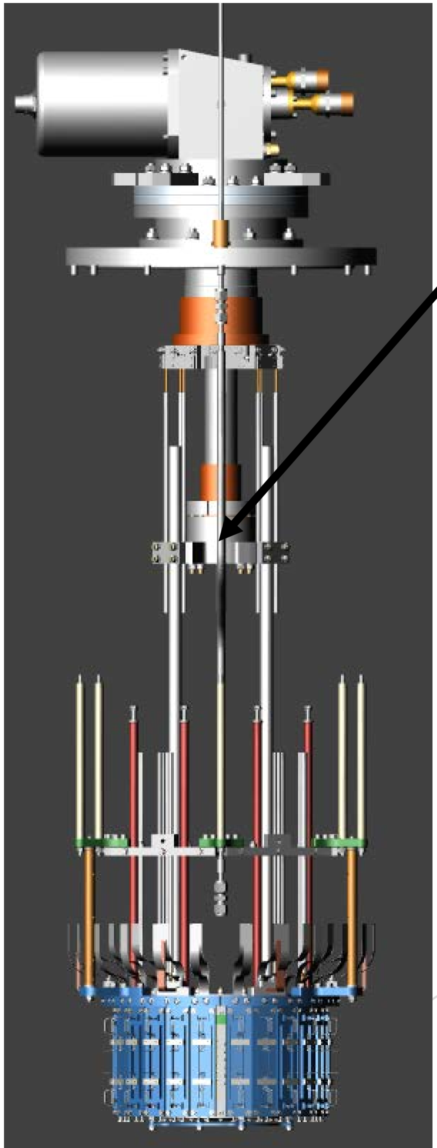
Optimization of SIDDHARTA-2 setup

- ✓ new solutions for the cooling scheme - target and SDD
- ✓ Better control of target parameters (pressure, temperature, density,….)

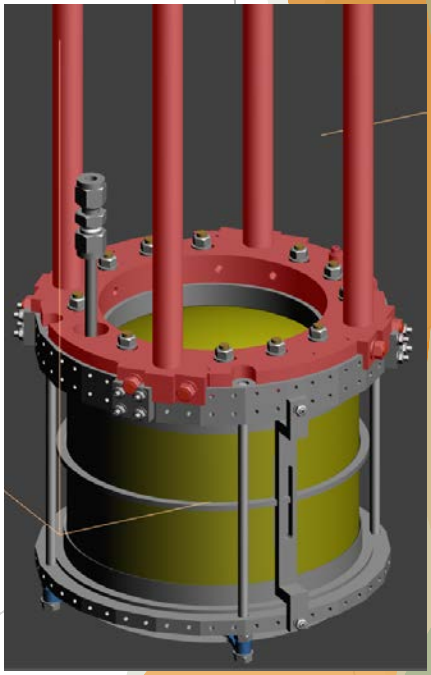


❖ Target + SDD cooling

Leybold MD10 – 18 W @ 20 K
target cell and SDDs are cooled
via ultra pure aluminum bars
T_{TC} = 20-30 K
T_{SDD} ~ 130 K



✓ **Second stage dedicated to target cooling**



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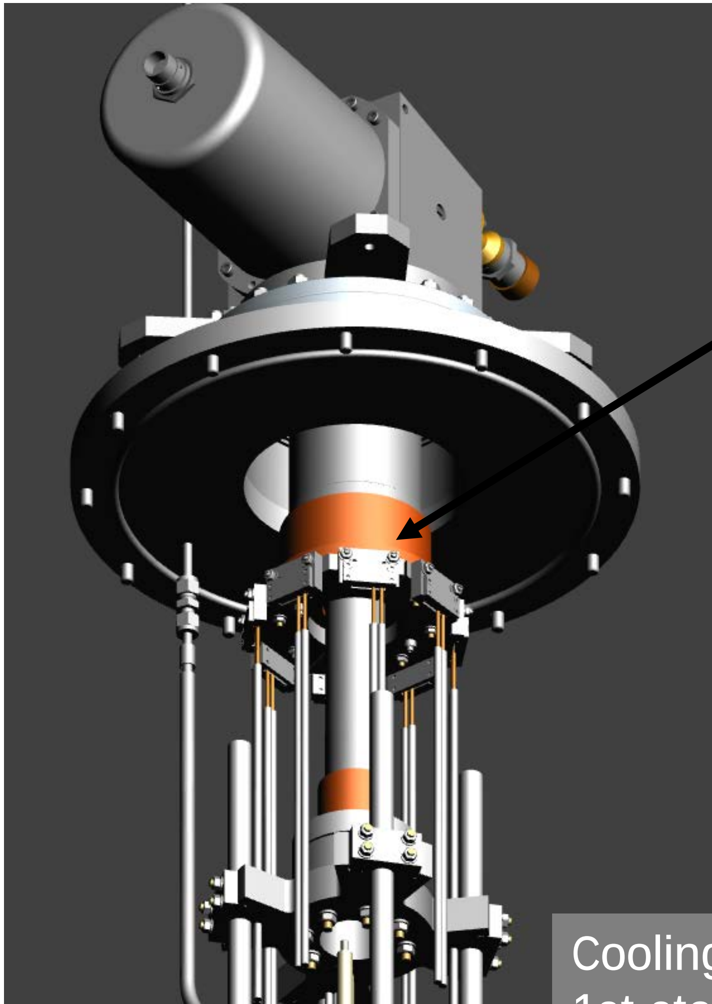
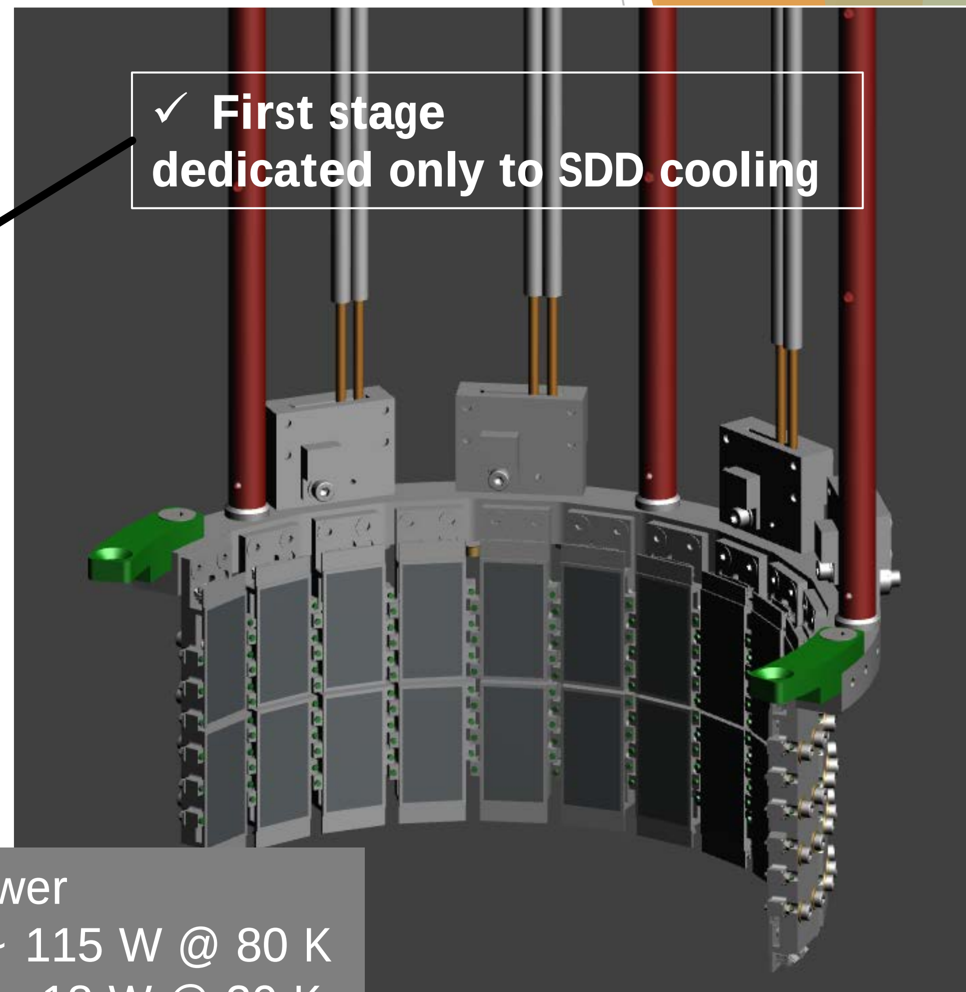
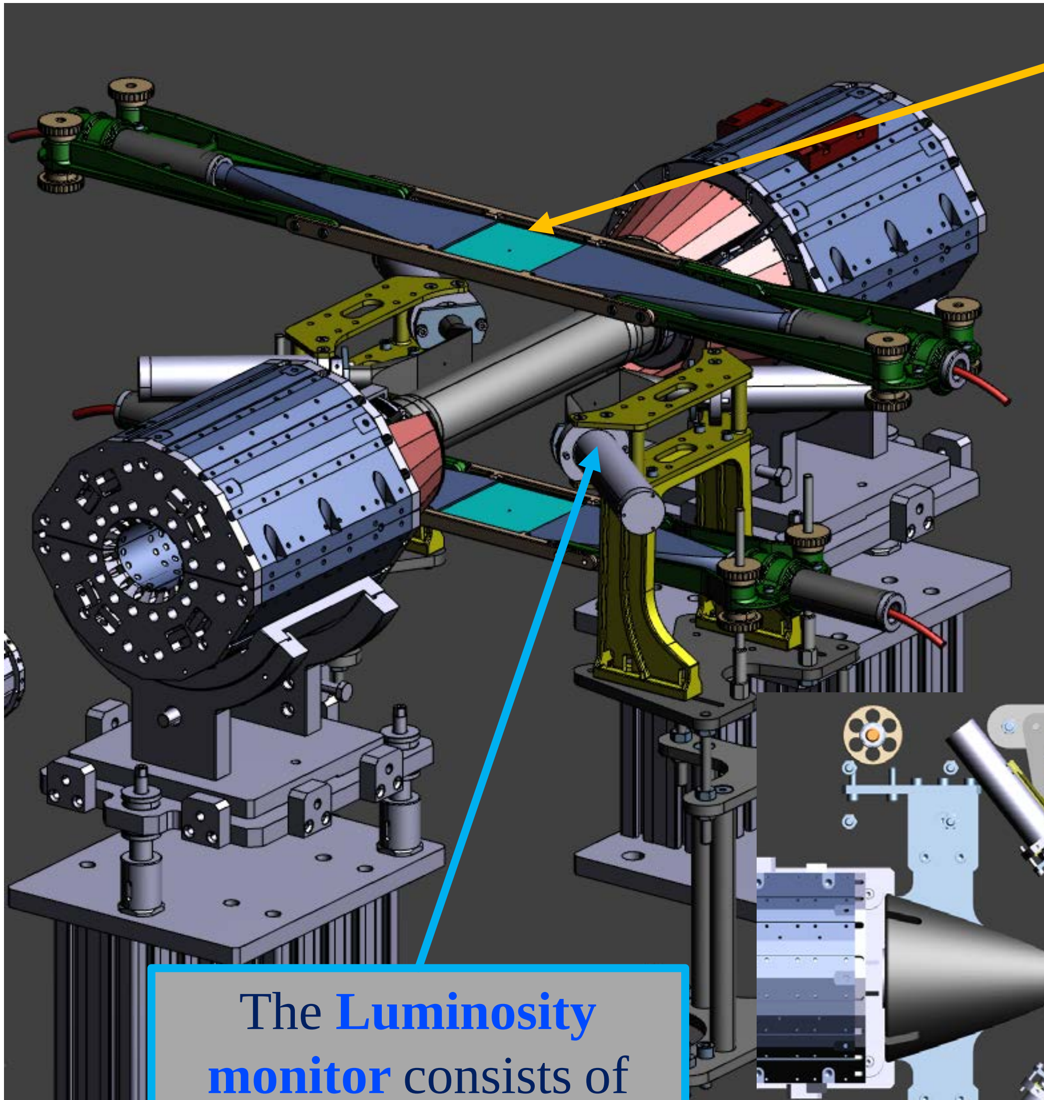


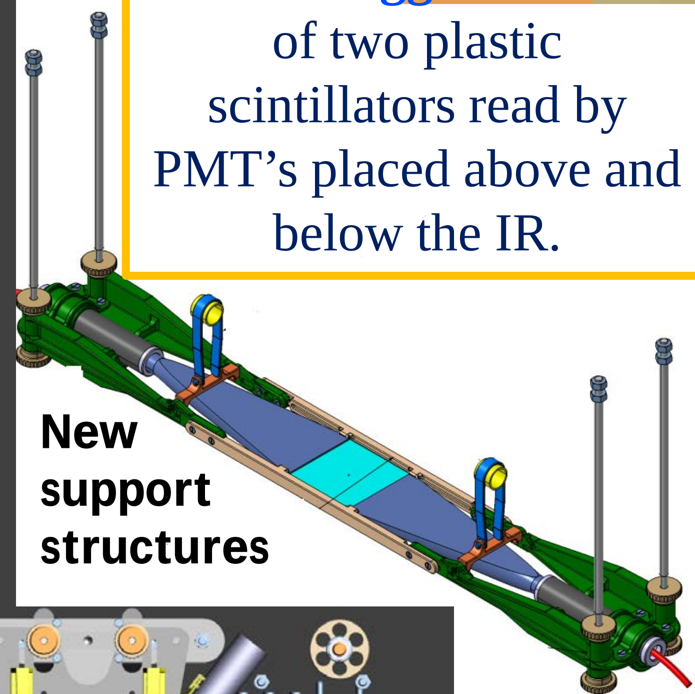


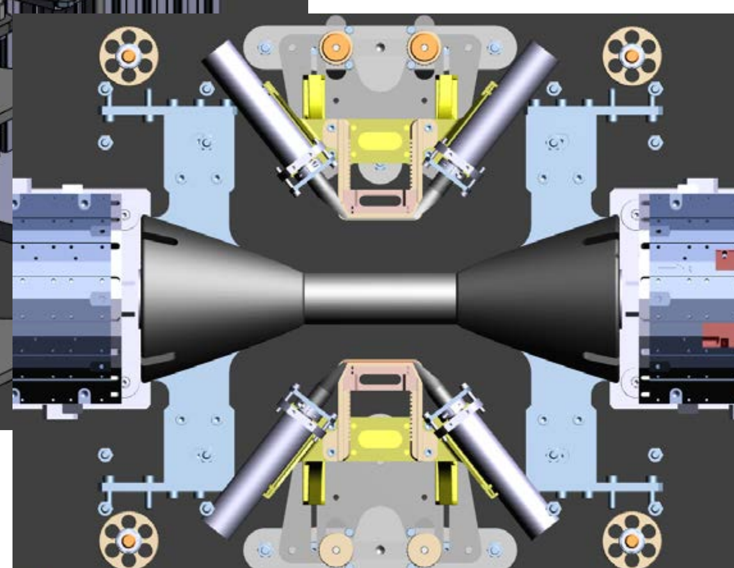
Cooling power
1st stage ~ 115 W @ 80 K
2nd stage ~ 18 W @ 20 K

Optimization of SIDDHARTA-2 setup



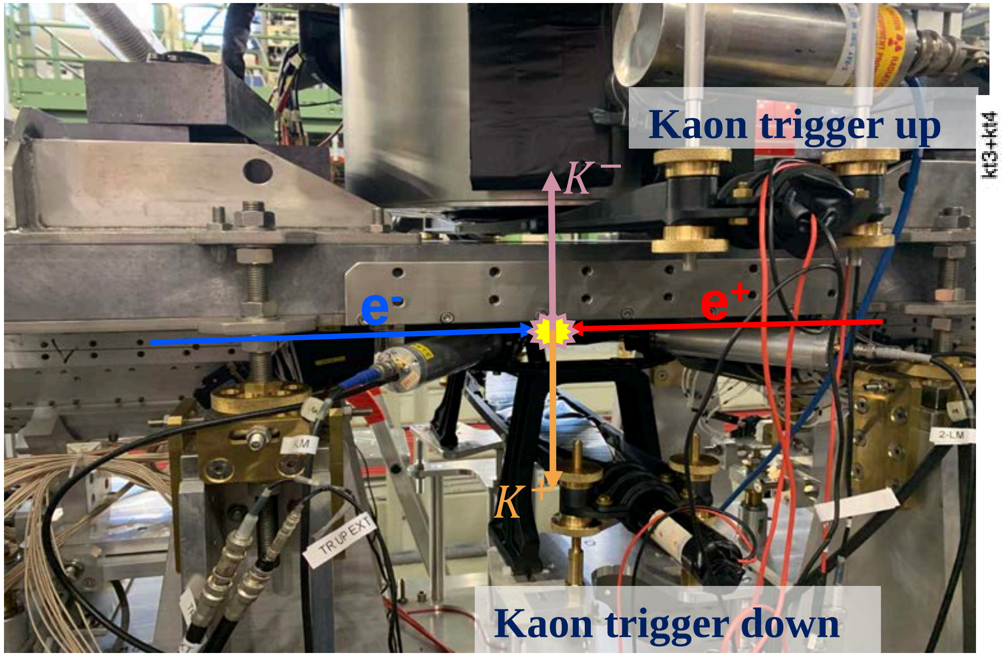
Kaon Trigger consists of two plastic scintillators read by PMT's placed above and below the IR.





The **Luminosity monitor** consists of two plastic scintillators in the horizontal plane

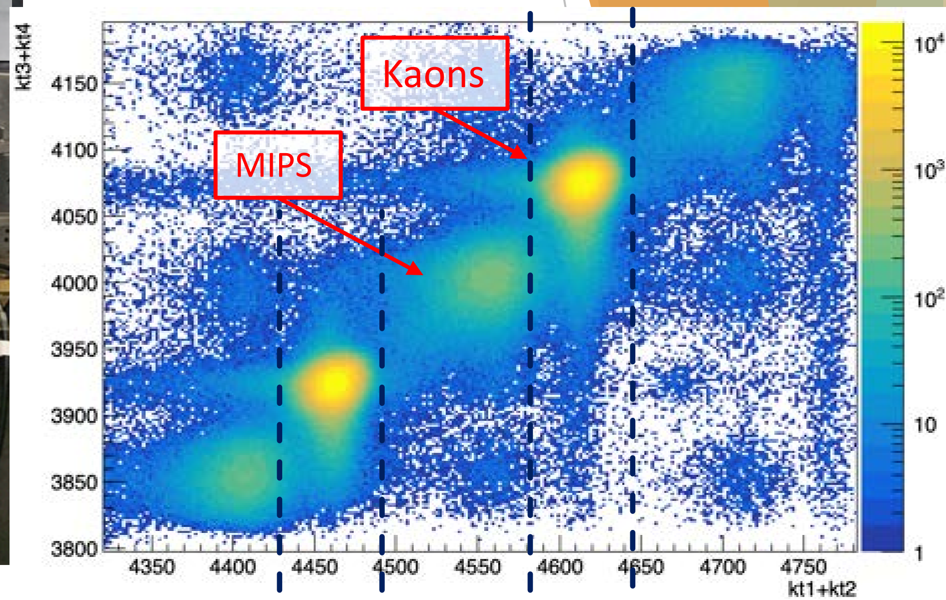
Optimization of SIDDHARTA-2 setup

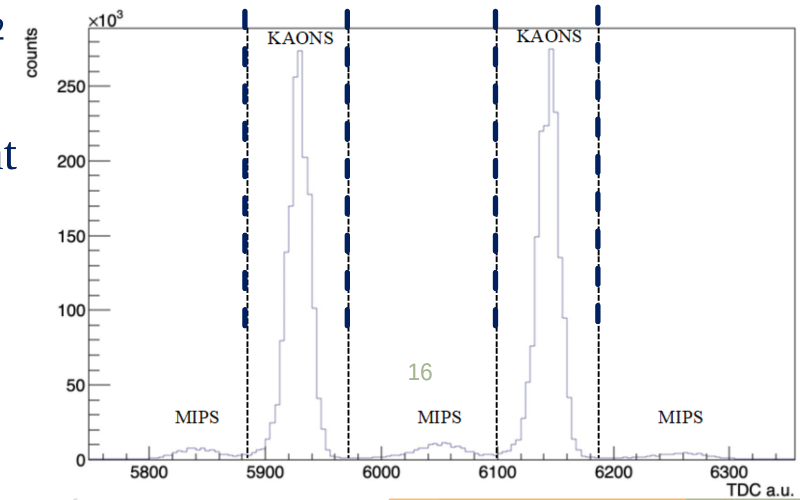


The ToF is different for Kaons, m(K)~ 500 MeV/c^2 and light particles originating from beam-beam and beam-environment interaction (MIPs).

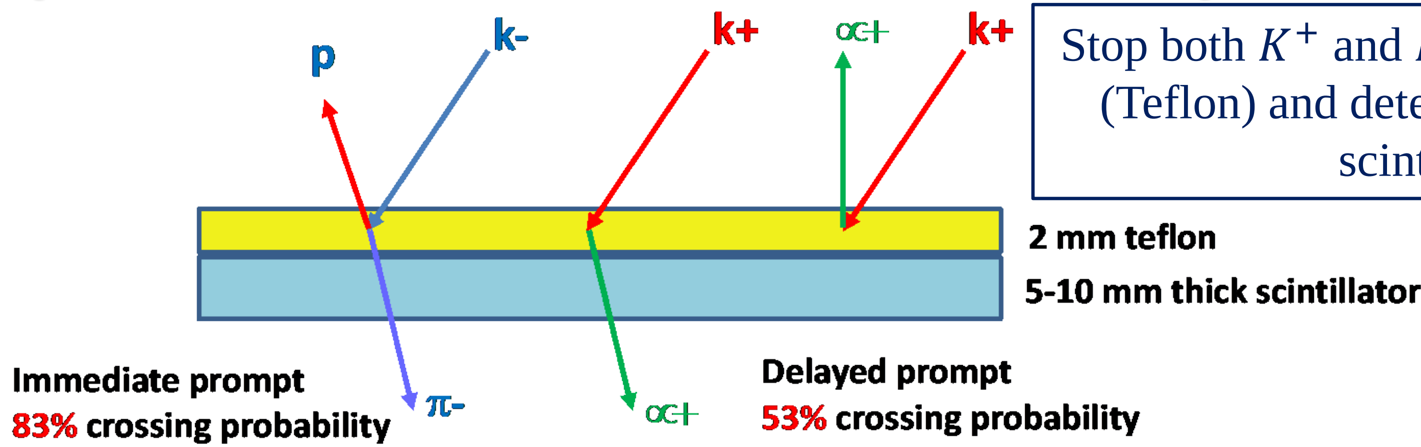
Can efficiently discriminate by ToF Kaons and MIPs!

Kaon Trigger – event selection



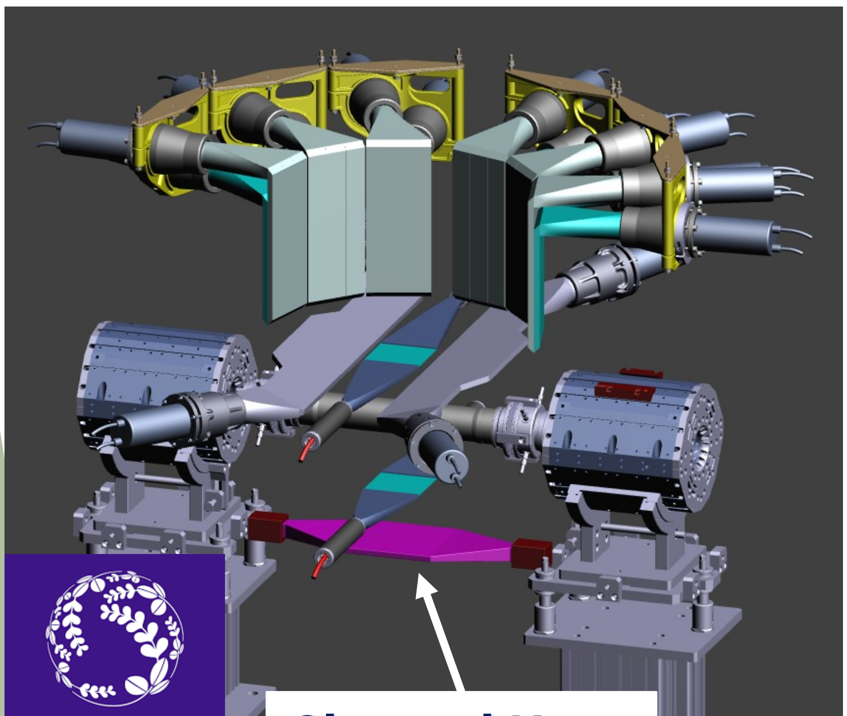


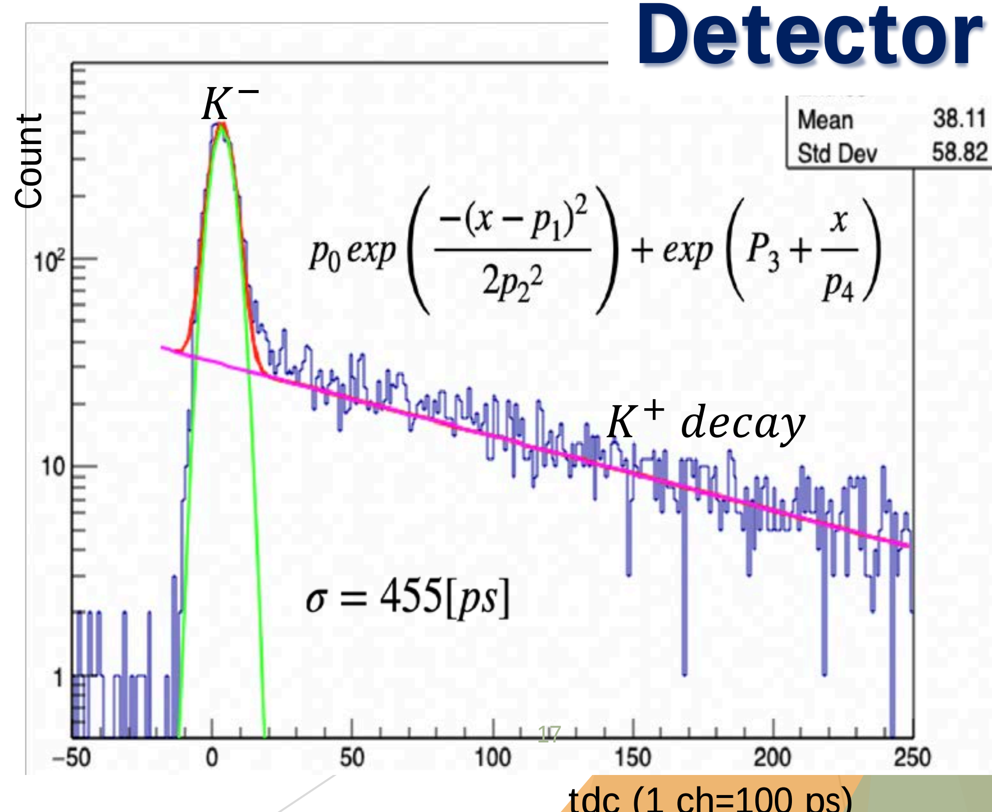
Optimization of SIDDHARTA-2 setup



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

Charged Kaon Detector

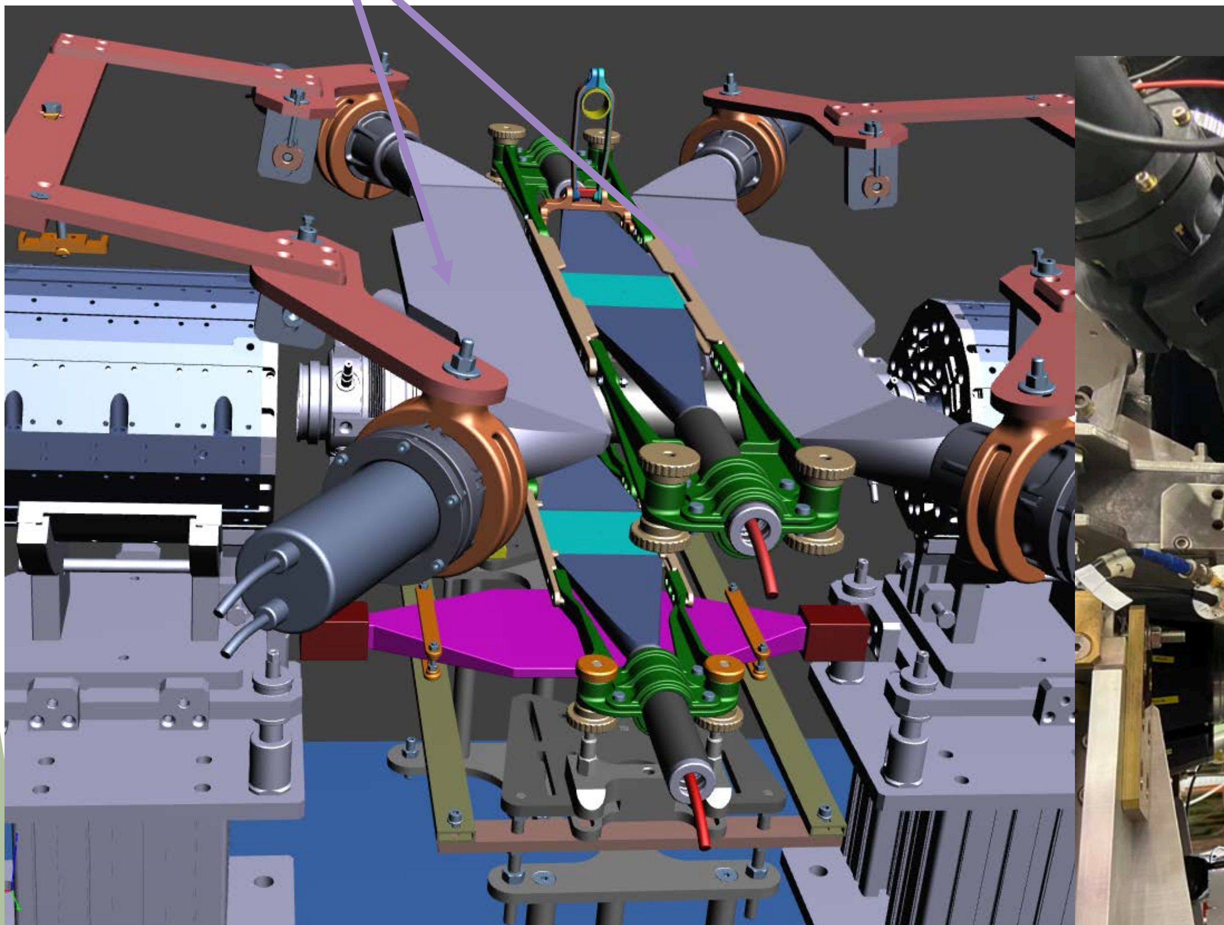


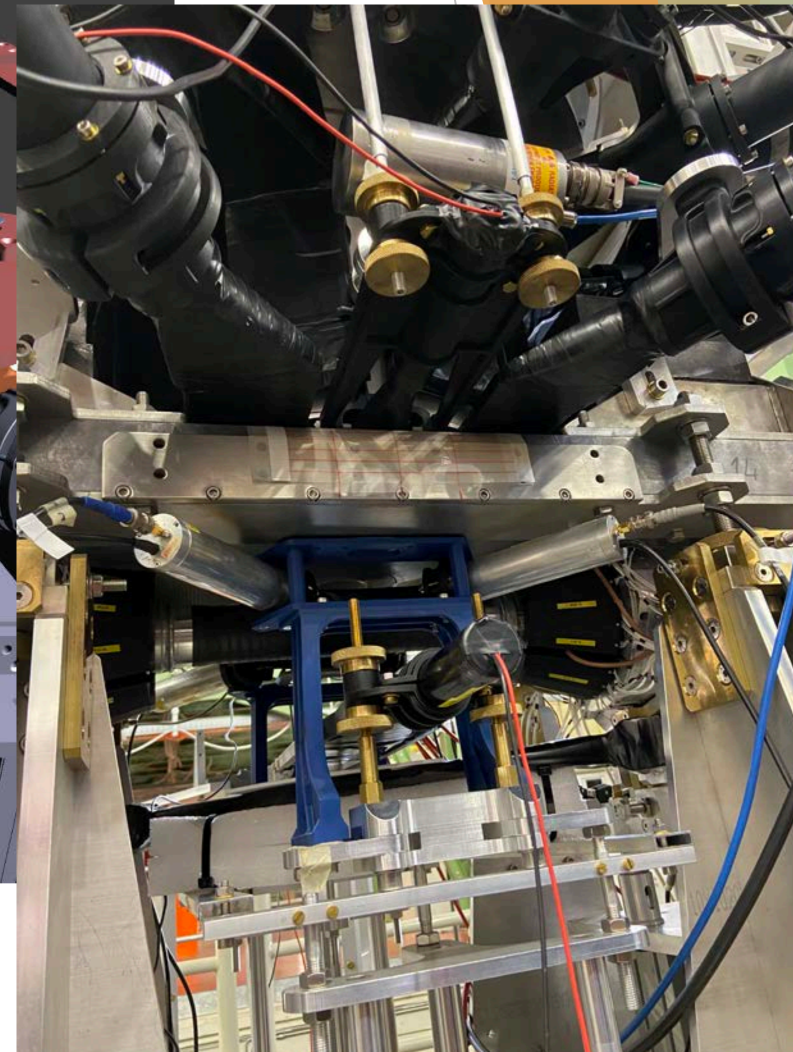


Optimization of SIDDHARTA-2 setup

VETO system adds – VETO3

- 2 pairs of scintillator
640 x 130 x 10 mm^3 Scionix EJ-200
- R10533 PMTs Hamamatsu

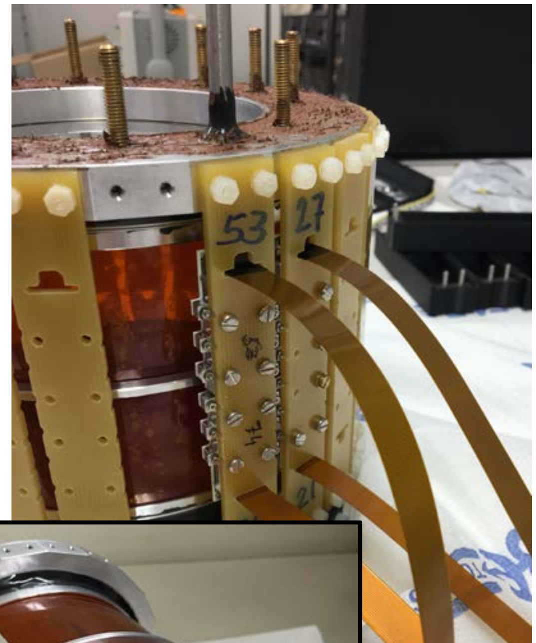


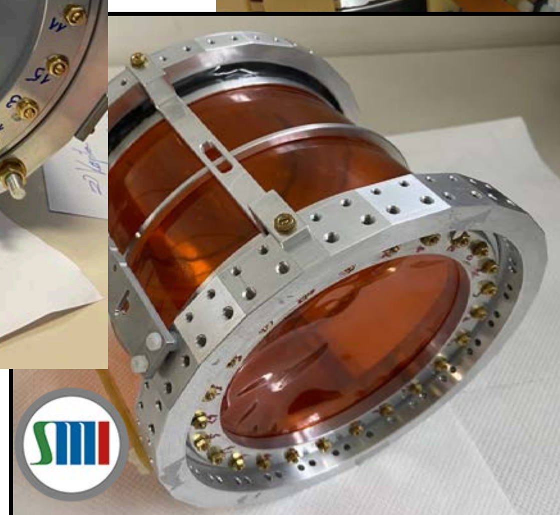


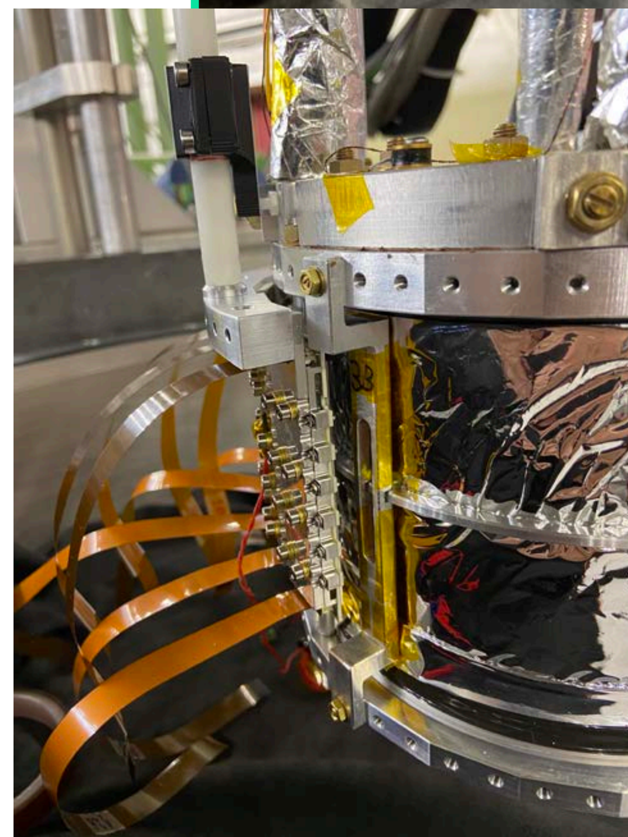
- light-guides
- Al tube + μMetal (0.1mm)
- reflective and light proof foil
- optical cement

Optimization of SIDDHARTA-2 setup

✓ **Selected materials in different configuration:**
  vacuum entrance windows
  target walls
  cooling supports

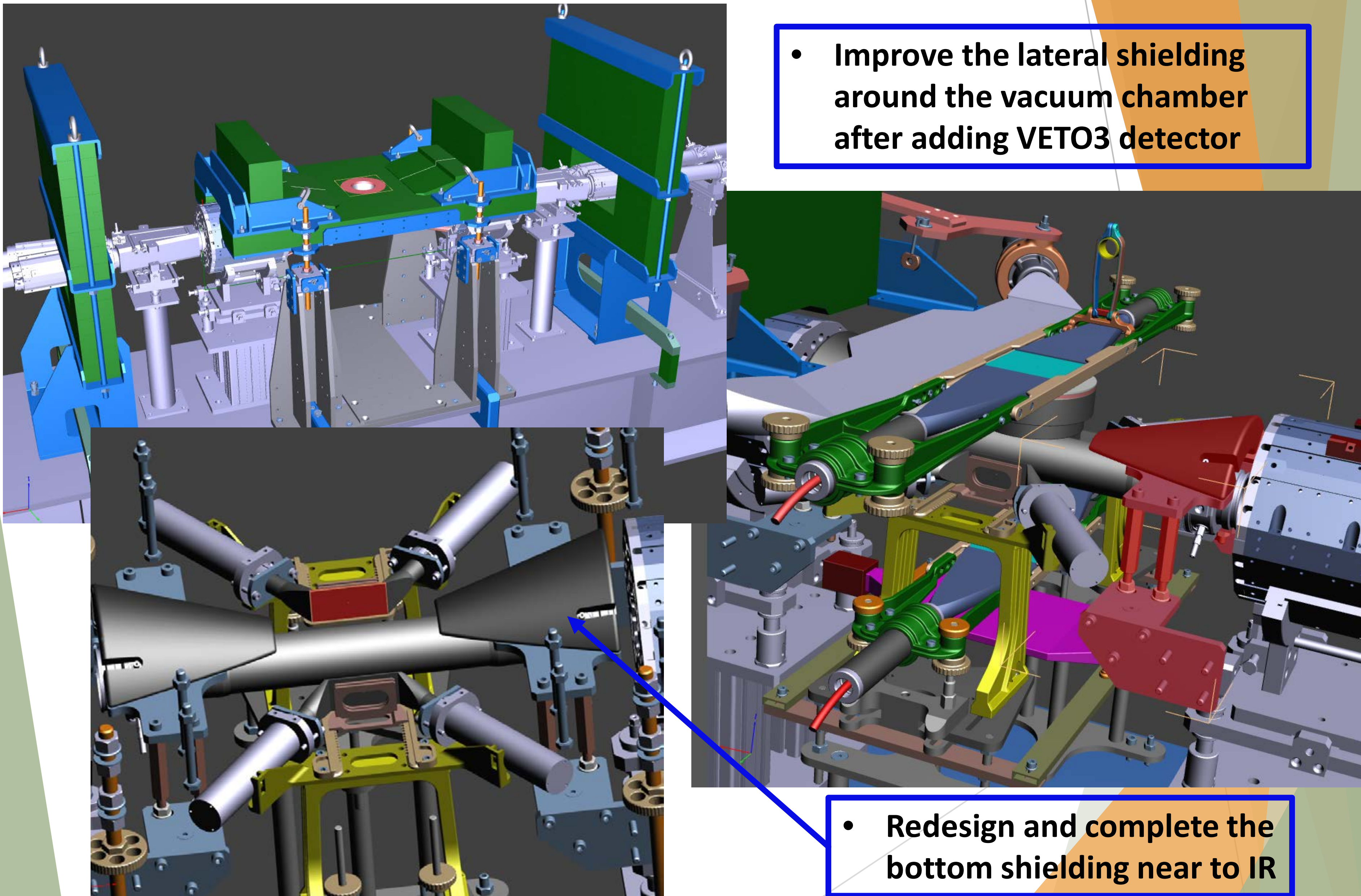






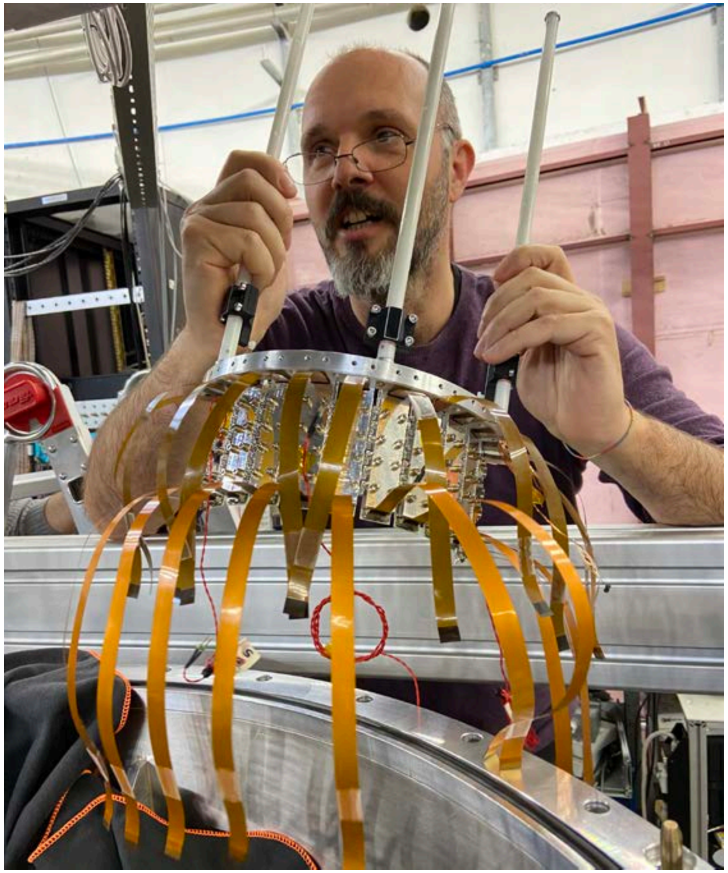
would eliminate Nitrogen and Oxygen contamination

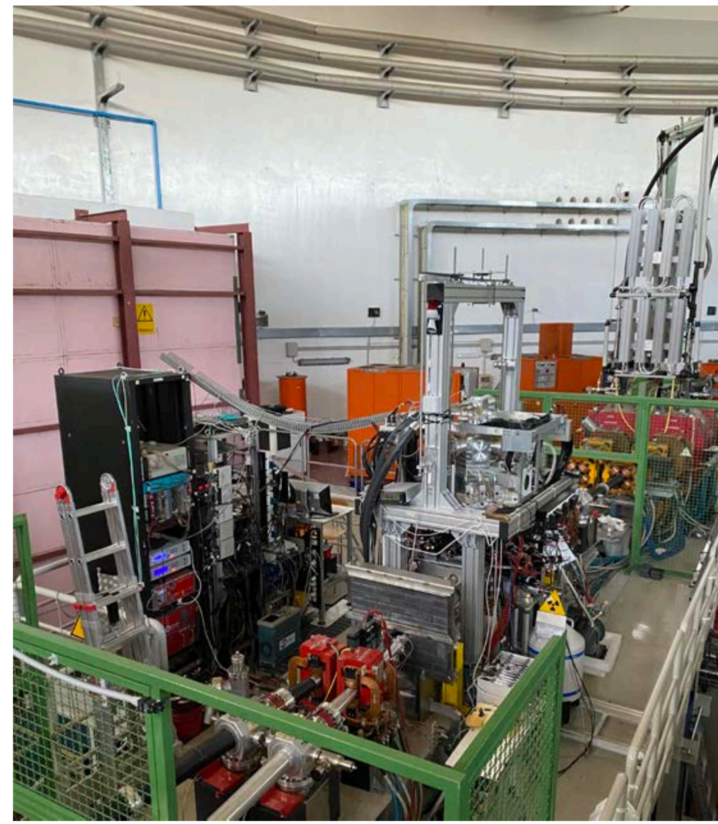
Optimization of SIDDHARTA-2 setup



- Improve the lateral shielding around the vacuum chamber after adding VETO3 detector

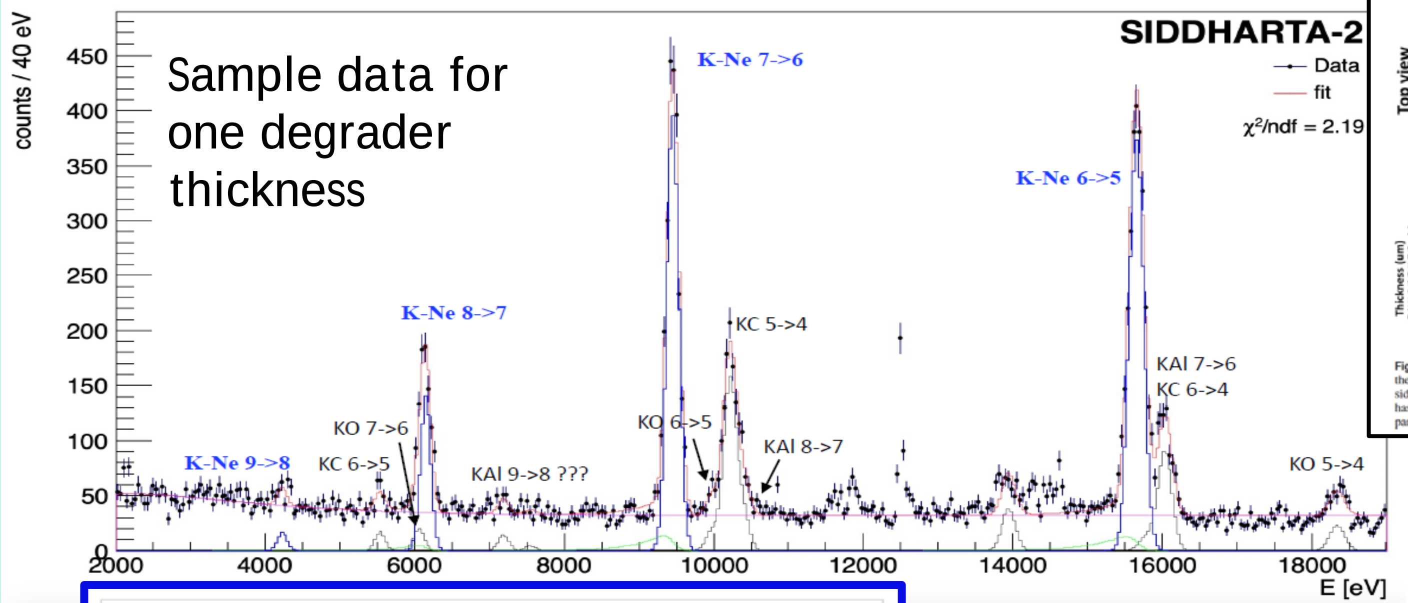
- Redesign and complete the bottom shielding near to IR





Optimization of SIDDHARTA-2 setup

Degrader optimization for Kaonic Neon



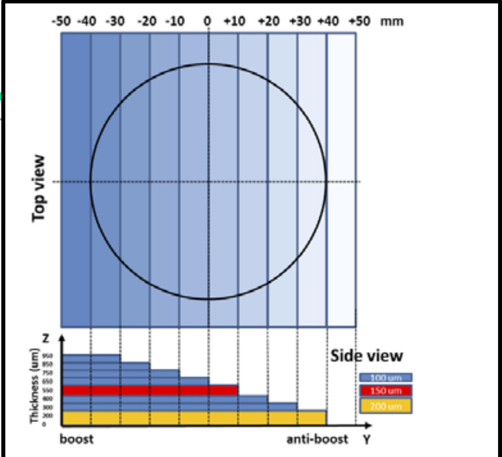
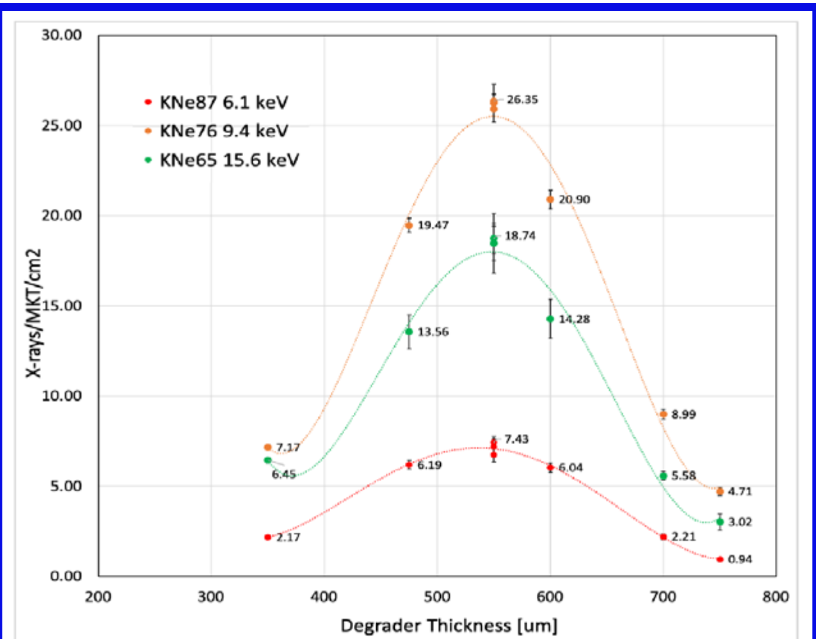
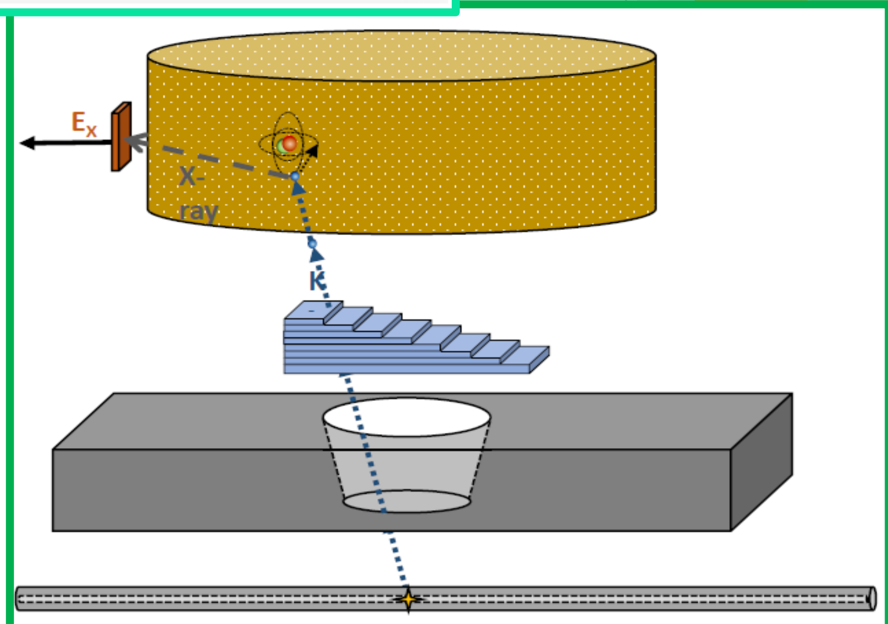
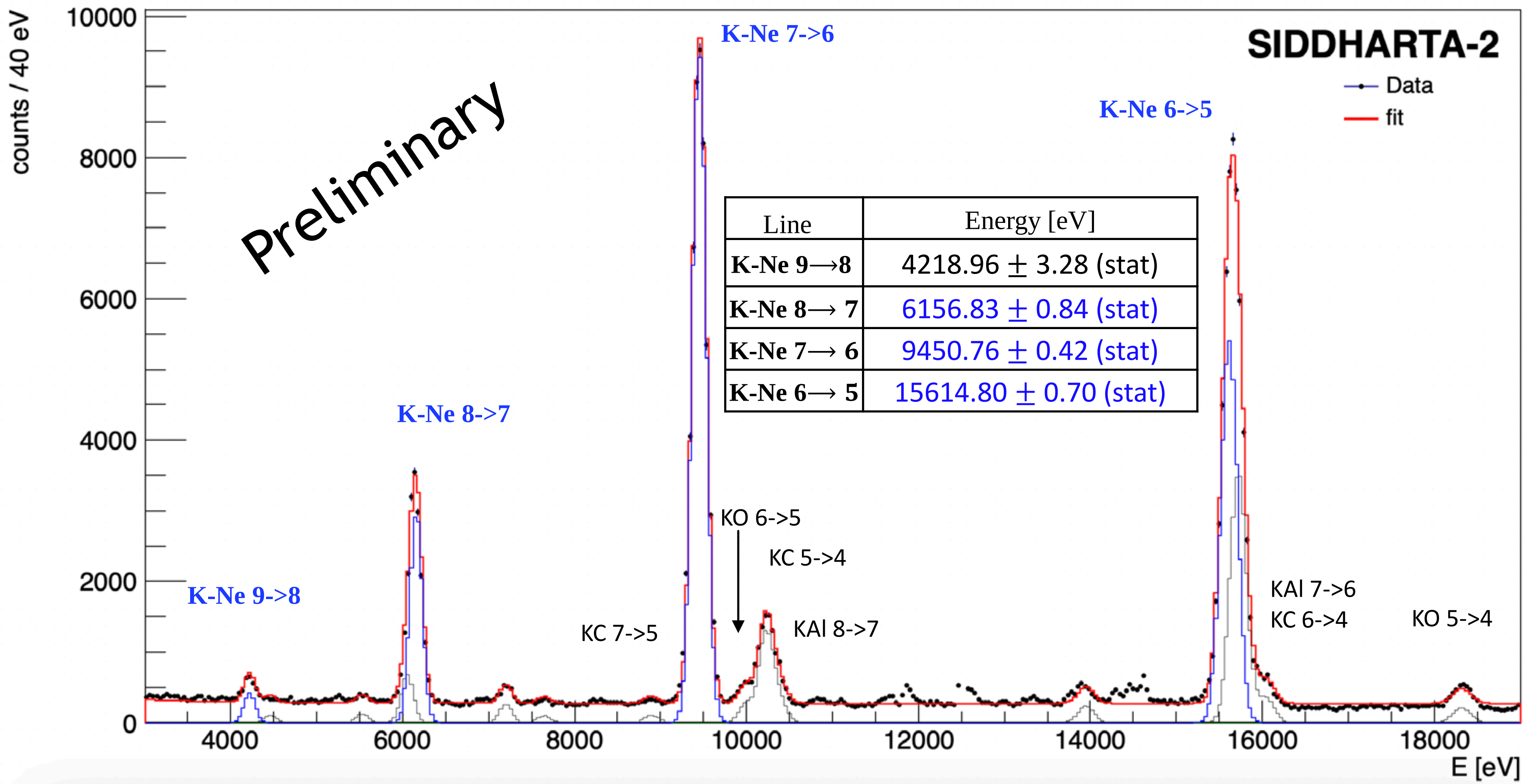


Figure 6. Nearest to optimal configuration of the Mylar degrader: the circle represents the size of the entrance window of the vacuum chamber; direction 'Y' points to the outer side of the DAΦNE ring, corresponding to the anti-boost side for kaons. The degrader has eight steps to compensate for the boost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





SIDDHARTA-2
Kaonic Neon (2023)



Line	Energy [eV]
K-Ne 9⟶8	4218.96 ± 3.28 (stat)
K-Ne 8⟶ 7	6156.83 ± 0.84 (stat)
K-Ne 7⟶ 6	9450.76 ± 0.42 (stat)
K-Ne 6⟶ 5	15614.80 ± 0.70 (stat)

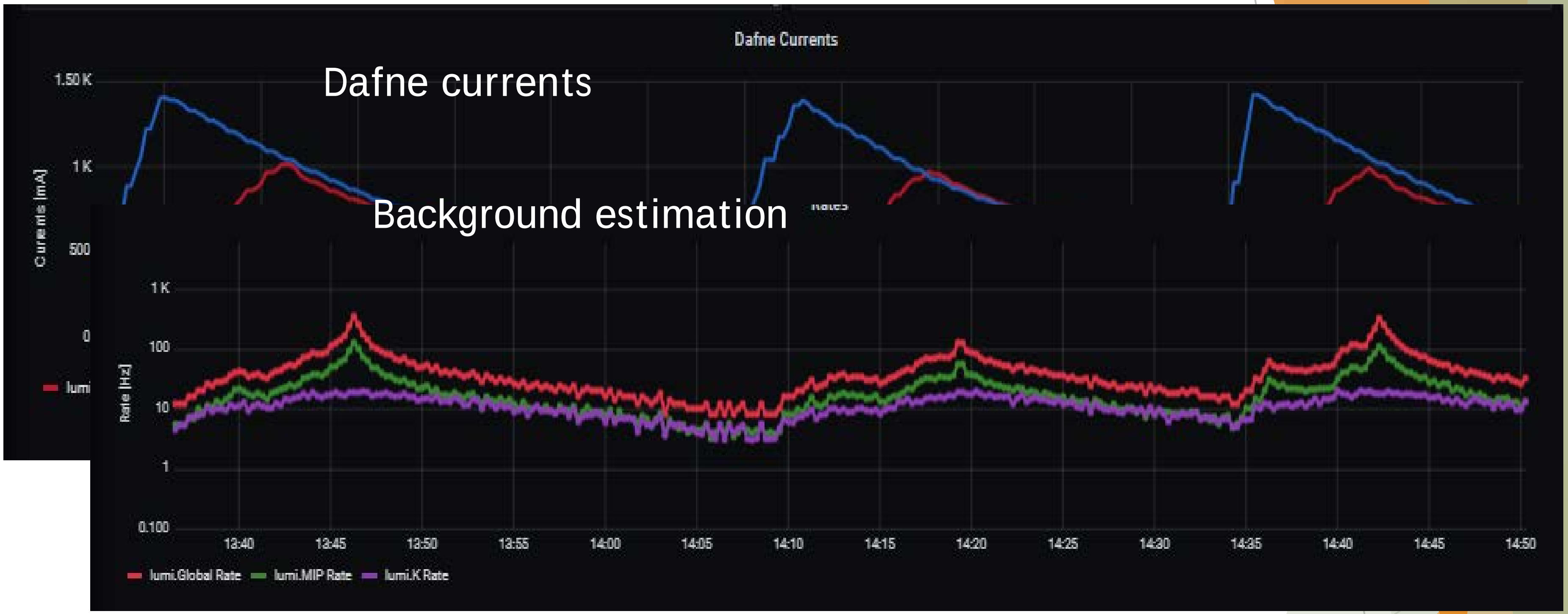
Optimization of SIDDHARTA-2 setup - results

Online monitoring tools for fast feedback

Reduce background and improve KAON/SDD ratio

Optimization of SIDDHARTA-2 setup - results

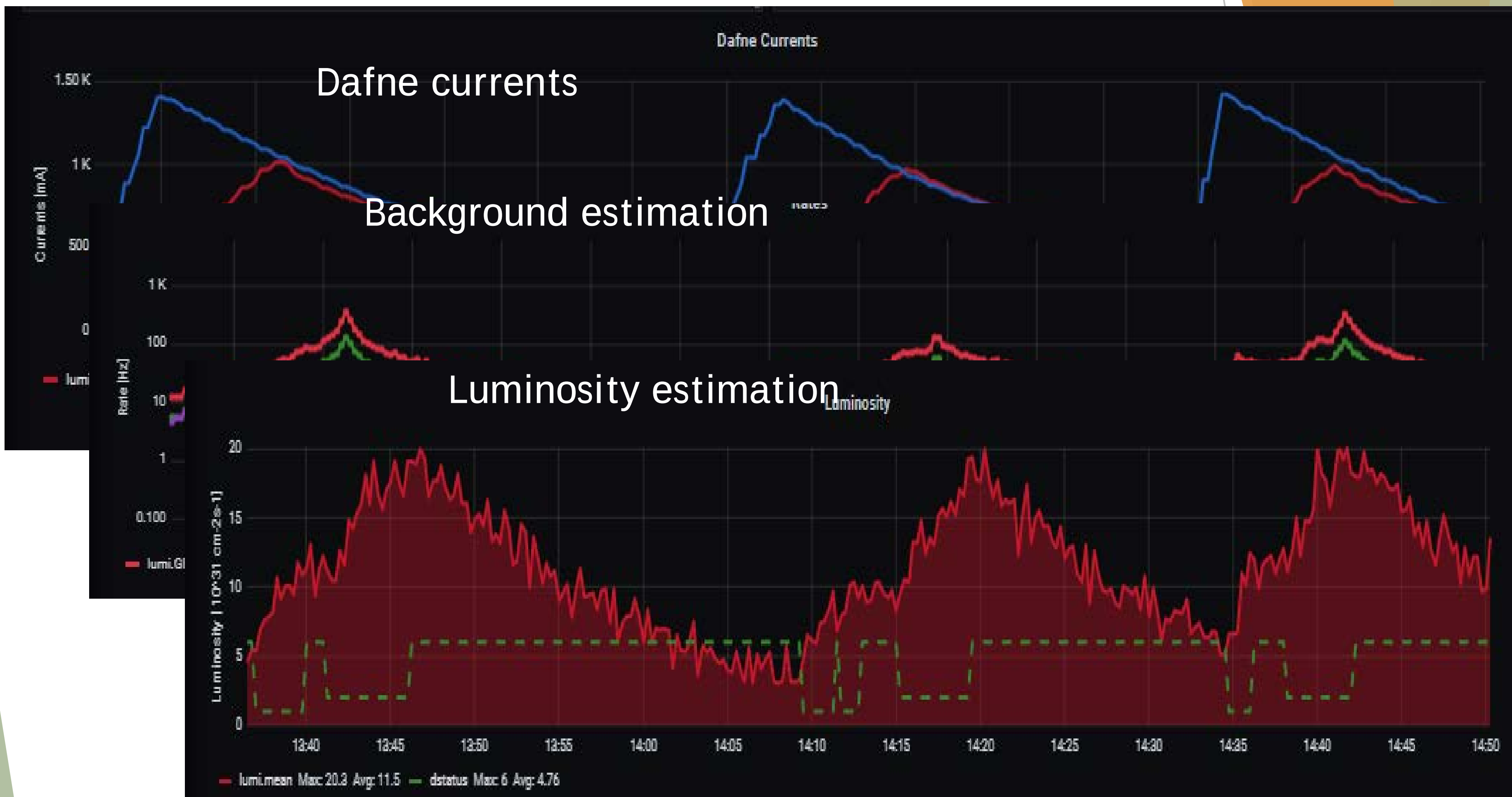
Online monitoring tools for fast feedback



Reduce background and improve KAON/SDD ratio

Optimization of SIDDHARTA-2 setup - results

Online monitoring tools for fast feedback



Reduce background and improve KAON/SDD ratio

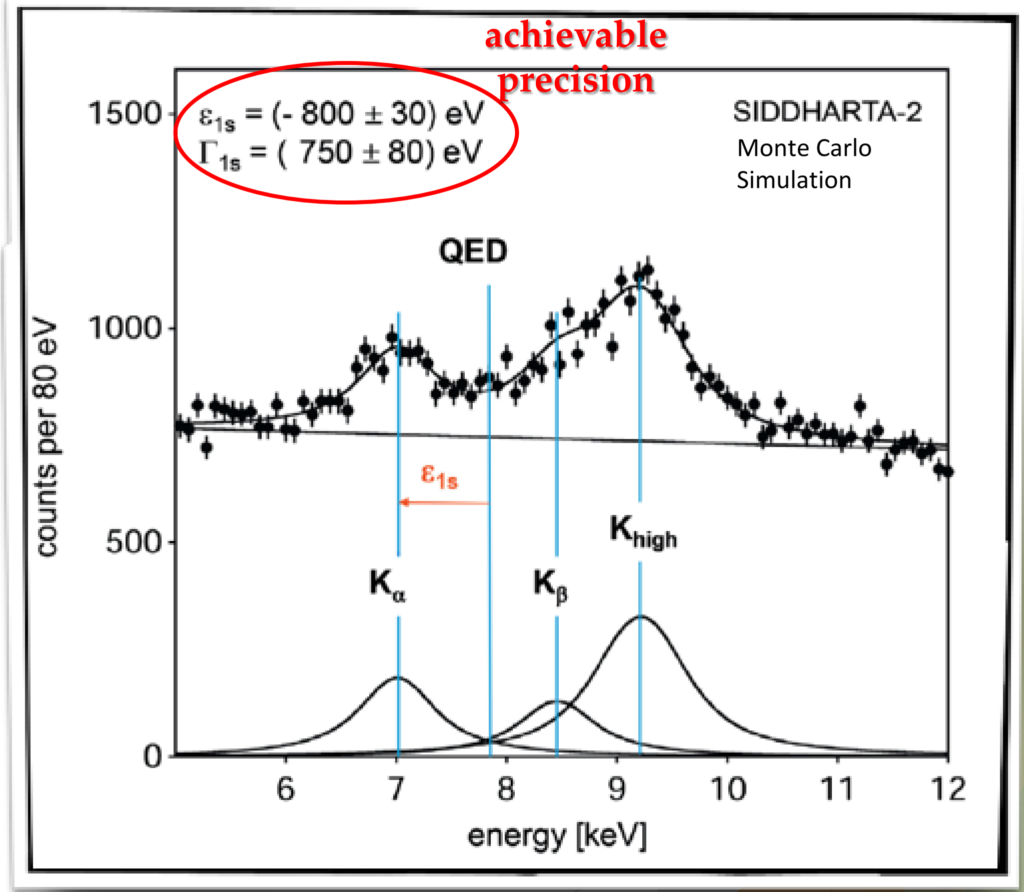
Kaonic deuterium - Monte Carlo simulation

Kaonic deuterium run ongoing

2023/2024

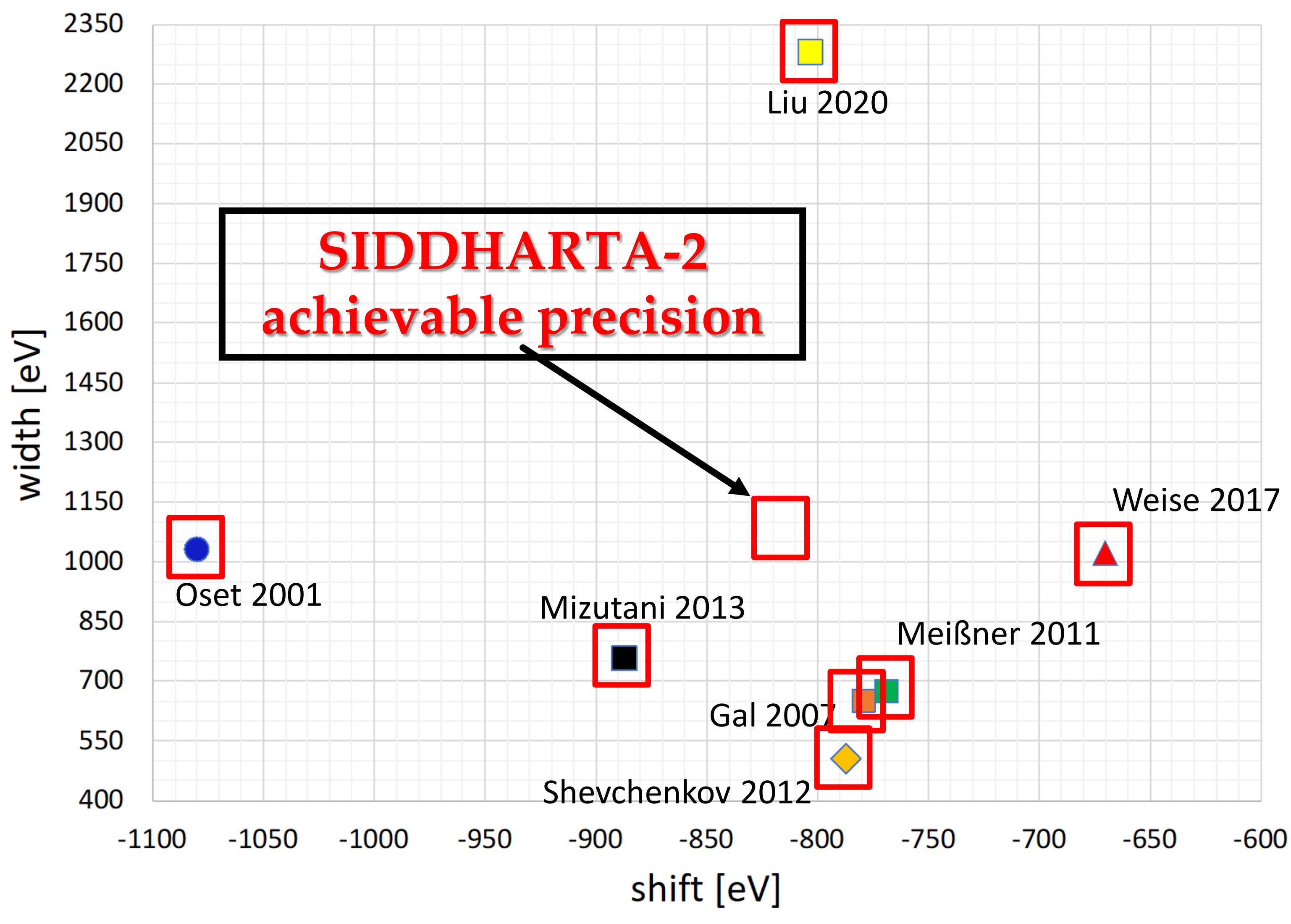
Monte Carlo for an integrated luminosity of 800 pb^{-1}

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

Kaonic deuterium shift and width



SIDDHARTA-2
Kaonic deuterium measurement plan

- **First Kaonic deuterium run finished in July**

optimized setup for about 110 pb^{-1} integrated luminosity

- **Second Kaonic deuterium run started in September**

with optimized shielding, readout, veto, trigger, …..

(for the remaining integrated luminosity: 600-700 pb^{-1} in 2023/2024)

- **Calibration/technical runs**

KHe, Neon, solid targets Li, Be

EXKALIBUR

KAONIC
ATOMS
RESEARCH

Future plans

proposal to perform fundamental physics at the strangeness frontier at DAΦNE for a 3-years period (post-SIDDHARTA-2)

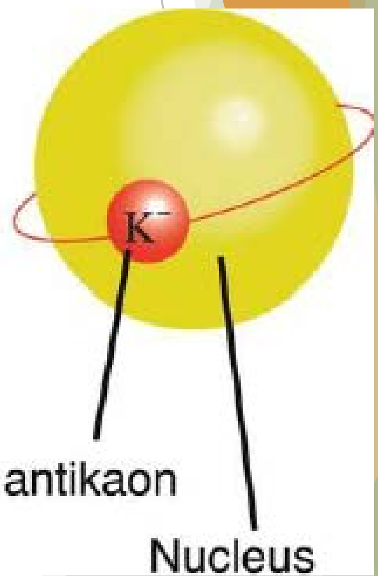
EXtensive
Kaonic
Atoms research: from
LIthium and
Beryllium to
URanium

Kaonic Hydrogen: 200 pb^{-1} - with SIDDHARTA2 setup - to get a precision < 10 eV (KH)

Selected light kaonic atoms (LHKA)

Selected intermediate and heavy kaonic atoms <u>charting the periodic table</u> (IMKA)

Ultra-High precision measurements of Kaonic Atoms (UHKA)



Dedicated runs with different types of detectors:
SDD 1mm, CZT detectors, HPGe, crystal HAPG spectrometer-VOXES project

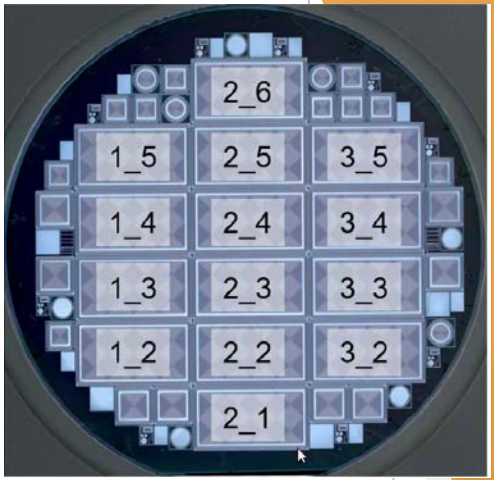
C. Curceanu et al., arXiv:2104.06076 [nucl-ex](2021)
C. Curceanu et al., Front. Phys. 11 (2023)

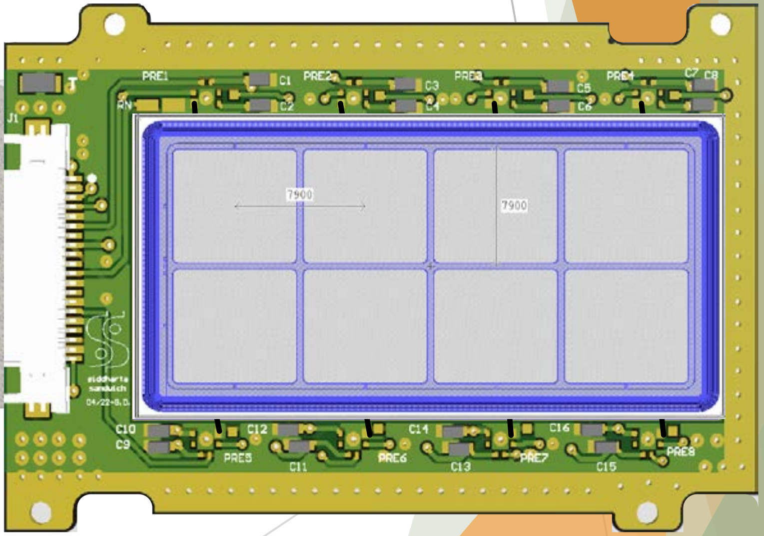
EXKALIBUR

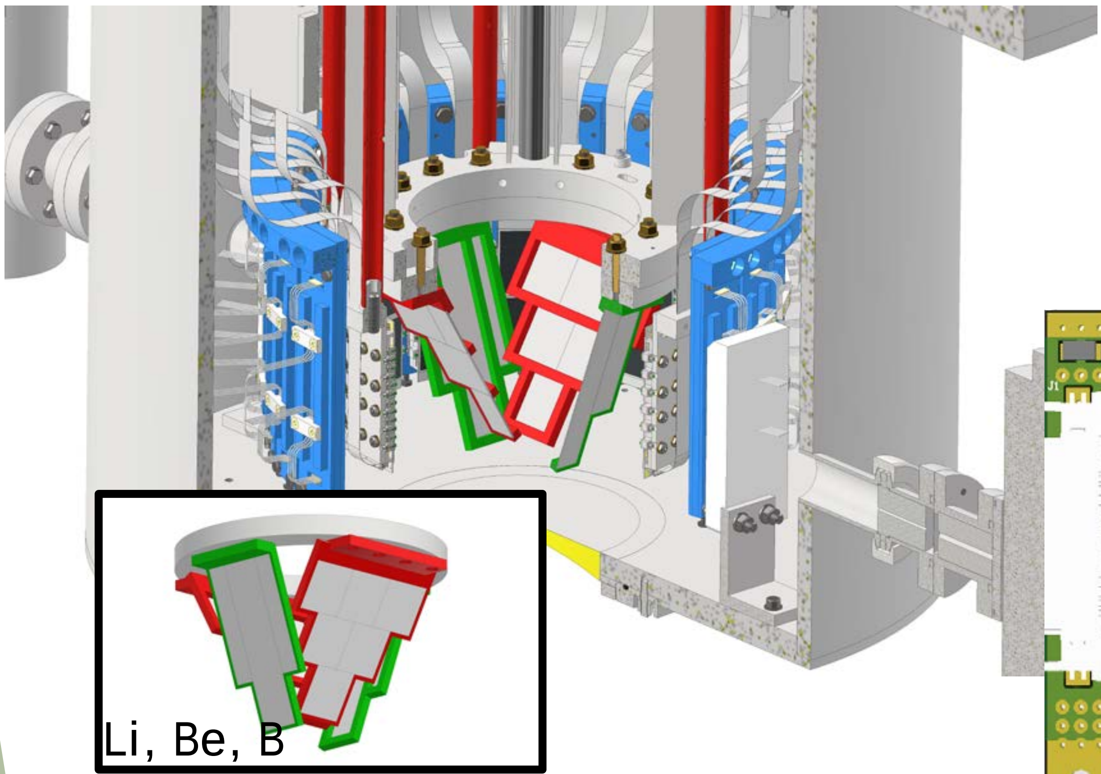
Future plans

SDD 1mm detector

- Thicker detectors are produced by FBK with larger guard rings
- Samples of detector under test in Milano
- Same active area
- New Focusing electrodes added







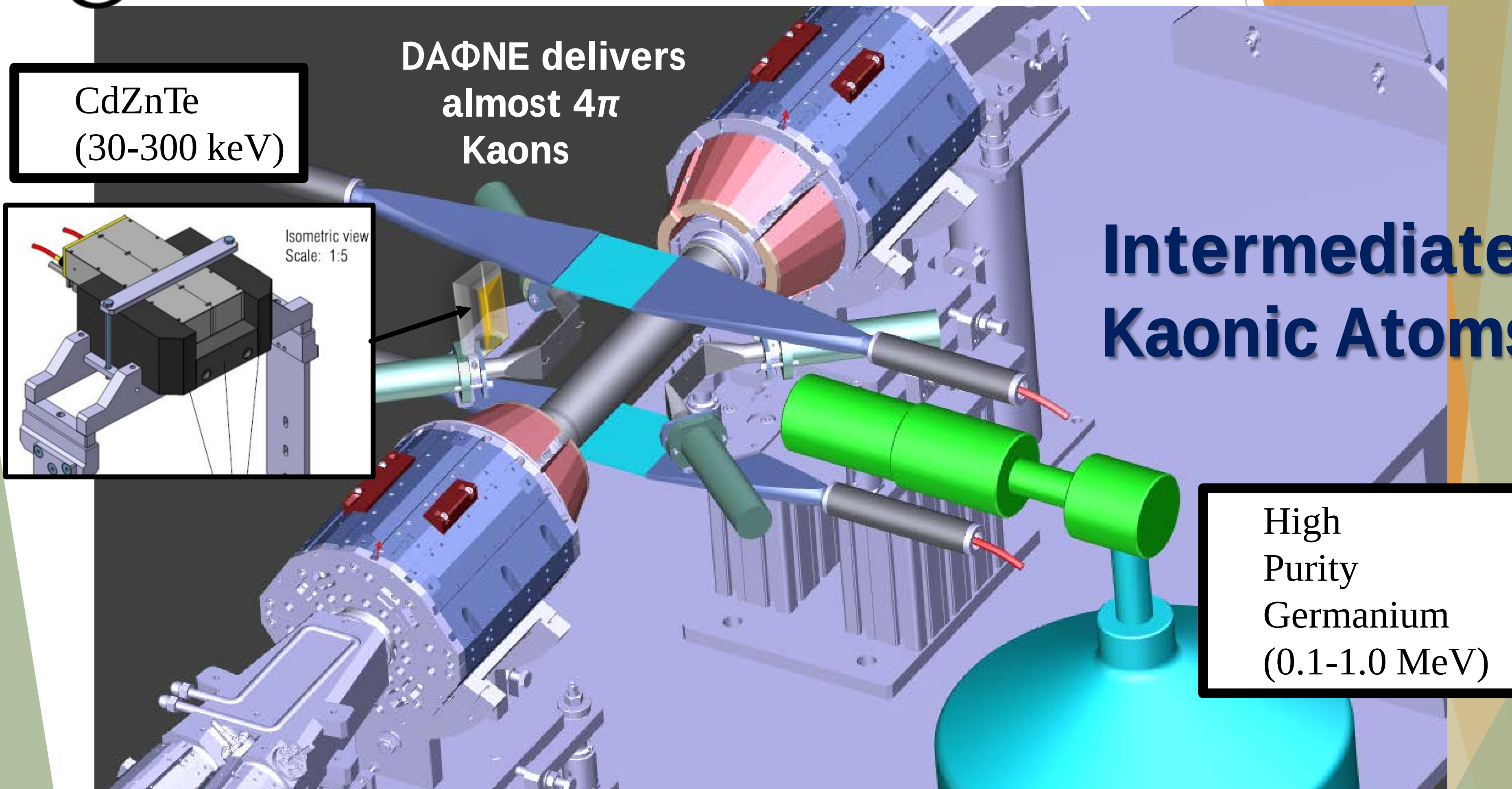
solid targets

FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

POLITECNICO MILANO 1863

INFN

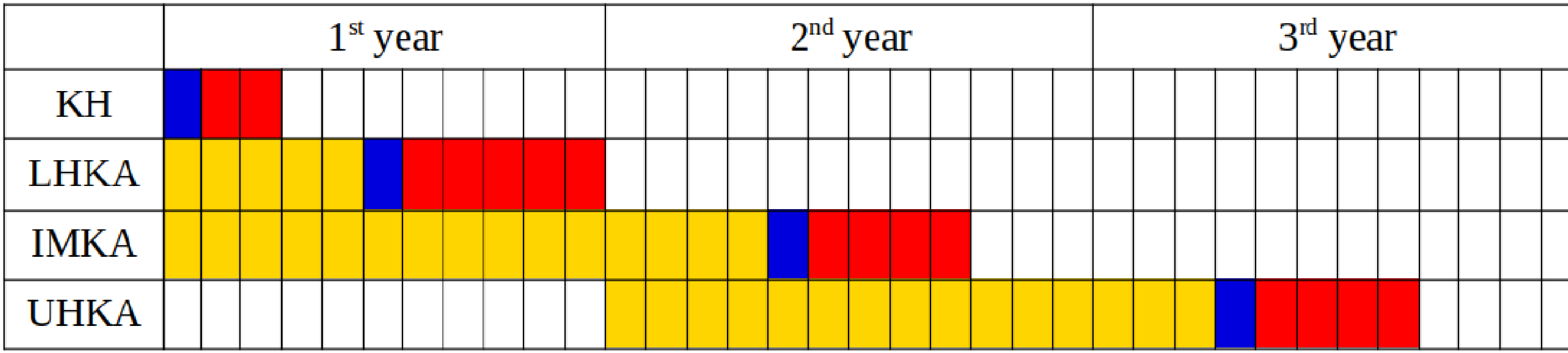
Take advantage of “free space” in DAΦNE



… more details in talk of Francesco Artibani and Francesco Sgaramella

Future plans

Gantt chart
possible implementation of the kaonic atoms measurements



Preparation of the experiment
Installation and commissioning
Data taking

Total integrated Luminosity:

200 + 400 (200) + 400 (200) + 400 pb-1

Fast, handy and significant physics measurements with very low costs and human efforts

Conclusions

The SIDDHARTA-2 NEON run (technical run)

First Kaonic deuterium run done - from May to July 2023
(optimized setup for about 110 pb^{-1} integrated luminosity)

We are confident in machine performance, ready and very motivated to continue the SIDDHARTA-2 program

Second Kaonic deuterium run - ongoing

Future measurements - proposal EXKALIBUR
we put forward several proposals for measurements with SIDDHARTA-2 setup and dedicated detectors systems for 200-300 pb^{-1}

SPARE