EXOTICO: EXOTIc atoms meet nuclear COllisions for a new frontier precision era in low-energy strangeness nuclear physics

Trento, 17 – 21 October 2022

General status of SIDDHARTA-2 experiment

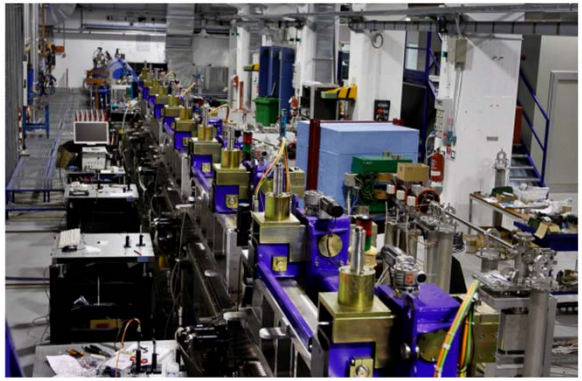
▶*Florin Sirghi*
on behalf of the SIDDHARTA-2 Collaboration

INFN Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

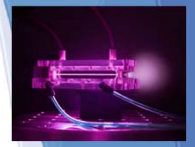
Kaonic atoms research at DAΦNE

DAFNE

SPARC

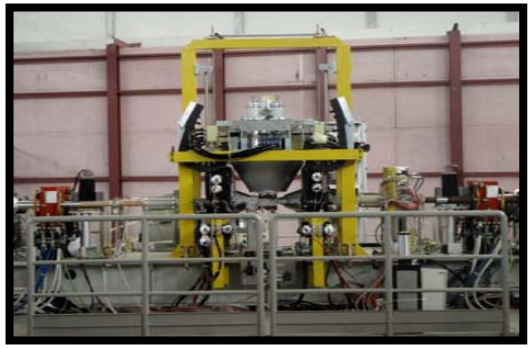


NOVEL FUNDAMENTAL RESEARCH COMPACT EUROPEAN PLASMA ACCELERATOR WITH SUPERIOR BEAM QUALITY

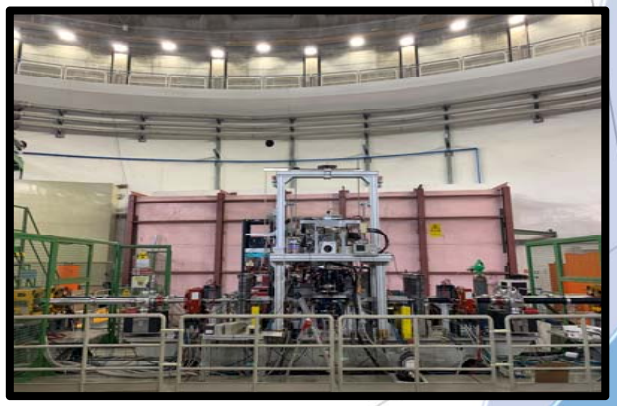


1999- today | 2009- today | futures

DEAR 2002

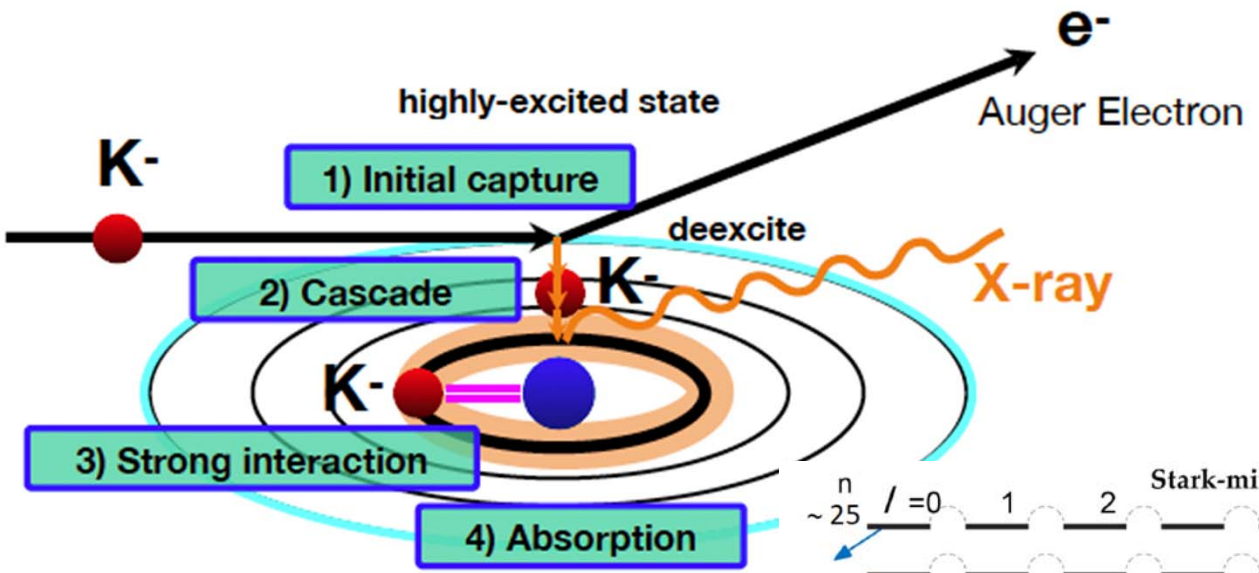


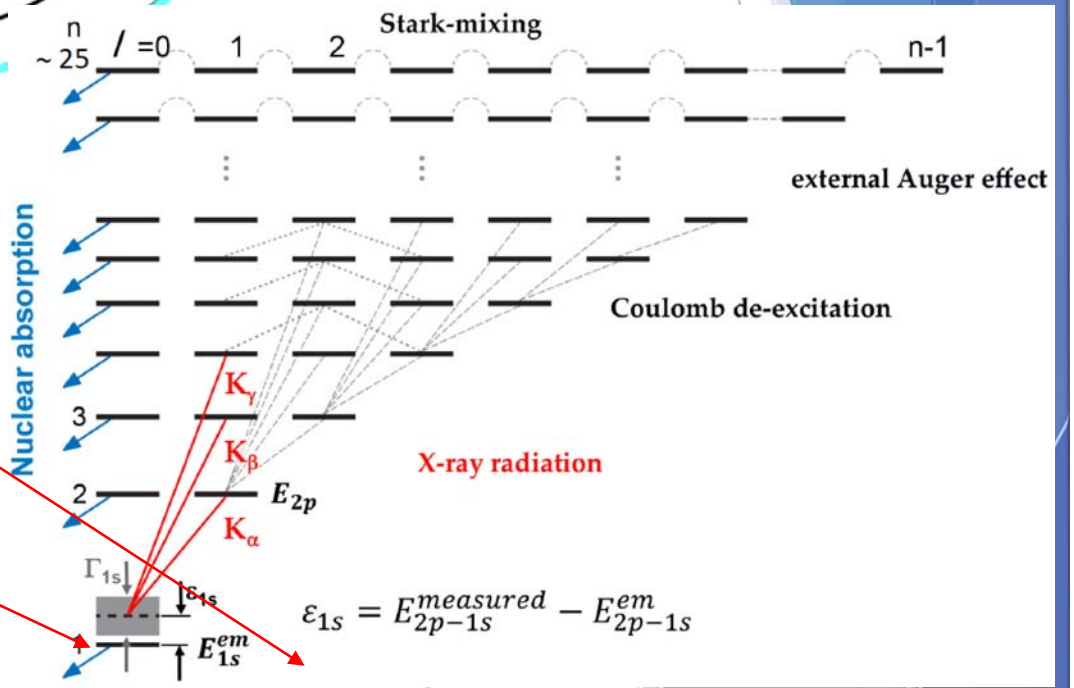
SIDDHARTA 2009



SIDDHARTA-2 2022

Kaonic atom formation





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

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.

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

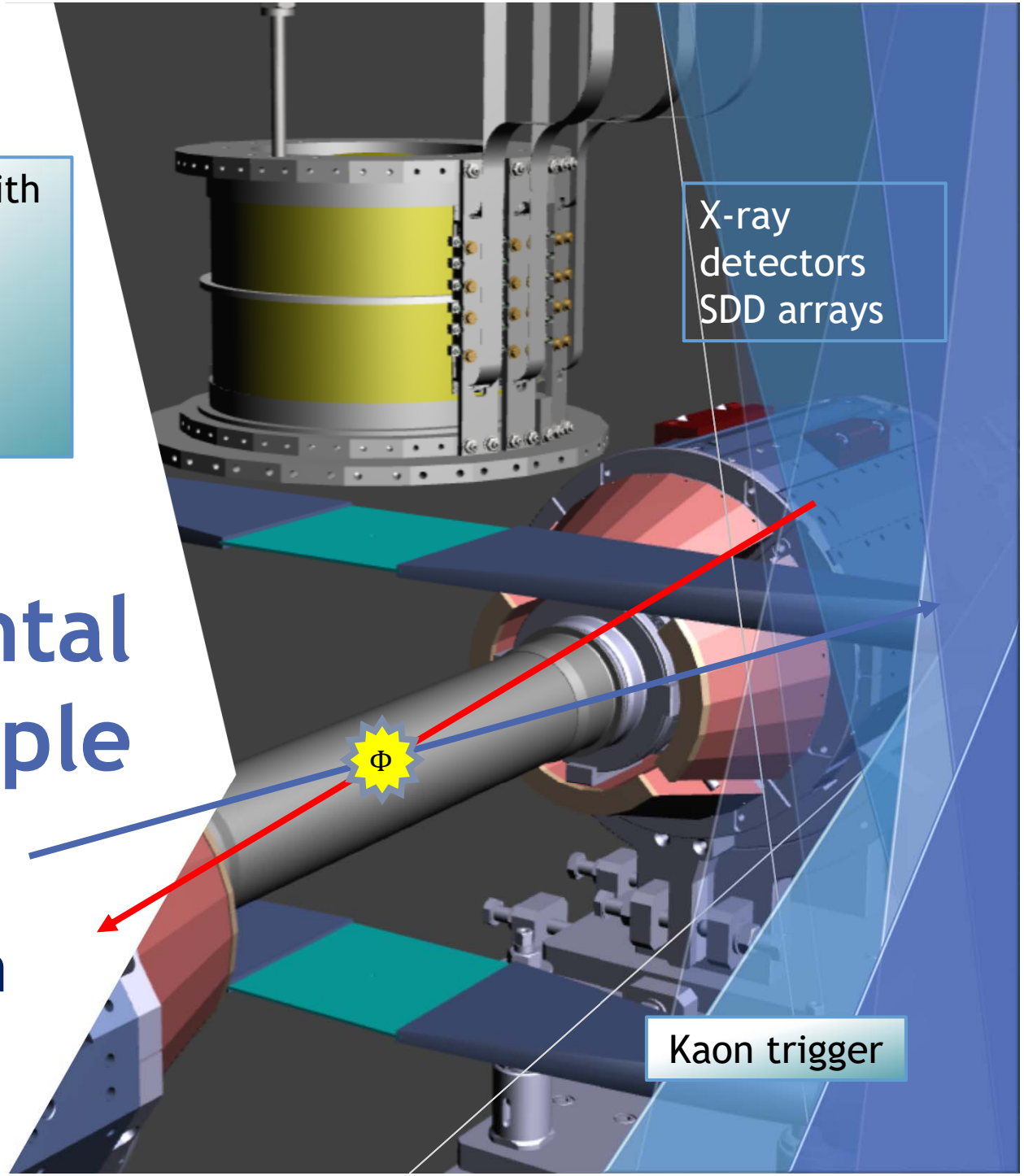
$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$
$$a_{K^-n} = a_1$$

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

completely solve Isospin-dependent K-N scattering length

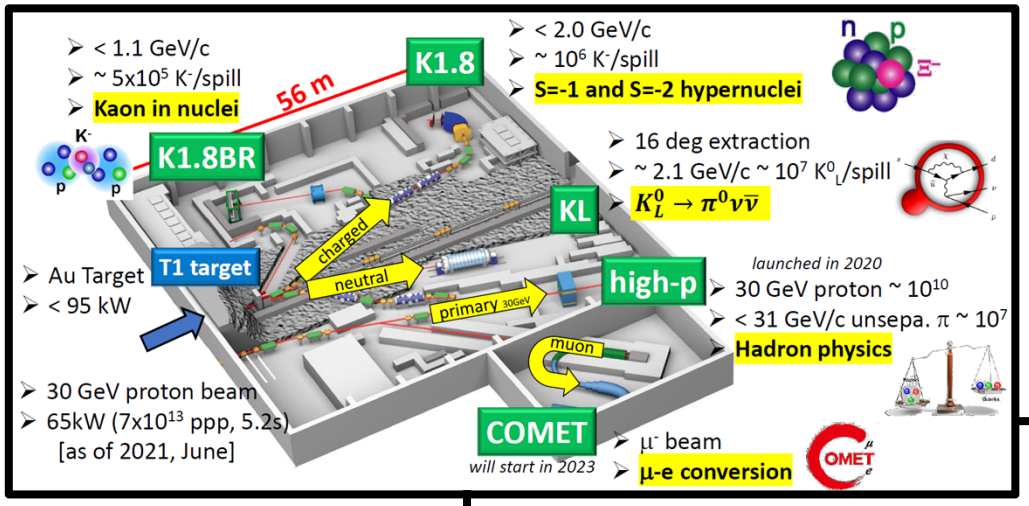
Experimental principle

- Gas target filled with
  He-4
  Deuterium
  Hydrogen
  Neon
- Solid targets



Kaon Beam

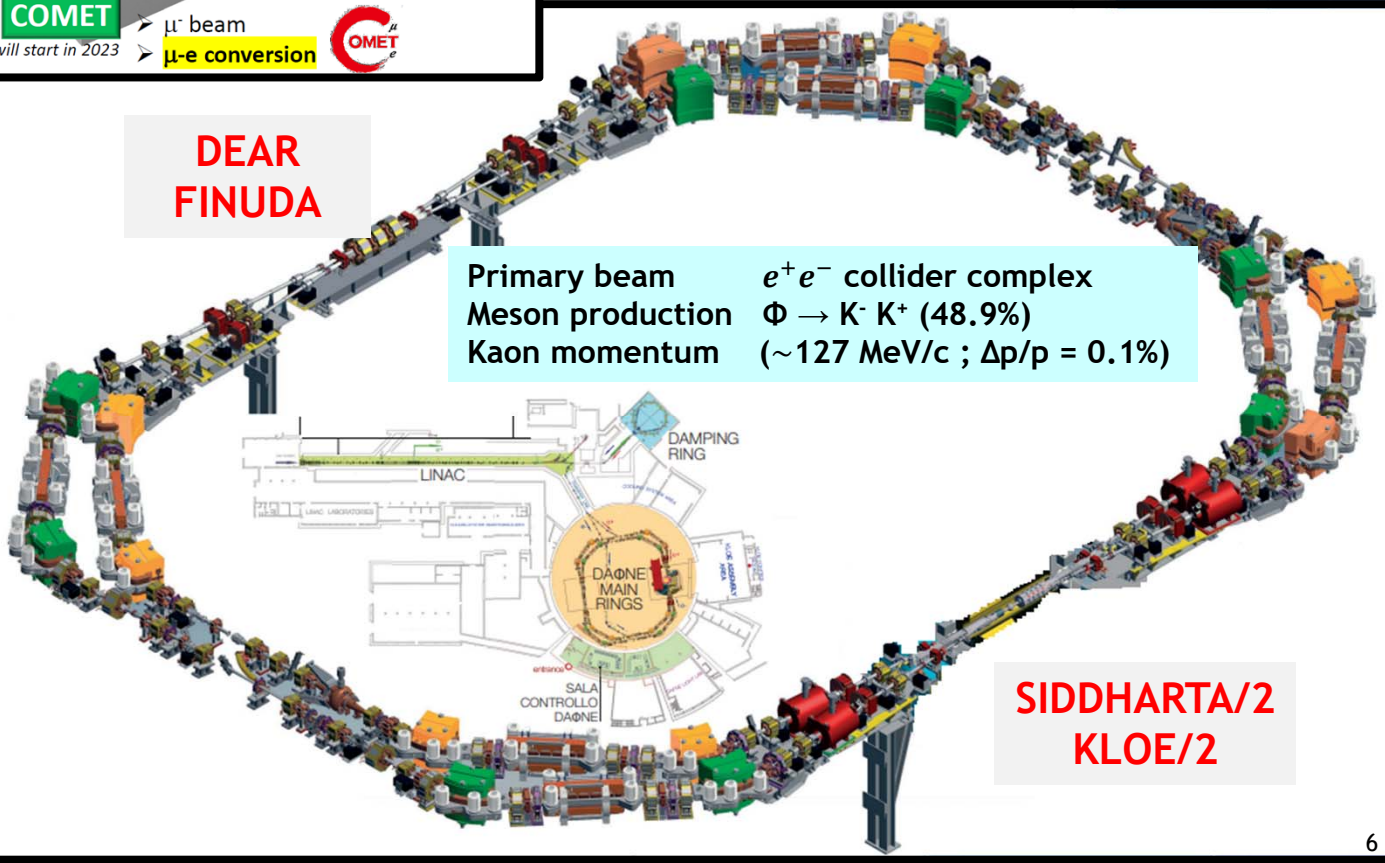
Kaon Beam Source



Hadron Experimental Facility at J-PARC

Primary beam:	30 GeV/c protons
Repetition cycle:	5 sec
Flat top:	3 sec
Production target:	Au
Kaon momentum:	1.2 GeV/c (max.)

DAΦNE collider at LNF



activities using the unique kaon beams available at J-PARC and DAΦNE.

SIDDHARTINO setup

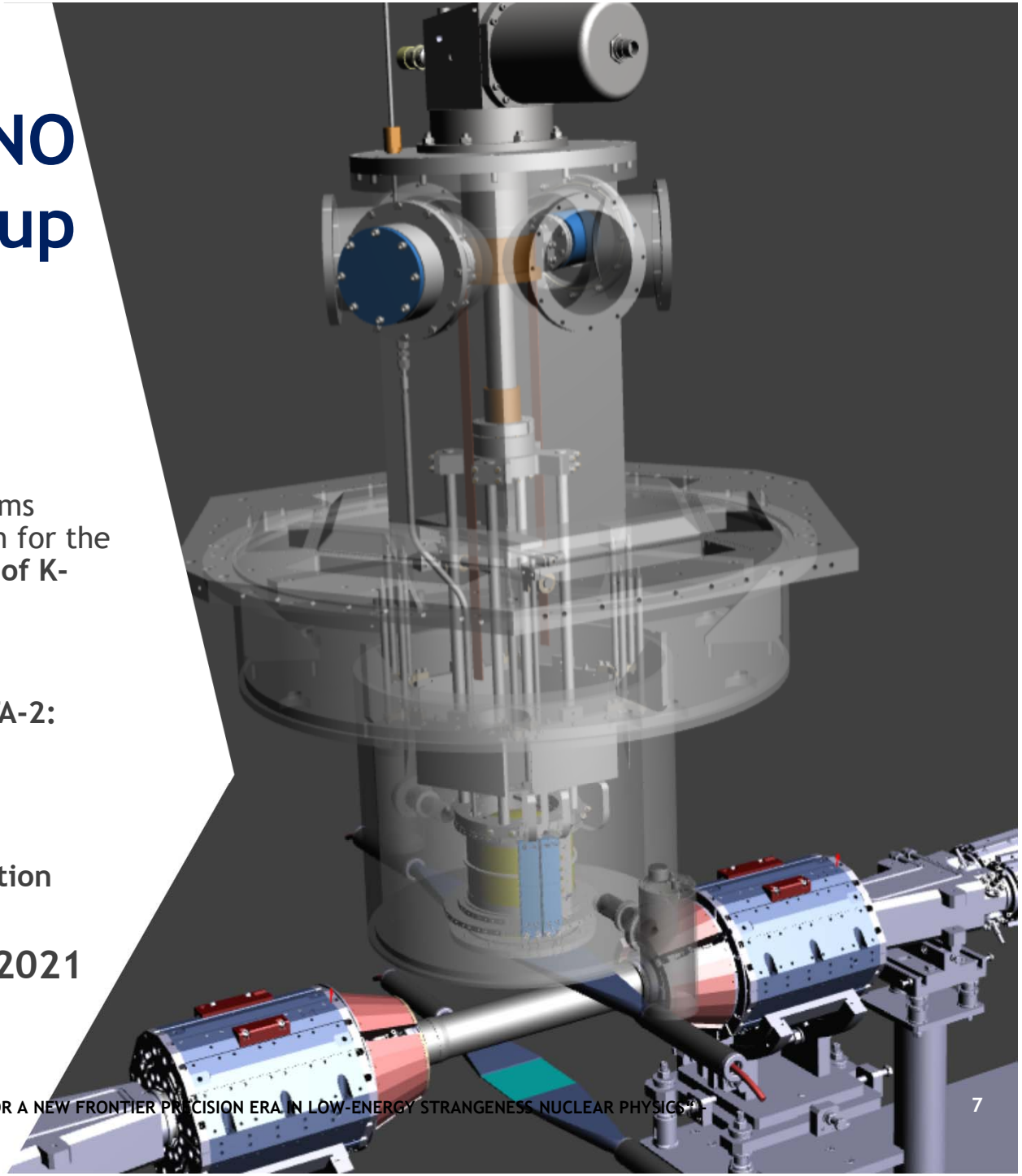
▶**phase 1** of SIDDHARTA-2

1/6 of the total SDD active area

▶**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 summer 2021



Degrader optimization

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*

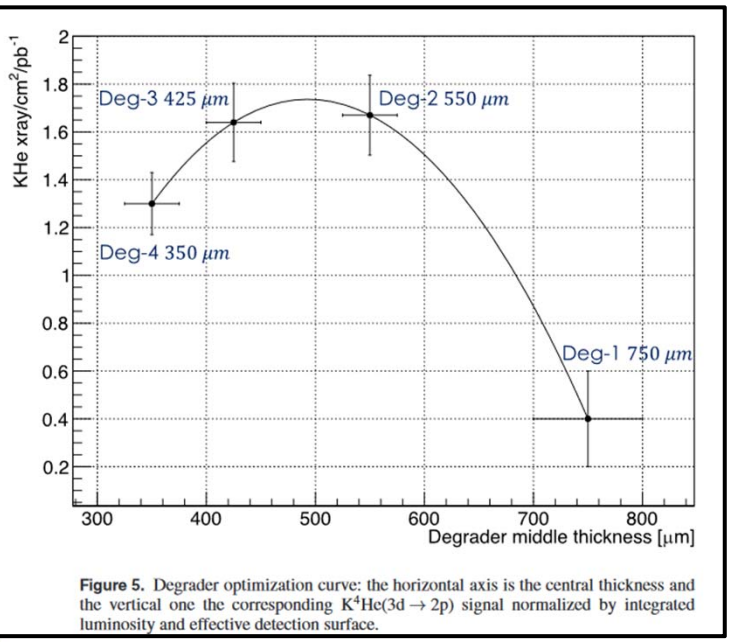
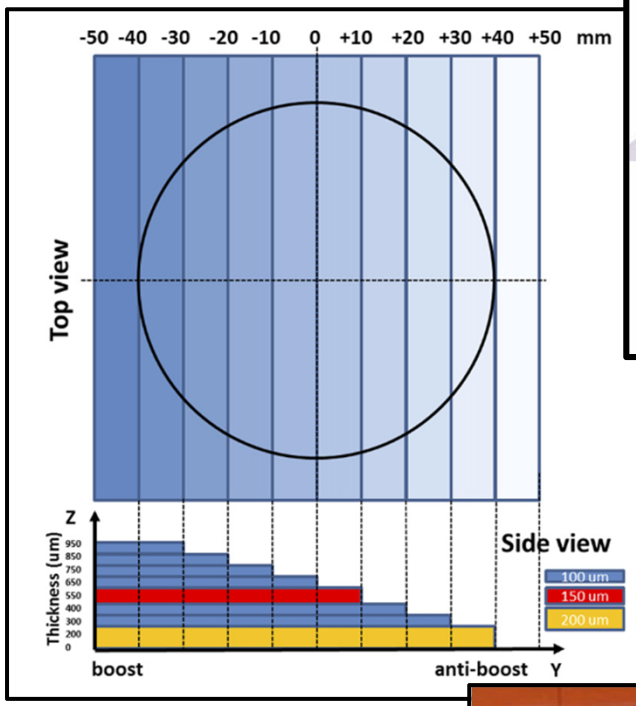
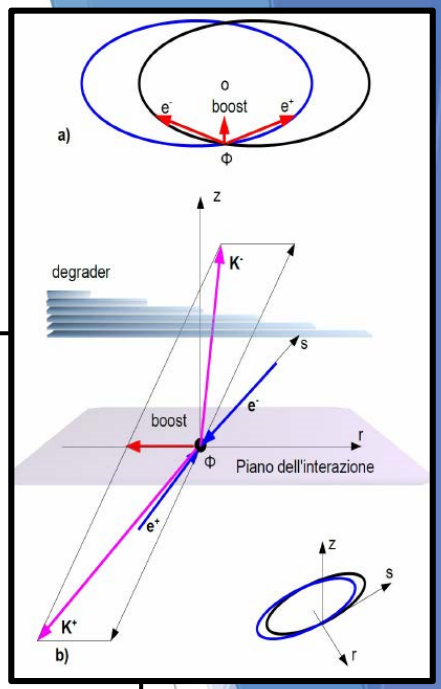
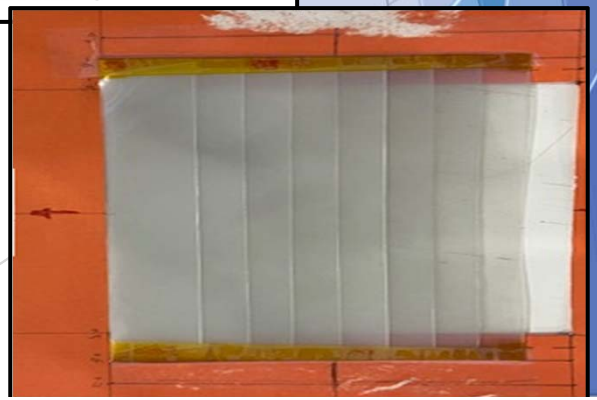


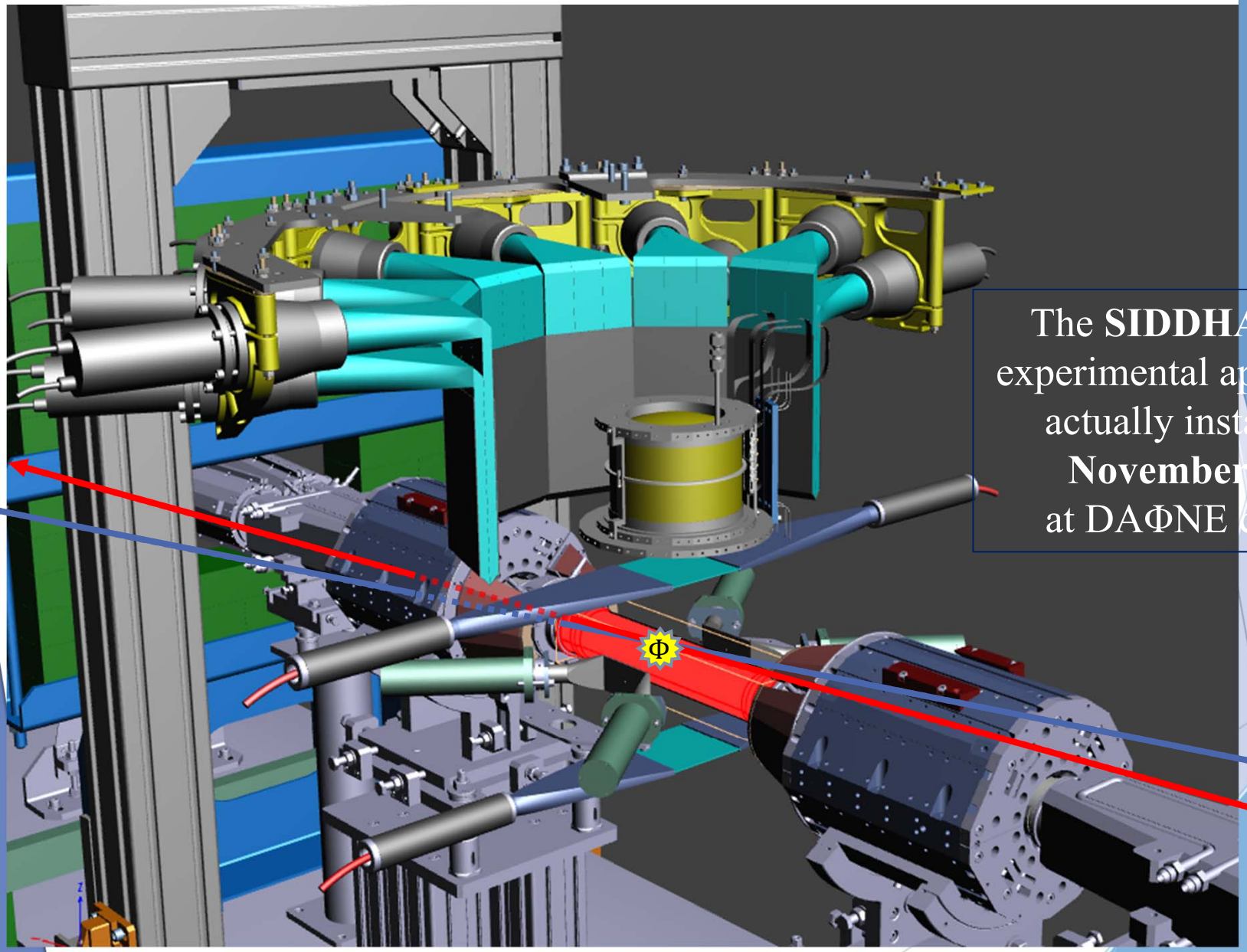
Figure 5. Degrader optimization curve: the horizontal axis is the central thickness and the vertical one the corresponding $K^4He(3d \rightarrow 2p)$ signal normalized by integrated luminosity and effective detection surface.







SIDDHARTA-2 setup



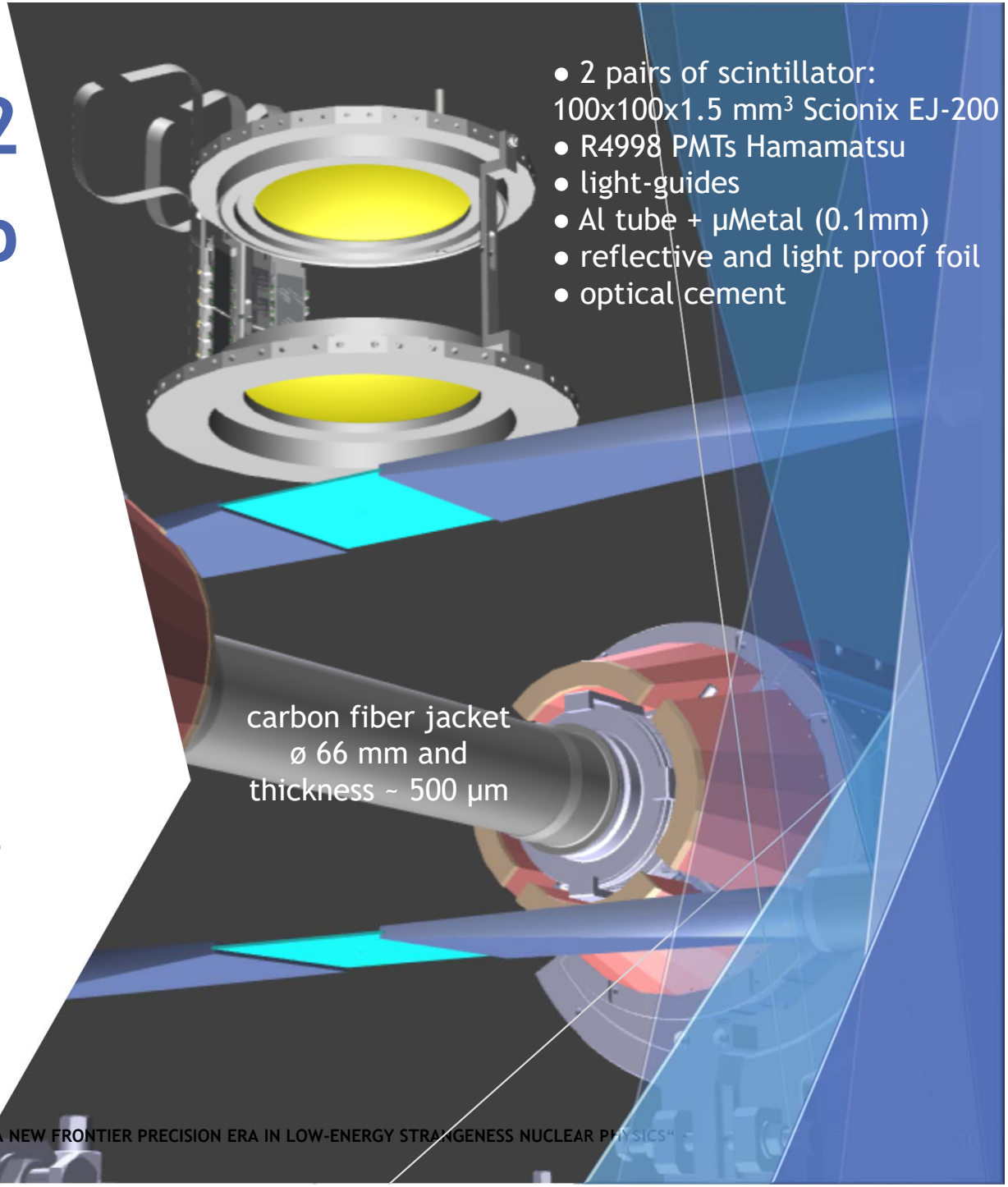
The **SIDDHARTA-2** experimental apparatus is actually installed in **November 2021** at DAΦNE collider

SIDDHARTA-2 setup

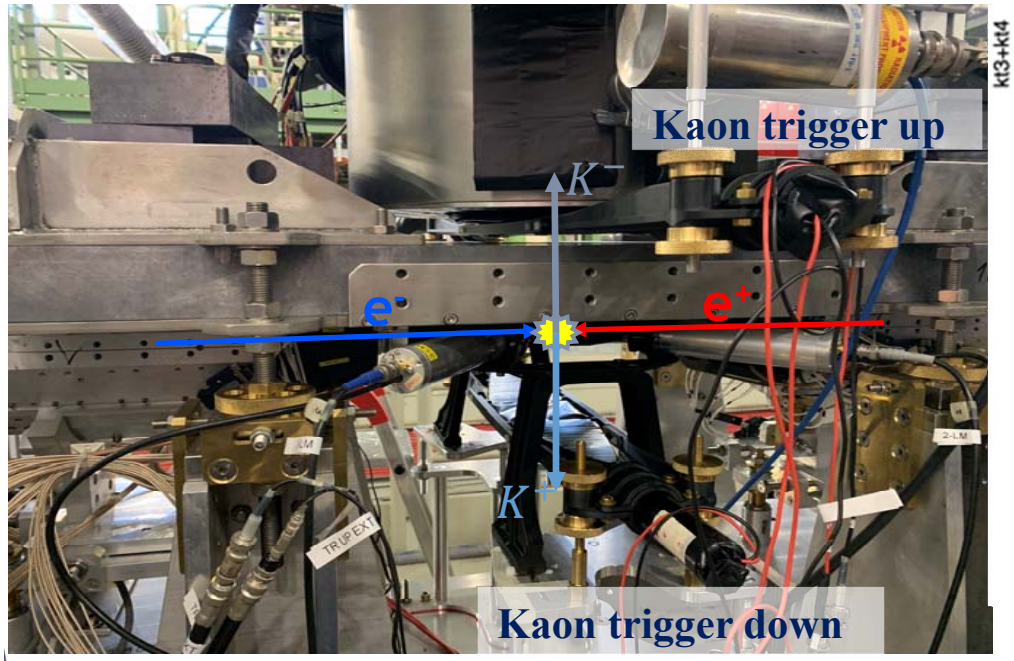
▶The **Kaon Trigger** consists of two plastic scintillators read by photomultipliers placed above and below the interaction region.

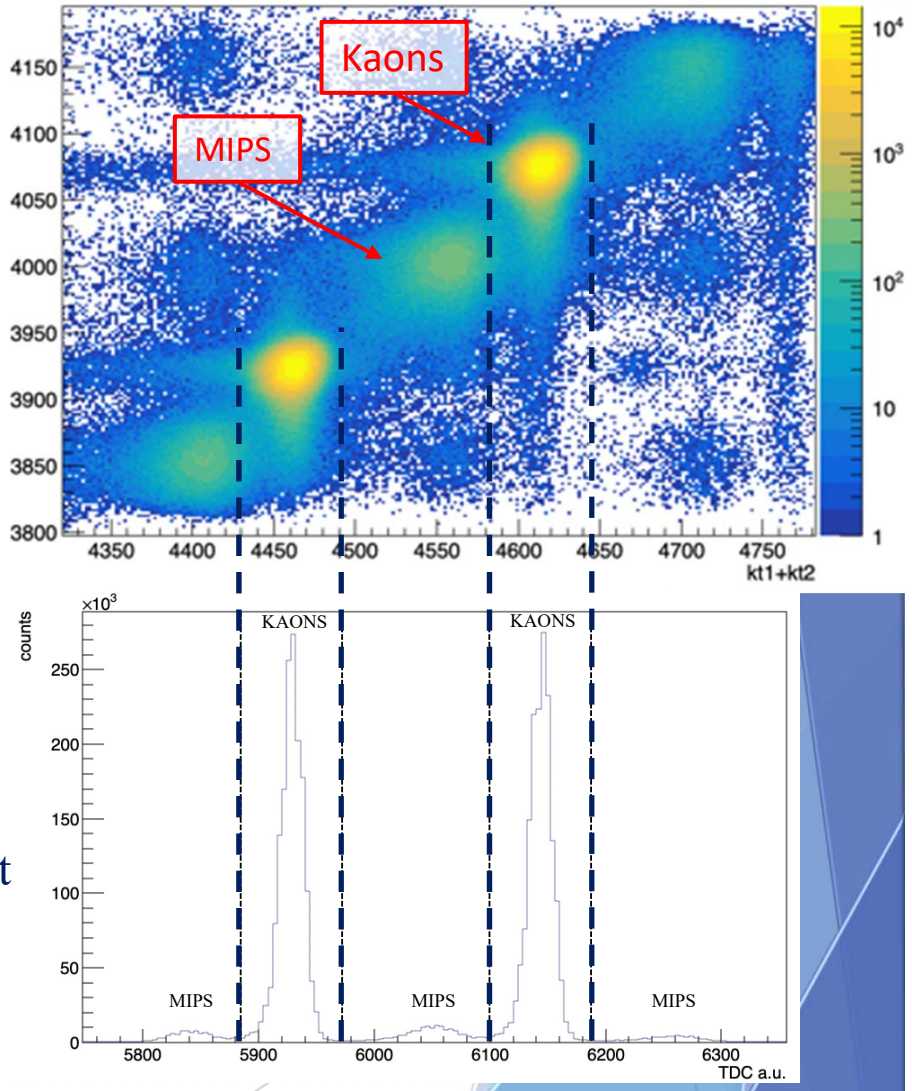
Needs:
- Fast detectors & FEE
- Real time acquisition
- Accidental rate << Signal rate

Allows:
- Collision optimization
- Machine feedback



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

❖ Target + SDD cooling

Leybold MD10 – 16 W @ 20 K
target cell and SDDs are cooled via ultra pure aluminum bars

T_{TC} = 20-30 K
T_{SDD} ~ 100 K

SIDDHARTA-2 target

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

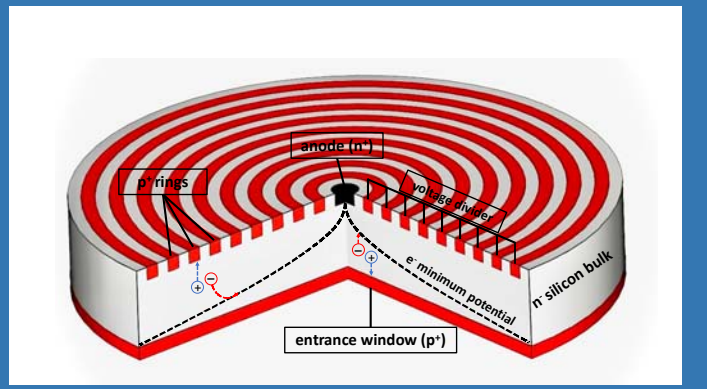
384 Silicon Drift Detectors (SDDs) mounted on aluminium finger support for cooling

Silicon Drift Detectors

- 8 SDD units (0.64 cm^2)

for a total active area of 5.12 cm^2

- Thickness of 450 µm ensures a high collection efficiency for X-rays of energy between 5 keV and 12 keV



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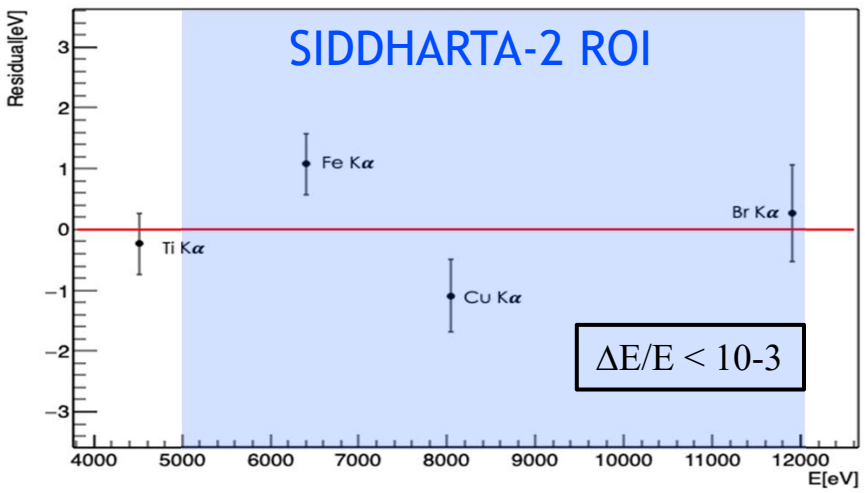
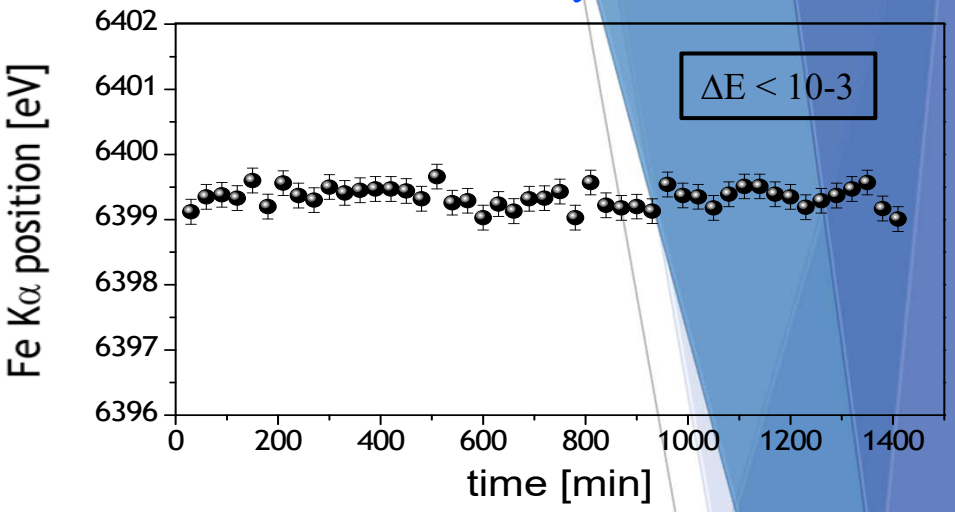
POLITECNICO MILANO 1863

Silicon Drift Detectors

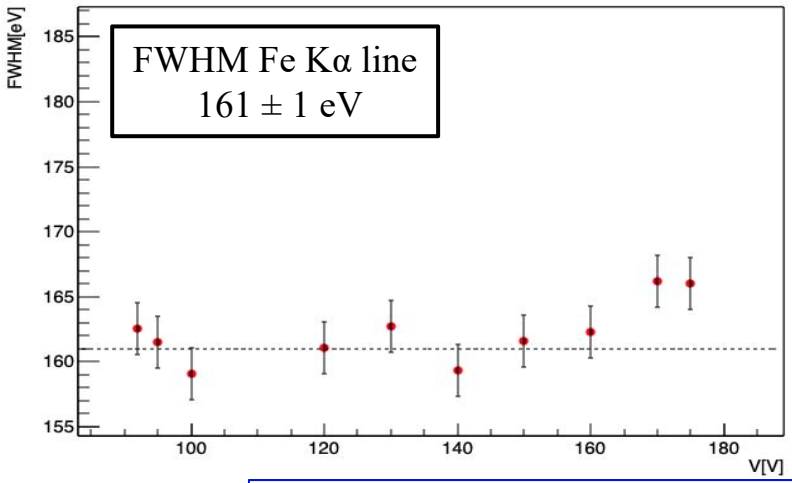
Linearity



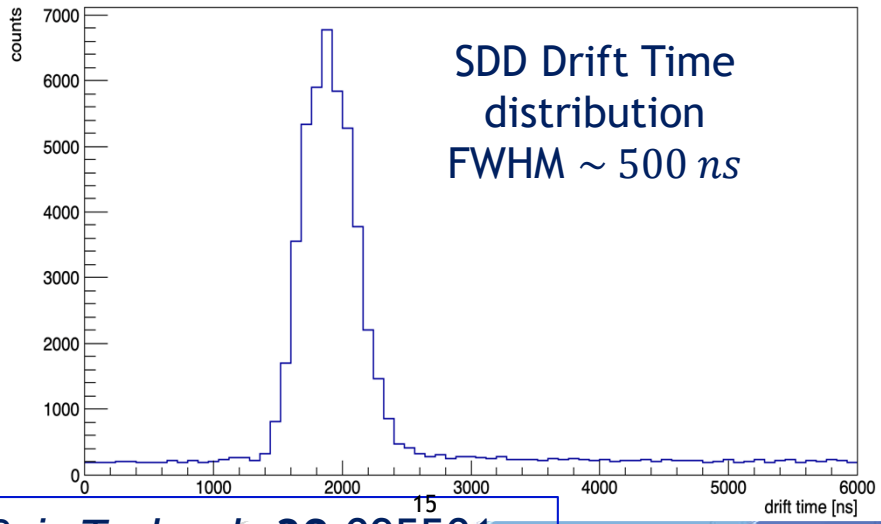
Stability



Energy Resolution



Timing Resolution

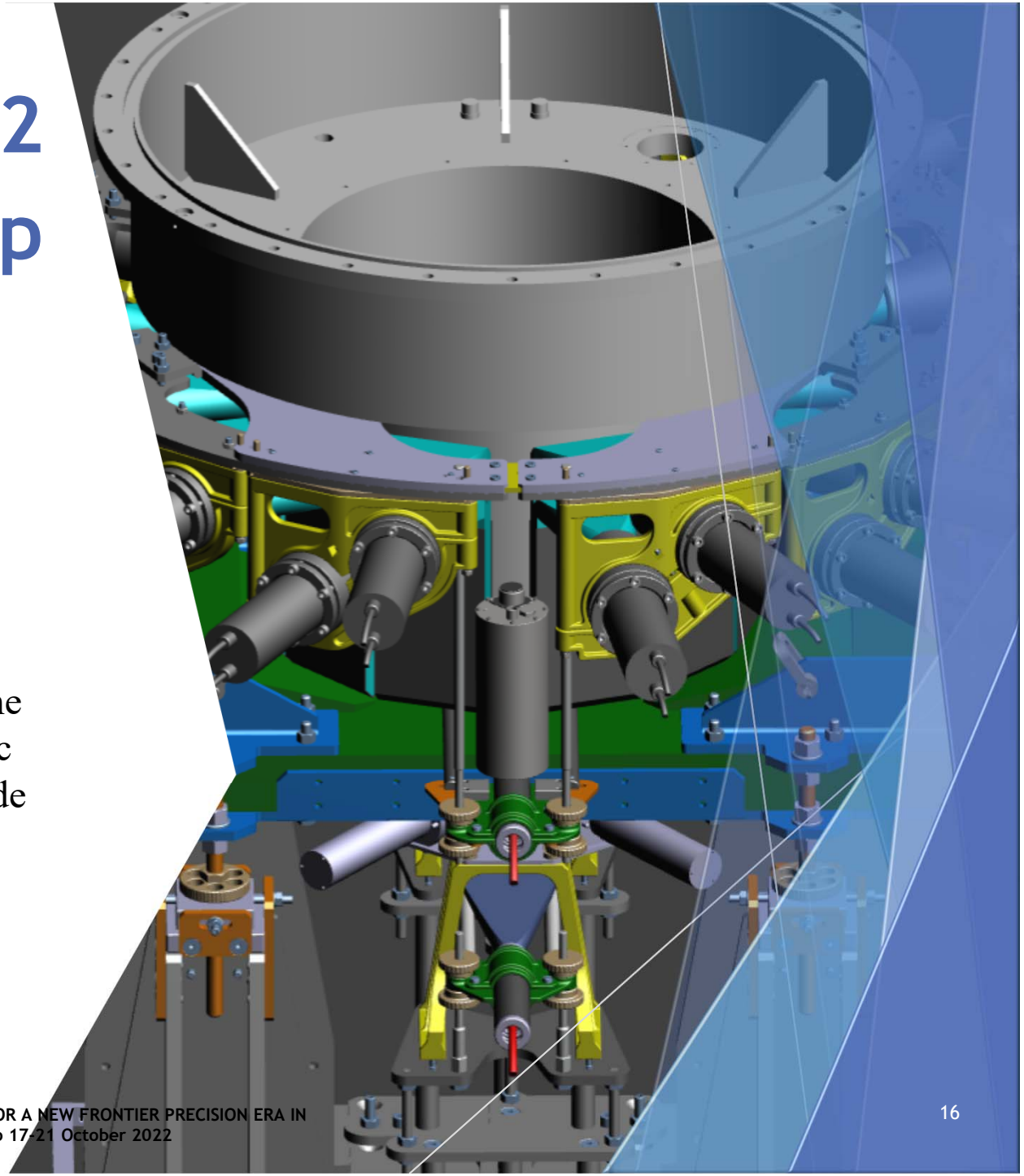


M Miliucci *et al* 2021 *Meas. Sci. Technol.* **32** 095501

SIDDHARTA-2 setup

The **VETO-1** consists of 12 plastic scintillators read by photomultipliers placed around the vacuum chamber.

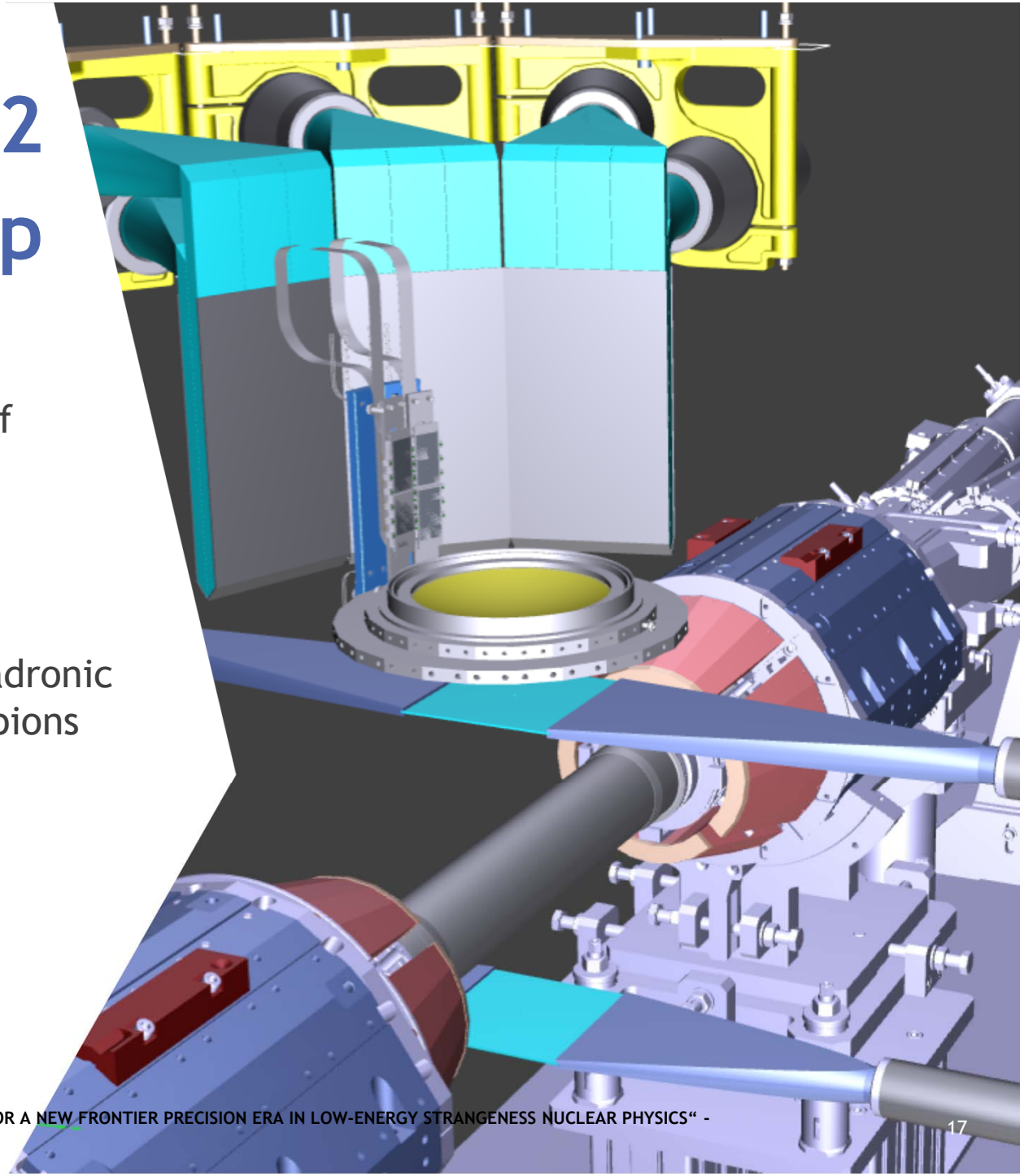
Is used to determine where the kaonic atom where the kaonic atom has been created if inside the gas target or not.



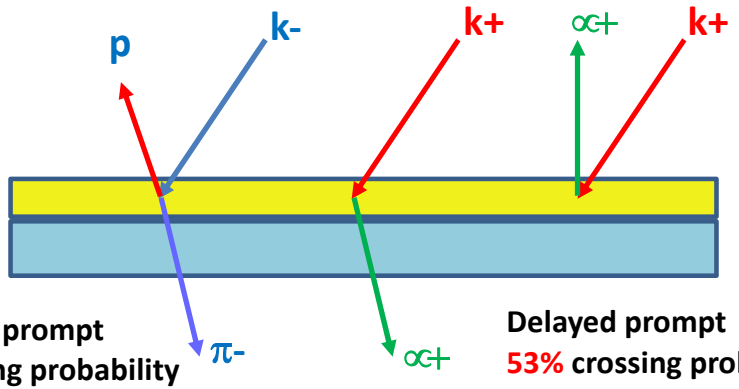
SIDDHARTA-2 setup

- 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.



Kaon Charge Detector



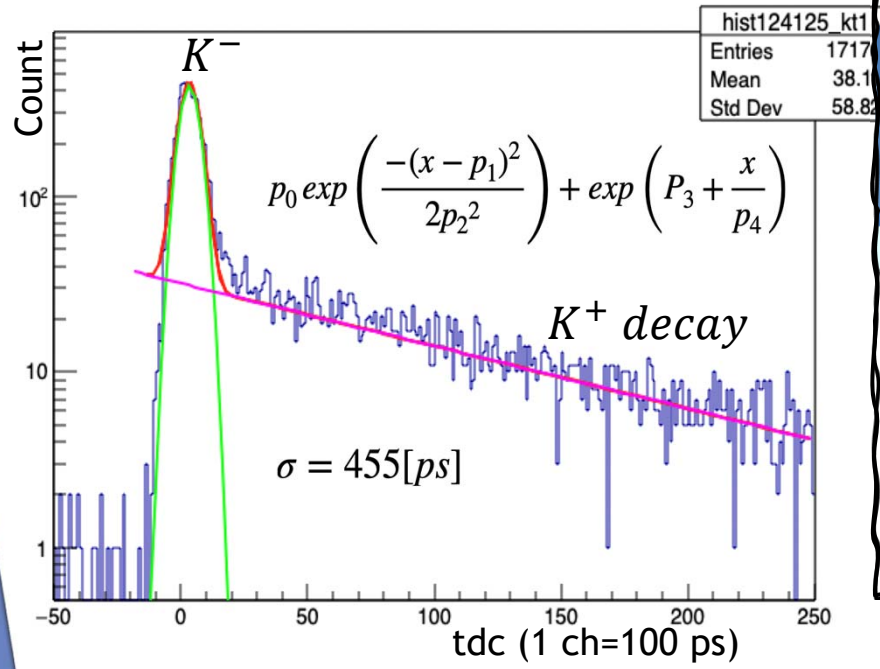
Stop both K^+ and K^- in a passive layer (Teflon) and detect secondaries in a scintillator

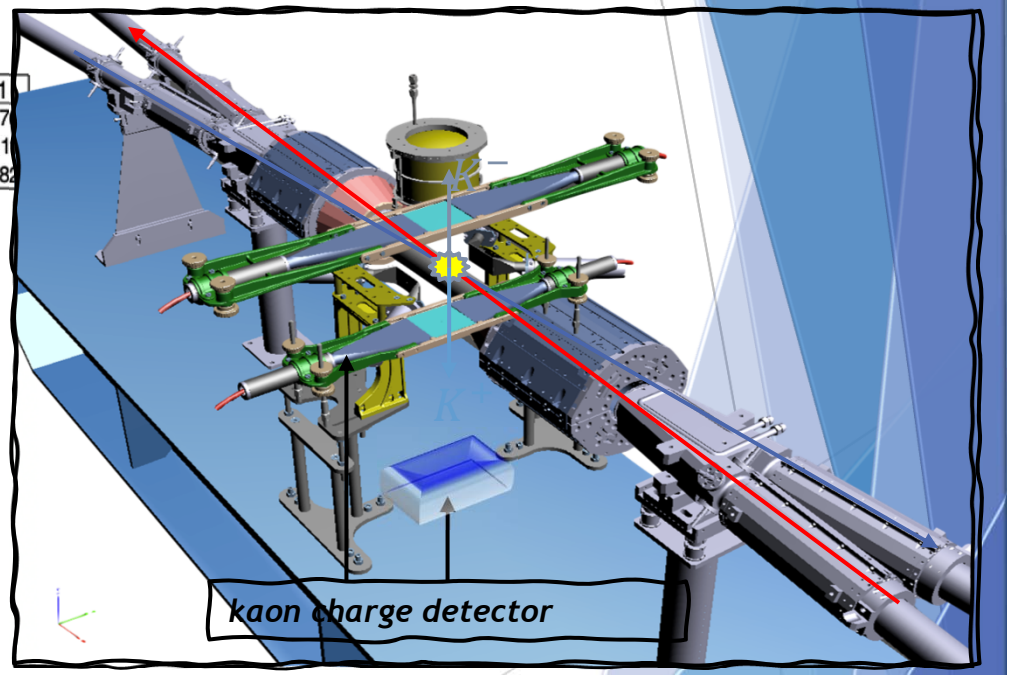
2 mm teflon

5-10 mm thick scintillator

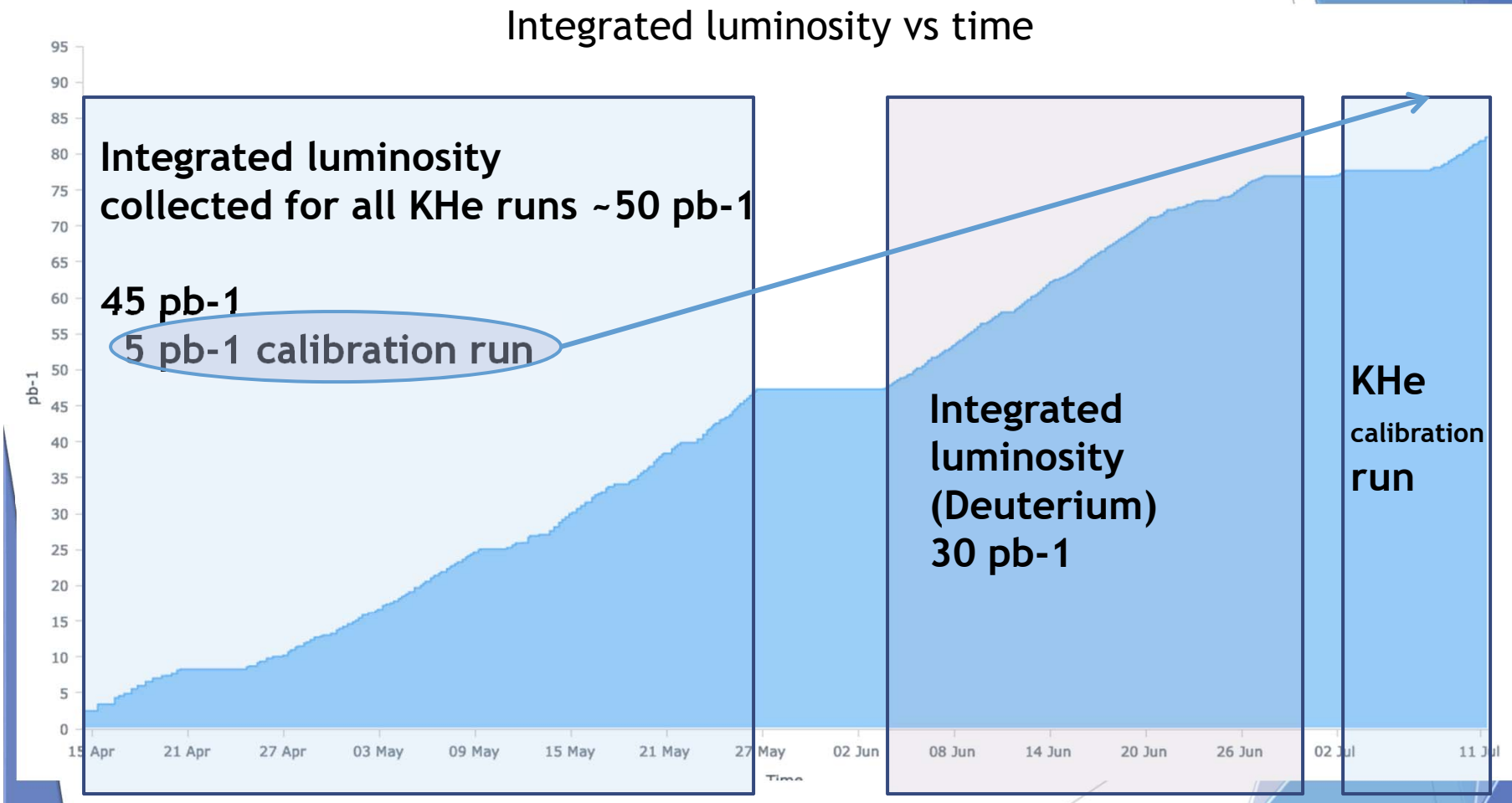
Immediate prompt
83% crossing probability

Delayed prompt
53% crossing probability

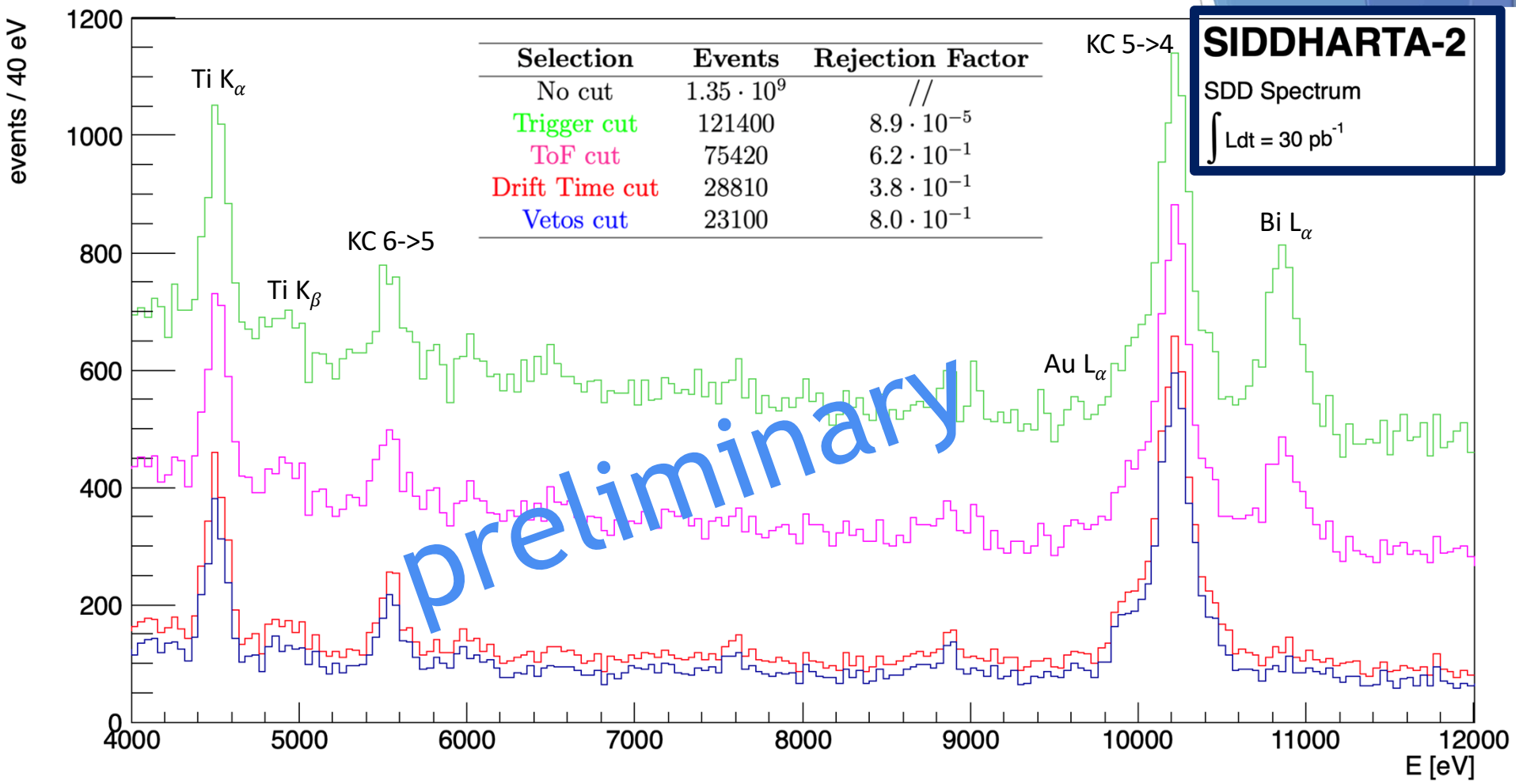




SIDDHARTA-2 First Run in 2022



SIDDHARTA-2 Kaonic deuterium

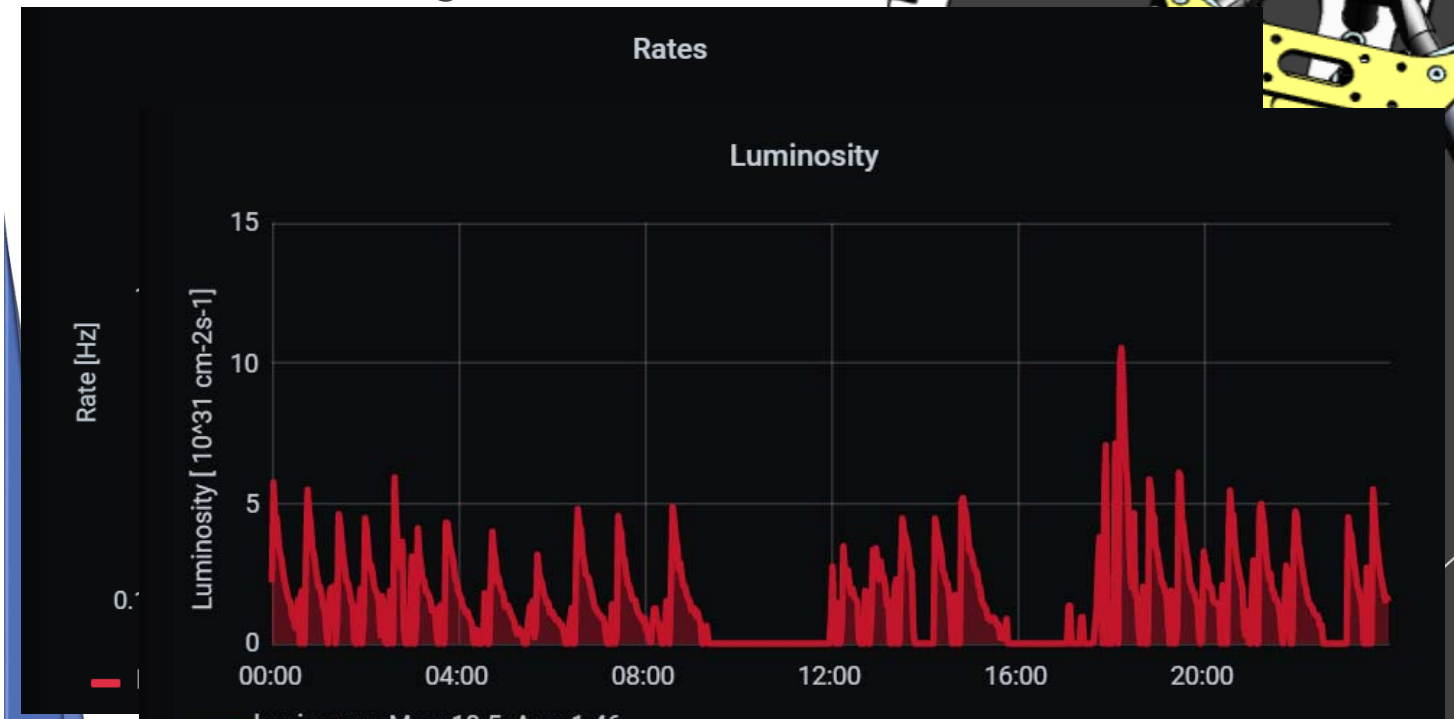


Selection	Events	Rejection Factor
No cut	$1.35 \cdot 10^9$	//
Trigger cut	121400	$8.9 \cdot 10^{-5}$
ToF cut	75420	$6.2 \cdot 10^{-1}$
Drift Time cut	28810	$3.8 \cdot 10^{-1}$
Vetos cut	23100	$8.0 \cdot 10^{-1}$

see F. Sgaramella talk

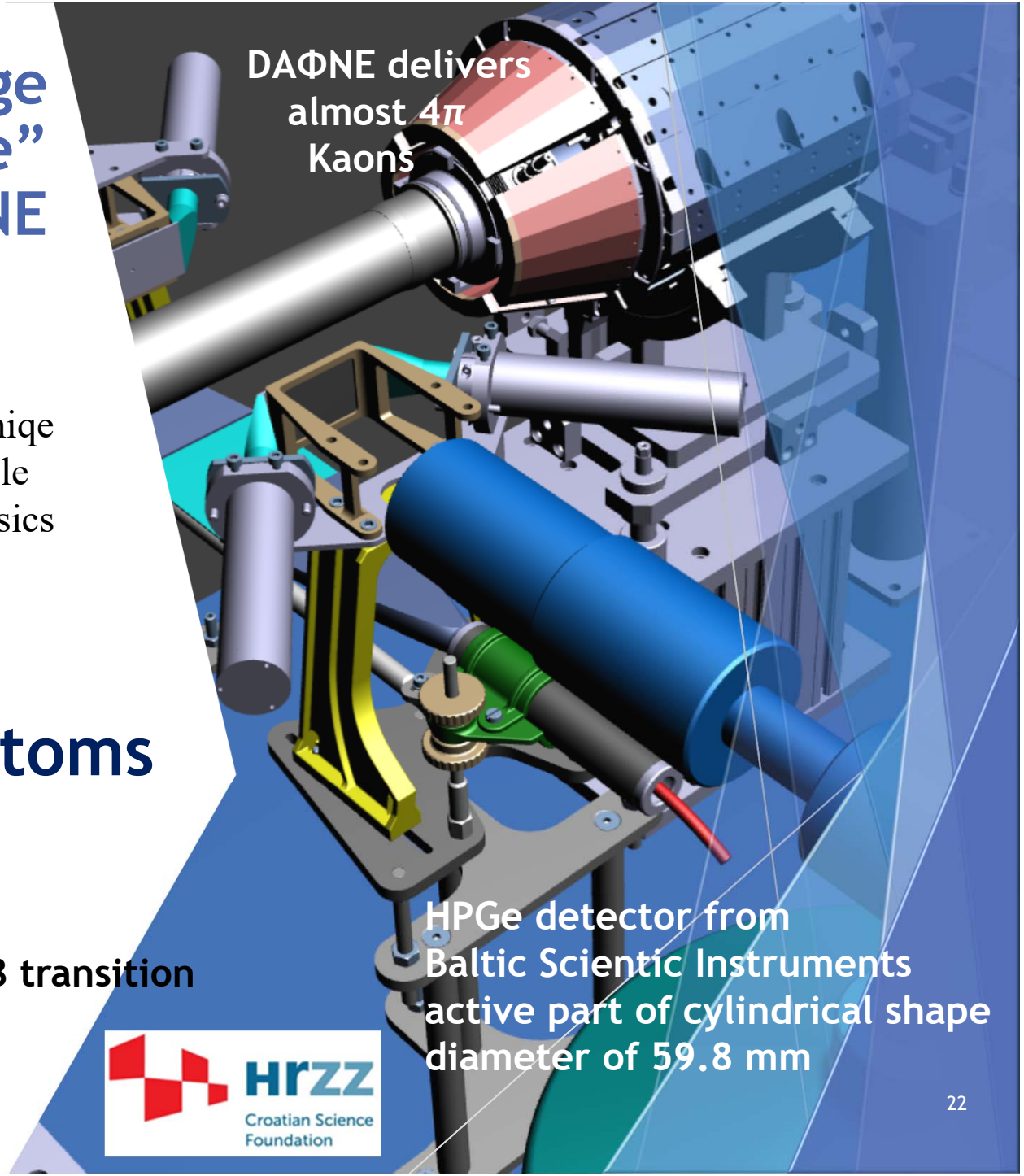
Take advantage of “free space” in DAΦNE

▶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.



- 2 pairs of scintillator: 80x40x2 mm^3 Scionix EJ-200
- R4998 PMTs Hamamatsu

Take advantage of "free space" in DAΦNE



We want to exploit this uniqe beam as much as possible to perform important physics measurements

Heavy Kaonic Atoms

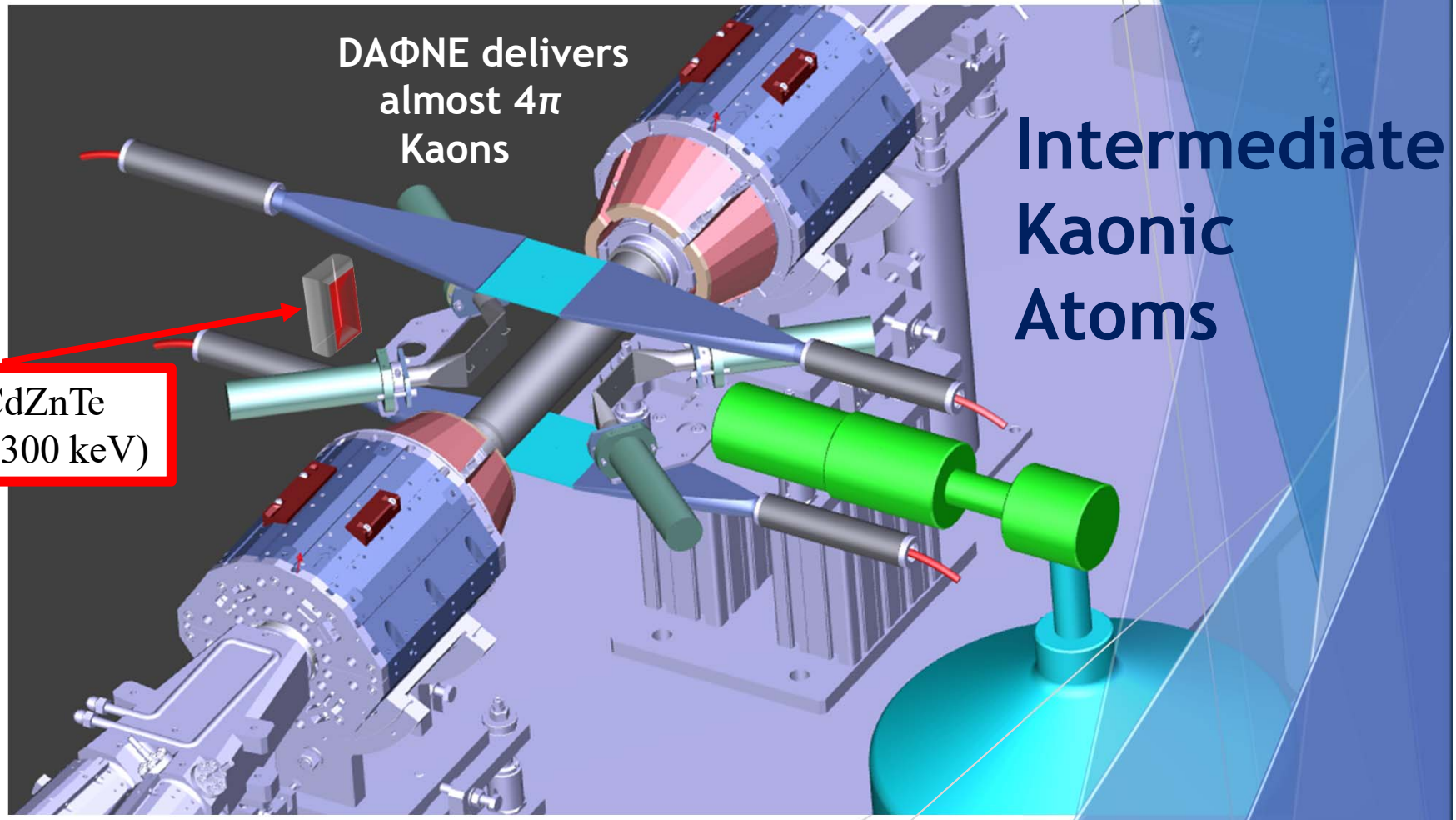
TARGET - lead
Trigger - luminomiter
e.g. 291.6 keV from 9 → 8 transition

see A. Scordo talk

HPGe detector from Baltic Scientic Instruments active part of cylindrical shape diameter of 59.8 mm

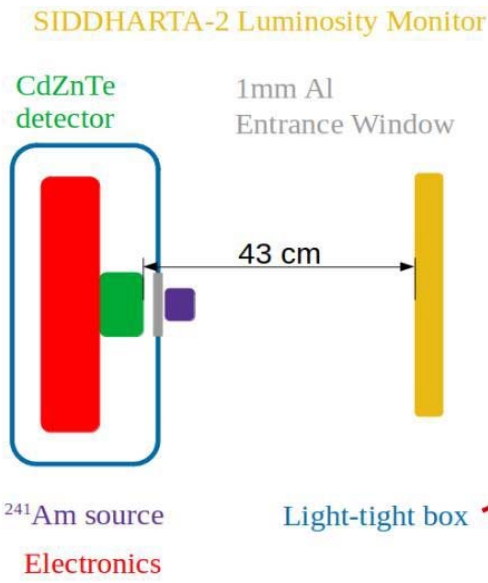
HRZZ Croatian Science Foundation

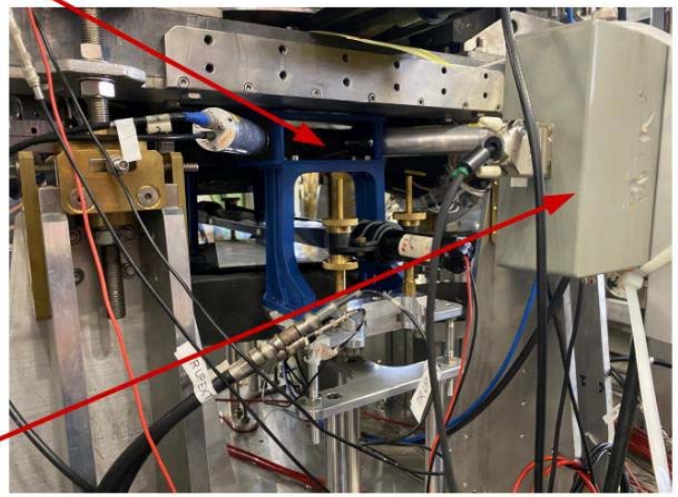
Take advantage of “free space” in DAΦNE



Intermediate Kaonic Atoms

Goal: background and resolution assessment in machine environment (first time)

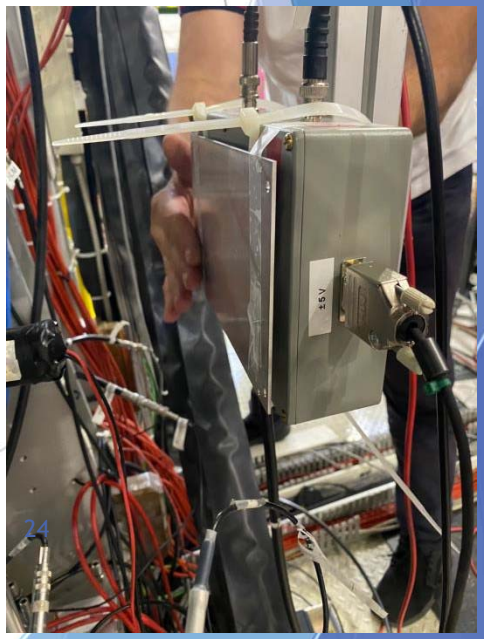




CdZnTe: first tests @ DAΦNE June 2022

First prototype installed in DAΦNE with the help of Palermo Team

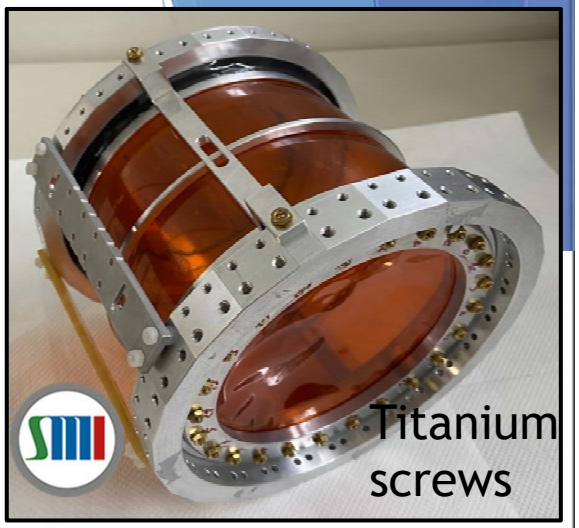
see A. Scordo talk

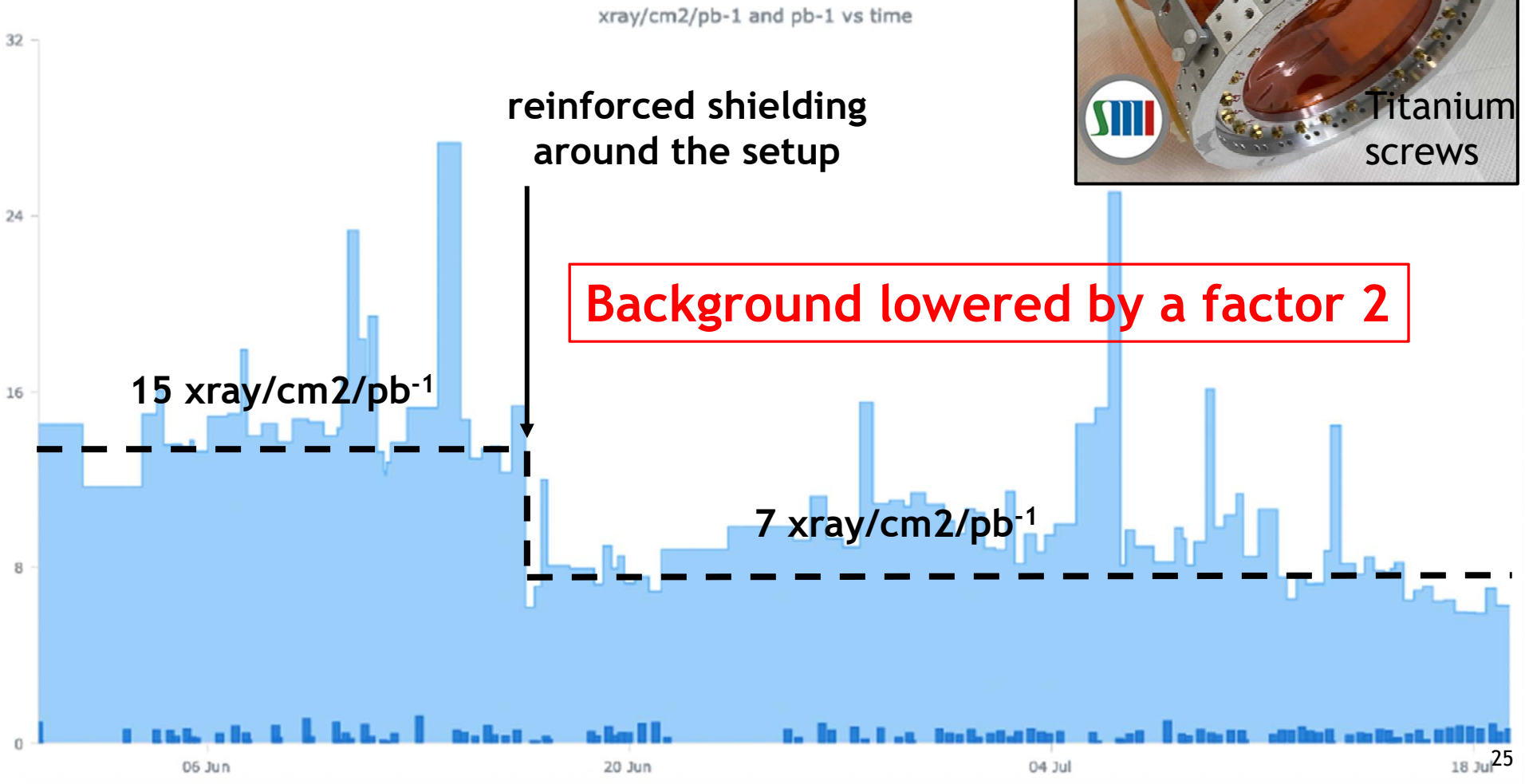


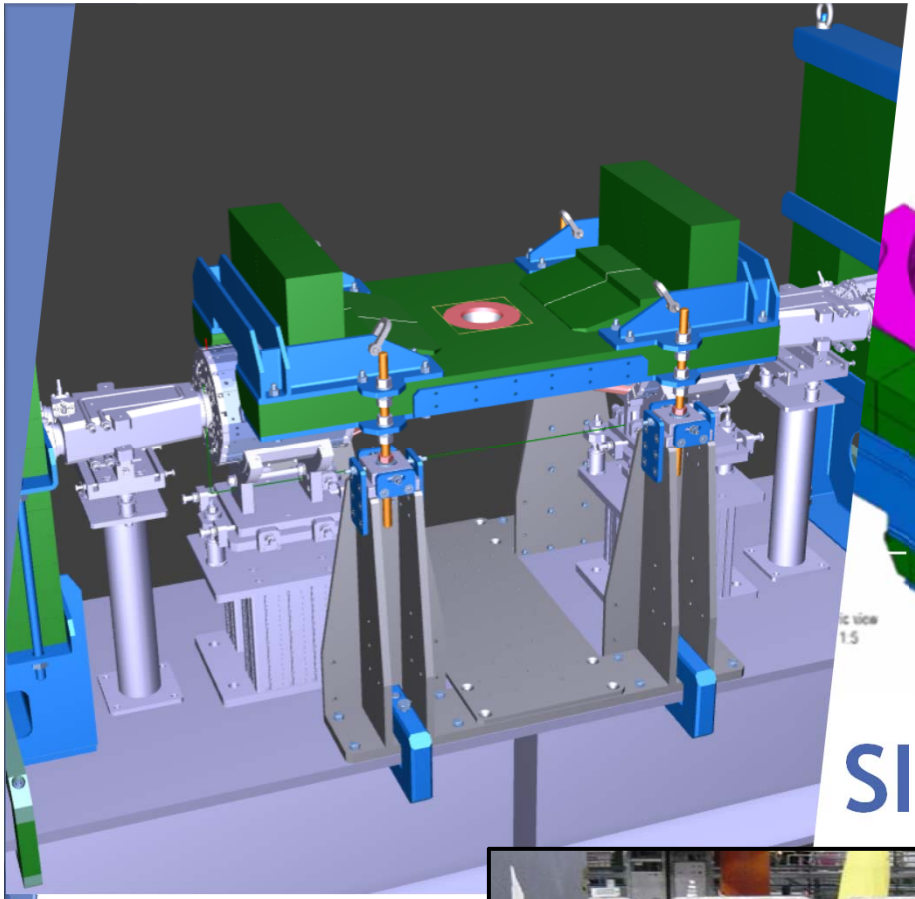
Optimize the SIDDHARTA-2 setup

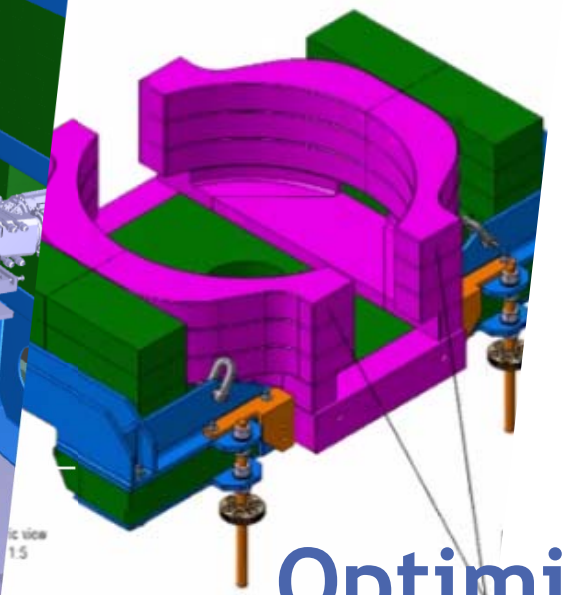
(Sept. 2022 – February 2023)

- **UHMWPE - new entrance windows material for target super-strong form of polyethylene, would eliminate both Nitrogen and Oxygen contamination**



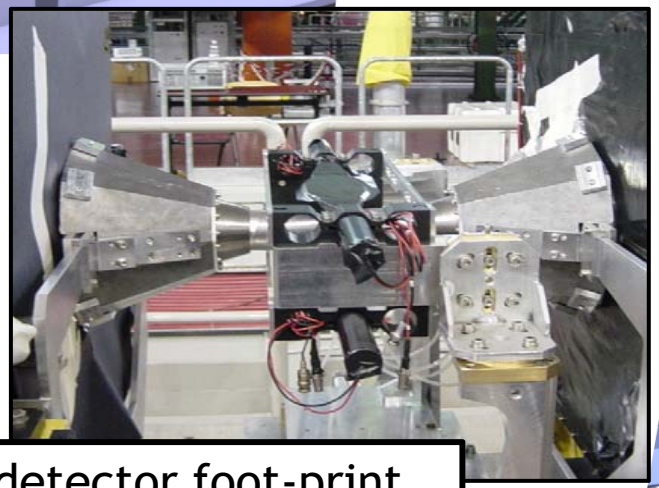




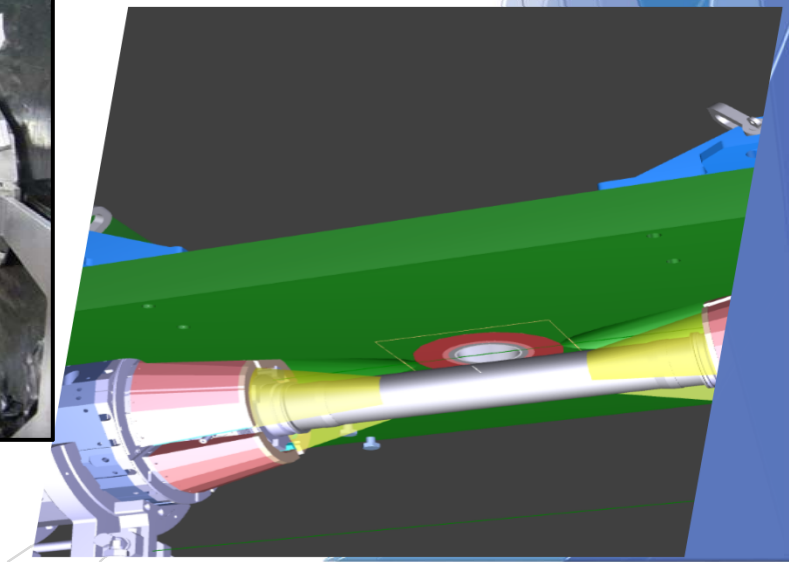


Improve the lateral shielding around the vacuum chamber

Optimize the SIDDHARTA-2 setup

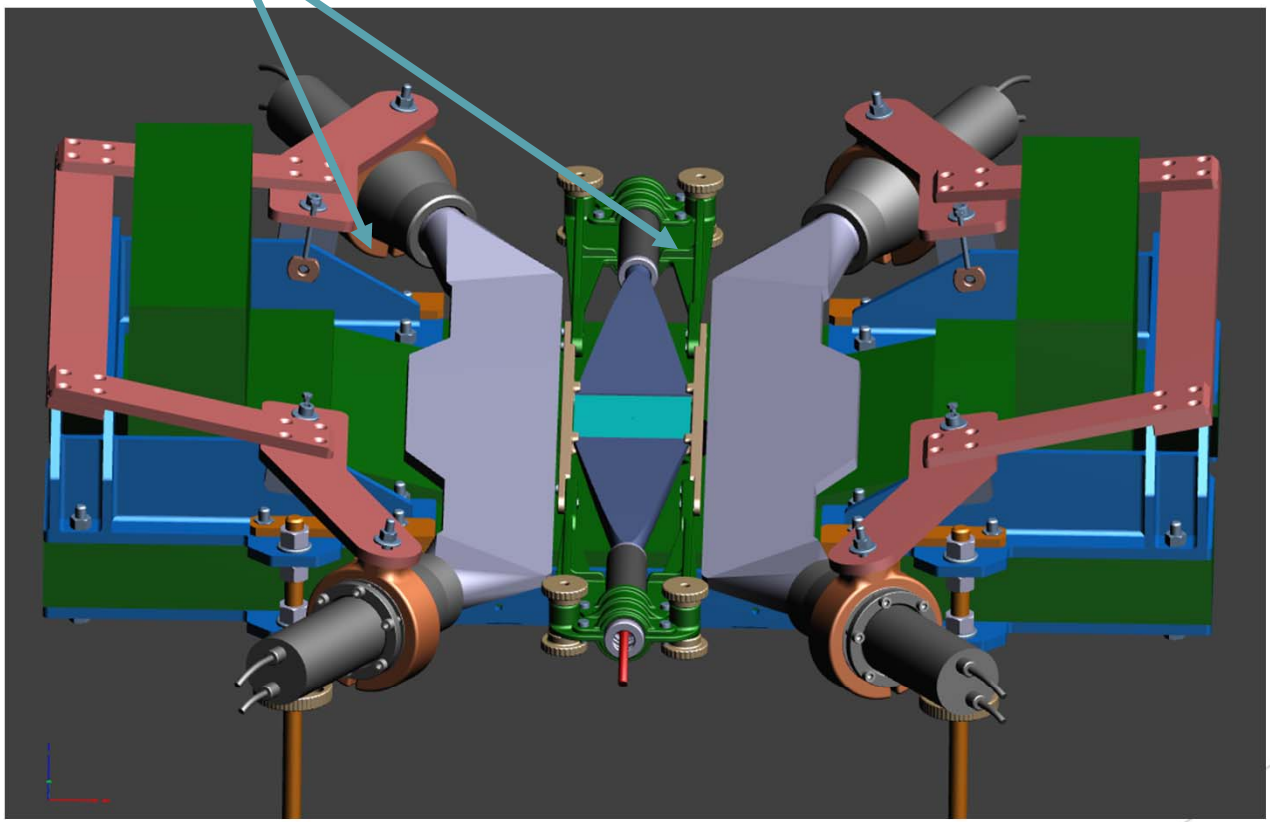


DAΦNE luminosity detector foot-print replaced by special re-design shielding



Optimize the SIDDHARTA-2 setup

VETO system adds – VETO3



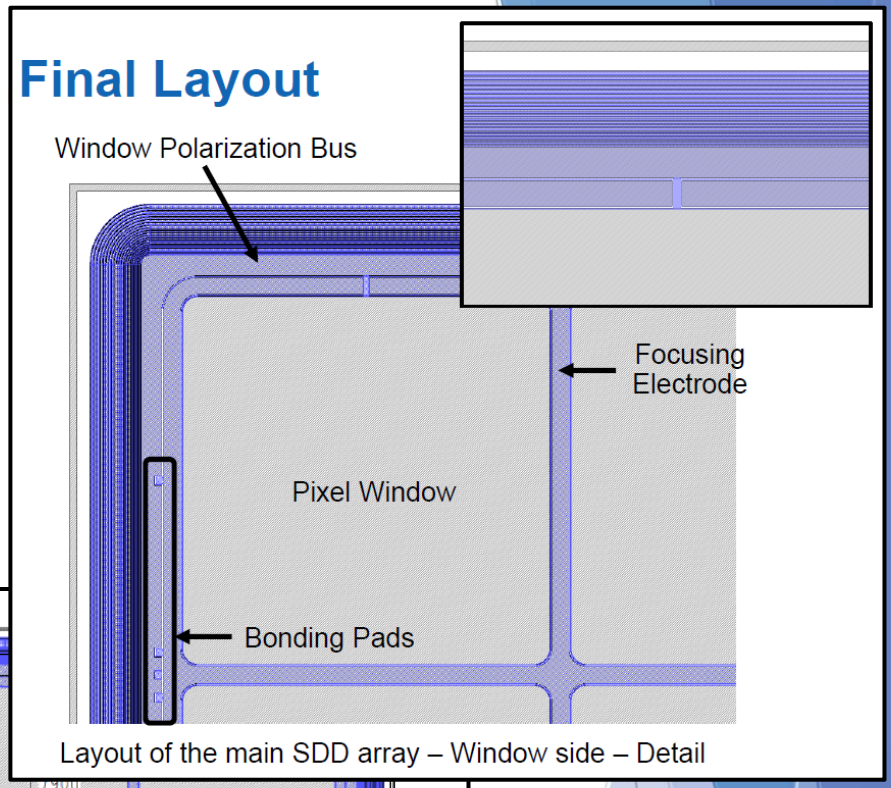
SDD 1mm development

Main SDD Array – 4 × 2 pixels

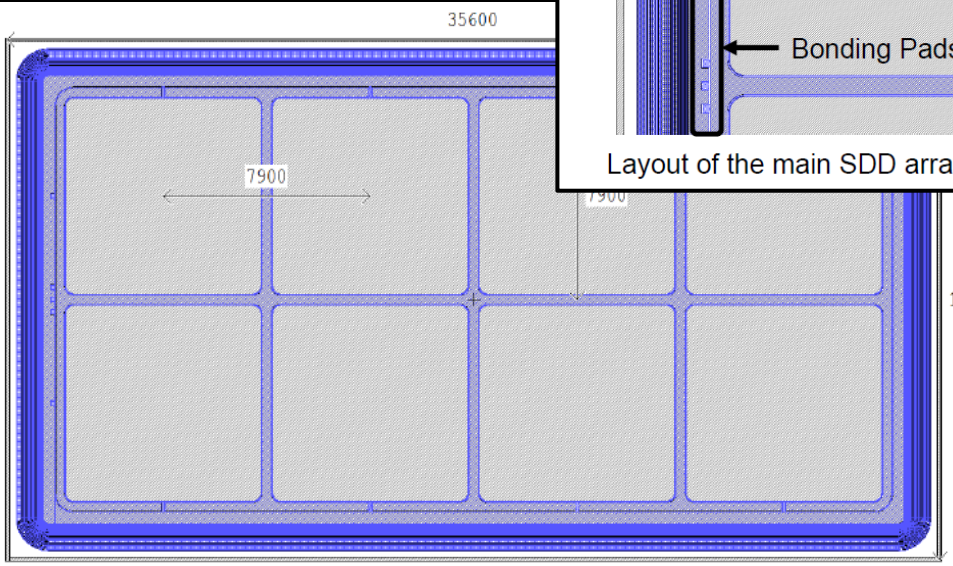
- Introduced focusing electrode on the window (reduce charge sharing)
- Single connection to polarize all the pixel windows
- Single connection to polarize focusing electrode
- Improved robustness of bonding pads

FBK production run in progress

delivery December 2022



Layout of the main SDD array – Window side – Detail



Layout of the main SDD array – Window side

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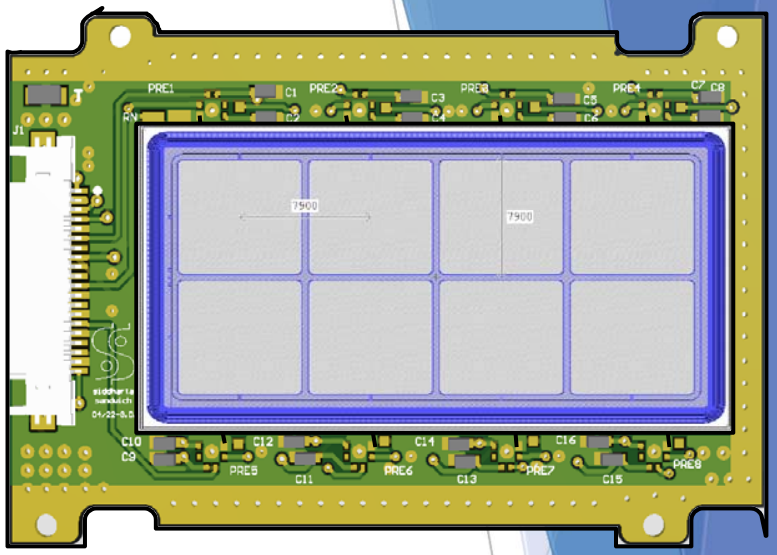
FUTURE BUILT ON KNOWLEDGE

SDD 1mm development

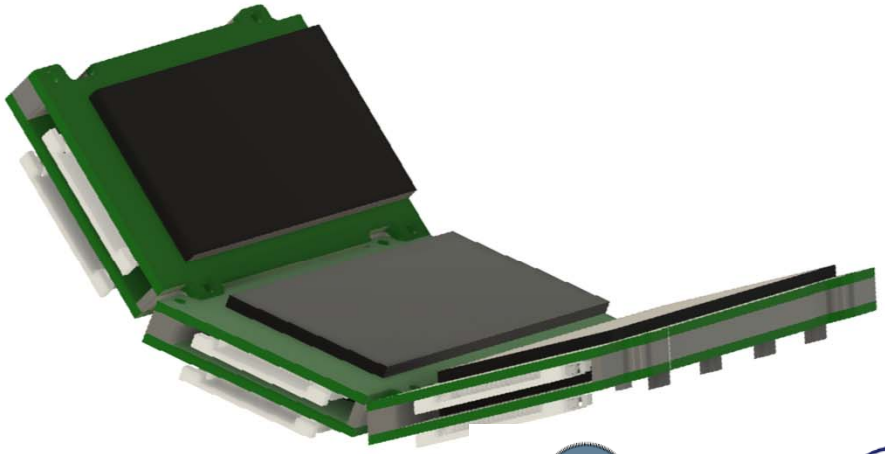
NEW SDD 1000 um



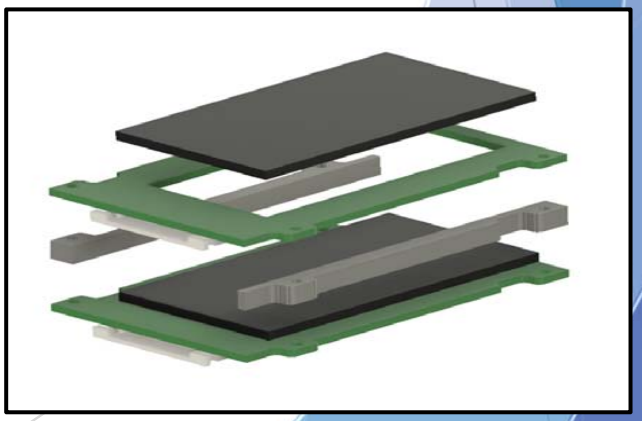
SDD modules design

Old SDD:
previous SDD chips (compact PCB)

New SDD:
new geometry, metal-only, cooling on the borders



Flexible configuration:
Single layer design
Stacked SDDs



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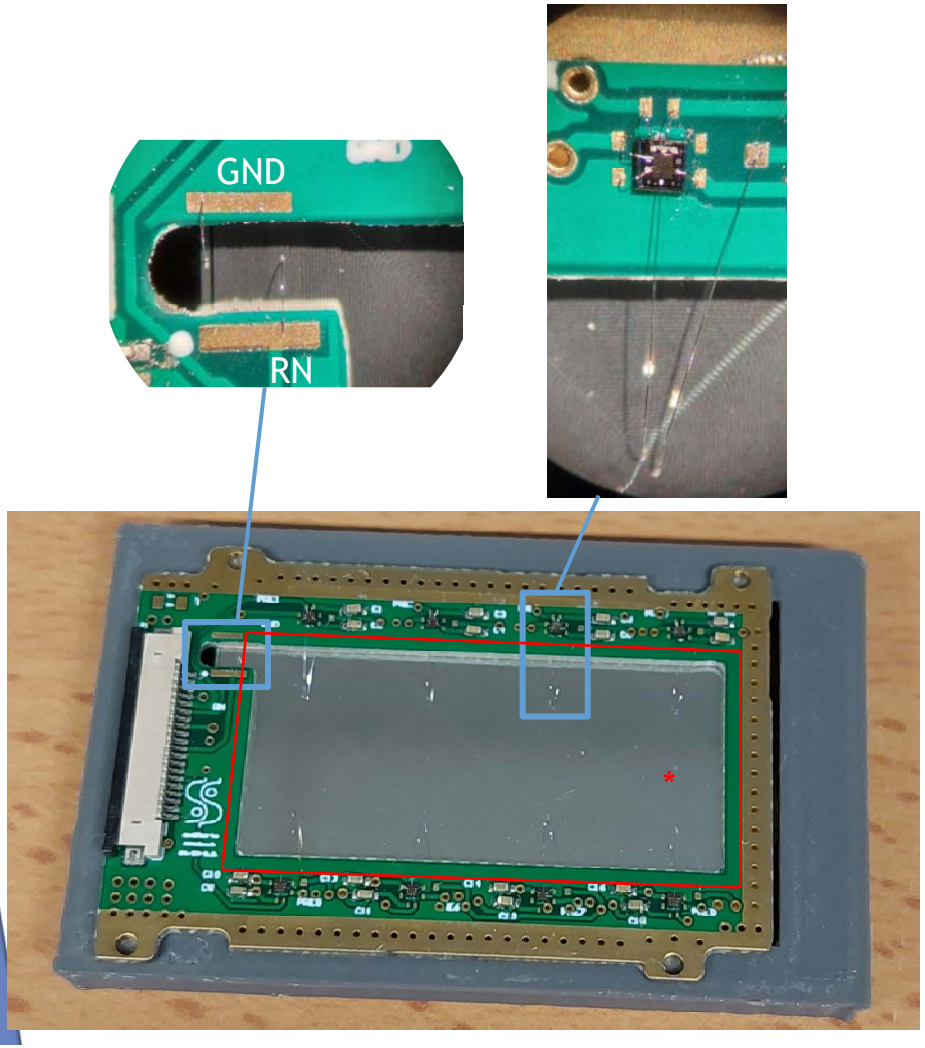
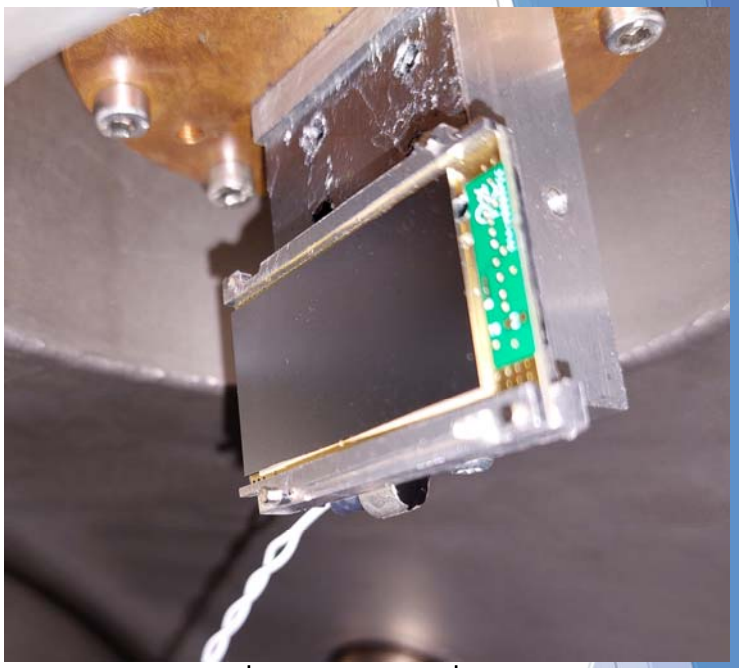
SDD 1mm development



Dummy array of SDD 1mm
test of cryogenics and bonding strategy



Module	Temp	Cycles
Dummy SDD	130K	6
Dummy SDD	100K	1
Dummy SDD	100K	1
Metal	100K	2
Metal	60K	2
Stacked	100K	1
Stacked	100K	1

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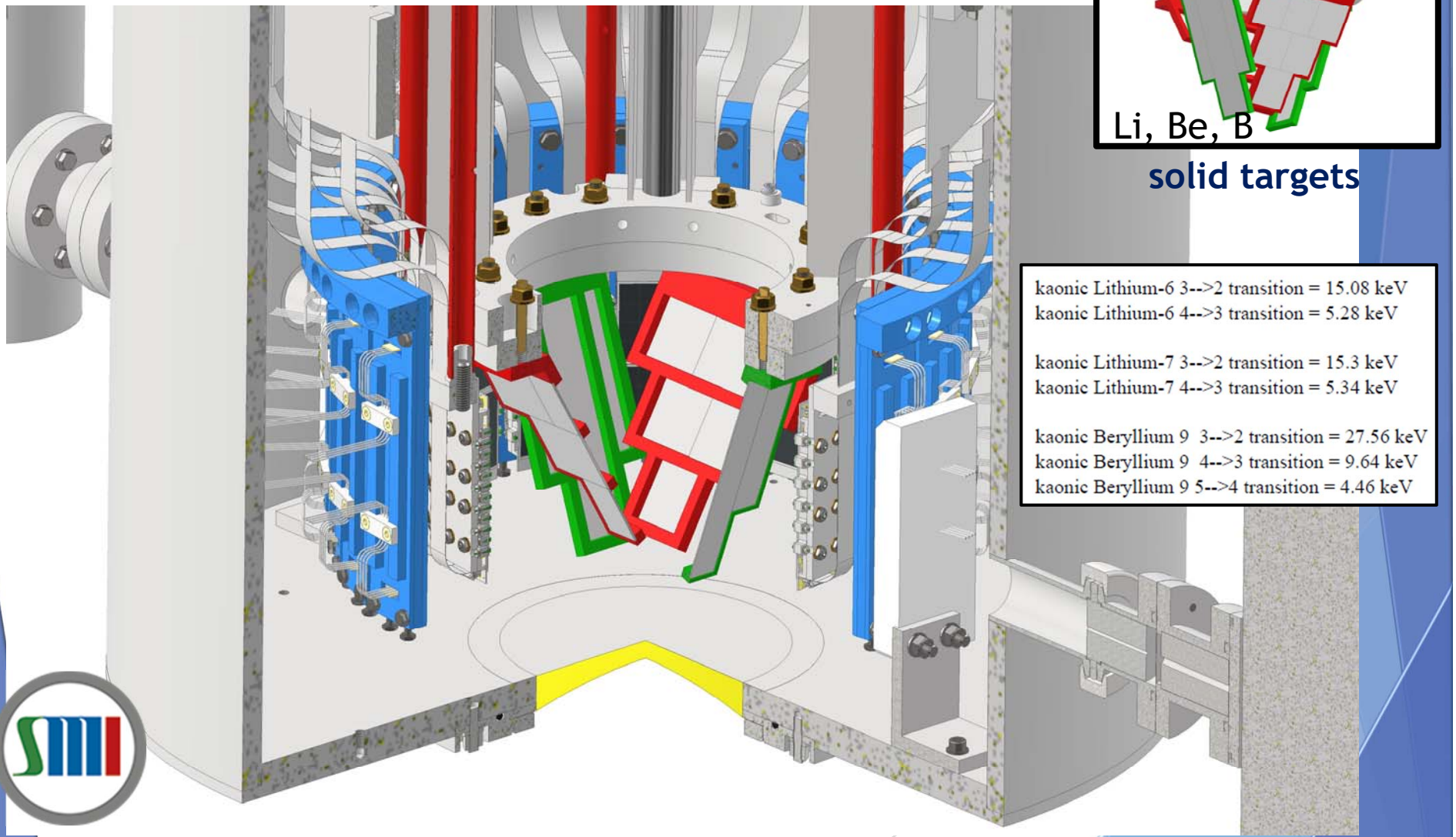
Cooling cycles report:

SDD 1mm development - Solid targets



Li, Be, B

solid targets

kaonic Lithium-6 3-->2 transition = 15.08 keV
kaonic Lithium-6 4-->3 transition = 5.28 keV

kaonic Lithium-7 3-->2 transition = 15.3 keV
kaonic Lithium-7 4-->3 transition = 5.34 keV

kaonic Beryllium 9 3-->2 transition = 27.56 keV
kaonic Beryllium 9 4-->3 transition = 9.64 keV
kaonic Beryllium 9 5-->4 transition = 4.46 keV

SIDDHARTA-2 K-d measurement plan

SIDDHARTA-2 strategy after the test run in 2022:

- **Optimize the SIDDHARTA-2 setup**

target entrance window materials, precise pressure measurement, shielding
(Sept. 2022 – February 2023)

- **Kaonic deuterium first 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

Conclusion

- Phase1 SIDDHARTINO concluded in 2021
  - SDDs characterization and Kaon Trigger tuning
  - Optimization of the machine background and degrader structure
- SIDDHARTA-2 at DAΦNE
  - Installation of the full SIDDHARTA-2 setup - (November 2021)
  - Kaonic ^{4}He test run concluded (June 2022)
  - Performed the most precise K-^{4}He $3d \rightarrow 2p$ measurement in gas
  - Several solid target high-n transition energies measured for the first time
  - First kaonic deuterium test run done (July 2022)
- Measurement of Kaonic-Deuterium key to fully disentangle isospin dependence on KN scattering lengths

SIDDHARTA-2 collaboration is ready for

Kaonic Deuterium Run

Thank You

SPARES

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) !