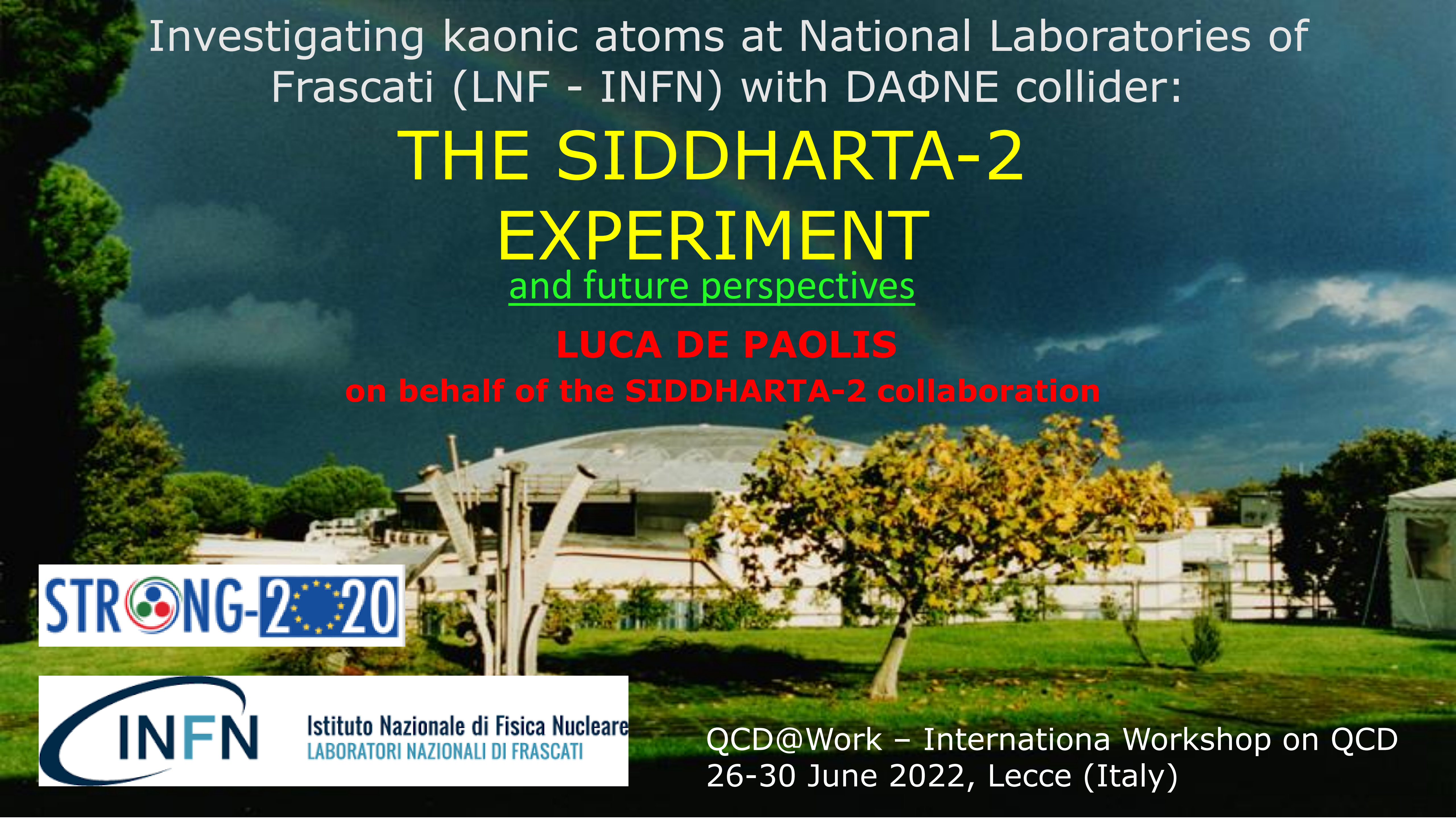


Investigating kaonic atoms at National Laboratories of Frascati (LNF - INFN) with DAΦNE collider:

THE SIDDHARTA-2 EXPERIMENT

and future perspectives

LUCA DE PAOLIS

on behalf of the SIDDHARTA-2 collaboration

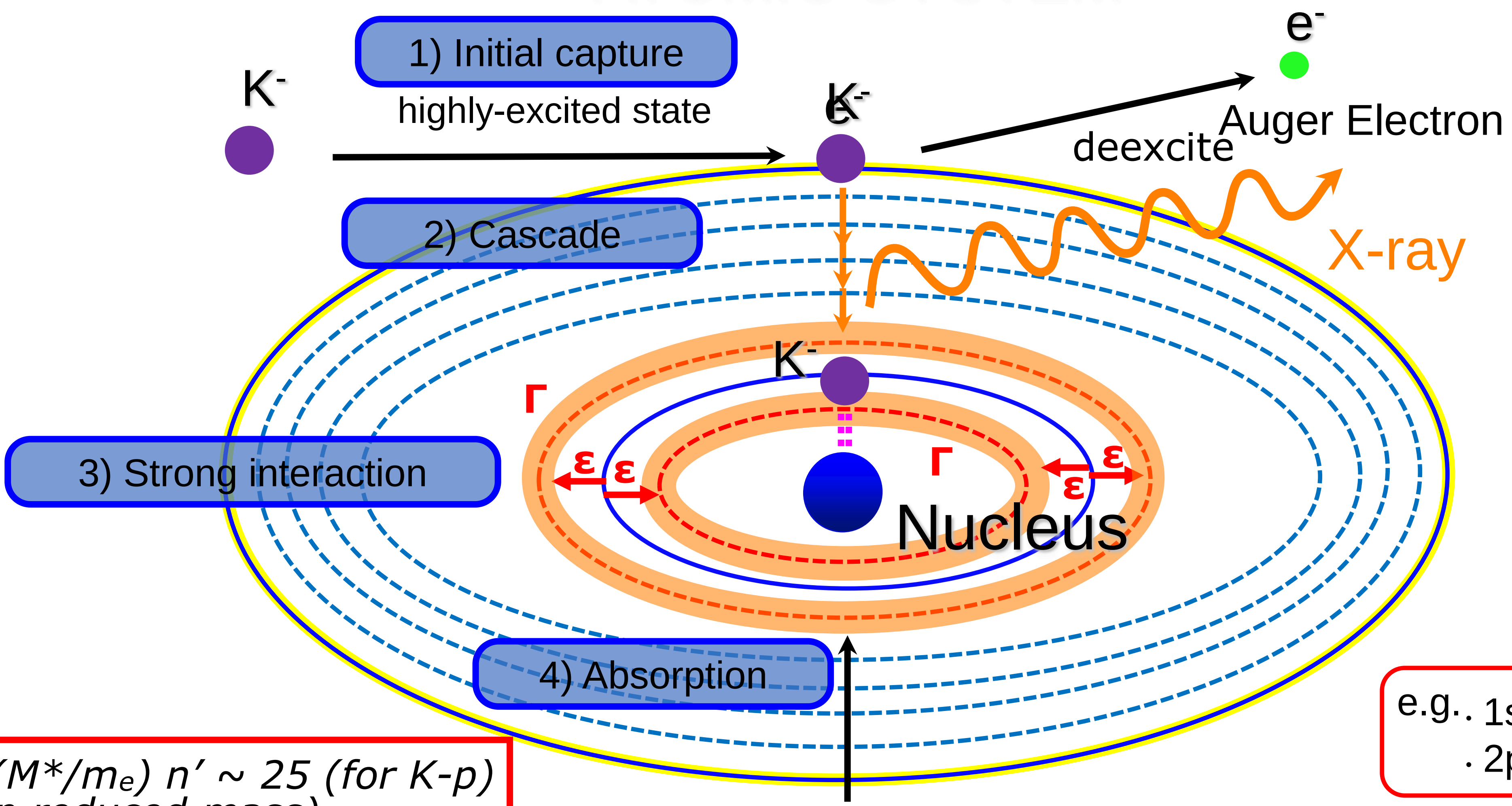
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

QCD@Work – Internationa Workshop on QCD
26-30 June 2022, Lecce (Italy)

Kaonic atoms formation

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

ATOMIC SYSTEM



1) Initial capture

highly-excited state

2) Cascade

3) Strong interaction

4) Absorption

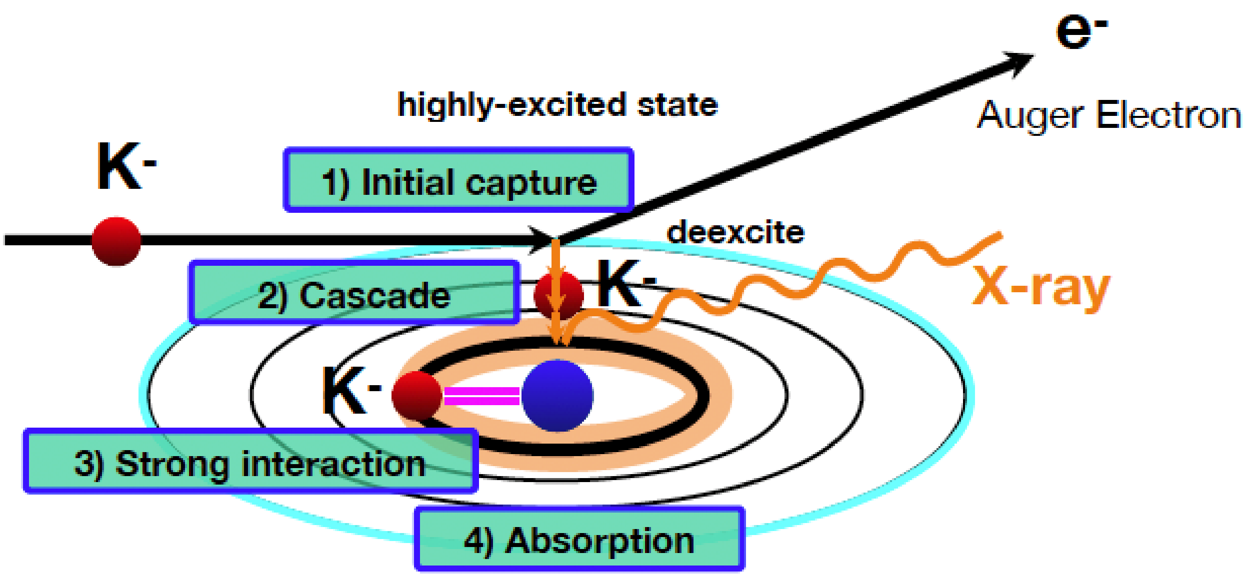
$n \sim \mathrm{sqrt}(M^*/m_e)\ n' \sim 25$ (for K-p)
(M^* : K-p reduced mass)

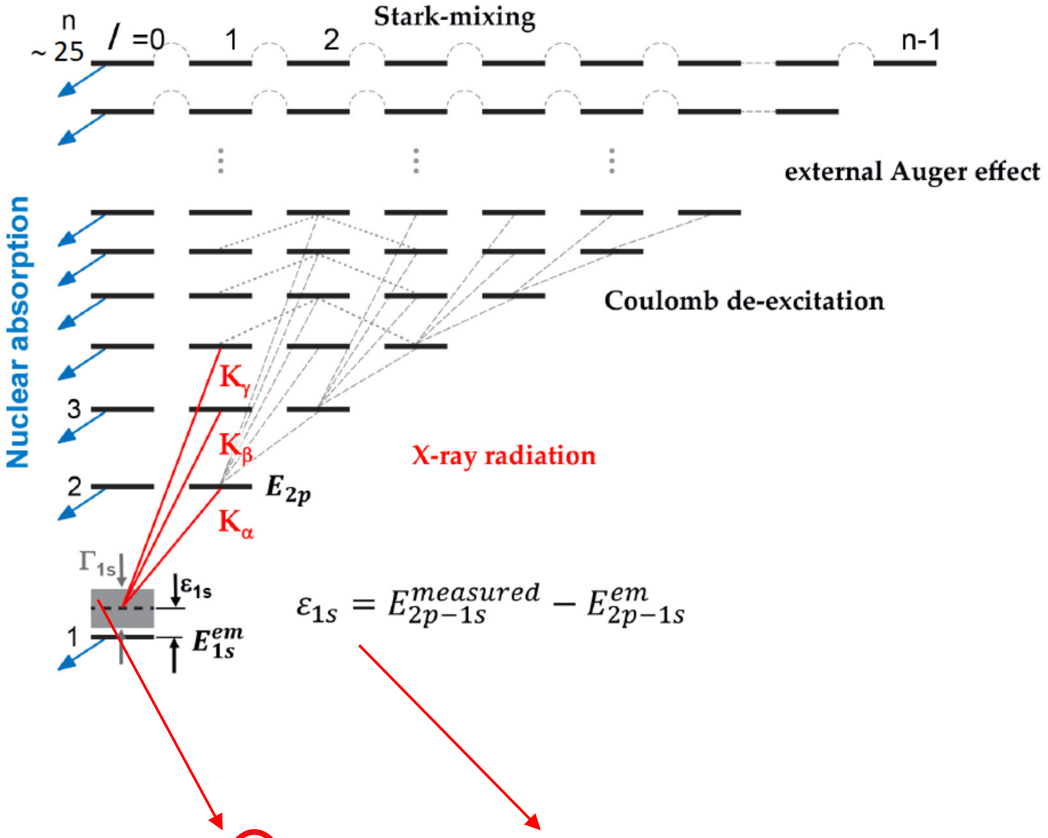
Shift (ε) and width (Γ) of the last orbit

e.g.
- 1s for K-p, K-d
- 2p for K-He

Kaonic atoms formation

In kaonic atoms, part of the shift (ε) and width (Γ) of the innermost atomic levels is due to the strong kaon-nucleus interaction, thus allowing the study of the strong interaction at low energy (keV) in the *strange* sector.





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

The measurement of shift and width of the 1S orbital in **Kaonic Hydrogen** and **Kaonic Deuterium**, provides fundamental and unique information on kaon-proton and kaon-neutron strong interaction at low energies.

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

The Scientific Goal

The $\bar{K}p$ and $\bar{K}d$ scattering lengths $(a_{\bar{K}p}, a_{\bar{K}d})$ are connected to to shift and width of kaonic hydrogen $(\varepsilon_{1s}^{H}, \Gamma_{1s}^{H})$ and kaonic deuterium $(\varepsilon_{1s}^{D}, \Gamma_{1s}^{D})$ by the Deser-Trueman Formula, improved by Meissner et al., taking into account the isospin breaking connections:

$$\left.\begin{aligned} \varepsilon_{1s}^{H} + \frac{i}{2}\Gamma_{1s}^{H} &= 2\alpha^3\mu_{\bar{K}p}^2 a_{\bar{K}p}\left(1 - 2\alpha\mu_{\bar{K}p}^2(\ln\alpha - 1)a_{\bar{K}p}\right) \\ \varepsilon_{1s}^{D} + \frac{i}{2}\Gamma_{1s}^{D} &= 2\alpha^3\mu_{\bar{K}d}^2 a_{\bar{K}d}\left(1 - 2\alpha\mu_{\bar{K}d}^2(\ln\alpha - 1)a_{\bar{K}d}\right) \end{aligned}\right\}$$

Next-to-leading order

α is the fine-structure constant and $\mu_{\bar{K}p}$ and $\mu_{\bar{K}d}$ are the reduced masses of $\bar{K}p$ and $\bar{K}d$systems

U.-G. Meißner, U. Raha, A. Rusetsky,
Eur. J. Phys. C **35** (2004) 349

$$\begin{aligned} a_{\bar{K}p} &= \frac{1}{2}(a_0 + a_1) \\ a_{\bar{K}n} &= a_1 \\ a_{\bar{K}d} &= \frac{k}{4}(a_0 + 3a_1) + C = \frac{k}{2}\left(a_{\bar{K}p} + a_{\bar{K}n}\right) + C \end{aligned}$$

Where:

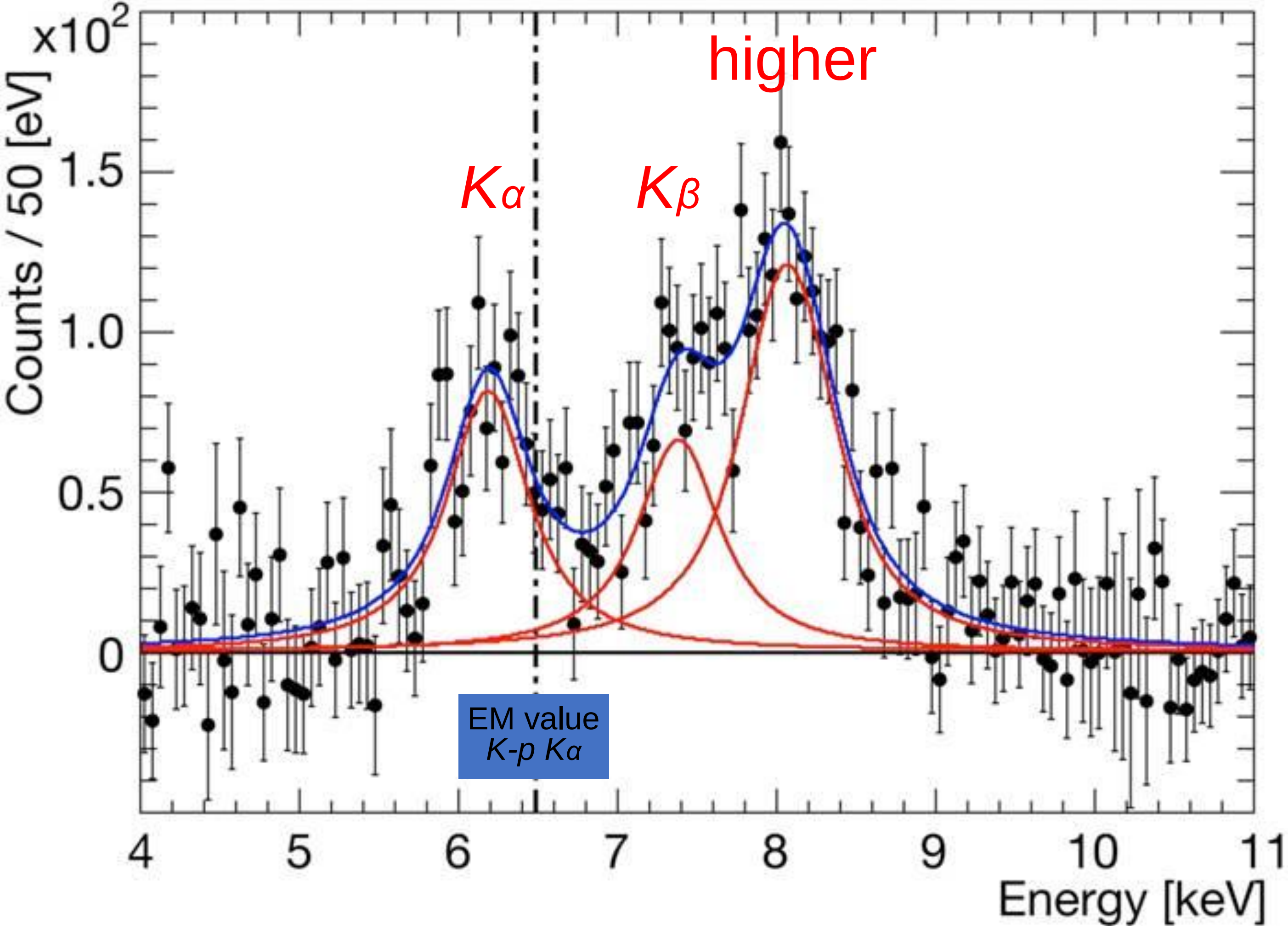
- a_0 and a_1 are $\bar{K}N$ isospin-dependent $(I = 0{,}1)$ lengths,
- $k = \frac{4(m_N + m_K)}{2m_N + m_K}$, with m_N and m_K respectively Nucleon and Kaon masses
- C is a term including all higher orders.

completely solve Isospin-dependent K-N scattering length

The SIDDHARTA experiment

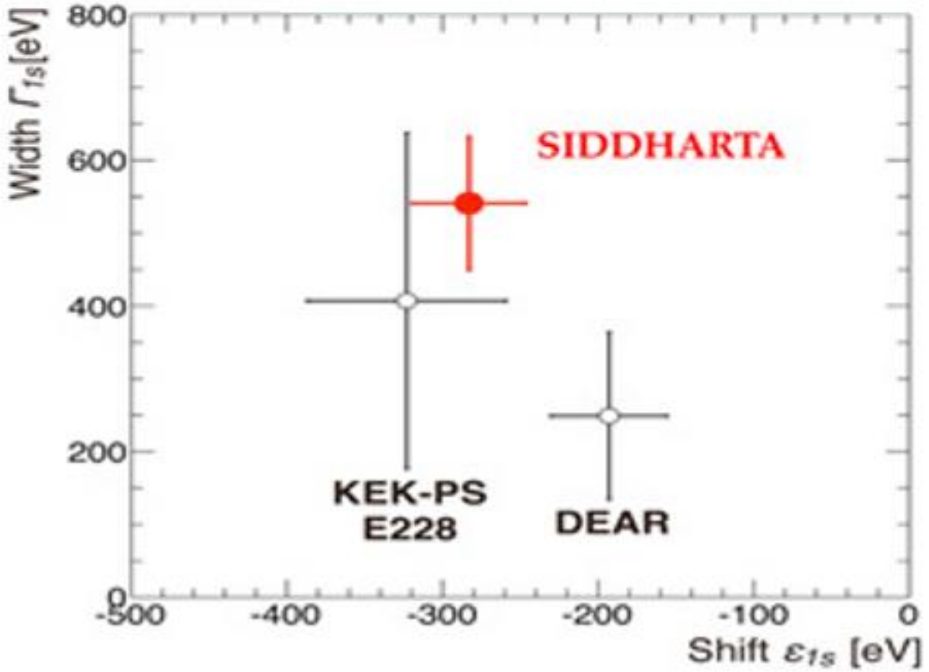
The SIDDHARTA experiment performed the first measurements of shift and width of kaonic hydrogen in 2011 at National Laboratories of Frascati (LNF-INFN).

Kaonic hydrogen



$$\varepsilon_{1s}^{H} = -283 \pm 36(stat) \pm 6(syst)eV$$

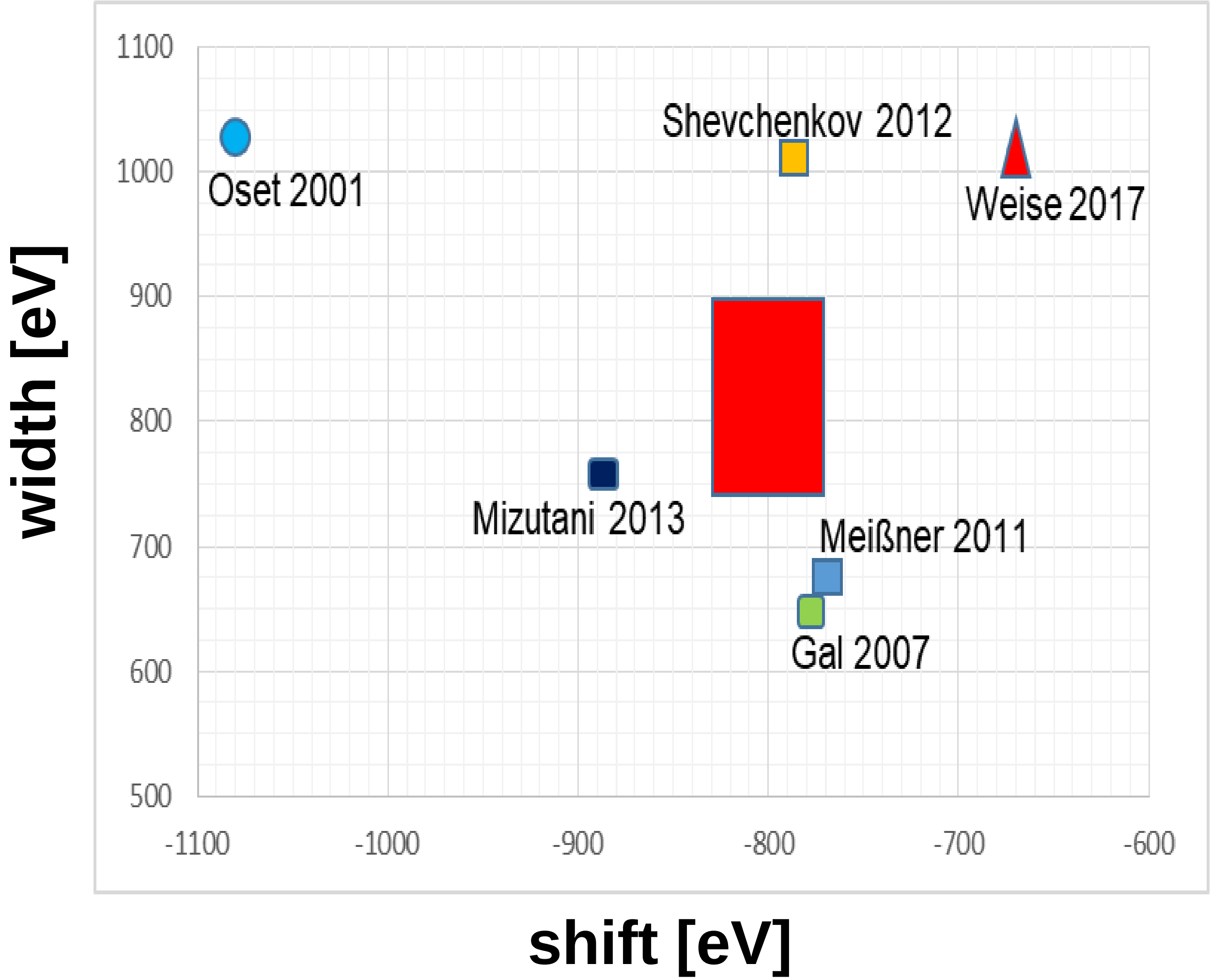
$$\Gamma_{1s}^{H} = 541 \pm 89(stat) \pm 22(syst)eV$$



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

The SIDDHARTA-2 scientific goal

The SIDDHARTA-2 experiment aims to perform the first measurement of shift and width of kaonic deuterium at the DAΦNNE e+e- collider at LNF-INFN.



ISOSPIN-DEPENDENT K-N SCATTERING LENGTH WILL BE COMPLETELY SOLVED

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

HadronPhysics2
Study of Strongly Interacting Matter

HadronPhysics I3
Study of Strongly Interacting Matter

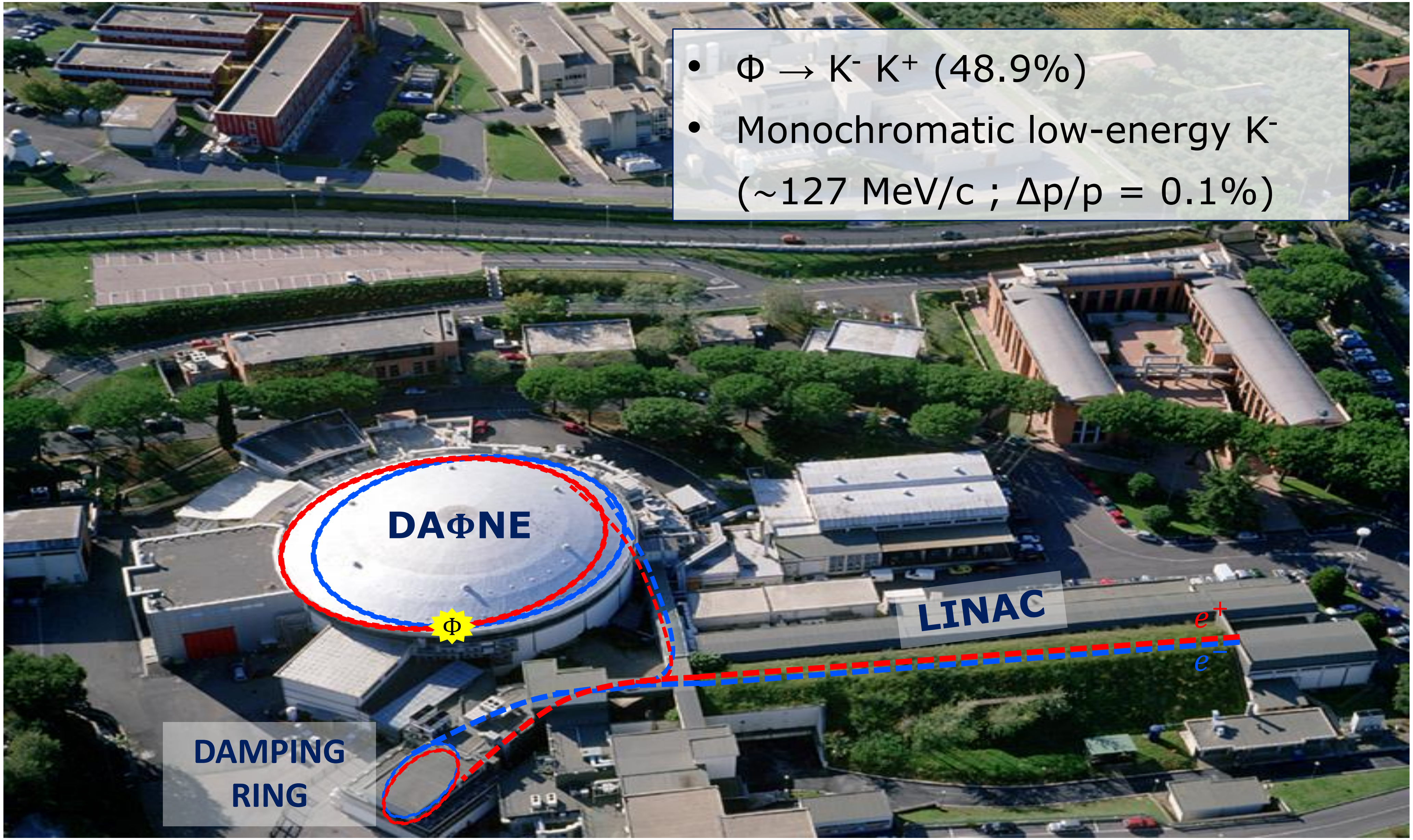
FWF Der Wissenschaftsfonds.

STRONG-2020

HrZZ
Croatian Science Foundation

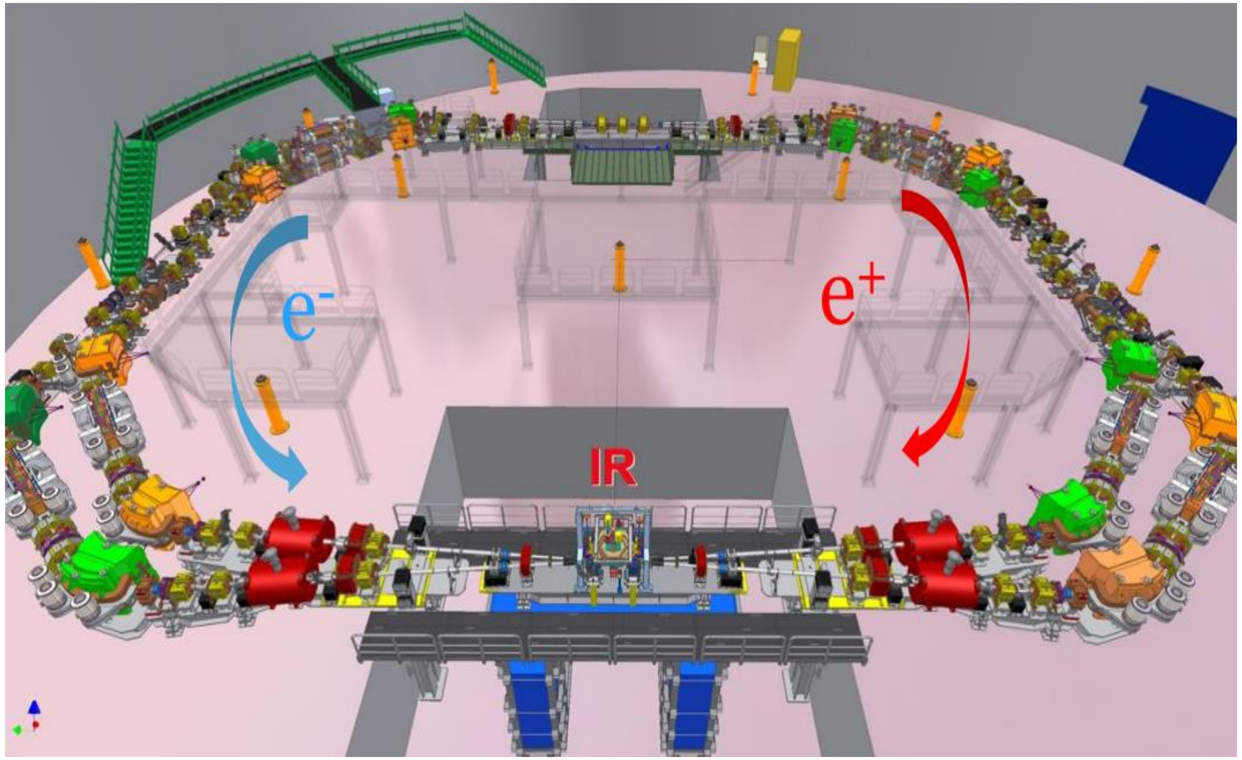
Farnesina
Ministero degli Affari Esteri
e della Cooperazione Internazionale

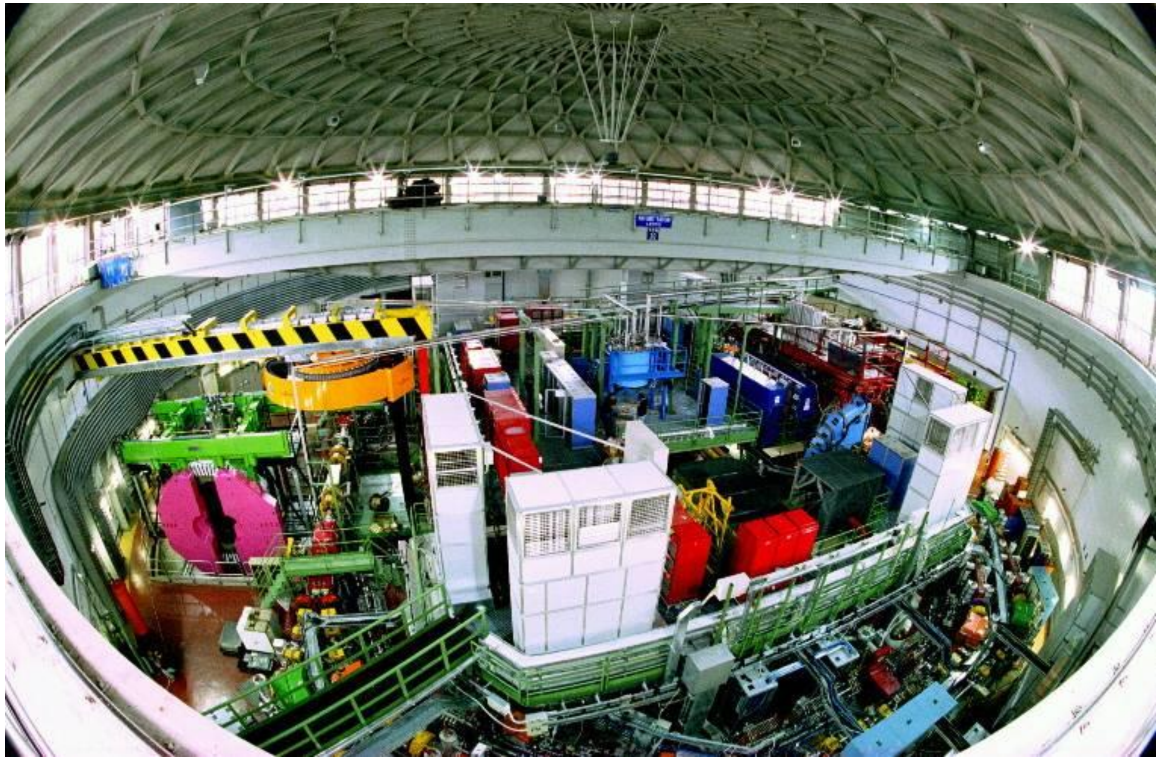
LNF e^+e^- Accelerators complex

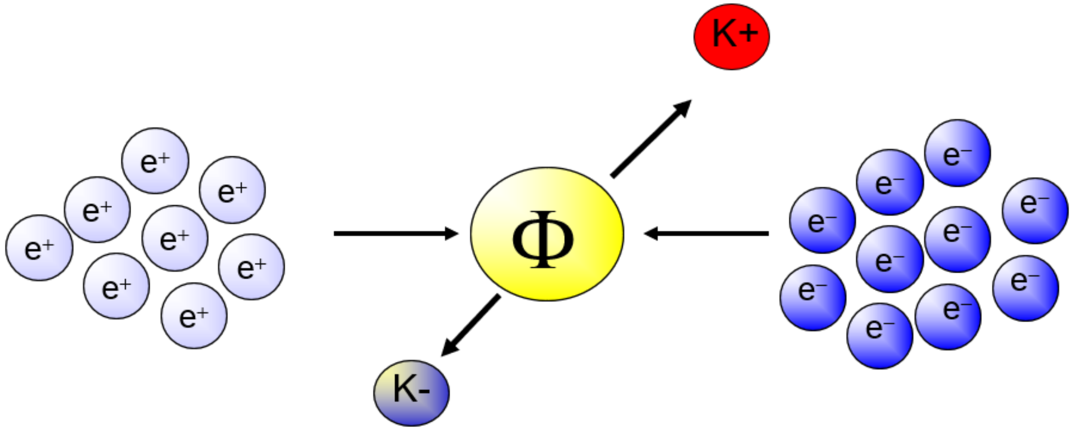


- $\Phi \rightarrow K^- K^+$ (48.9%)
- Monochromatic low-energy K^- (~127 MeV/c ; $\Delta p/p$ = 0.1%)

The DAΦNE e^+e^- Collider



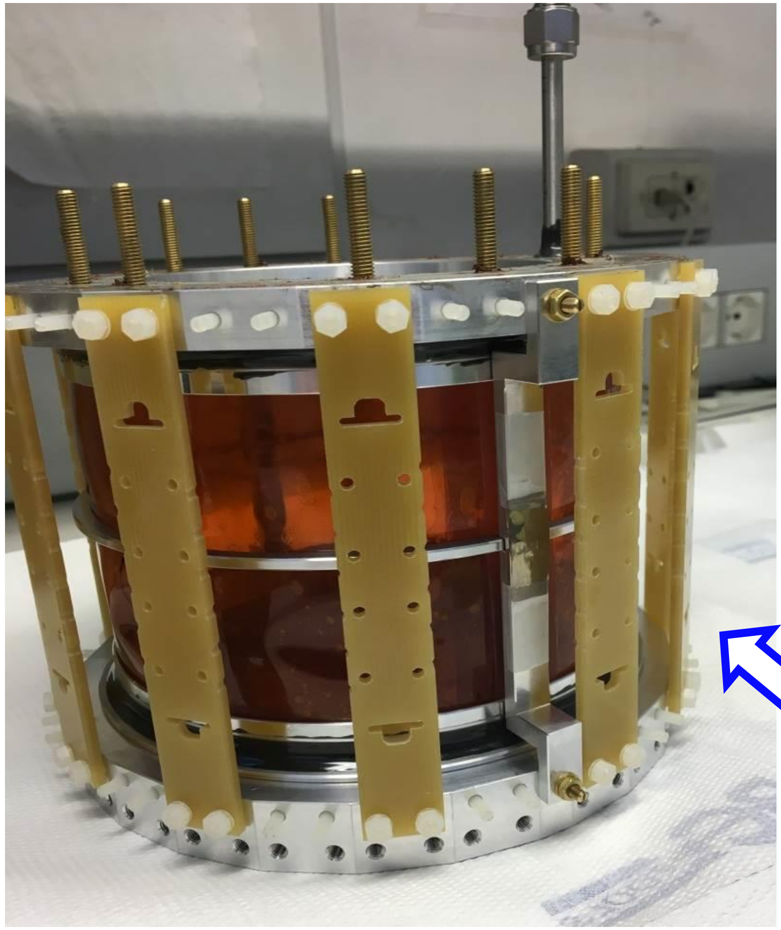


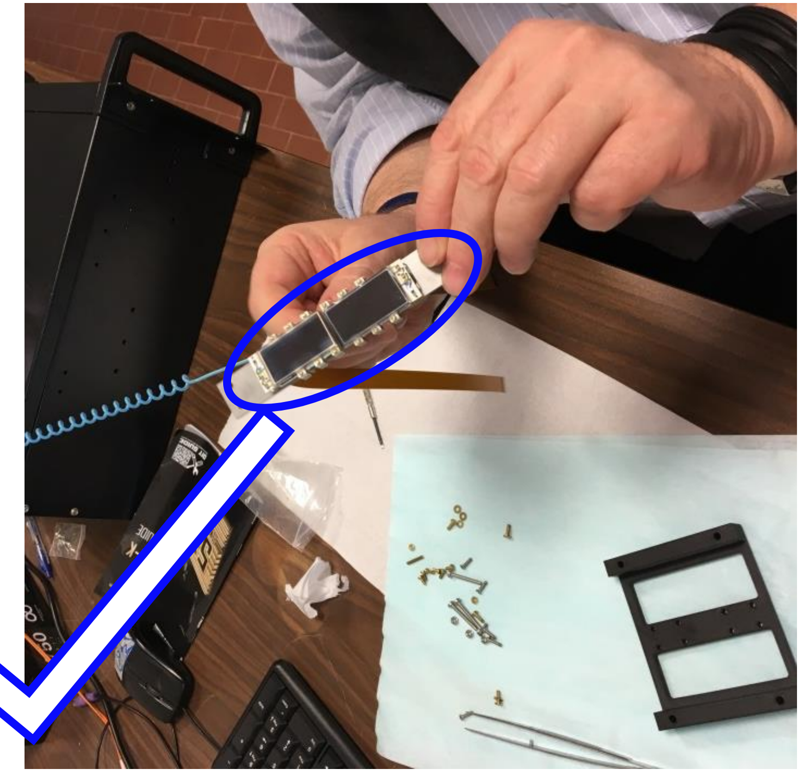


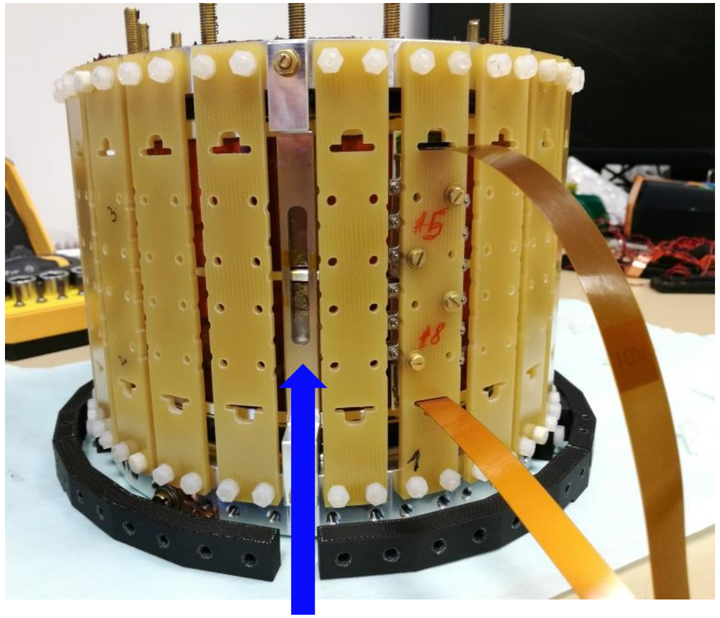
- $\Phi \rightarrow K^- K^+$ (48.9%)
- Monochromatic low-energy K^- (~127 MeV/c ; $\Delta p/p = 0.1\%$)
- **Flux of produced kaons: about 1000/second**

The SIDDHARTA-2 target

The cylindric target cell consists of a wall made of a 2-Kapton layer structure (75 μm + 75 μm + Araldit), placed on aluminum support.







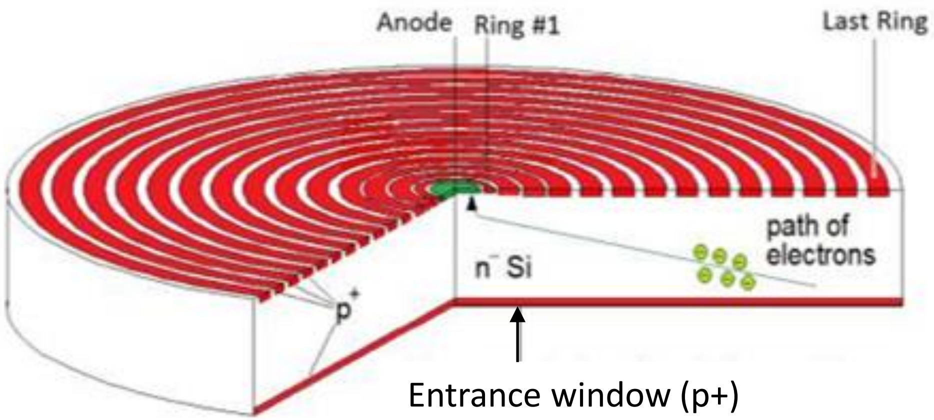
calibration foils inserted near to the SDD are activated by the X-ray tubes

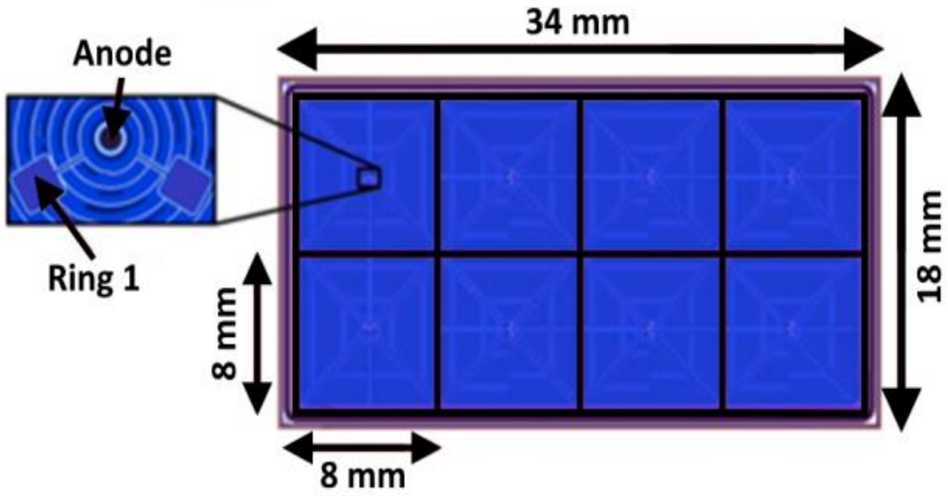
Silicon Drift Detectors (SDDs) are placed 5 mm from the target wall for the x-ray spectroscopy

GASEOUS DEUTERIUM IS FLUXED WITHIN THE TARGET CELL

The Silicon Drift Detectors

SDD CELL CROSS SECTION





POLITECNICO
MILANO 1863

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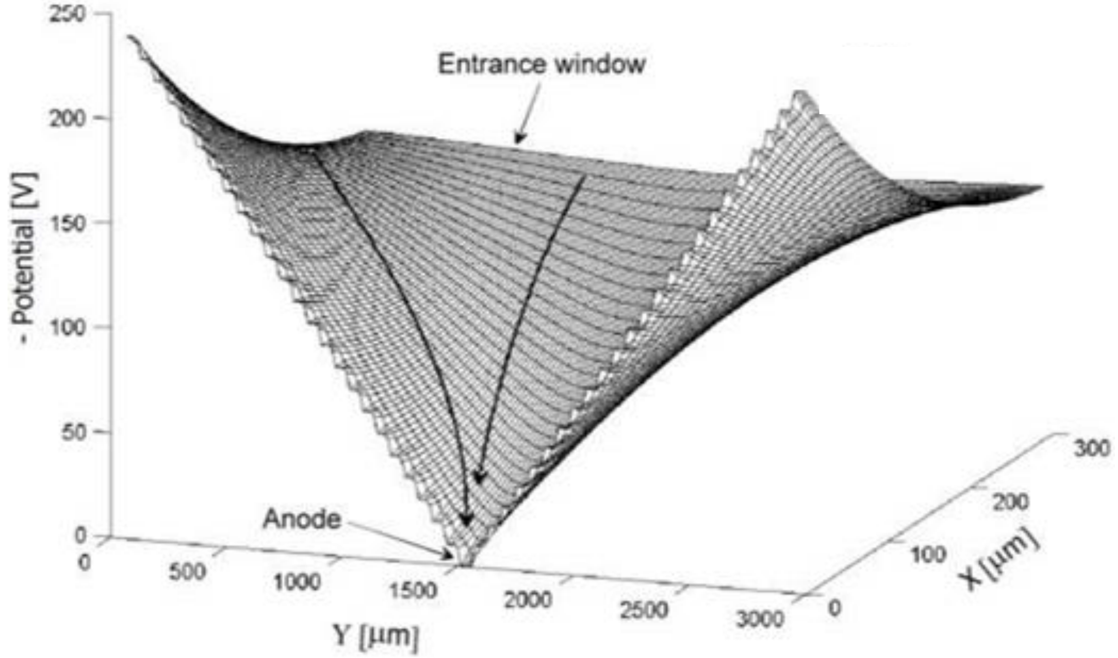
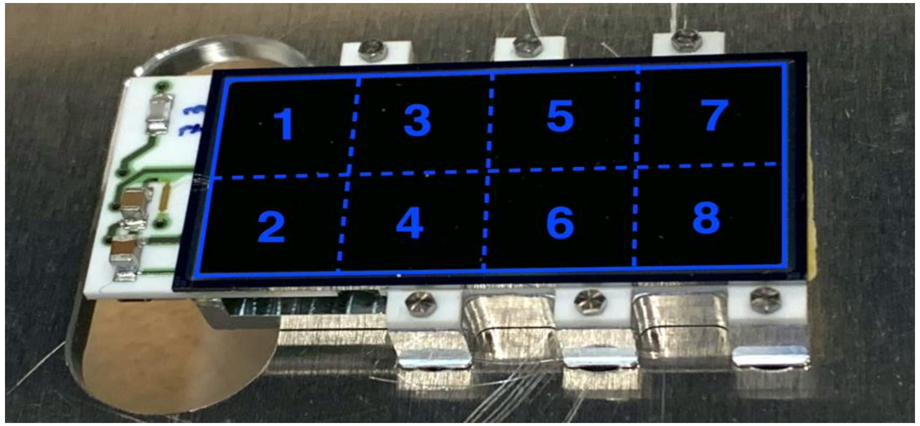
di Fisica Nucleare
Laboratori Nazionali di Frascati

FONDAZIONE
BRUNO KESSLER
FUTURE BUILT
ON KNOWLEDGE

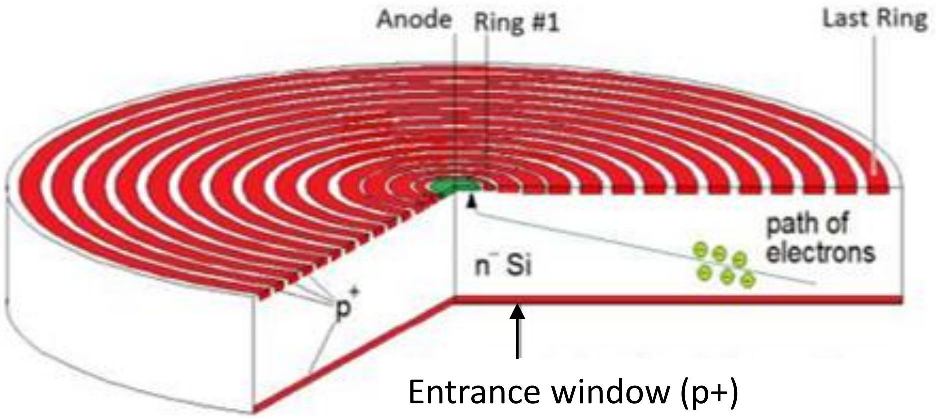


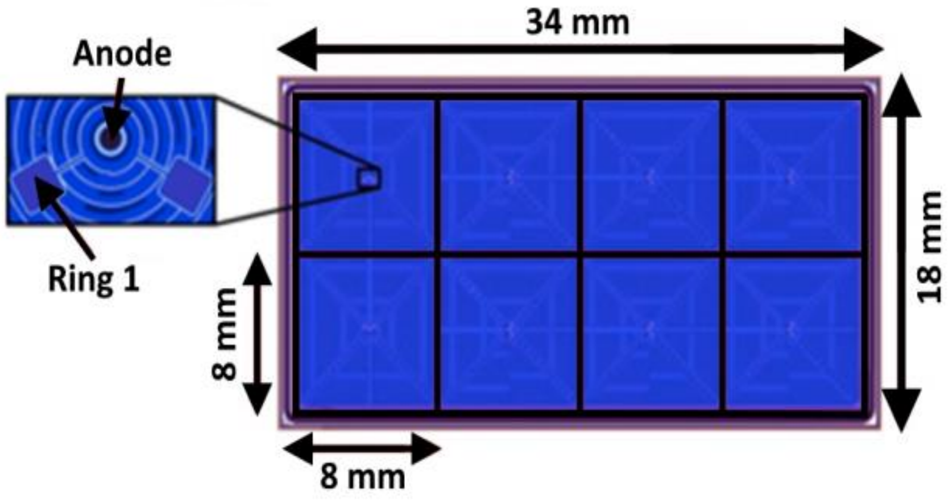


Each array consists of 8 SDD cells with 0.64 cm^2 of active area and 450 μm thickness each, which ensures a high collection efficiency for X-rays of energy between 5 keV and 12 keV

The Silicon Drift Detectors

SDD CELL CROSS SECTION





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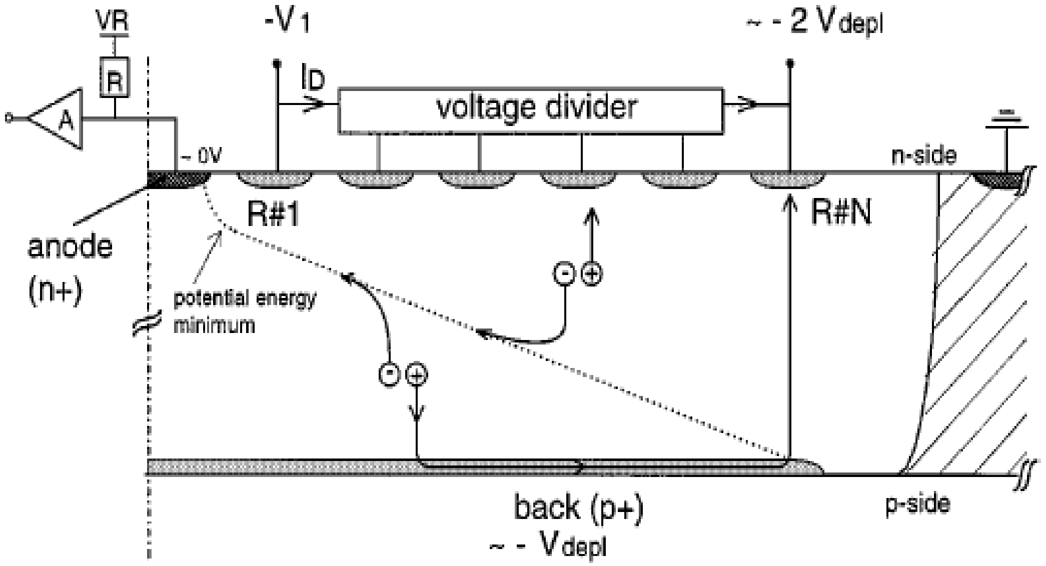
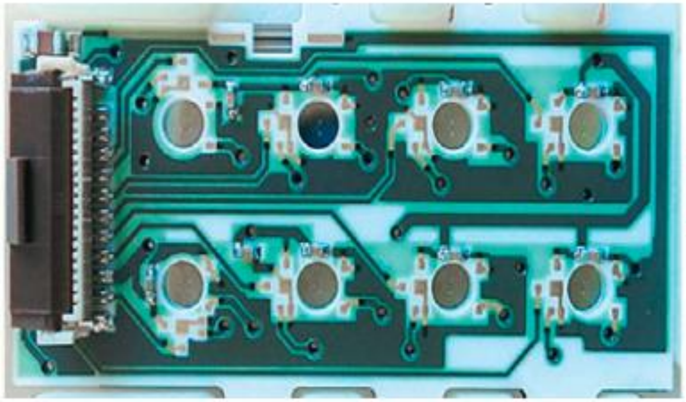
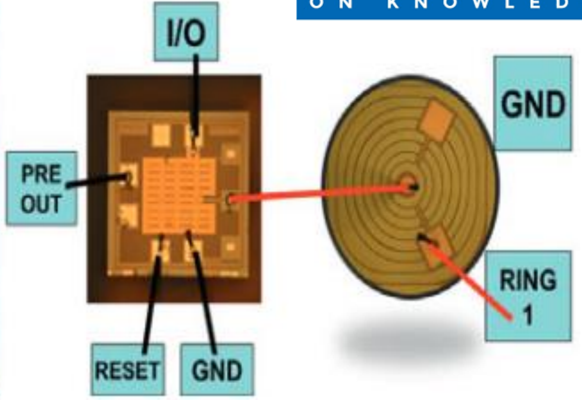


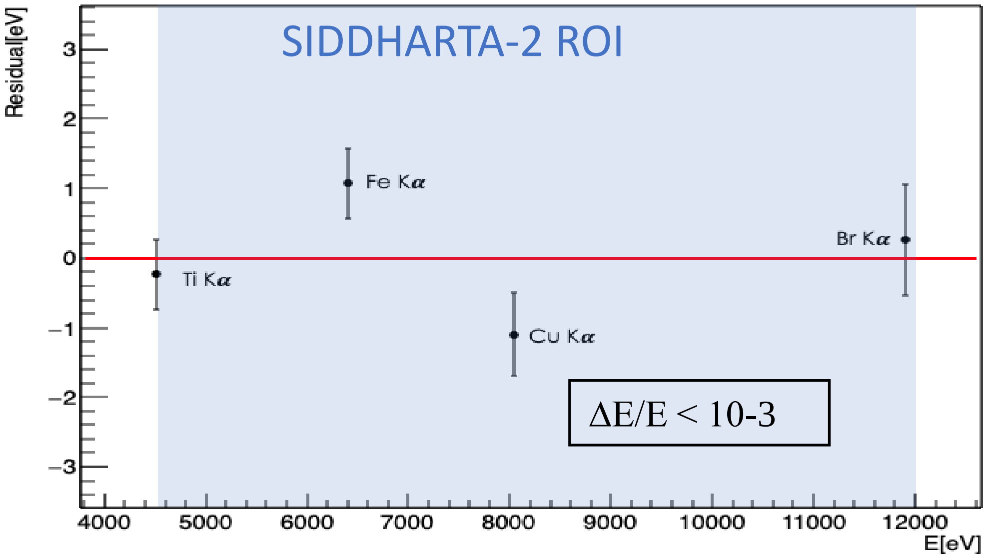




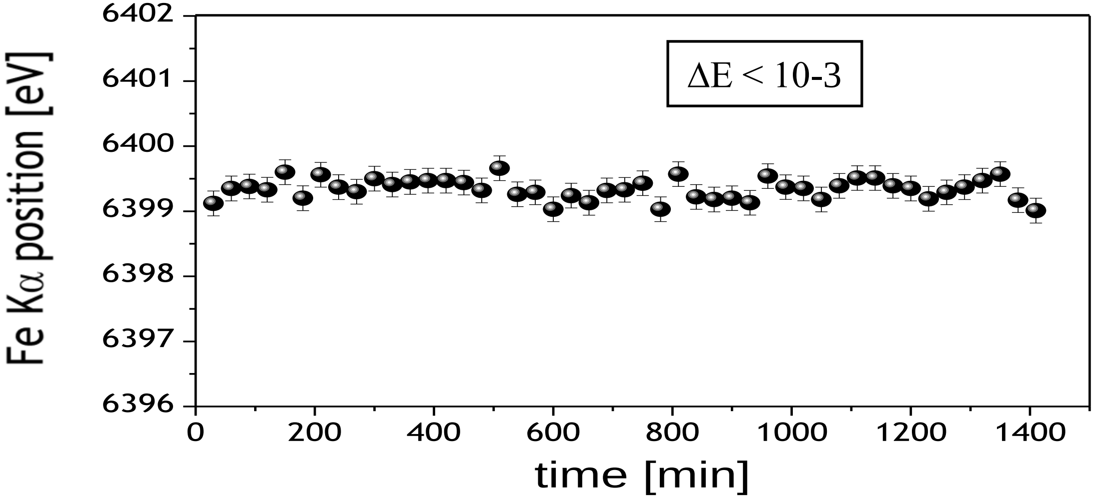
The SIDDHARTA-2 experiment equips 48 SDD arrays, for a total of 384 SDD cell detectors. Each SDD array has a total active area of 5.12 cm^2

The Silicon Drift Detectors

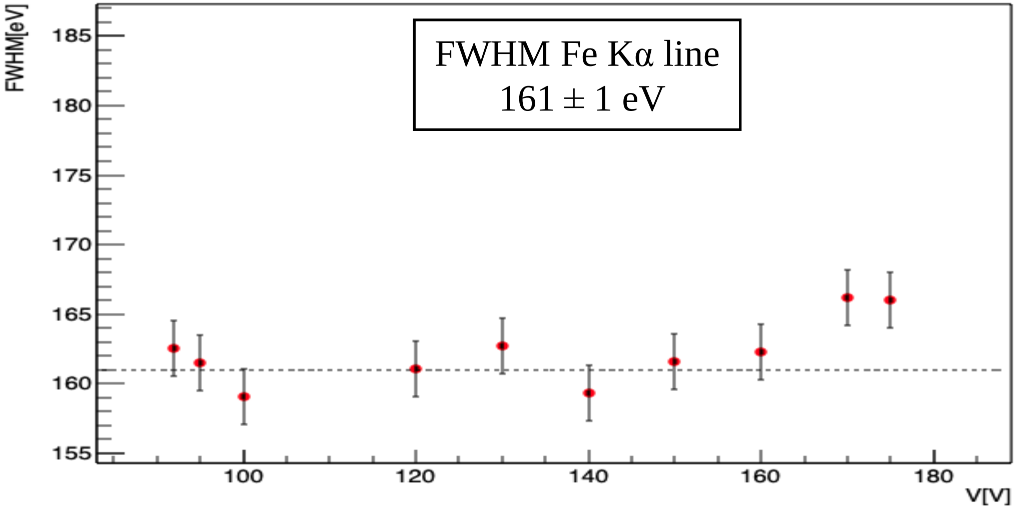
Linearity



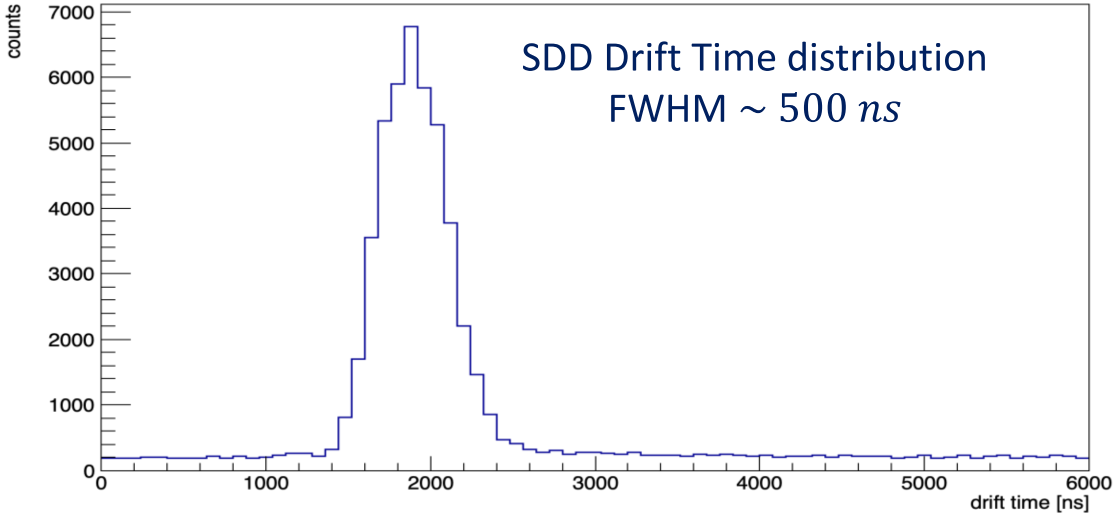
Stability



Energy Resolution

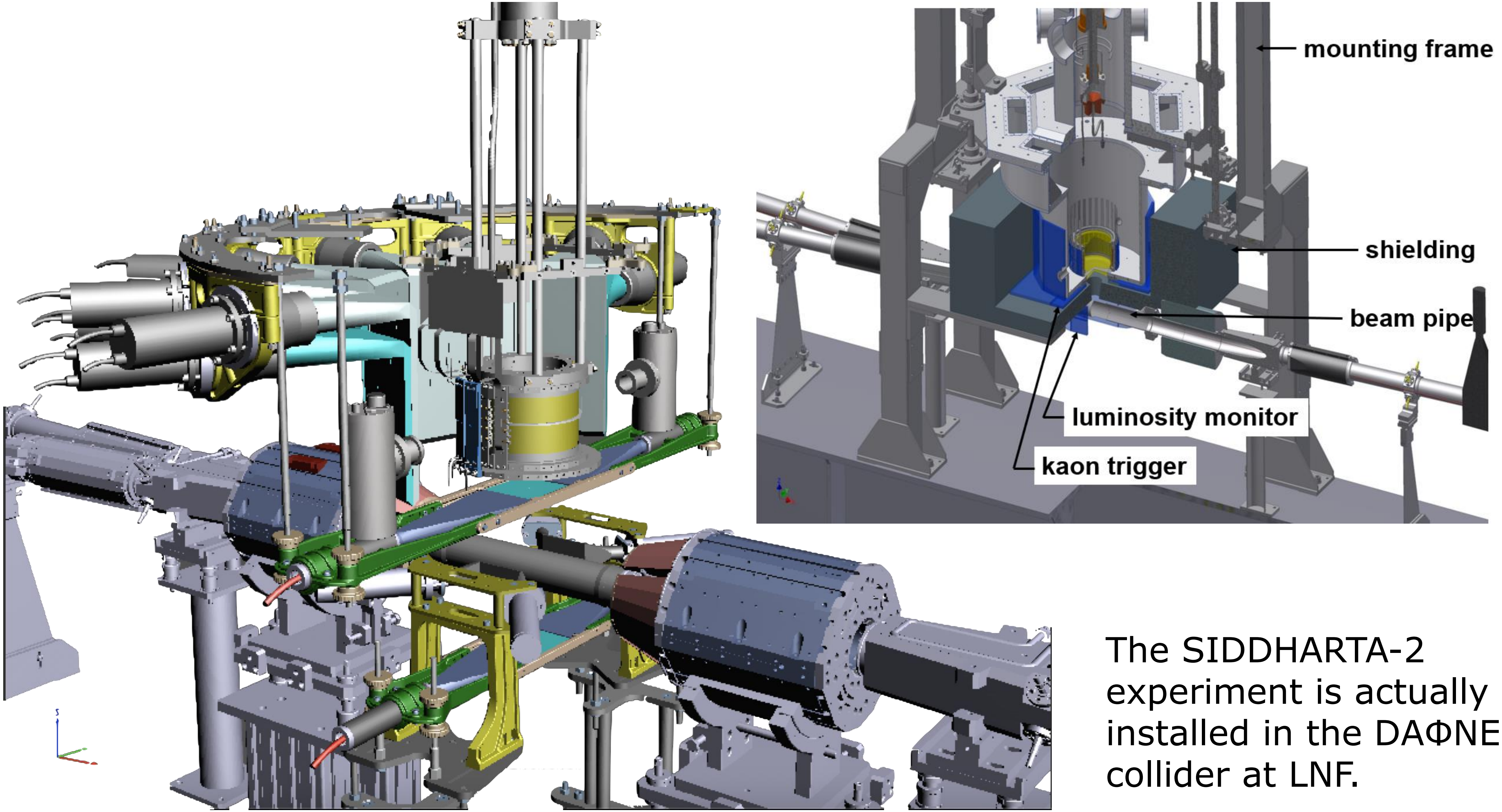


Timing Resolution



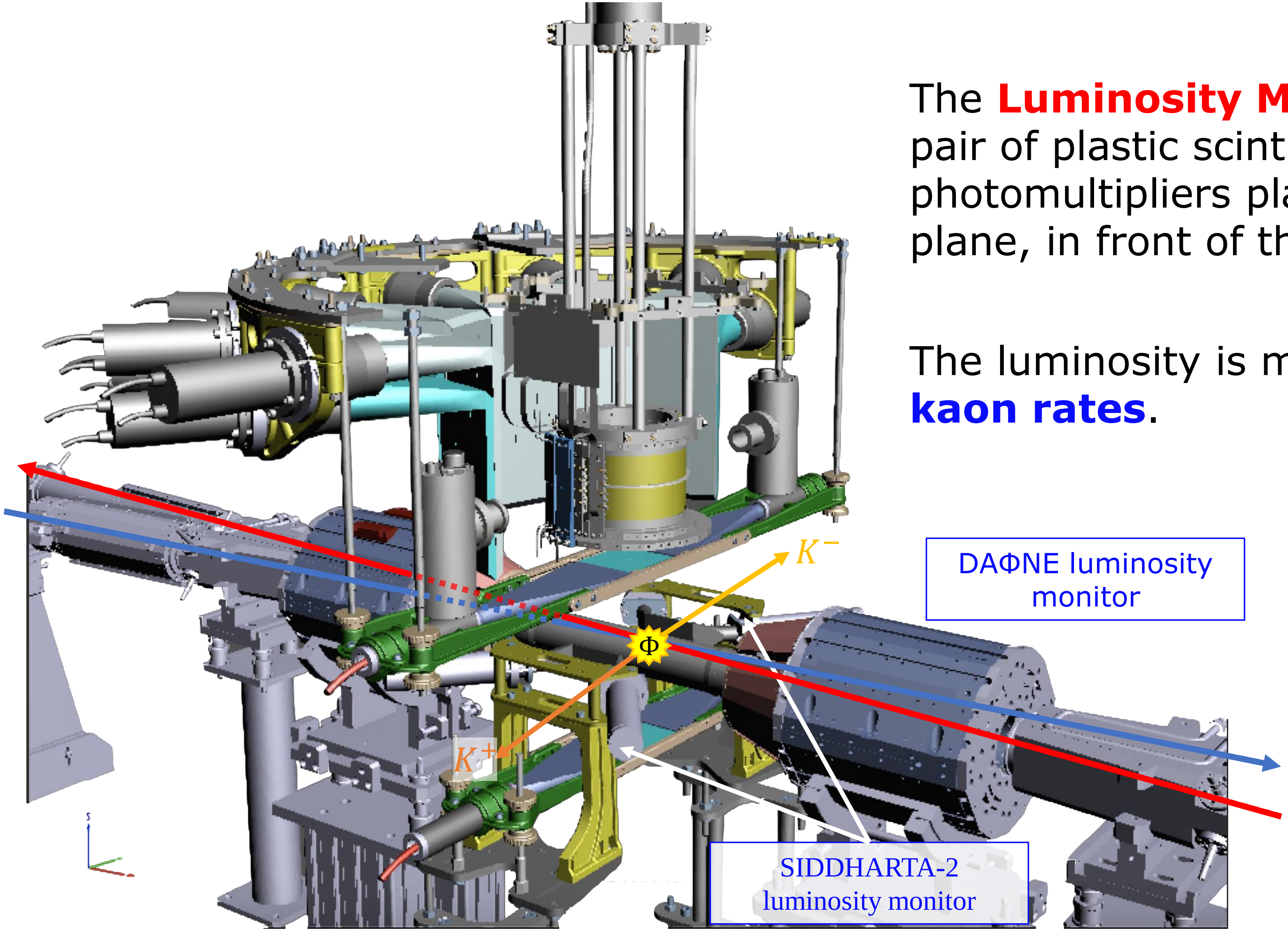
M Miliucci *et al* 2021 *Meas. Sci. Technol.* **32** 095501

The SIDDHARTA-2 setup



The SIDDHARTA-2 experiment is actually installed in the DAΦNE collider at LNF.

The SIDDHARTA-2 setup

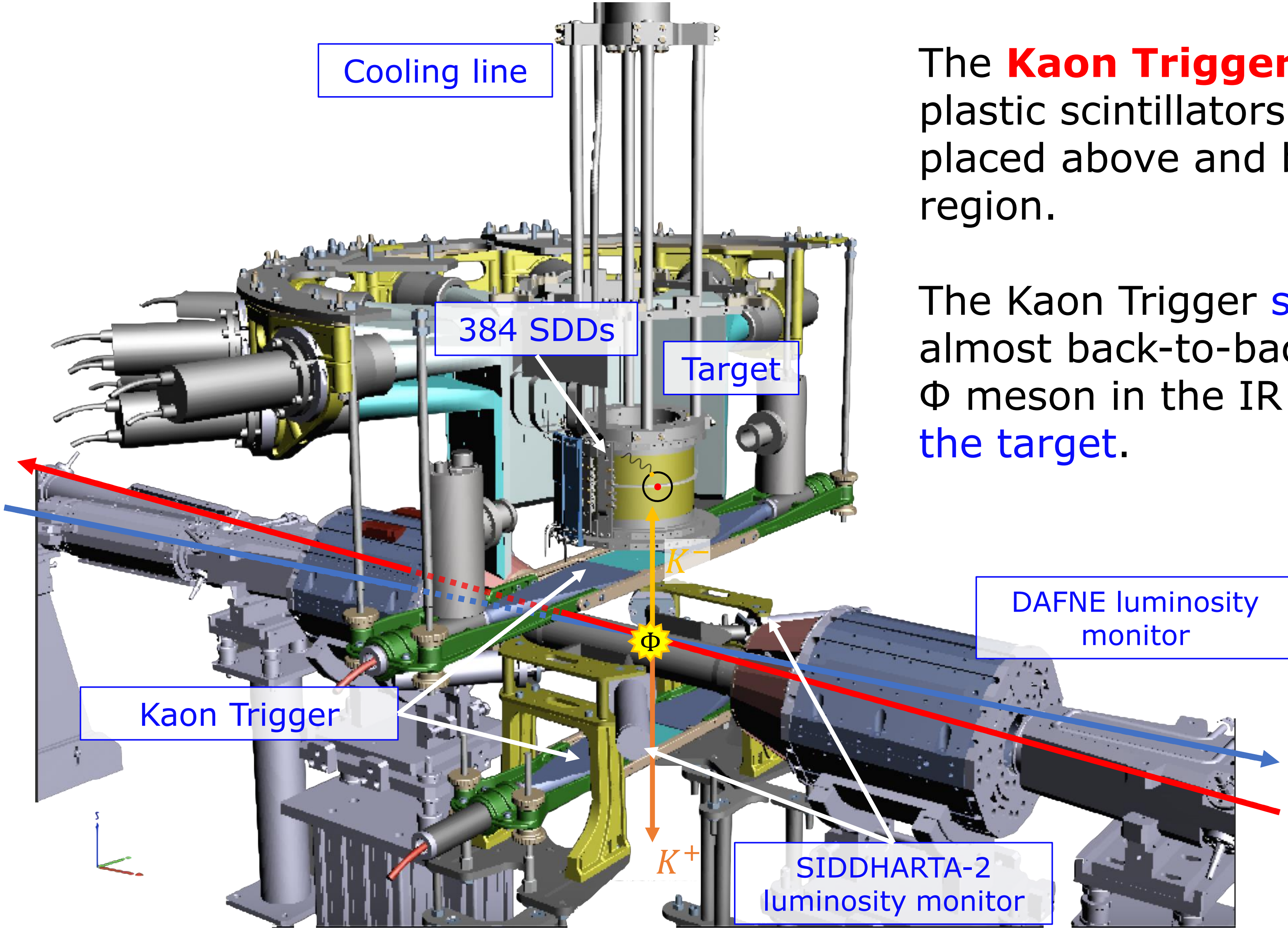


The **Luminosity Monitor** consists of a pair of plastic scintillators read by photomultipliers placed on the longitudinal plane, in front of the interaction region.

The luminosity is measured using the **kaon rates**.

The SIDDHARTA-2 luminosity monitor is complementary to the DAΦNE luminosity monitor, which use the Bhabha scattering $e^+e^- \rightarrow e^+e^-$

The SIDDHARTA-2 setup



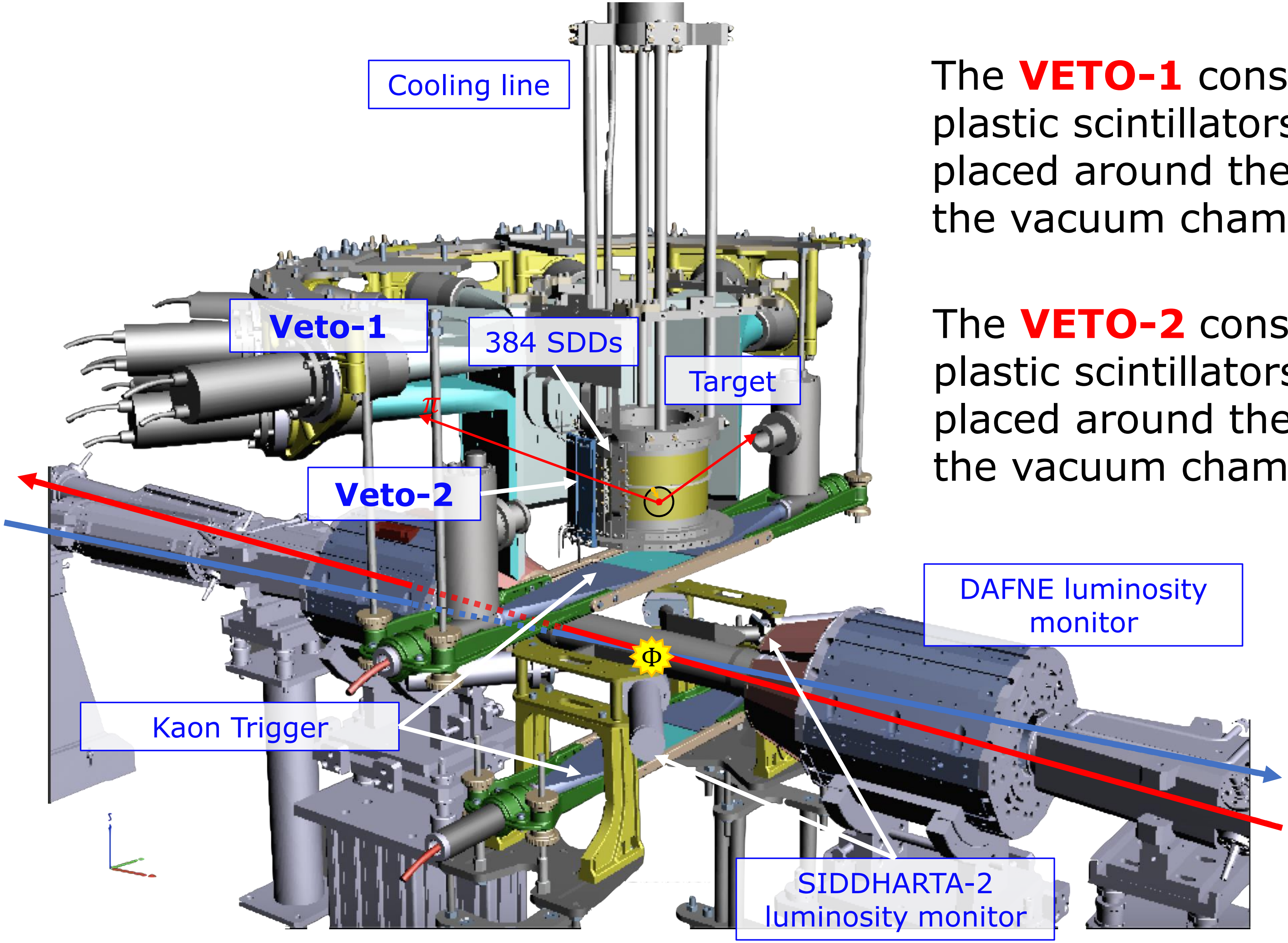
The **Kaon Trigger** consists of two pair of plastic scintillators read by photomultipliers placed above and below the Interaction region.

The Kaon Trigger selects kaons emitted almost back-to-back from the decay of the Φ meson in the IR and directed towards the target.

A cylindrical vacuum chamber is placed above the interaction point and contains target and SDDs.

SDDs are cooled to 170 K.

The SIDDHARTA-2 setup



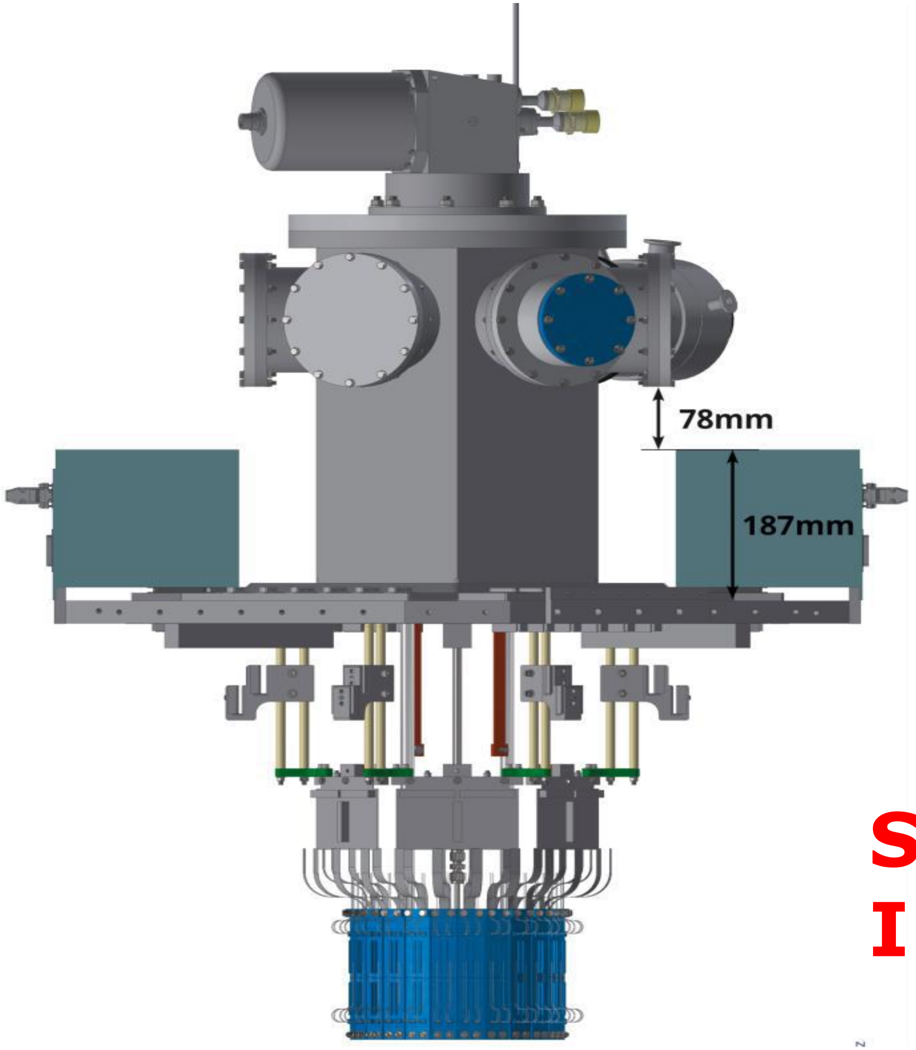
The **VETO-1** consists of twelve pair of plastic scintillators read by photomultipliers placed around the cryogenic target, outside the vacuum chamber.

The **VETO-2** consists of smaller pair of plastic scintillators read by photomultipliers placed around the cryogenic target, inside the vacuum chamber.

The Veto systems are used to suppress the synchronous and asynchronous background from the accelerator, and limit the fake signals due to minimum ionizing particles (MIPs)

SIDDHARTINO

SIDDHARTINO was the phase 1 of the SIDDHARTA-2 experiment, which consisted of 1/6 of the SIDDHARTA-2 apparatus, installed in the DAΦNE collider during the DAΦNE beams commissioning phase



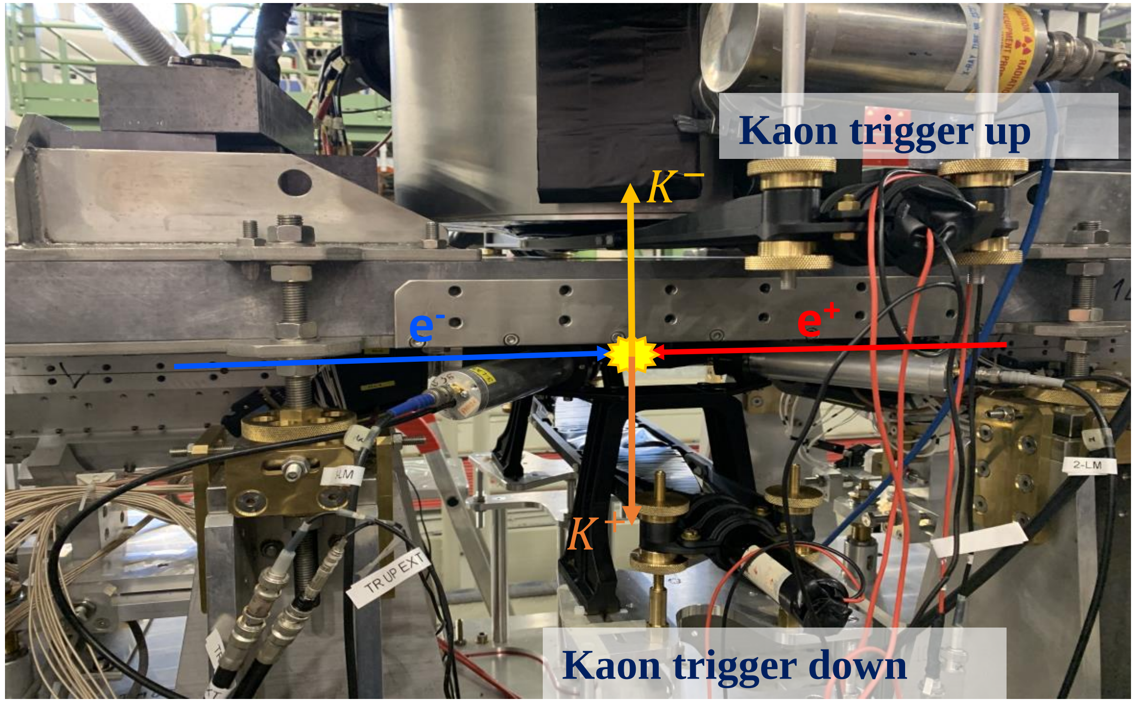
SIDDHARTINO goals:

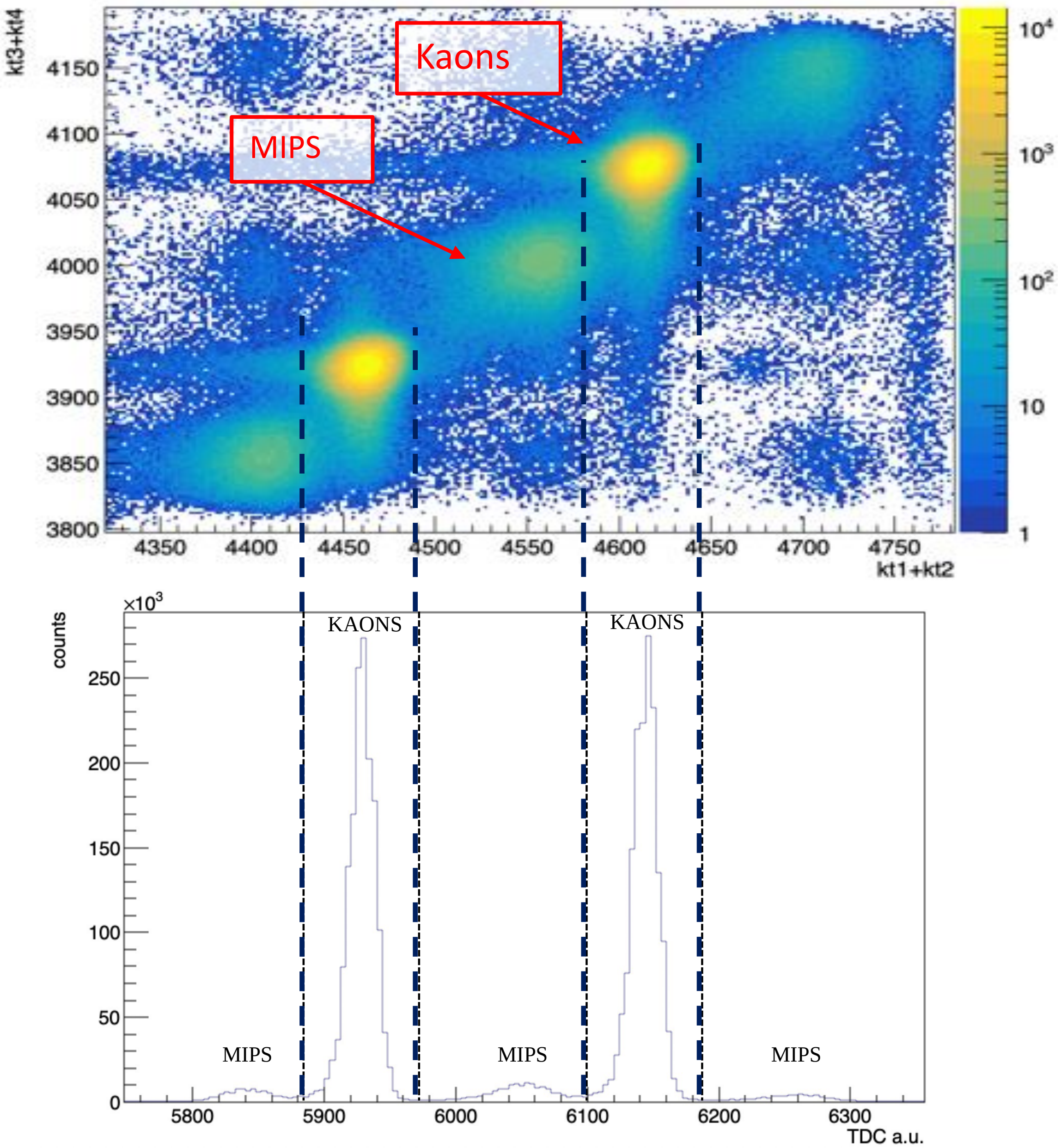
- Evaluation of the machine background (in preparation for the K-d run) through the measurement of the shift ε_{2p} and width Γ_{2p} in kaonic Helium 4

- Tuning of the SDD detectors
- Test and tuning of the Kaon trigger

SIDDHARTINO WAS CONCLUDED IN 2021

The Kaon Trigger



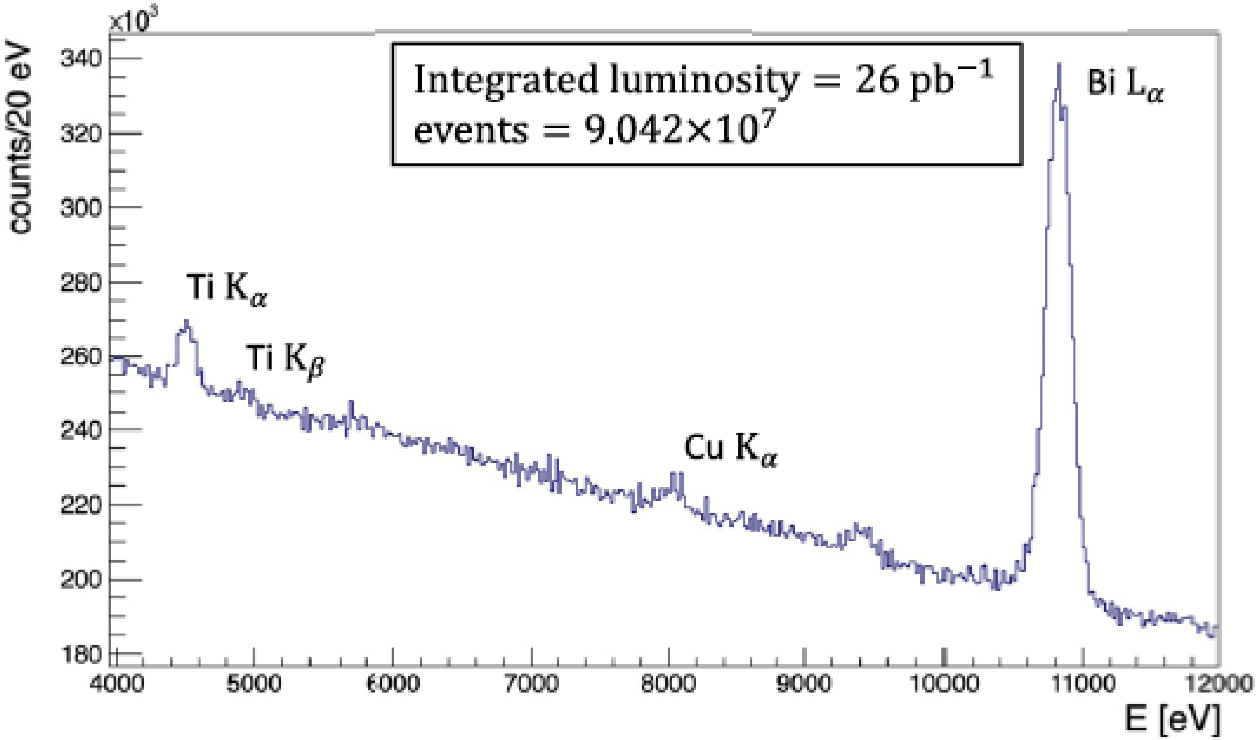


The Time of Flight (ToF) is different for Kaons, m(K)~ 500 MeV/c^2 and light particles originating from beam-beam and beam-environment interaction (MIPs).

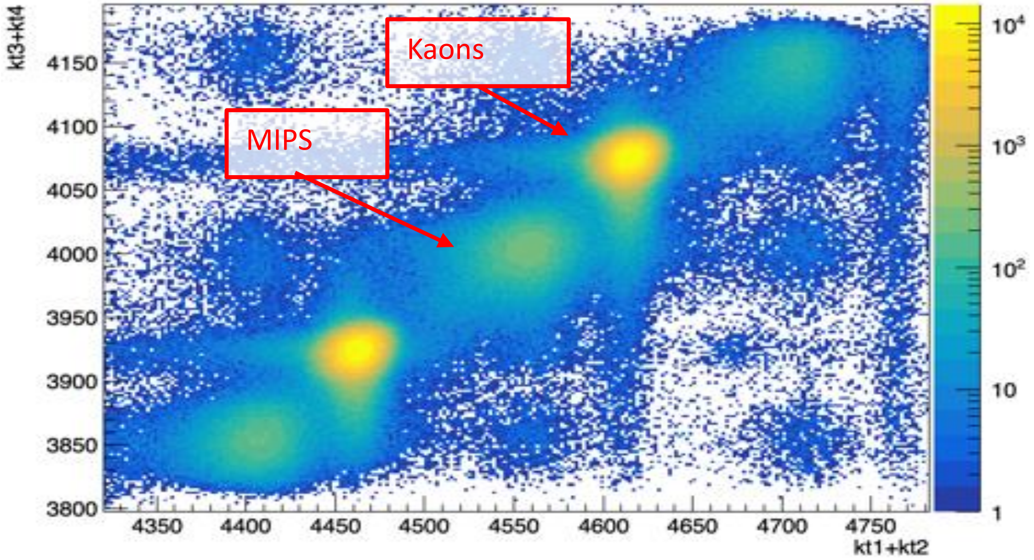
Can efficiently discriminate by ToF Kaons and MIPs!

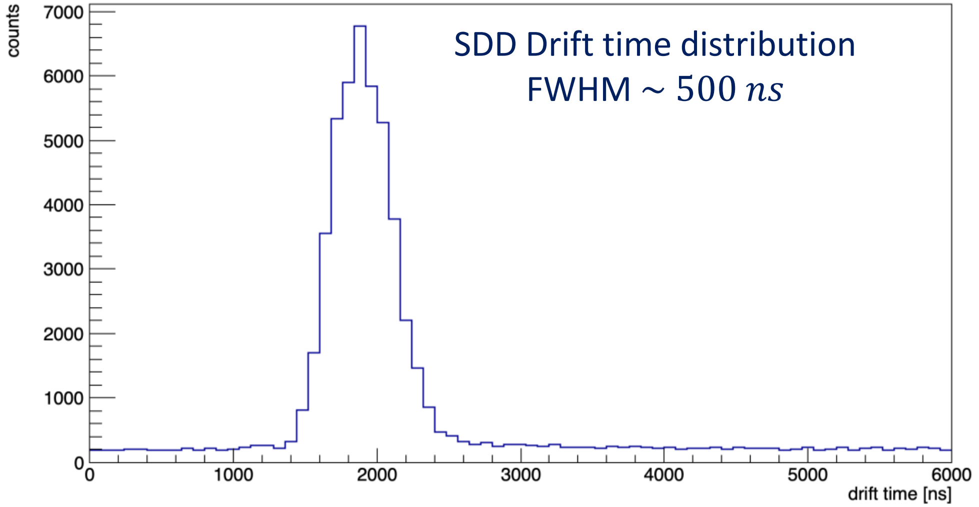
The Kaon Trigger

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



Integrated luminosity = 26 pb^{-1}
events = 9.042×10^7

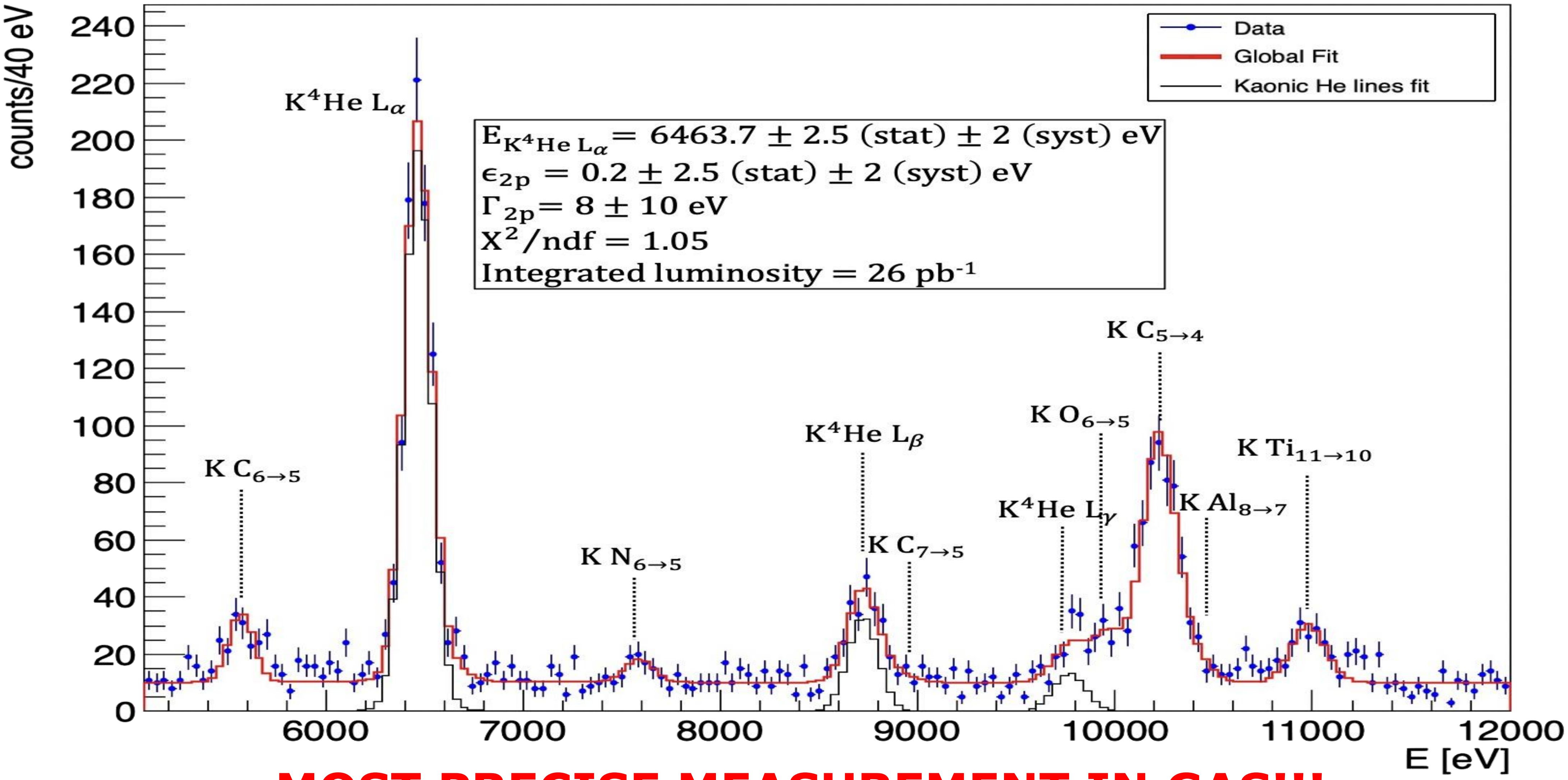




SDD Drift time distribution
FWHM $\sim 500\ ns$

Triggered rejection factor $\sim 10^{-5}$

Kaonic Helium 4 measurement

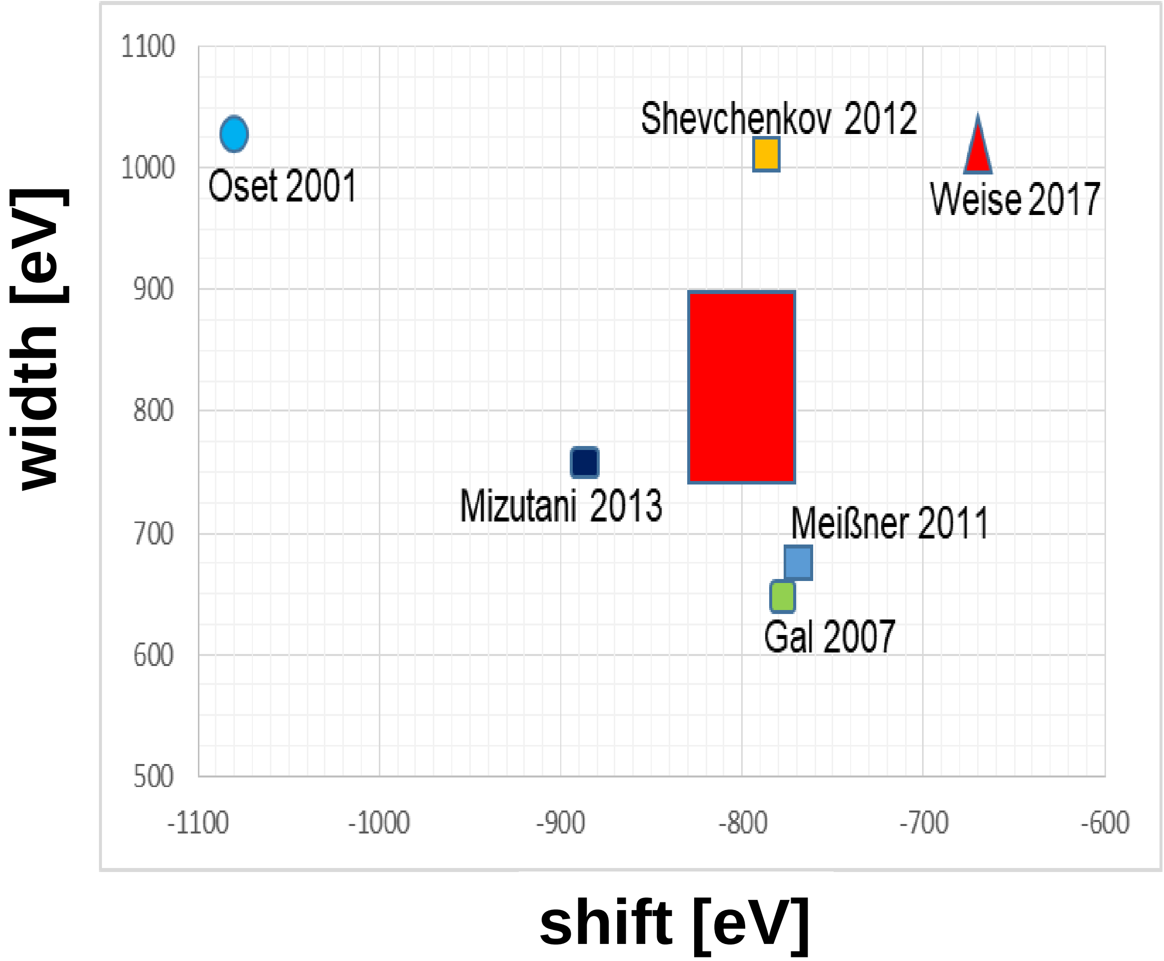


MOST PRECISE MEASUREMENT IN GAS!!!

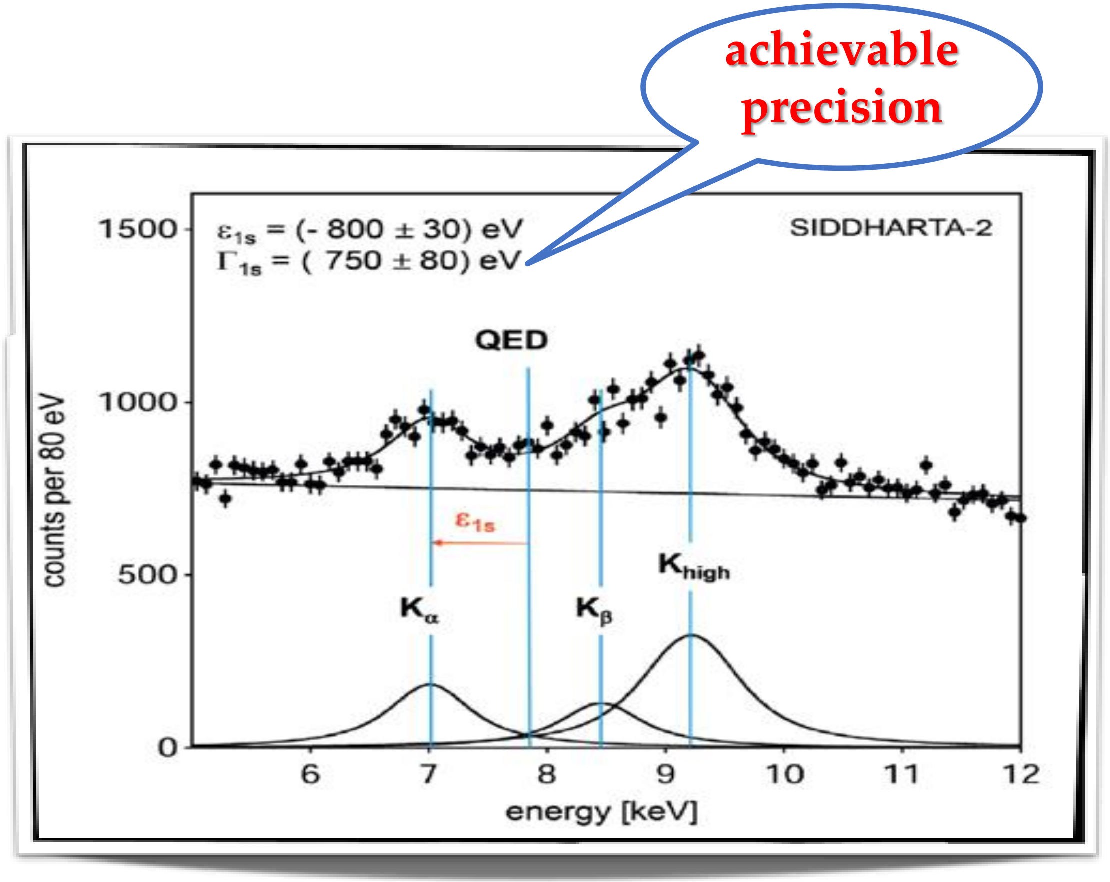
Sirghi *et al* 2022 *J. Phys. G: Nucl. Part. Phys.*

SIDDHARTA-2 setup
Ready for Run

SIDDHARTA-2 $\bar{K}d$ measurement



SIDDHARTA-2 WILL RUN DURING 2022/3 TO PERFORM THE FIRST $\bar{K}d$ 1s ATOMI LEVEL SHIFT AND WIDTH MEASUREMENT



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) !

Beyond SIDDHARTA-2

- **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 – $\Lambda(1405)$ study*
  - *Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen)*
  - *Measurement of Nuclear Resonance Effects in Kaonic Molybdenum Isotopes ($^{94}_{42}Mo, ^{96}_{42}Mo, ^{98}_{42}Mo, ^{100}_{42}Mo$) with investigation on nuclear pheriphery changement adding pair of neutrons from the lightest isotope (possible implication in* neutrinoless double beta ($0v\beta\beta$) decay*)*

Thank you!

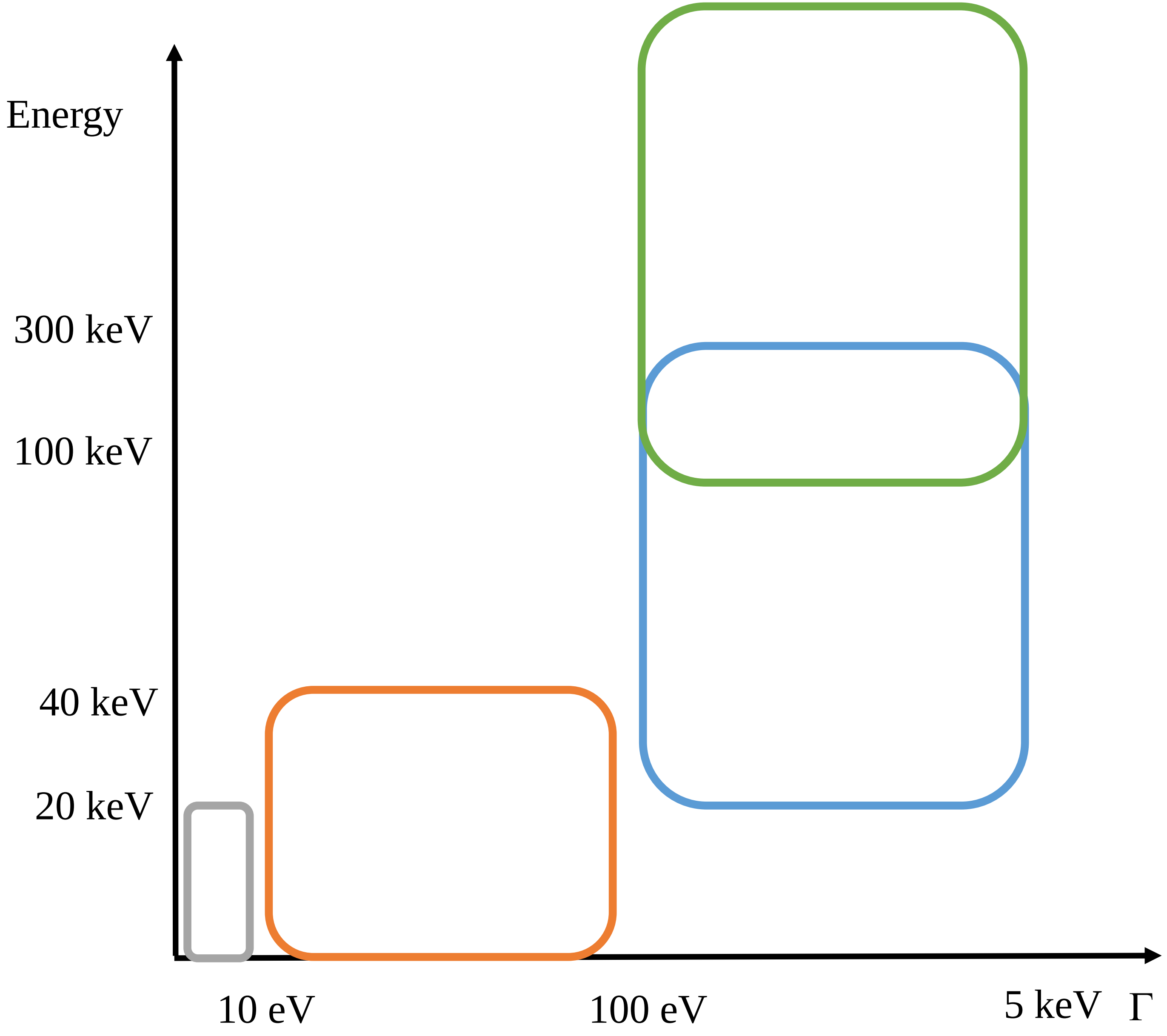
Transitions: energies and widths…which detector?

Crystal spectrometers:
- High resolution
- Low efficiency
- 0-20 keV range

SDDs
- 100 eV max resolution
- 4-40 keV range
- High efficiency

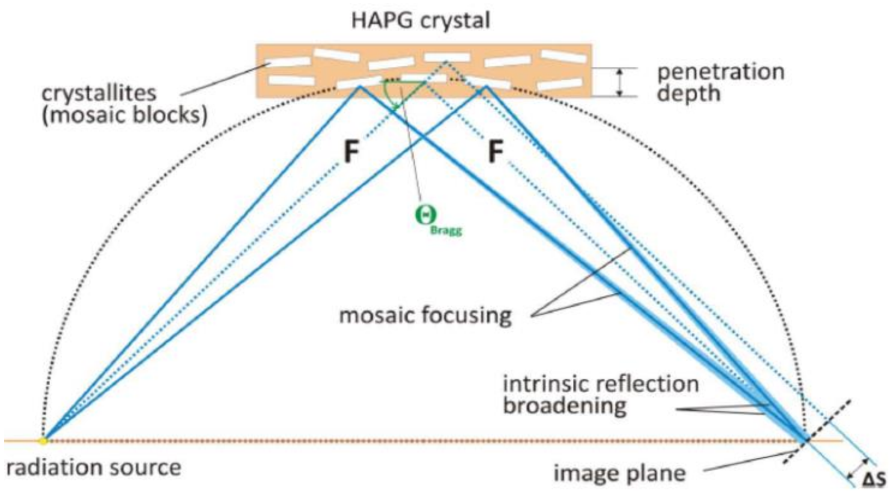
Cd(Zn)Te
- 20-300 keV range
- FWHM / E ~ %
- High efficiency
- Room Temperature

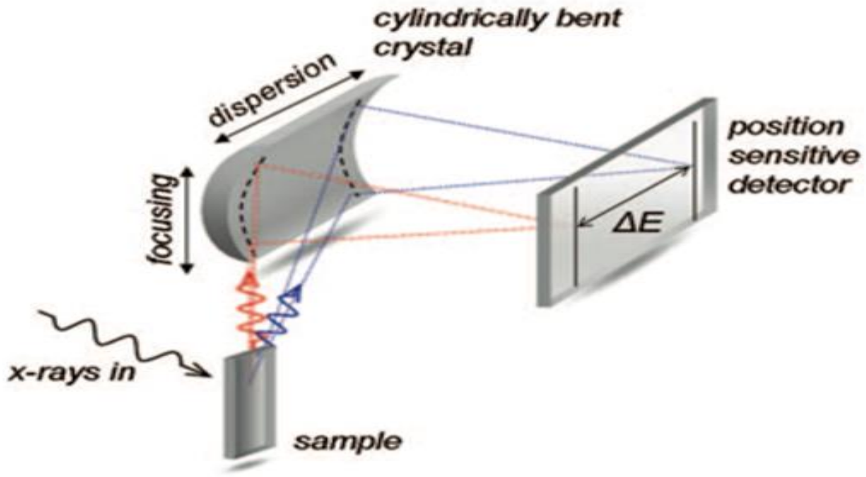
HPGe
- 100-1000 keV range
- FWHM / E ~ %
- High efficiency
- Cooling needed



Crystal spectrometers: VOXES

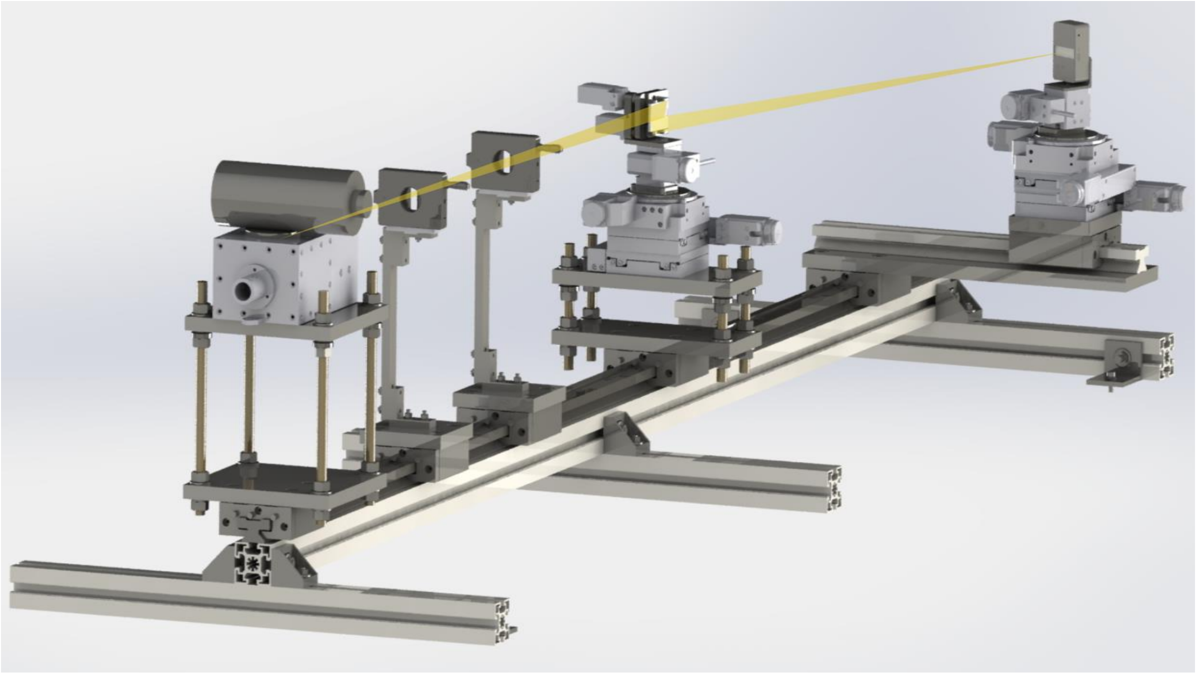
Spectrometer developed under CSN5 Young Researcher Grant (2016-2018)



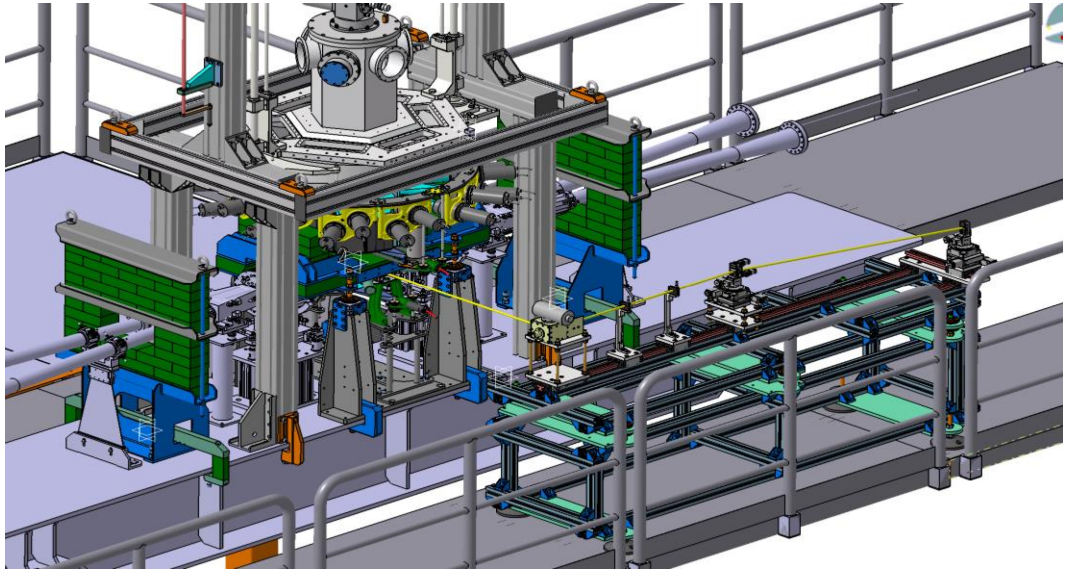


HAPG mosaic crystals in Von Hamos configuration:

- Higher intrinsic reflectivity wrt standard crystals
- VH configuration to exploit sagittal focusing
- Optical optimisation to work with milli/centimetric sources



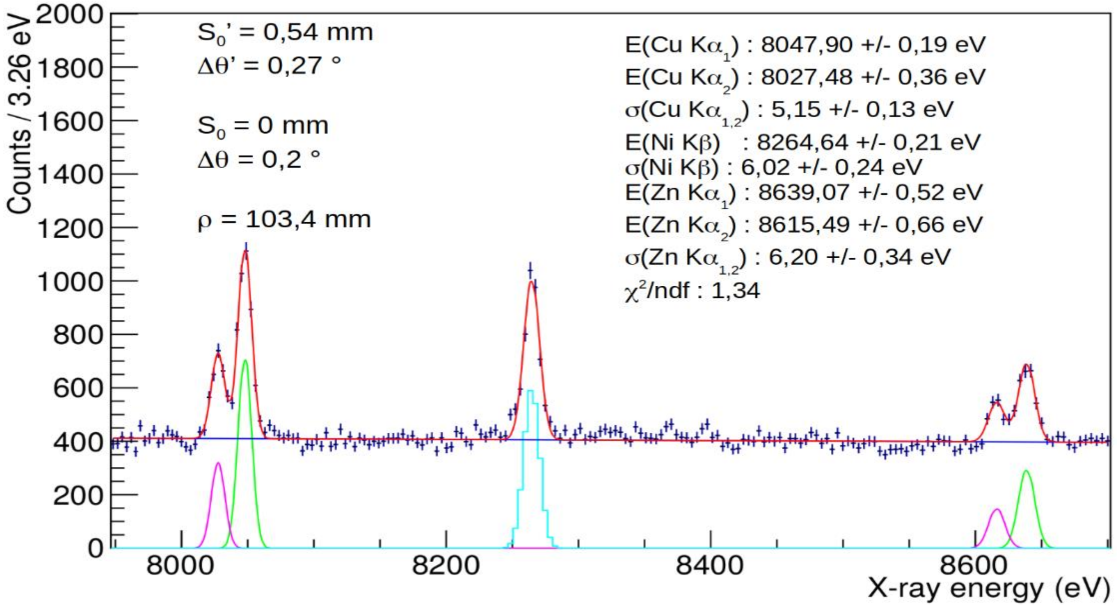
Crystal spectrometers: VOXES

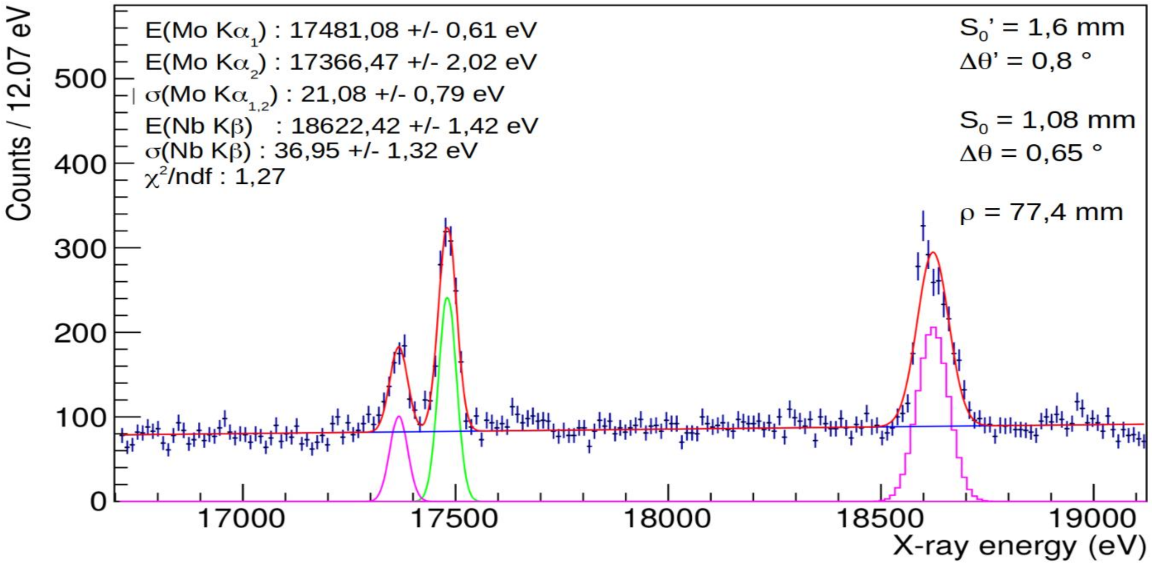


Possible feasibility test to be done in parallel with SIDDHARTA-2

Main goal: assess background and on beam behaviour of crystals and strip detector

High precision measurements with VOXES in LNF Lab

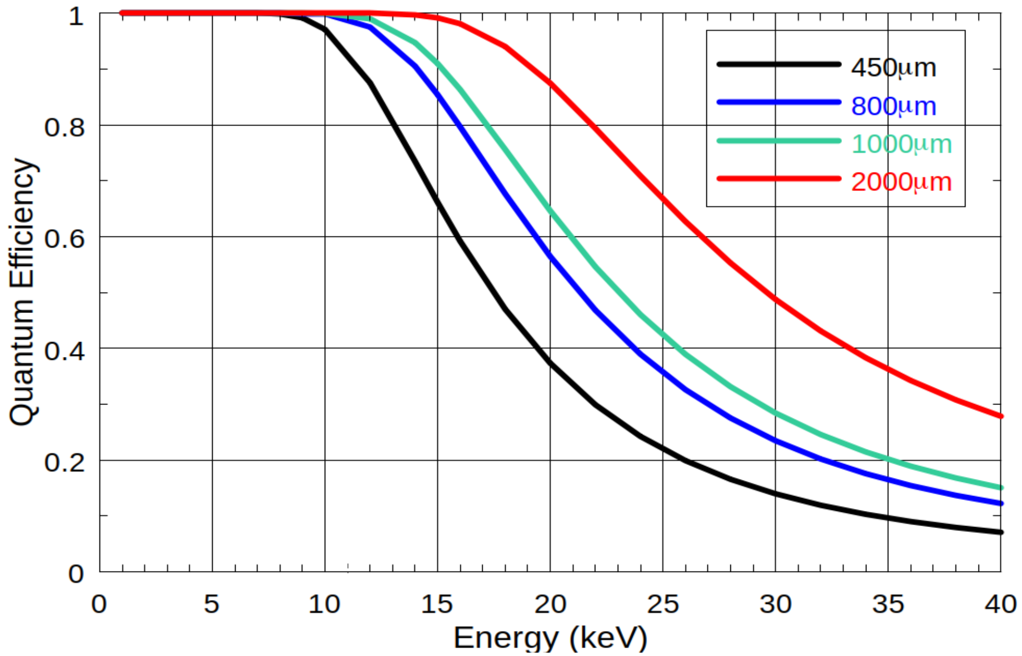




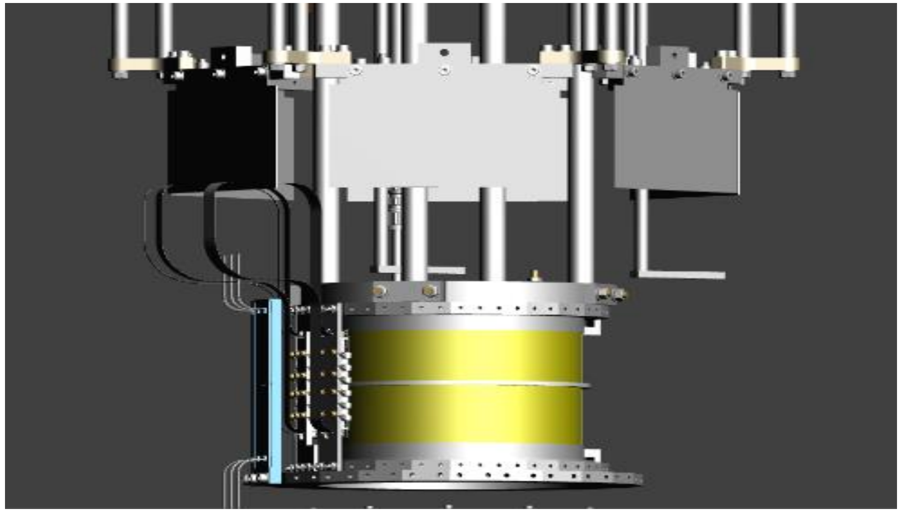
SDD: present and future at DAFNE

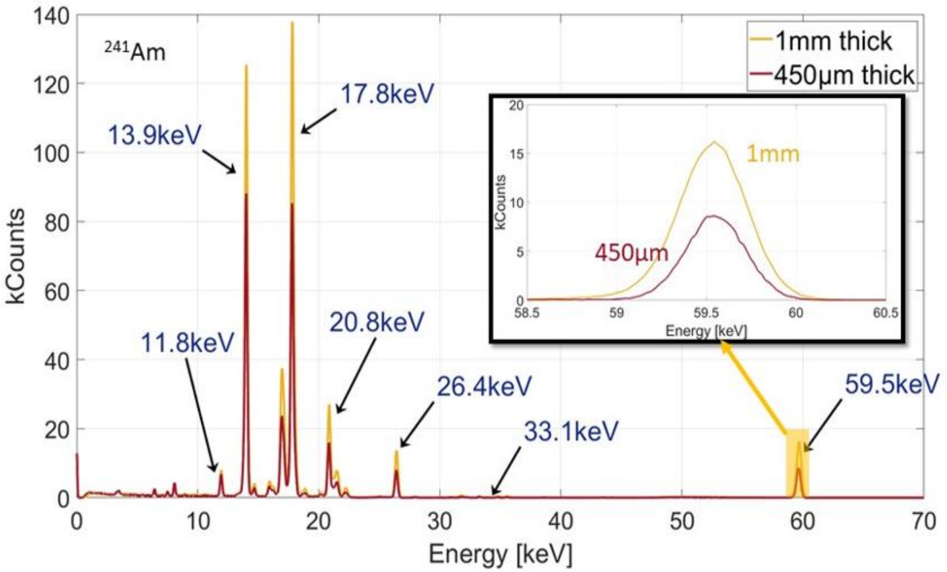
Kaonic Helium transitions on 1s level would be accessible (very difficult):

K^{3}He(2→1) : 33 keV
K^{4}He(2→1) : 35 keV



SIDDHARTA-2 – like setup with 1-2 mm thick SDDs





SDD: present and future at DAFNE

Kaonic Helium transitions on 1s level would be accessible (very difficult):

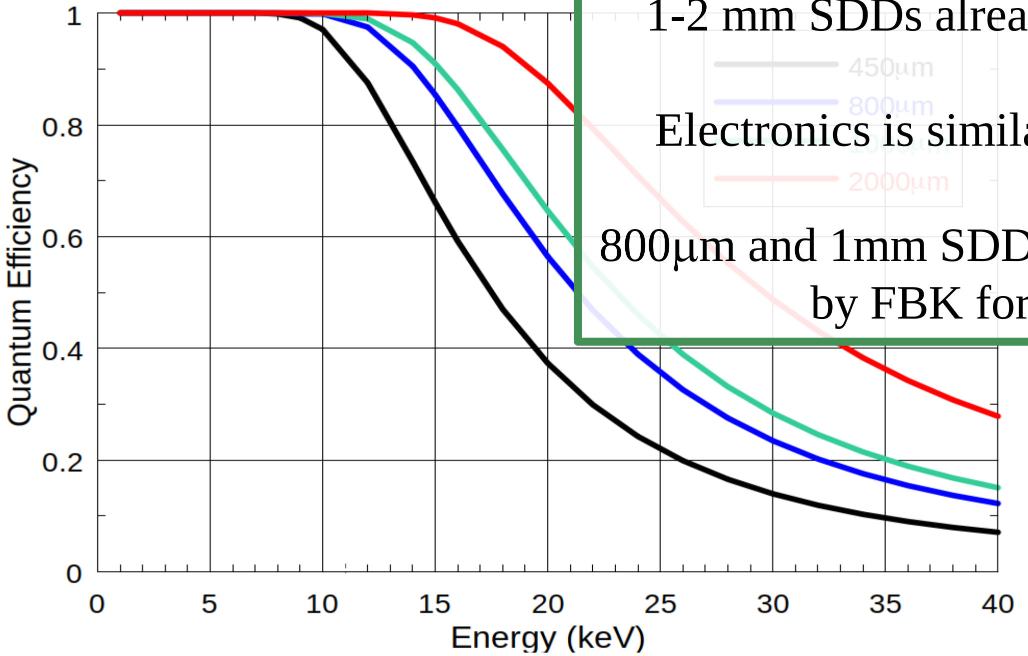
$K^3He(2\rightarrow1)$: 33 keV
$K^4He(2\rightarrow1)$: 35 keV

Feasibility:

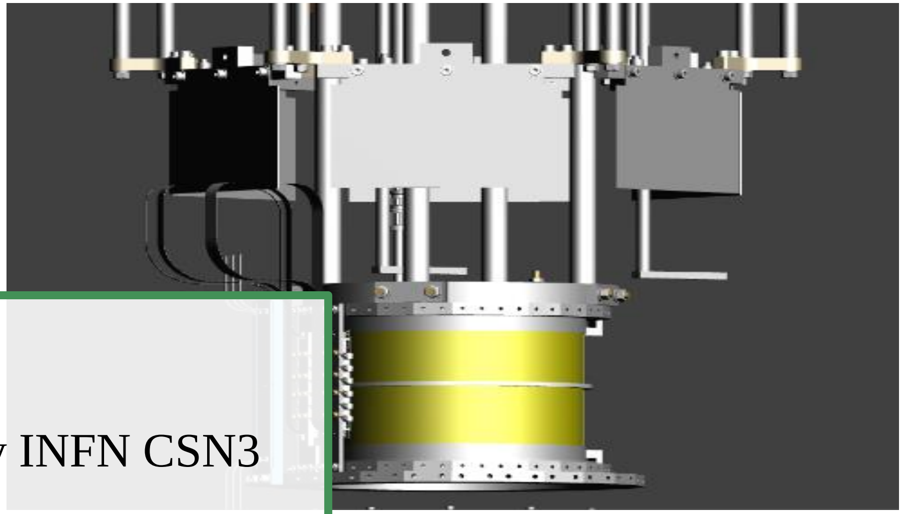
1-2 mm SDDs already financed by INFN CSN3

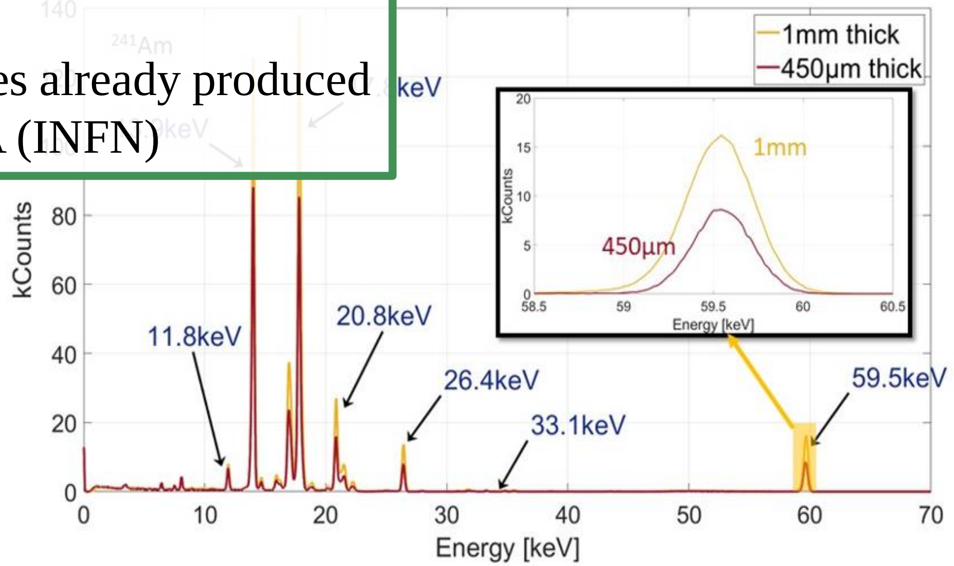
Electronics is similar to SIDDHARTA-2 SDDs

800µm and 1mm SDDs prototypes already produced by FBK for ARDESIA (INFN)



SIDDHARTA-2 – like setup with 1-2 mm thick SDDs

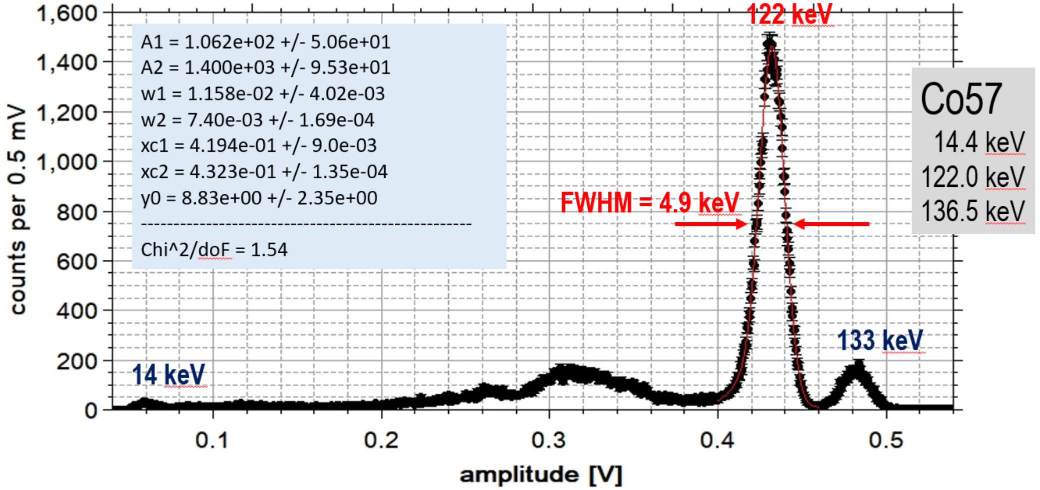




CZT: proposal for new measurements at DAFNE

Detector Key Points:

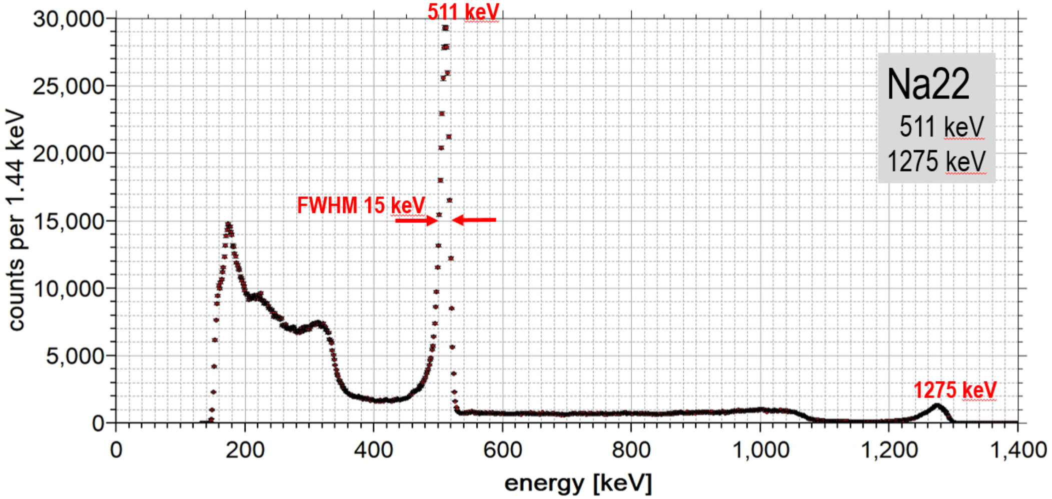
- High efficiency in the 20-100 keV region
- Reasonable efficiencies up to 300 keV
- Good resolution (FHWM/E ~ %)
- Fast response and time resolution (< 50 ns)


Sample A – Co57 bias: 1000 V

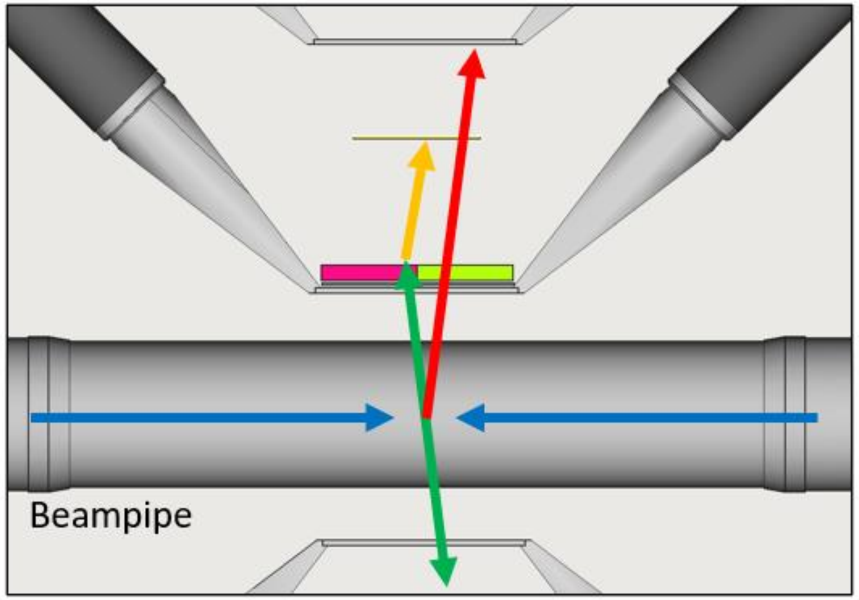
```
A1 = 1.062e+02 +/- 5.06e+01
A2 = 1.400e+03 +/- 9.53e+01
w1 = 1.158e-02 +/- 4.02e-03
w2 = 7.40e-03 +/- 1.69e-04
xc1 = 4.194e-01 +/- 9.0e-03
xc2 = 4.323e-01 +/- 1.35e-04
y0 = 8.83e+00 +/- 2.35e+00
------------------------------------------------
Chi^2/doF = 1.54
```

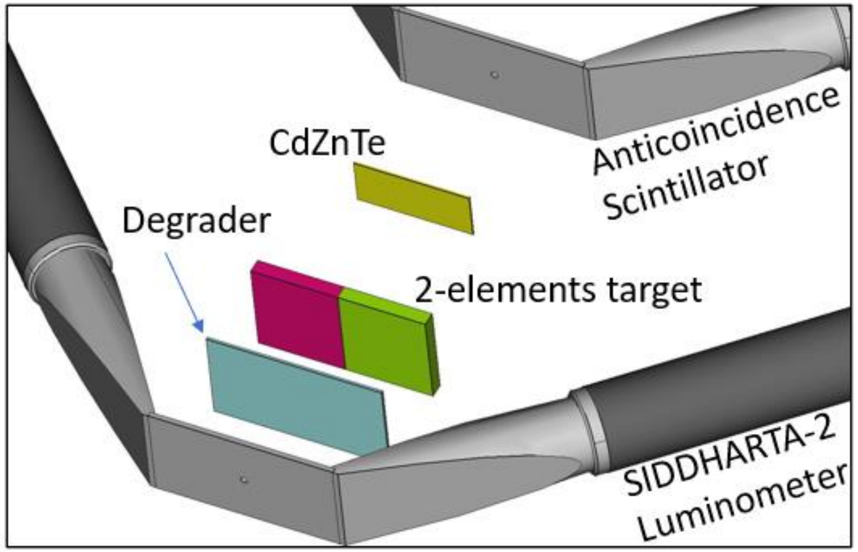
Precisions < 10 eV (ε) and <20 eV (Γ) are reachable in few months

First prototypes of Cd(Zn)Te delivered by JRA8-ASTRA (STRONG-2020) and tested


CZT-500 – Na22 bias: 600 V

CZT: proposal for new measurements at DAFNE



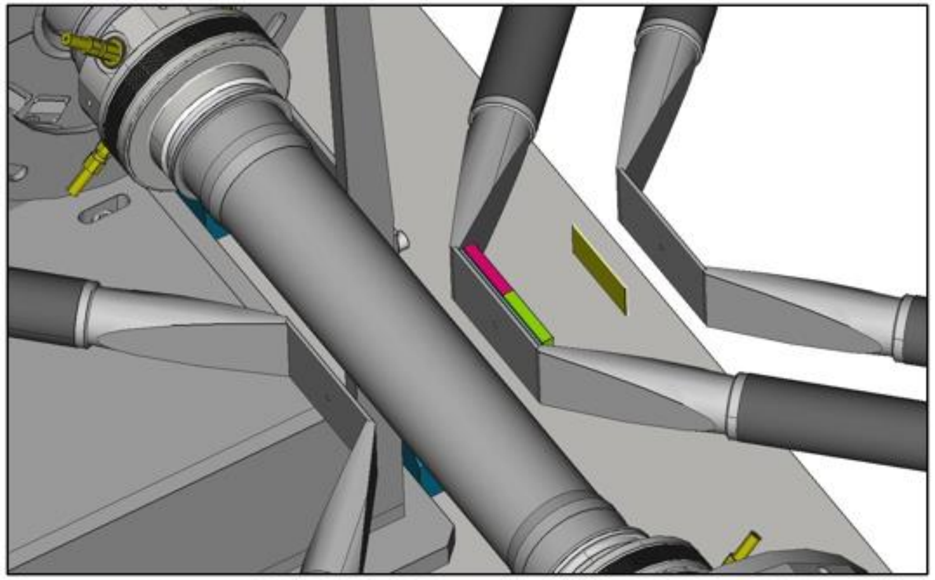


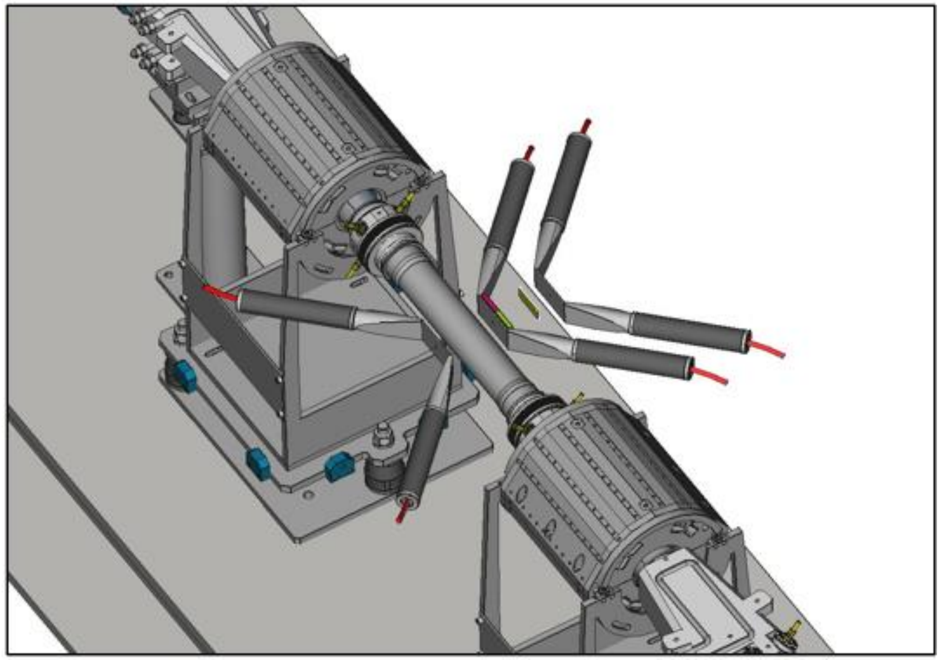
Kaonic atoms X-rays

e^+e^-

K^+K^-

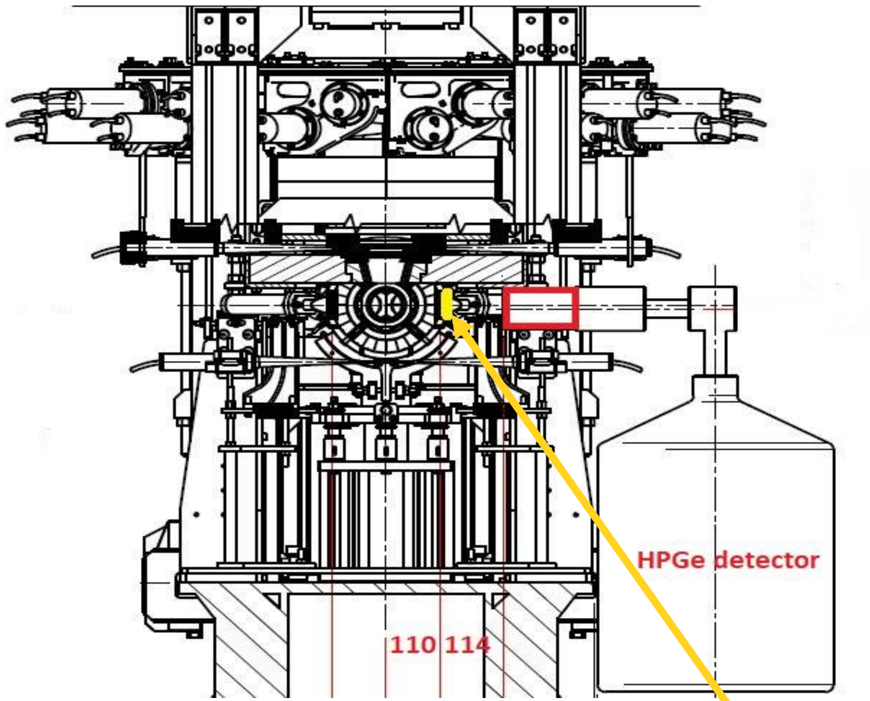
MIP

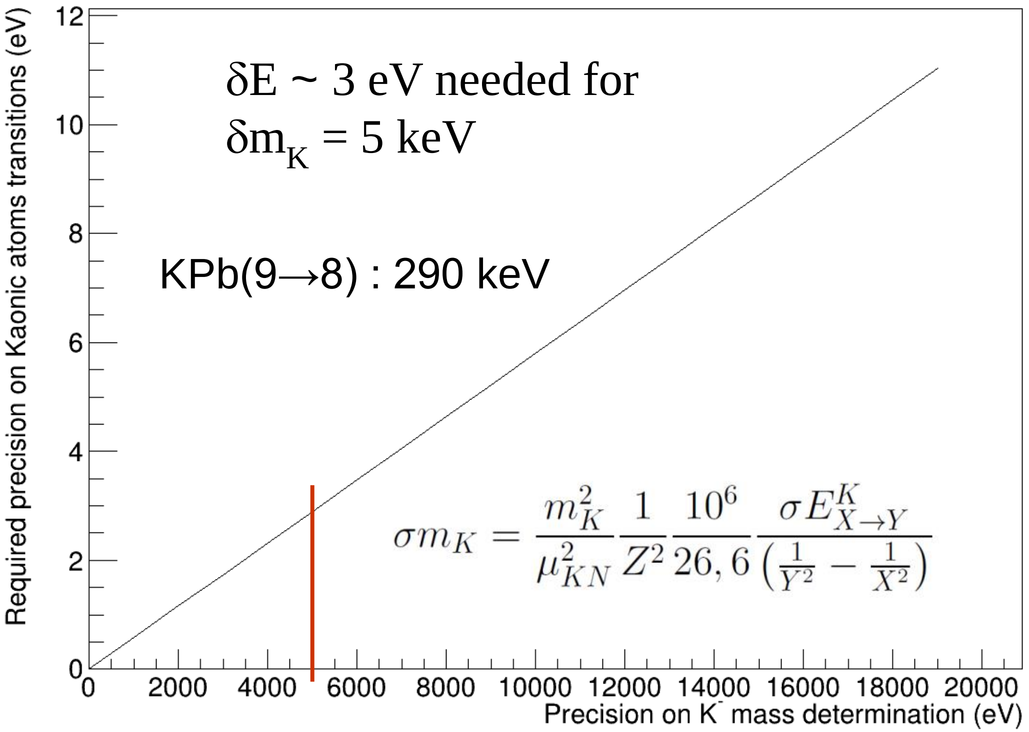




New Kaon Mass measurement with HPGe

Parallel run with SIDDHARTA-2: (already installed)

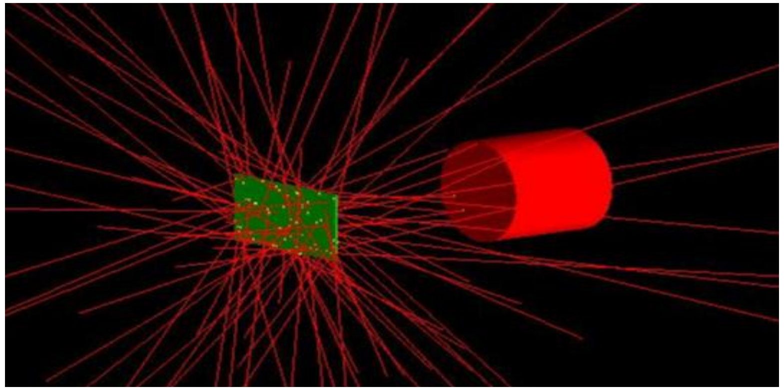




δE ~ 3 eV needed for δm_K = 5 keV

KPb(9→8) : 290 keV

$$\sigma m_K = \frac{m_K^2}{\mu_{KN}^2}\,\frac{1}{Z^2}\,\frac{10^6}{26,6}\,\frac{\sigma E^K_{X\to Y}}{\left(\frac{1}{Y^2}-\frac{1}{X^2}\right)}$$



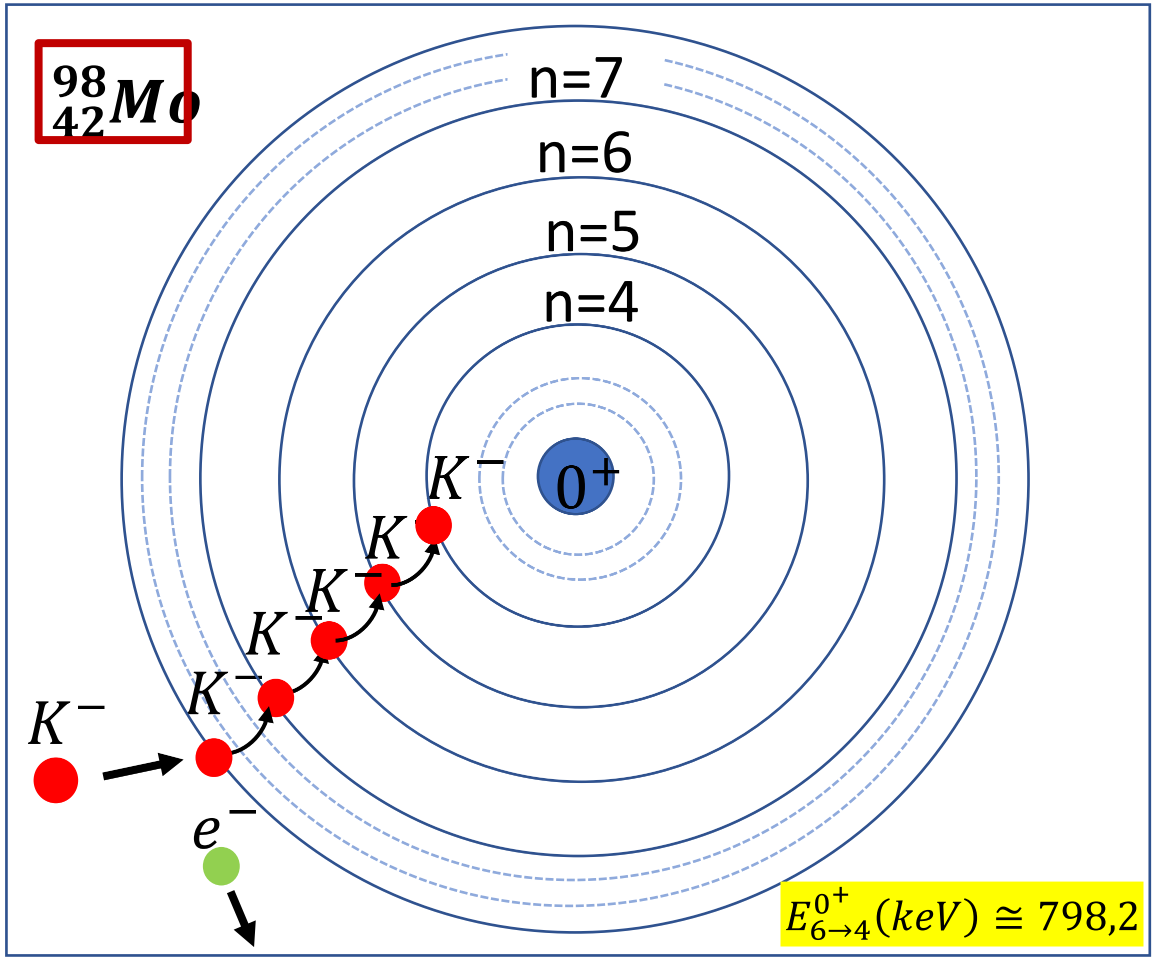
Pb target just behind the SIDDHARTA-2 luminometer, which is used as trigger

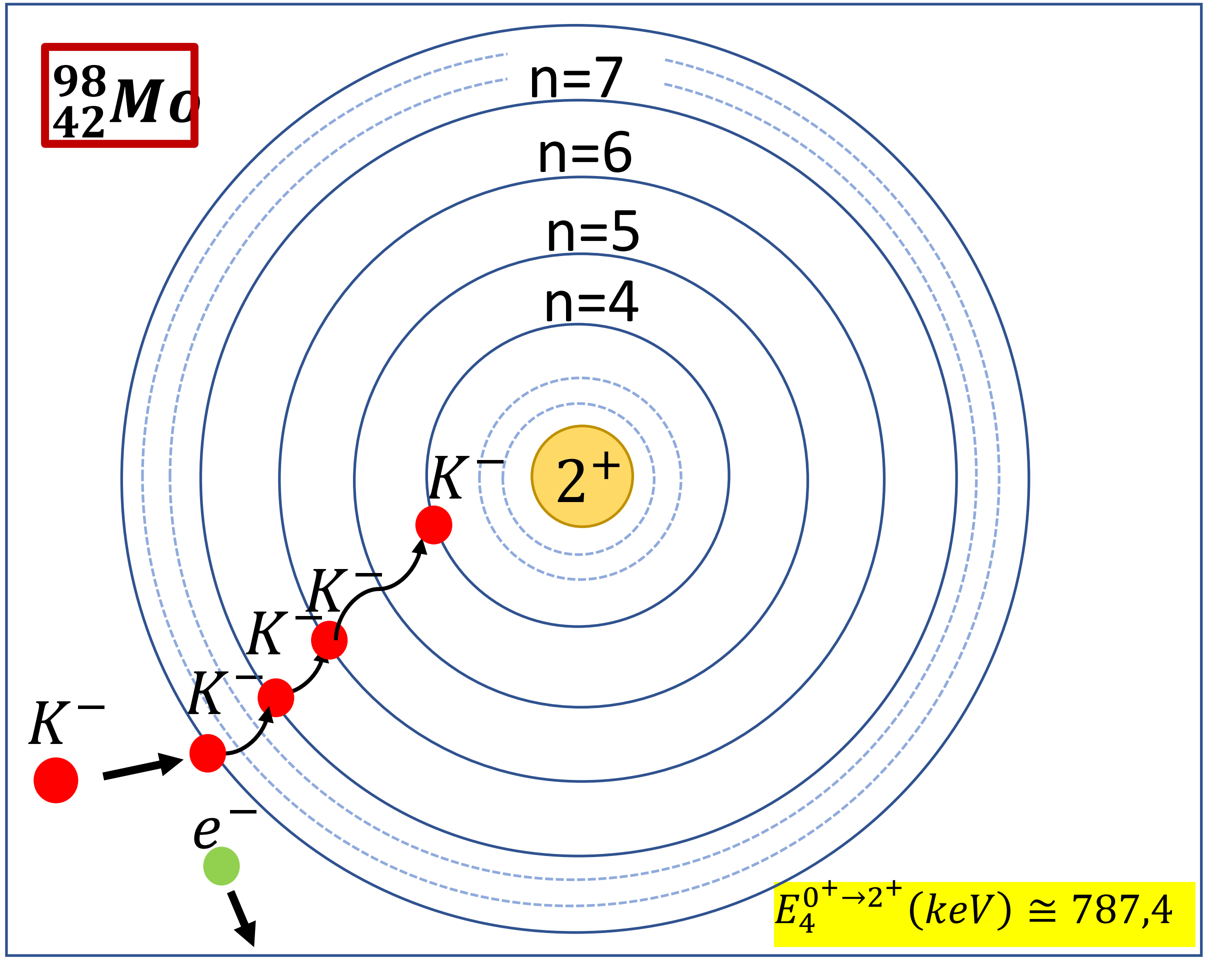
Resolutions (FWHM) obtained with ^{60}Co, ^{133}Ba sources :

0.870 keV @ 81 keV
1.106 keV @ 302.9 keV
1.143 keV @ 356 keV
1.167 keV @ 1330 keV

The E2 Nuclear Resonance Effect

In “thicklish nuclei” kaonic atoms, when an atomic de-excitation energy is closely matched by a nuclear excitation energy, a resonance condition occurs, which produces an attenuation of some of the atomic x-ray lines from a resonant versus a normal isotope target – as Mo(98).





The E2 Nuclear Resonance Effect

The E2 Nuclear Resonance effect is a mixing of the atomic states due to the electrical quadrupole excitations of nuclear rotational states.

Quanto-mechanically, *the effect mixes* $(n, l, 0^+)$ *levels with* $(n', l-2, 2^+)$ *levels* producing a wave function which contains a small admixture of excited nucleus-deexcited atom wavefunctions:

$$\psi = \sqrt{1-|\alpha|^2}\,\phi(n, l, 0^+) + \alpha\,\phi(n', l-2, 2^+)$$

where the admixture coefficient $\alpha = \pm \dfrac{\langle n, l, 2^+ | H_q | n', l-2, 0^+ \rangle}{E_{(n,l,2^+)} - E_{(n,l,0^+)}}$ (very small), and H_Q expresses the *electric quadrupole interaction* between hadron and nucleus.

As example, for the nuclear E2 resonance effect in $K^- - Mo$ isotopes:

$$\psi = \sqrt{1-|\alpha|^2}\,\phi(6h, 0^+) + \alpha\,\phi(4f, 2^+) \quad \text{with} \quad \alpha = \pm \frac{\langle 4f, 2^+ | H_q | 6h, 0^+ \rangle}{E_{(4f,2^+)} - E_{(6h,0^+)}}$$

The E2 Nuclear Resonance Effect

HADRONIC ATOMS ARE VERY SENSITIVE TO QUITE AMOUNTS OF CONFIGURATION MIXING

The nuclear absorption rate increases very drasically (by a factor of several hundred) for each unit decrease of orbital angular momentum; thus for a decrease of $\Delta l = 2$, the factor may be around 10^5.

A very small admixture coefficient a (typically 1%) can mean a significant induced width!

INDUCED WIDTH: $\Gamma_{n,l}^{Ind} = |a^2|\Gamma_{n',l-2}^{0}$

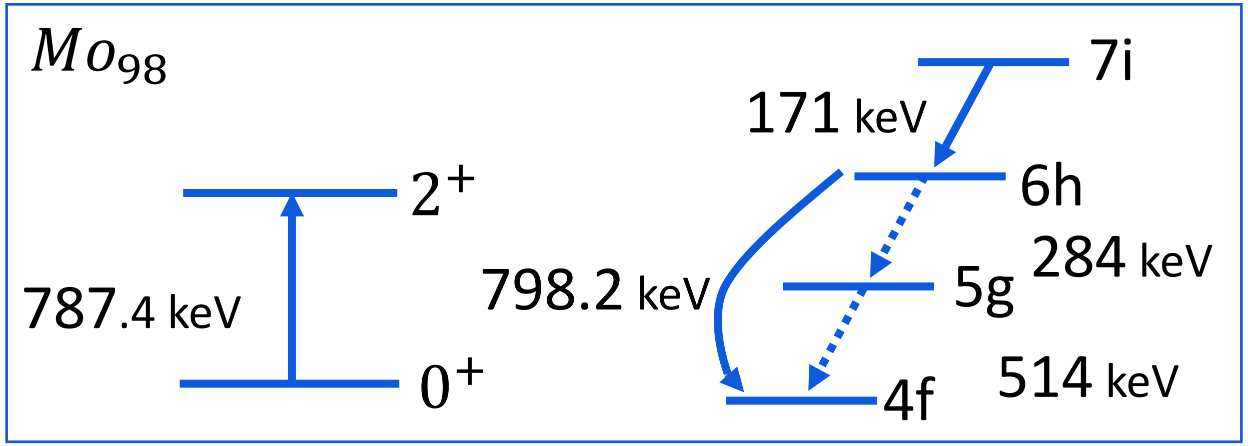
A significant weakening/attenuation of corresponding hadronic x-ray line and any lower lines can be observed.

Moreover, comparing the ratio of intensities (attenuated line/reference) from the resonant isotope (thicklish) to a non resonant one, we have the **direct measure of the fraction of hadrons absorbed by the excited nucleus**.

The Molybdenum 98 experiment

An experiment measuring E2 Nuclear Resonance Effects in Molybdenum 98 was performed in 1975 by G. L. Goldfrey, G- K. Lum and C. E. Wiegand at Lawrence Berkeley Laboratory (LBL) in California.

In kaonic molybdenum (98), the energy difference between 6h and 4f levels, 798.2 keV, is very nearly equal to the nuclear excitation energy of 787.4 keV.

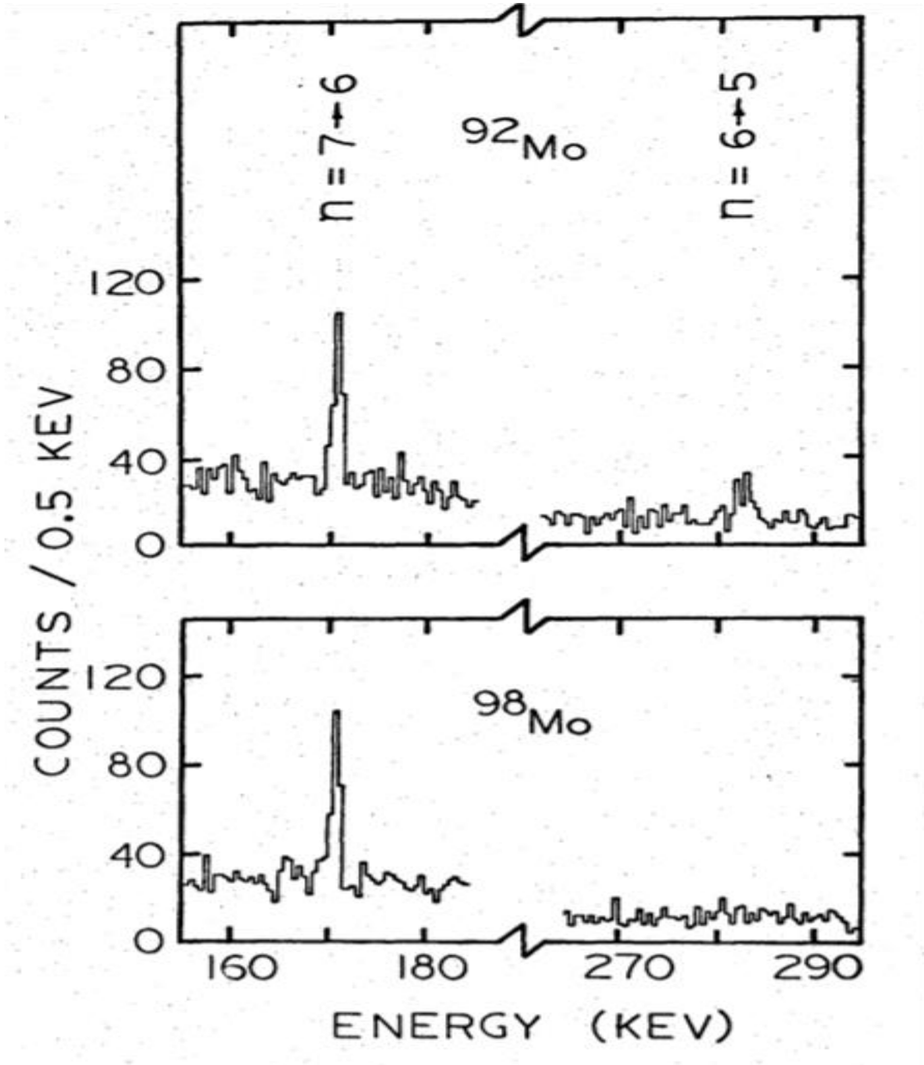


Experimental apparatus and measurement features:

- The experiment was performed with a negative kaon beam, turning the targets of Mo(98), and Mo(92) as reference.
- The spectra were collected using **germanium detectors** feeding a pulse height analyzer.

The Molybdenum 98 experiment

The E2 Nuclear Resonance effect was observed $K^{-} - {}^{98}_{42}Mo$, expressed as the attenuation of x-ray line .



Target	$E^{K-Mo}_{(6,5)\rightarrow(4,3)}(keV)$	$E^{Nucl}_{0^{+}\rightarrow 2^{+}}(keV)$	$\|a\|$	R_{α}
${}^{98}_{42}Mo$	798.2	787.4	0.033	0.16 ± 0.16
${}^{92}_{42}Mo$	799.1	1540.0	0.001	1.00 (ref)

Only 25 hours of data taking with K-beam was **not enough for a conclusive result!!**

IMPROVABLE WITH MODERN DETECTORS AND MORE DATA TAKING TIME

Nuclear Resonance in Kaonic atoms

Nuclear Resonances are expected also for kaonic atoms. Such predictions have been obtained by integrating the Klein-Gordon equation with a phenomenological kaon-nucleon potential.

Nucleus	$E_{2^+} - E_{0^+}[keV]$	Levels mixed	$E_{n,l} - E_{n,l-2}[keV]$	$\Gamma_{n,l-2}[keV]$	Atten lines	Energy [keV]	Ref lines	Energy [keV]
${}^{94}_{42}Mo$	871	(6,5)+(4,3)	798.8	24.8	6 → 5	284.3	7 →6	171.1
${}^{96}_{42}Mo$	778	(6,5)+(4,3)	798.5	25.2	6 → 5	284.3	7 →6	171.1
${}^{98}_{42}Mo$	787.4	(6,5)+(4,3)	798.2	25.5	6 → 5	284.3	7 →6	171.1
${}^{100}_{42}Mo$	535.5	(6,5)+(4,3)	797.9	25.8	6 → 5	284.3	7 →6	171.2
${}^{96}_{44}Ru$	832.3	(6,5)+(4,3)	874.9	29.8	6 → 5	312.1	7 →6	187.9
${}^{122}_{50}Sn$	1140.2	(6,5)+(4,3)	1105.8	70.4	6 → 5	403.5	7 →6	243.1
${}^{138}_{56}Ba$	1426.0	(6,5)+(4,3)	1346.3	126.1	6 → 5	505.7	7 →6	305.4
${}^{198}_{80}Hg$	411.8	(8,7)+(7,5)	406.1	7.8	8 → 7	403.2	9 →8	276.1

MOLYBDENUM OFFERS A UNIQUE OPPORTUNITY TO INVESTIGATE WITH NUCLEAR RESONANCES THE STRONG $K^- - N$ INTERACTION

Double-β decay in Mo-98 isotope

Double beta (ββ) decay is a nuclear process in which two neutrons turn in two protons (or vice versa) and two electrons are emitted.

STANDARD double-beta decay: $^{98}_{42}Mo \rightarrow {}^{98}_{44}Ru + e^- + e^- + 2\overline{\nu}_e$ → Lepton number conserved

Neutrinoless double-beta decay: $^{98}_{42}Mo \rightarrow {}^{98}_{44}Ru + e^- + e^-$ →

VIOLATION OF LEPTON NUMBER CONSERVATION LAW

Neutrinoless double-beta decay is only possible if neutrino is a Majorana particle

The ββ-decay nuclear matrix elements can be calculated using two different theory frameworks: proton-neutron quasiparticle random phase approximation (pnQRPA) and microscopic interacting boson model (IBM-2)

These model depends on the relative distance between the two neutron decays, which is estimated to be:

$\boxed{r_{12} \leq 2R_{nucl}}$ with $\boxed{R_{nucl} \approx 1.2A^{1/3}}$

The *rms* neutron radius could provide further constrains to define relative distance among neutrons in $^{98}_{42}Mo$

SCIENTICIC IMPORTANCE OF KAMEO

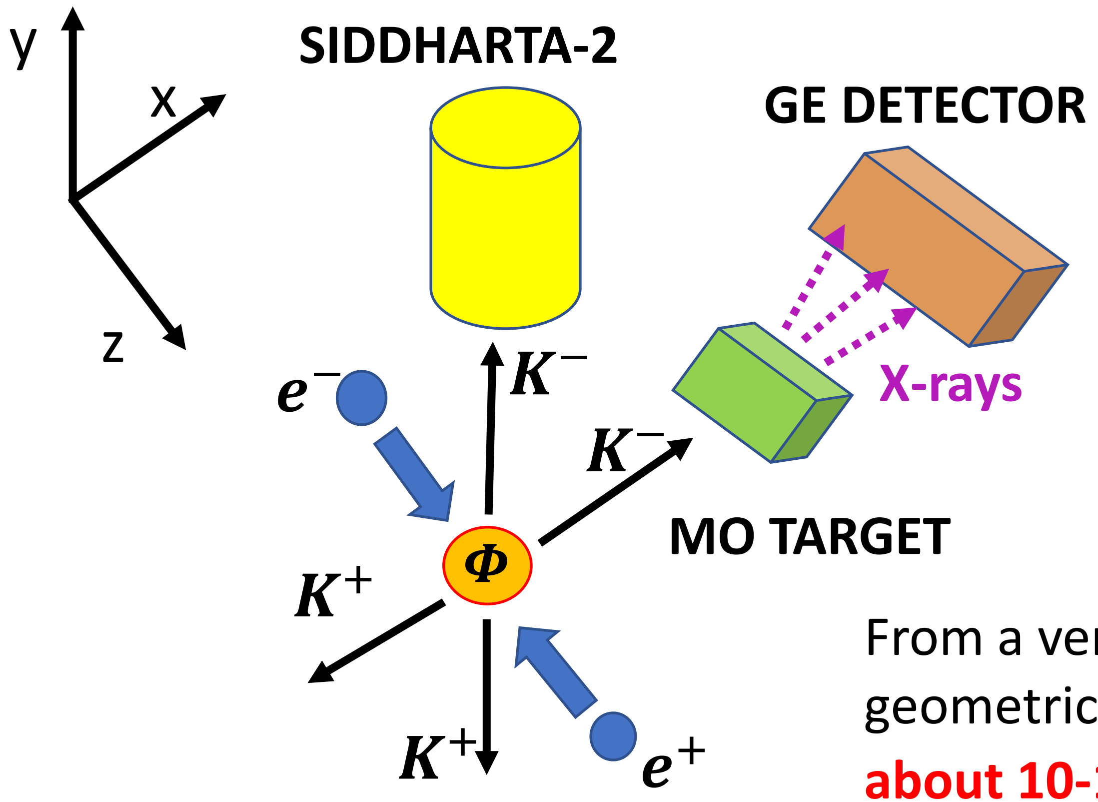
- To obtain informations on the properties of deeply bound kaonic atoms, not accessible by the kaonic cascade, in ticklish nuclei → shift and width of the $n = 4$ level!

- In $K^- - {}^{98}_{42}Mo$ the attenuation coefficient (α) due to the nuclear resonance effect can be measured with higher precision.
- The α coefficient can be measured in ${}^{94}_{42}Mo$, ${}^{96}_{42}Mo$ and ${}^{100}_{42}Mo$ for the first time, providing new reference value for theorical models.
- The comparison of measurements in ${}^{94}_{42}Mo$, ${}^{96}_{42}Mo$, ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$ could reveal new properties of strong kaon-nucleon interaction (also ${}^{96}_{44}Ru$).
- The search for isotope effects in the level shift (ε) and width (Γ) would reveal sign of changes in the nuclear periphery when pair of neutrons are added to the lighest isotope (${}^{94}_{42}Mo$)
- To study nuclear distribution in ${}^{98}_{42}Mo$, providing important details to investigate neutrinoless double beta ($0\nu\beta\beta$) and two-neutrino double beta decay ($2\nu\beta\beta$)

EXPERIMENTAL PROPOSAL: KAMEO

Kaonic Atoms Measuring nuclear resonance Effects Observables

The measurement of Nuclear resonance E2 effects in Molybdenum kaonic isotopes could be performed during the SIDDHARTA-2 data taking period, exploiting the horizontal emitted kaons with dedicated targets and a Germanium detector.



Mo isotope	**Abundance**	**Half-Time**
${}^{94}_{42}Mo$	9%	*stable*
${}^{96}_{42}Mo$	16%	*stable*
${}^{98}_{42}Mo$	24%	*stable*
${}^{100}_{42}Mo$	10%	$7.7 \times 10^{18}\ y$

From a very **preliminary estimation**, with a target maximizing the geometrical efficiency, **the measurements could be performed in about 10-15 days for each isotope, including (for reference) the $\boldsymbol{{}^{92}_{42}Mo}$.**