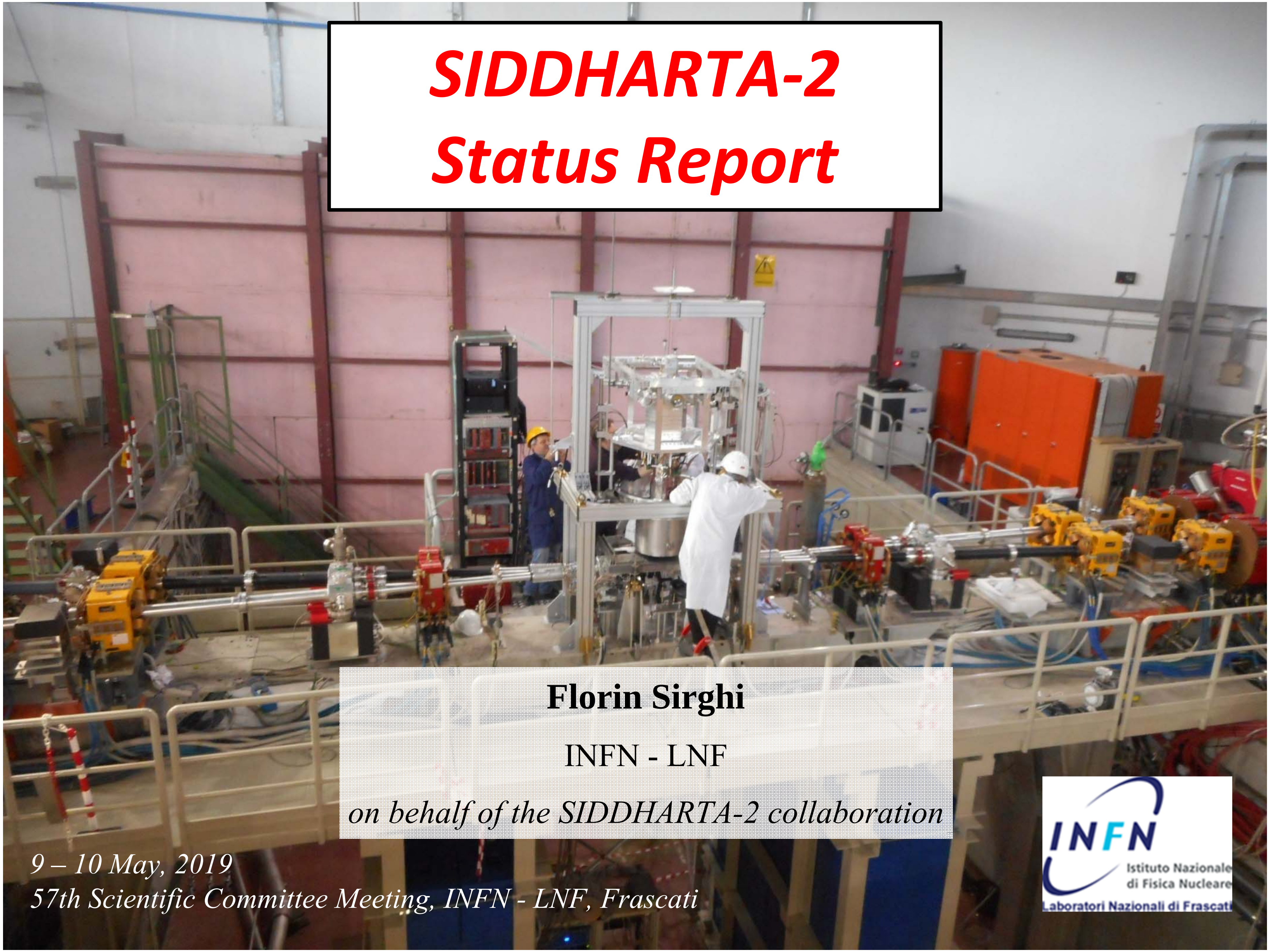


SIDDHARTA-2 Status Report

Florin Sirghi

INFN - LNF

on behalf of the SIDDHARTA-2 collaboration

9 – 10 May, 2019
57th Scientific Committee Meeting, INFN - LNF, Frascati

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SIDDHARTA-2

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

HadronPhysics2
Study of Strongly Interacting Matter

HadronPhysics I3
Study of Strongly Interacting Matter

FWF Der Wissenschaftsfonds.

Farnesina
Ministero degli Affari Esteri
e della Cooperazione Internazionale

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
Research Center for Electron Photon Science (ELPH), Tohoku University
CERN, Switzerland

STRONG-2020

Croatian Science Foundation, research project 8570

SIDDHARTA-2 - new organization structure

Spokespersons:
Catalina Curceanu (LNF-INFN)
Johann Zmeskal (SMI)

Technical Coordinator:
Florin Sirghi (LNF-INFN)
Contact person DAFNE - SIDDHARTA-2:
Alberto Clozza (LNF-INFN)
DAQ responsible:
Mihai Iliescu (LNF-INFN, SMI and CERN)
Readout electronics:
Massimiliano Bazzi (LNF-INFN)
Carlo Fiorini (Politecnico di Milano)
Slow Control:
Mario Bragadireanu (IFIN-HH)
SDD detector system:
Marco Miliucci (LNF-INFN)

Veto systems and trigger:
Alessandro Scordo (LNF-INFN)
Luminometer:
Magda Skurzok
Alessandro Scordo (LNF-INFN)
Monte Carlo simulations:
Diana Sirghi (LNF-INFN)
Michael Cargnelli (SMI)
Data analysis group:
Luca De Paolis, Raffaele Del Grande,
Alessandro Scordo, Magda Skurzok,
Diana Sirghi (LNF-INFN)
Marlene Tuchler (SMI)
VOXES system:
Alessandro Scordo (LNF-INFN)
Germanium detector system:
Damir Bosnar (Uni. Zagreb)

CONTENT

1. Scientific Motivation

2. SIDDHARTINO installation on DAΦNE

- SIDDHARTINO apparatus and aim
- SIDDHARTINO installation on DAΦNE
- First results on DAΦNE:
  calibration of SDD detectors and beam visibility
- Monte Carlo simulations for SIDDHARTINO: expected results

3. Strategy and Time Schedule

The scientific goal of SIDDHARTA-2 in brief

To perform precision measurements of *kaonic atoms X-ray transitions*

- unique information about QCD in the non -perturbative regime in the strangeness sector not obtainable otherwise

SIDDHARTA-2 main goal:

- 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)

Fundamental to understand:

- The chiral symmetry breaking mechanisms
- EOS for neutron stars (strangeness content of neutron stars)

First experimental determination of the kaon-nucleon scattering lengths

Deser-type relation (including the isospin-breaking corrections) connects shift ε_{1s} and width Γ_{1s} to the real and imaginary part of $a_{\text{K-p}}$

Done by SIDDHARTA Phys.Lett. B704 (2011) 113

$$\varepsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K-p}[1 - 2\alpha\mu(ln\alpha - 1)a_{K-p} + \ldots]$$

A similar formula holds for $a_{\text{K-d}}$

Aim of SIDDHARTA-2

$$\varepsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K-d}[1 - 2\alpha\mu(ln\alpha - 1)a_{K-d} + \ldots]$$

The connection between the scattering lengths $a_{\text{K-p}}$ and $a_{\text{K-d}}$ and the s-wave $\bar{K}N$ isospin dependent (I=0,1) isoscalar a_0 and isovector a_1 scattering length:

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

$$a_{K-n} = a_1$$

$$a_{K-d} = \frac{4[m_N + m_K]}{[2m_N + m_K]}Q + C$$

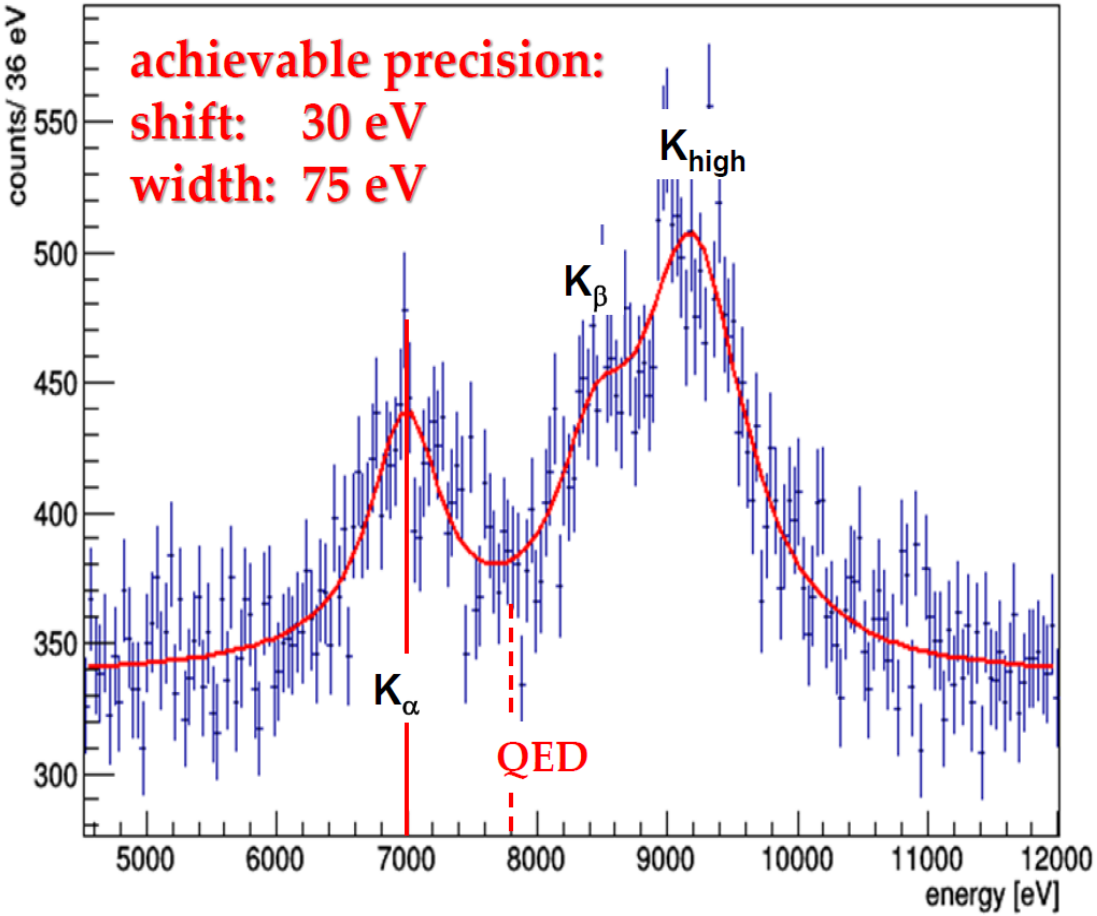
$$Q = \frac{1}{2}[a_{K-p} + a_{K-n}] = \frac{1}{4}[a_0 + 3a_1]$$

C, includes all higher-order contributions, namely all other physics associated with the K^-d three-body interaction.

Fundamental inputs of low-energy QCD effective theories

SDDHARTA-2 expected result

Geant4 simulated $K^{-}d$ X-ray spectrum for 800 pb^{-1}

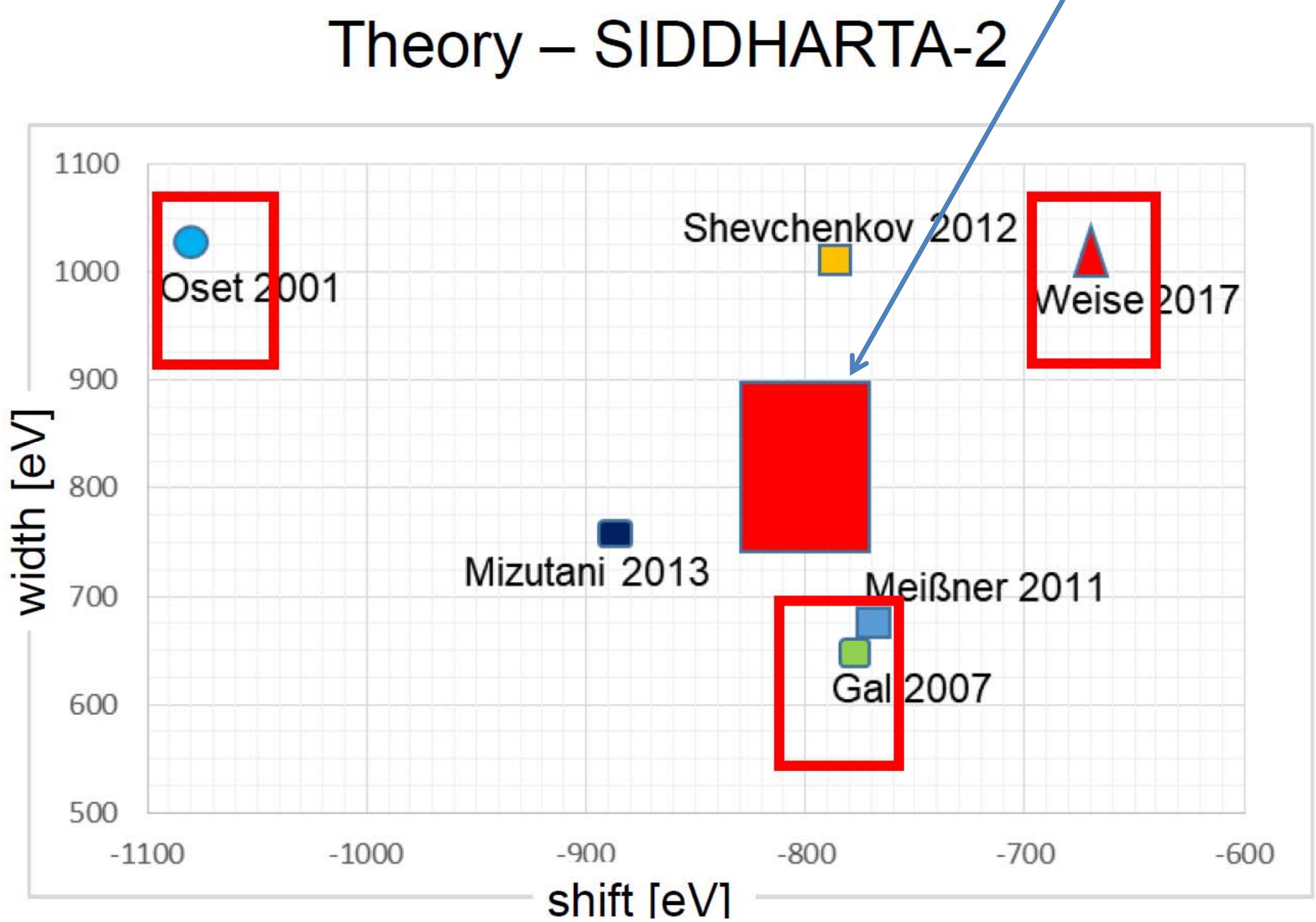


signal: shift - 800 eV
width 800 eV
density: 3% (LHD)
detector area: 246 cm^2

Kα yield: 0.1 %
yield ratio as in $K^{-}p$
S/B ~ 1 : 3

- charged particle veto
- asynchronous BG

SIDDHARTA-2 targeted precision



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Accepted Paper

The modern era of light kaonic atom experiments

Rev. Mod. Phys.

Catalina Curceanu, Carlo Guaraldo, Mihail Iliescu, Michael Cargnelli, Ryugo Hayano, Johann Marton, Johann Zmeskal, Tomoichi Ishiwatari, Masa Iwasaki, Shinji Okada, Diana Laura Sirghi, and Hideyuki Tatsuno

Accepted 8 March 2019

Scheduled publication: June 2019

ABSTRACT

ABSTRACT

This review article covers the mode… …ental kaonic atoms studies, encompassing twenty years of activity, defined by breakthrou… …cal developments which allowed performing a series of long-awaited precision measurements… …e atomic systems where an electron is replaced by a negatively charged kaon, containing the… …hich interacts in the lowest orbits with the nucleus also by the strong interaction. As a result, thei… …unique opportunity to perform experiments equivalent to scattering at vanishing relative en… …to study the strong interaction between the antikaon and the nucleon or the nucleus "at thres… …ero relative energy, without the need of {} extrapolation to zero energy, as in scattering … …fast progress achieved in performing precision light kaonic atoms experiments, which also solved

SIDDHARTA-2 strategy

Phase 1:

during the commissioning of DAΦNE

SIDDHARTINO measurement of K-^{4}He (8 SDD arrays)

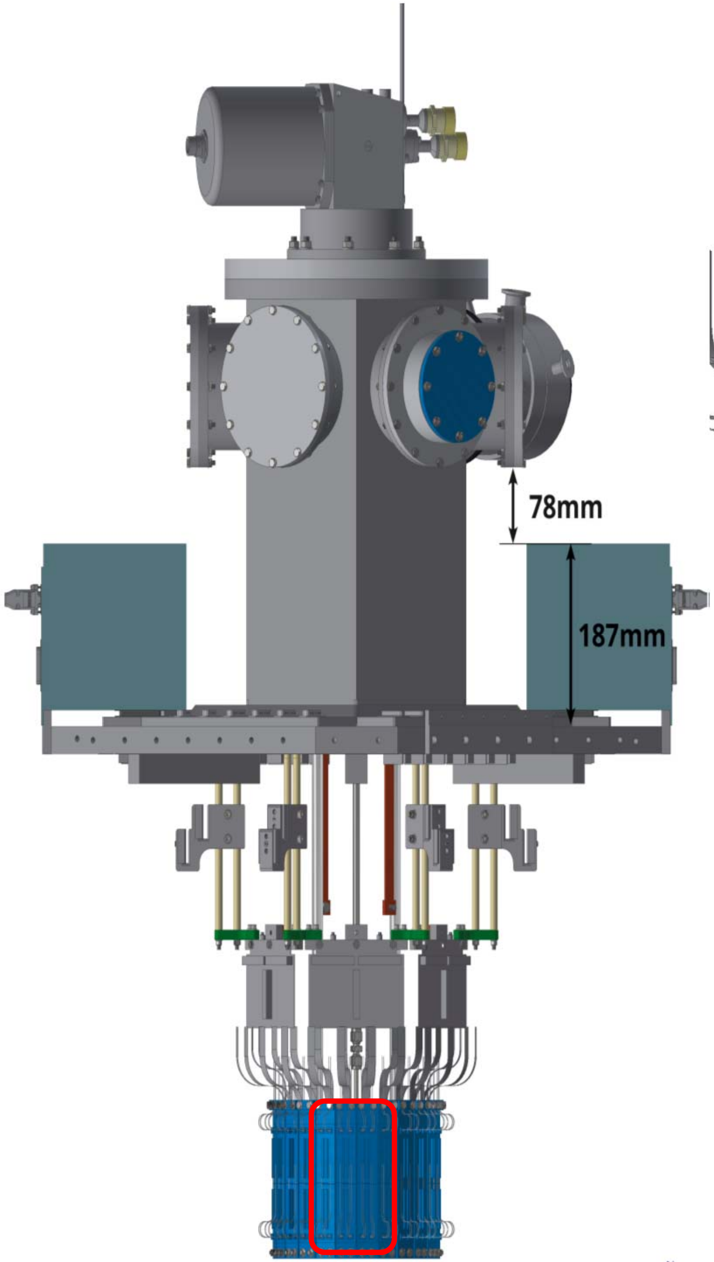
Phase 2:

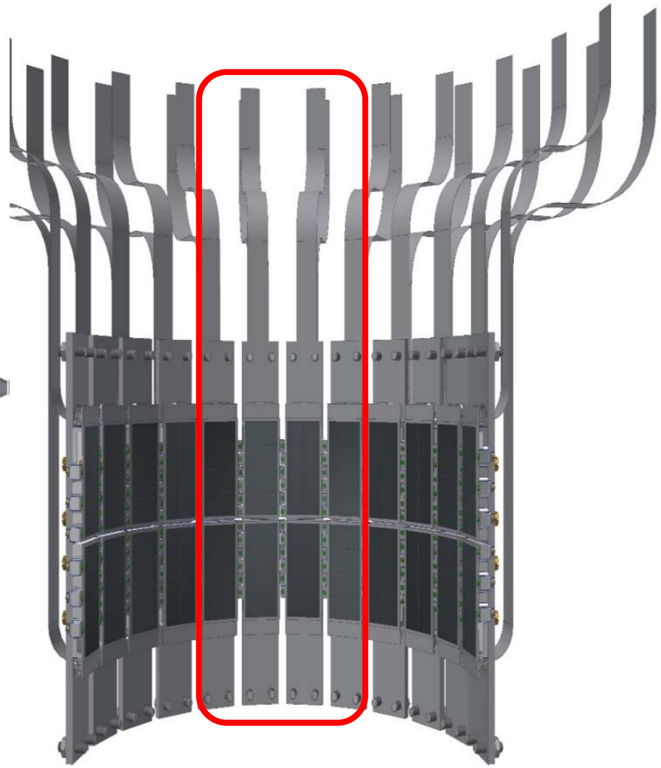
when DAΦNE operating condition is

comparable (S/B) with SIDDHARTA ones

kaonic deuterium **(48 SDD arrays) run for 800 pb^{-1}**

SIDDHARTINO = SIDDHARTA-2 with 8 SDDs

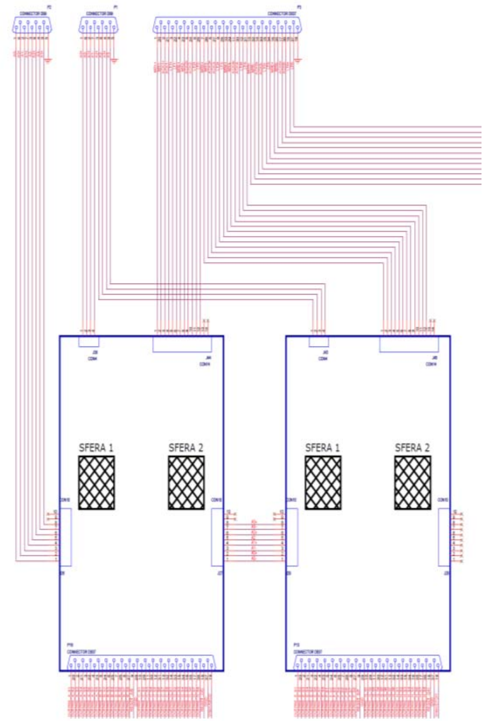




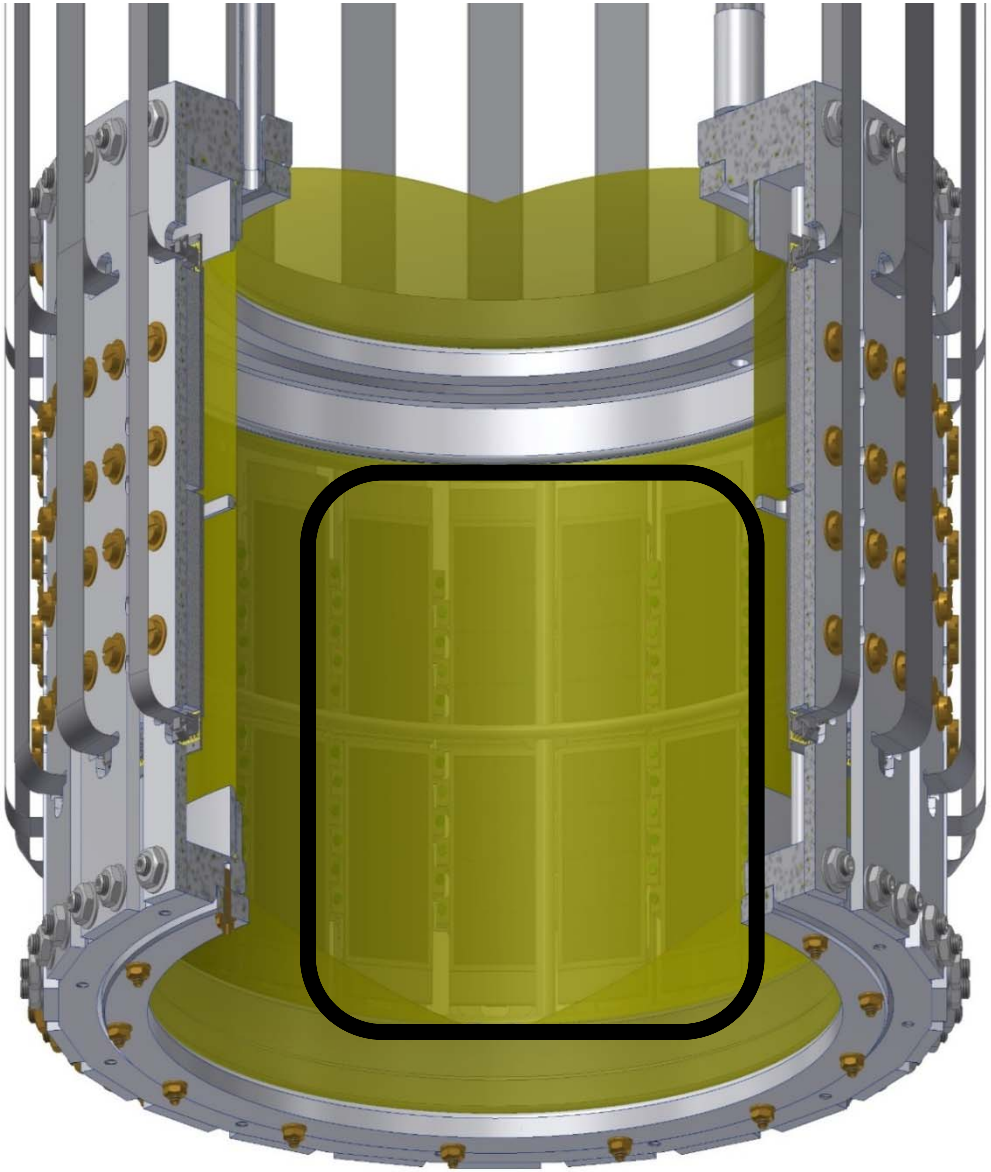
ONLY
8 SDD arrays
(out of 48)
1 BUS structure

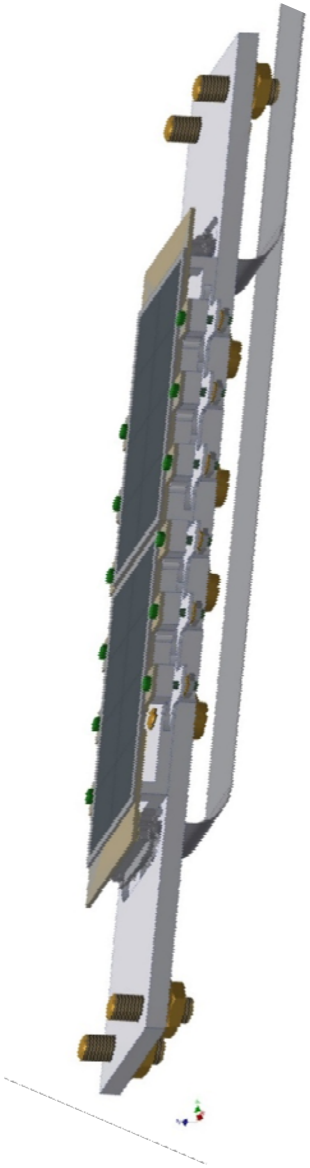
DAQ – BUS structure

- 4 SFERA ASICs
- 8 SDD arrays
- 4 ADC channels

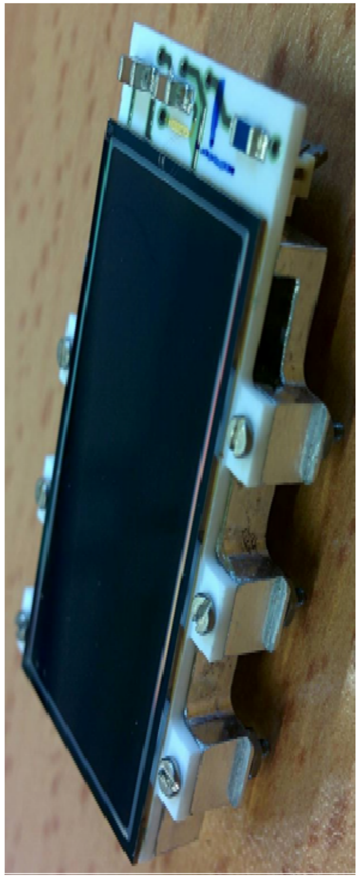


SIDDHARTINO - SDD arrangement



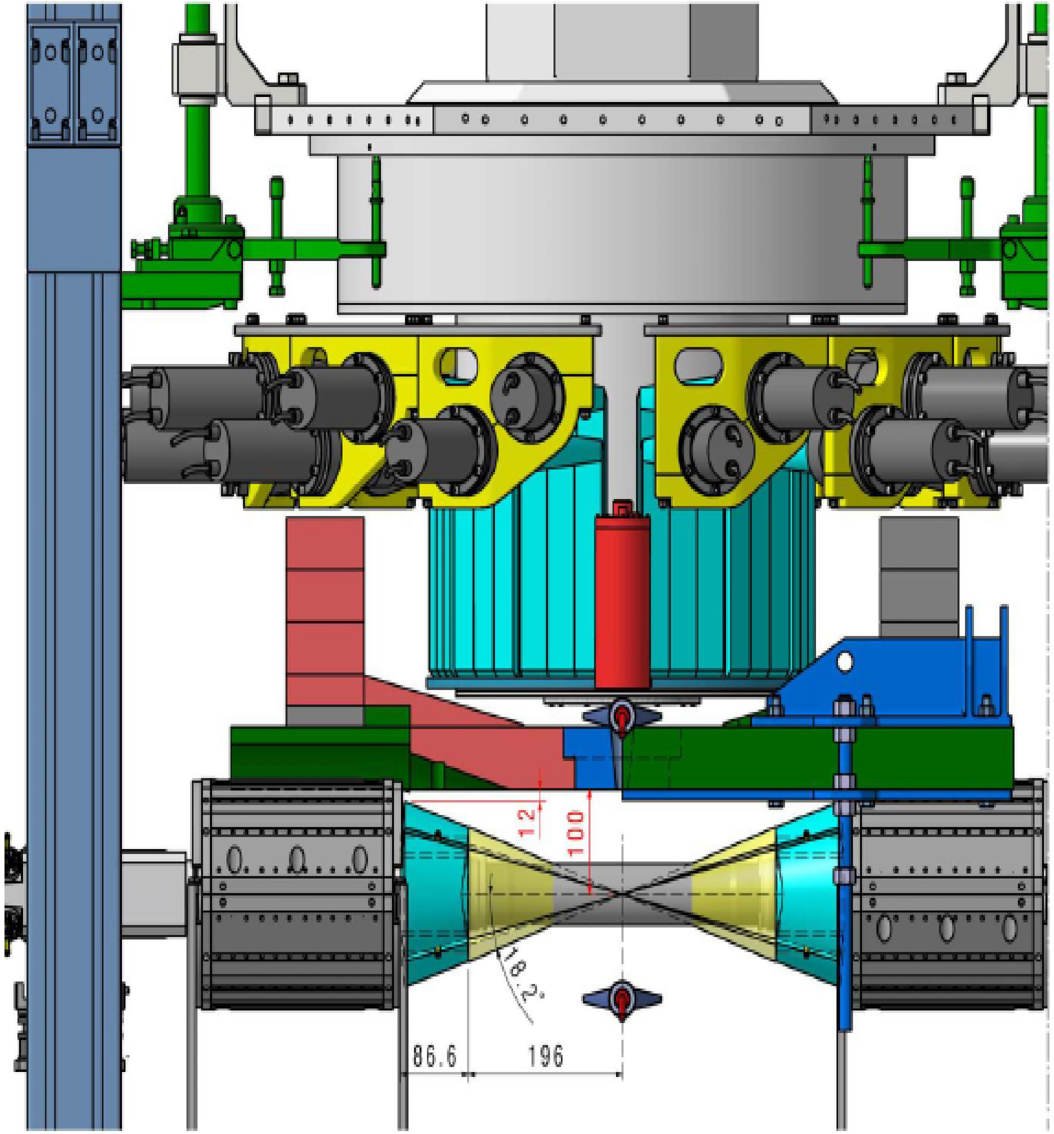


8 SDD arrays will be used



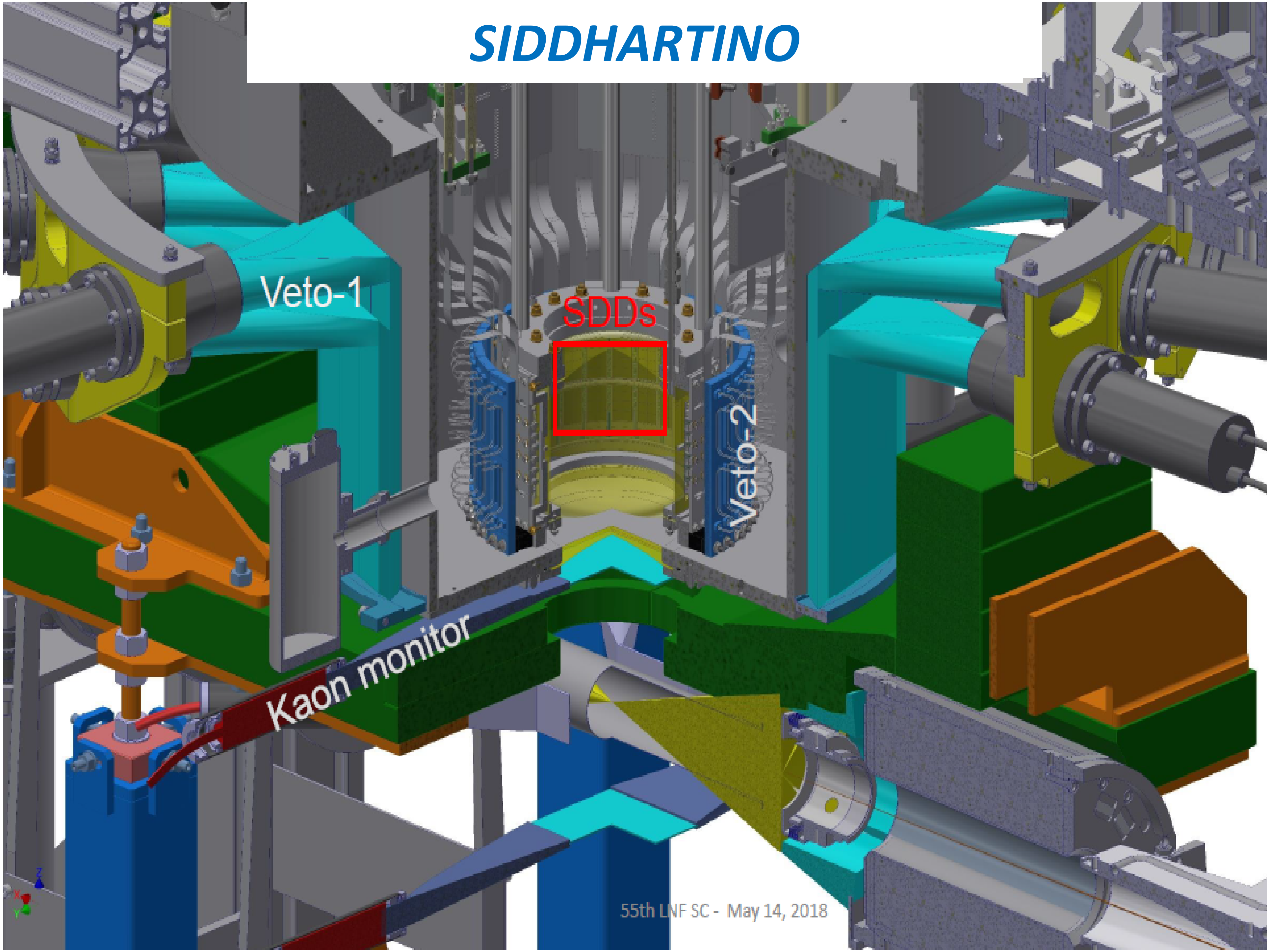
SIDDHARTINO

- with full operation of DAΦNE luminosity monitor
- setup lifted by ~100 mm
- SIDDHARTA-2 luminosity monitor
- equipped with 8 SDD arrays
- complete Veto system
- target filled with He-4 gas
  (to compare with SIDDHARTA)



verify when the DAΦNE background is equal to, or lower then in SIDDHARTA 2009

SIDDHARTINO

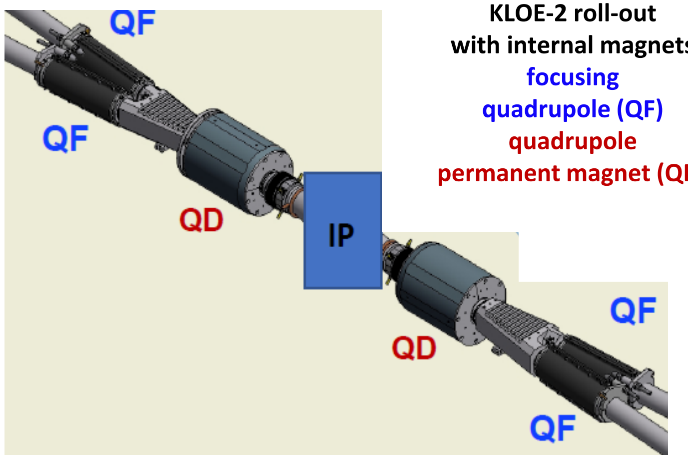


SIDDHARTINO was ready for installation on DAFNE in November 2018

SIDDHARTINO was installed on DAFNE in April 2019

(compatible with DAFNE schedule) and started the commisioning run

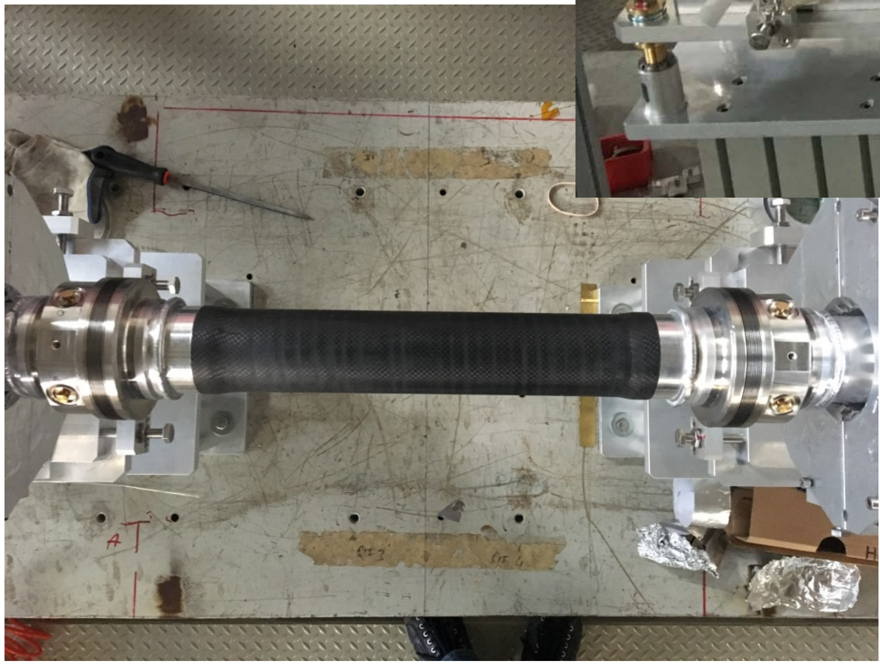
New platform near to interaction region



KLOE-2 roll-out
with internal magnets
focusing
quadrupole (QF)
quadrupole
permanent magnet (QD)

New beam pipe

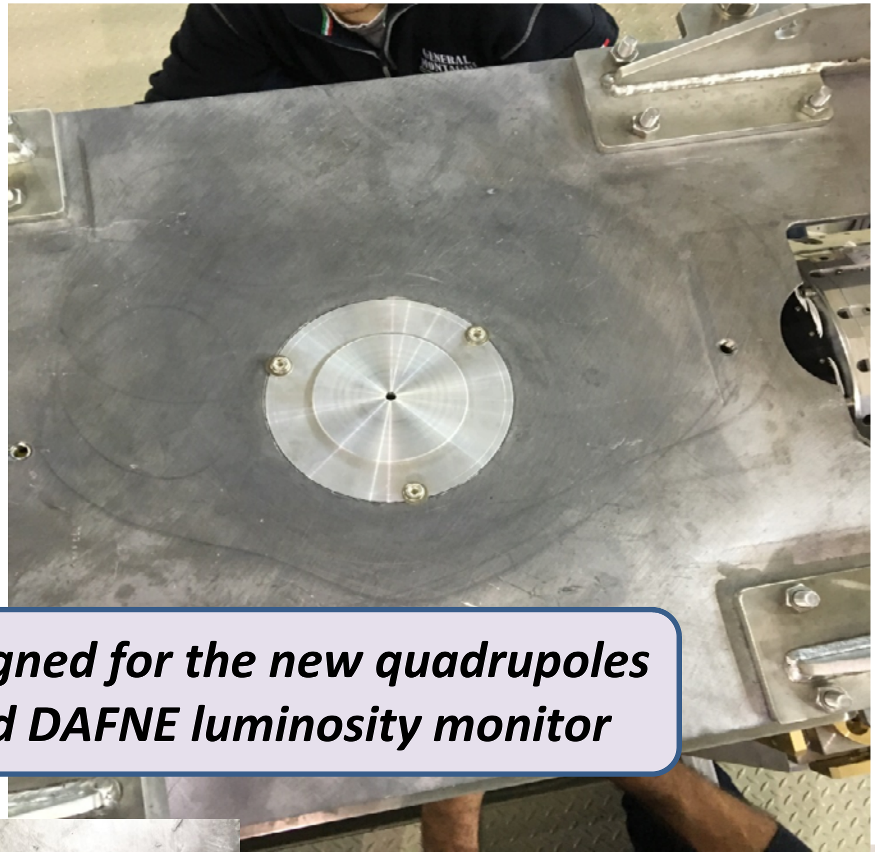
flanges removed
major source of
asynchronous background



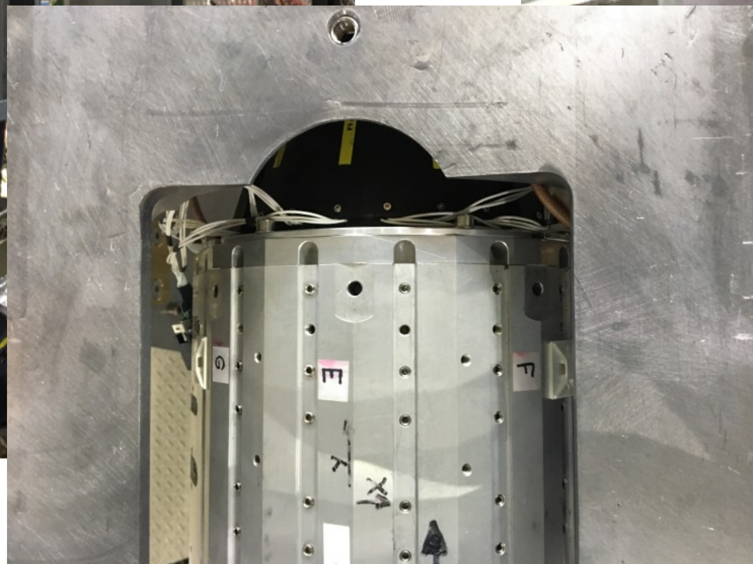
external carbon fiber jacket
ø 66 mm and thickness ~ 500 micron
internal ultra pure aluminum
ø 55mm and thickness ~ 150 micron

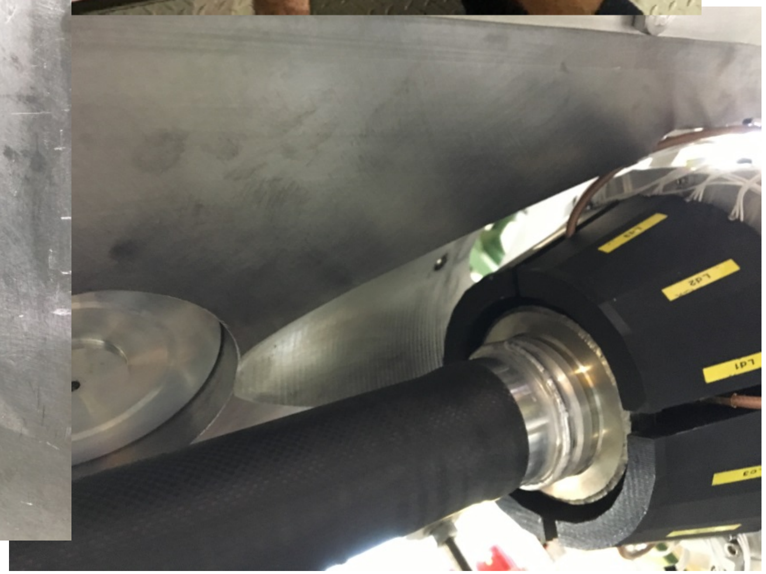
DAFNE luminosity monitor

Special SIDDHARTINO designed shielding

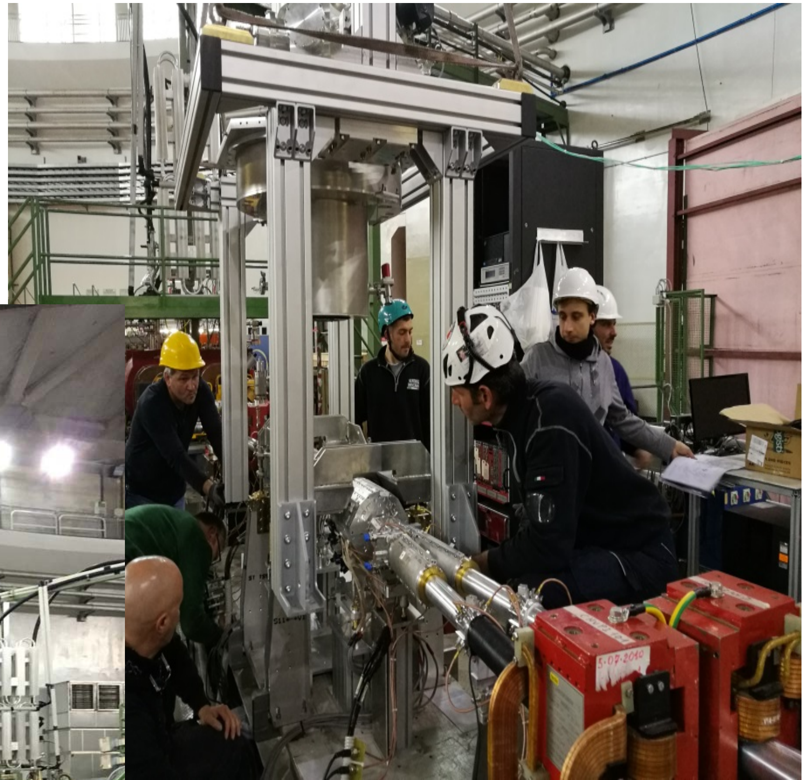


Designed for the new quadrupoles and DAFNE luminosity monitor





SIDDHARTA-2 aluminum support frame



With the help of DAFNE experts the setup and the shielding were aligned with the beam line axis

Details about the SIDDHARTINO setup

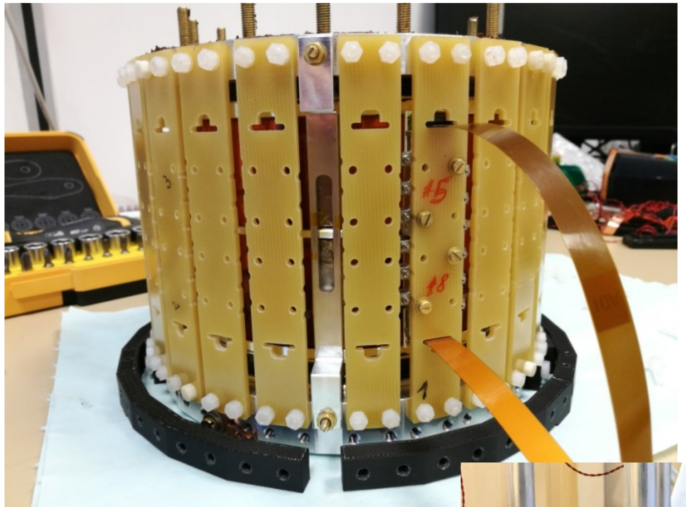
- 2-stage cooling system + CryoTiger
- Light target and Silicon Drift Detector
- Veto-2 system
- Luminosity monitor
- Veto-1 system
- Kaon Trigger system

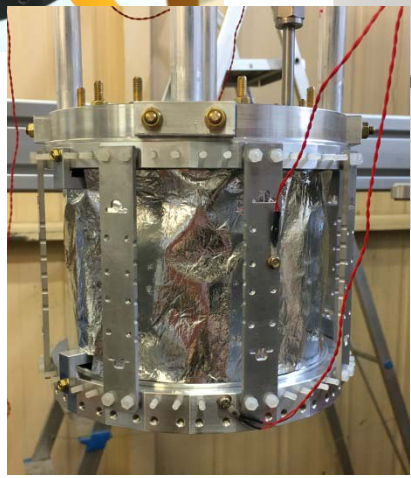
Cooling systems

add additional cooling power
to the SDD and cryogenic target

❖ **Target + SDD cooling**

Leybold MD10 – 16 W @ 20 K
target cell and SDDs are cooled
via ultra pure aluminum bars
T_{TC} = 30 K and T_{SDD} = 100 K



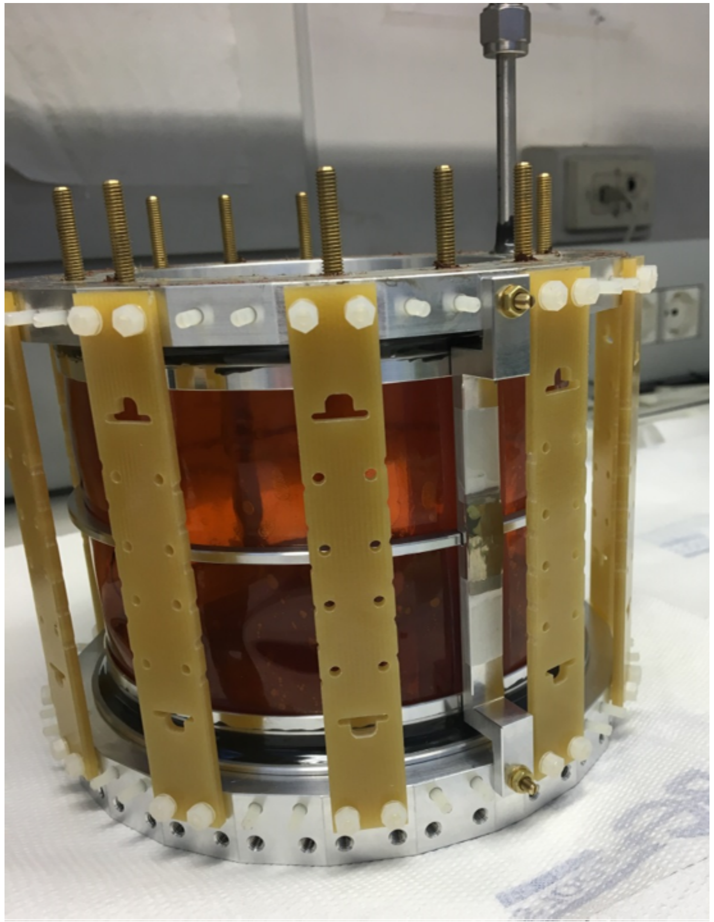


Optimization for
the SDD cooling using
different materials
epoxy, aluminum

❖ **Line driver boards**

4 CryoTiger – 30 W @ 120 K
Copper - band cooling lines
T_{LD} = 120 K

Light target and Silicon Drift Detector assembly

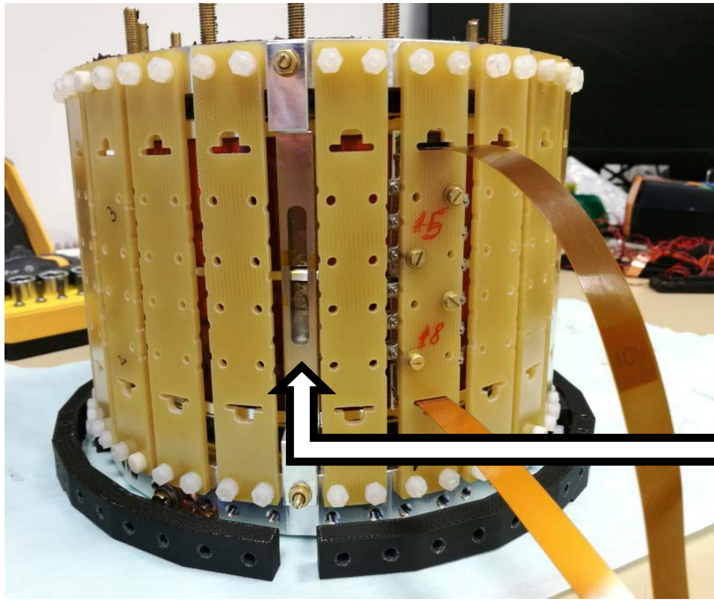


increase the target stopping power

almost double gas density with respect to SIDDHARTA (3% LHD)

SDDs placed 5 mm from the target wall

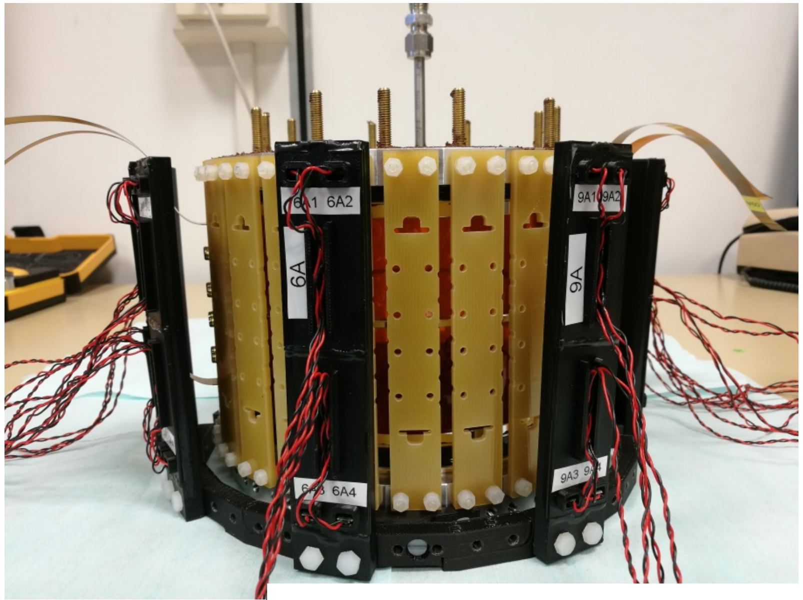
Target cell wall is made of a 2-Kapton layer structure (75 µm + 75 µm + Araldit)

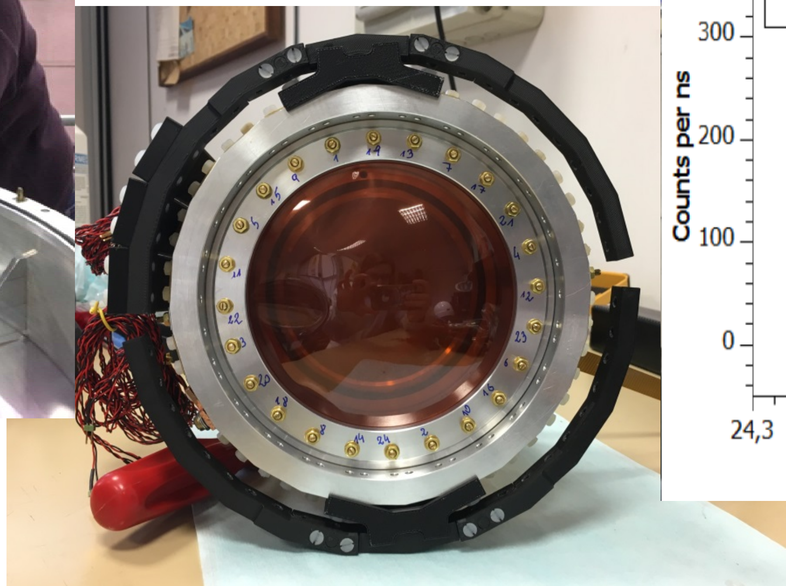


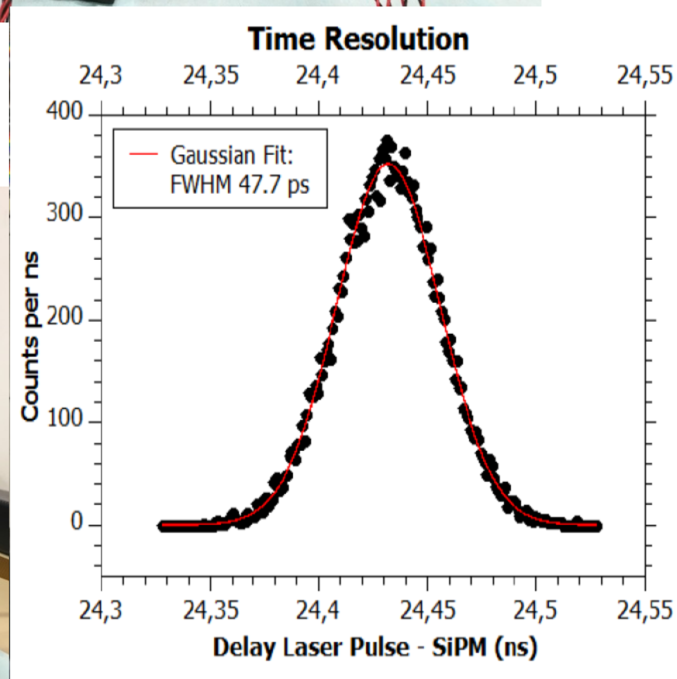
calibration foils inserted near to the SDD are activated by the X-ray tubes

The veto-2 system:

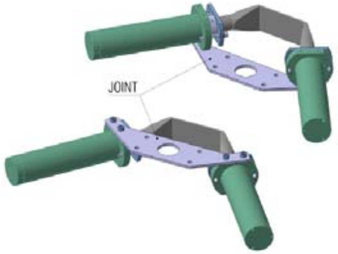
an inner ring of scintillator tiles (SciTiles) placed as close as possible behind the SDDs for charge particle tracking



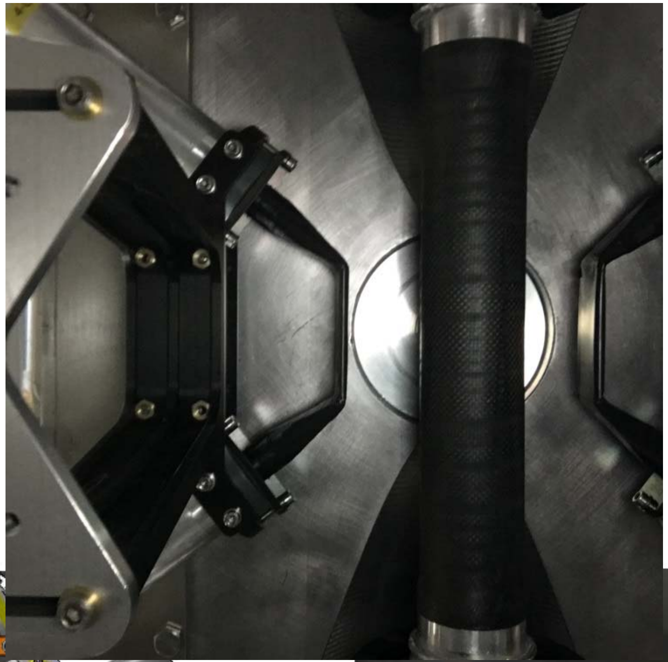




SIDDHARTA-2 Luminosity monitor



- 2 pairs of scintillator: 80x40x2 mm^3
  Scionix EJ-200
- R4998 PMTs Hamamatsu
- light-guides
- aluminum tube + µMetal (0.1mm)
- reflective and light proof foil
- optical cement



Fast

Needs:

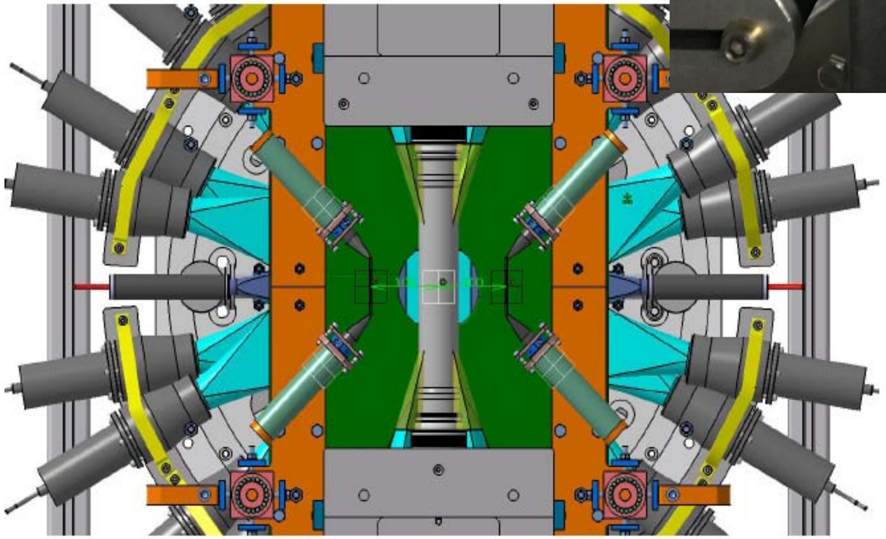
- Fast detectors & FEE
- Real time acquisition
- Accidental rate << Signal rate

Allows:

- Collision optimization
- Machine feedback

Luminosity ~ 10^{32} cm^{-2} s^{-1}

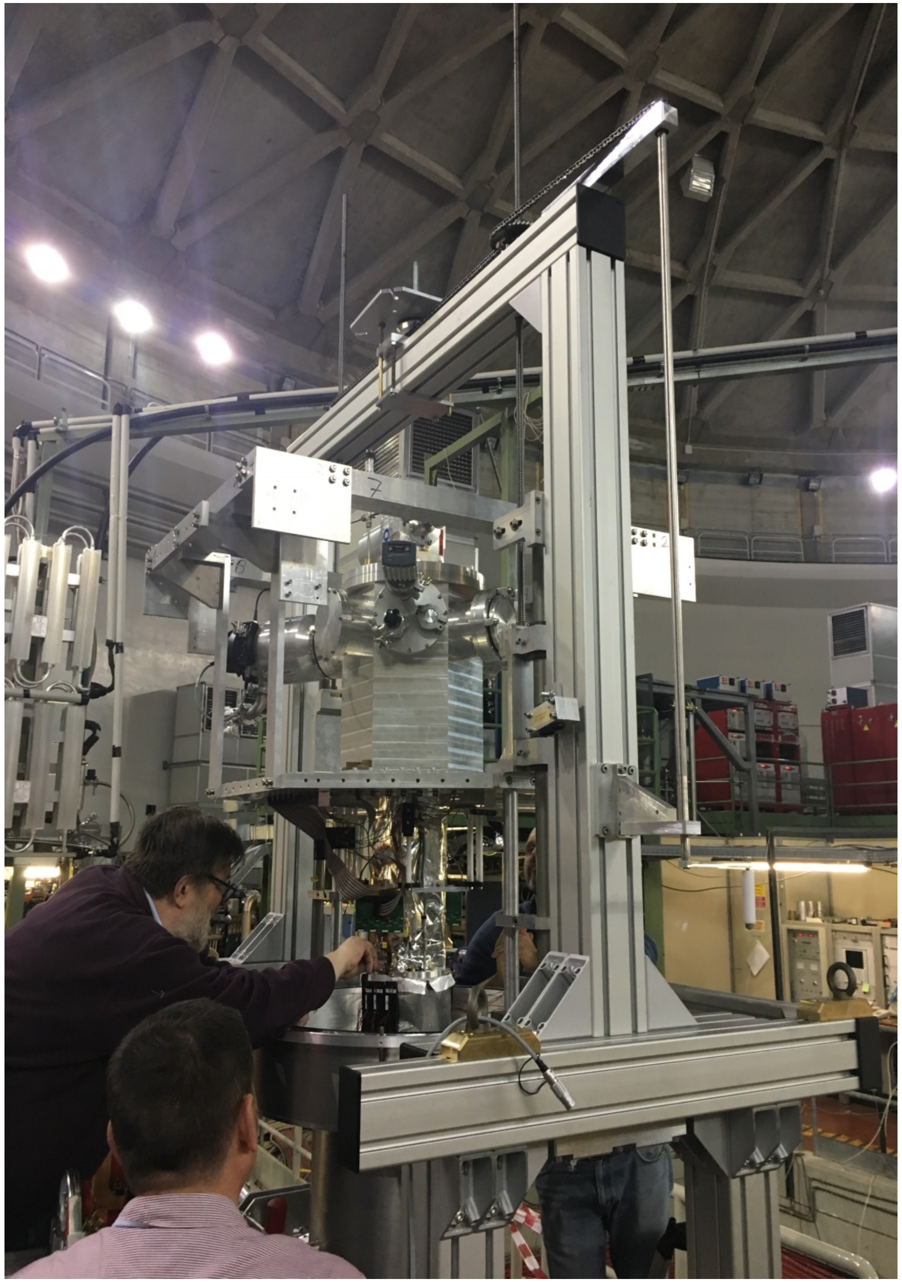
Rate ~ 50 - 60 Hz



SIDDHARTA-2
Interaction regions bottom view



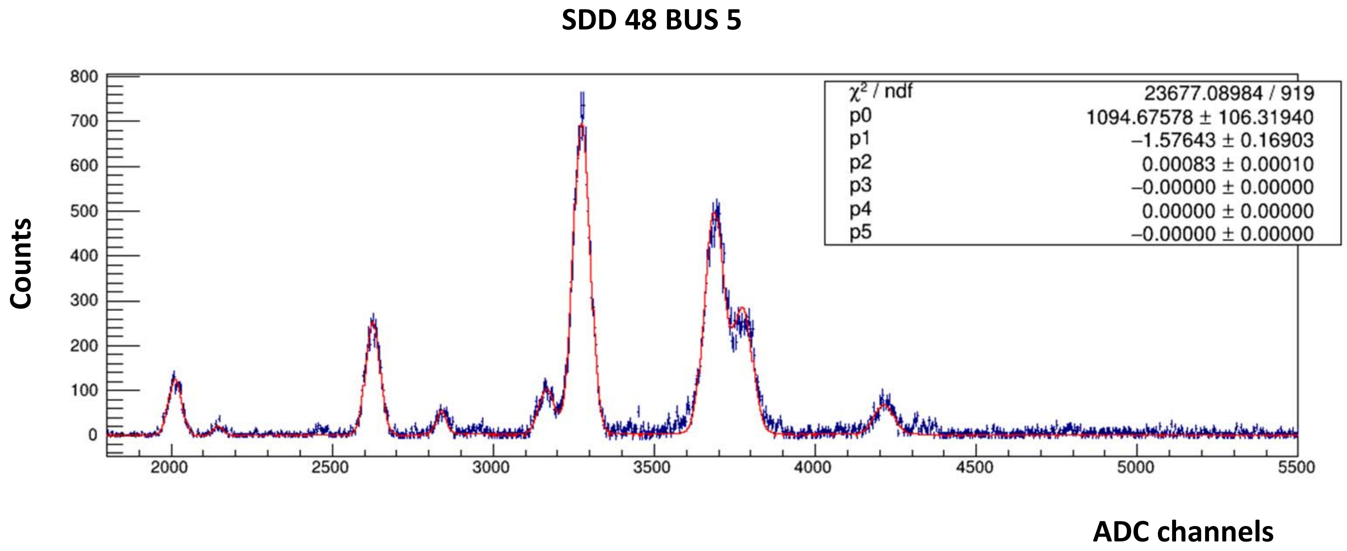
… precise adjustments …

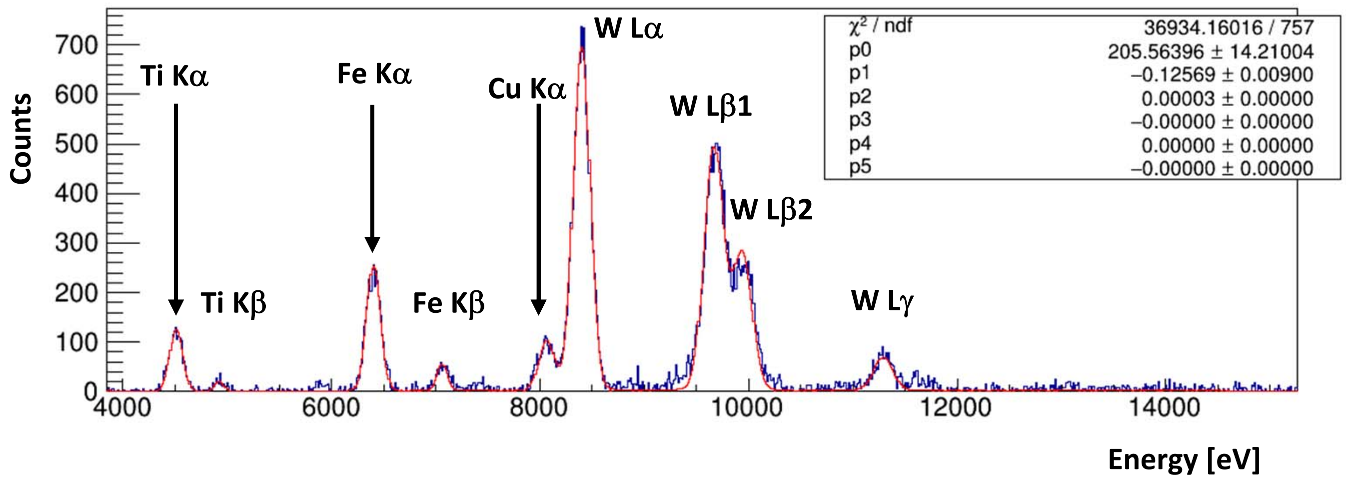


… internal components

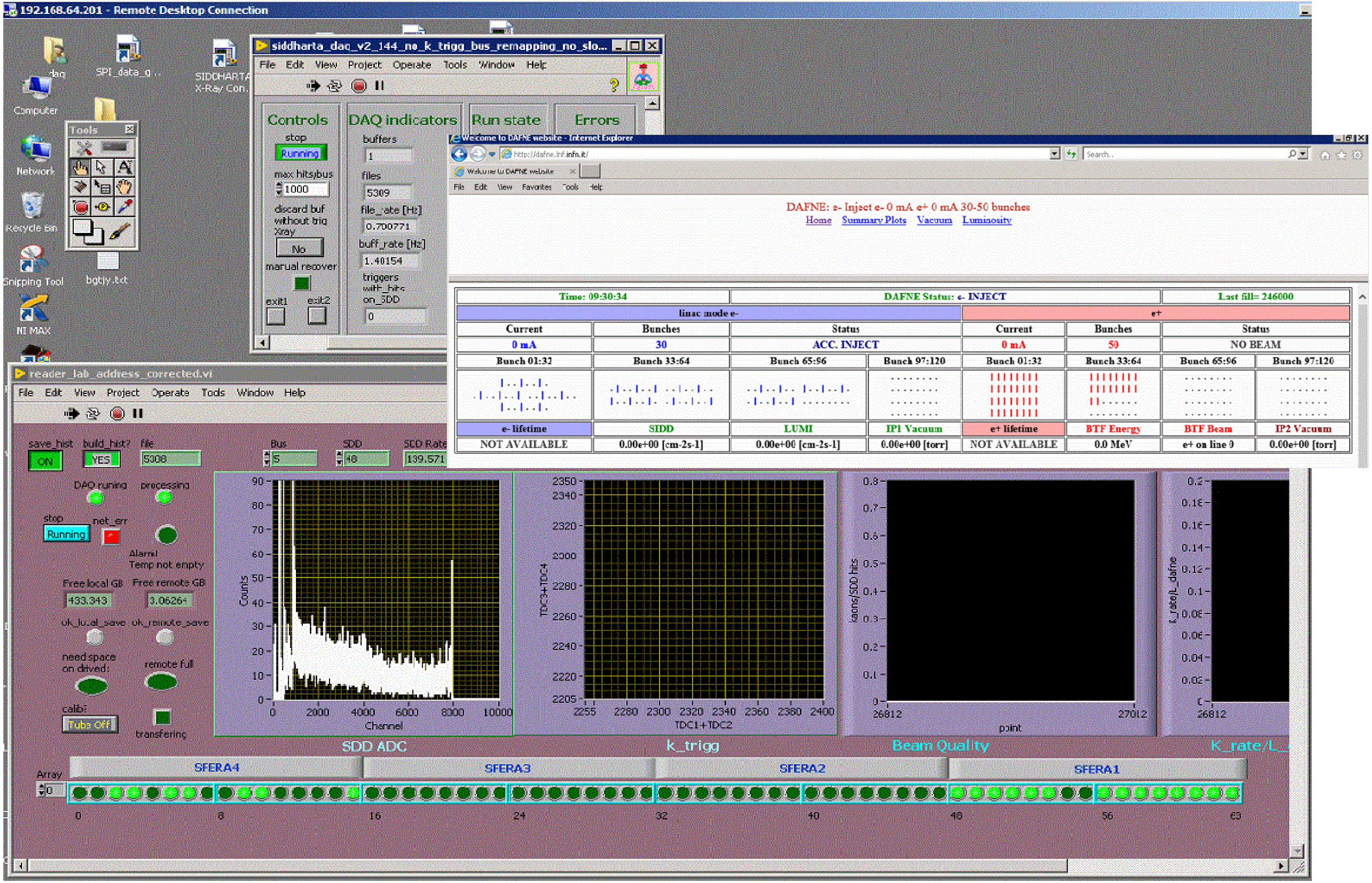
SIDDHARTINO installed on DAΦNE (17 April 2019)

Calibration of SDDs with the x-ray tube in DAΦNE

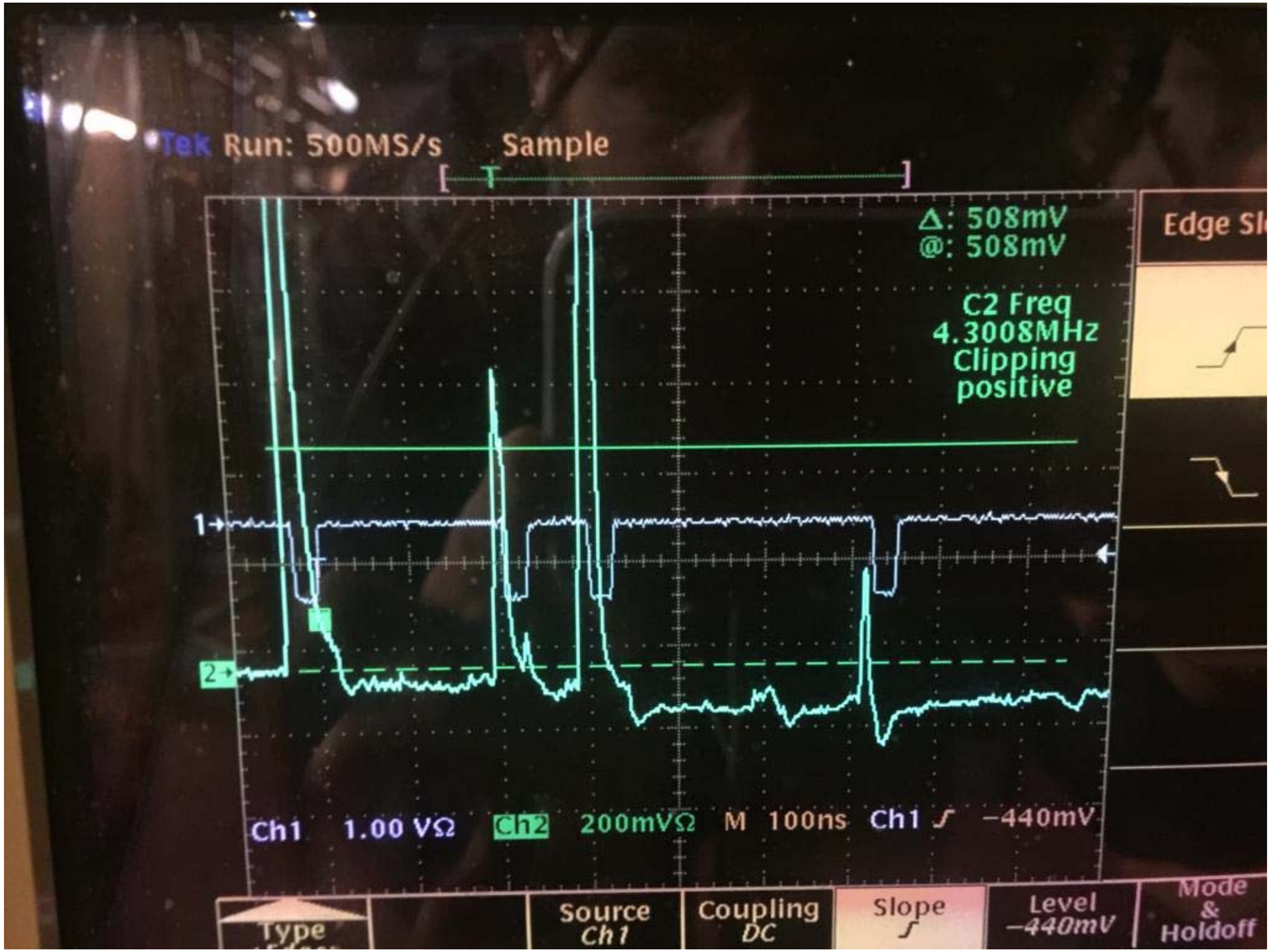




SDD signals during circulating beam in DAΦNE

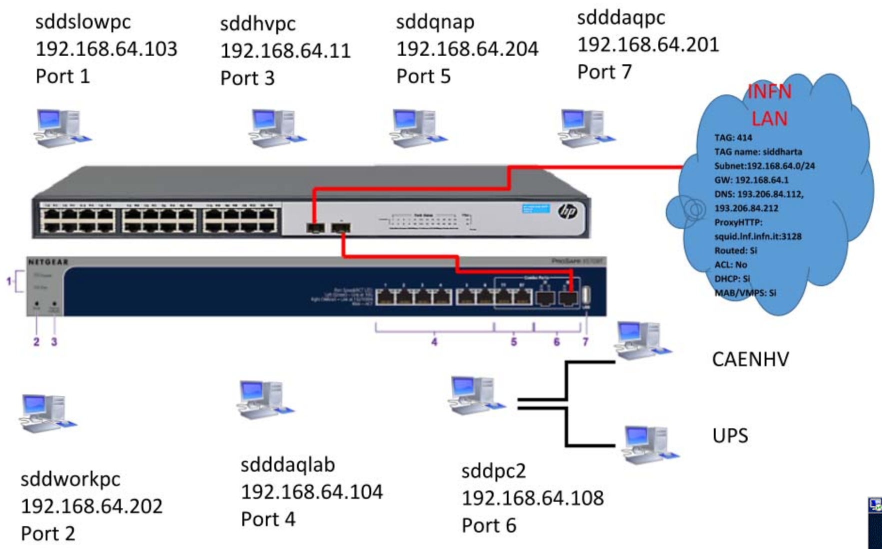


First signals from the Luminosity monitor with beam



optimization with the beam in progress

SIDDHARTA-2 access infrastructures



- dedicated VLAN network
- optical fiber connection with DAΦNE and LNF computing services
- dedicated file storage server for data (NAS)
- 10G interconnection between our computers
- online control and monitoring of our setup parameters (target pressure, SDD cooling, remote control of x-ray tubes, etc.)

Data exchange protocol with DAΦNE team

- beam conditions measured by our detectors – veto system (very useful information for machine/background optimization)
- luminosity parameters (kaon rates, estimation of integrated luminosity, etc.)

SIDDHARTA-2 schedule

We are starting:

<u>Phase 1</u>:

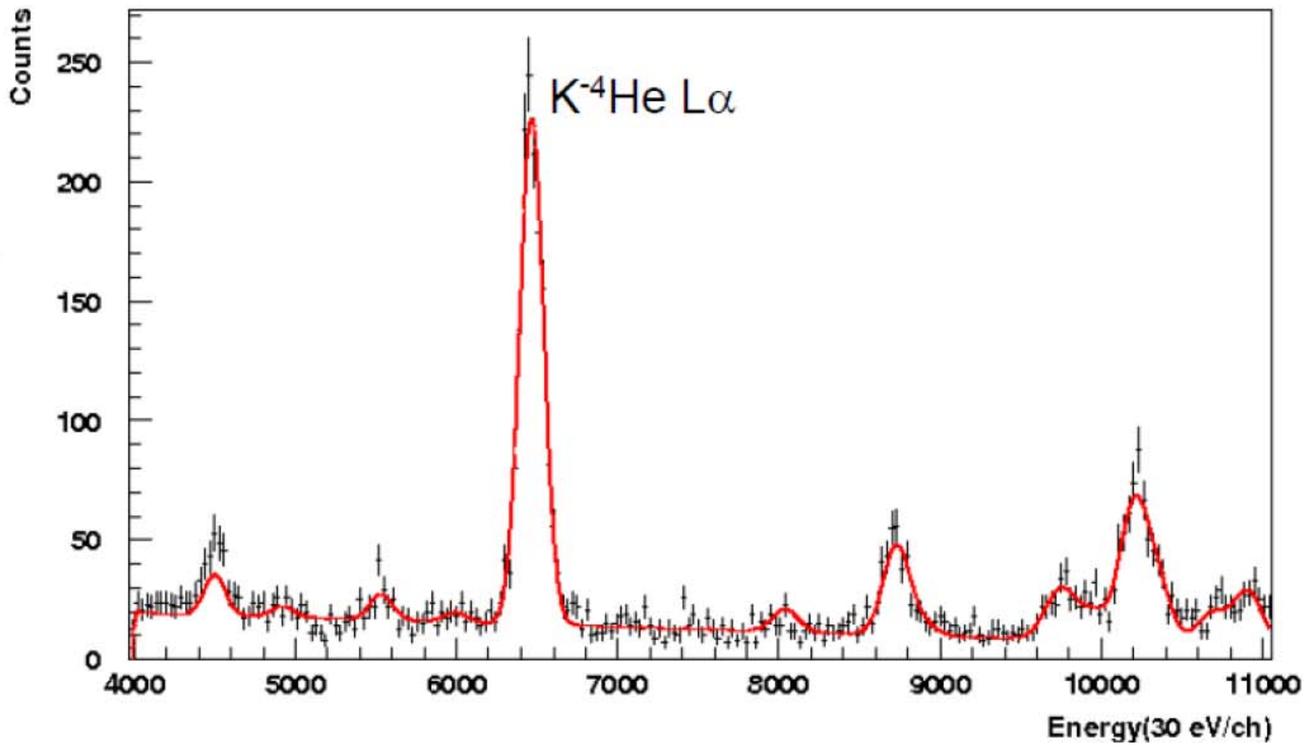
during the commissioning of DAΦNE

SIDDHARTINO K-^{4}He (8 SDD arrays)

May 2019 – 1 November 2019 (?)

SIDDHARTINO – K-^{4}He test measurement

kaonic helium-4
about 28 pb^{-1}
S/B 10:1



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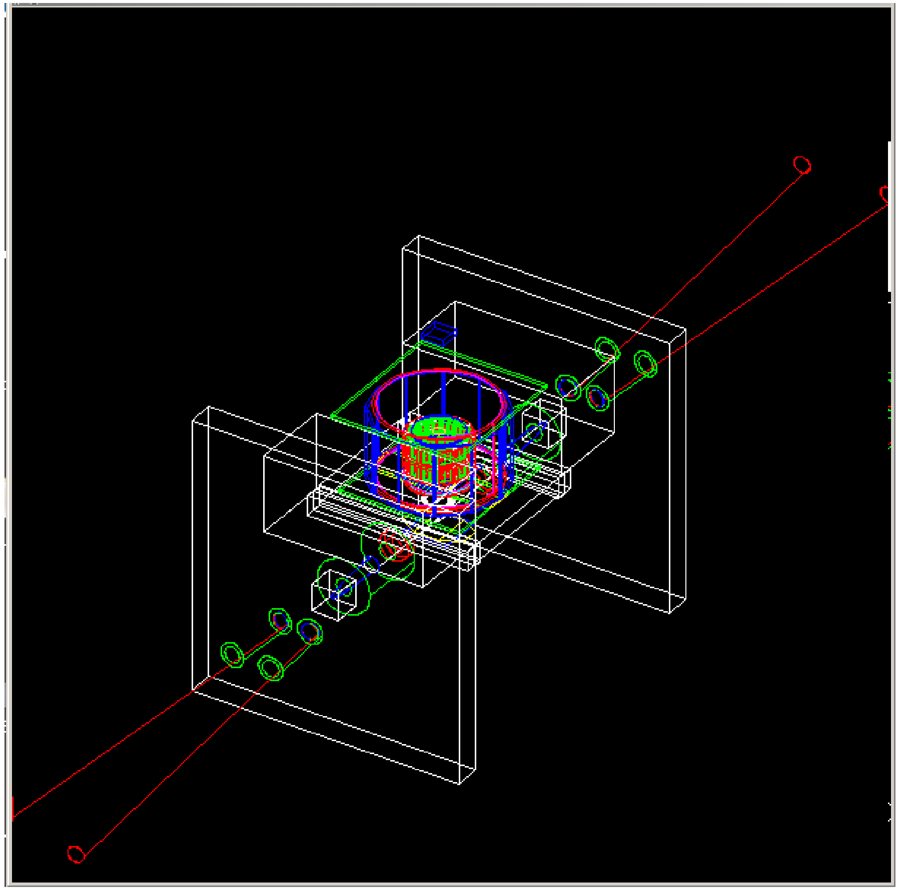
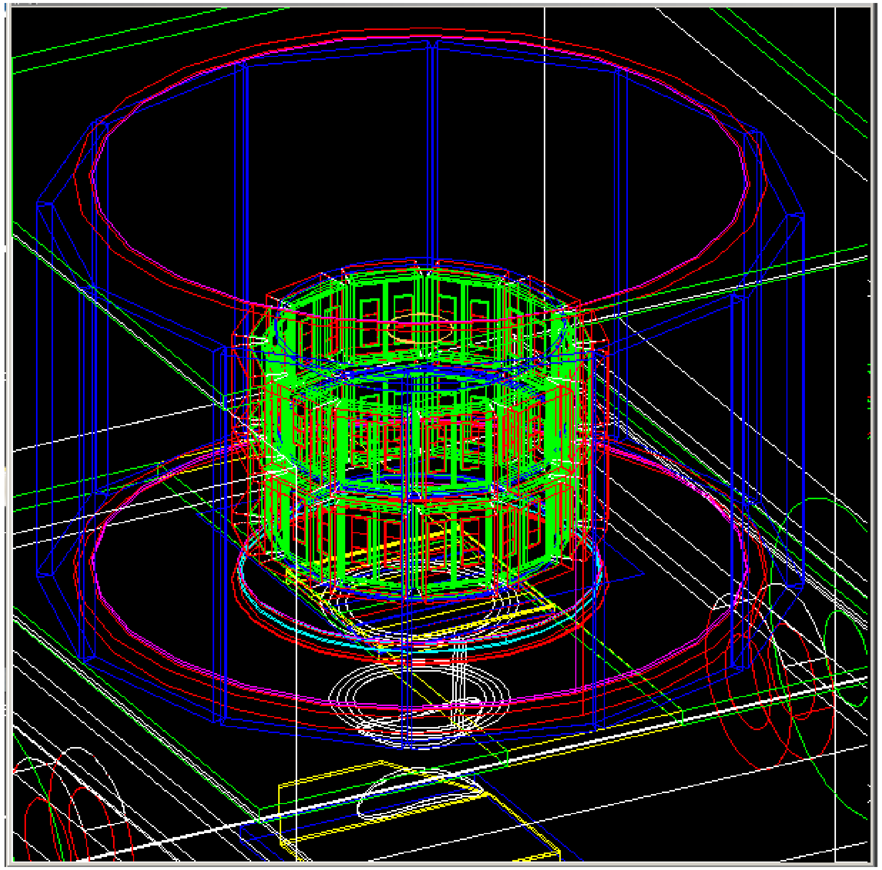
SciVerse ScienceDirect
Nuclear Physics A 914 (2013) 305–309
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

Monte Carlo simulations

Simulation in the framework of GEANT4

Machine conditions – similar with SIDDHARTA 2009

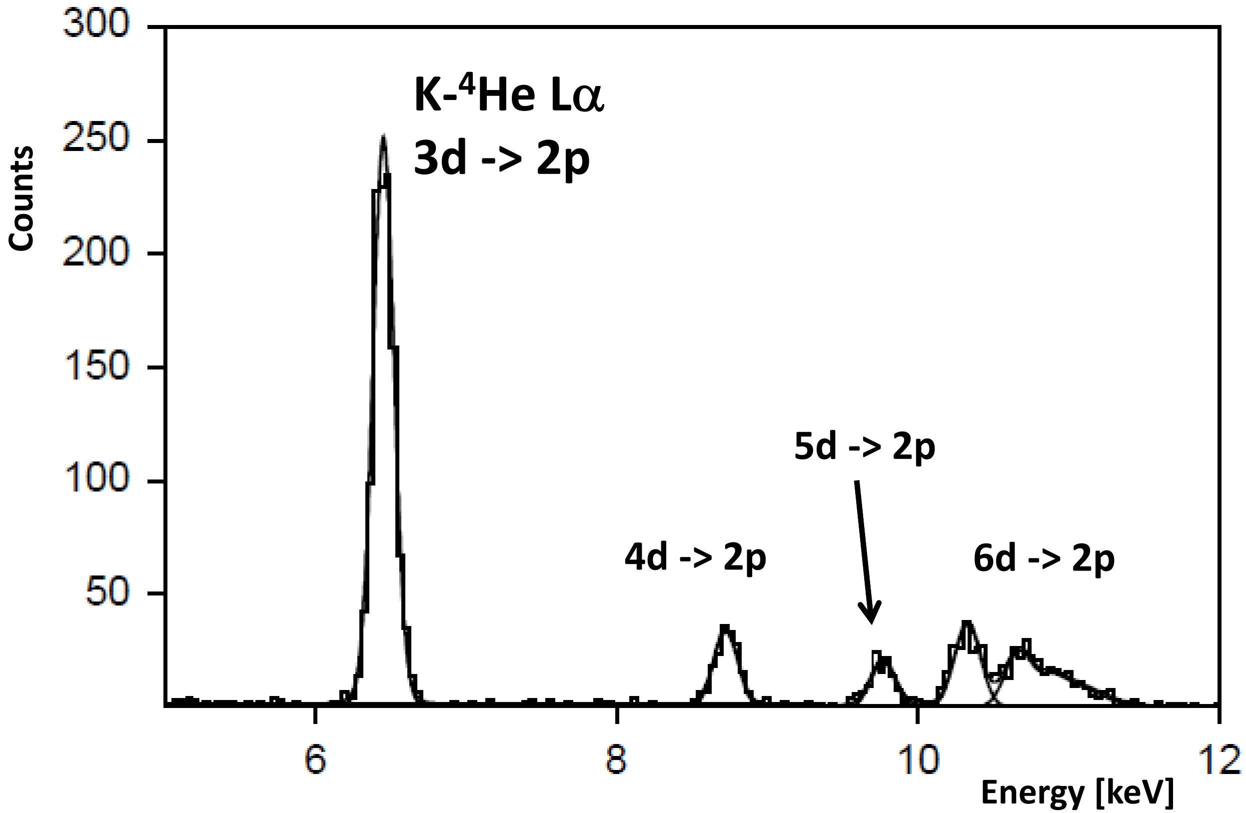




Kaonic Helium-4 SIDDHARTINO expected spectrum for about 50 pb^{-1}

(one week of data taking in SIDDHARTA-like conditions)

About 1000 events in La peak, S/B > 100/1
Position precision : 6.452 +- 0.002 (stat) keV



SIDDHARTA-2 schedule

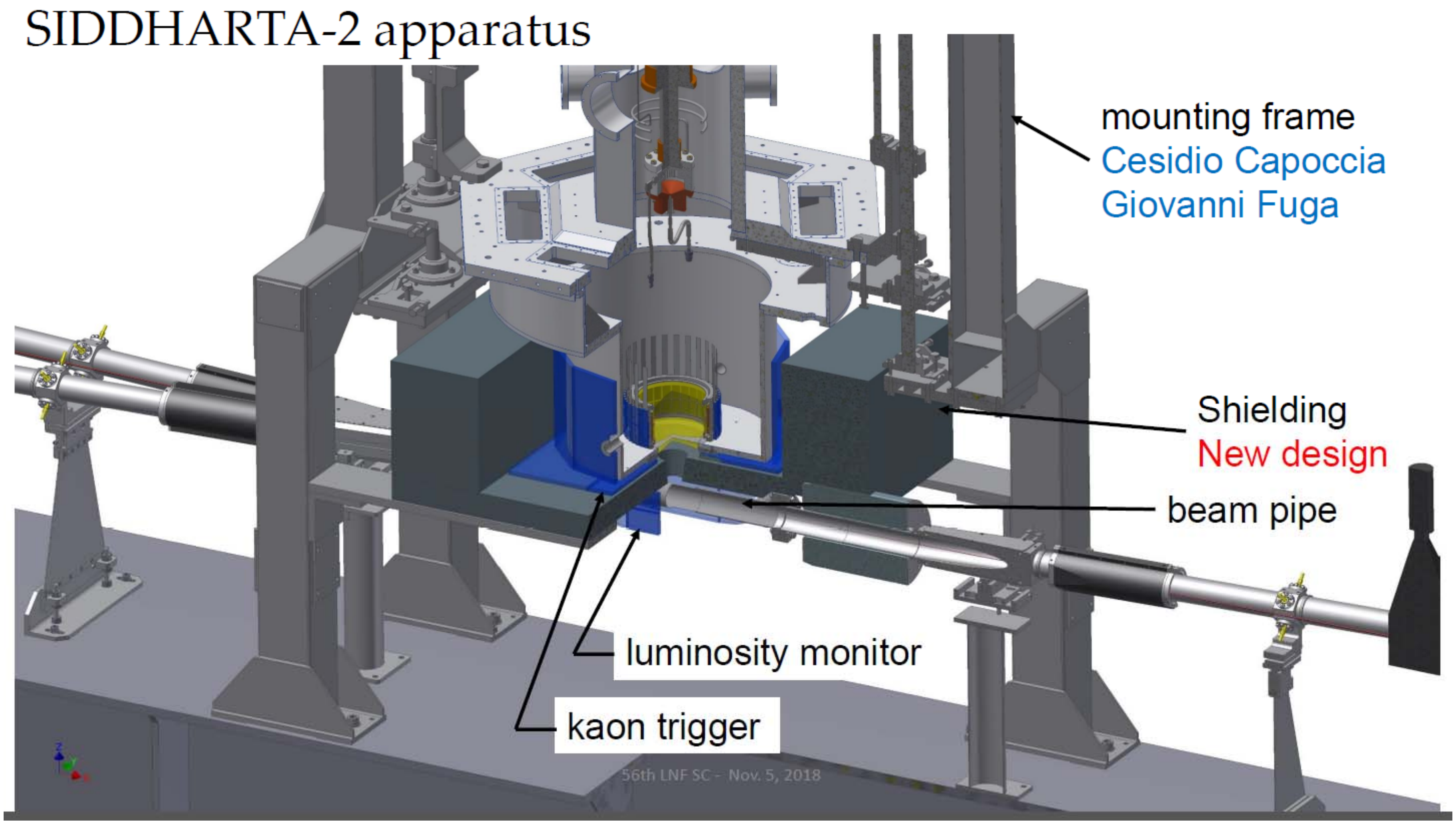
When Phase 1 is over
(basically when S/B for K-^{4}He is about 100/1)
we go for:

Phase 2:

SIDDHARTA-2 run:
we will install all the SDDs of SIDDHARTA-2
(48 SDD arrays) and start the *kaonic deuterium measurement* with a run for 800 pb^{-1}

(in addition/parallel feasibility tests for future measurements)

SIDDHARTA-2 setup



Feasibility tests for future measurements

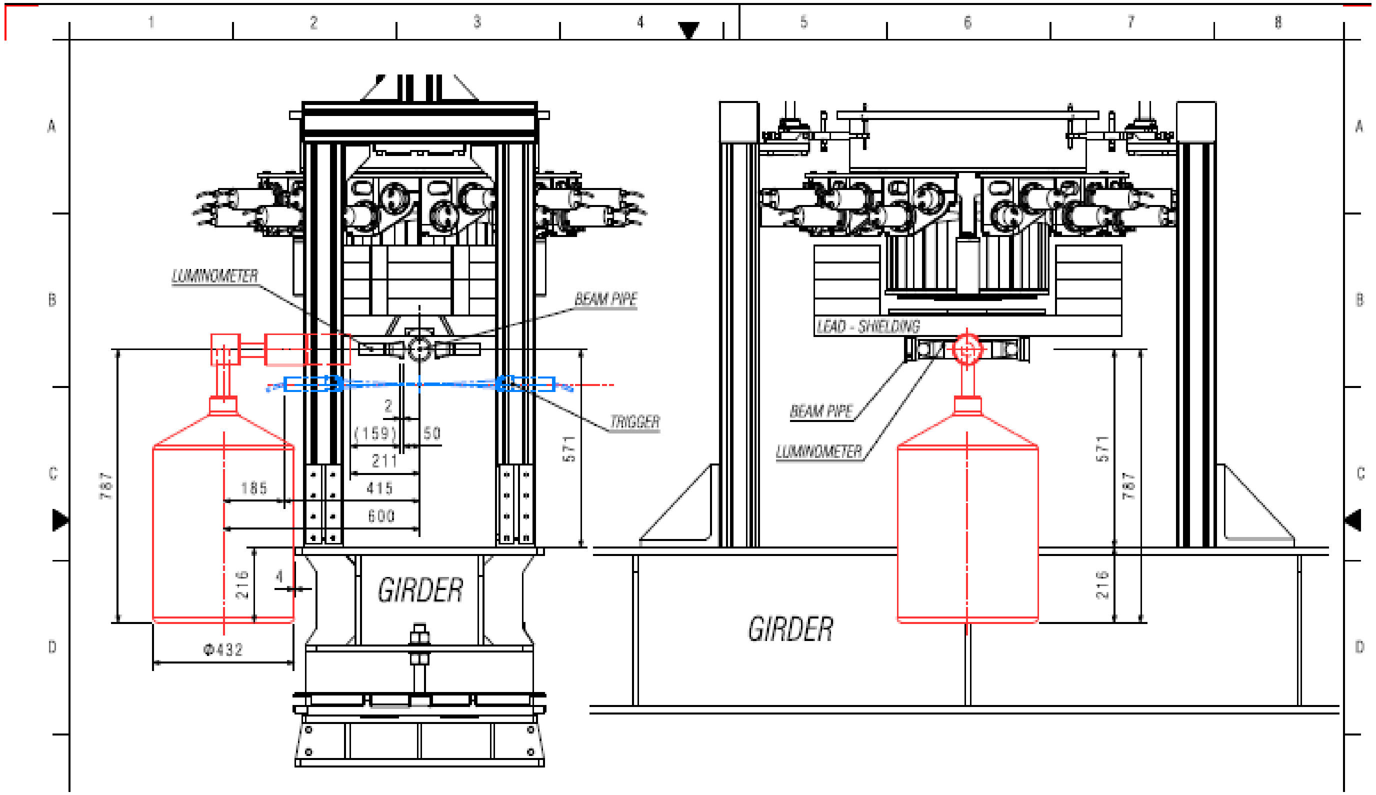
GEKA **proposal presented at DAΦNE as Open Accelerator Test Facility, LNF December 17, 2018**

Precision measurement of X and gamma-ray transitions in selected Kaonic Atoms with High Purity Germanium detectors

- **measurement of kaonic atoms on selected solid targets (Tungsten, lead, etc..) using HPGe**
- **100 pb^{-1} per data point**

Simulations – work in progress

- **estimate background – from the beam and from the kaon absorption and to determine optimal position of the detector and target (+ target size) and shielding .**
- **estimate required time for the measurements.**
- **Not all parameters are known – test measurements with the beam is required.**

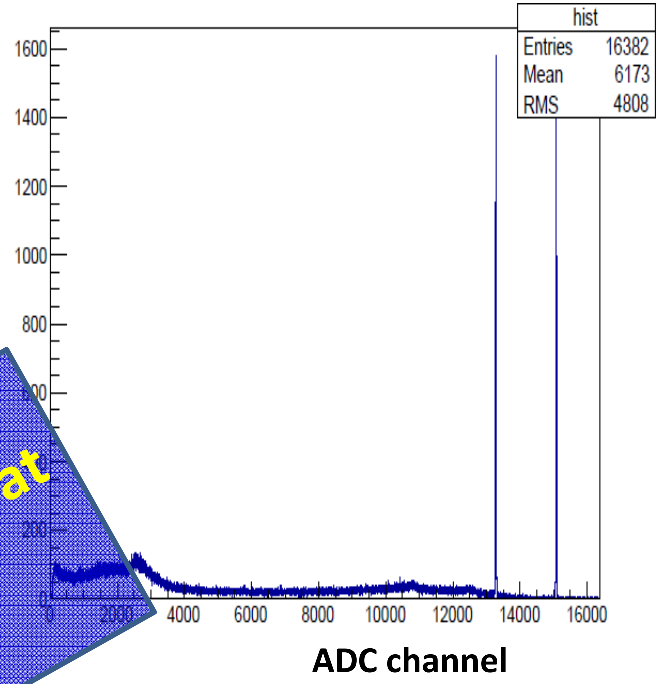


HPGe active detector diameter 60 mm, height 60 mm.
Signal from the luminometer (80x40x2 mm^3) as a trigger for HPGe detector.

HPGe LABORATORY TESTS & ANALOGUE ELECTRONICS

Croatian Science Foundation - Project 8570

Signal from spectroscopy amplifier

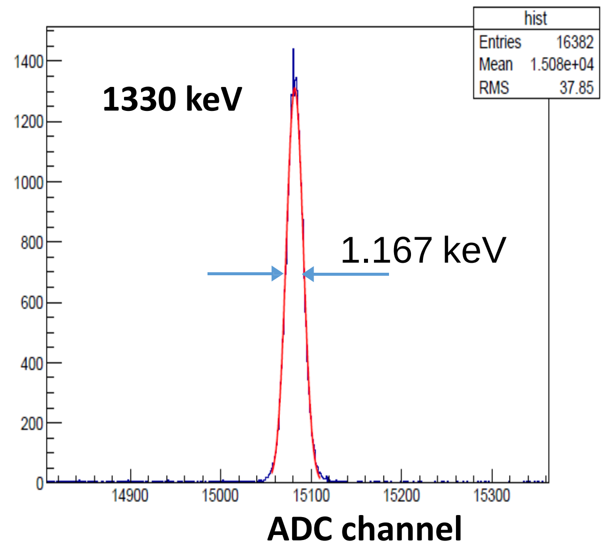


^{133}Ba and ^{60}Co spectra

Resolutions with fast readout:

0.87[illegible] keV	**at**	**81 keV**
1.106 keV	**at**	**302.9 keV**
1.143 keV	**at**	**356 keV**
1.167 keV	**at**	**1330 keV**

A Report will be presented at the next SC meetings



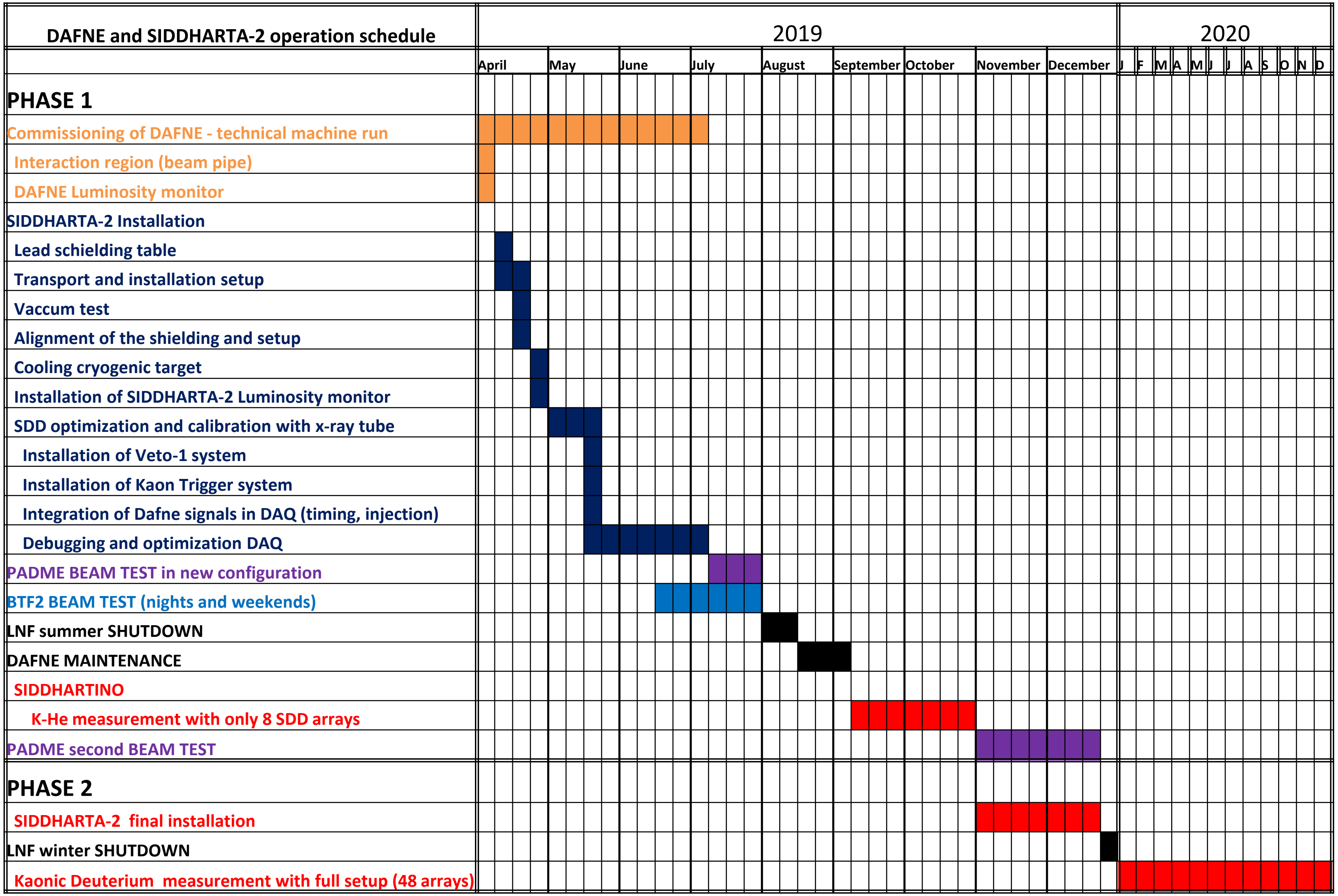
CAEN spectroscopy amplifier N968
Canberra Multiport II
Canberra Genius DAQ + analysis

Setup is ready for transport and installation in DAΦNE!


Special thanks to Cesidio Capoccia and
Giovanni Fuga (we dedicate this talk to him),
to the accelerator, research and technical
divisions,
and in particular to the DAFNE staff and
to the LNF Director
Thank you!

Spares

Strategy and Time Schedule



56th MEETING OF THE LNF SCIENTIFIC Committee – 5-6/11/2018
Recommendations:

- *The SC encourages the SIDDHARTA-2 and DAPHNE teams to maintain the tight collaboration towards achieving optimal beam conditions for the test run before summer 2019.*

- *The use of the SIDDHARTA-2 set-up for parasitic tests is a welcome initiative, which should be properly analyzed to discard possible unwanted interferences with the experiment. A document describing the details of these tests should be provided.*

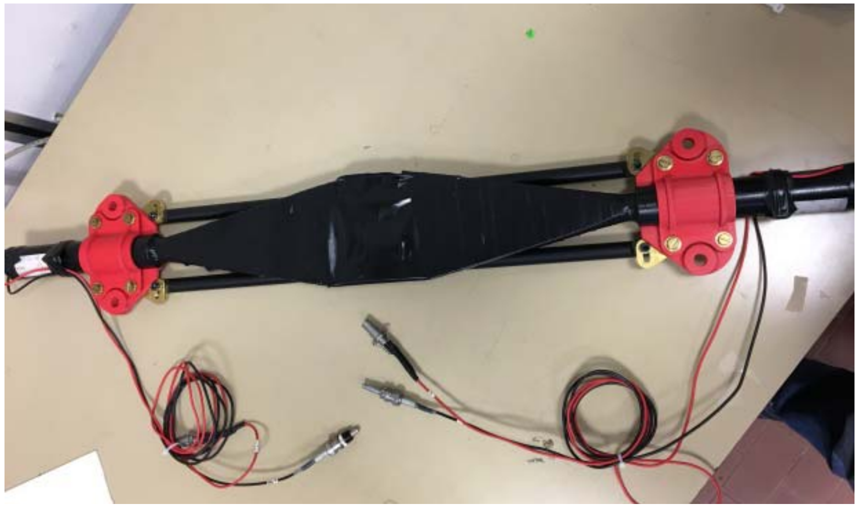
The veto-1 system

outer barrel of scintillators, acting as a gas stopping detector (and, possibly, as active shielding) - to identify the products of K- absorption on gas nuclei, characterized by a long moderation time (4-5 ns).

The trigger system

The basic change in the trigger configuration:

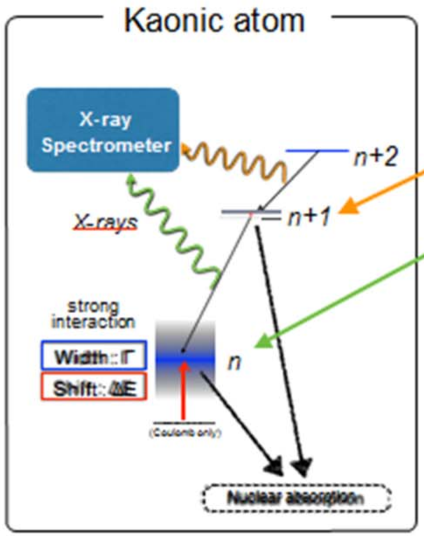
- **a new shape for the upper scintillator of the kaon monitor**
- **its placement just below the kaon entrance window, above the shielding**



Feasibility tests for future measurements – (II)

WIKAMP proposal presented at DAFNE as Open Accelerator Test Facility, LNF December 17, 2018

Investigation of single-and multi-nucleon processes of antikaons in nuclei by simultaneous measurements of upper and lower levels transition widths of selected kaonic atoms with ultra-high energy resolution detectors



Simultaneous measurement of the widths of the radiative transitions occurring from upper and lower levels from the same element

common density distribution
-> removing the density uncertainties

providing fundamental information on **single-** and **multi-nucleon** processes of anti-K in nuclei

Very different radial dependences of the 1N and 2N terms

rms radii of various terms of the K^--nucleus potential (in fm). r_m is the rms radius of the nucleus.

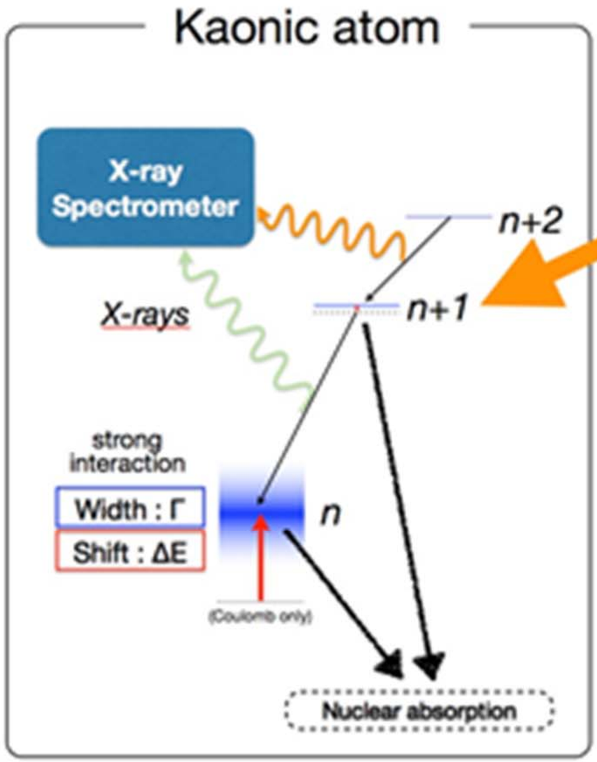
	r_m	Re(full)	Re(1N)	Re(mN)	Im(full)	Im(1N)	Im(mN)
Ni	3.72	3.34	3.82	2.86	3.73	4.46	3.12
Pb	5.56	5.21	5.71	4.78	5.46	6.23	5.00
			1N	mN		1N	mN

E. Friedman, S. Okada, Nucl. Phys. A915 (2013) 170-178

DAFNE-TF workshop - Dec. 17, 2018 15

- ❖ kaon single-and multi-nucleon processes **using VOXES / TES**
  300 pb-1 for 3 data points
- ❖ determination of the charged kaon mass (K-) **using VOXES / TES**
  300 pb-1 per data point

CHALLENGE WITH NEW X-RAY DETECTORS



determined so far only with indirect measurement
(with relative yields of the upper to lower level transitions)

No direct measurement
due to quite small strong-interaction widths

⇩

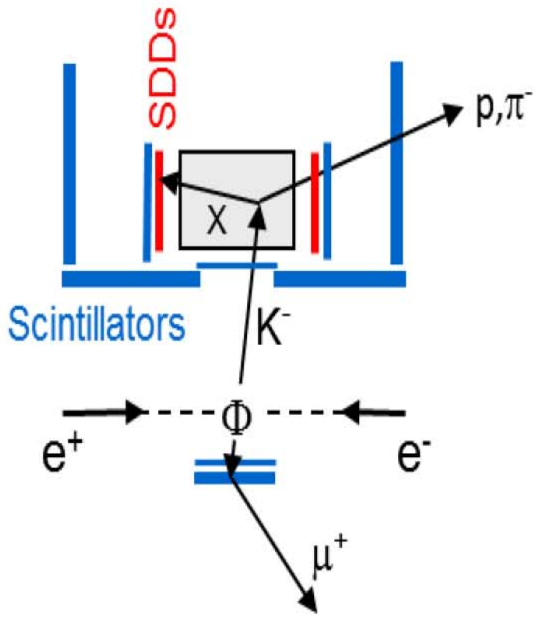
Breakthrough with ultra-high resolution
X-ray spectrometers :

(1) Superconducting Transition Edge Sensor Microcalorimeters

(2) Pyrolitic Graphite mosaic crystals (HAPG or HOPG)

The Monte Carlo simualtions

The following main improvements are included in the final GEANT 4 simulation for the SIDDHARTA-2 experiment at DAΦNE, LNF-INFN:



- Changed geometry and gas-density: closer distance between IP and target cell, doubled gas density (3%), distance centre to SDDs
- Trigger system: upper kaon monitor (smaller then entrance window) DIRECTLY in front of target
- Added kaon live time detector for K+- discrimination: identification of the K+ by (τ_K = 12.8 ns)
- Veto-1 and veto-2 system
- SDDs operation at lower temperature to improve timing resolution (~ 400 ns)

S/B =1/100 in SIDDHARTA ➡ **S/B =1/3 in SIDDHARTA-2**

SIDDHARTA-2 future perspectives

- Feasibility studies in parallel with SIDDHARTA-2 (HPGe and VOXES)
- Plans for the extension of the scientific programme (abstracts for Dec.17, 2018)
  - Kaon mass - precision measurement at a level < 7 keV
  - Kaonic helium transitions to the 1s level

- Other light kaonic atoms (K^-O, K^-C,…) TES → Japan
- 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 ?)

SIDDHARTA-2 winning cards

SIDDHARTA-2 relies on a major upgrade (w.r.t. SIDDHARTA)

of the detectors systems and of the cryogenic target

SIDDHARTA-2 builds up based on a series of improvements with respect to the previous SIDDHARTA setup aiming to dramatically:

- increase the S/B ratio and also the signal rate:

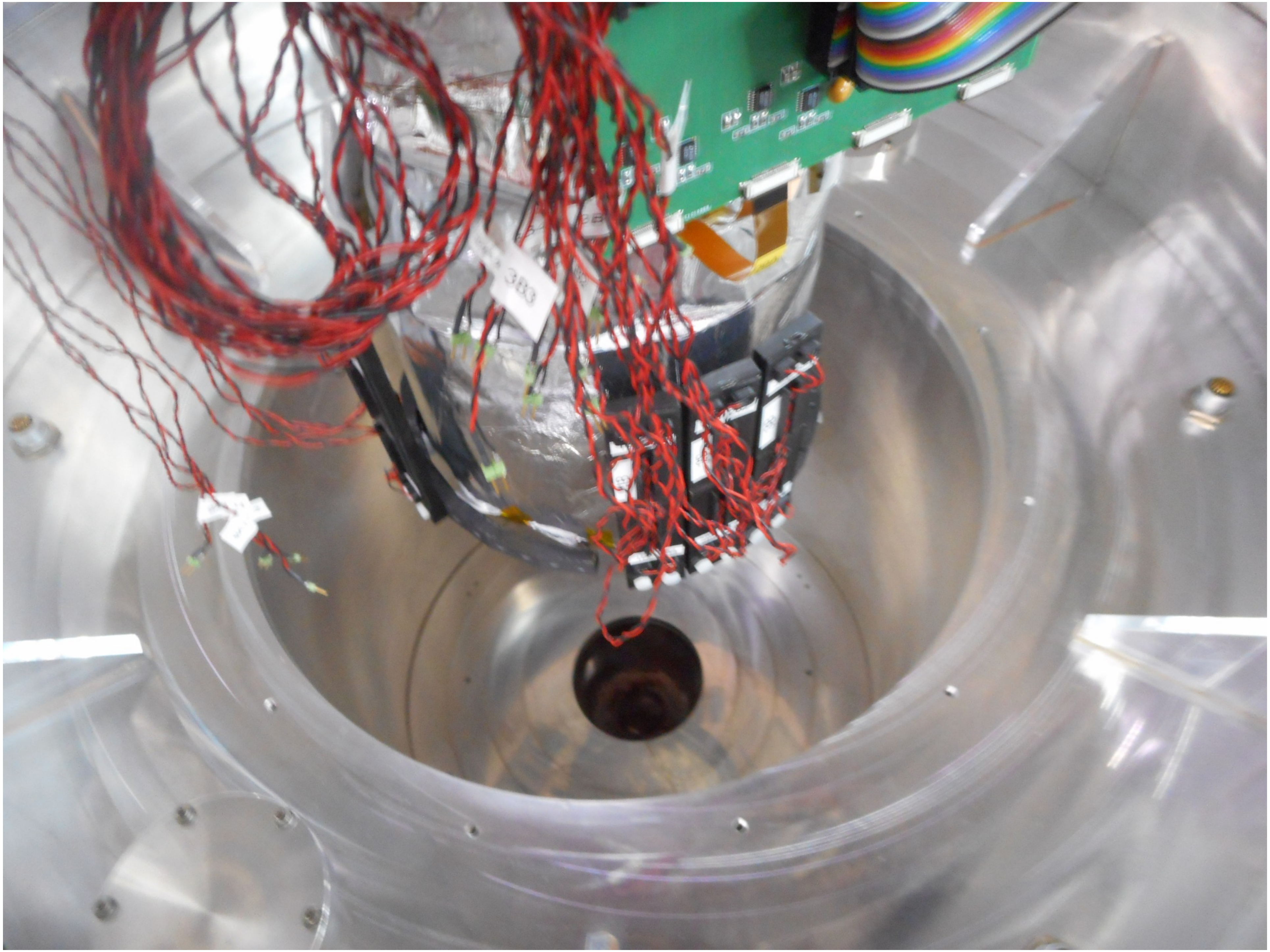
  by gaining in solid angle taking advantage of

  new SDDs form factor (more active area)

- reduction of the background:

  by improving the SDDs timing resolution (~ 400 ns)

  and implementing additional veto systems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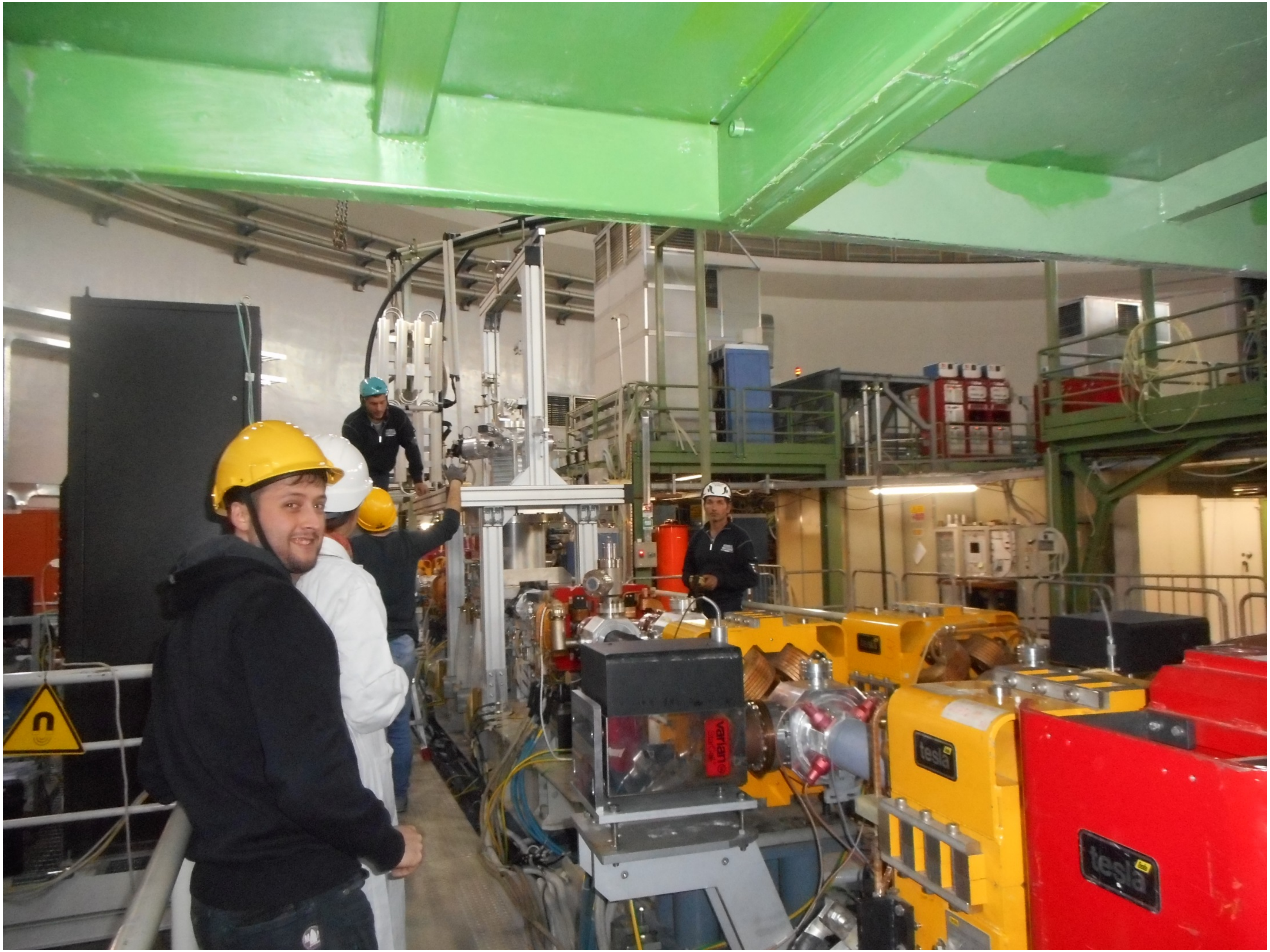
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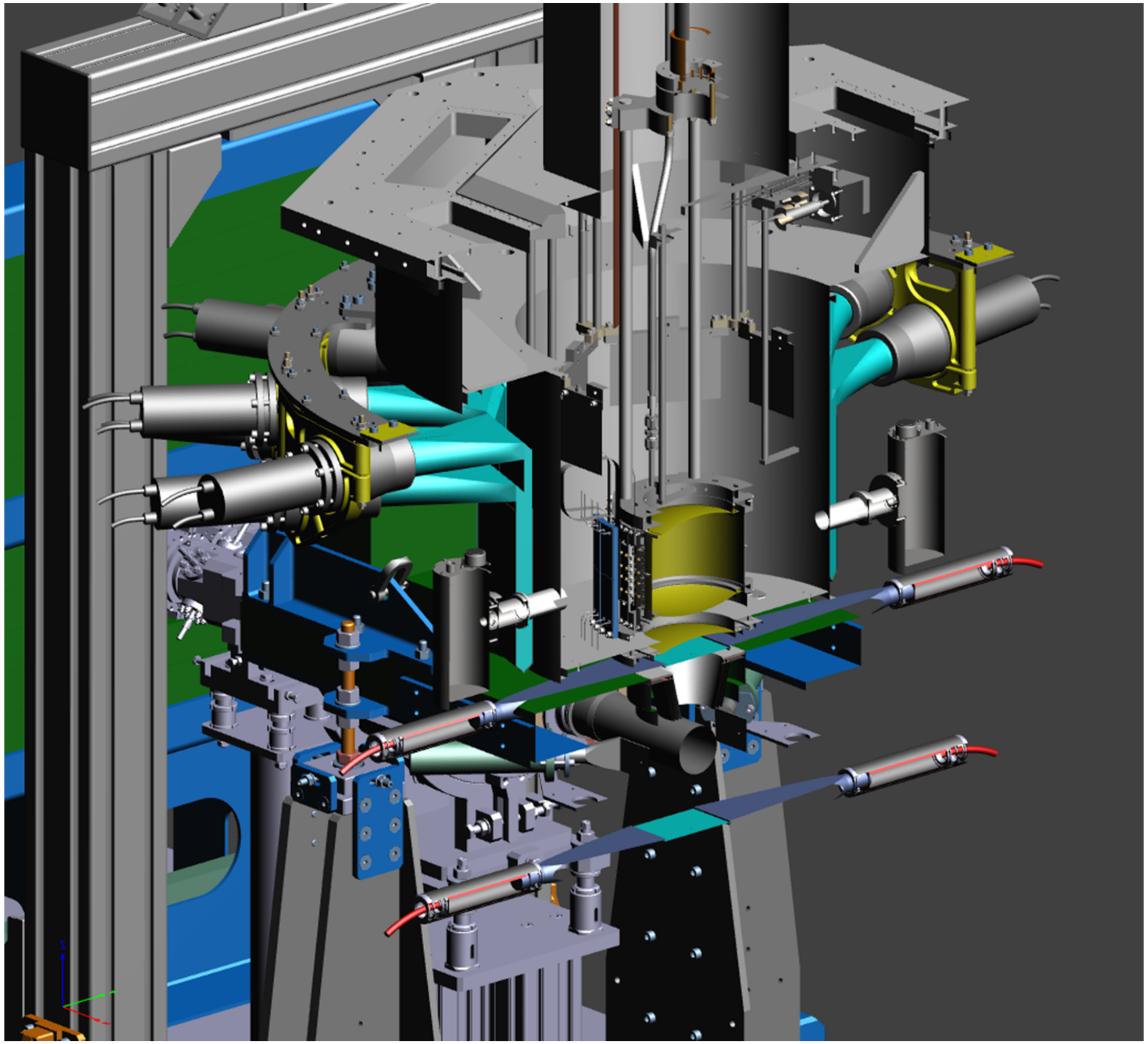

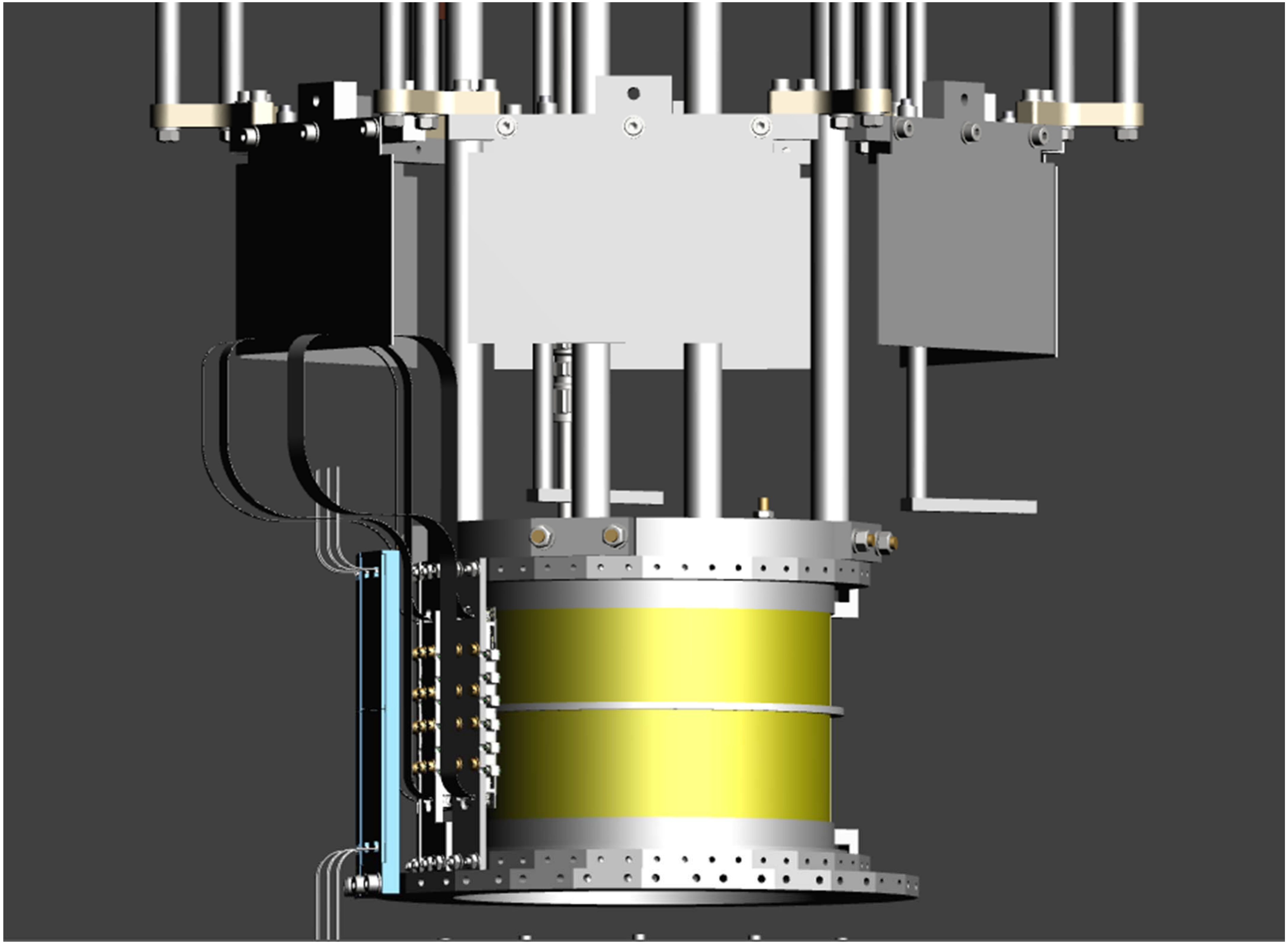

SIDDHARTINO installed on DAΦNE