SIDDHARTA-2 experiment at DAΦNE collider

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INFN - LNF

on behalf of the SIDDHARTA-2 collaboration

21-25 October 2019, ECT, Trento, Italy*

STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics

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.

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Univ. Jagiellonian Krakow, Poland
Research Center for Electron Photon Science (ELPH), Tohoku University

STRONG-2020

Croatian Science Foundation, research project 8570

CONTENT

1. **SIDDHARTINO installed on DAΦNE**

- SIDDHARTINO apparatus and aim
- SIDDHARTINO installation on DAΦNE

- First results from DAΦNE:
  calibration of the SDD detectors and beam visibility

- Strategy for the measurement of kaonic helium

2. From SIDDHARTINO to SIDDHARTA-2

SIDDHARTA-2 strategy

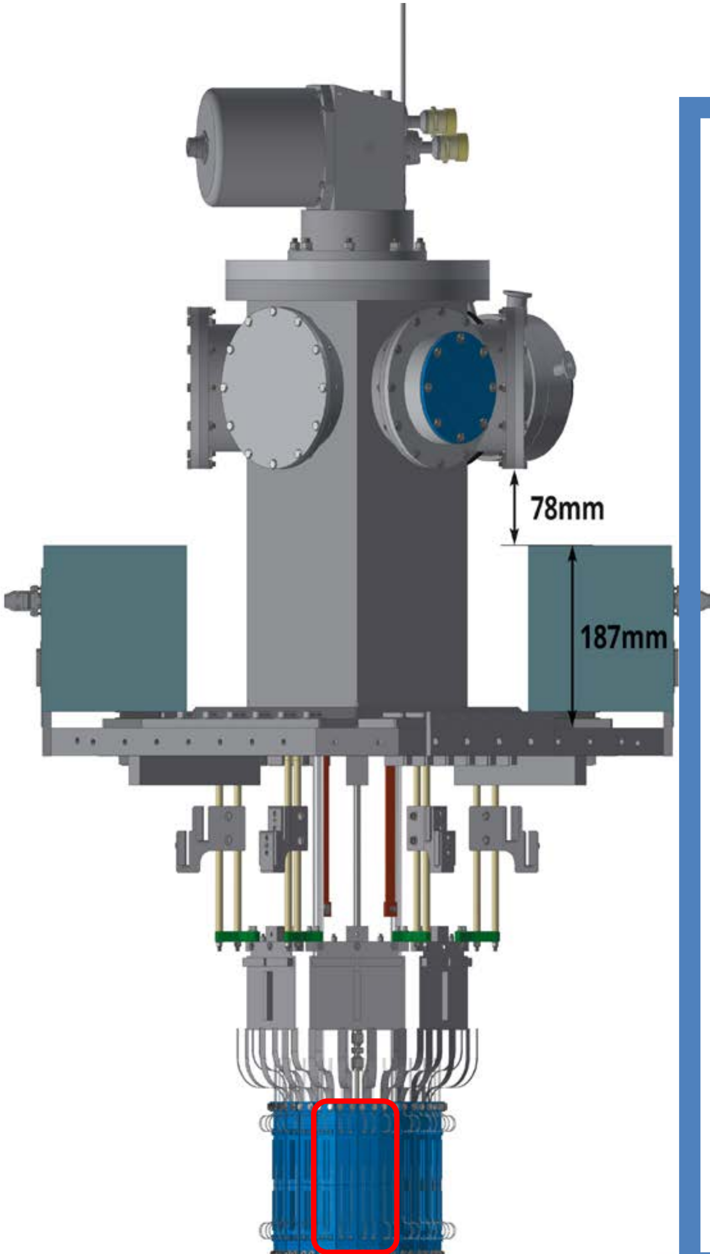
Phase 1

during the commissioning of DAΦNE
SIDDHARTINO
measurement of $K^{-4}He$ (8 SDD arrays)

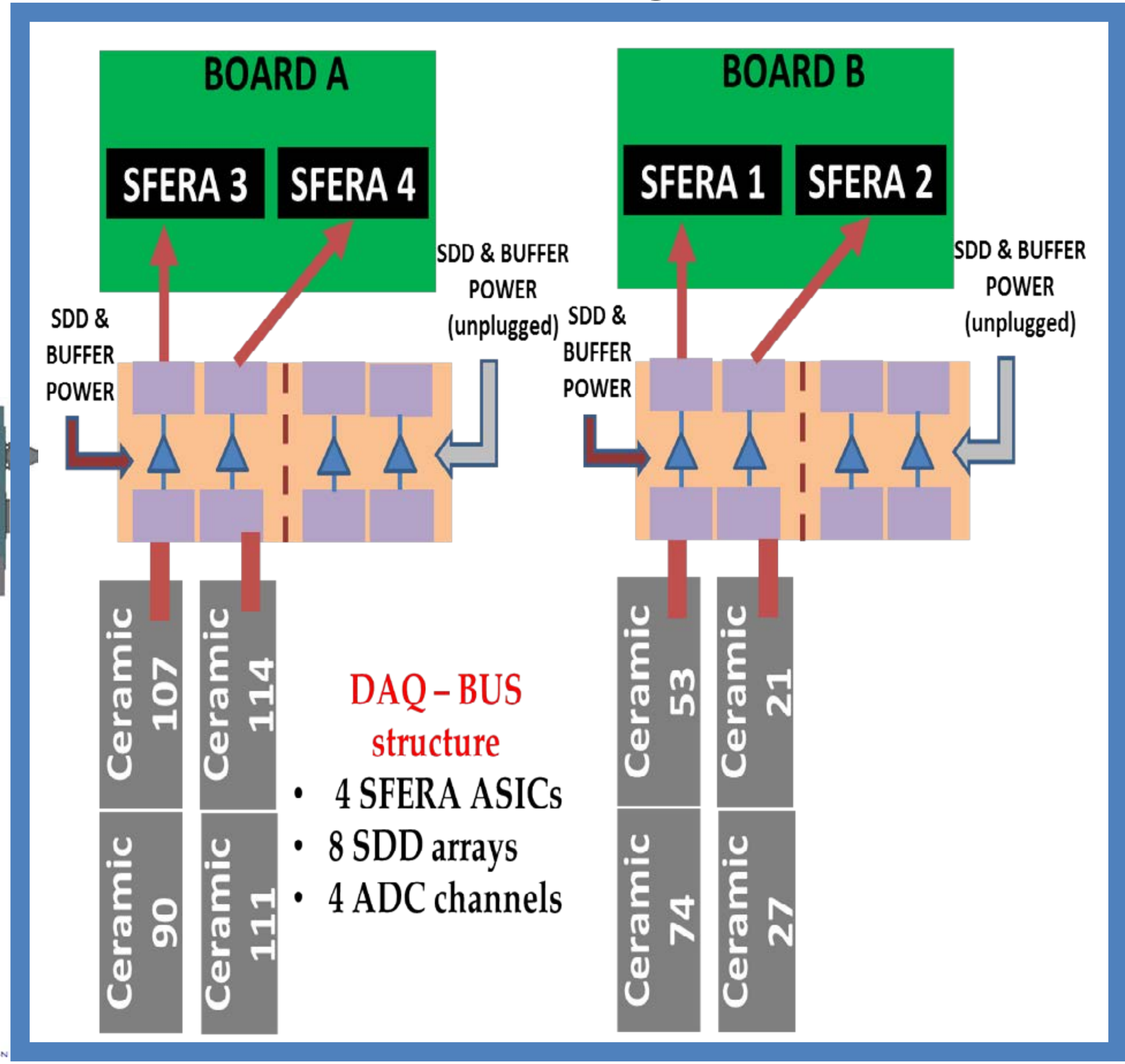
Phase 2

when DAΦNE operating condition
is comparable (S/B) with SIDDHARTA ones
kaonic deuterium **(48 SDD arrays)**
run for 800 pb^{-1}

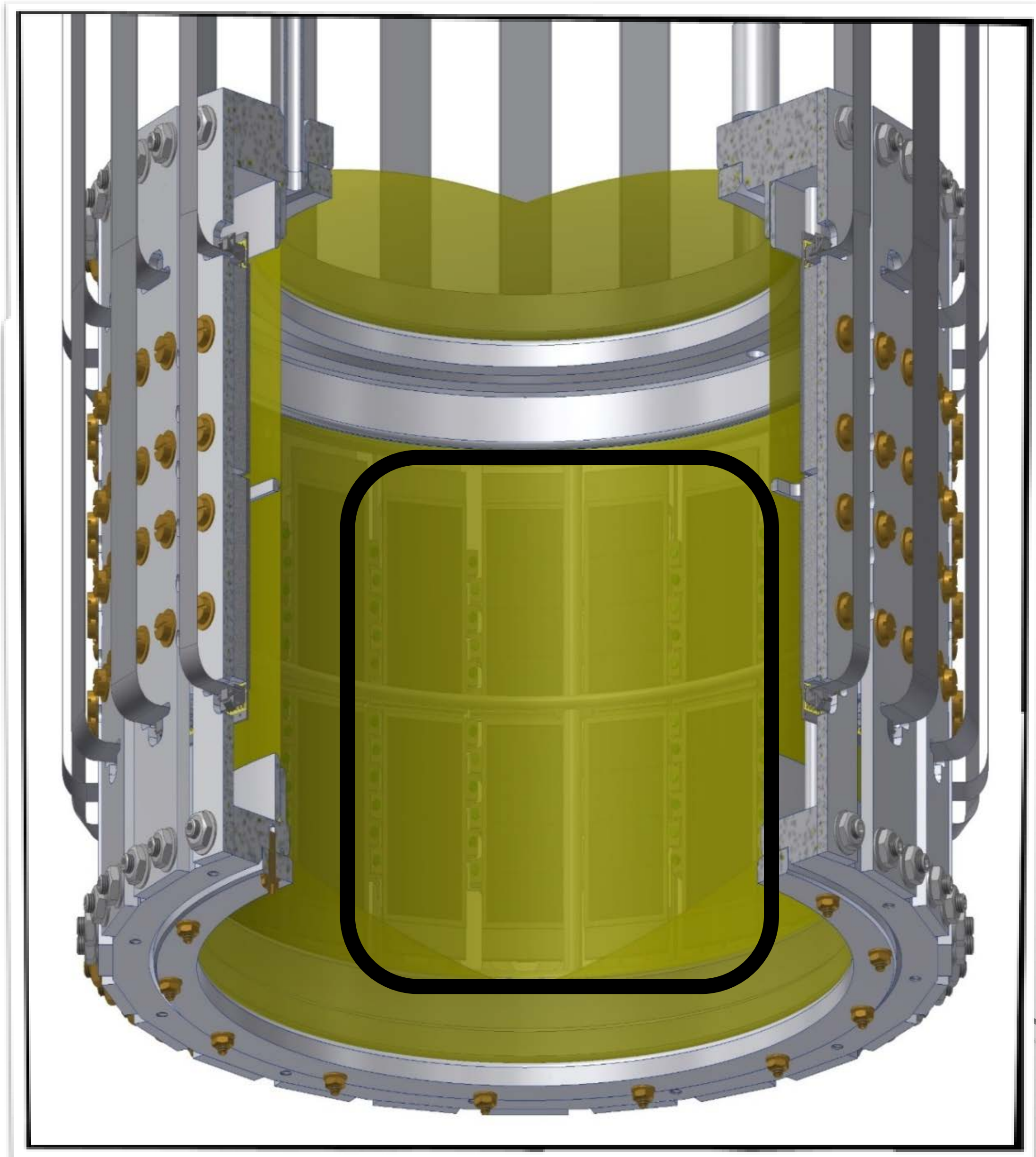
SIDDHARTINO = SIDDHARTA-2 with 8 SDD's

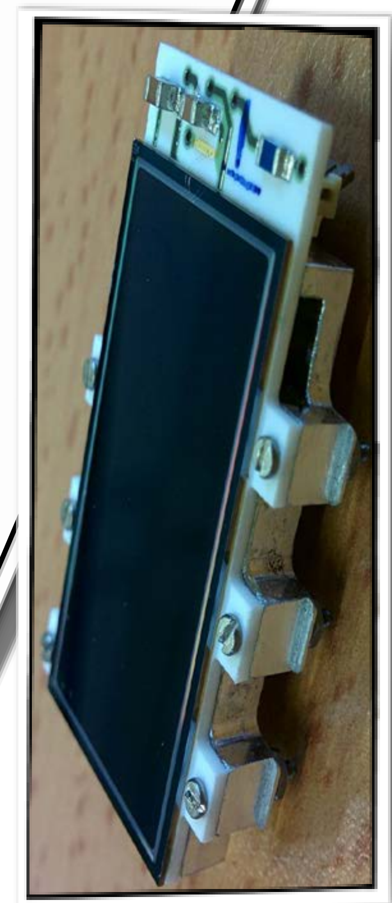


DAQ BUS configuration



SIDDHARTINO - SDD arrangement

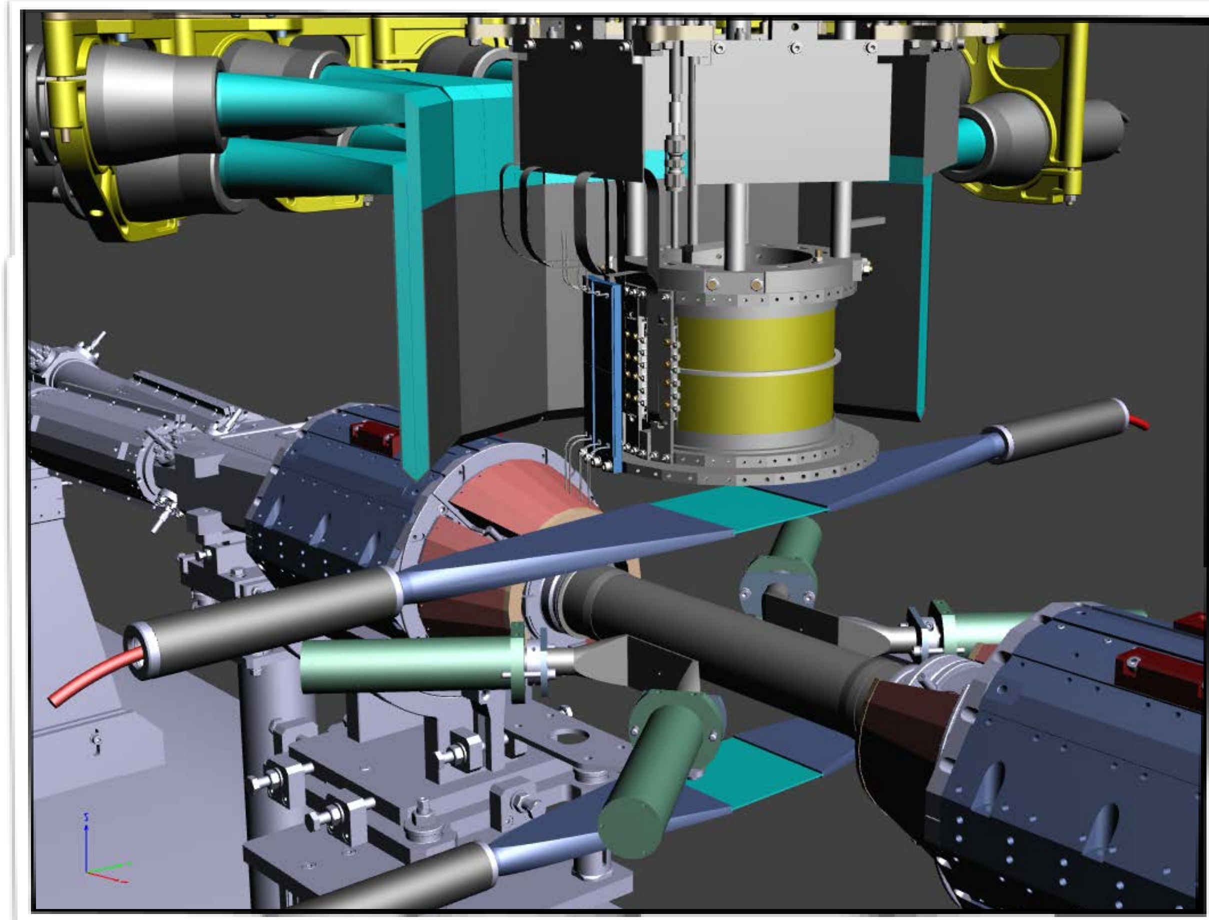




SIDDHARTINO apparatus

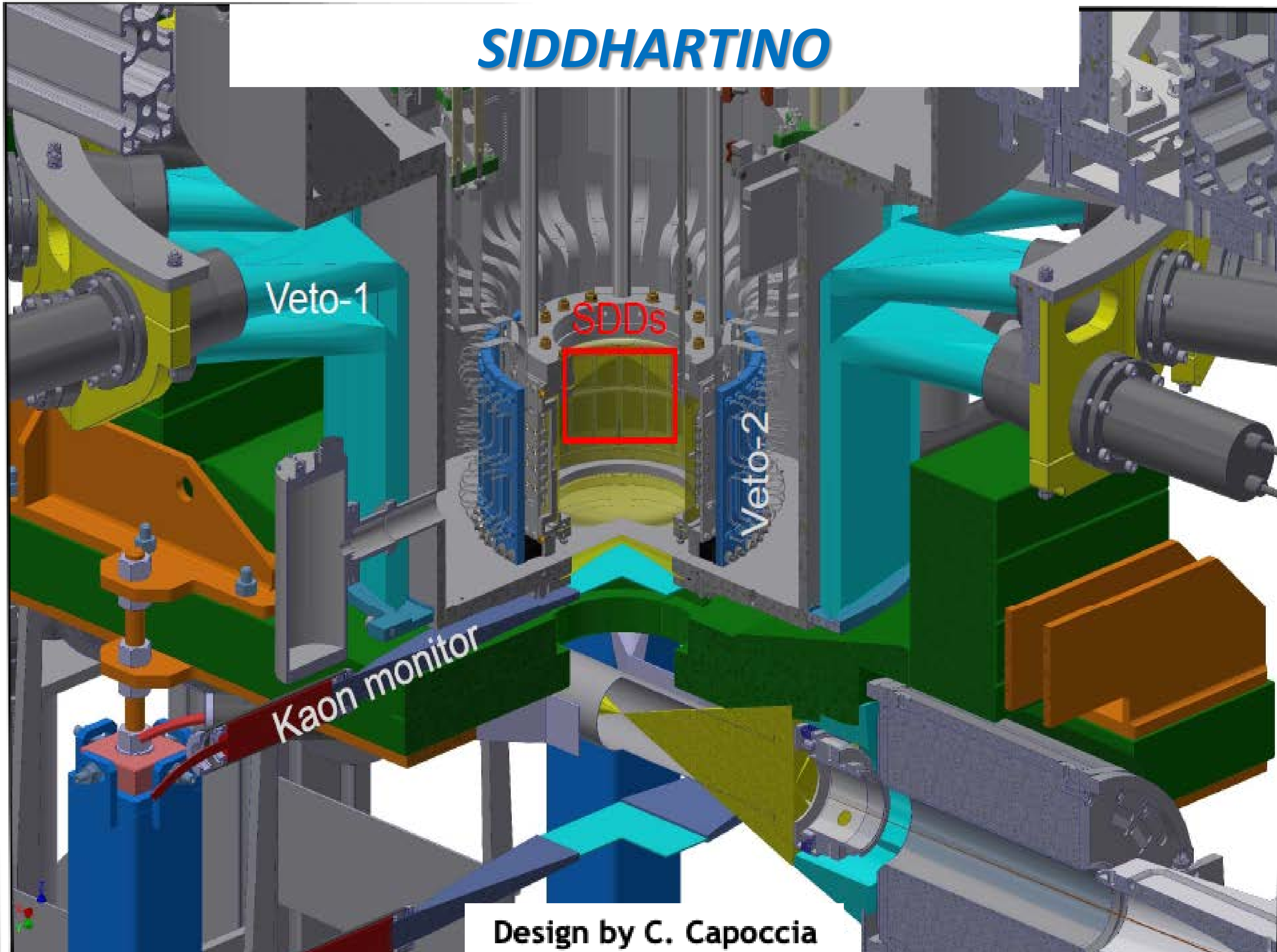
- **Needs to work with DAΦNE luminosity monitor**
- **setup lifted by ~100 mm**
- **w.r.t. nominal position**
- **SIDDHARTA-2 luminosity**
- **monitor included**
- **equipped with 8 SDD arrays**
- **complete Veto system**
- **target filled with He-4 gas**

(to compare with SIDDHARTA)



Aim: verify when DAΦNE background is similar to the one in SIDDHARTA 2009

SIDDHARTINO



Design by C. Capoccia

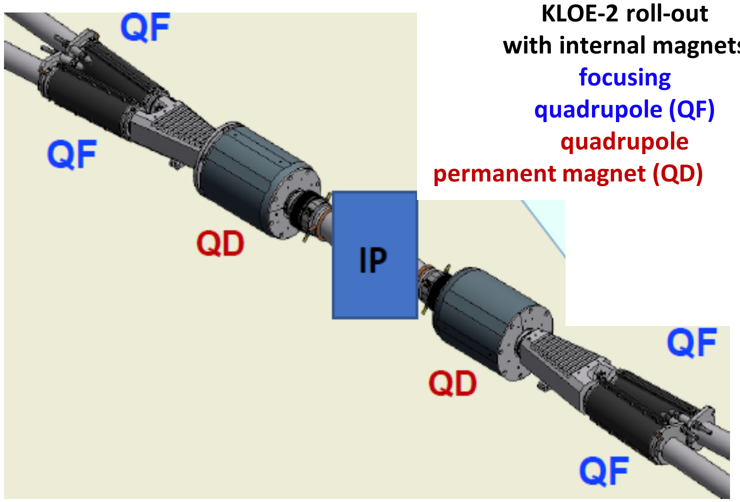
SIDDHARTINO was installed on DAFNE in April 2019

Summer shutdown period for more optimization and debugging

Restart operation in September

(compatible with DAFNE schedule)

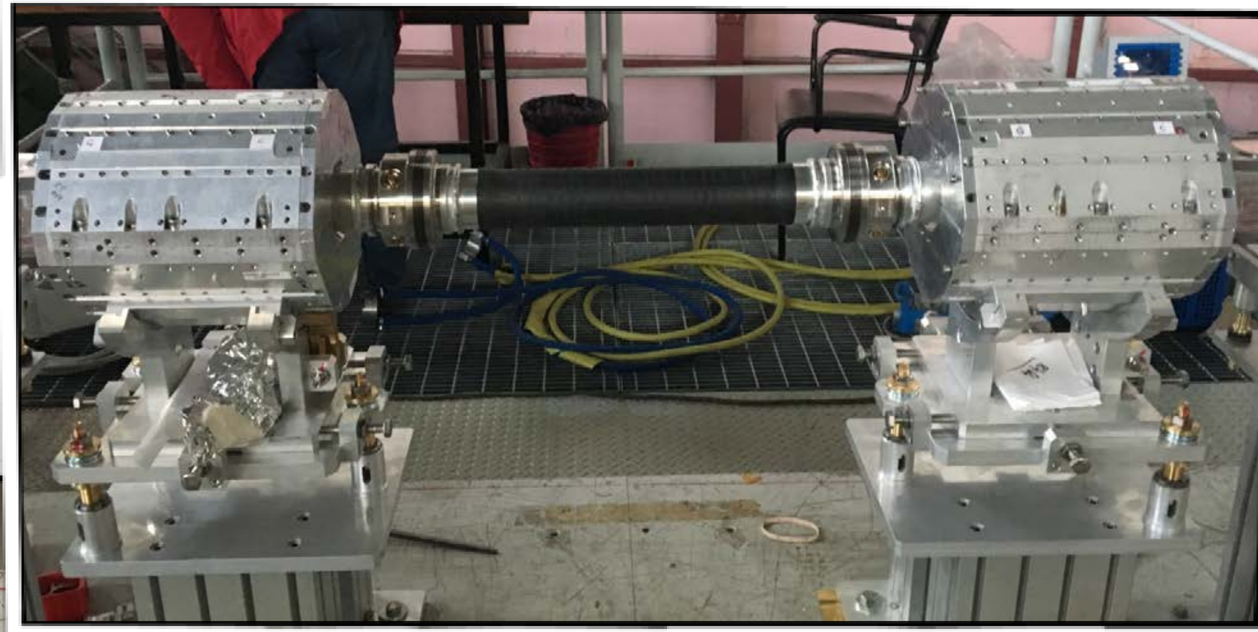
New platform and interaction region

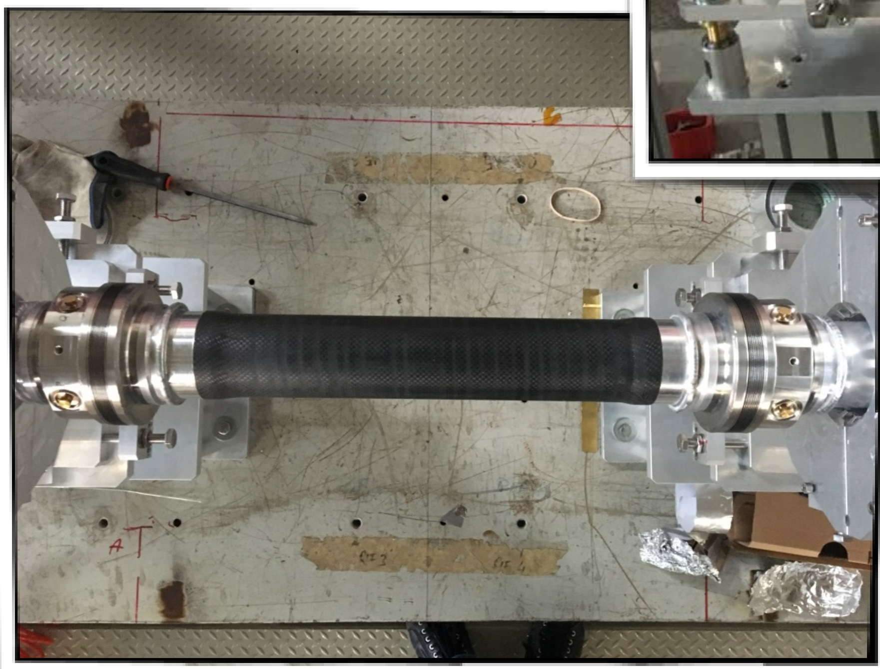


KLOE-2 roll-out
with internal magnets
focusing
quadrupole (QF)
quadrupole
permanent magnet (QD)

New beam pipe

flanges removed
major source of
asynchronous
background



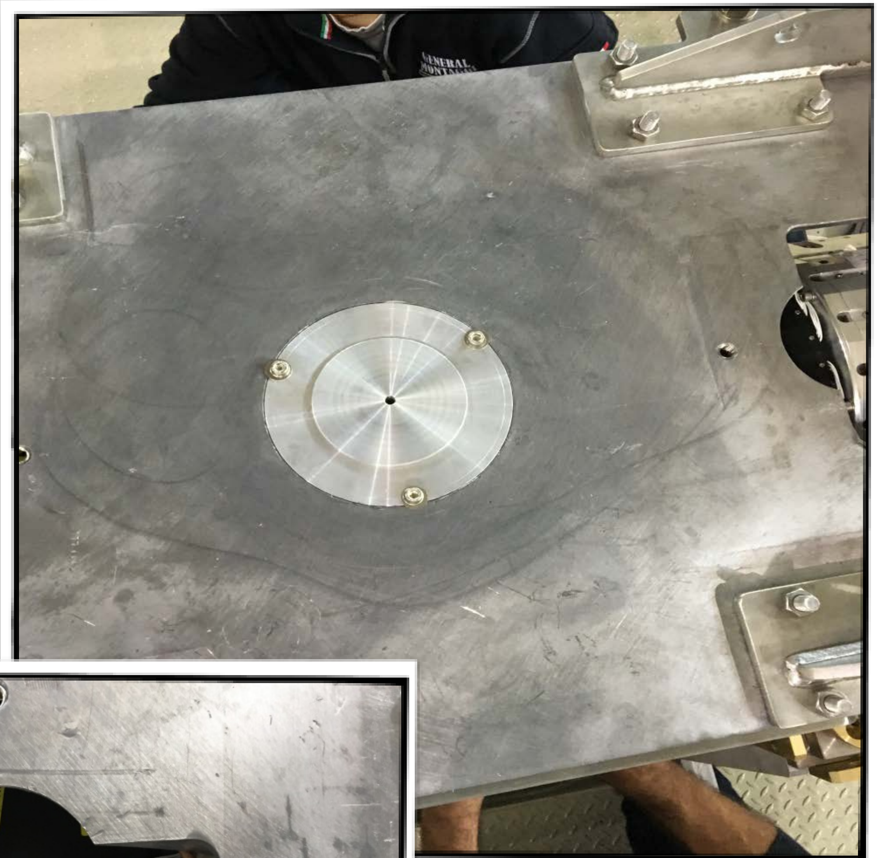


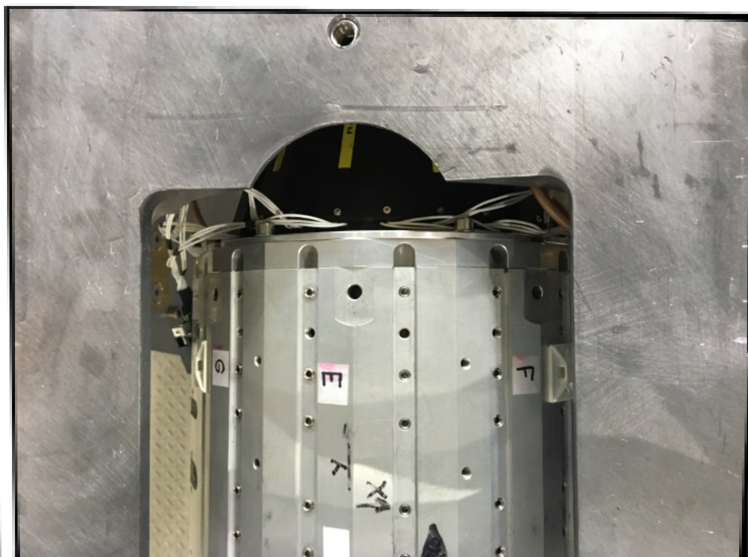
external carbon fiber jacket
ø 66 mm and thickness ~ 500 micron
internal ultra pure aluminum
ø 55mm and thickness ~ 150 micron

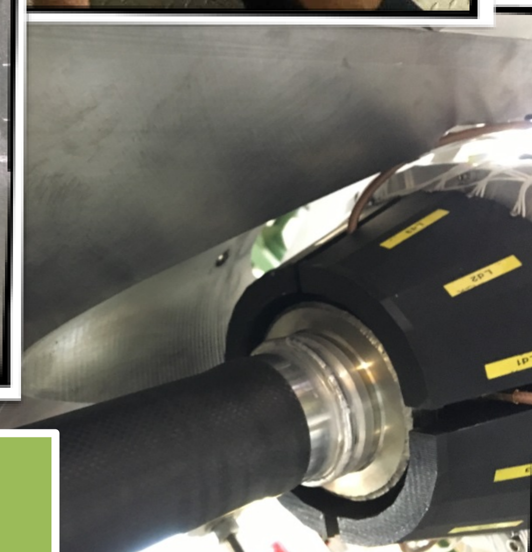
DAFNE luminosity monitor

SIDDHARTINO

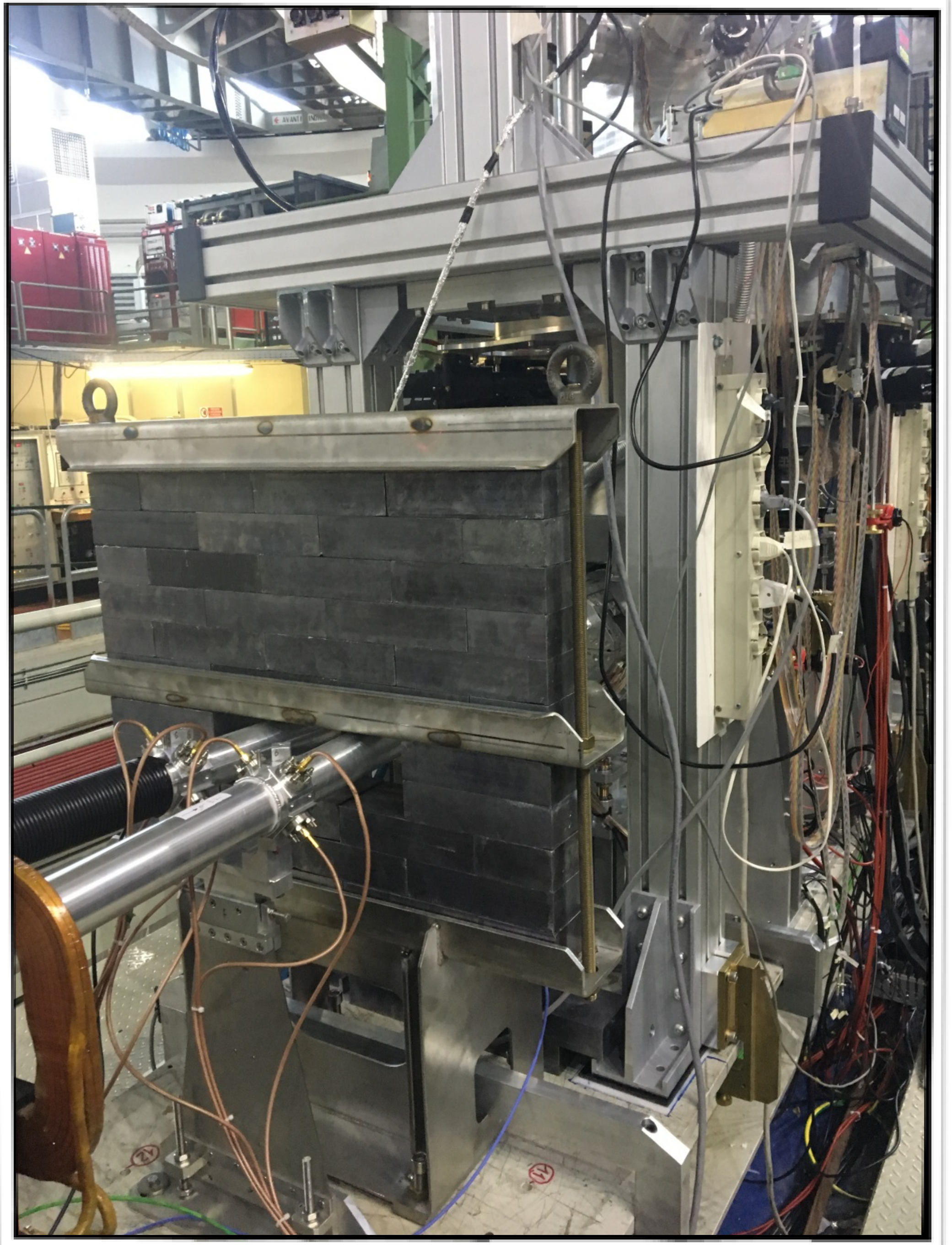
shielding – we need modifications/integration







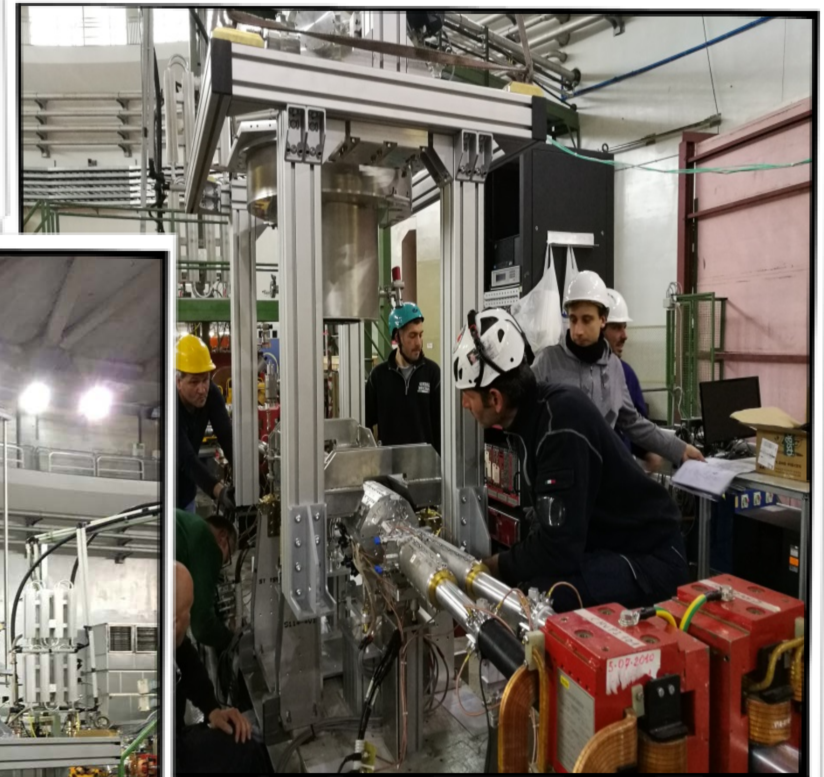
Designed for the new quadrupoles and DAFNE luminosity monitor



SIDDHARTINO

Lateral shielding completed in summer shutdown period

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

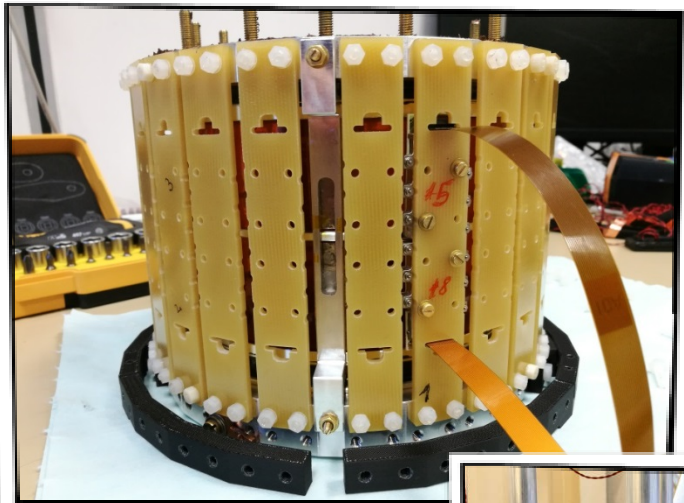
- 2-stage cooling system + Cryo Tiger
- Light target and Silicon Drift Detector
- Veto-2 system
- Luminosity monitor
- Veto-1 system
- Kaon Trigger system

Cooling systems

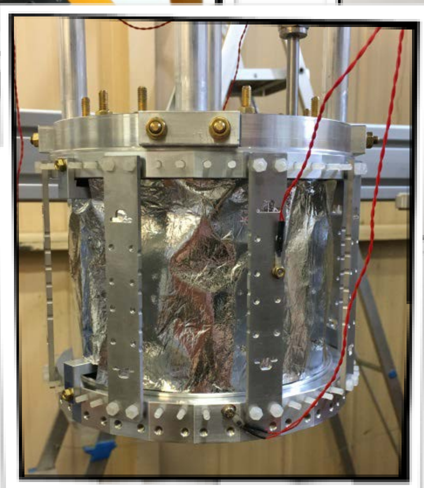
add additional cooling power to the SDD and electronics

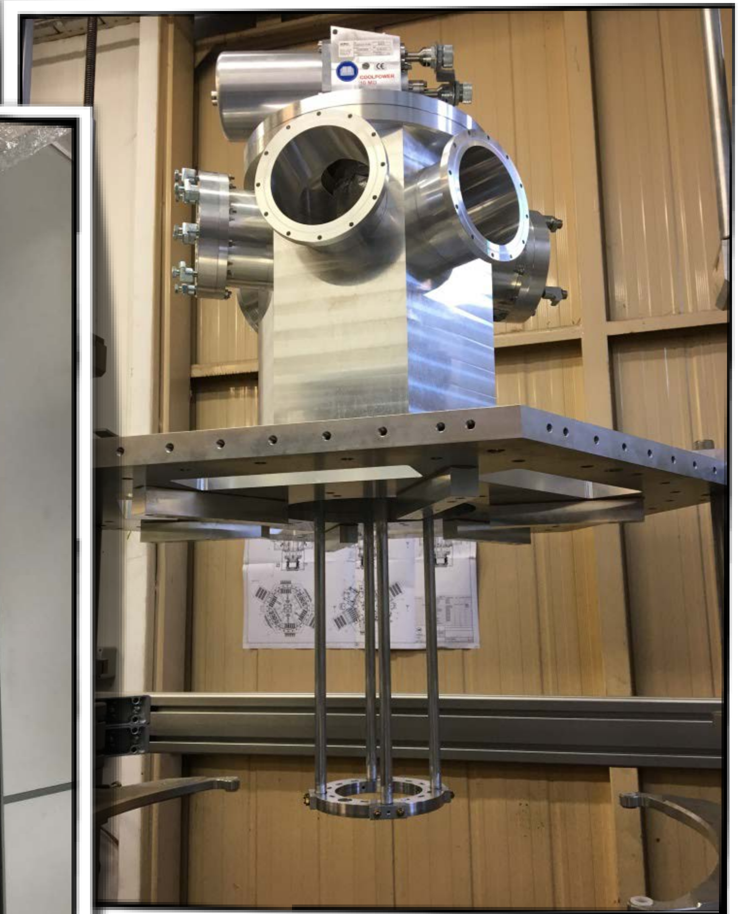
❖ **Target + SDD cooling**

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

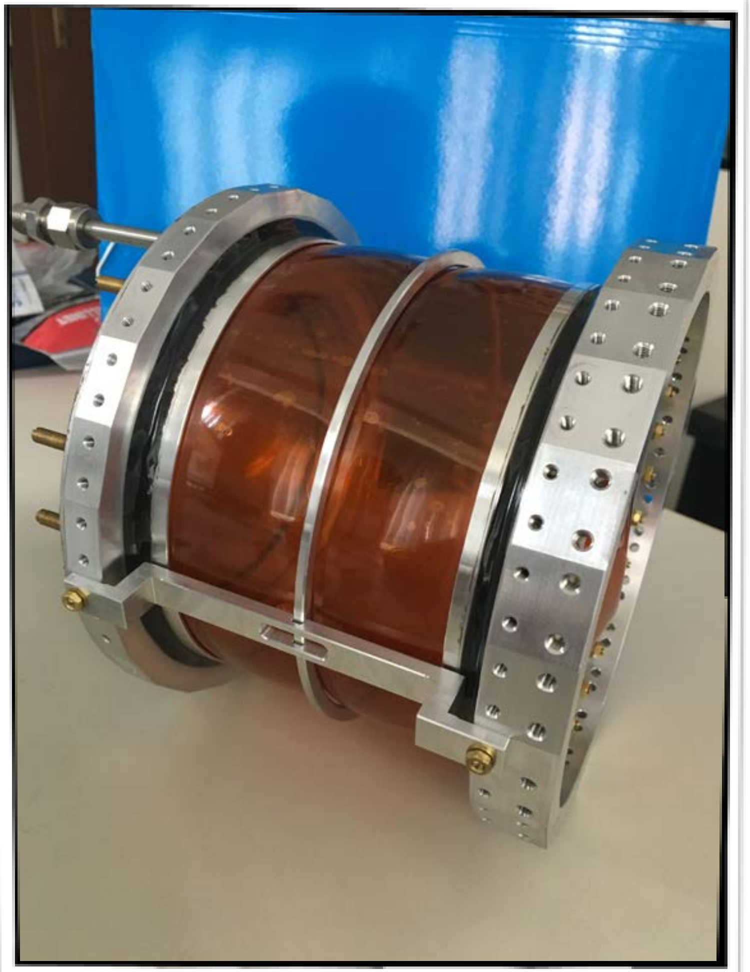




❖ **Line driver boards**

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

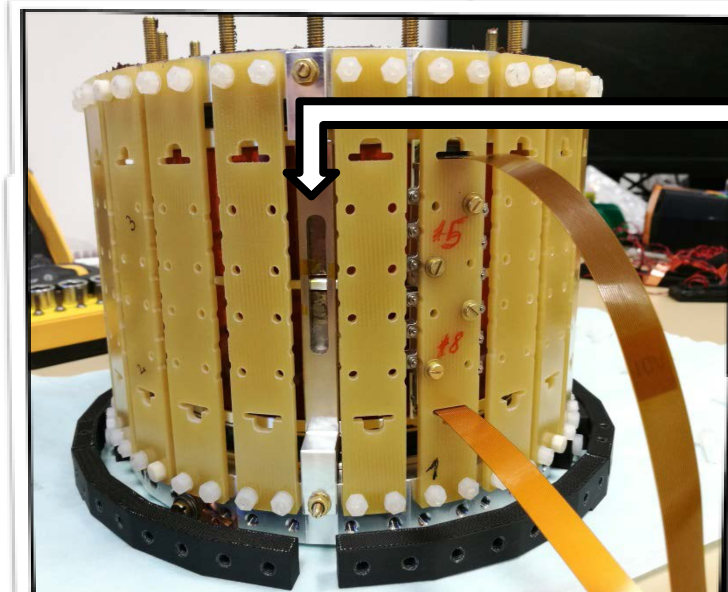
Light target and SDD detector assembly



increase the target stopping power

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

SDDs placed 5 mm from the target wall

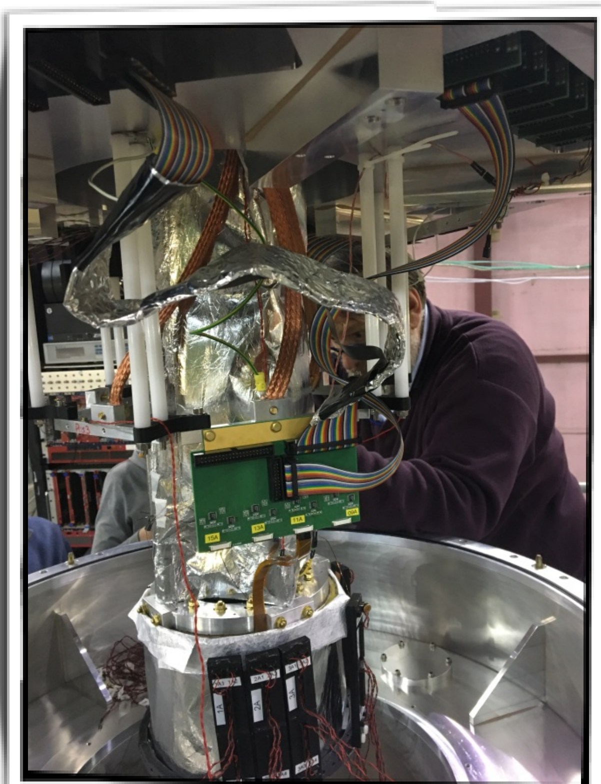


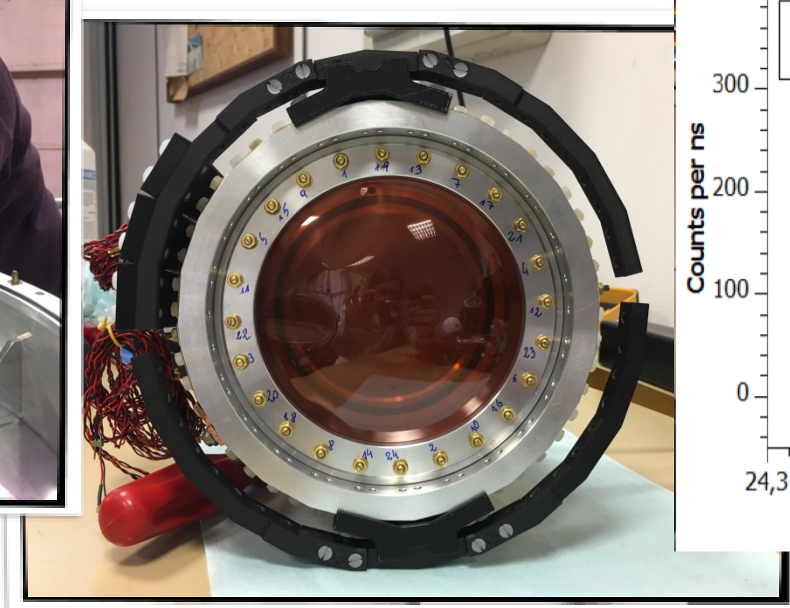
calibration foils inserted near to the SDD are activated by the X-ray tubes

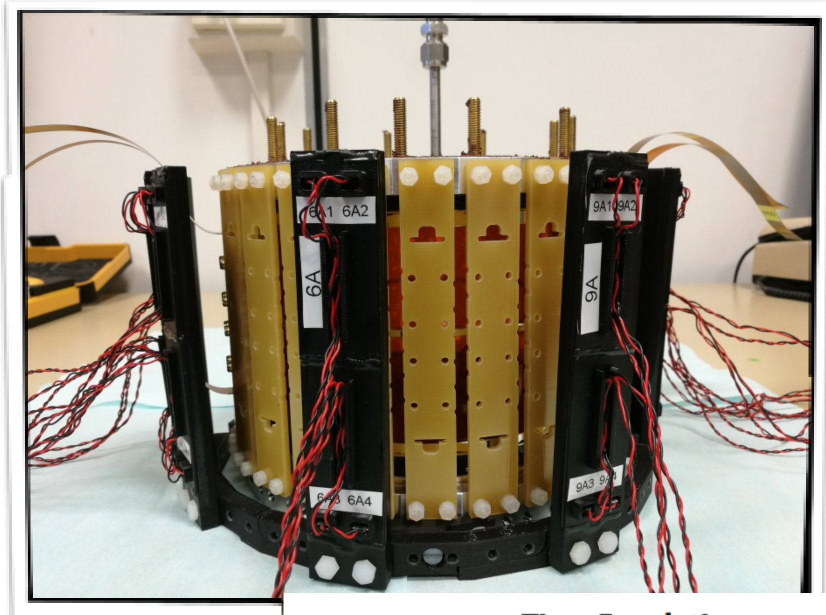
Target cell wall is made of a 2-Kapton layer structure (75 µm + 75 µm + Araldit)

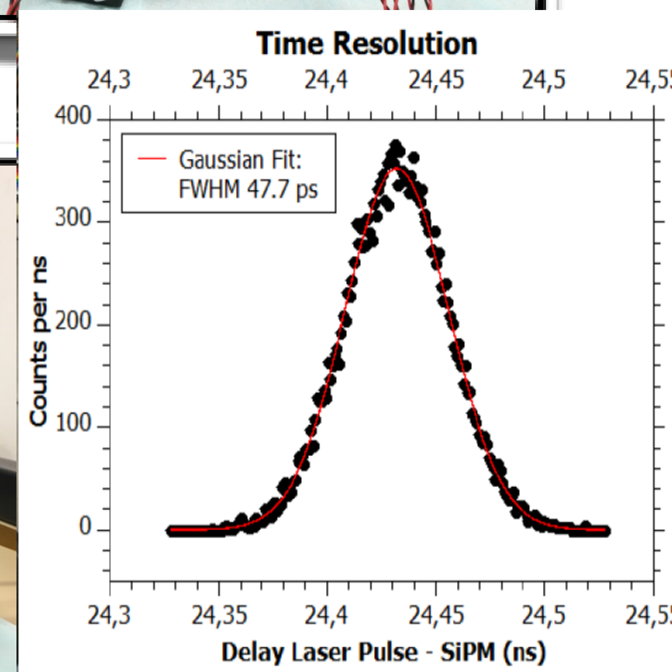
The VETO-2 system

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

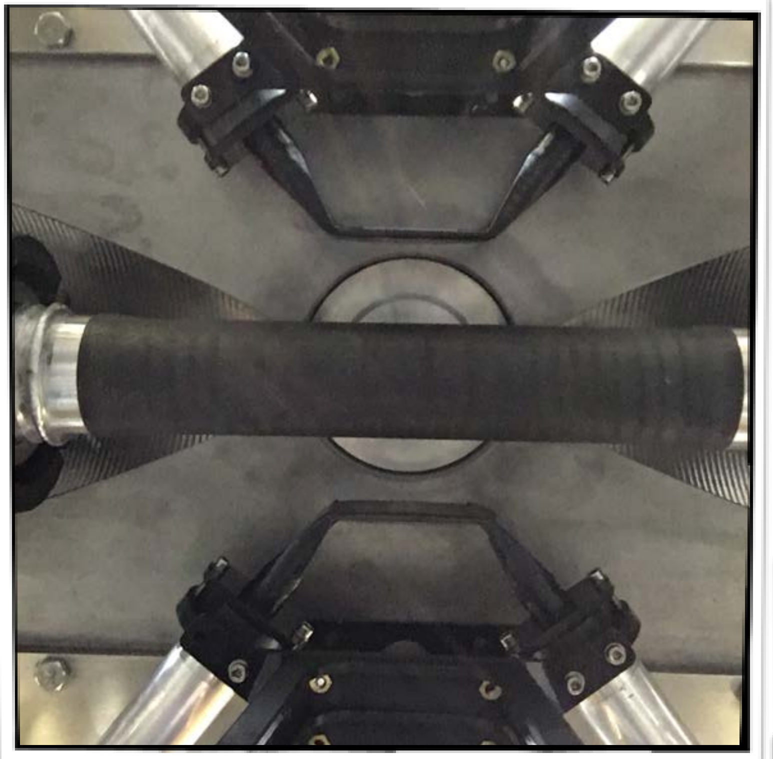








Luminosity monitor

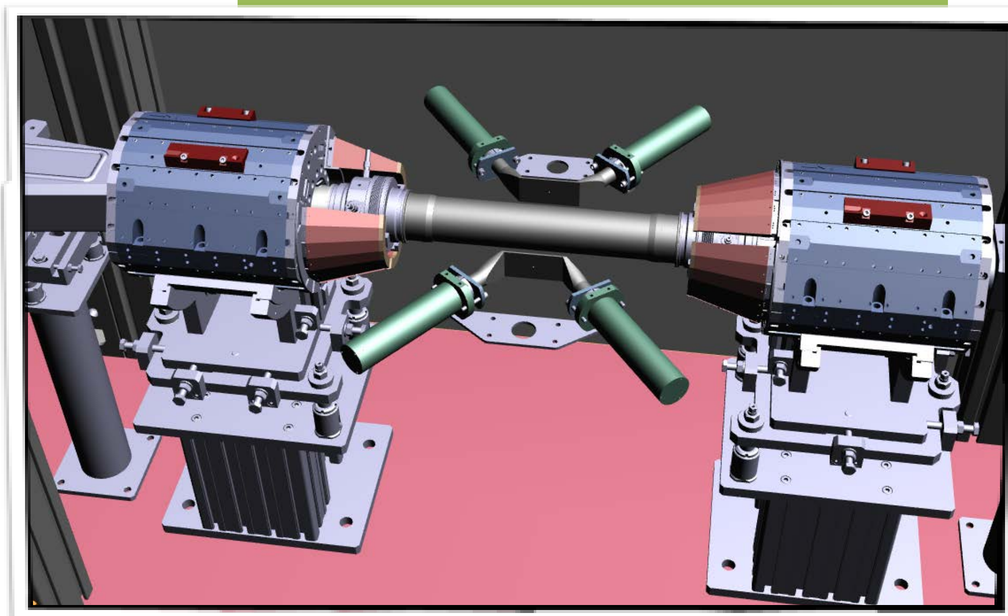


- 2 pairs of scintillator: 80x40x2 mm^3
  Scionix EJ-200
- R4998 PMTs Hamamatsu
- light-guides
- aluminum tube + μMetal (0.1mm)
- reflective and light proof foil
- optical cement

Luminosity ~ 10^{32} cm^{-2} s^{-1}
Rate ~ 50-60 Hz

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

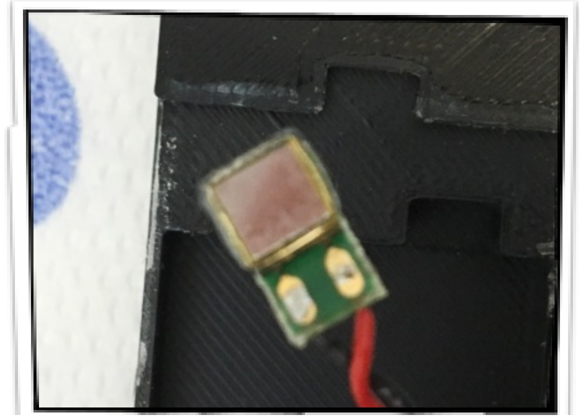
Allows:
- Collision optimization
- Machine feedback

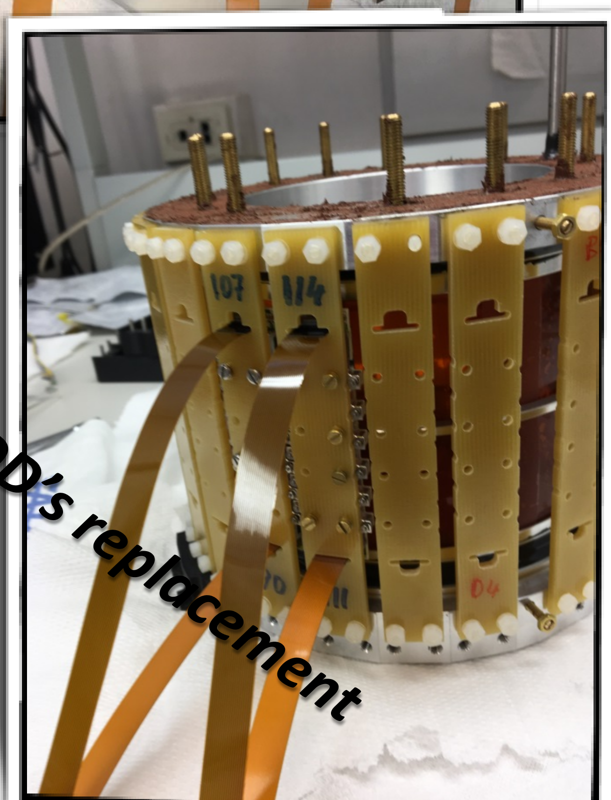


SIDDHARTA-2 Interaction regions

SIDDHARTINO installed on DAΦNE (April 2019)

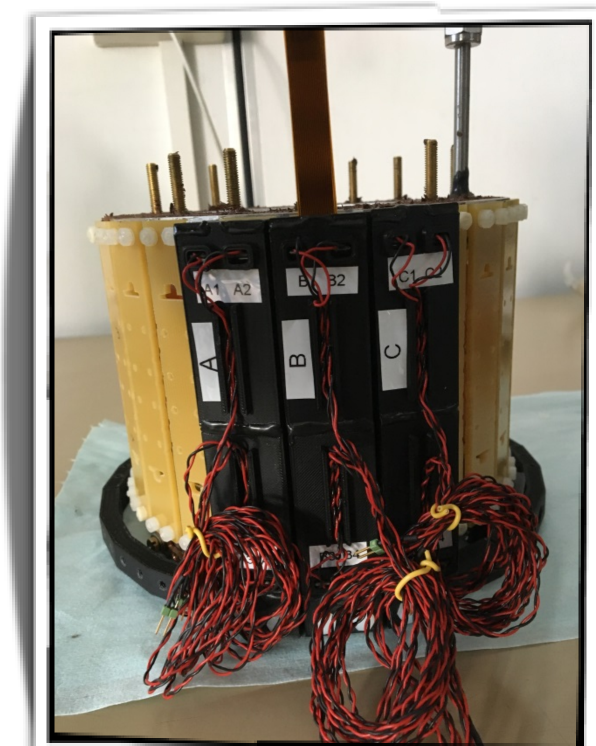
Summer shutdown work





SDD's replacement

new calibration materials



Commissioning of SDD's in DAΦNE

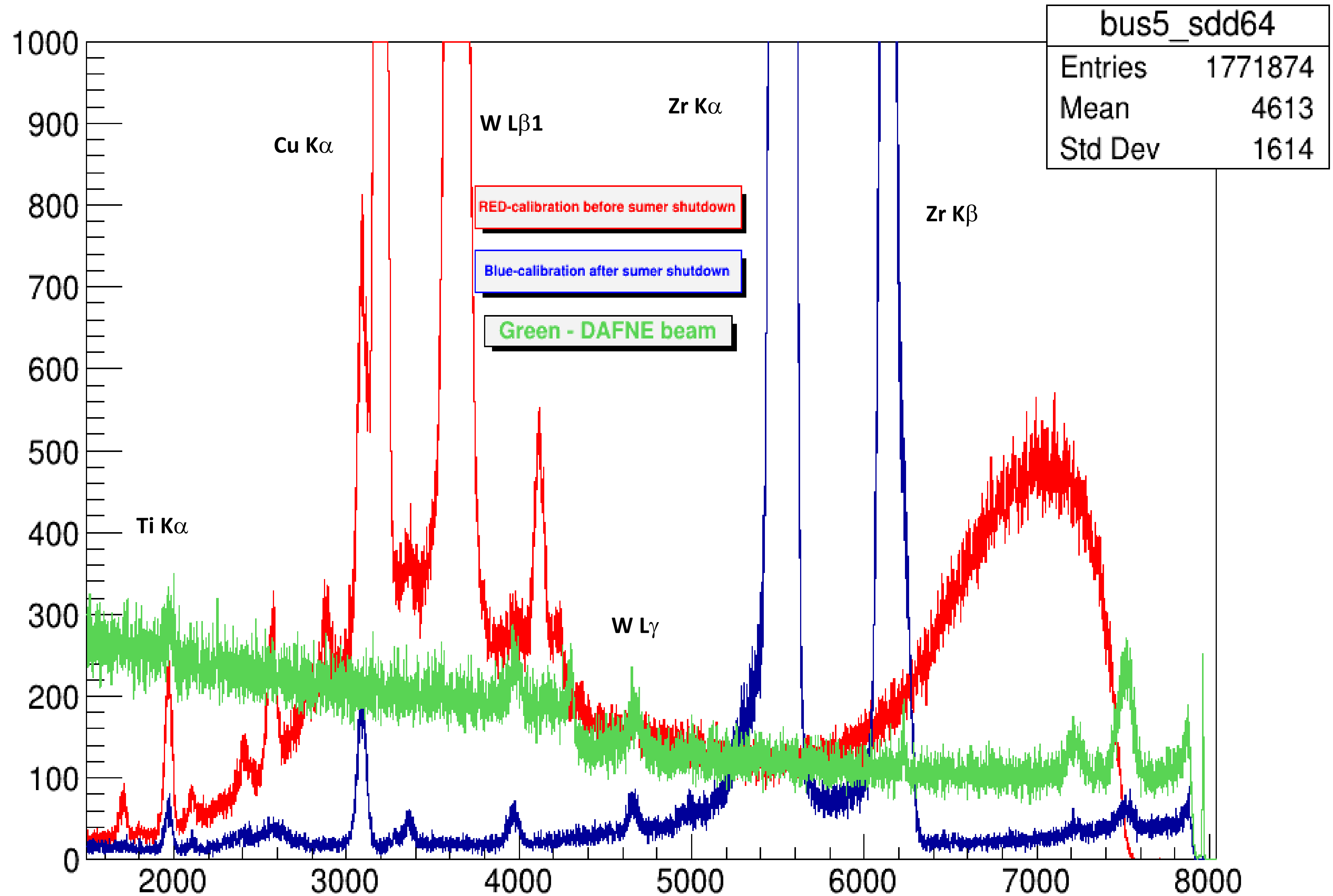
- **Test of the first signals in the accelerator environment (SFERA-SDD coupling, noise test, EMI/RFI filters on power lines)**

- **Tuning of the power supply parameters**

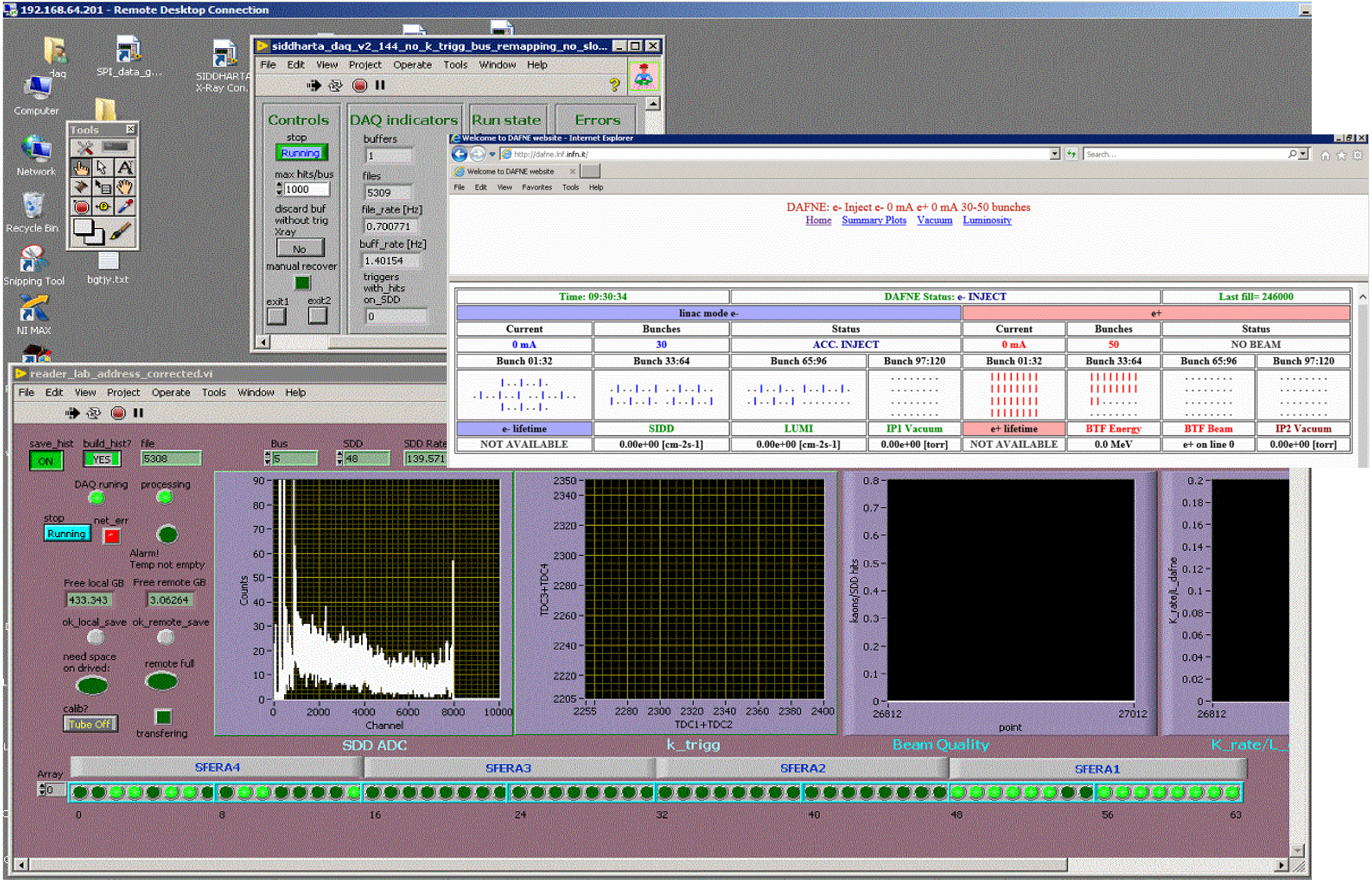
- **Calibration with the x-ray tube**

- **Comparison x-ray tube vs beam**
  (more details in the M. Miliucci talk)

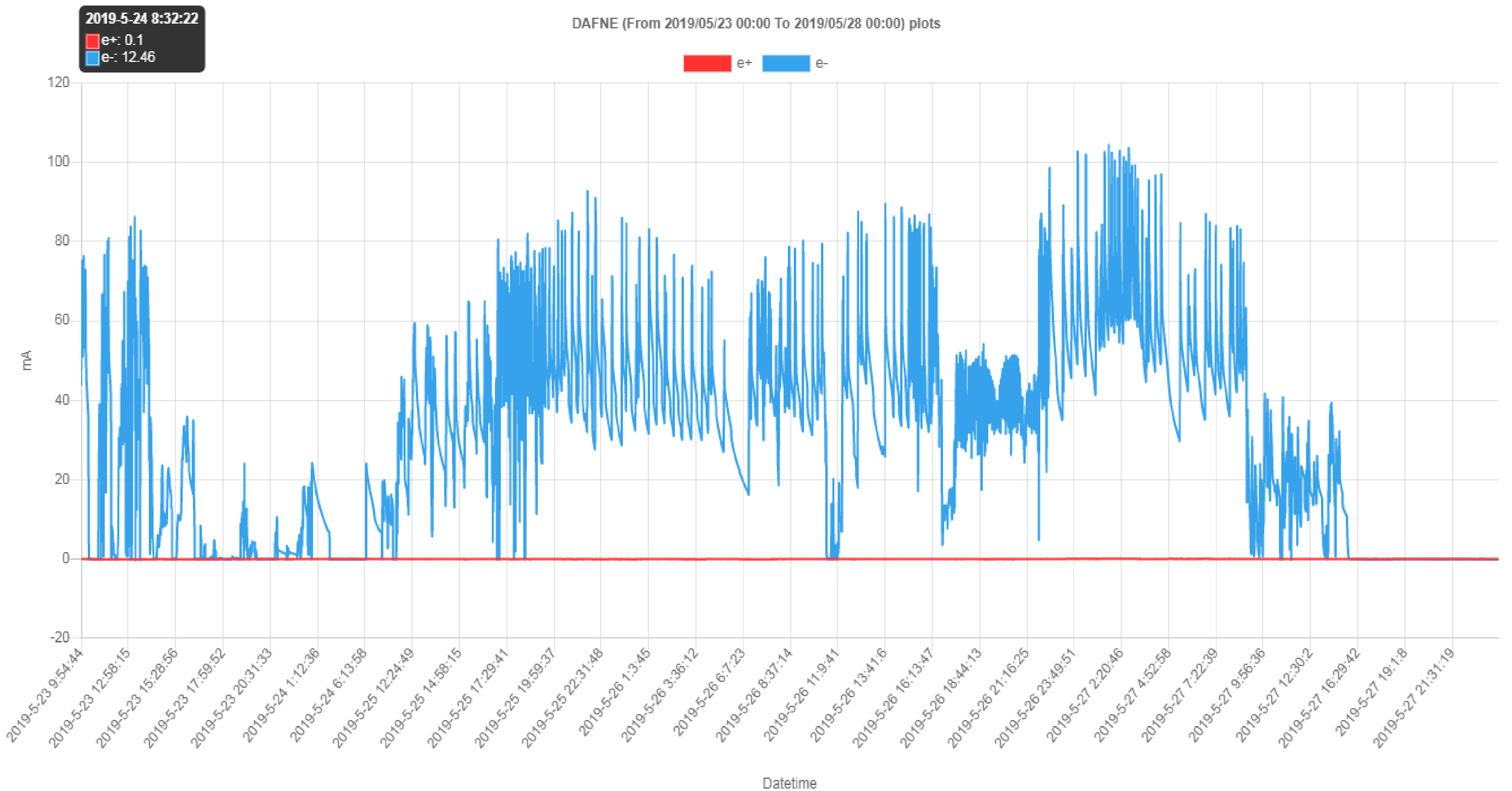
Calibration of SDDs



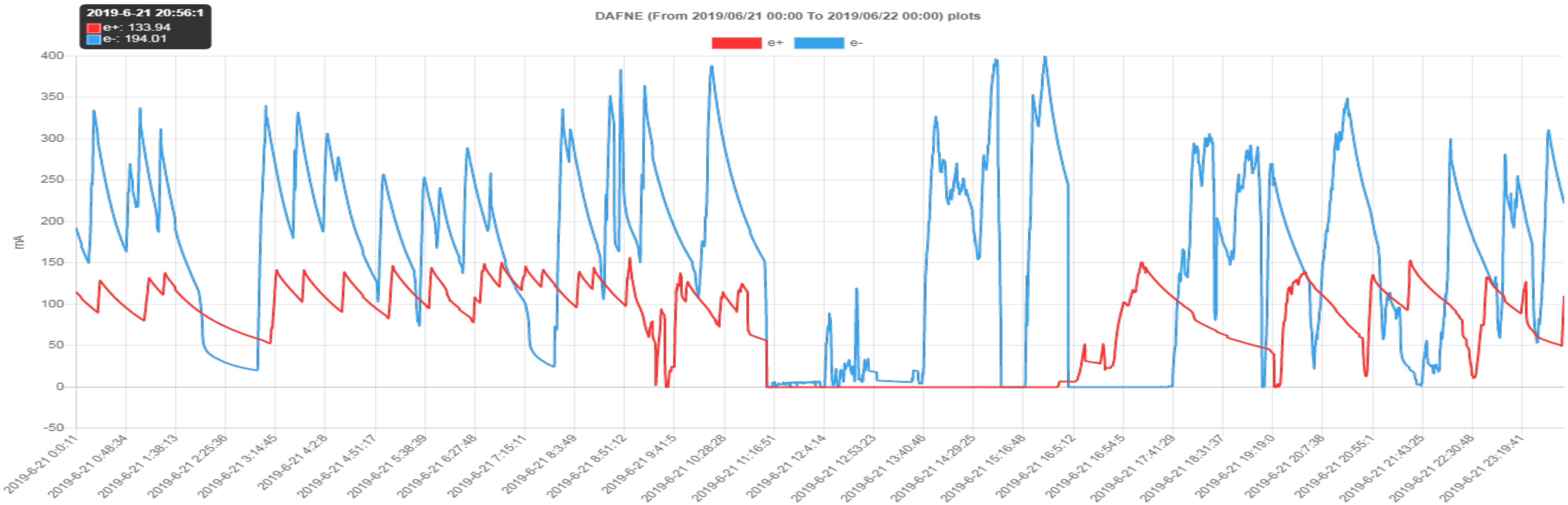
SDD's and DAFNE operation

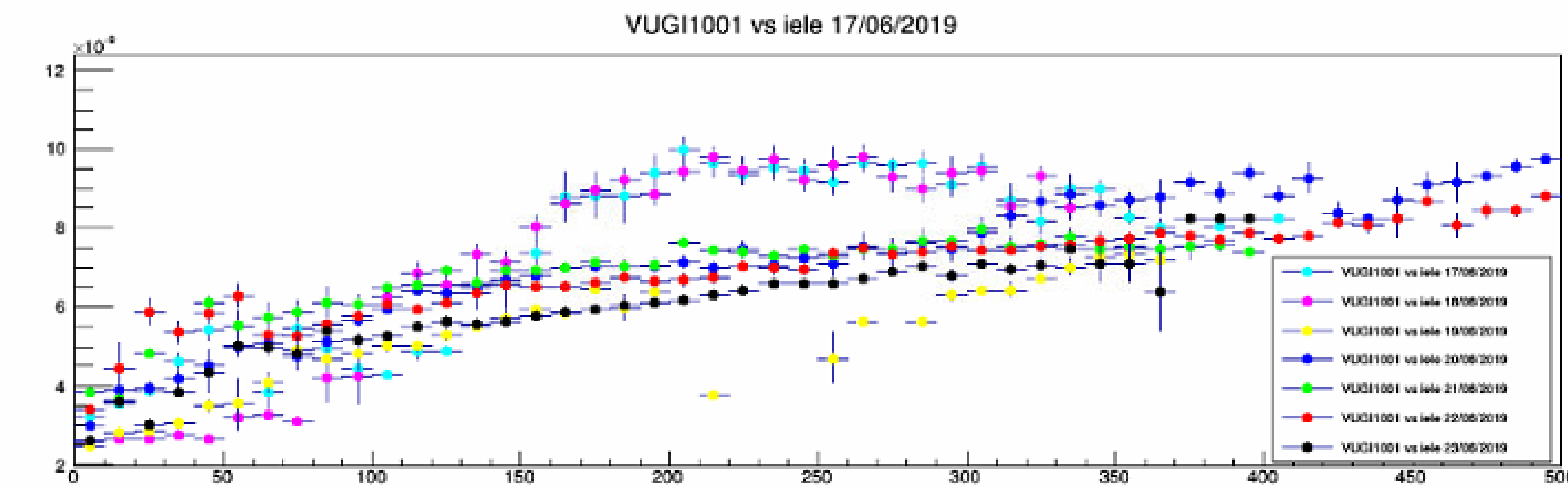


Circulating beam in DAFNE

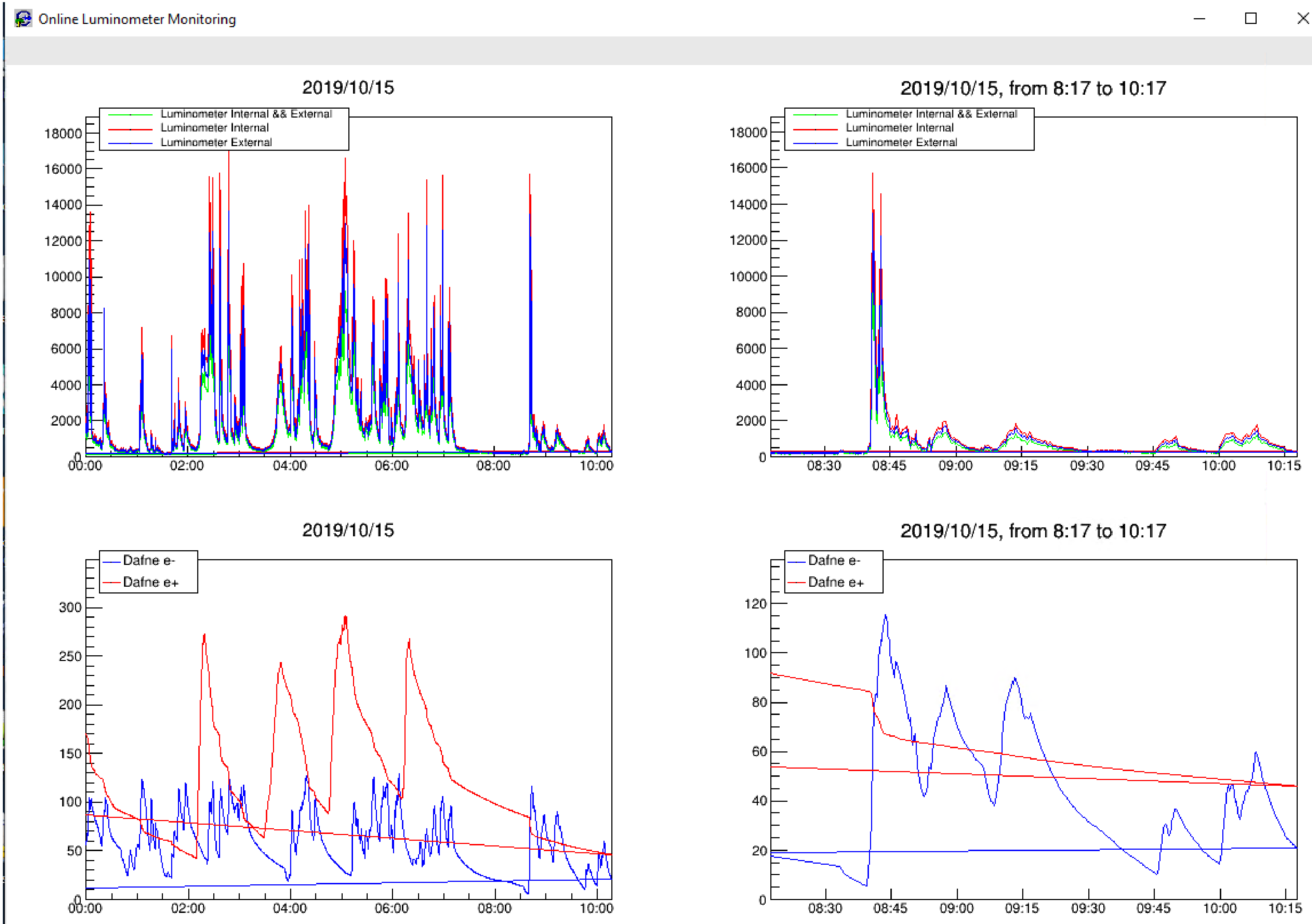


… two beams circulating … but no collision yet …
vacuum improvement with the beam current

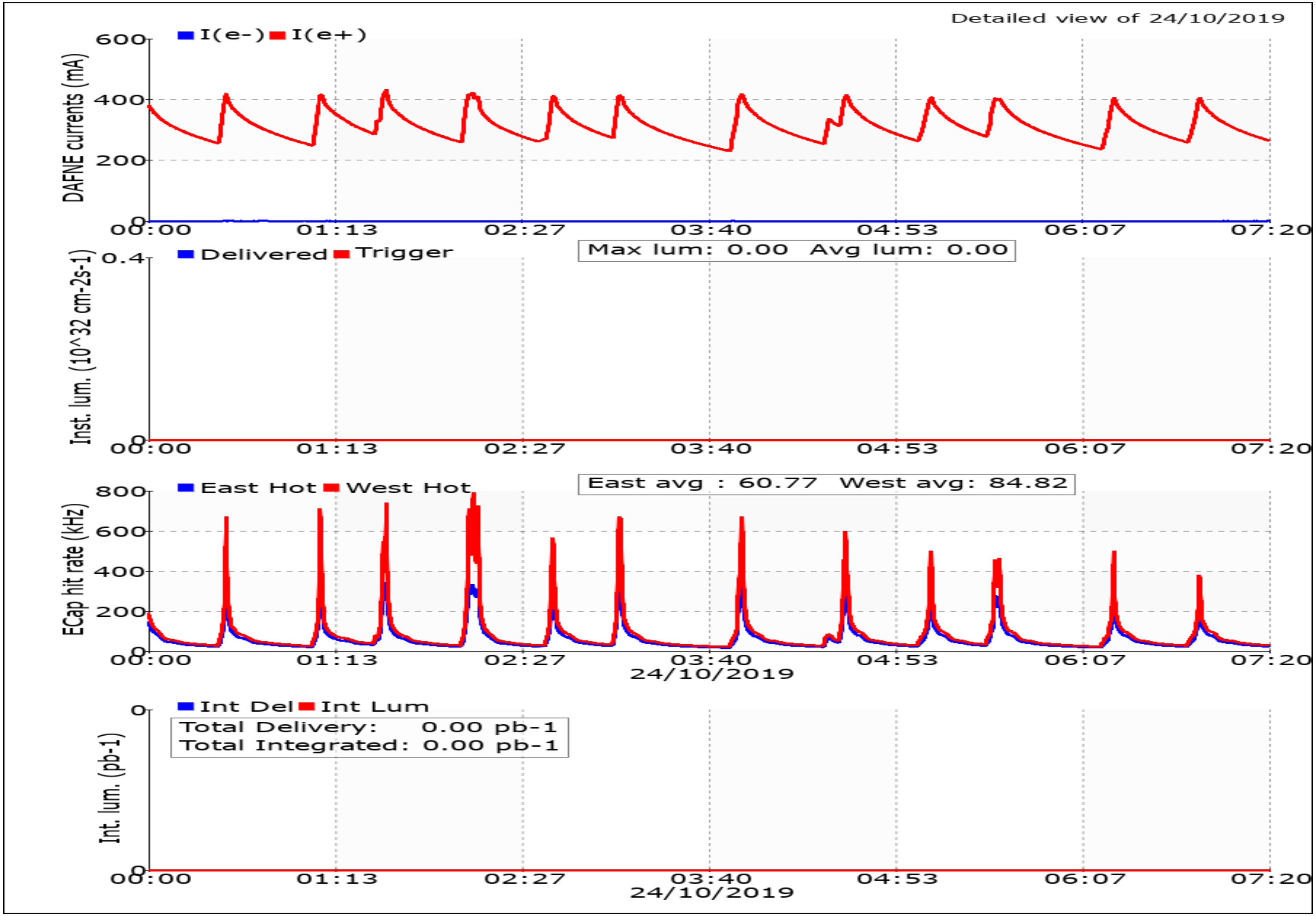




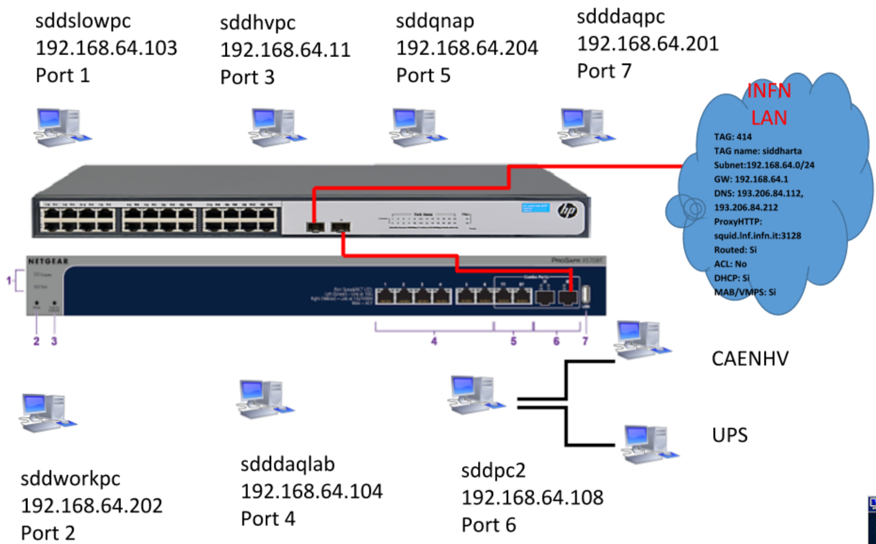
Online *beam* monitoring



Online beam monitoring



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.)

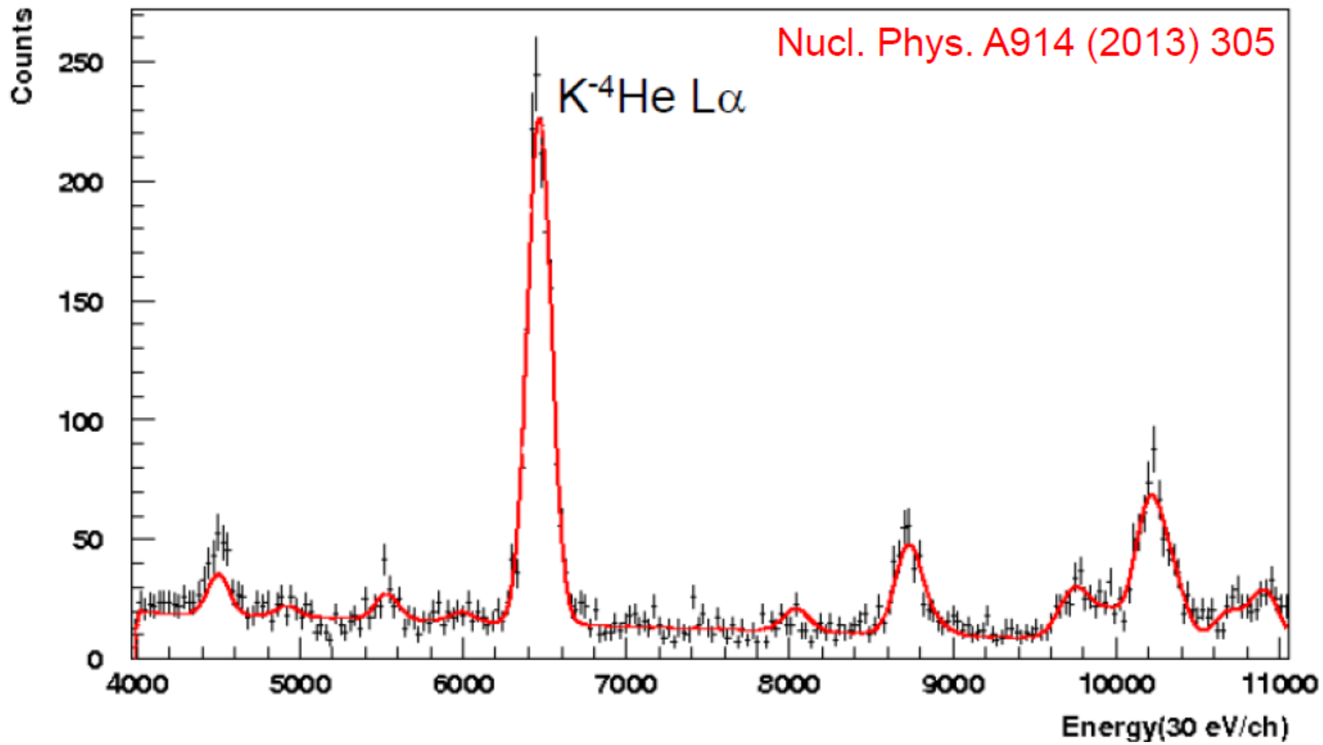
SIDDHARTA-2 present status

We are presently in Phase 1

during the commissioning of DAΦNE
optimisation of SIDDHARTINO for K-4He
(8 SDD arrays)

May 2019 – December 2019
or until the aim is reached
(S/B on K-^{4}He as better than 100/1)
in agreement with the LNF management

SIDDHARTINO – K-^{4}He test measurement



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Nuclear Physics A 914 (2013) 305–309

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

S/B was 10/1 for the K-^{4}He measurement with ~ 30 pb^{-1}

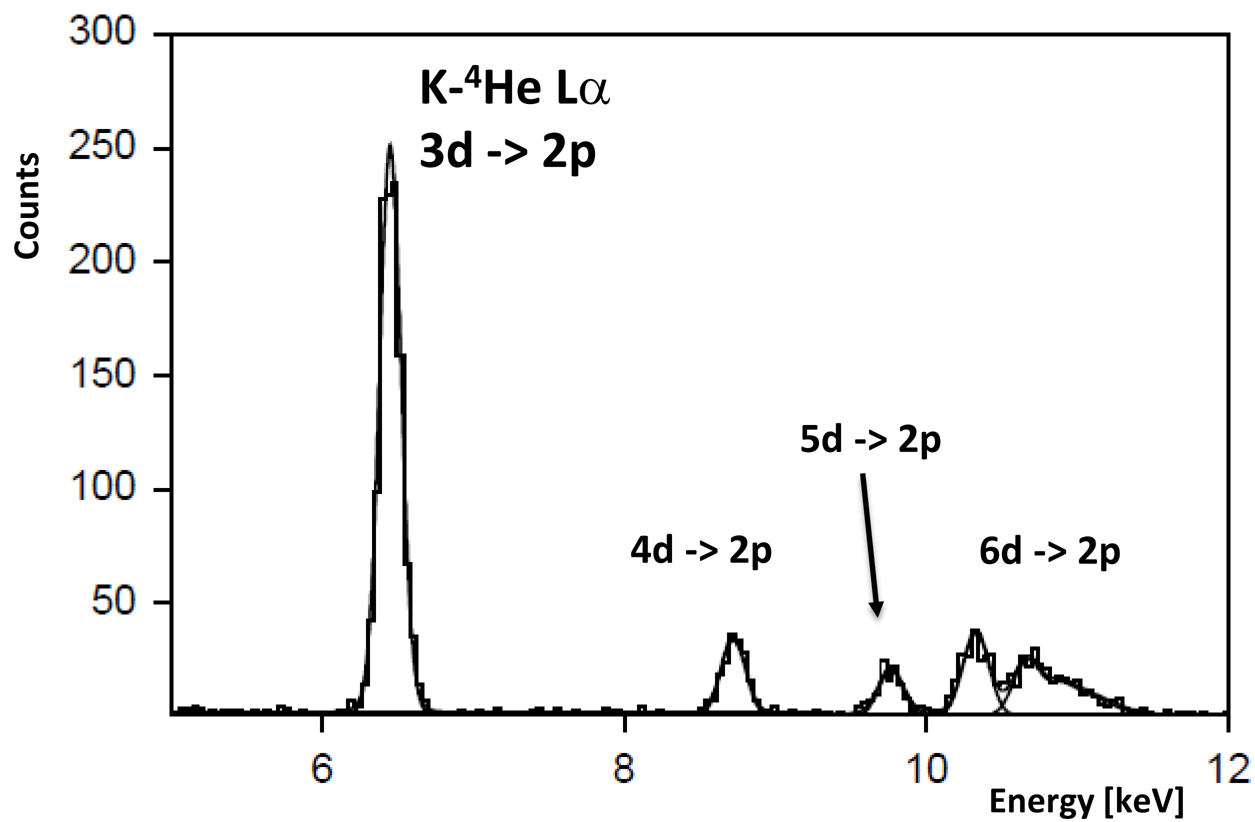
Kaonic Helium-4 SIDDHARTINO expected spectrum for about 50 pb^{-1}

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

About 1000 events in La peak, S/B > 100/1

(ideally should be 300/1)

Position precision : 6.452 +- 0.002 (stat) keV



SIDDHARTA-2 K-d measurement

Kaonic deuterium run in

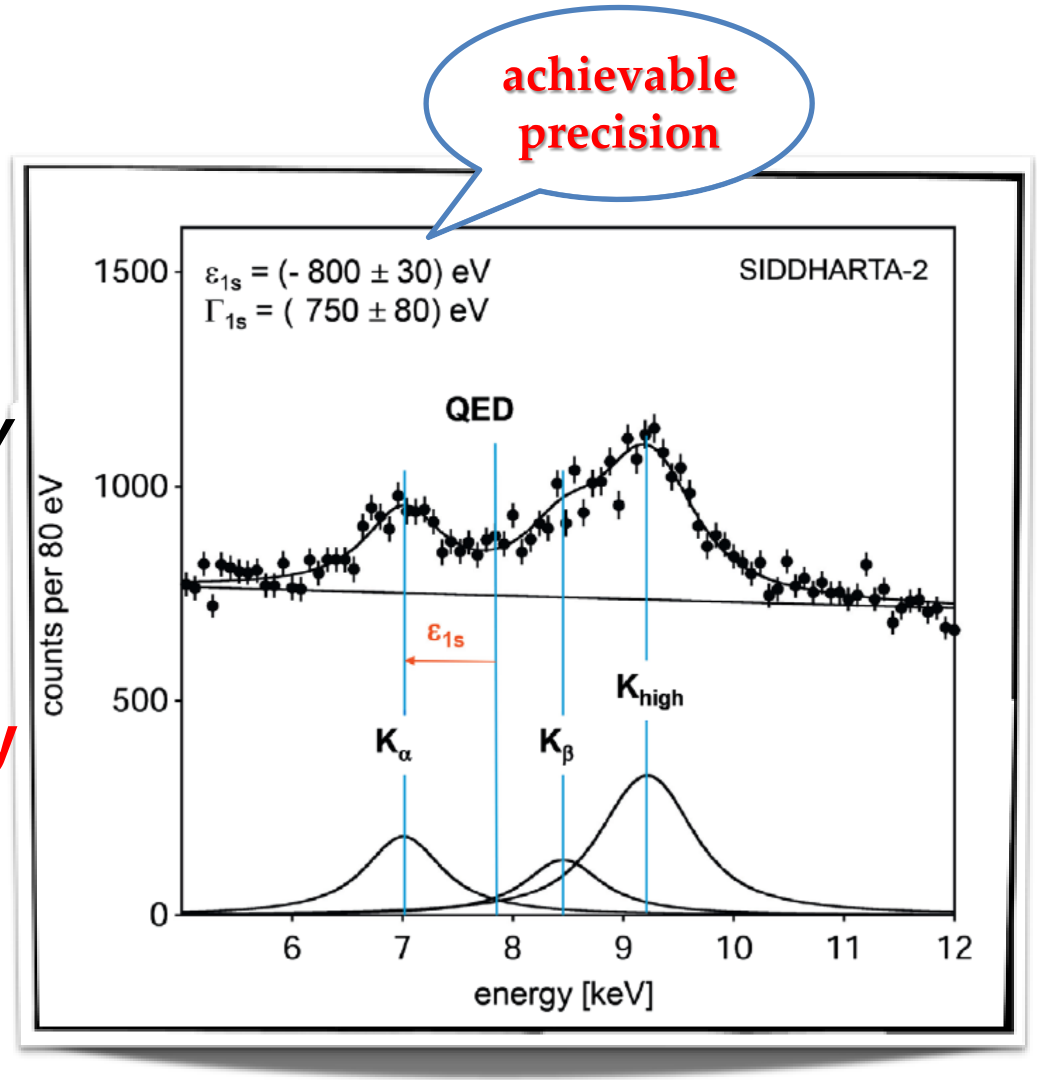
2020/2021

for S/B as 1/3:

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 $K^{-}p$) !



SIDDHARTA-2 plan

Phase 1

is over (S/B for K-^{4}He is about 100/1) we pass to

Phase 2

we will install all the SDDs (48 SDD arrays) at beginning of 2020 and start the *kaonic deuterium measurement* with a run for 800 pb^{-1}

Action plan for Kd measurement:

- run until summer (June 2020) with actual setup (about 300 pb^{-1} integrated);
- during summer break install veto2 second layer, adjust shielding, readout electronics and other optimizations;
- restart run from autumn 2020 with optimized setup (for other 500 pb-1);


Thank you!

SIDDHARTA-2 plan

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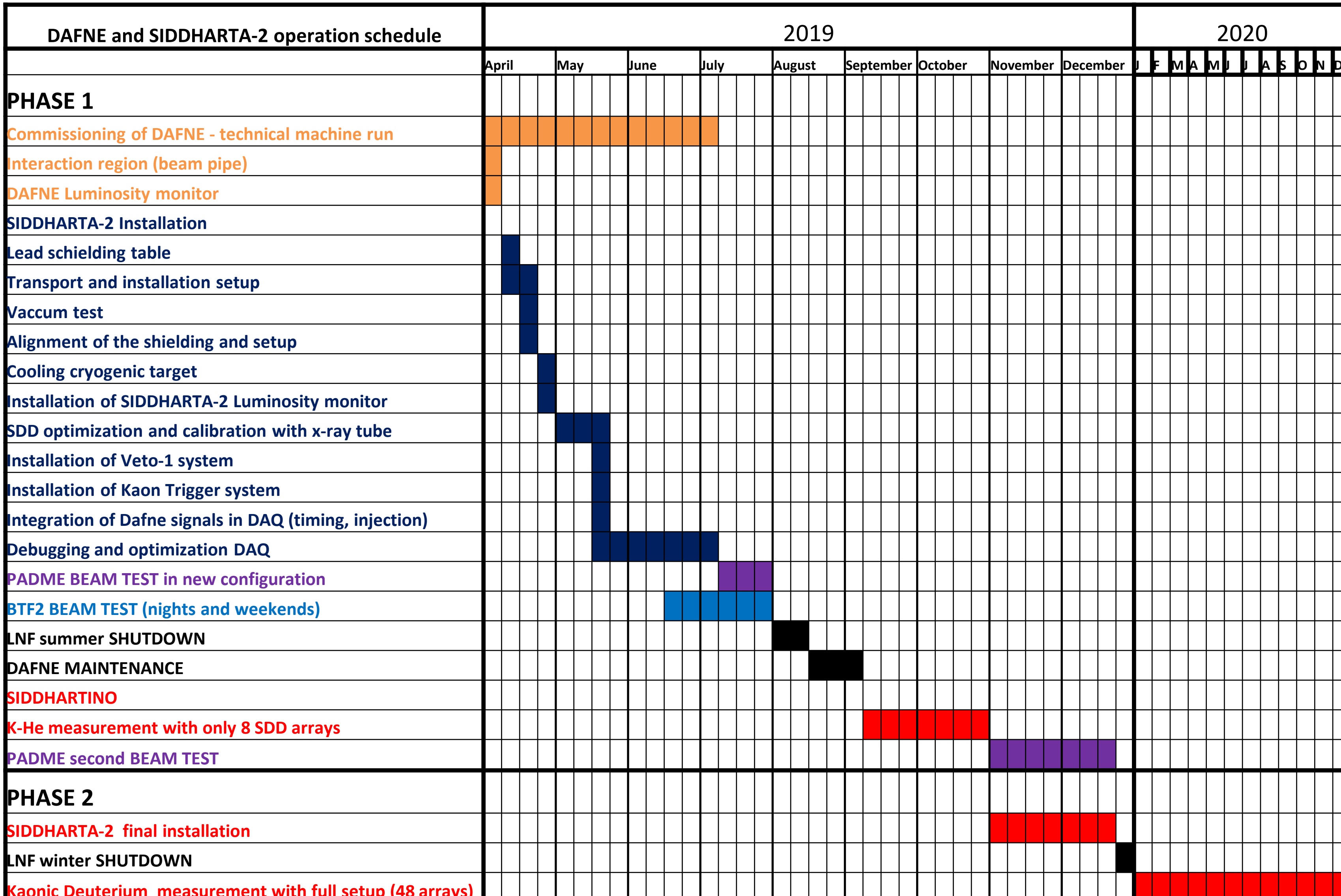
Spares

Strategy and Time Schedule



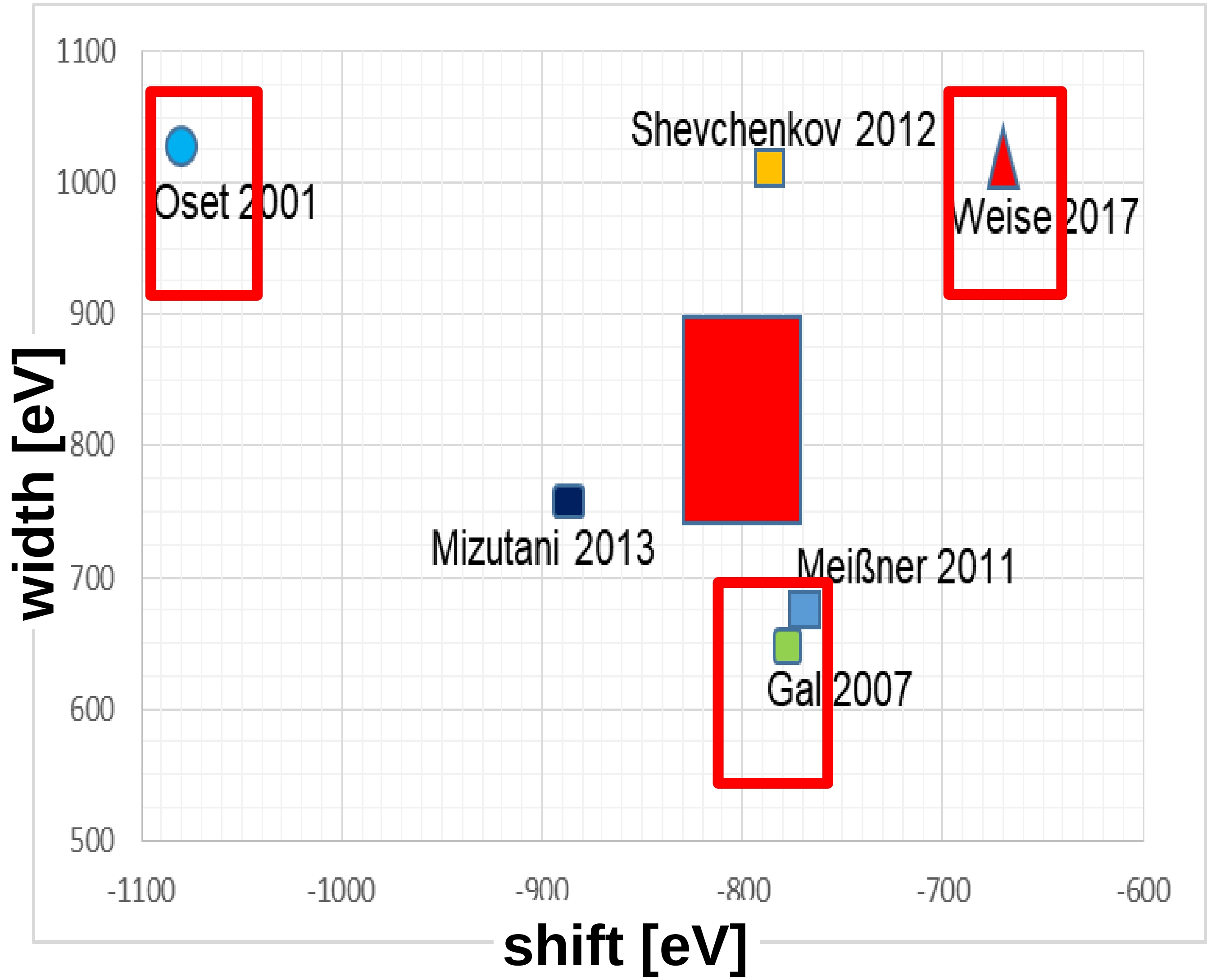
More details:

The modern era of light kaonic atom experiments

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

Rev. Mod. Phys. 91, 025006 – Published 20 June 2019

SIDDHARTA-2 kaonic deuterium at DAΦNE



Future programme and perspectives:

- **Feasibility studies in parallel with Siddharta-2**
  (Ge and VOXES) -> Alessandro Scordo
- **Proposal for Extension/New Scientific Program**

- **Kaon mass - precision measurement at a level < 7 keV**

- **Kaonic helium transitions to the 1s level**

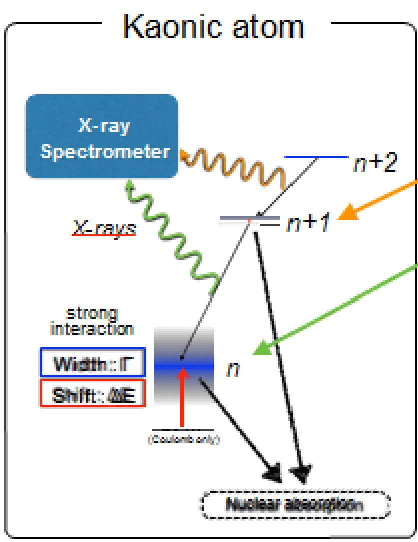
- **Other light kaonic atoms (K^- O, K^- C,…)**
- **Heavier kaonic atoms (K^- Si, K^- Pb…)**
- **Radiative kaon capture – Λ(1405) study**
- **Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)**

New ideas will be discussed during: STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics workshop at ECT* - 21- 15 October – we invite you to participate!

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.

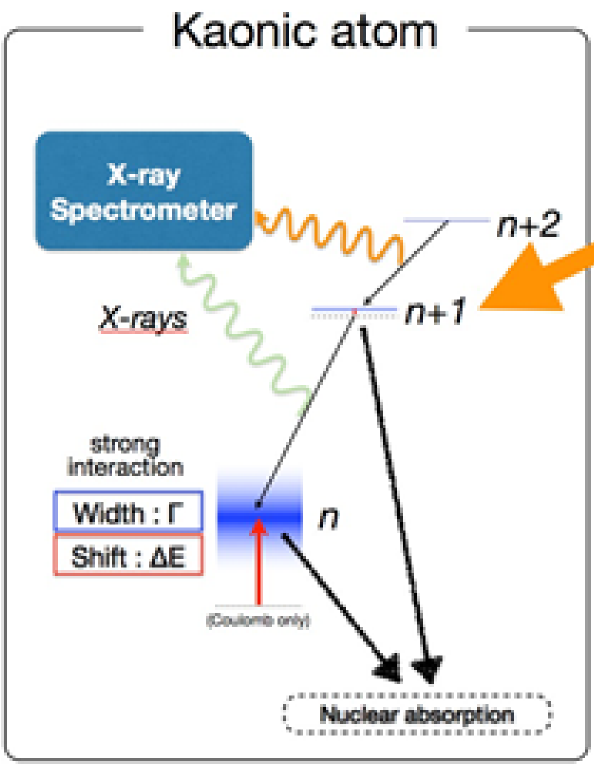
	r_m	Re(full)	Re(1N)	Re(mN)	Im(full)	Im(1N)	Im(mN)
Ni	3.72	3.34	3.82	2.86	3.73	4.46	3.12
Pb	5.56	5.21	5.71	4.78	5.46	6.23	5.00
			1N	mN		1N	mN

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)

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:

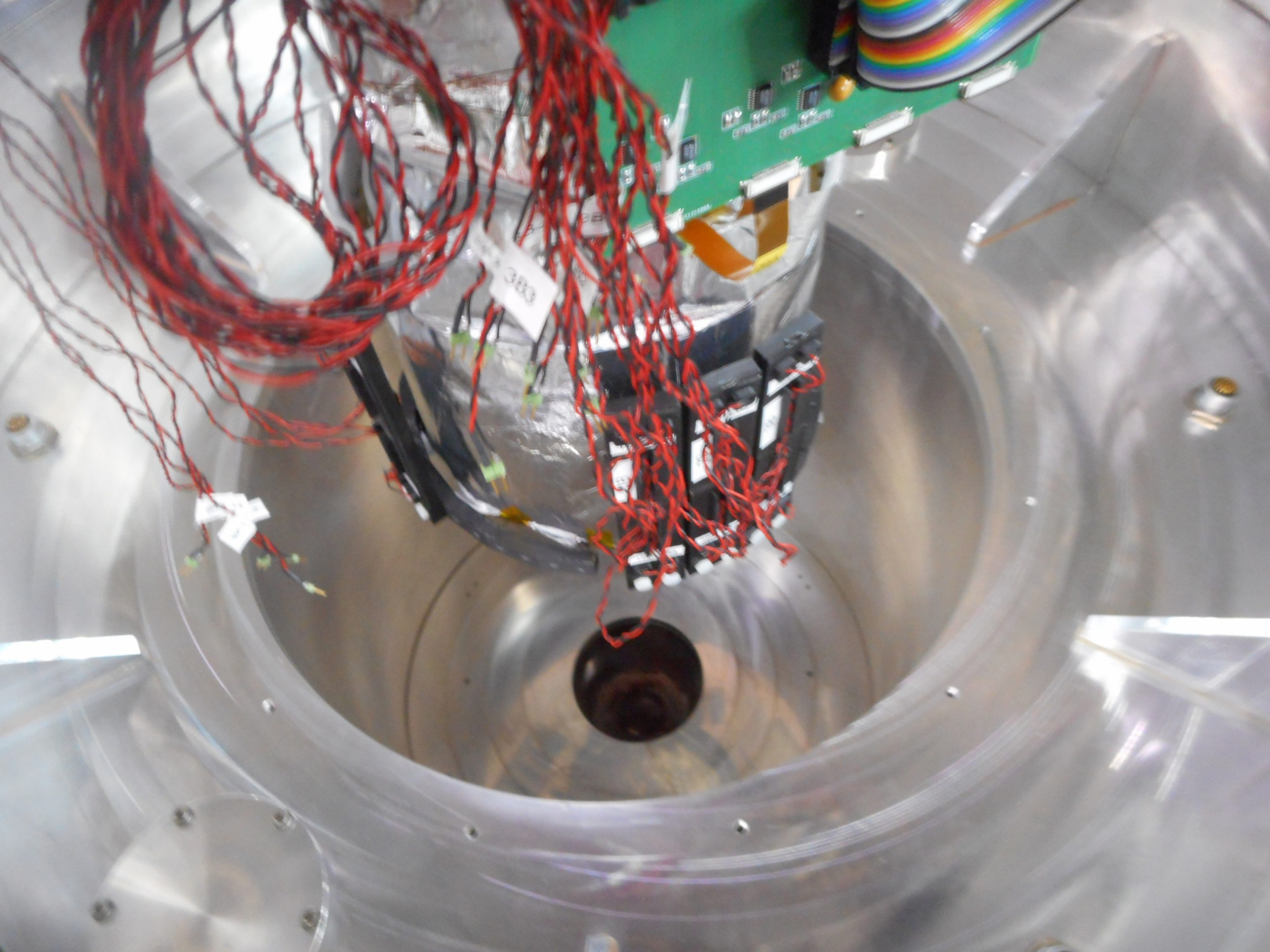
  by gaining in solid angle taking advantage of

  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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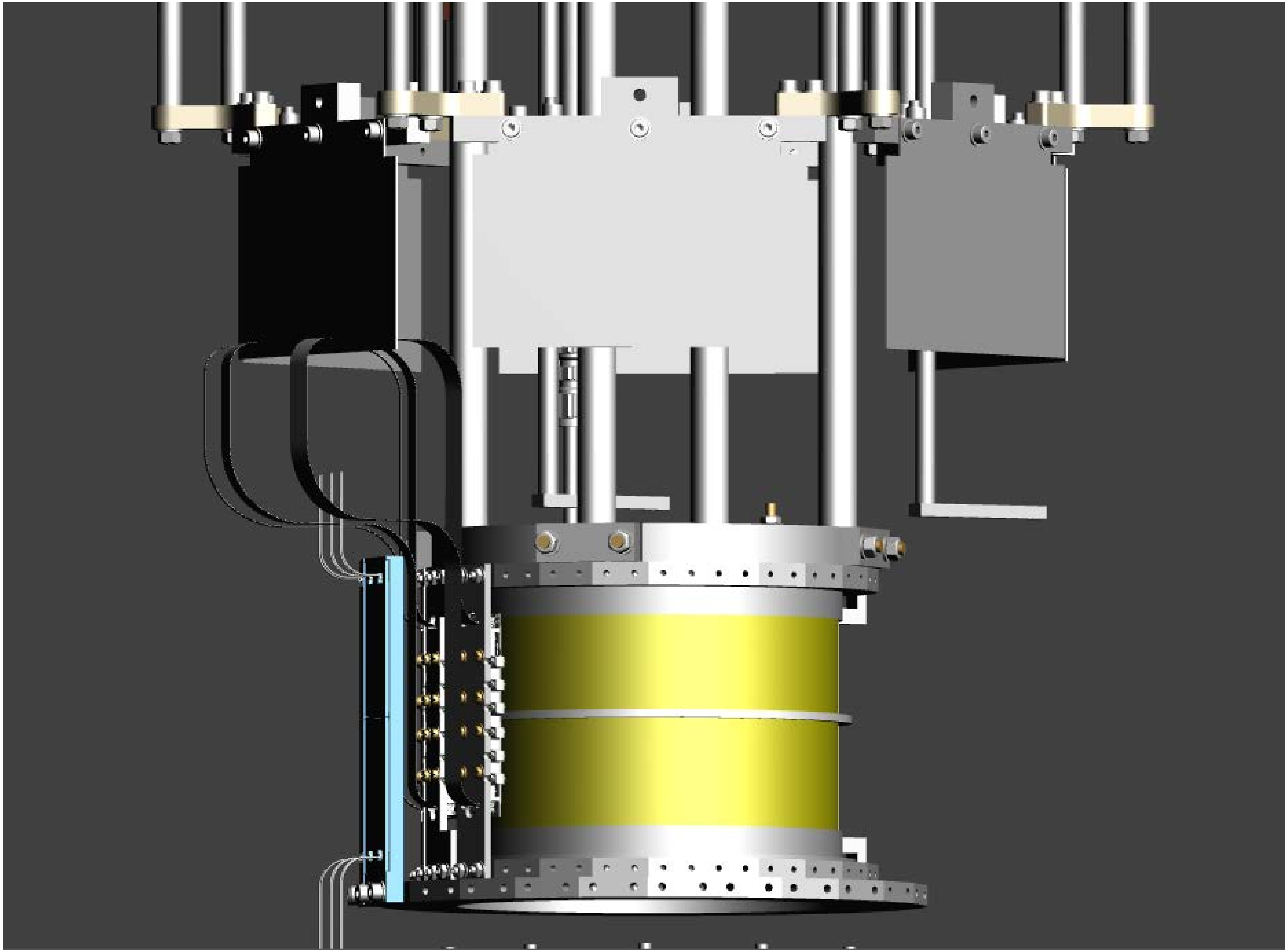
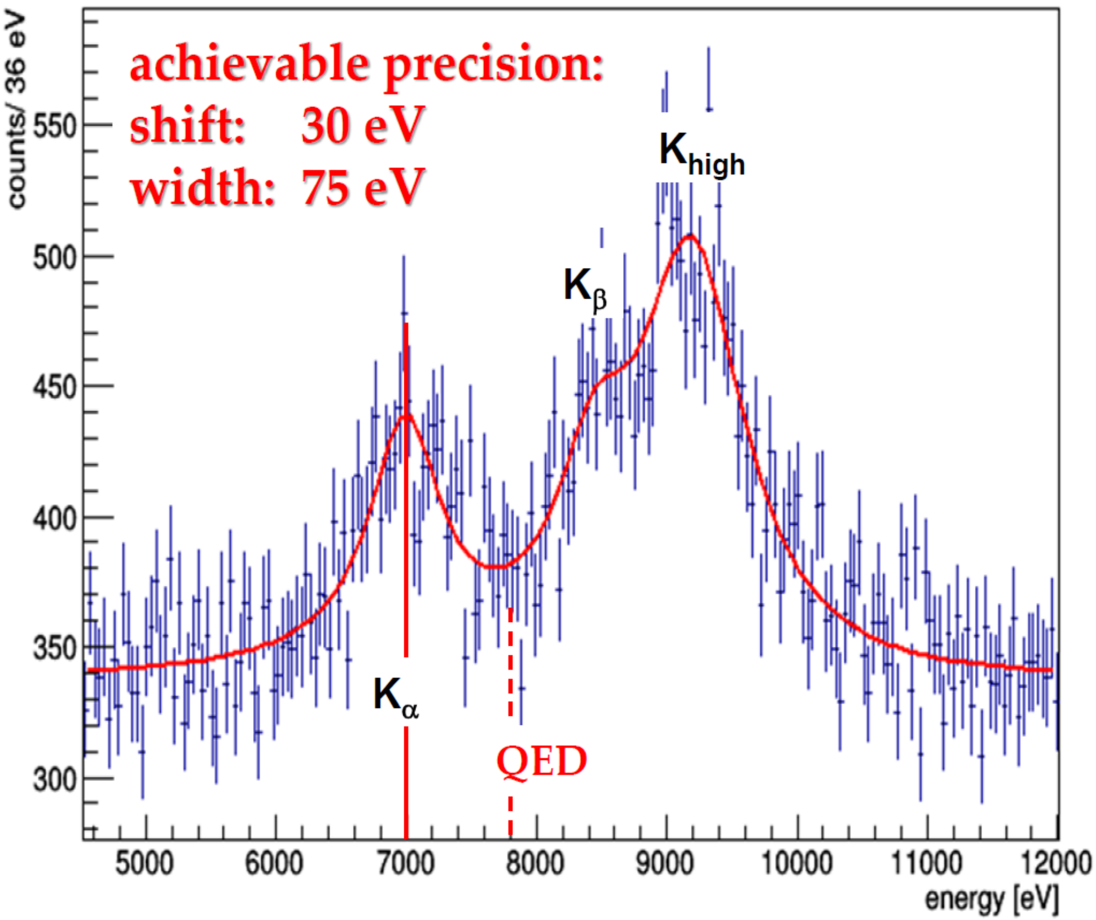


SDDHARTA-2 expected result

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

For more information

REVIEWS OF MODERN PHYSICS

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

ABSTRACT

ABSTRACT

This review article covers the modern era of experimental kaonic atoms studies, encompassing twenty years of activity, defined by breakthroughs in technological developments which allowed performing a series of long-awaited precision measurements. Kaonic atoms are atomic systems where an electron is replaced by a negatively charged kaon, containing the strange quark, which interacts in the lowest orbits with the nucleus also by the strong interaction. As a result, their study offers the unique opportunity to perform experiments equivalent to scattering at vanishing relative energy. This allows to study the strong interaction between the antikaon and the nucleon or the nucleus "at threshold", namely at zero relative energy, without the need of {} extrapolation to zero energy, as in scattering experiments. The fast progress achieved in performing precision light kaonic atoms experiments, which also solved

SIDDHARTA-2 - new organization structure

Spokespersons:
Catalina Curceanu (LNF-INFN)
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Carlo Fiorini (Politecnico di Milano)
Slow Control:
Mario Bragadireanu (IFIN-HH)
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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:
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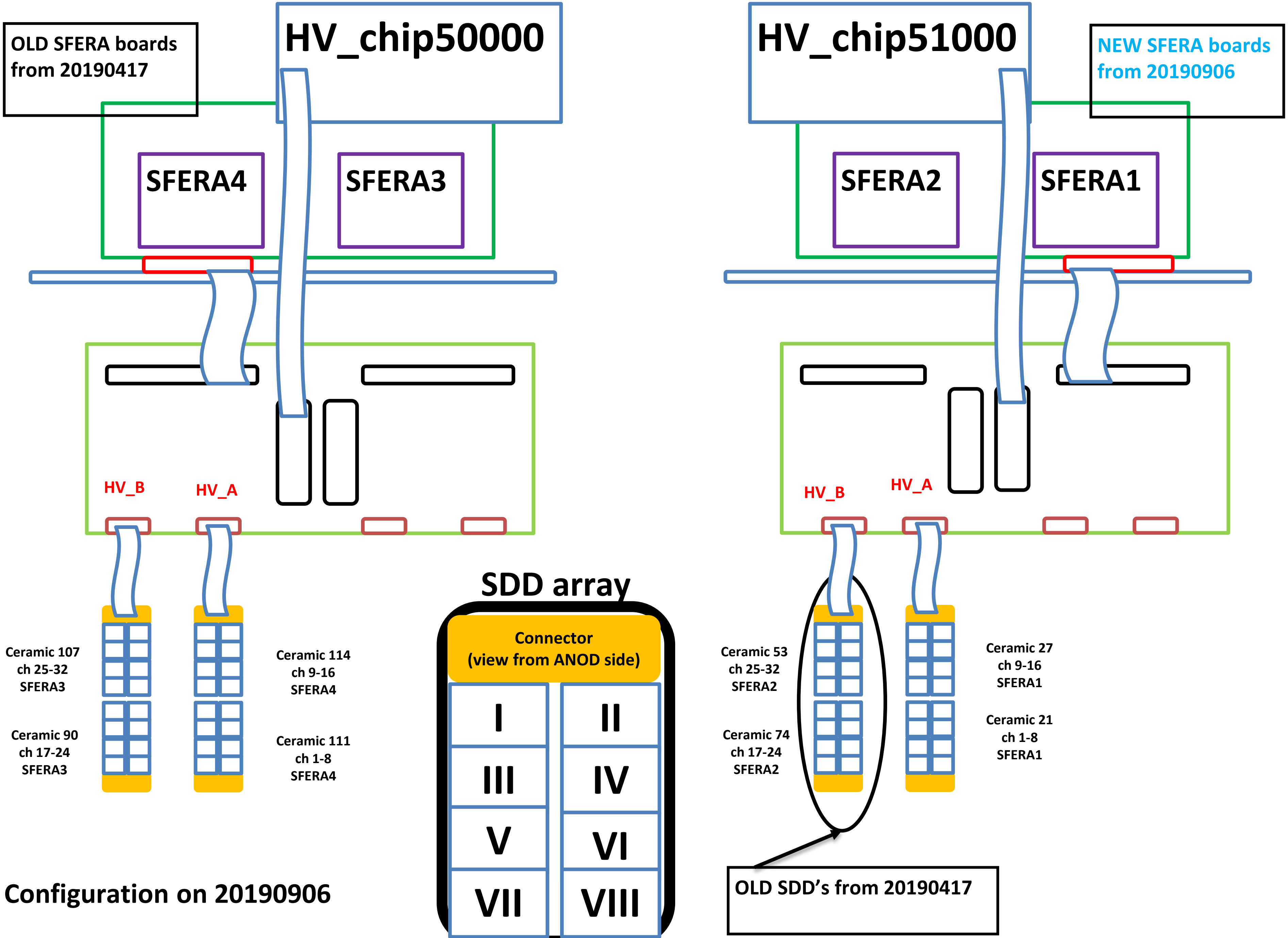
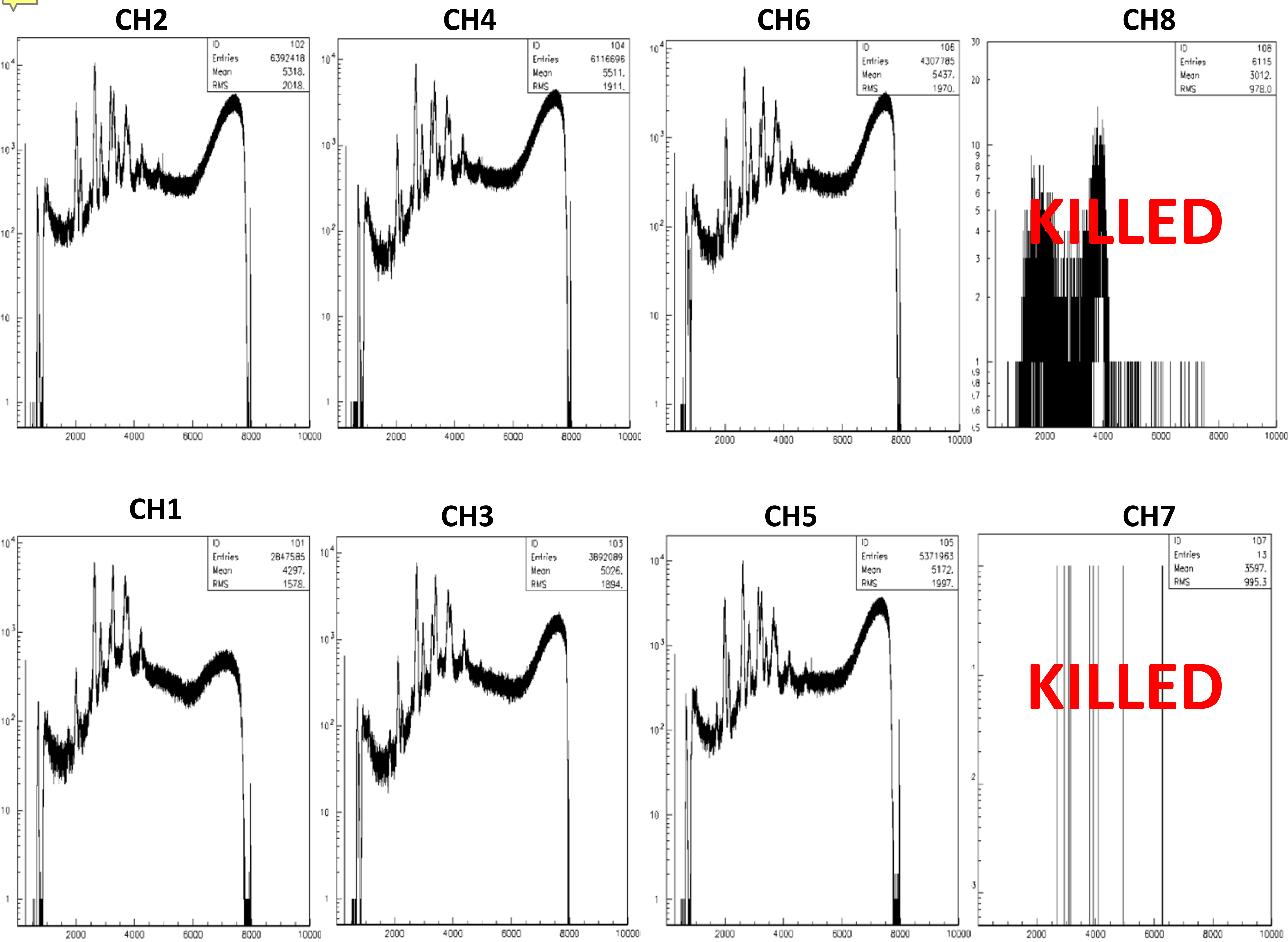
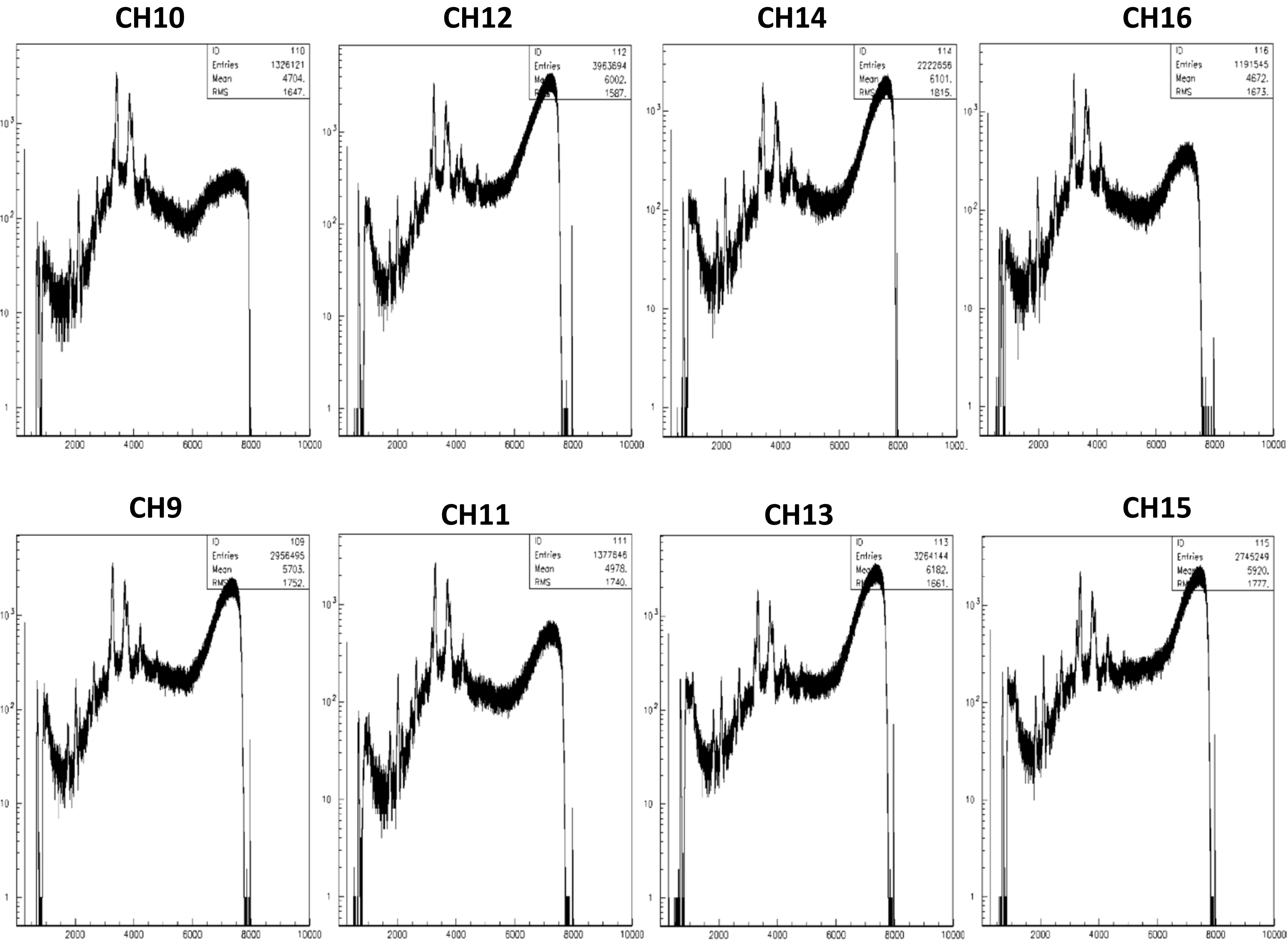
Alessandro Scordo, Magda Skurzok,
Diana Sirghi (LNF-INFN)
Marlene Tuchler (SMI)
VOXES system:
Alessandro Scordo (LNF-INFN)
Germanium detector system:
Damir Bosnar (Uni. Zagreb)



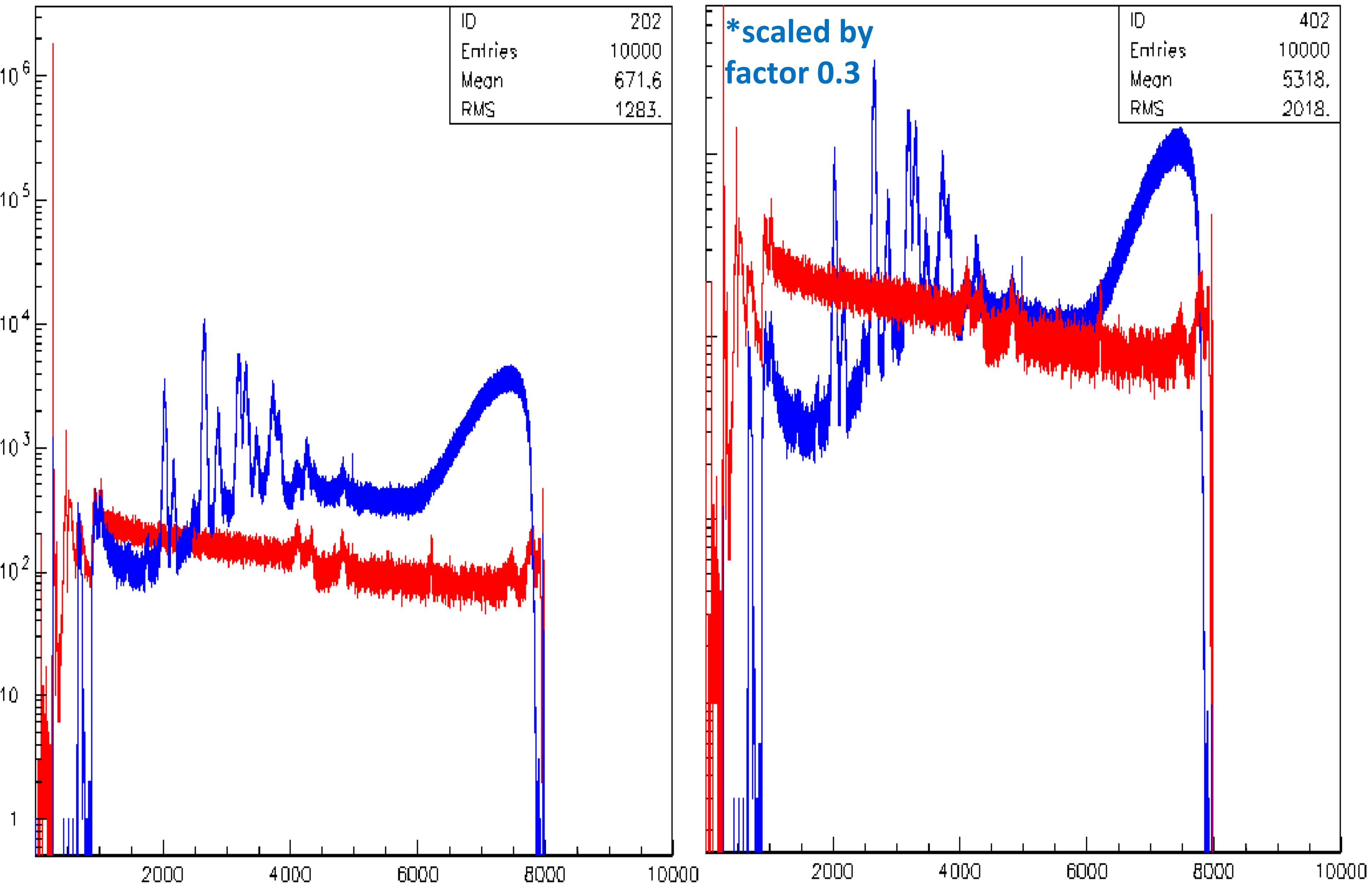
Configuration on 20190906



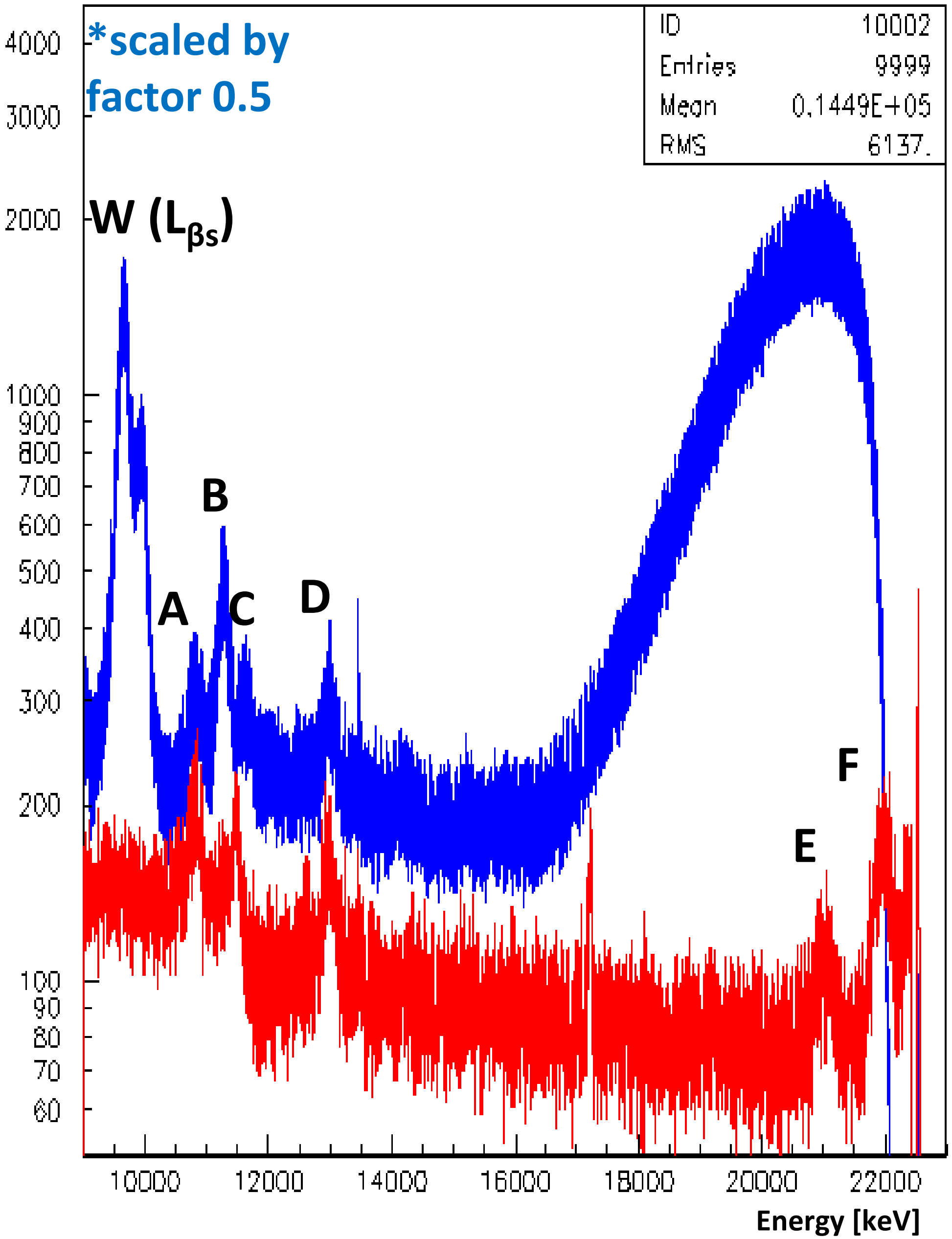
CH2
ID 102
Entries 6392418
Mean 5318.
RMS 2018.
CH4
ID 104
Entries 6116696
Mean 5511.
RMS 1911.
CH6
ID 106
Entries 4307785
Mean 5437.
RMS 1970.
CH8
ID 108
Entries 6115
Mean 3012.
RMS 978.0
KILLED
CH1
ID 101
Entries 2847585
Mean 4297.
RMS 1578.
CH3
ID 103
Entries 3892089
Mean 5026.
RMS 1894.
CH5
ID 105
Entries 5371963
Mean 5172.
RMS 1997.
CH7
ID 107
Entries 13
Mean 3597.
RMS 995.3
KILLED


CH10
ID 110
Entries 1326121
Mean 4704.
RMS 1647.
CH12
ID 112
Entries 3963694
Mean 6002.
RMS 1587.
CH14
ID 114
Entries 2222656
Mean 6101.
RMS 1815.
CH16
ID 116
Entries 1191545
Mean 4672.
RMS 1673.
CH9
ID 109
Entries 2956495
Mean 5703.
RMS 1752.
CH11
ID 111
Entries 1377646
Mean 4978.
RMS 1740.
CH13
ID 113
Entries 3264144
Mean 6182.
RMS 1661.
CH15
ID 115
Entries 2745249
Mean 5920.
RMS 1777.

DAFNE vs x-ray TUBES (raw) (BUS 5 CH 49)



DAFNE vs x-ray TUBES (calibrated spectra)



A: ^{83}Bi (L_α)

B: ^{74}W (L_γ)

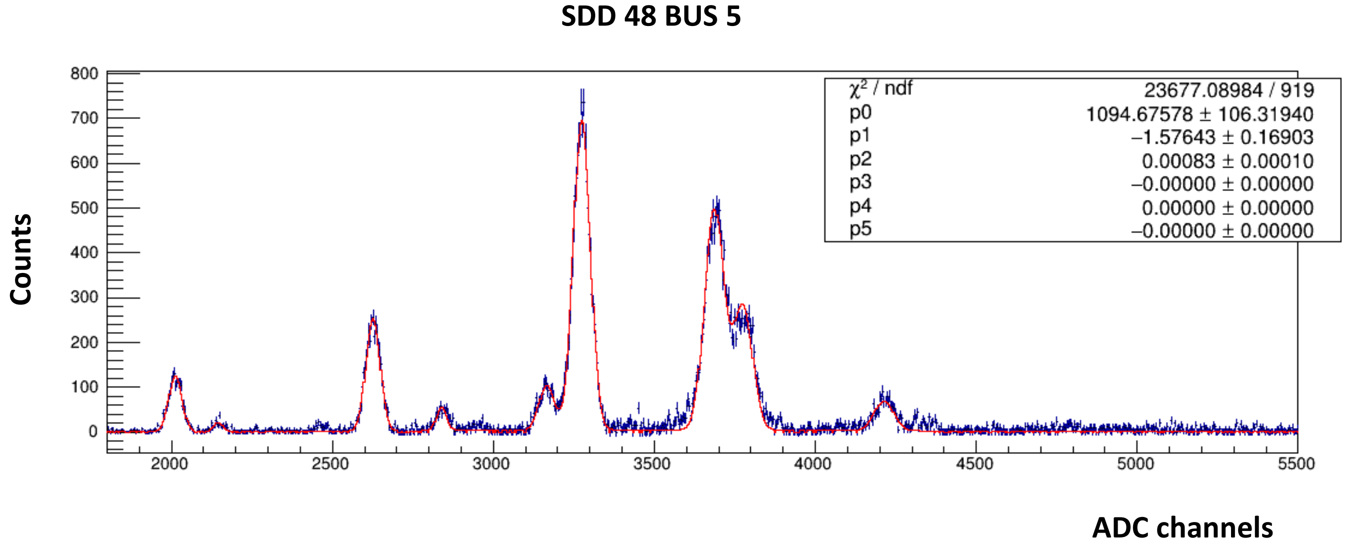
C: ^{79}Au (L_β)

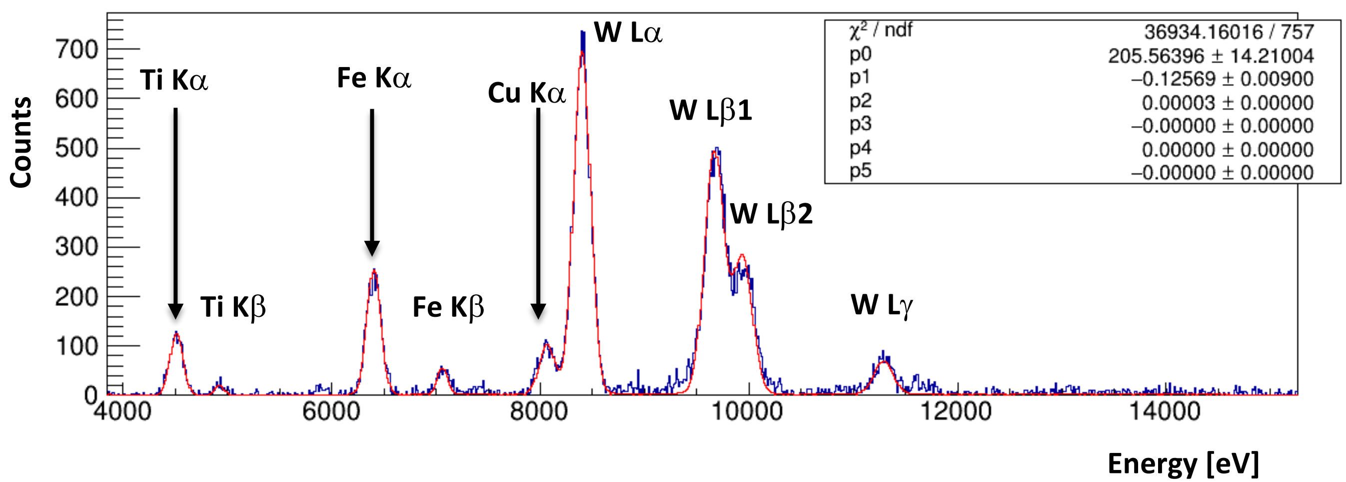
D: ^{83}Bi (L_β)

E: ^{46}Pd (K_α)

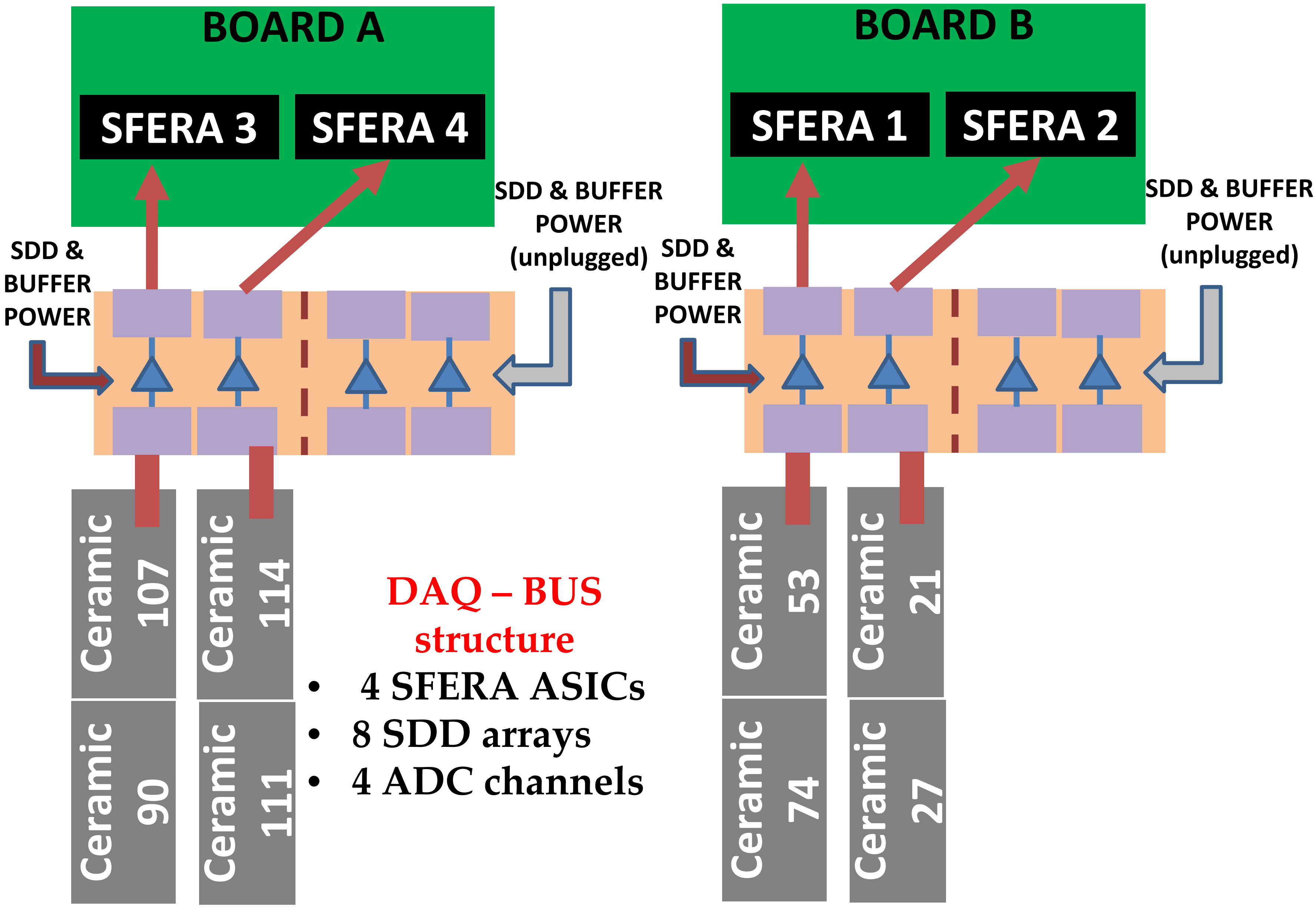
F: ^{47}Ag (K_α)

Calibration of SDDs with the x-ray tube in DAFNE





BUS configuration



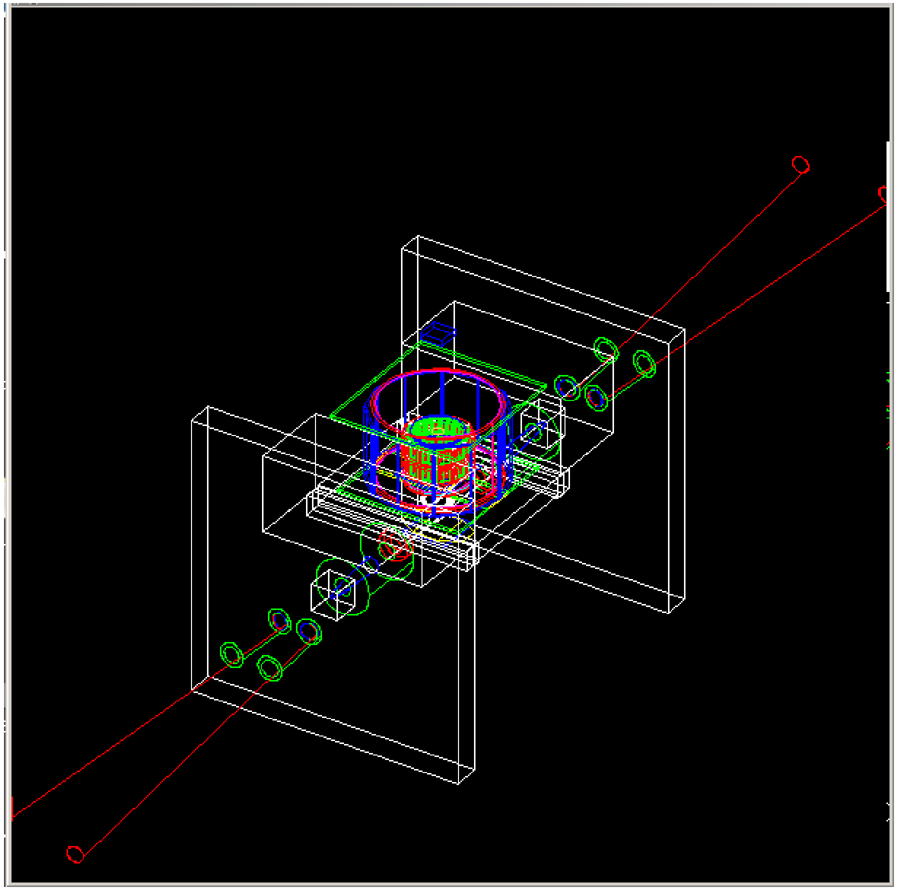
DAQ – BUS structure

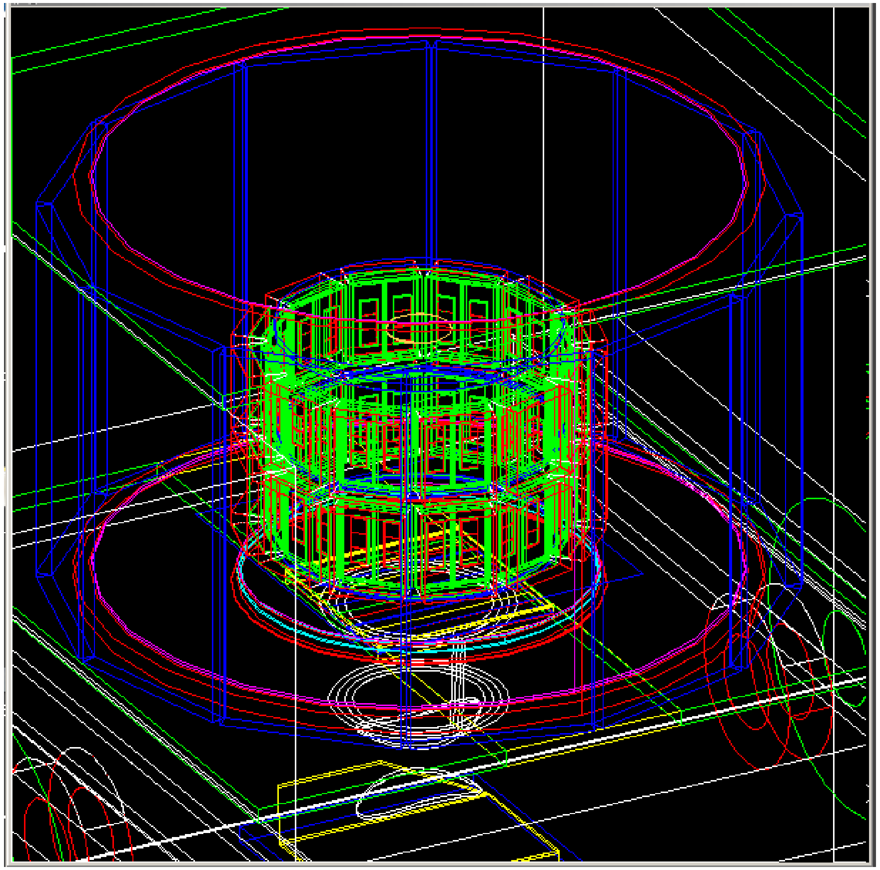
- 4 SFERA ASICs
- 8 SDD arrays
- 4 ADC channels

Monte Carlo simulations

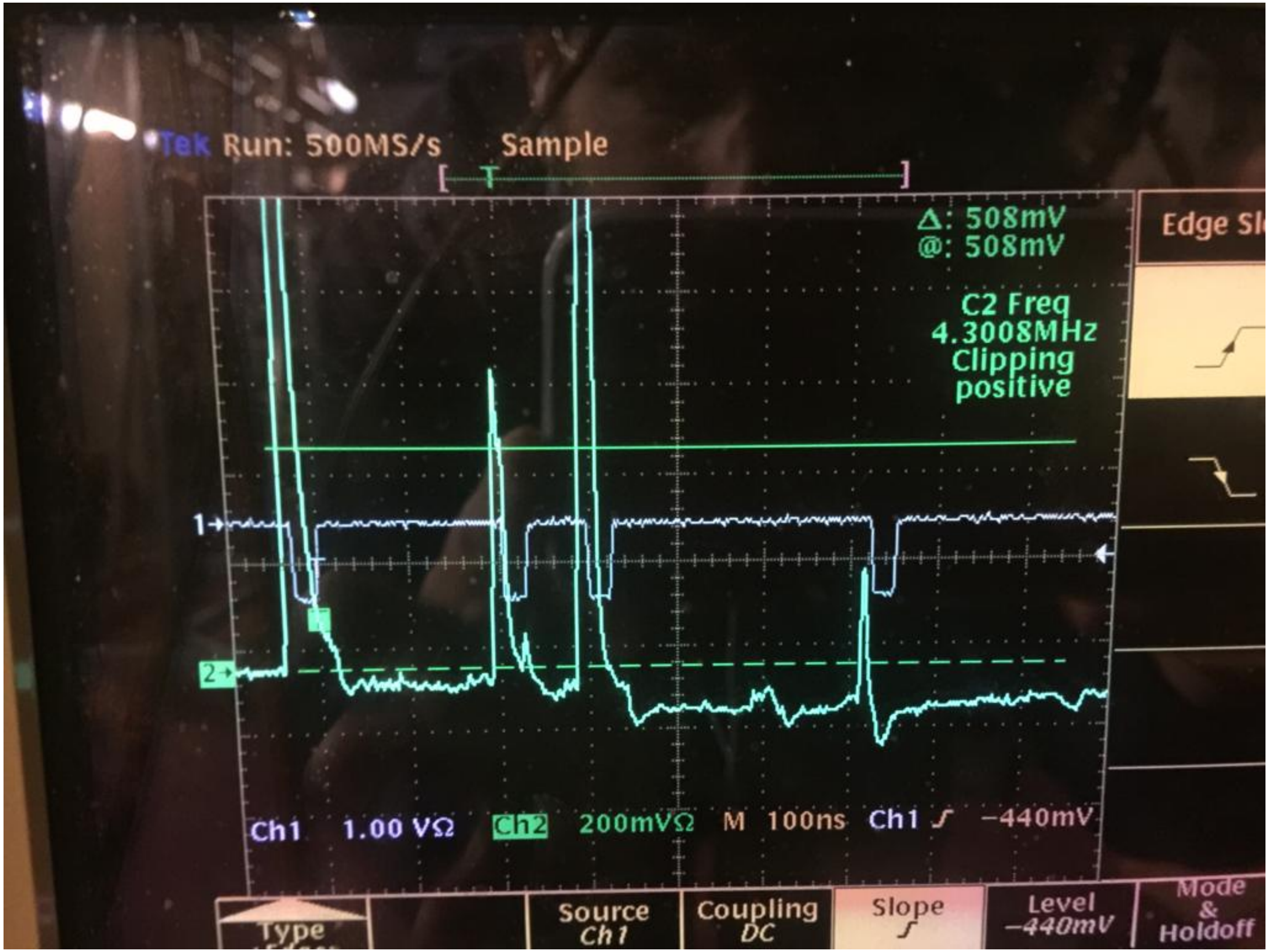
Simulation in the framework of GEANT4

Machine conditions – similar with SIDDHARTA 2009
(more details in the D. Sirghi talk)

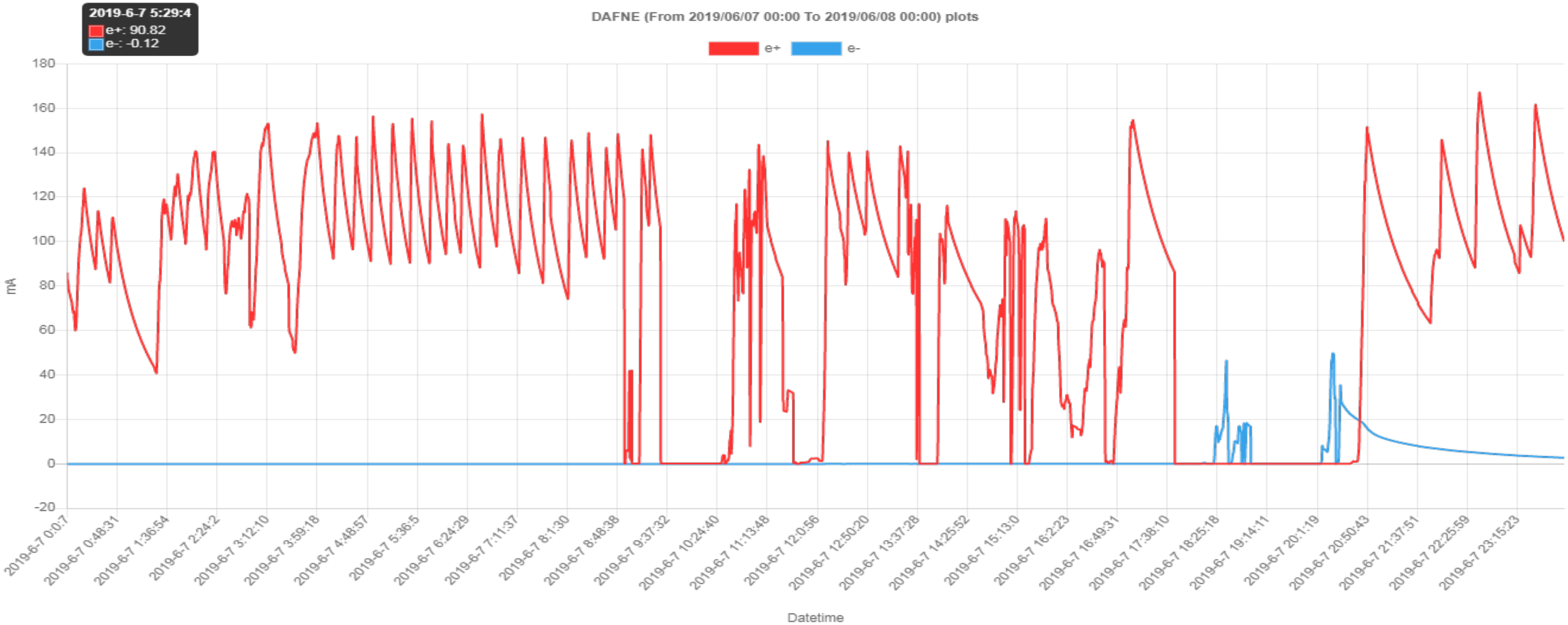


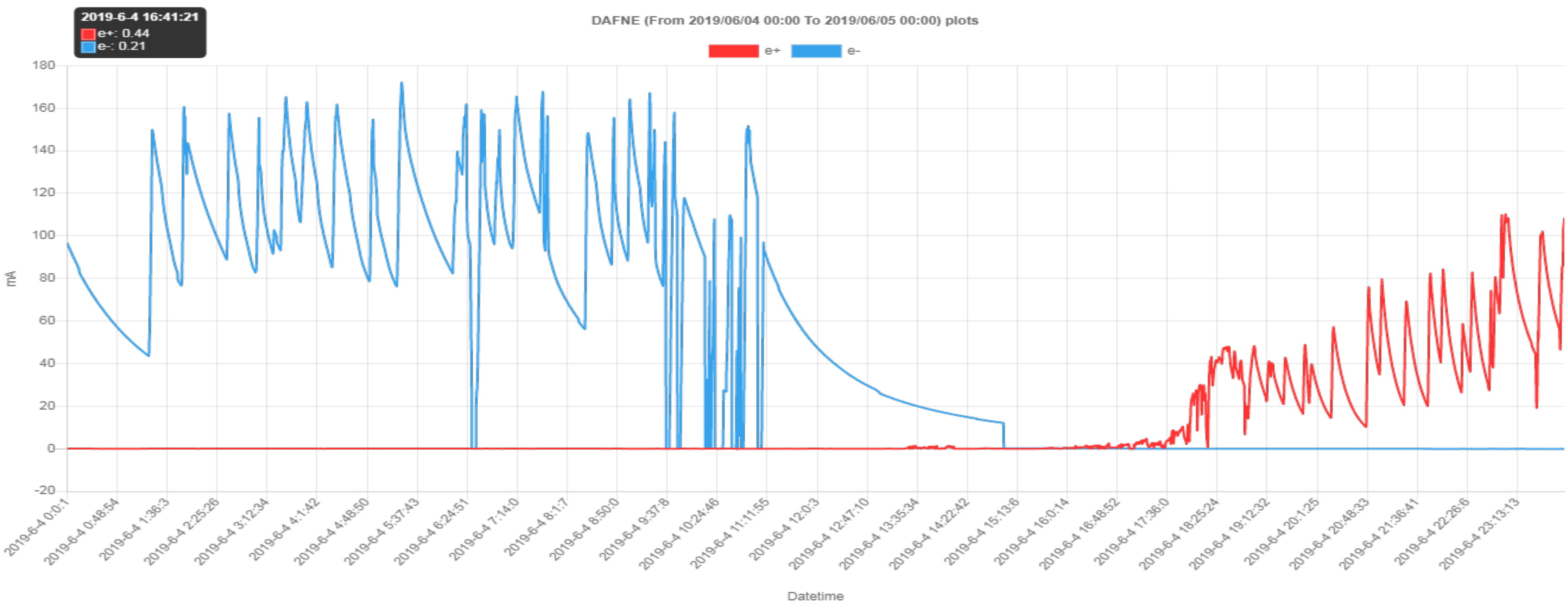


First signals from the Luminosity monitor with beam

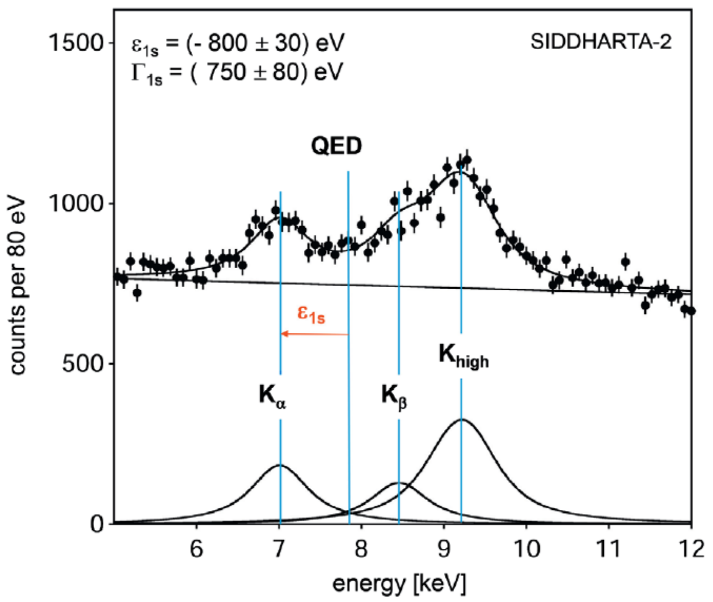


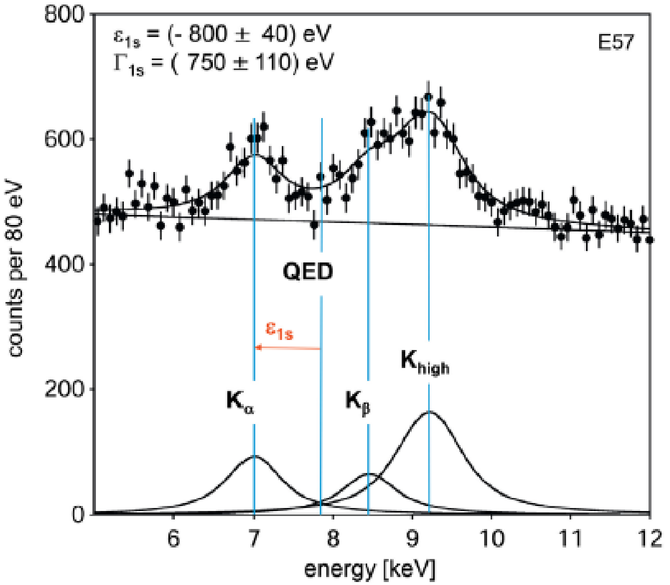
optimization with the beam in progress


2019-6-7 5:29:4
e+: 90.82
e-: -0.12
DAFNE (From 2019/06/07 00:00 To 2019/06/08 00:00) plots
e+
e-
mA
180
160
140
120
100
80
60
40
20
0
-20
2019-6-7 0:0:7
2019-6-7 0:48:31
2019-6-7 1:36:54
2019-6-7 2:24:2
2019-6-7 3:12:10
2019-6-7 3:59:18
2019-6-7 4:48:57
2019-6-7 5:36:5
2019-6-7 6:24:29
2019-6-7 7:11:37
2019-6-7 8:1:30
2019-6-7 8:48:38
2019-6-7 9:37:32
2019-6-7 10:24:40
2019-6-7 11:13:48
2019-6-7 12:0:56
2019-6-7 12:50:20
2019-6-7 13:37:28
2019-6-7 14:25:52
2019-6-7 15:13:0
2019-6-7 16:2:23
2019-6-7 16:49:31
2019-6-7 17:38:10
2019-6-7 18:25:18
2019-6-7 19:14:11
2019-6-7 20:1:19
2019-6-7 20:50:43
2019-6-7 21:37:51
2019-6-7 22:25:59
2019-6-7 23:15:23
Datetime


2019-6-4 16:41:21
e+: 0.44
e-: 0.21
DAFNE (From 2019/06/04 00:00 To 2019/06/05 00:00) plots
e+
e-
mA
180
160
140
120
100
80
60
40
20
0
-20
2019-6-4 0:0:1
2019-6-4 0:48:54
2019-6-4 1:36:3
2019-6-4 2:25:26
2019-6-4 3:12:34
2019-6-4 4:1:42
2019-6-4 4:48:50
2019-6-4 5:37:43
2019-6-4 6:24:51
2019-6-4 7:14:0
2019-6-4 8:1:7
2019-6-4 8:50:0
2019-6-4 9:37:8
2019-6-4 10:24:46
2019-6-4 11:11:55
2019-6-4 12:0:3
2019-6-4 12:47:10
2019-6-4 13:35:34
2019-6-4 14:22:42
2019-6-4 15:13:6
2019-6-4 16:0:14
2019-6-4 16:48:52
2019-6-4 17:36:0
2019-6-4 18:25:24
2019-6-4 19:12:32
2019-6-4 20:1:25
2019-6-4 20:48:33
2019-6-4 21:36:41
2019-6-4 22:26:6
2019-6-4 23:13:13
Datetime

The Monte Carlo simulations for kaonic deuterium

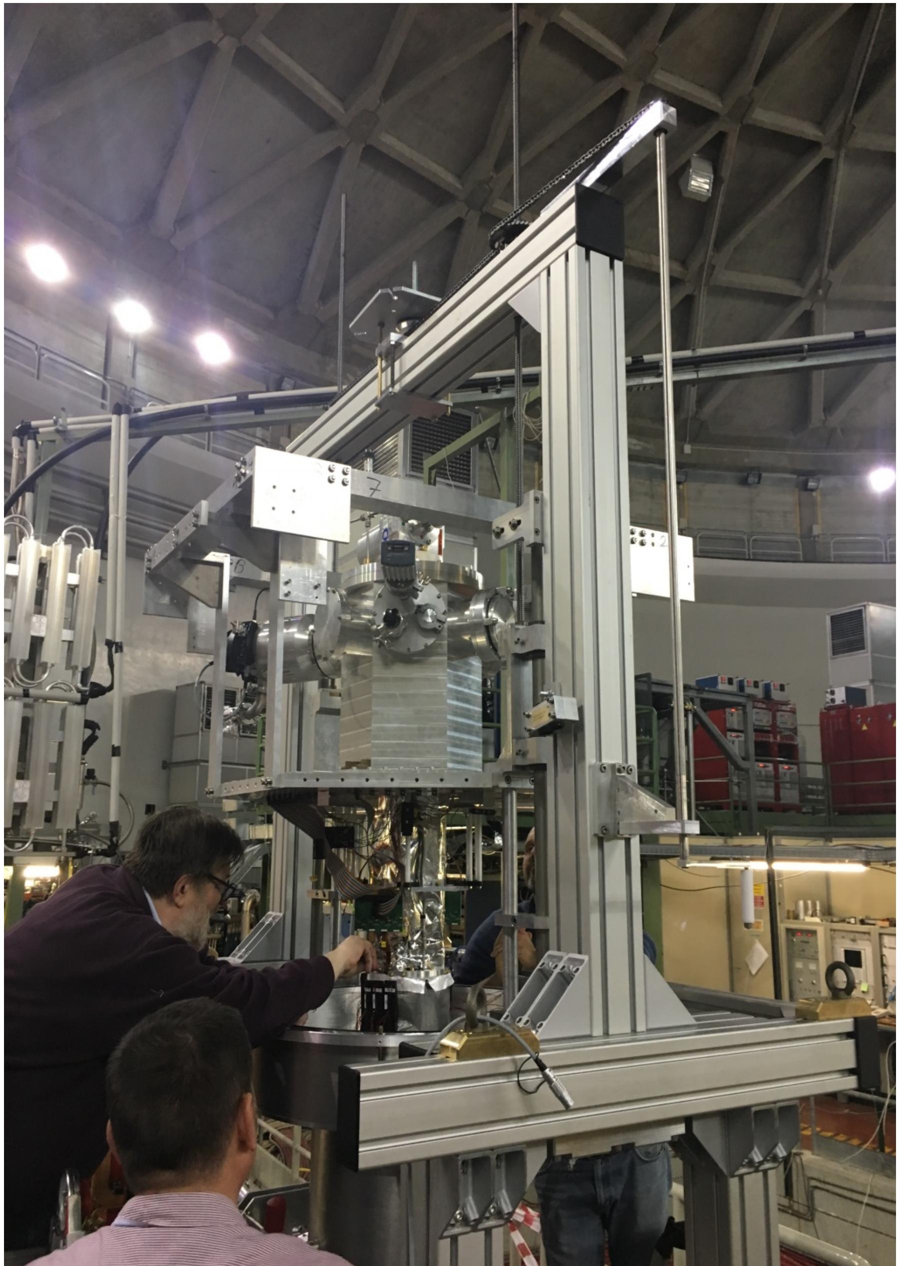




KH results:

$\varepsilon_{1S} = -283 \pm 36(\text{stat}) \pm 6(\text{syst})$ eV

$\Gamma_{1S} = 541 \pm 89(\text{stat}) \pm 22(\text{syst})$ eV



… internal components

… experienced adjustments . …