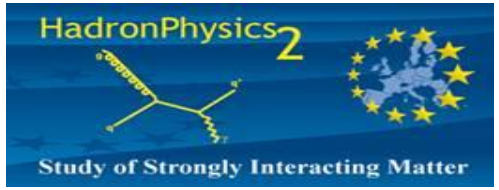
SIDDHARTA - 2
STATUS REPORT

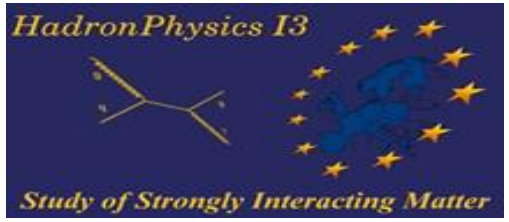
Johann Zmeskal
for the SIDDHARTA-2 Collaboration

56th LNF-INFN SCIENTIFIC COMMITTEE
November 5, 2018

SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications





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

CONTENT

Scientific Motivation

SIDDHARTA-2 Setup

- Platform / mounting frame
- Installation of SIDDHARTA-2 apparatus
  - 2-stage cooling + CryoTiger
  - Silicon Drift Detector
  - Veto-2 systems
  - Luminosity monitor

Strategy and Time Schedule

The scientific goal

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

Started with the precision measurement of ***shift*** and ***width*** of ***kaonic hydrogen***

- **NOW first measurement of kaonic deuterium**
  to extract the antikaon-nucleon isospin dependent scattering lengths

- ❑ chiral symmetry breaking (mass problem)
- ❑ EOS for neutron stars

The modern era of light kaonic atoms experiments

Catalina Curceanu,* Carlo Guaraldo, and Mihail Iliescu

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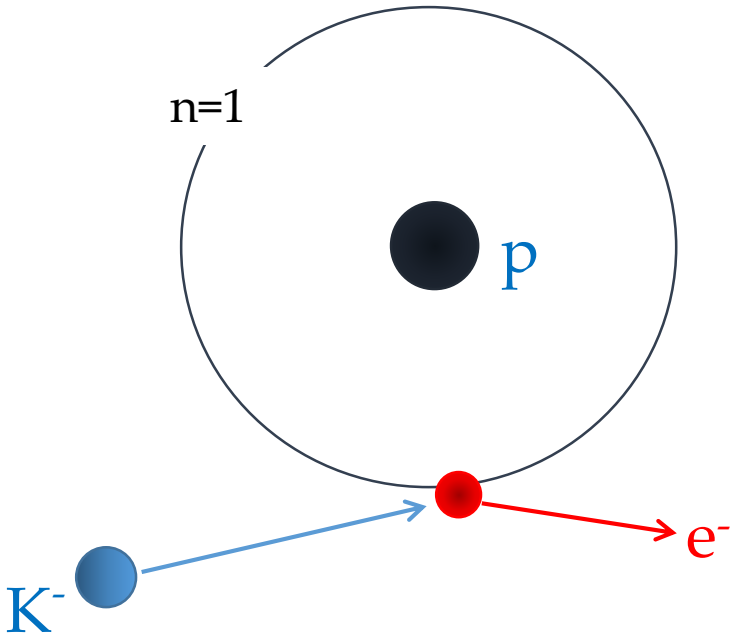
Lund Univeristy, Box 117,
SE-221 00, Lund,
Sweden

(Dated: October 22, 2018)

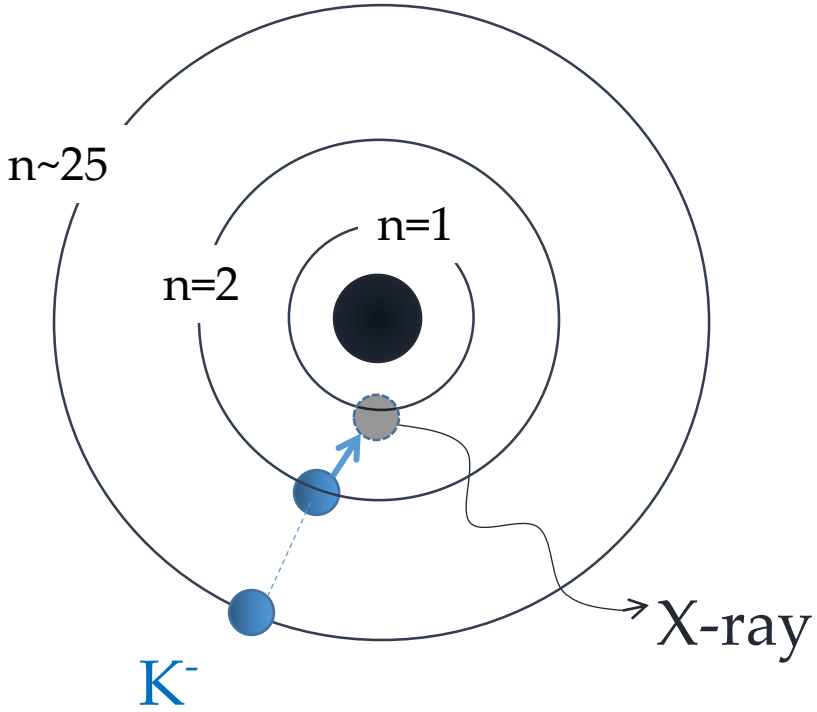
Invited review paper
to Reviews of Modern Physics
(47 pages)
in advanced reviewing process

FORMING "EXOTIC" ATOMS

"normal" hydrogen



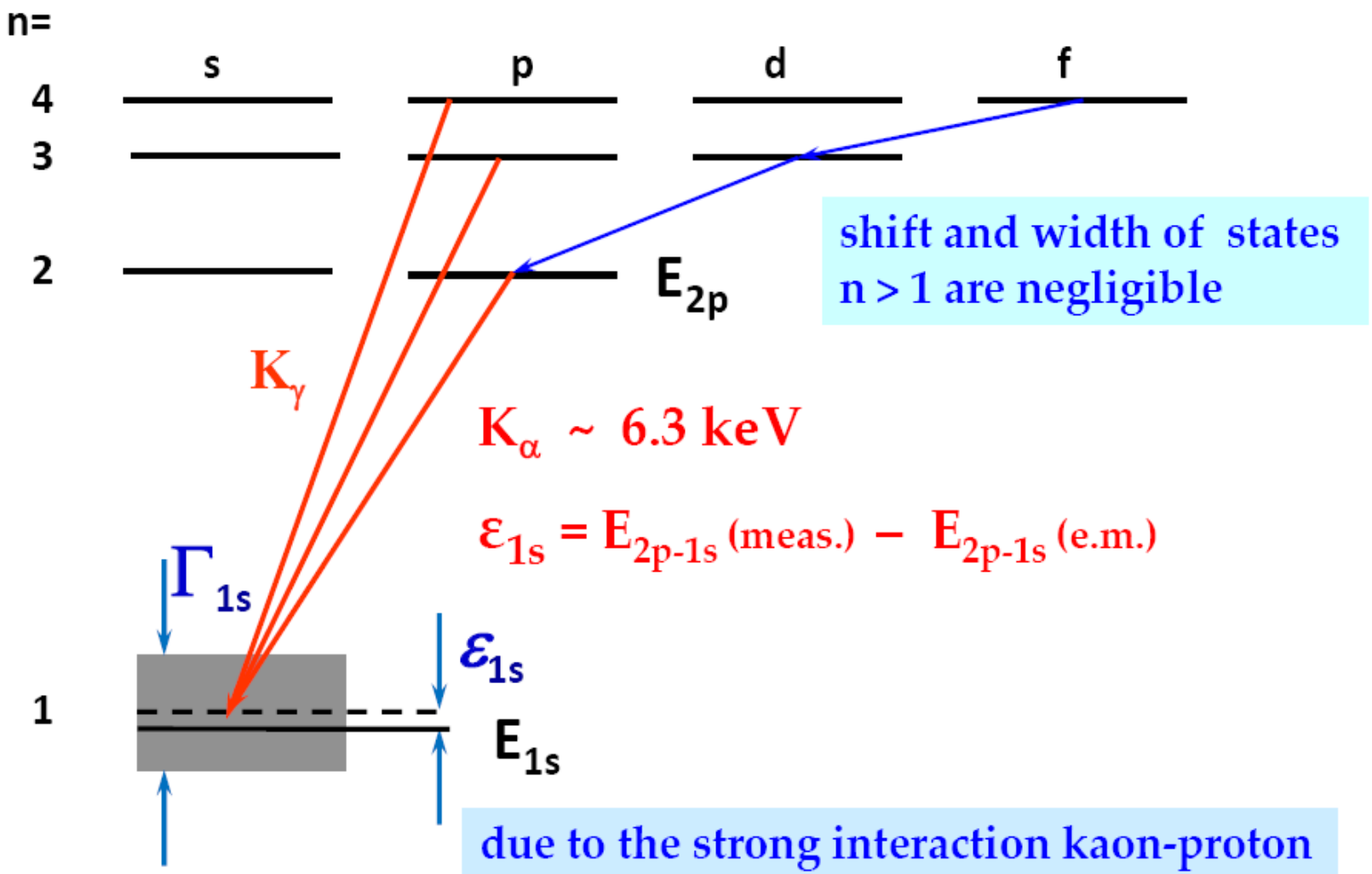
"exotic" (kaonic) hydrogen



$$n \approx \sqrt{\frac{m_{\text{red}}}{m_e}} \cdot n_e$$

$2p \rightarrow 1s$
K_α transition

X-RAY TRANSITIONS TO THE 1s STATE



shift and width of states
n > 1 are negligible

$K_\alpha \sim 6.3$ keV

$\varepsilon_{1s} = E_{2p\text{-}1s}$ (meas.) – $E_{2p\text{-}1s}$ (e.m.)

due to the strong interaction kaon-proton
the 1s level is shifted and broadened

SCATTERING LENGTHS

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

$$\varepsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3 \mu_c^2 a_{K^- p}\left(1 - 2\alpha\mu_c\left(\ln\alpha - 1\right)a_{K^- p}\right)$$

(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

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

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

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

$$k = \frac{4\left[m_n + m_K\right]}{\left[2m_n + m_K\right]}$$

Physical Review C96 (2017) 045204
arXiv:1705.06857v1 [nucl-th] 19 May 2017

Constraining the $\bar{K}N$ interaction from the $1S$ level shift of kaonic deuterium

Tsubasa Hoshino,[1] Shota Ohnishi,[1] Wataru Horiuchi,[1] Tetsuo Hyodo,[2] and Wolfram Weise[2,3]

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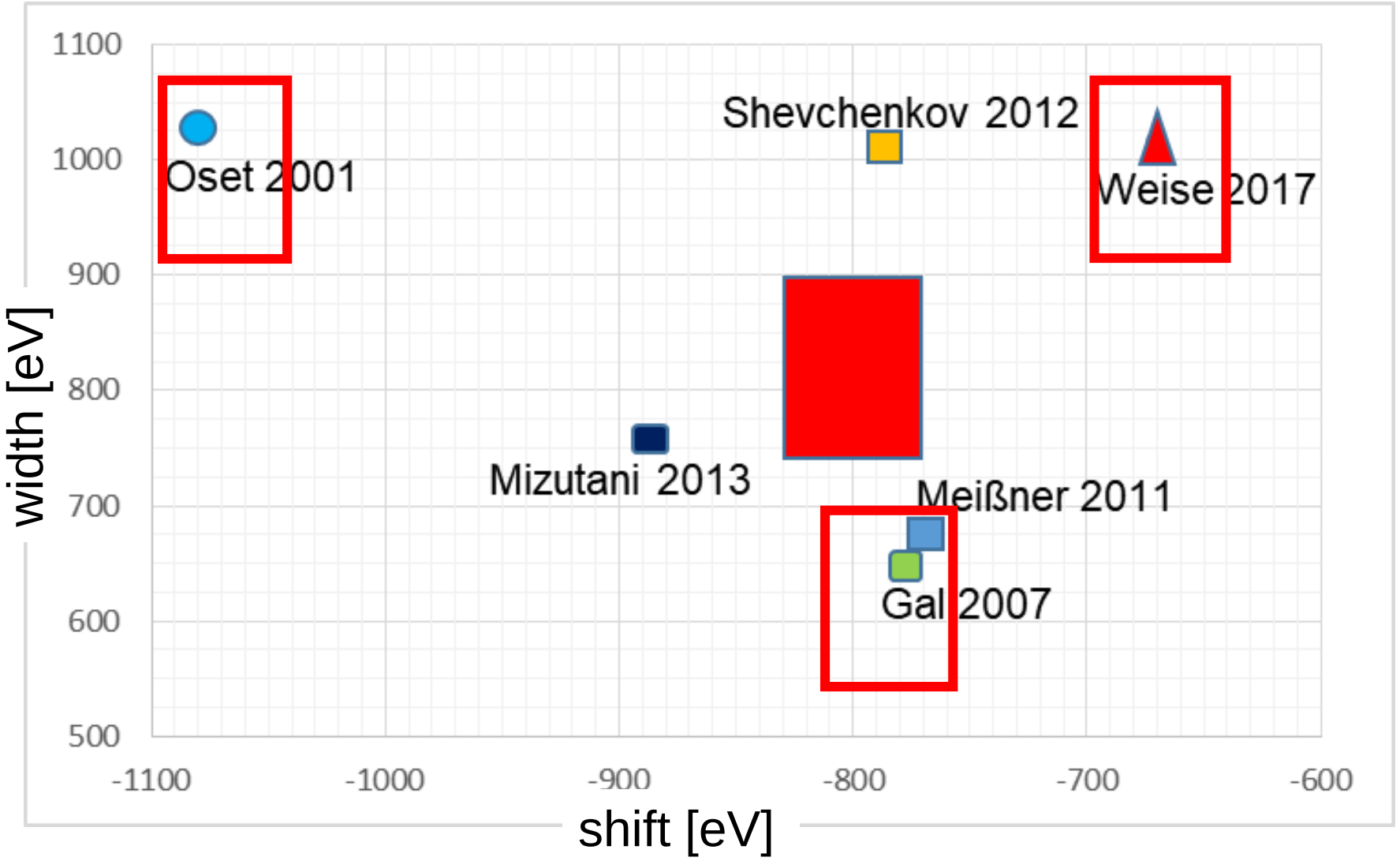
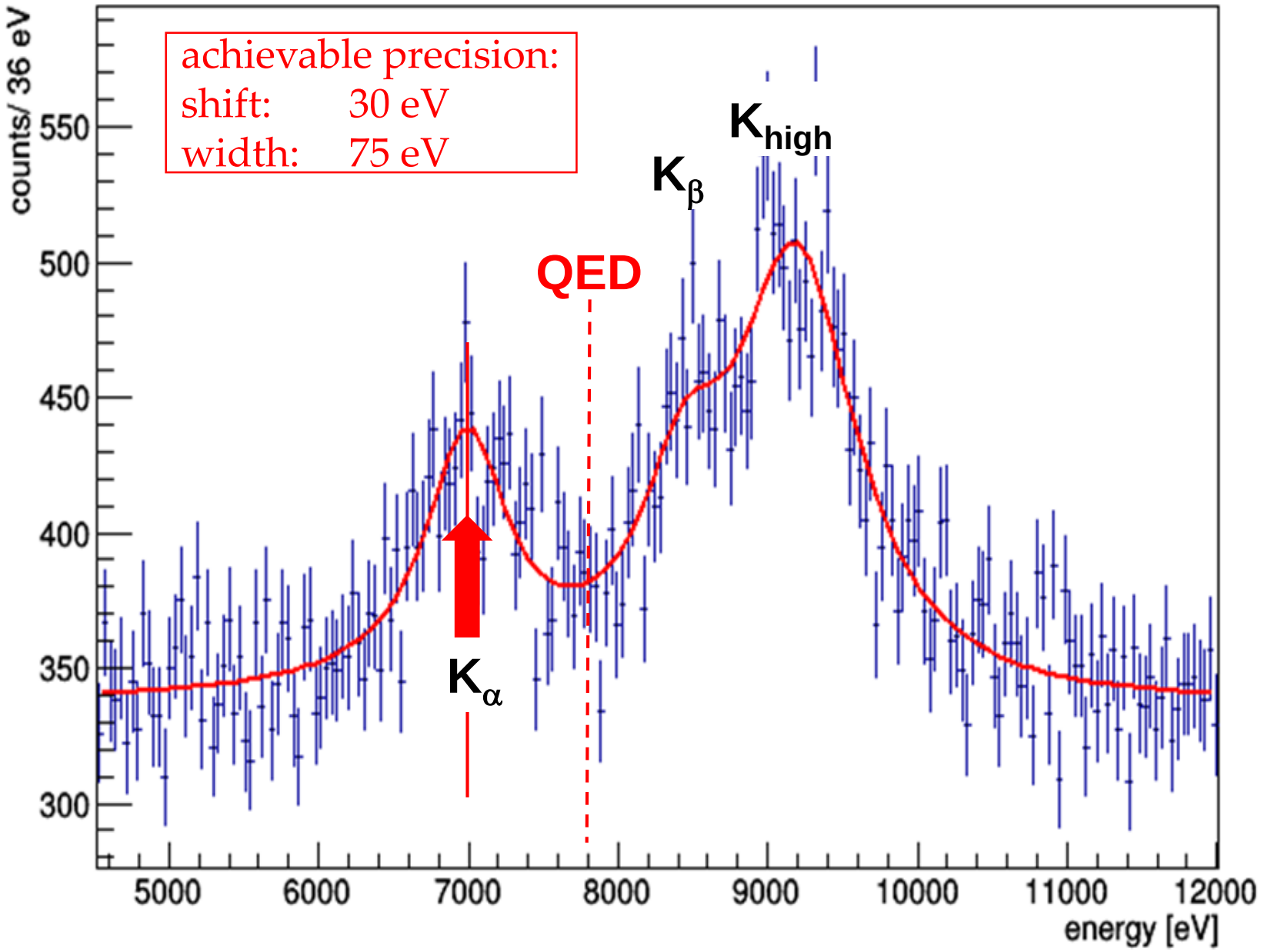
[2] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
[3] *Physik-Department, Technische Universität München, 85748 Garching, Germany*

Motivated by the precise measurement of the $1S$ level shift of kaonic hydrogen, we perform accurate three-body calculations for the spectrum of kaonic deuterium using a realistic antikaon-nucleon ($\bar{K}N$) interaction. In order to describe both short- and long-range behavior of the kaonic atomic states, we solve the three-body Schrödinger equation with a superposition of a large number of correlated Gaussian basis functions covering distances up to several hundreds of fm. Transition energies between $1S$, $2P$ and $2S$ states are determined with high precision. The complex energy shift of the $1S$ level of kaonic deuterium is found to be $\Delta E - i\Gamma/2 = (670 - i\,508)$ eV. The sensitivity of this level shift with respect to the isospin $I = 1$ component of the $\bar{K}N$ interaction is examined. It is pointed out that an experimental determination of the kaonic deuterium level shift within an uncertainty of 25 % will provide a constraint for the $I = 1$ component of the $\bar{K}N$ interaction significantly stronger than that from kaonic hydrogen.

Theory – SIDDHARTA-2



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



INPUT

signal: shift - 800 eV
width 800 eV

density: 5% (LHD)
detector area: 246 cm^2

Kα yield: 0.1 %
with the yield ratio
as in K^-p

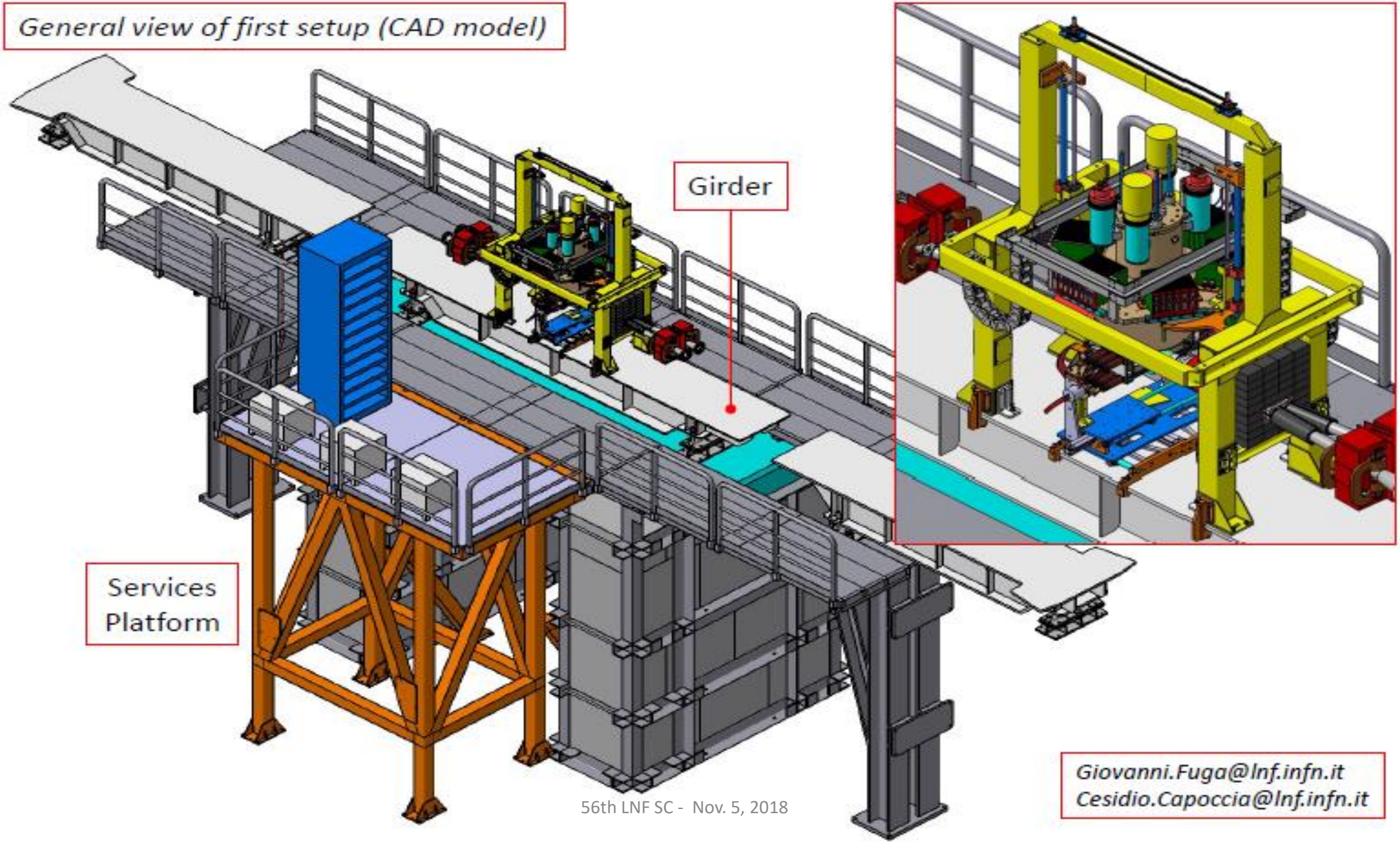
S/B ~ 1 : 4

SIDDHARTA-2 setup

- Platform / mounting frame /shielding

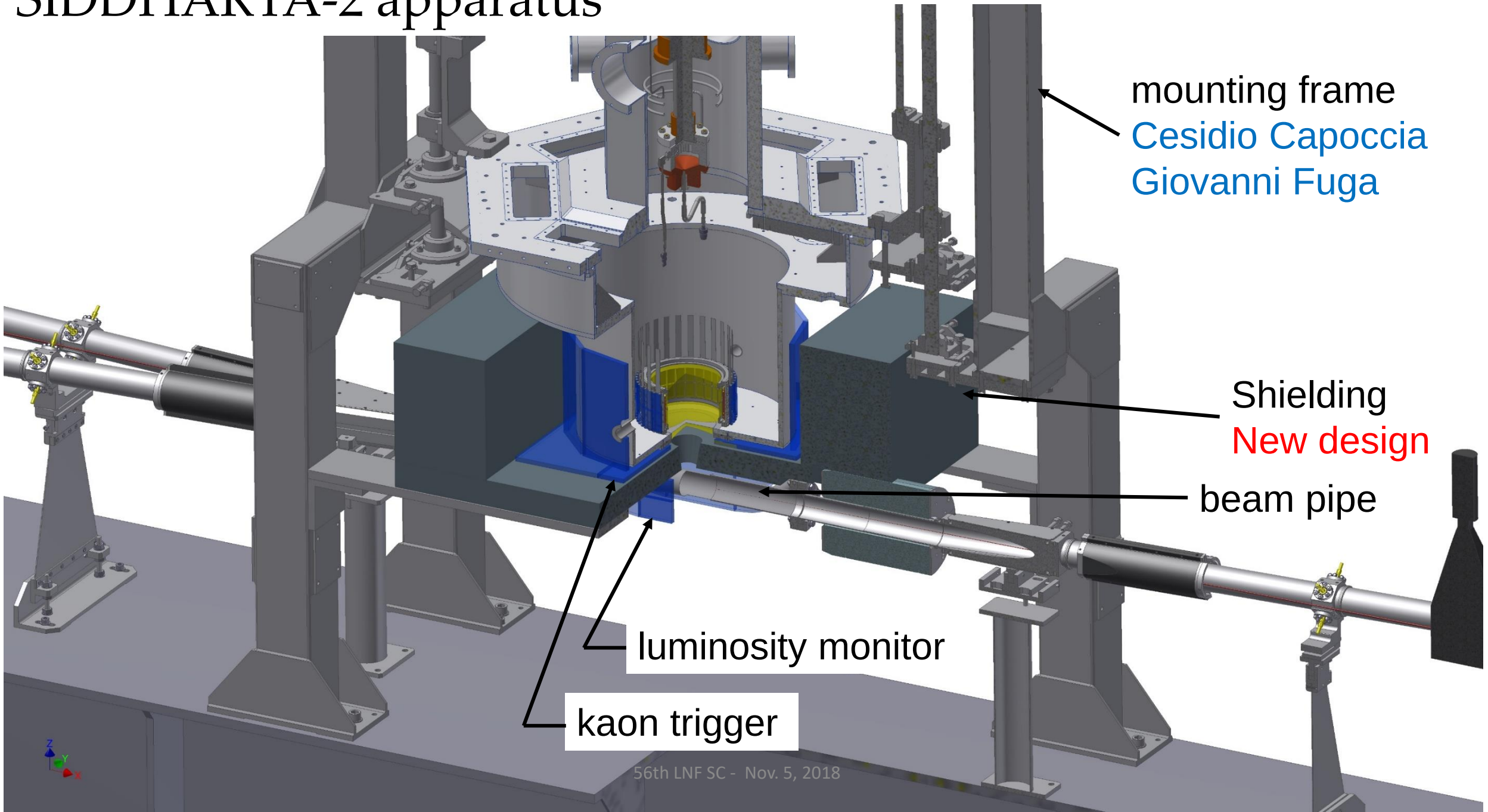
- Start installation of SIDDHARTA-2
  - 2-stage cooling + CryoTiger
  - Silicon Drift Detector
  - Veto-2 systems
  - Luminosity monitor

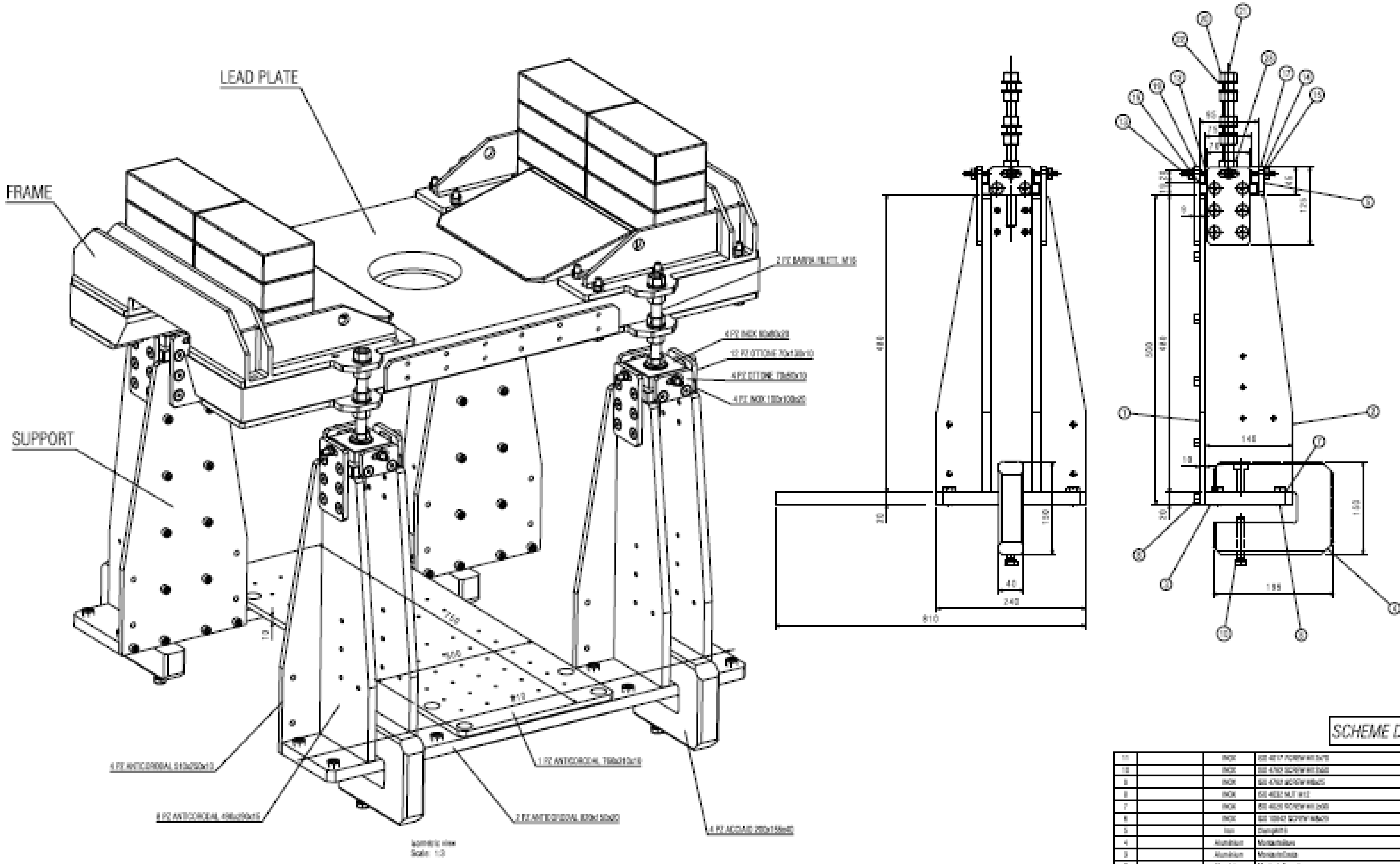
General view of first setup (CAD model)



Giovanni.Fuga@lnf.infn.it
Cesidio.Capoccia@lnf.infn.it

SIDDHARTA-2 apparatus





SCHEME DRAWING

11		INOX	ISO 4017 SCREW M16x70	0	1
10		INOX	ISO 4762 SCREW M10x40	0	1
9		INOX	ISO 4762 SCREW M8x25	0	36
8		INOX	ISO 4032 NUT M12	0	4
7		INOX	ISO 4026 SCREW M12x50	0	4
6		INOX	ISO 10642 SCREW M8x25	0	12
5		Iron	[illegible]	6,7	1
4		Aluminium	[illegible]	1,76	1
3		Aluminium	[illegible]	3,84	3
2		Aluminium	[illegible]	0,97	1
1		STEEL	[illegible]	0,97	1
PART N.	DRAWING	MATERIAL	DENOMINATION	WEIGHT	Q.TY

General tolerance ISO 2768-mK-E | Geometrical tolerance ISO 8015-E | Roughness ISO 1302

INFN

FRASCATI NATIONAL LAB

S.P.A.S

SIZE A1

C. Capoccia

1:3

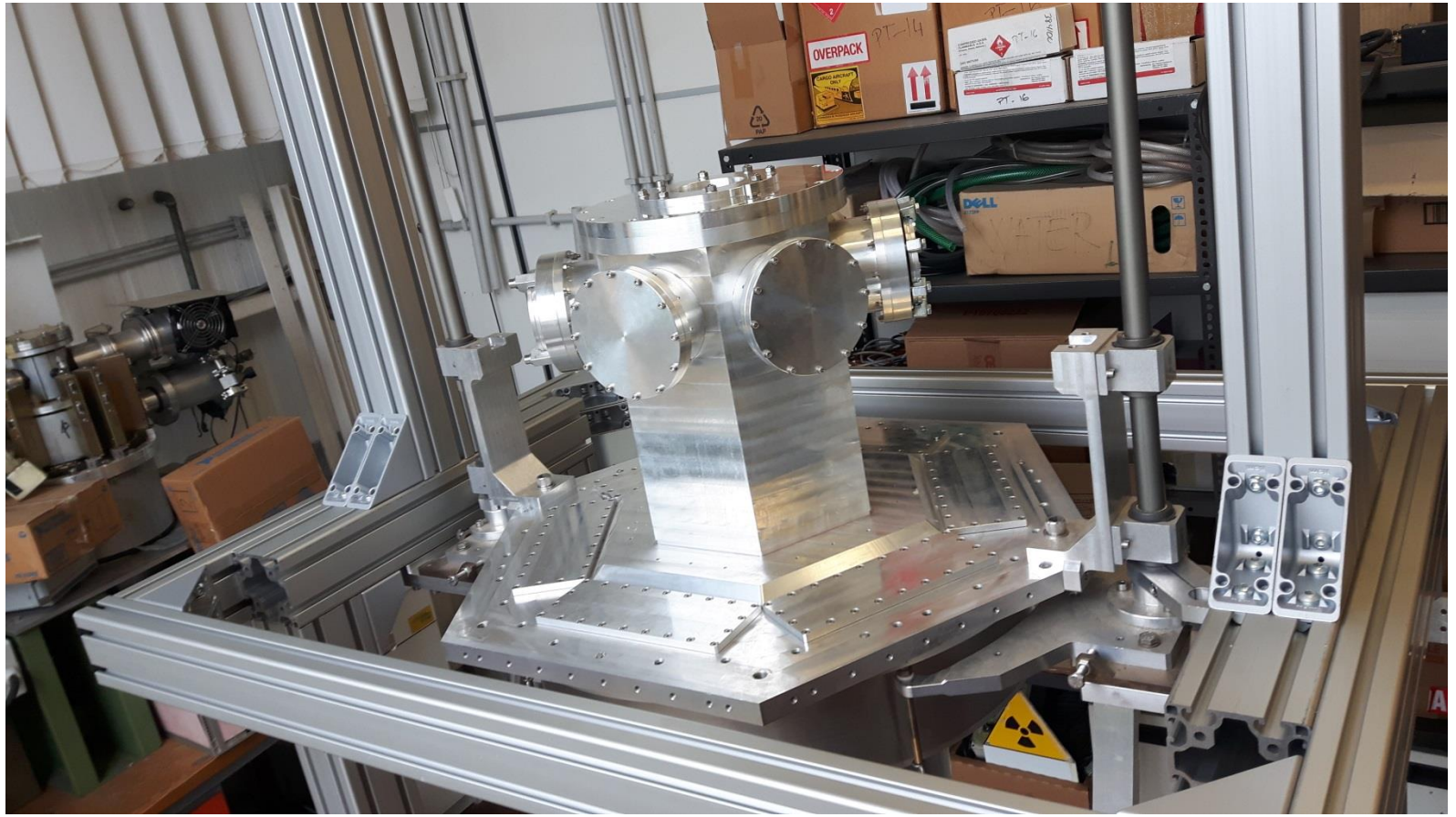
1/1

SIDDHARTA 2 EXPERIMENT

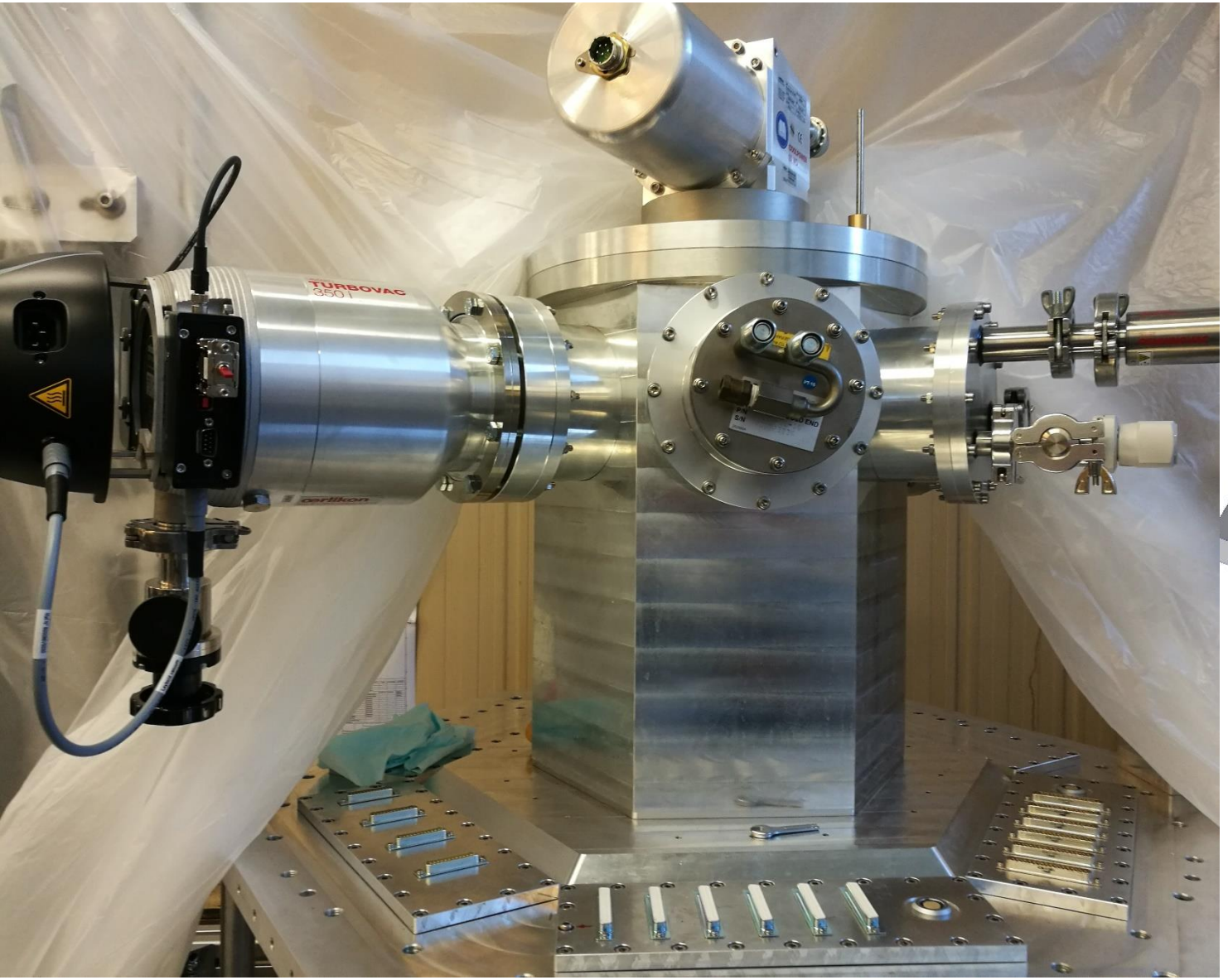
MAIN SHIELDING (LEAD TABLE ASSEMBLY)

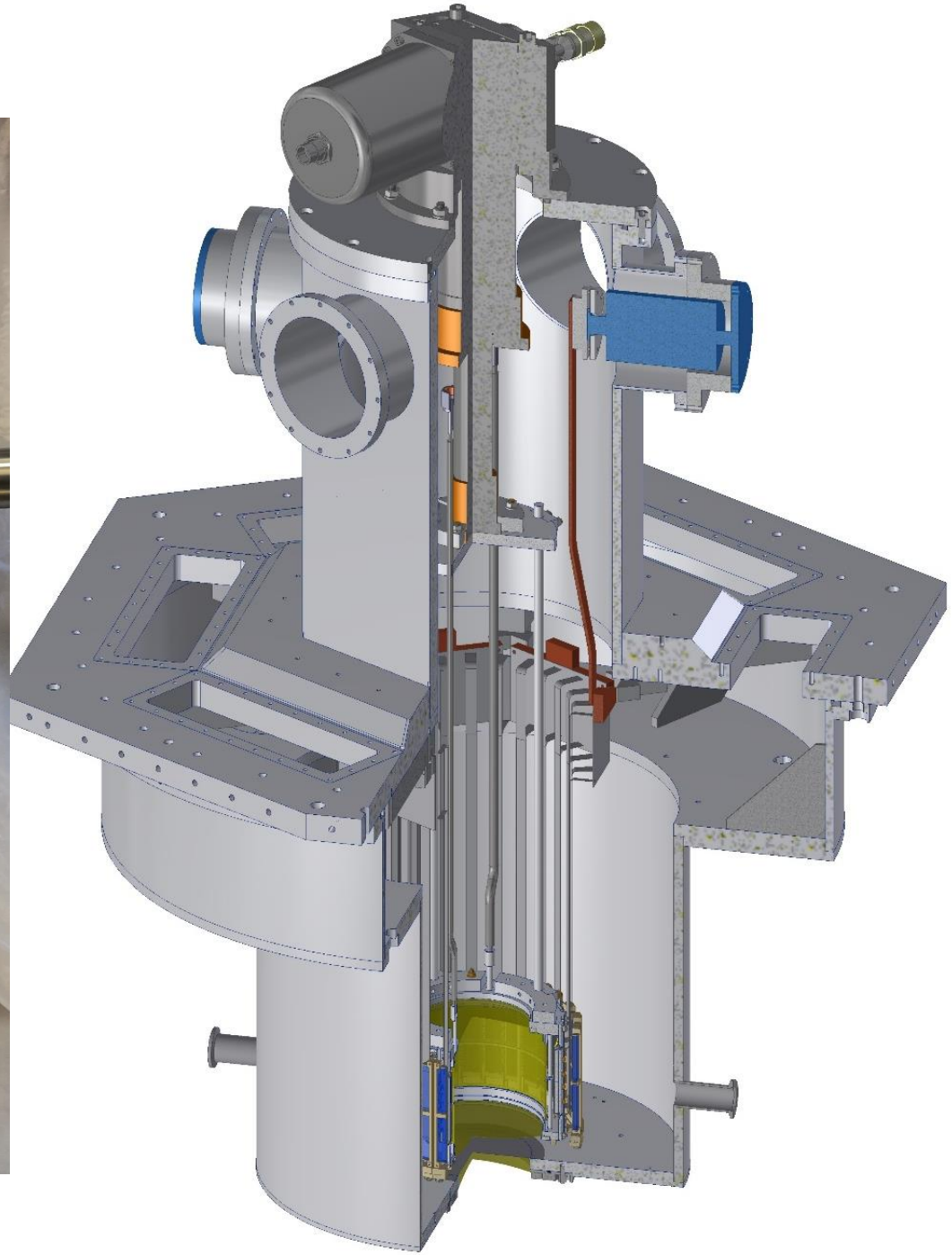
New mounting frame with the SIDDHARTA-2 upper vacuum chamber

New mounting frame with the SIDDHARTA-2 upper vacuum chamber



SIDDHARTA-2 installation





SIDDHARTA-2 installation

SIDDHARTA-2 cooling

- ✓ **Target + SDD cooling:**

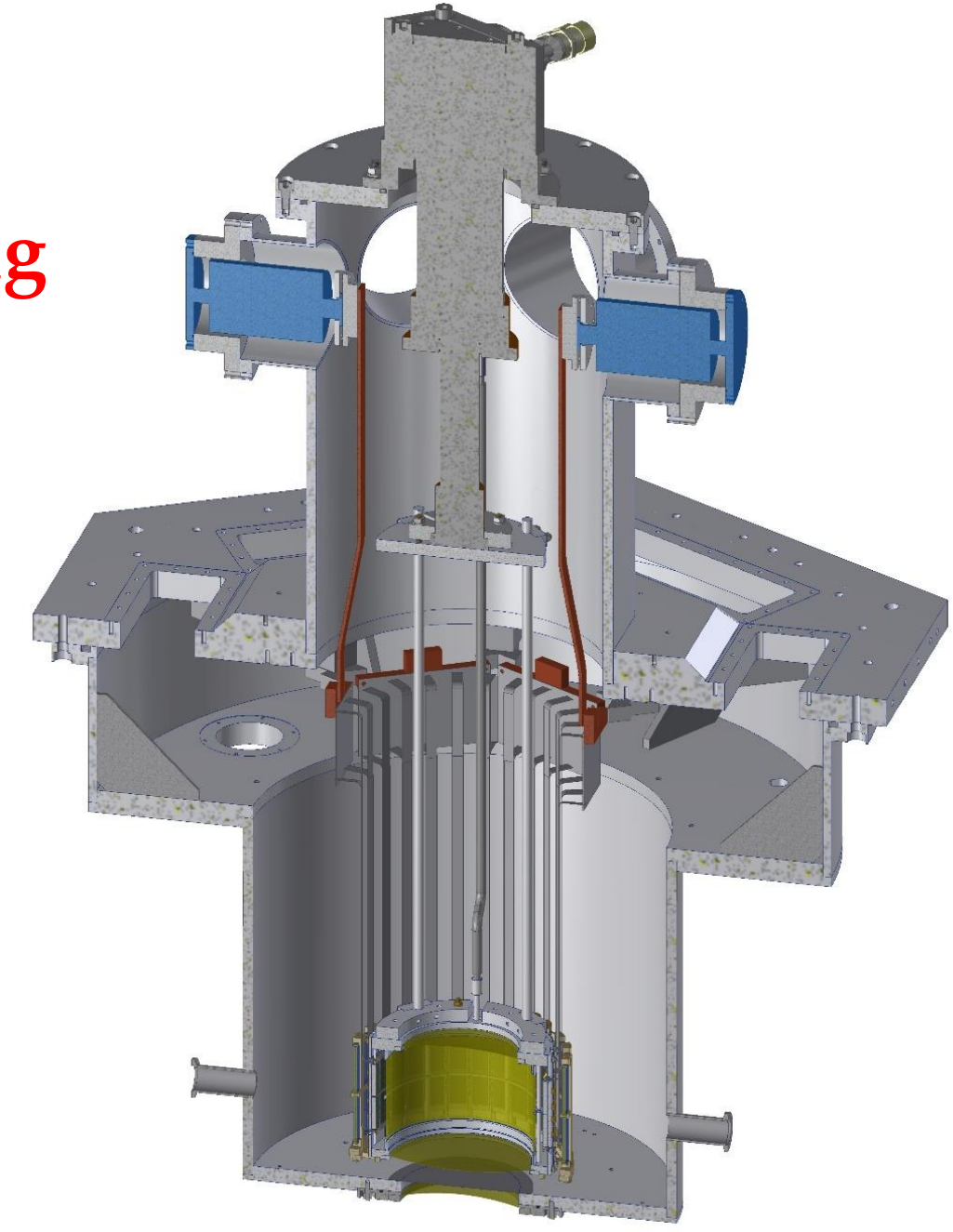
1 Leybold MD10

16 W @ 20 K

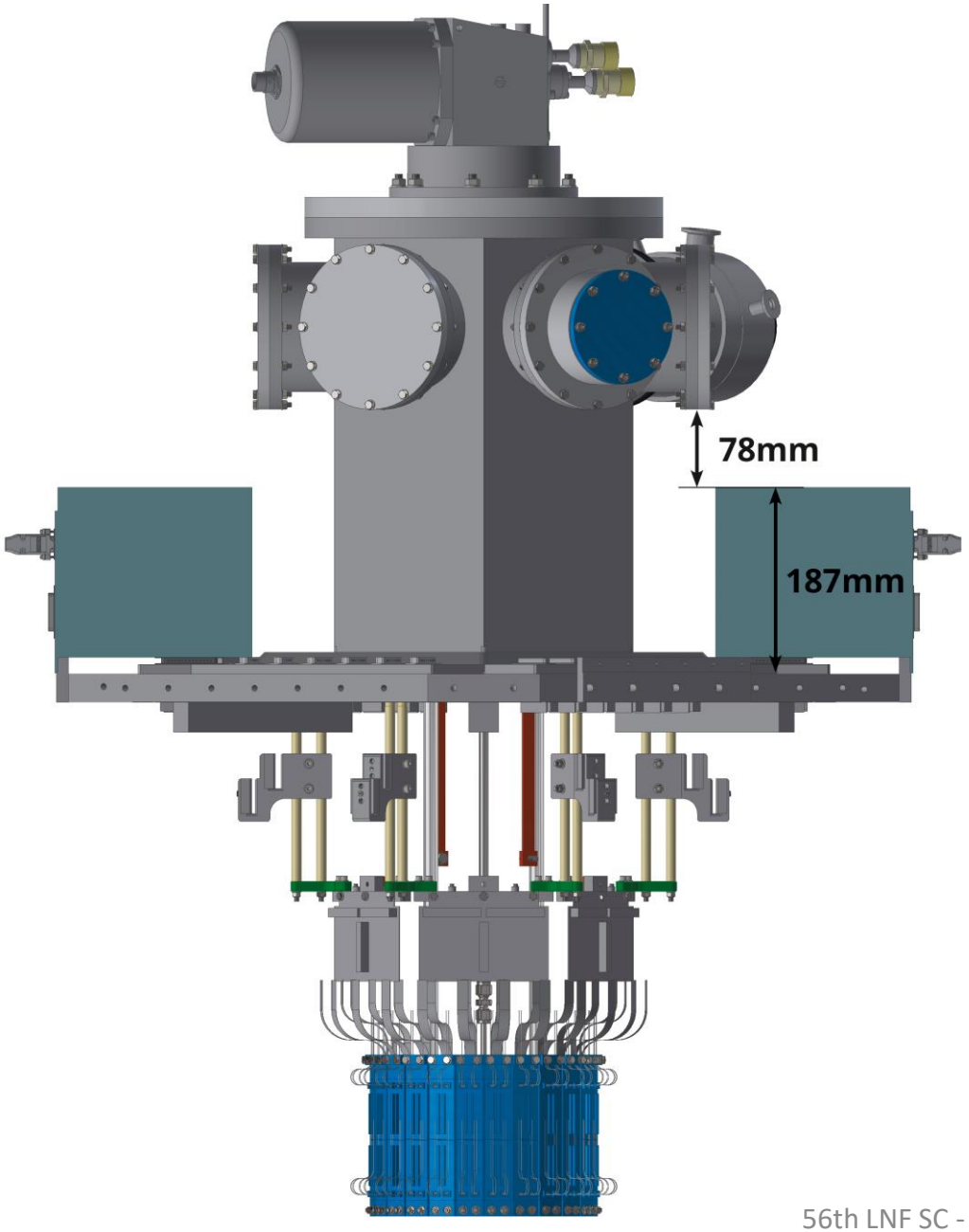
target cell and SDDs will be cooled via ultra pure aluminum bars

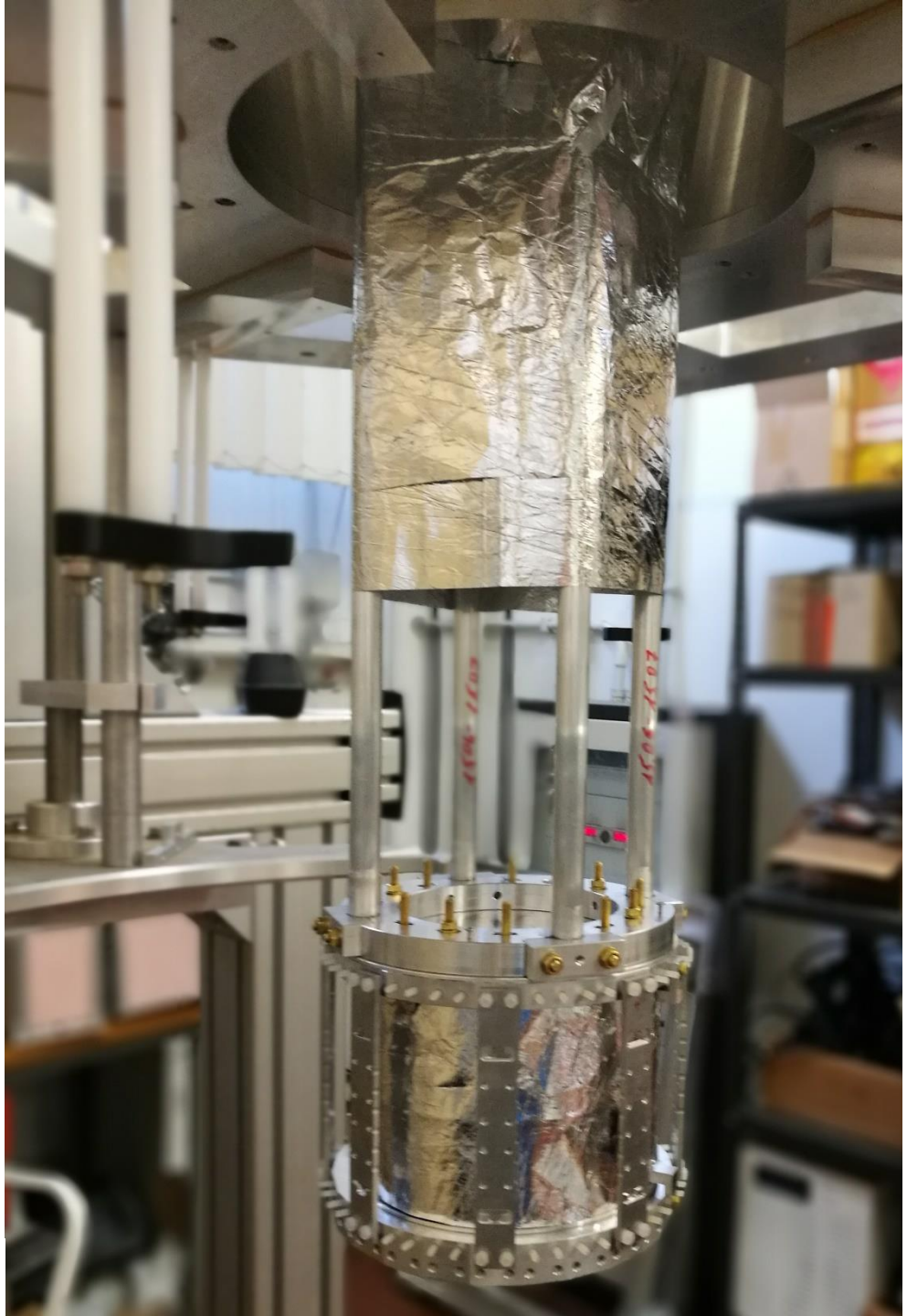
T_{TC} = 30 K

T_{SDD} = 120 K

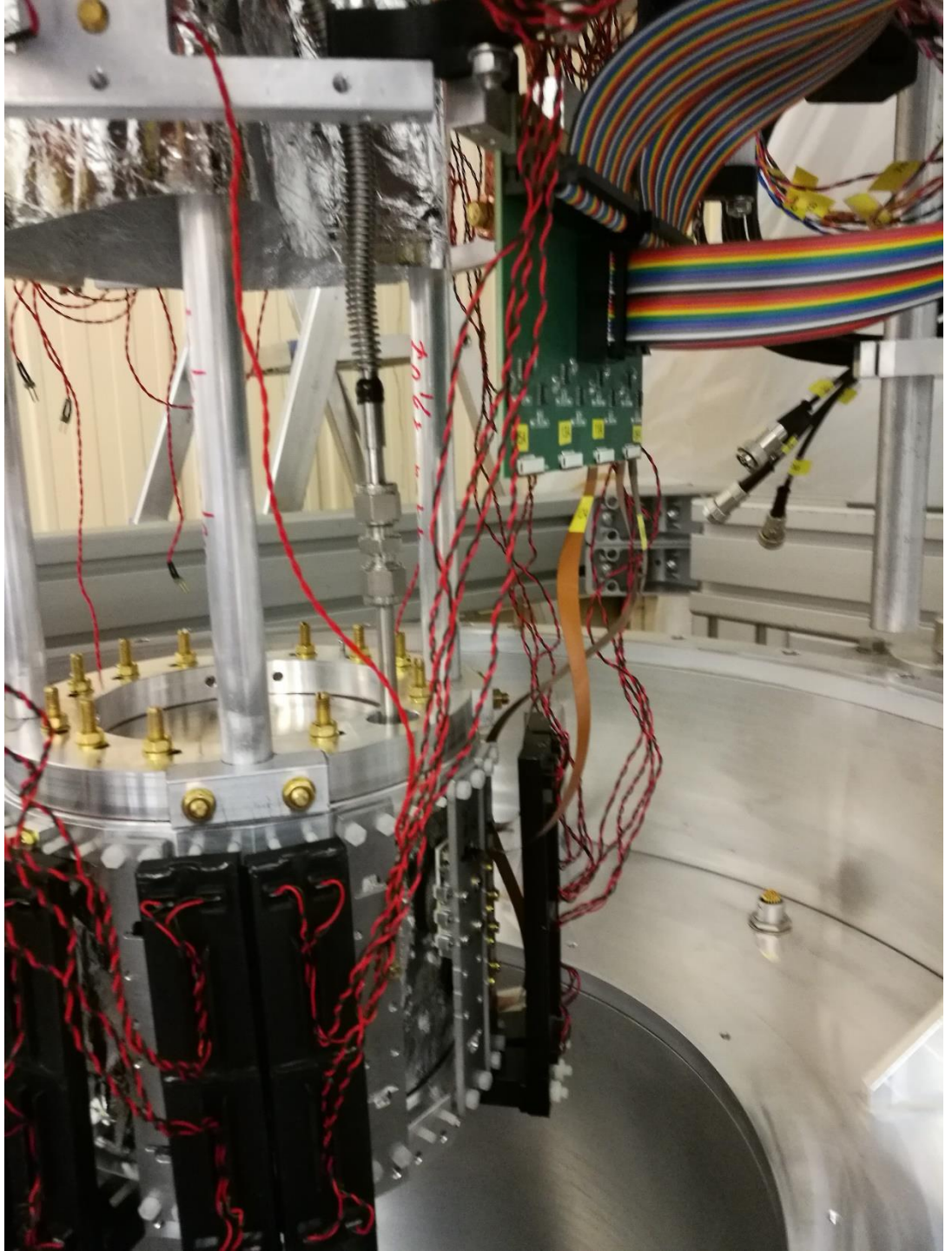


SIDDHARTA-2 installation

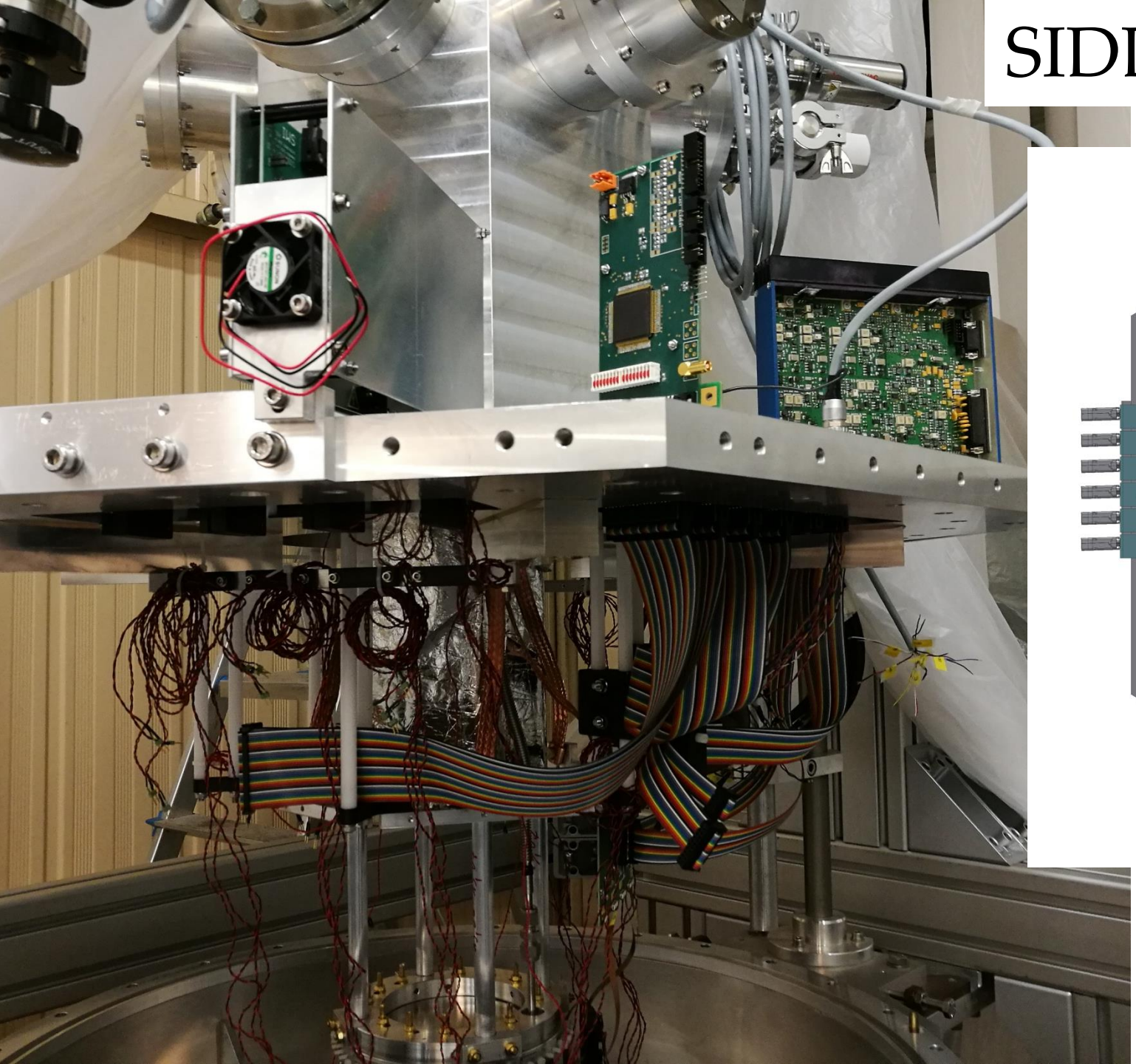


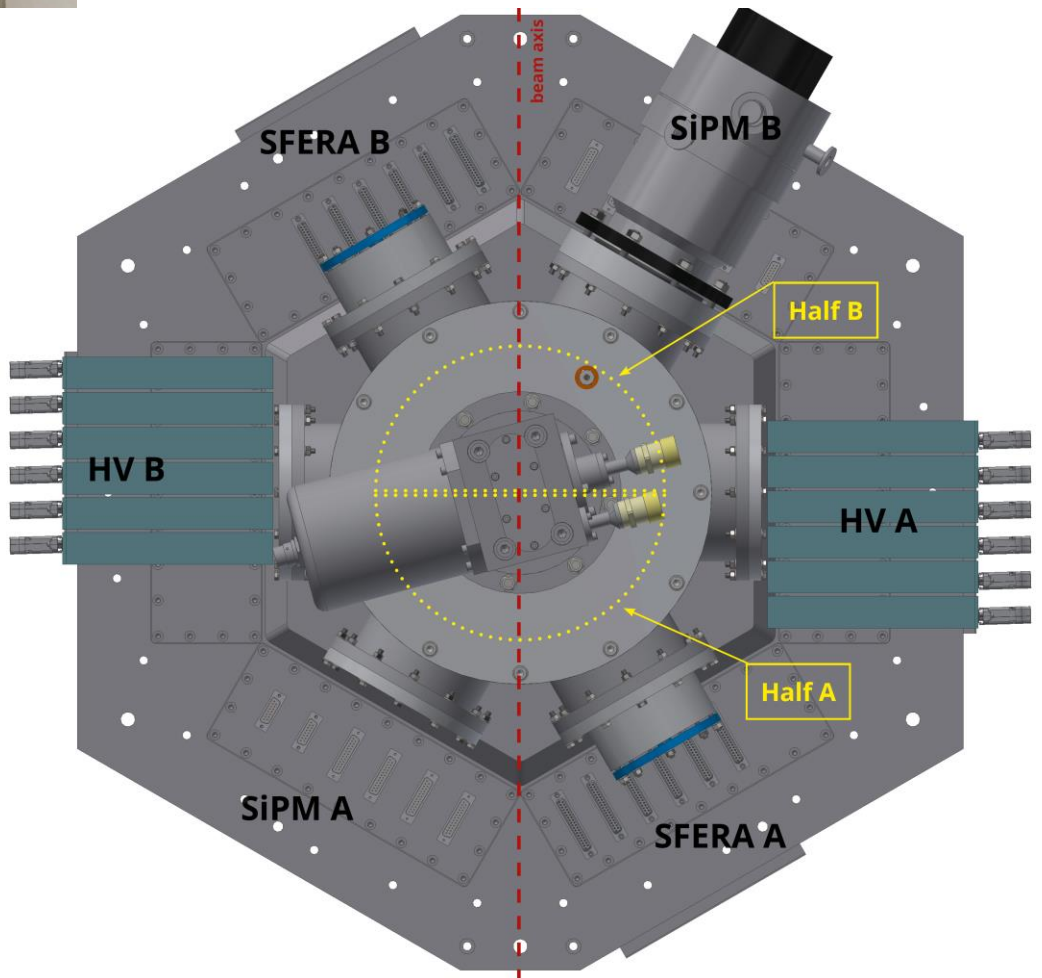


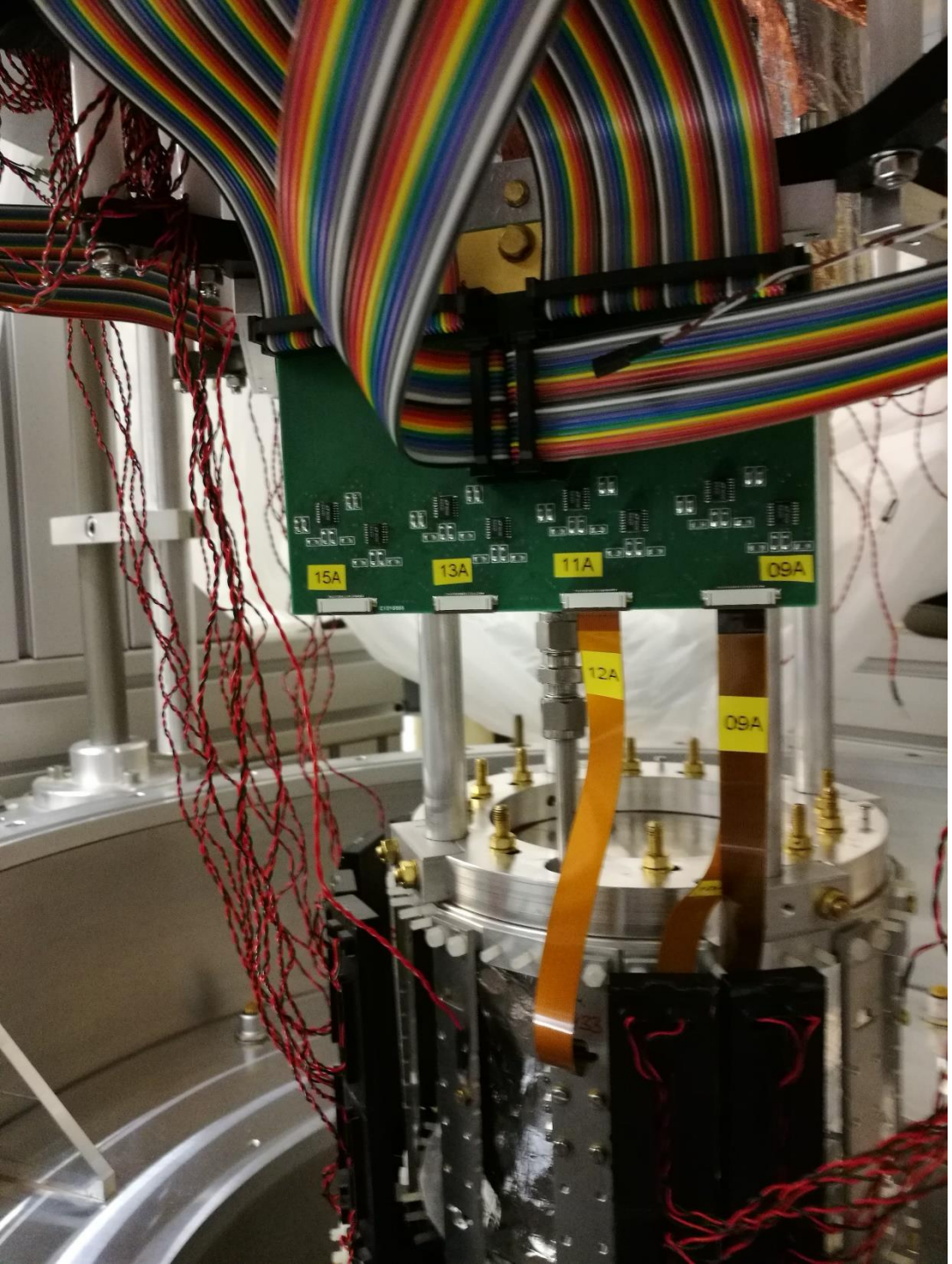
SIDDHARTA-2 installation

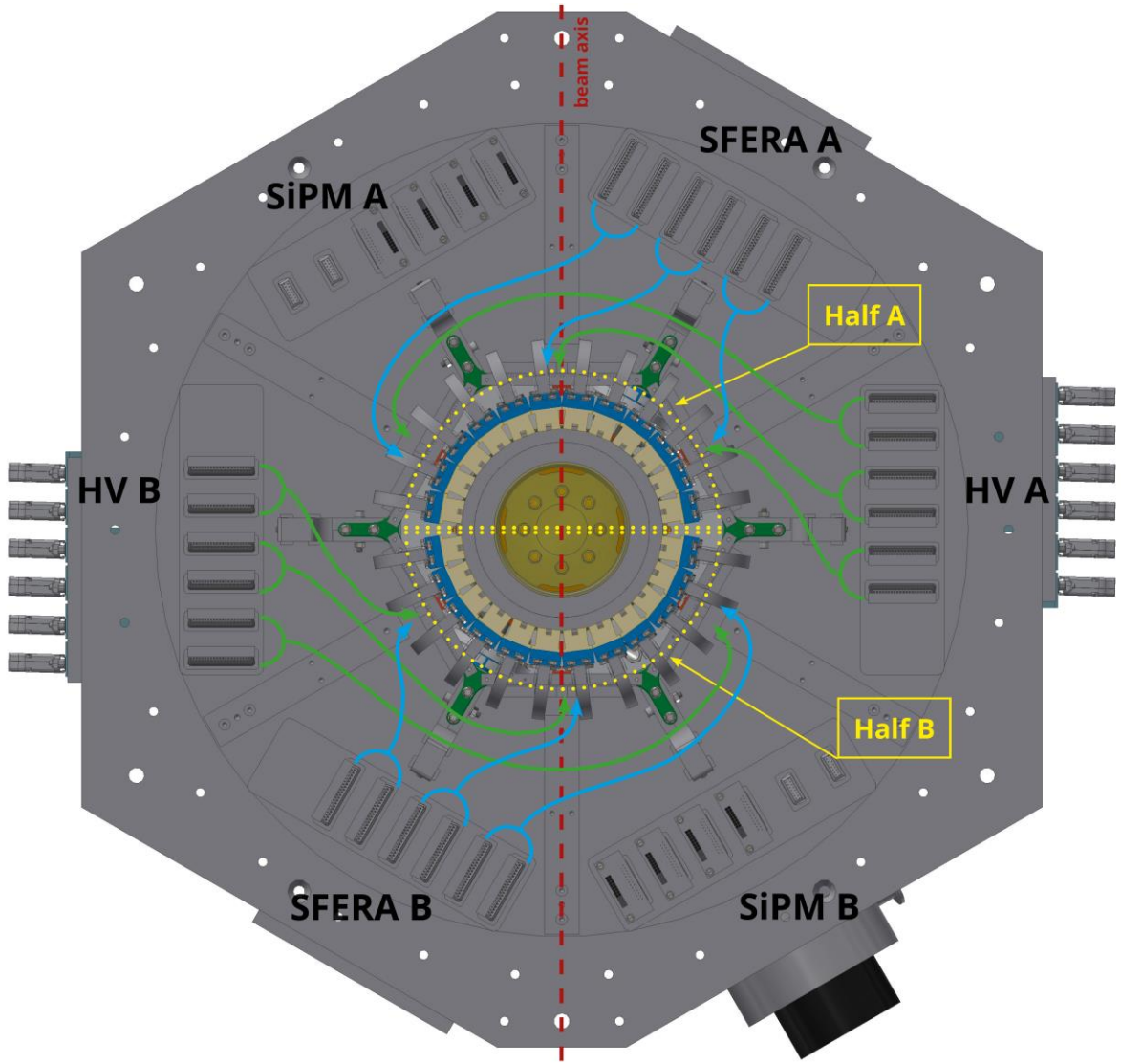


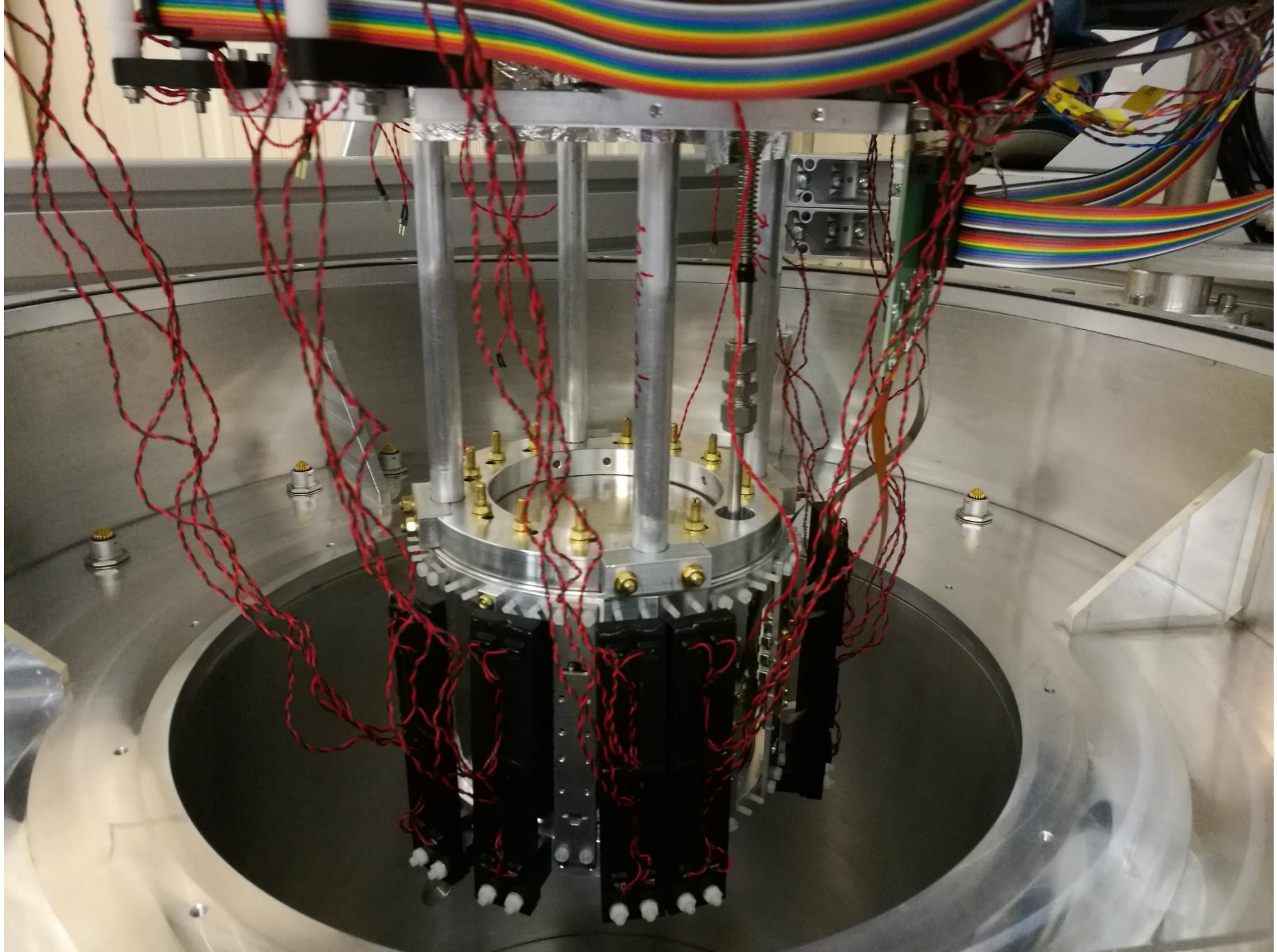
SIDDHARTA-2 installation



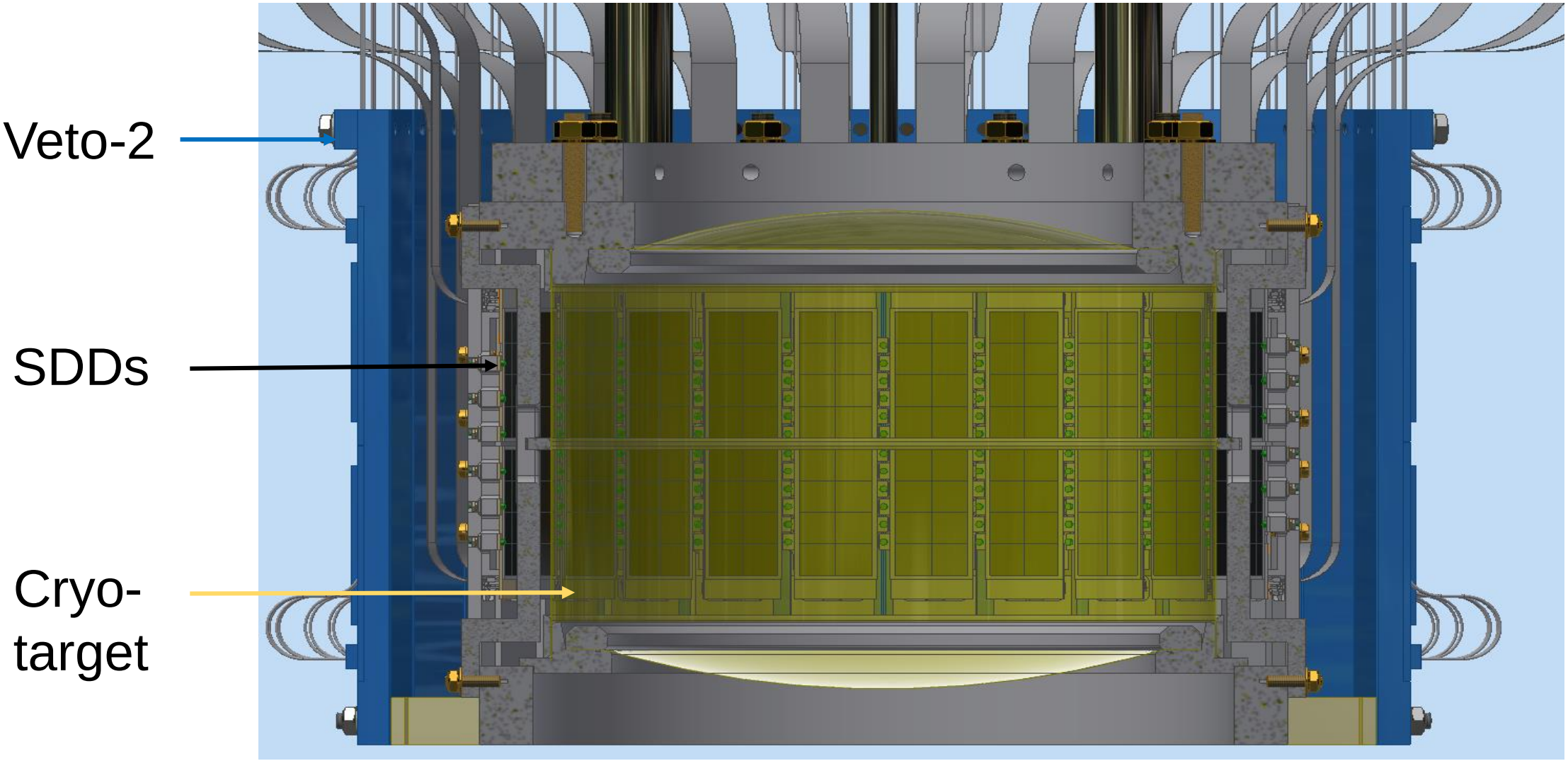



15A
13A
11A
09A
12A
09A

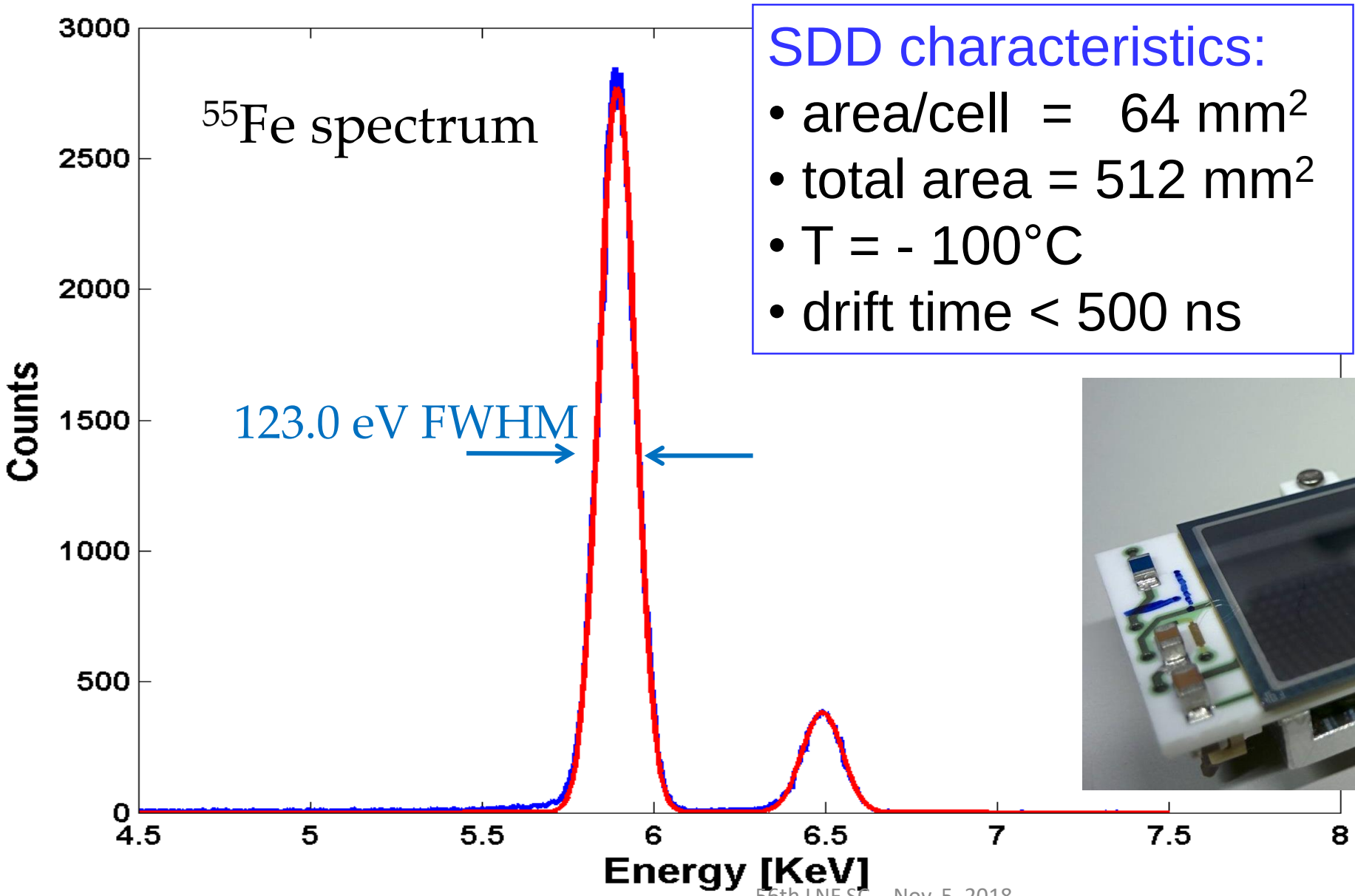

beam axis
SFERA A
SiPM A
Half A
HV B
HV A
Half B
SFERA B
SiPM B



Cryogenic target – SDDs – veto-2 arrangement

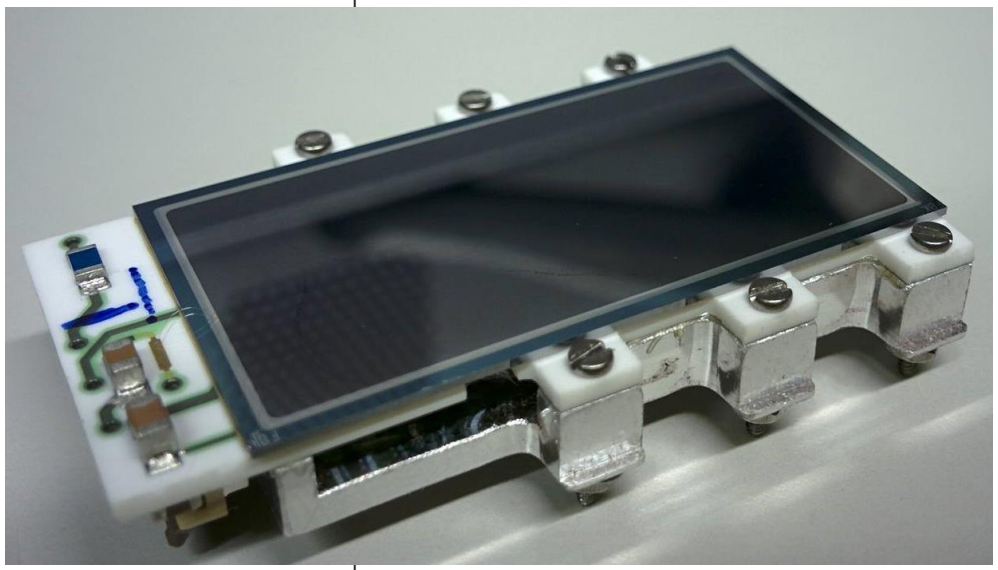


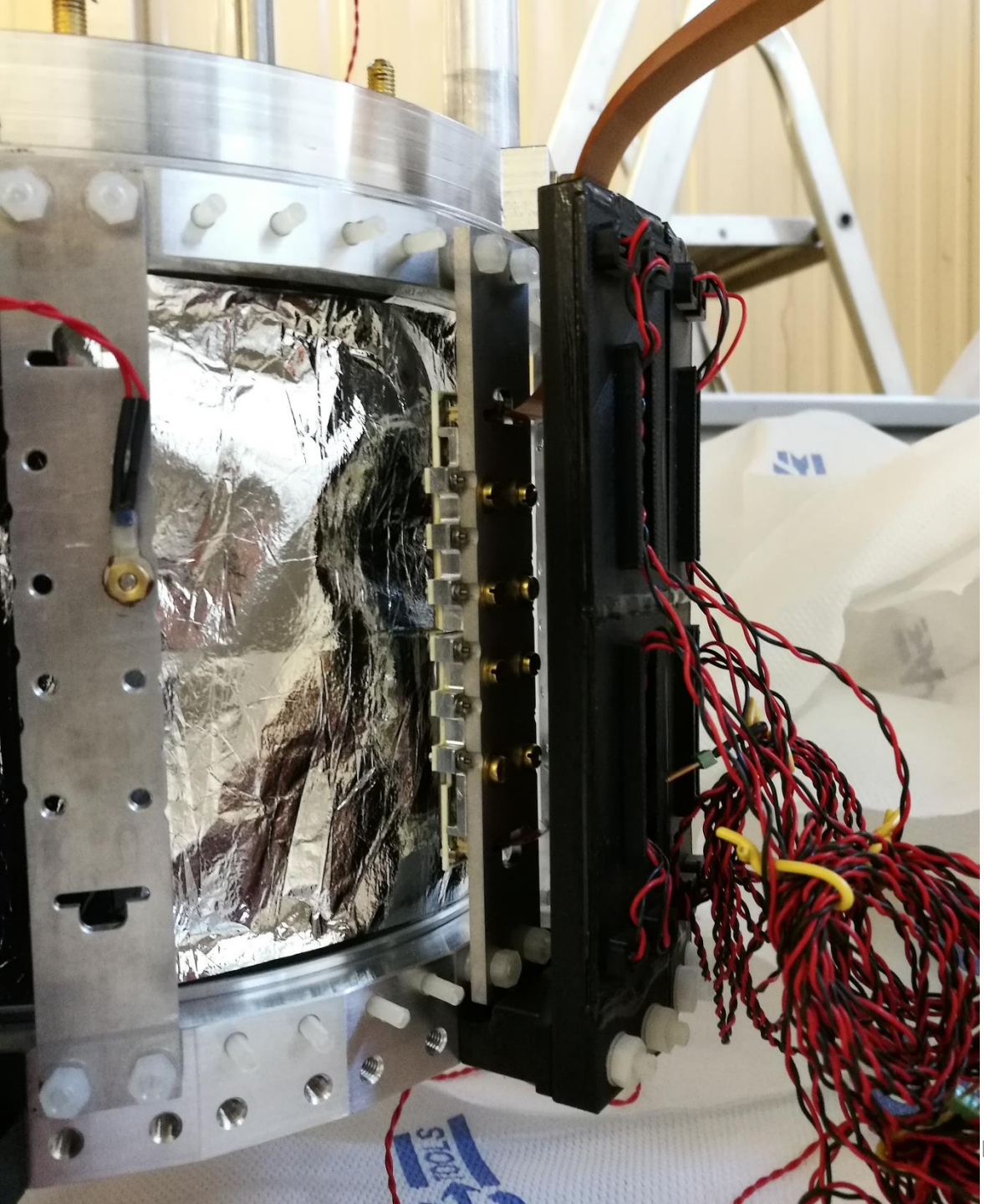
New SDD technology: CUBE preamplifier

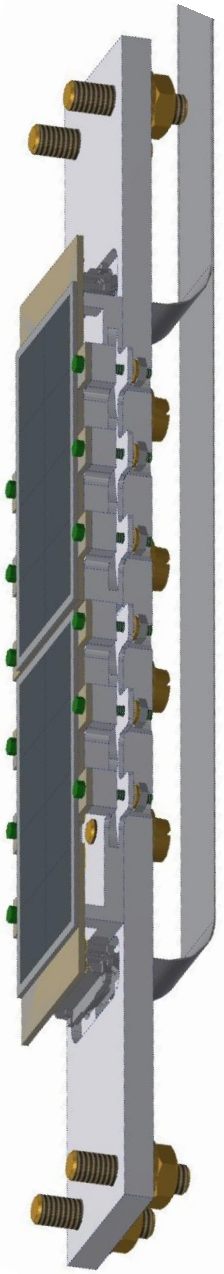


SDD characteristics:

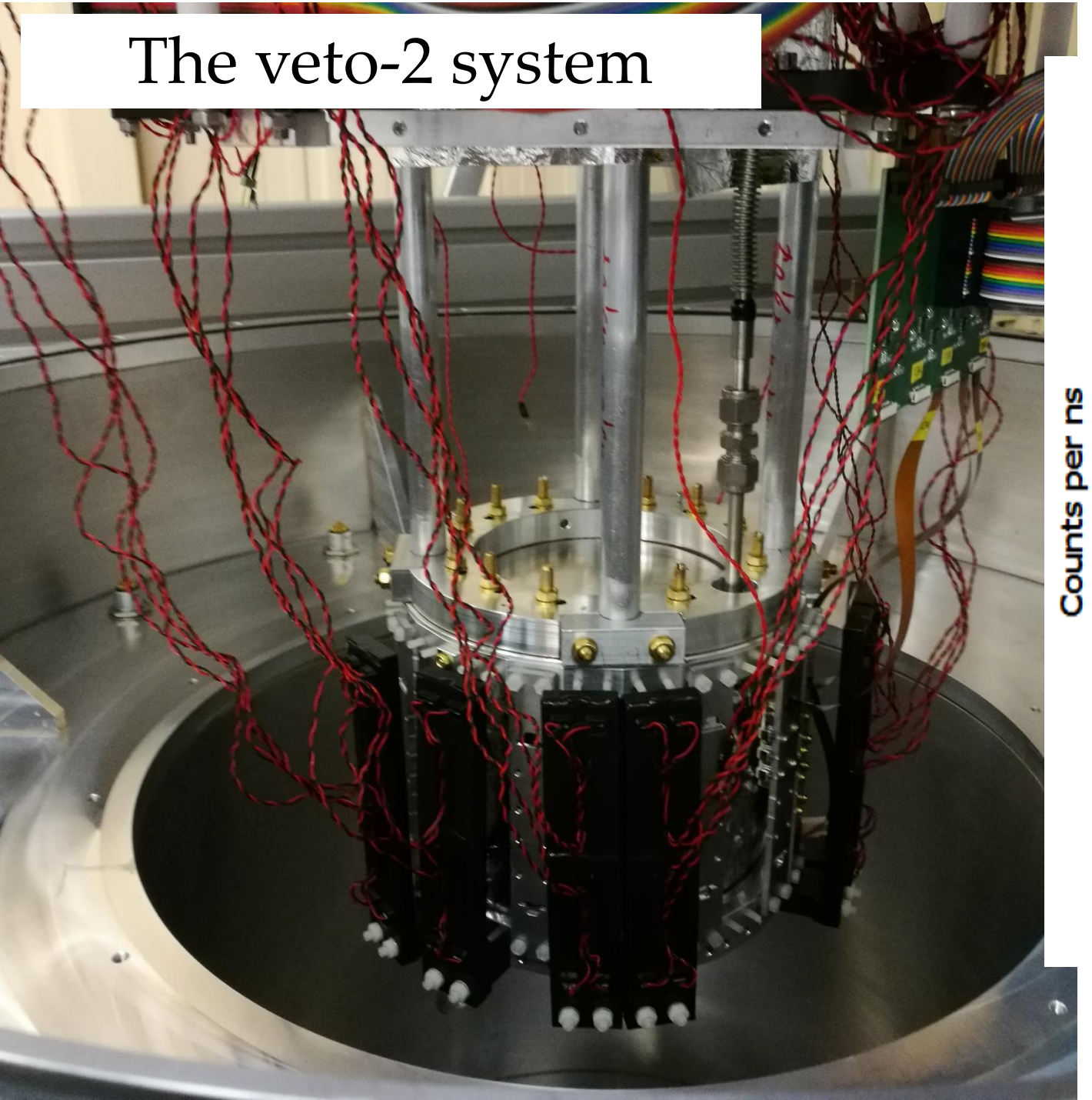
- area/cell = 64 mm^2
- total area = 512 mm^2
- T = - 100°C
- drift time < 500 ns

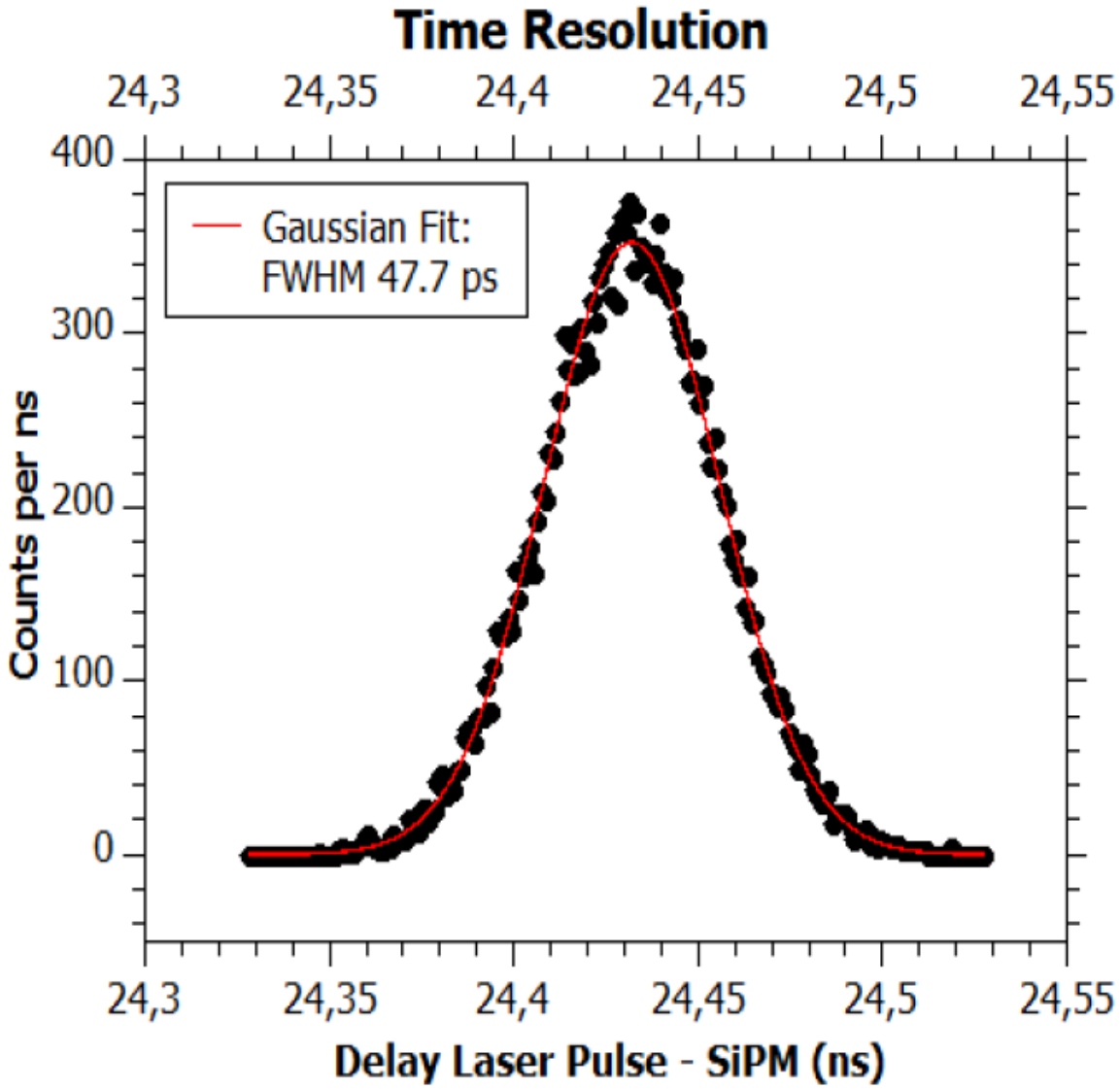


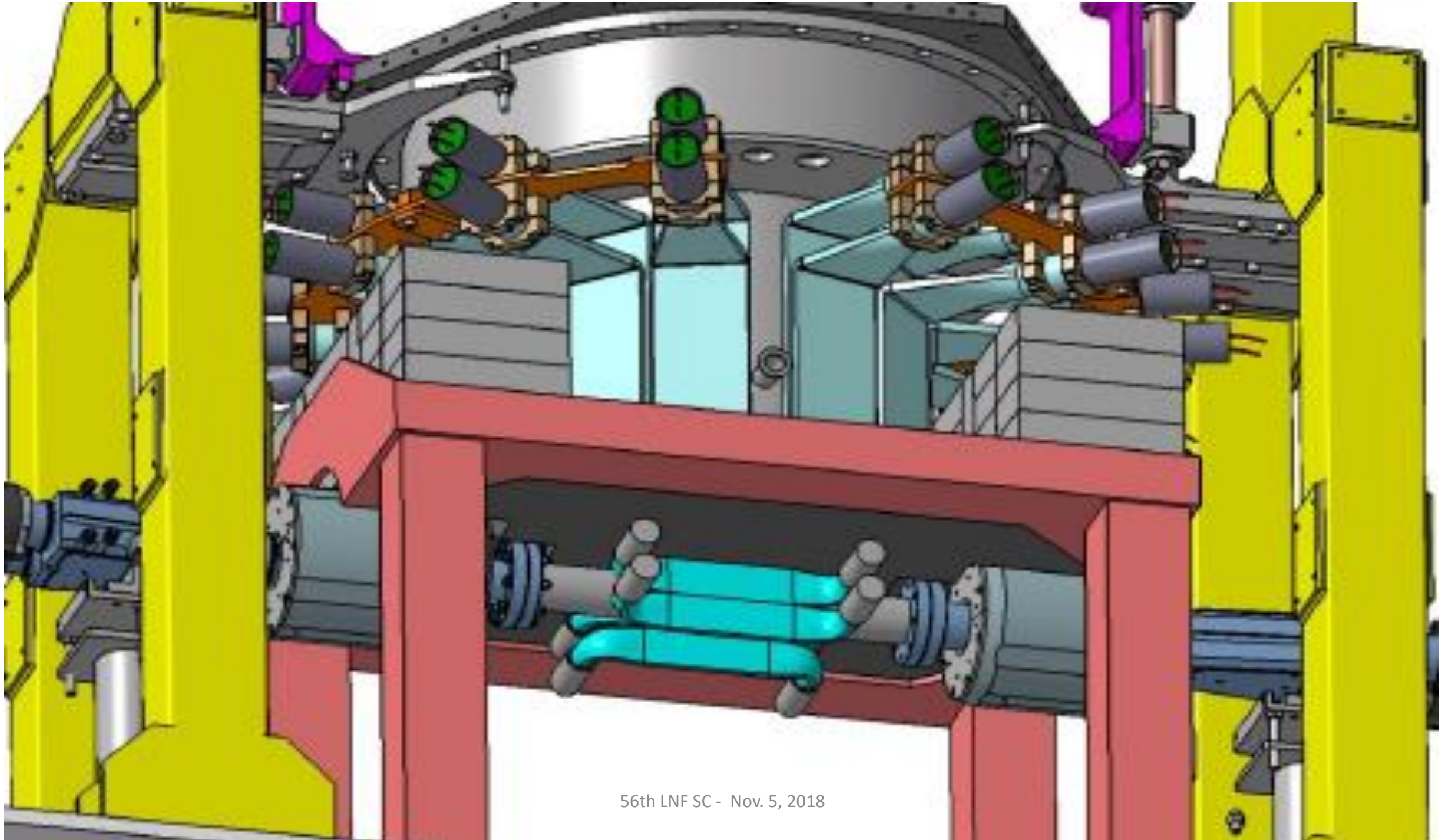




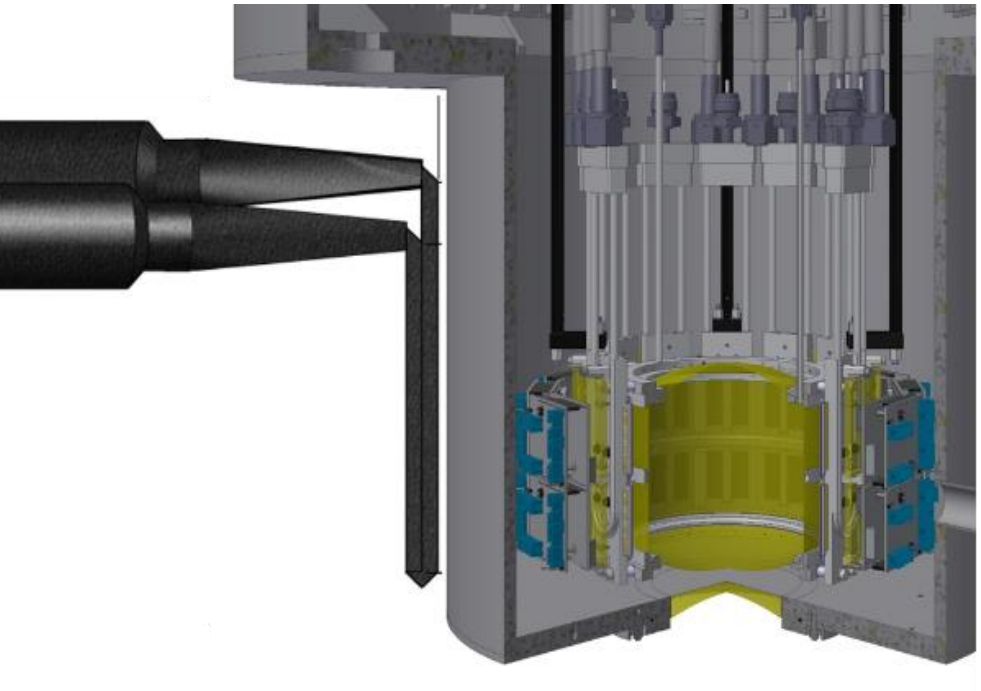
The veto-2 system

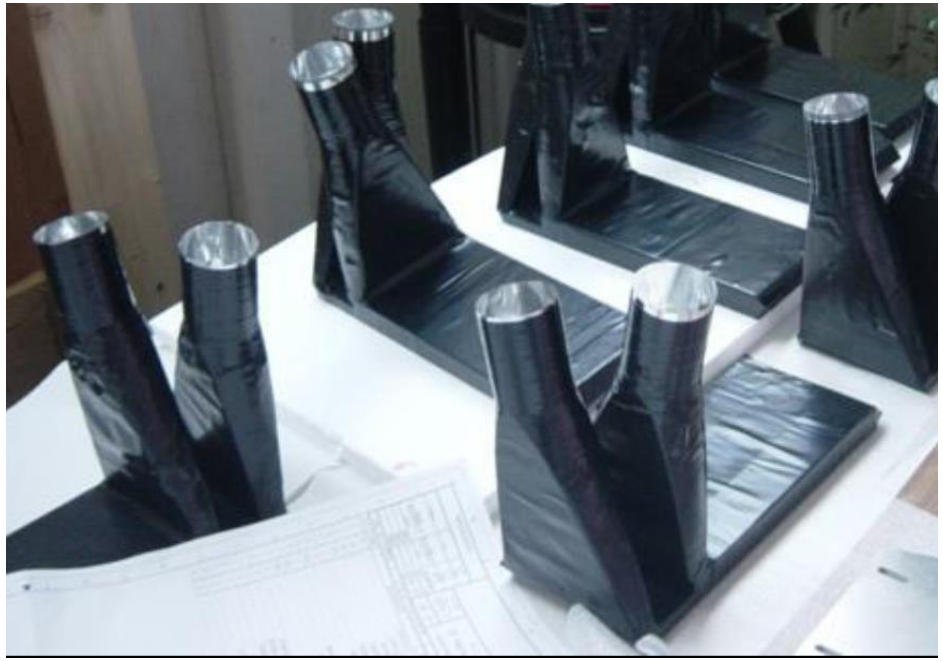






The veto-1 system





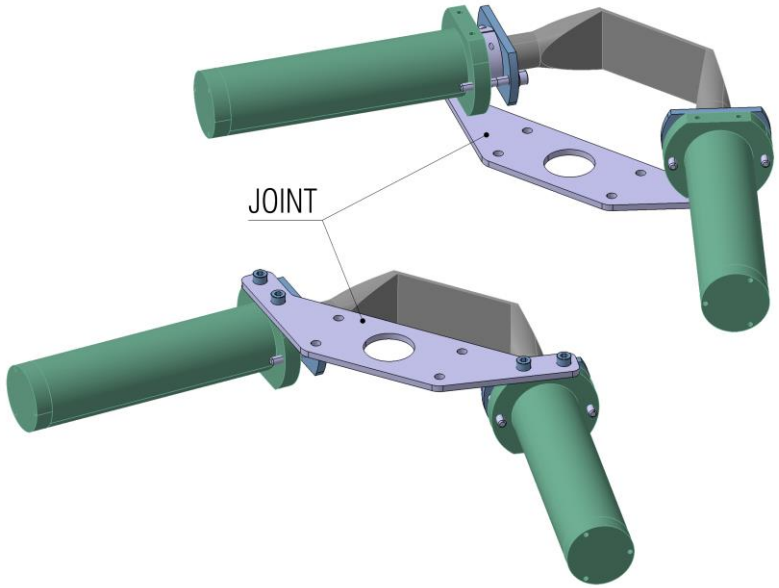
To achieve a good timing resolution, (independent of the "hit" position) < 600 ps (FWHM),the scintillator has to be read out on both side.

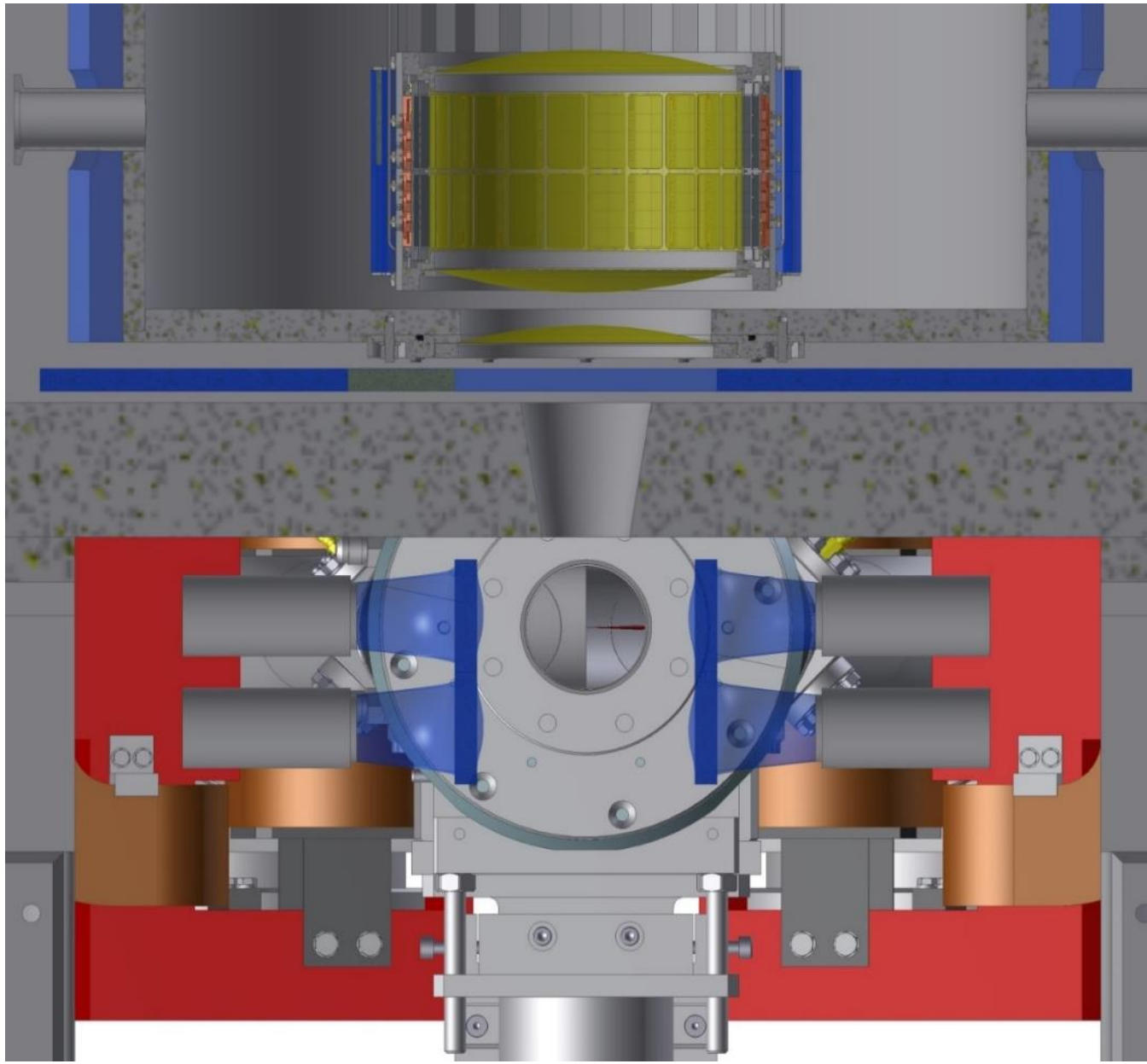
Because the available space is limited due to shielding material, the photomultiplier tubes have to be on the same side (a special light-guide mirror design was used).

M Bazzi et al., Journ. of. Instr. 8 (2013) T11003

SIDDHARTA-2 - Luminosity monitor (based on kaons)

Size: 8 x 8 cm^2, on both sides of the beam pipe, made of 2 pieces 8 x 4 cm^2
thickness = 2 mm
distance v = ± 4 cm off beam





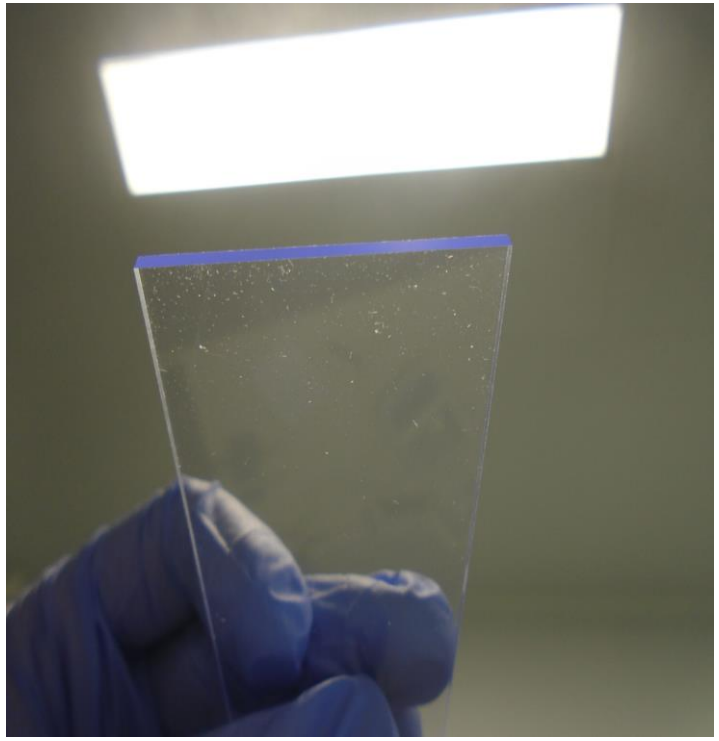
- coincidence rate: 25.7 %
- single rate at boost side: 42.7 %

with a luminosity $L = 10^{32} \rightarrow 62$ Hz (on boost-side)

in 5 seconds: 310 counts

Scintillators

Scionix **EJ-200** (BC408)



- rise time: 0.9ns
- decay time: 2.1ns
- wavelength of max. emission: 425nm
- light attenuation length: 210cm
- pulse width, FWHM: 2.5ns
- light output of anthracene: 64%

PMTs

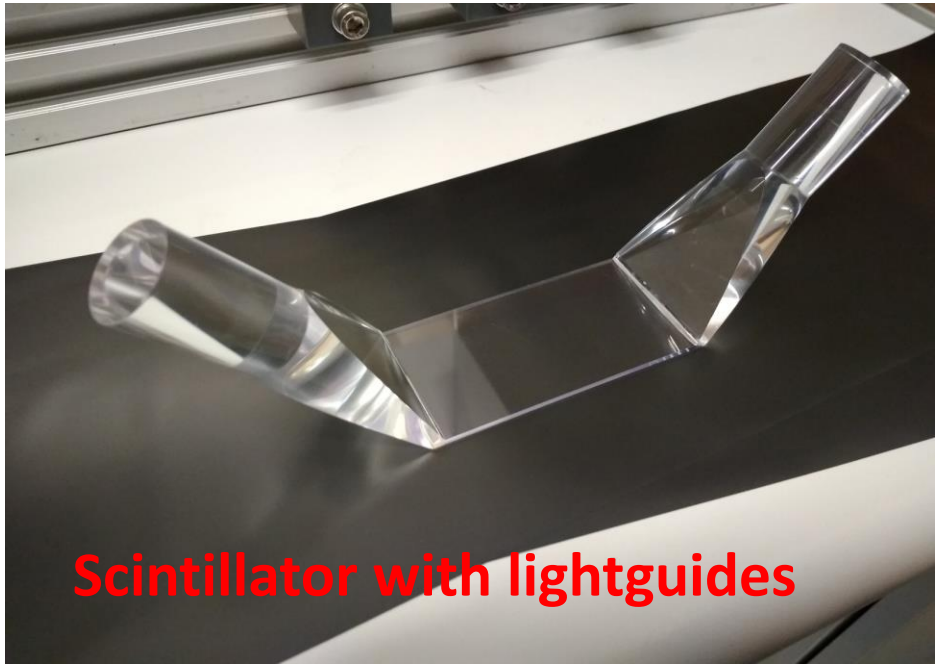
Hamamatsu **R4998**

- short rise time: 0.7ns
- small time spread: 160ps (FWHM)
- voltage: 1800-2500V (nominal 2250V)
- wavelength peak: 420nm
- gain: ~3*10^6
- quantum eff.: about 20%

August 2018

Luminosity monitor
by Wojciech Migdał


Lightguides gluing


Scintillator with lightguides

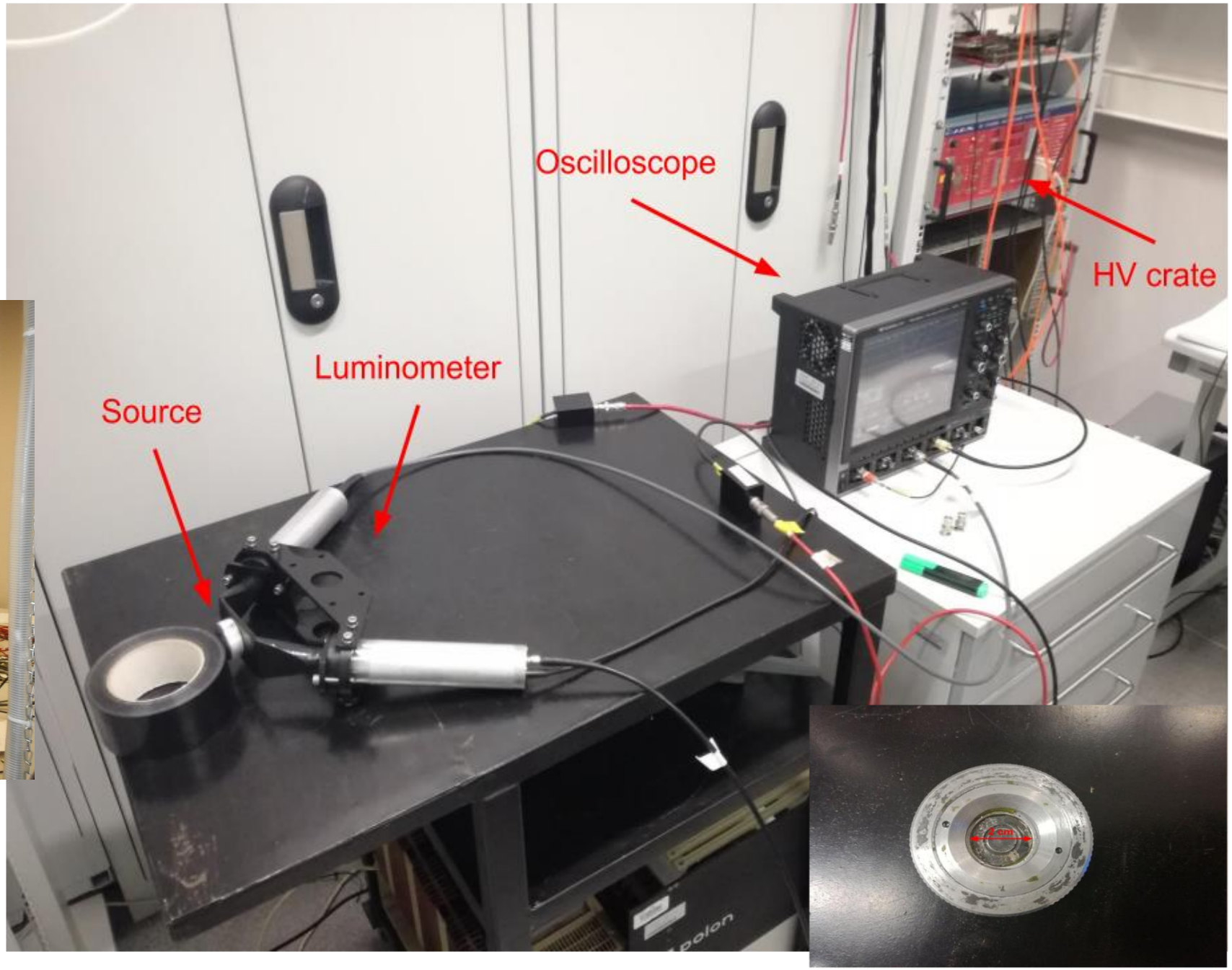

Wrapped in reflective and lightproof foil


Prepared for PMTs

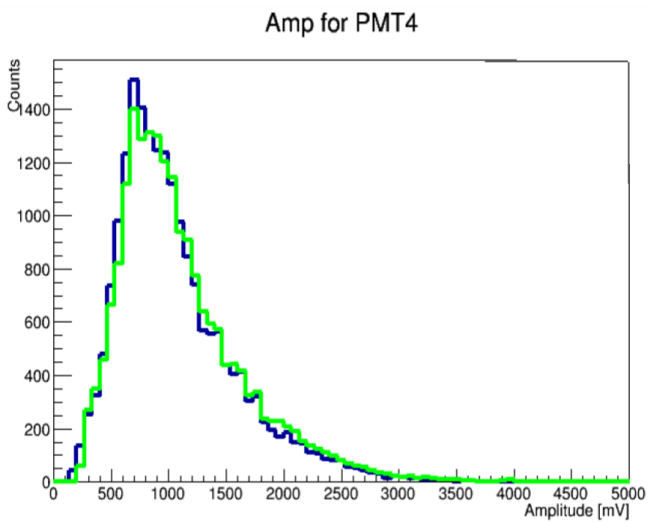

2 modules built

Tests in Krakow

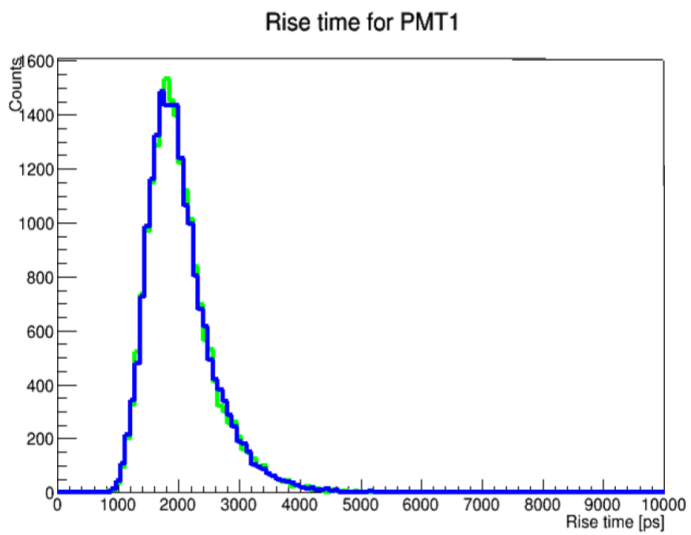
with Strontium-90 source



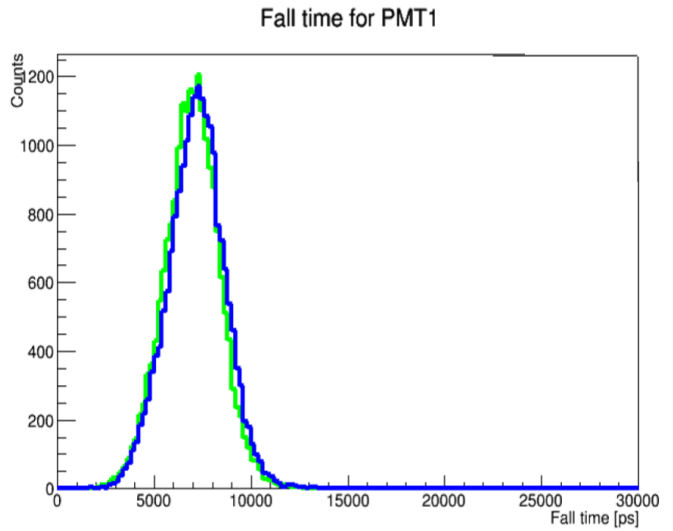
Tests in Krakow - results



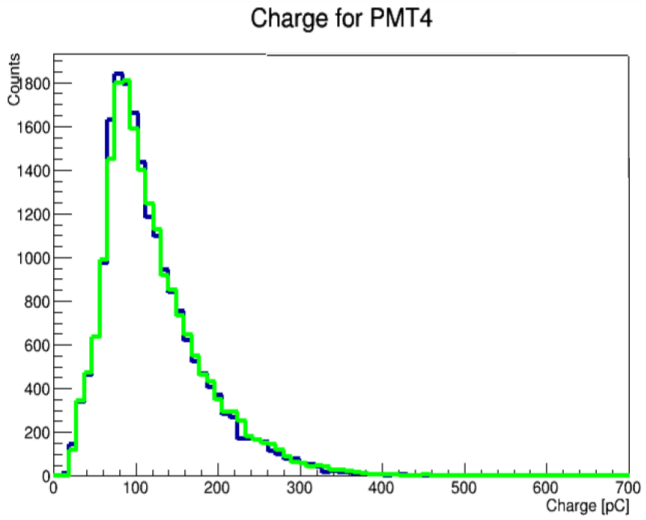
Amplitude spectrum for HV=2394V



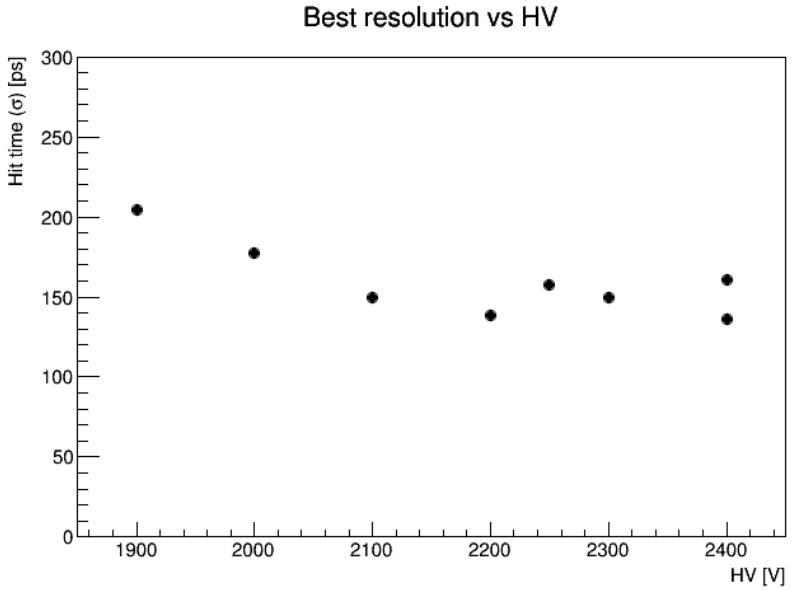
Rise time spectrum for HV=2394V



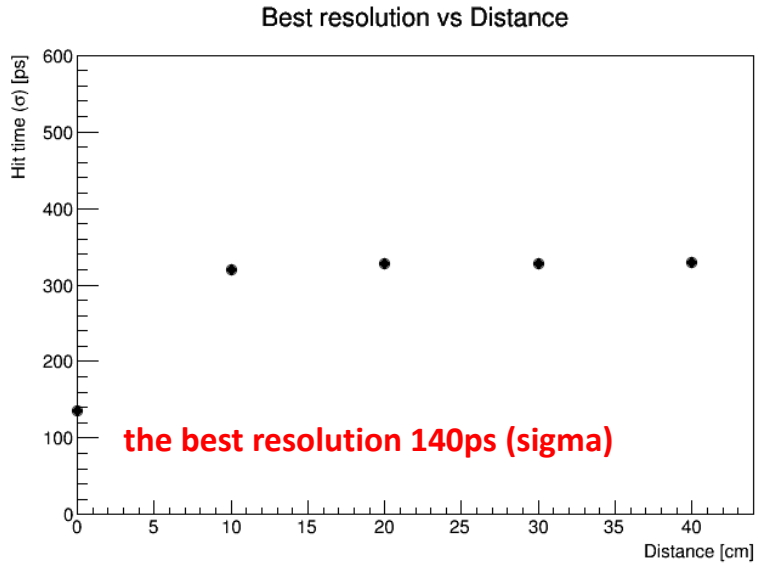
Fall time spectrum for HV=2394V



Charge spectrum for HV=2394V



Resolution vs. HV

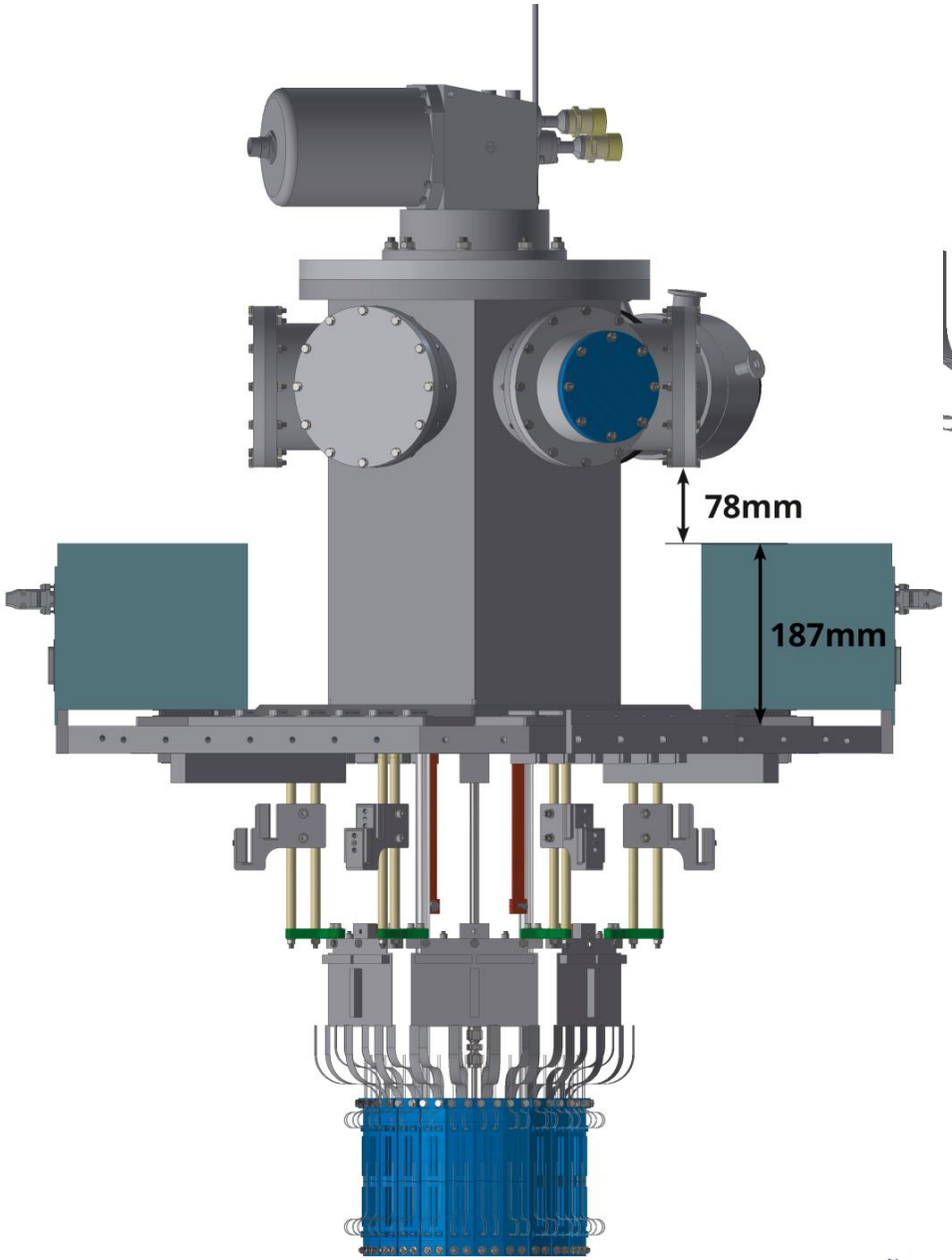


Resolution vs. source distance for HV=2394V

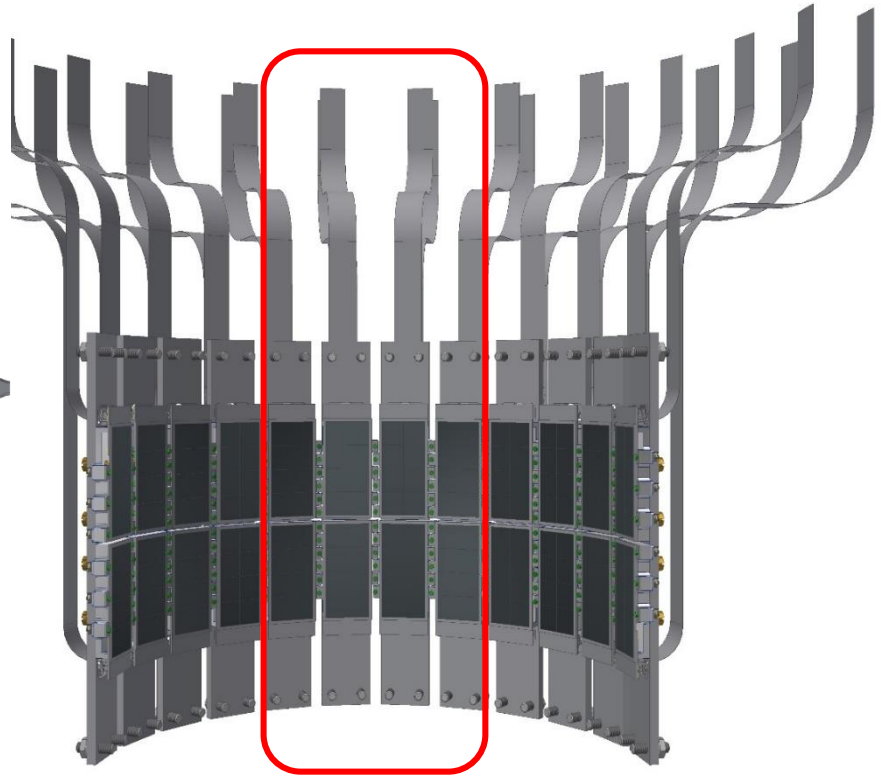
SIDDHARTA-2 schedule

- Commissioning of DAΦNE with SIDDHARTINO
- SIDDHARTA-2 Installation at DAΦNE anad run

SIDDHARTINO – SIDDHARTA-2 with 8 SDDs

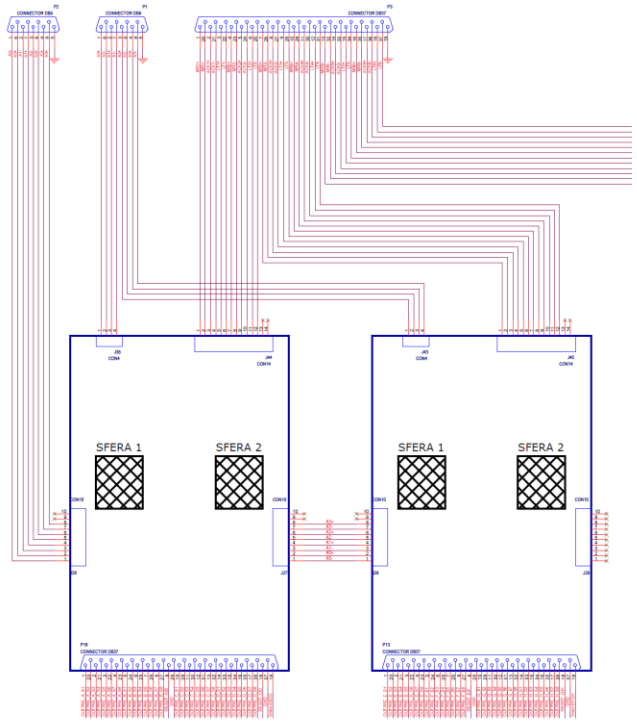


Technical run setup
8 SDD arrays
1 BUS structure

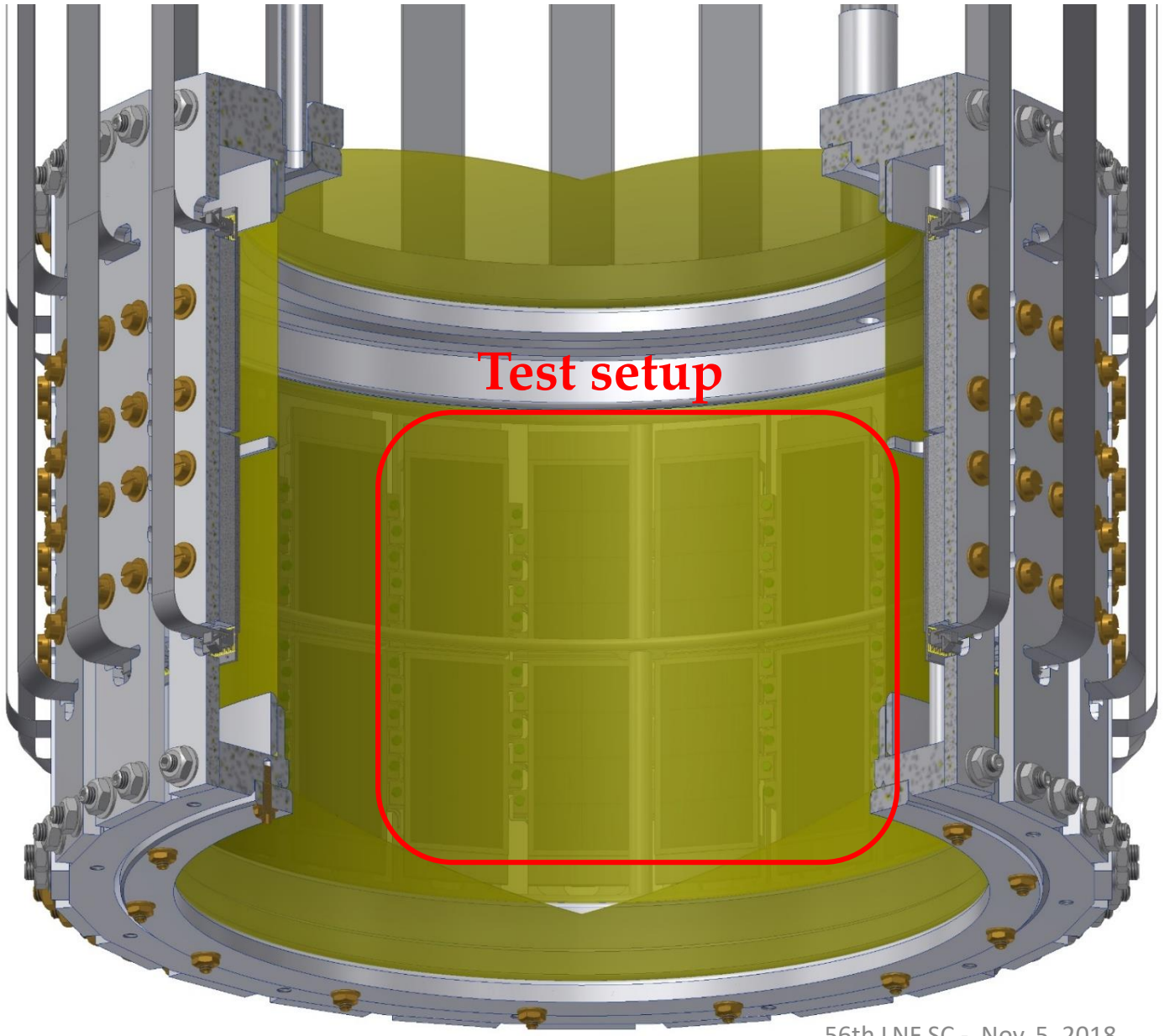


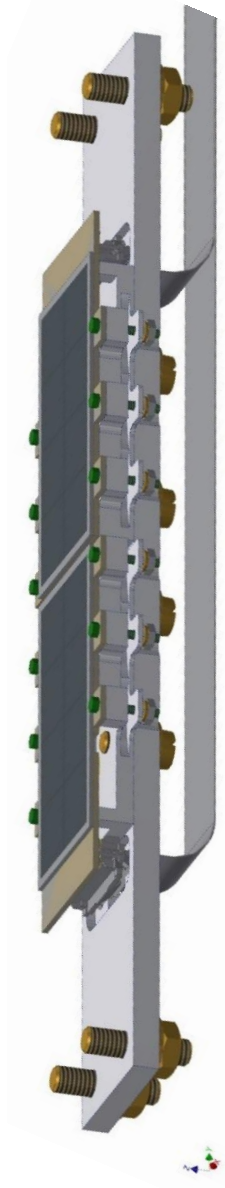
DAQ – Bus structure

- 4 SFERA boards
- 8 SDD arrays



SIDDHARTINO SDD arrangement

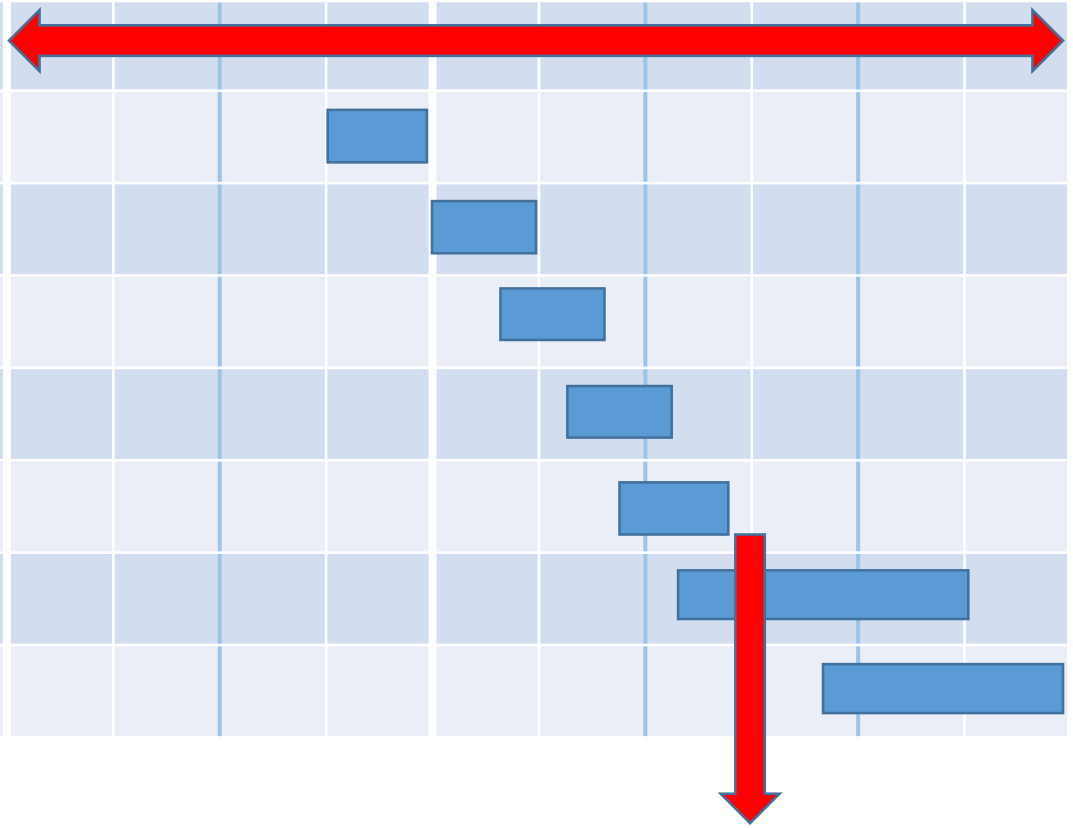




8 SDD arrays will be used

SIDDHARTINO time schedule

	Aug	Sept	Oct	Nov	Dec
SDD characterisation (test chamber)					
Installation of SIDDHARTA-2 chamber in Lab					
Installation cryogenic target (vacuum tests)					
Cryogenic target testing					
Installation of 8 SDDs (= one DAQ bus system)					
Installation Veto + DAQ					
DAQ test: SDD + Veto + kaon monitor					
SDD calibration					



SIDDHARTINO is ready for installation at DAΦNE

SIDDHARTA-2 schedule:

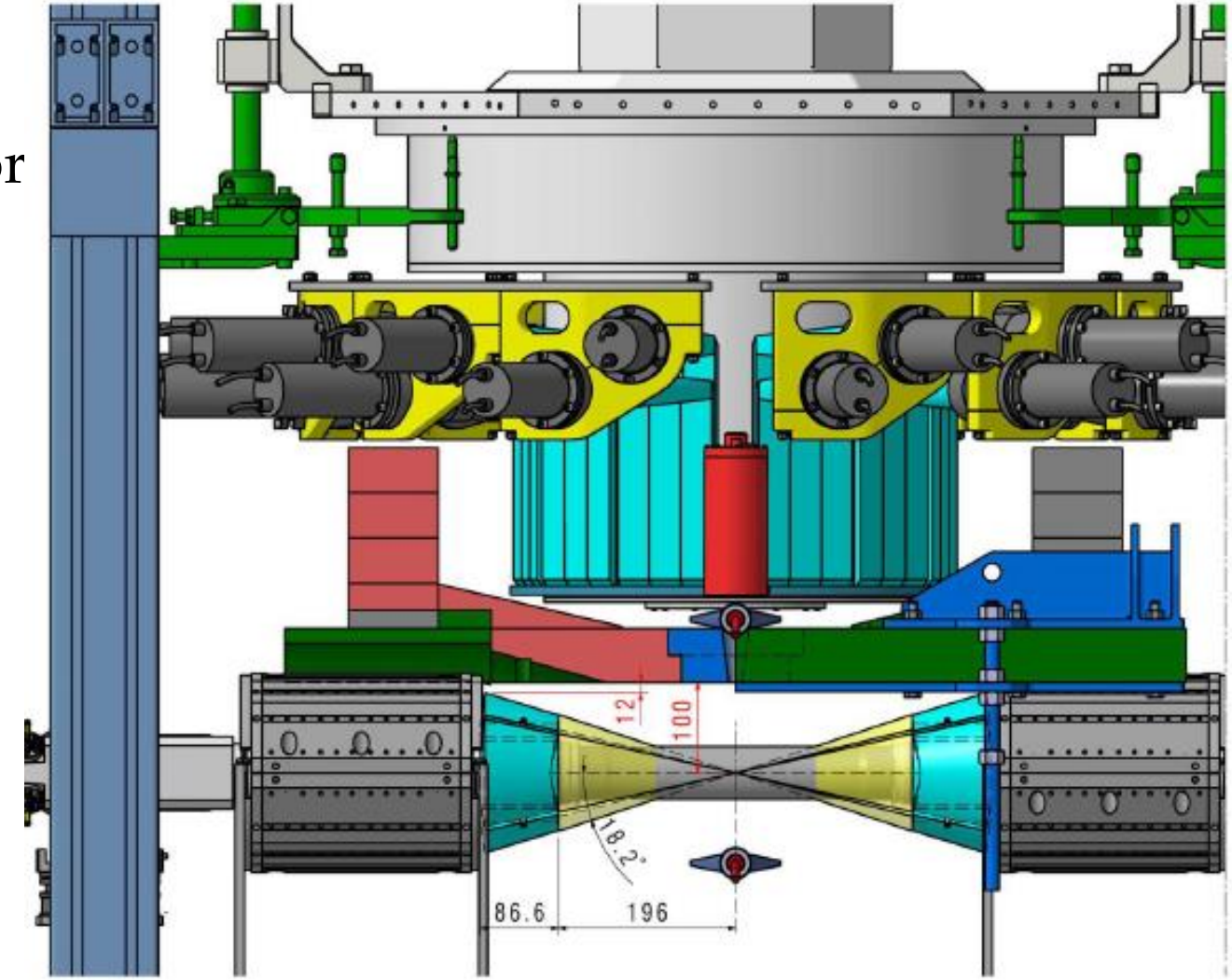
Phase 1: commissioning of DAΦNE - technical run,
SIDDHARTINO (K^-He with 8 SDD units)
?March – June? 2019

Phase 2: when DAΦNE operating condition is
comparable (S/B) with SIDDHARTA
kaonic deuterium (48 SDD units):
summer? 2019 – summer 2020? for 800 pb^{-1}
(in addition/parallel feasibility tests for
future measurements)

Commissioning – SIDDHARTINO

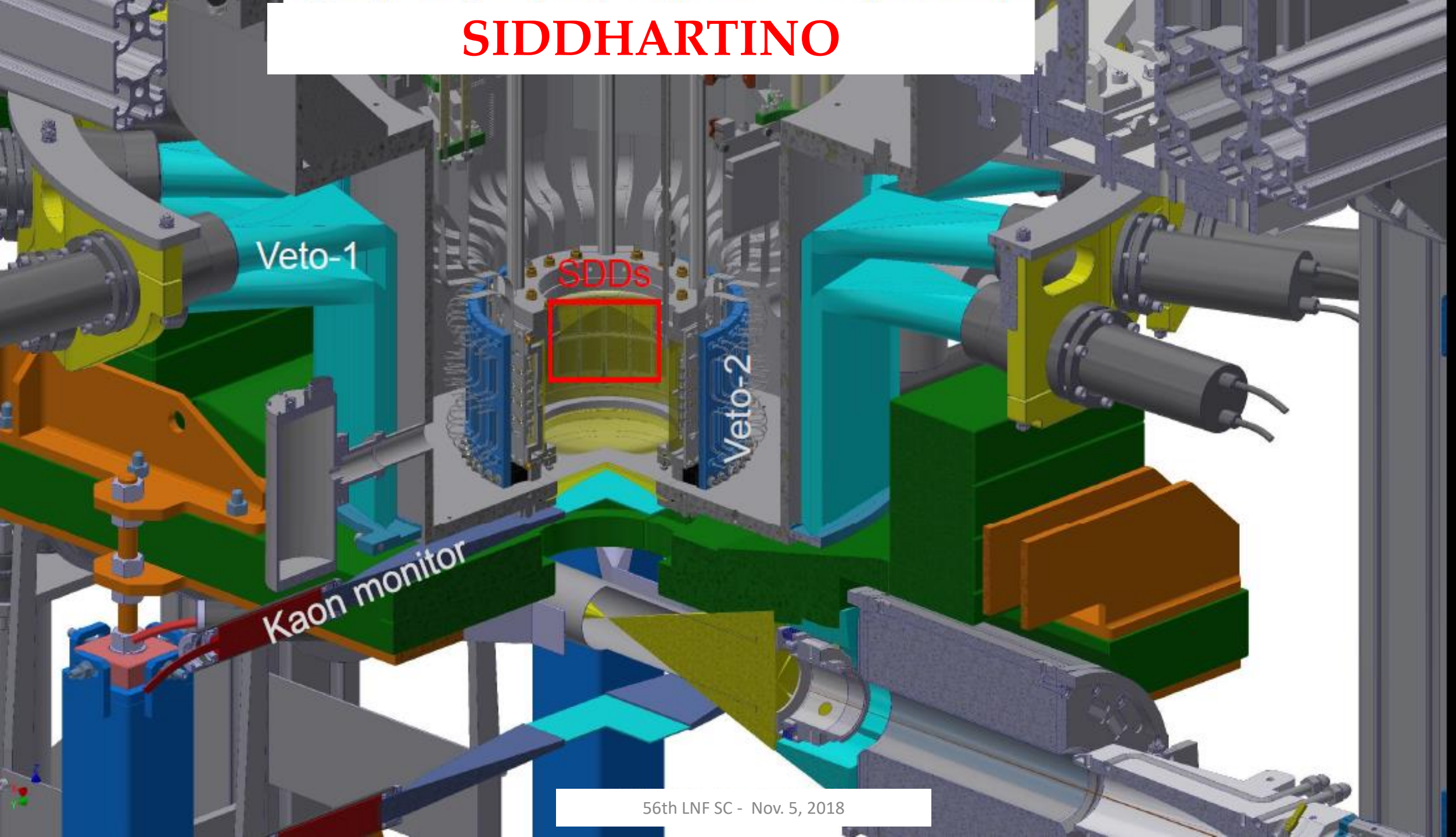
start March 2019?
(depends on DAΦNE)

- with full DAΦNE luminosity monitor
  → SIDDHARTA2 lifted by ~100 mm
- equipped with 8 SDD arrays
  → 1 DAQ sub-system
- complete Veto system
- SIDDHARTA2 luminosity monitor
- run with He-4 (we know it very
- well from SIDDHARTA)

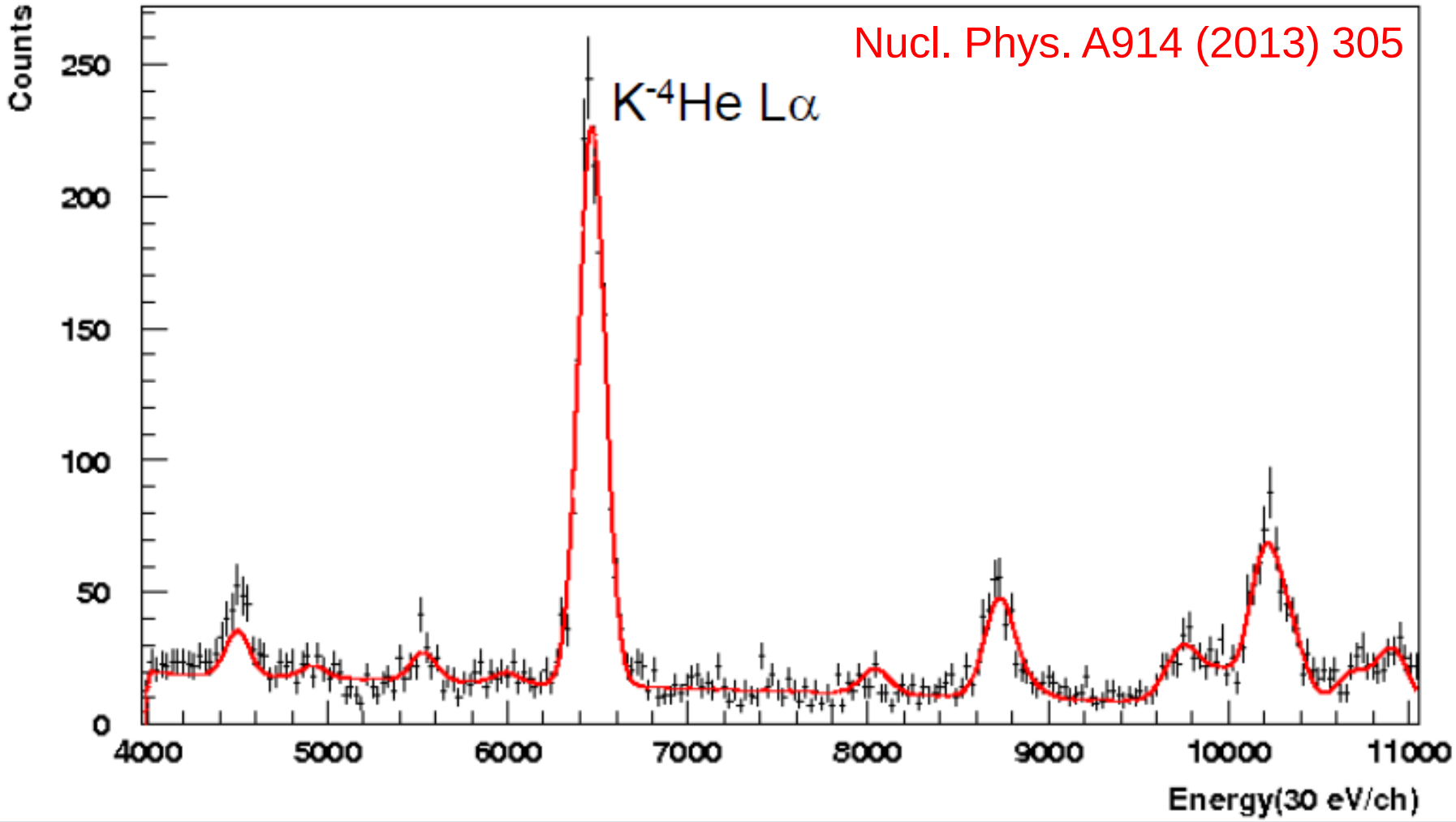


verify when the DAΦNE background is equal to, or lower then in SIDDHARTA 2009

SIDDHARTINO



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



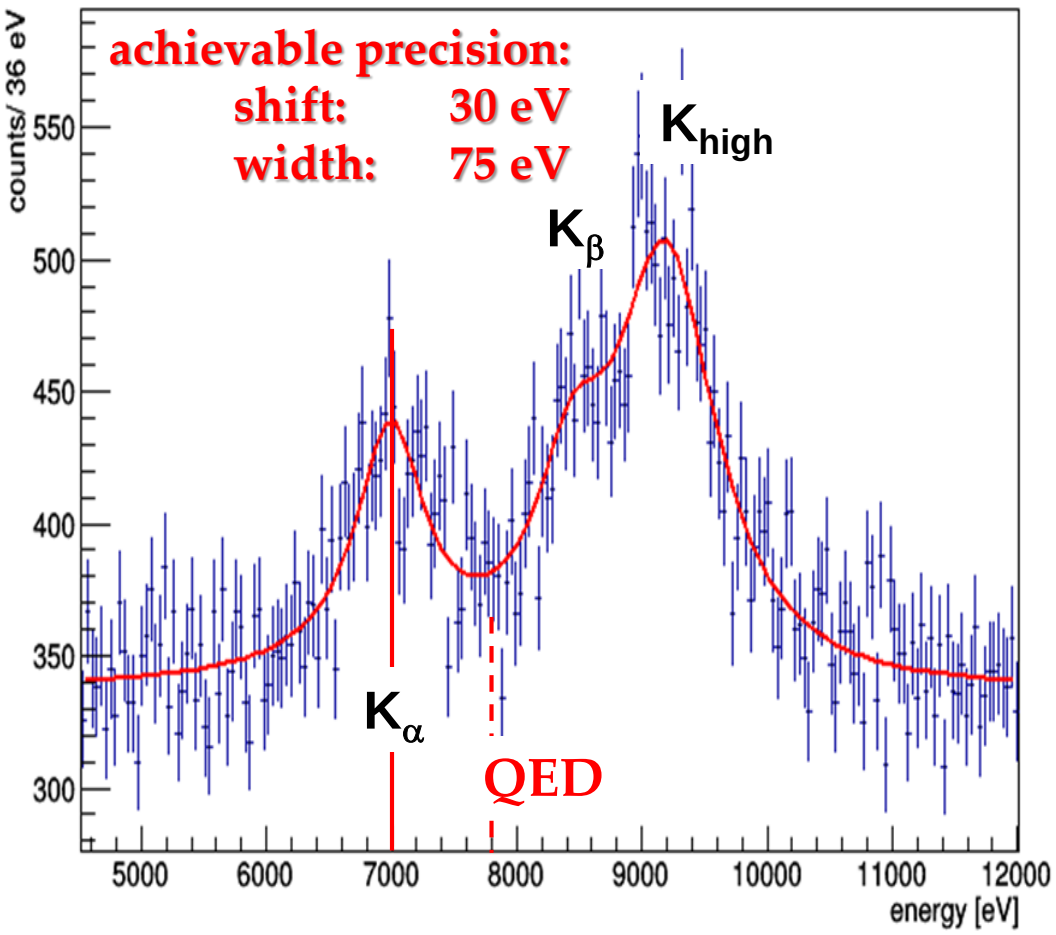
MCarlo simulations undergoing (input from DAΦNE)
SIDDHARTINO: Signal 30 – 50 events/pb (depending of distance from IP)
We aim: S/B 50(100) to 1 → SIDDHARTA-2 K^-d

SIDDHARTA-2 plan for the K-d measurement

During the SIDDHARTINO run March-June(?) 2019:

- Preparation/tests of all SDD, readout electronics, DAQ
- Optimization of shielding and supports, input from tech run
- Optimization of veto systems, input from tech run
- Deuterium generator tested

- When technical run will be over (DAFNE delivers beams in conditions at least as good as for final SIDDHARTA) June 2019? whole SIDDHARTA-2 setup will be installed:
- 2 weeks installation at DAΦNE
- 2 weeks test, debug and calibration
- September 2019 ? ready to run K^-d



Kaonic deuterium run in 2019/20:

800 pb^{-1} to perform the first measurement of the strong interaction induced energy shift and width of the kaonic deuterium 1s ground state (similar precision as K^-p) !

Future programme and perspectives on exotic atom research

- **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 ?)**

New projects financed in connection with SIDDHARTA-2

1) Grant from Croatian Science Foundation,
research project number 8570, period 16.10.2018 - 15.10.2022.

Title: Electrons, kaons and neutrons in high precision measurements of hadrons and nuclei properties

2) EU Project: STRONG-2020
with relation to SIDDHARTA-2:

- Network THEIA (Strange Hadrons and EOS of Neutron Stars)
- JRA: ASTRA (CdZnTe - exotic atoms)

Horizon 2020

Call: H2020-INFRAIA-2018-2020

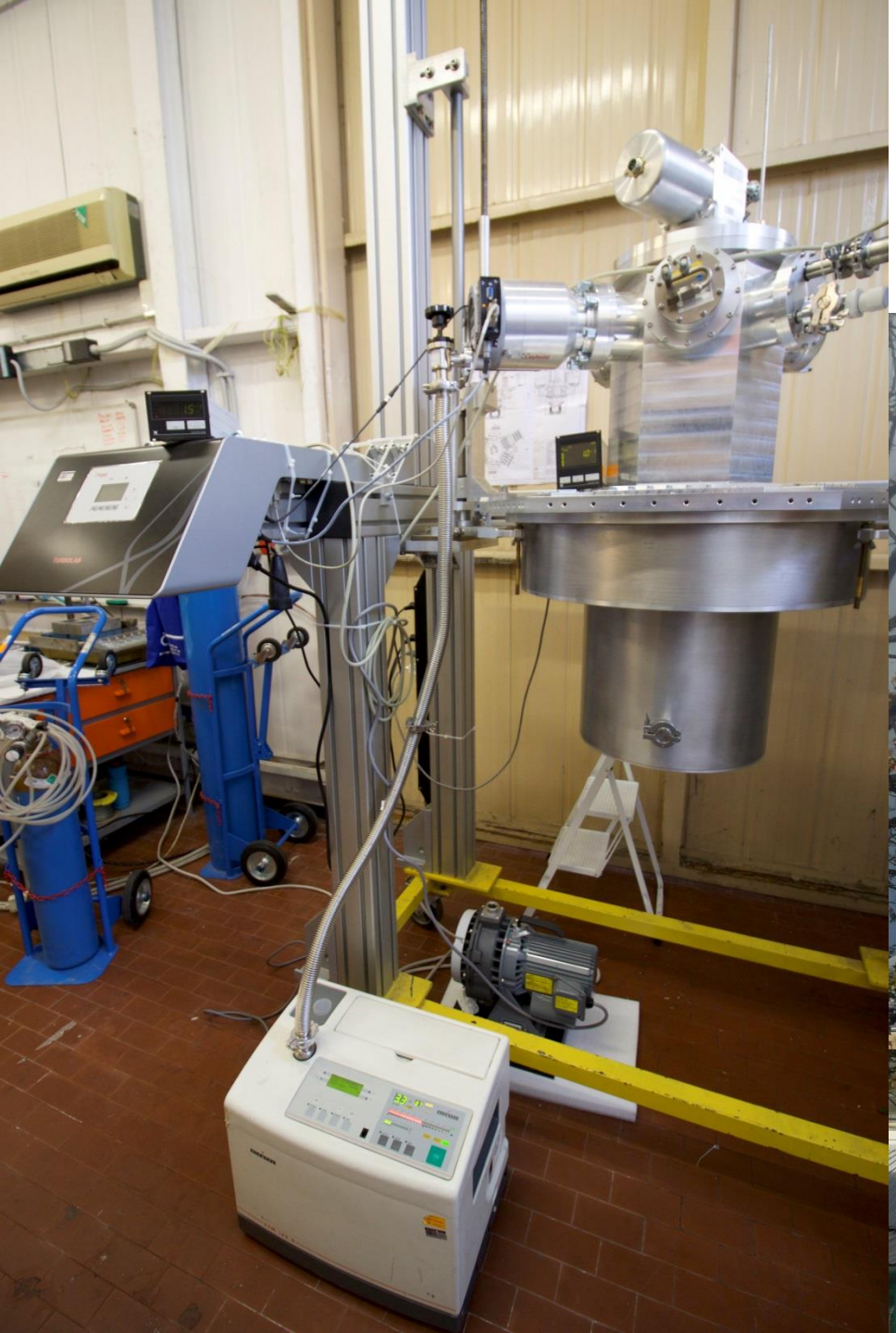
(Integrating and opening research infrastructures of European interest)

Topic: INFRAIA-01-2018-2019

Type of action: RIA

Proposal number: SEP-210495756

Proposal acronym: STRONG-2020



SIDDHARTINO is ready in the laboratory

WE INViTE YOU TO VISIT US!

We are eagerly awaiting installation on DAΦNE

Special thanks to the accelerator division,
to DAΦNE and BTF staffs,
to the LNF Director and to the responsible
of the LNF Research Division

Thank you !