SIDDHARTA - 2
STATUS REPORT

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for the SIDDHARTA-2 Collaboration

55^{th} LNF-INFN SCIENTIFIC COMMITTEE
May 14, 2018

CONTENT

Scientific Motivation

SIDDHARTA-2 apparatus

Time schedule

SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

LNF- INFN, Frascati, Italy
SMI- ÖAW, Vienna, Austria
Politecnico, Milano, Italy
IFIN – HH, Bucharest, Romania
TUM, Munich, Germany, Germany
RIKEN, Japan
Univ. Tokyo, Japan
Victoria Univ., Canada
Univ. Zagreb, Croatia
Helmhotlz Inst. Mainz, Germany
Univ. Jagellonian, Krakow

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***

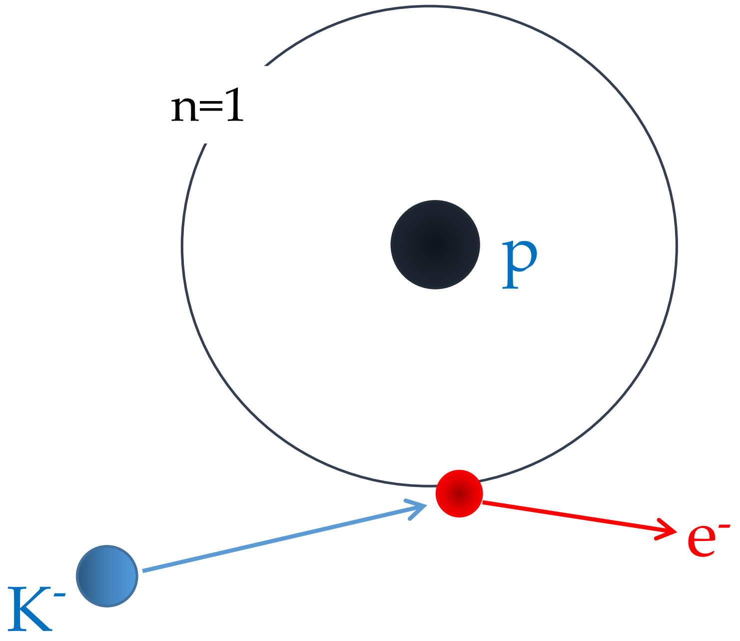
- NOW **first measurement of kaonic deuterium**

to extract the antikaon-nucleon isospin dependent scattering lengths

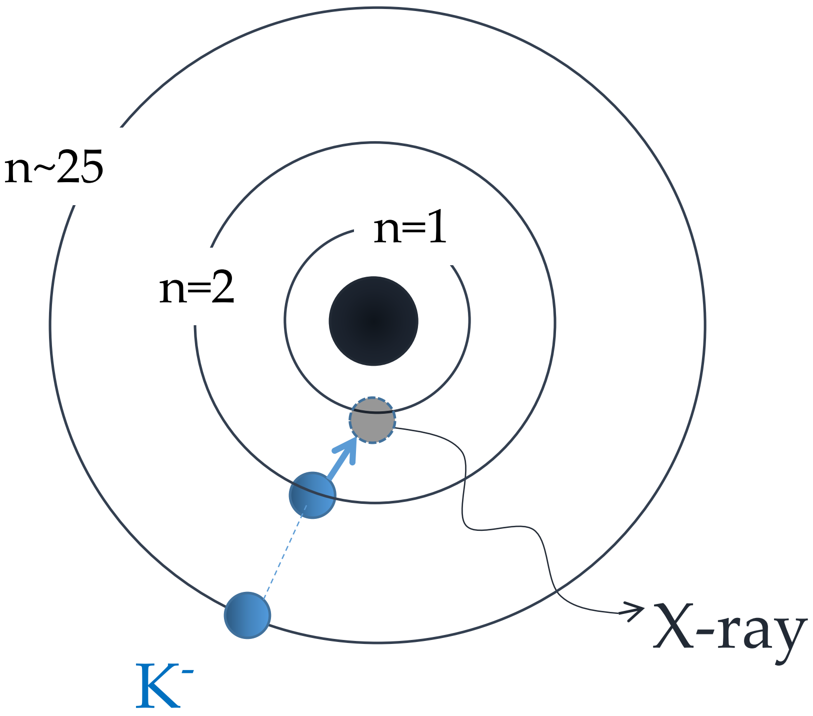
- chiral symmetry breaking (mass problem), EOS for neutron stars

FORMING "EXOTIC" ATOMS

"normal" hydrogen



"exotic" (kaonic) hydrogen

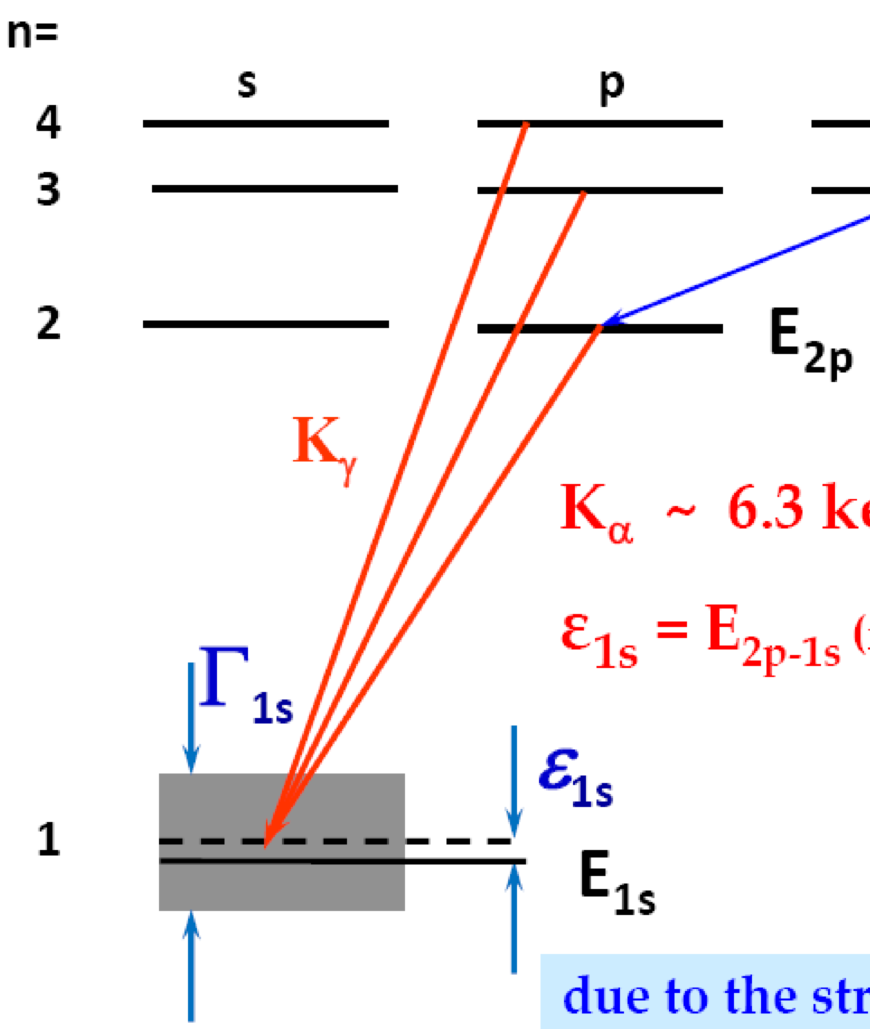


$$n \approx \sqrt{\frac{m_{\text{red}}}{m_e}} \cdot n_e$$

$2p \rightarrow 1s$

K_α transition

X-RAY TRANSITIONS TO THE 1s STATE



shift and width of states n > 1 are negligible

K_α ~ 6.3 keV

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

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 $a_{\text{K-p}}$

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

(μ_C reduced mass of the K^-p system, α fine-structure constant)

U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

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

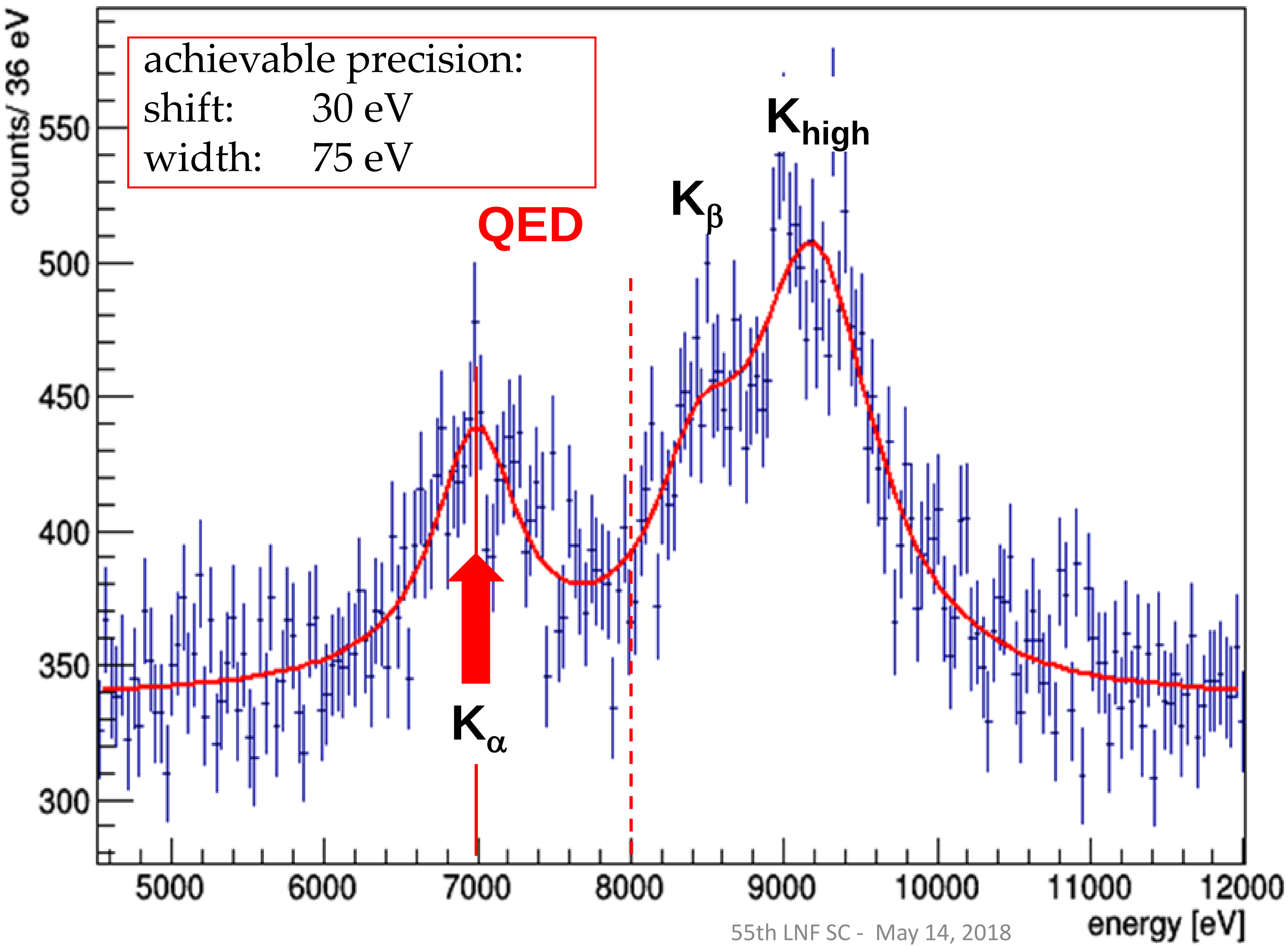
$$a_{K^-n} = a_1$$

←

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

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

Geant4 simulated $K^{-}d$ X-ray spectrum



signal: shift - 800 eV
width 800 eV
density: 5% (LHD)
detector area: 246 cm^2

Kα yield: 0.1 %
yield ratio as in $K^{-}p$
S/B ~ 1 : 4

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

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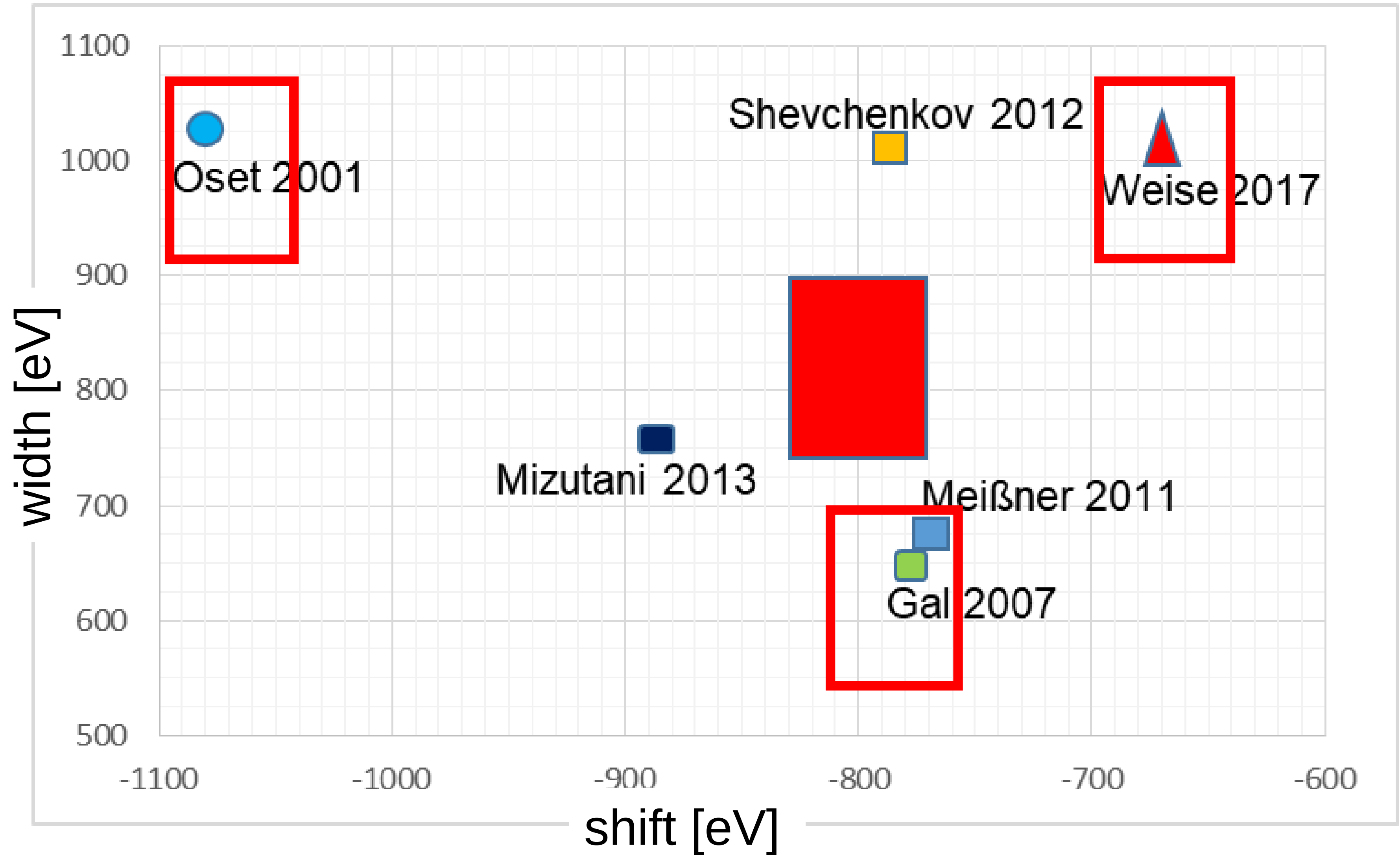
[2] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
[3] *Physik-Department, Technische Universität München, 85748 Garching, Germany*

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.

- **Hot topic: Neutron star, strangeness content - EOS**

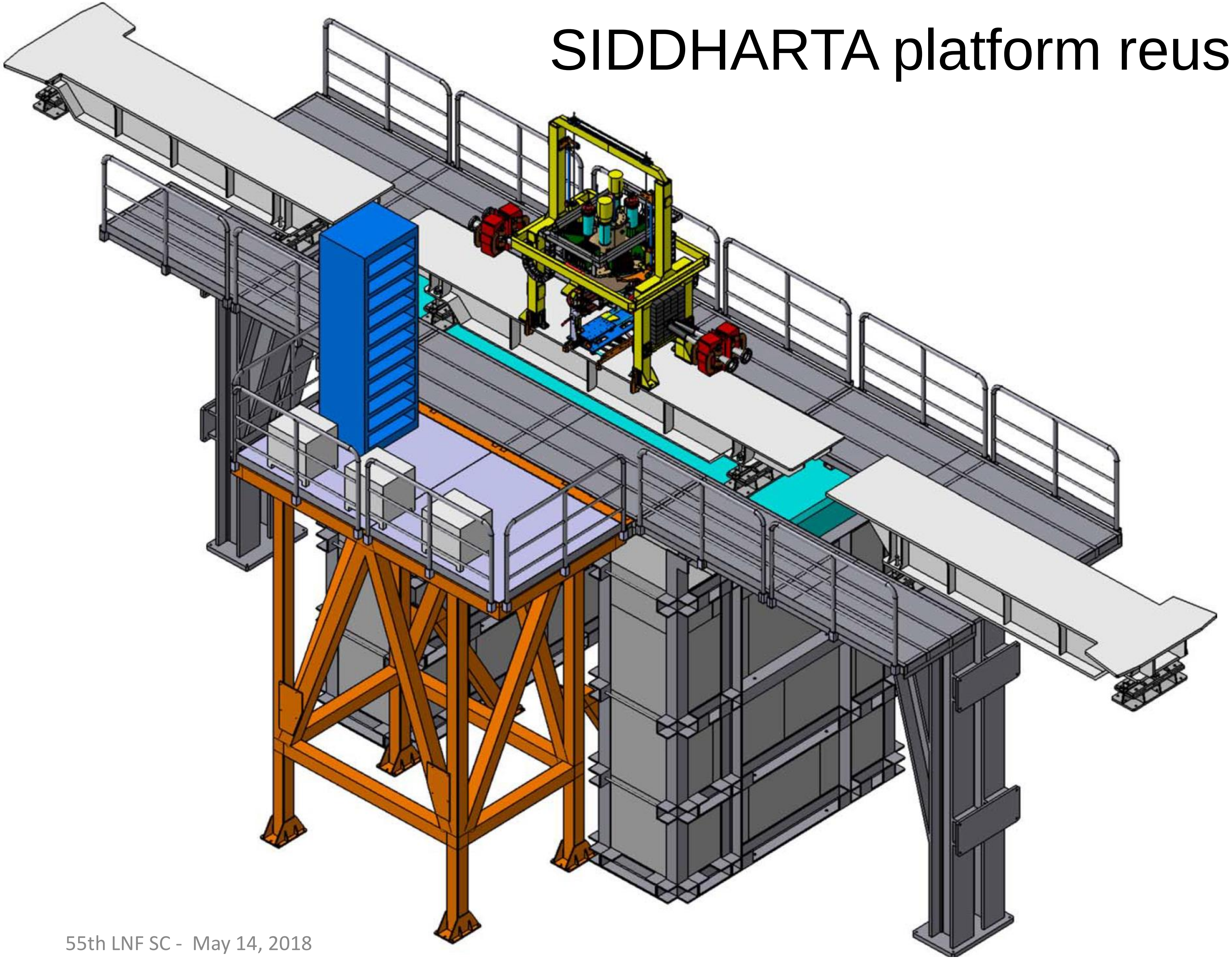
Theory – SIDDHARTA-2



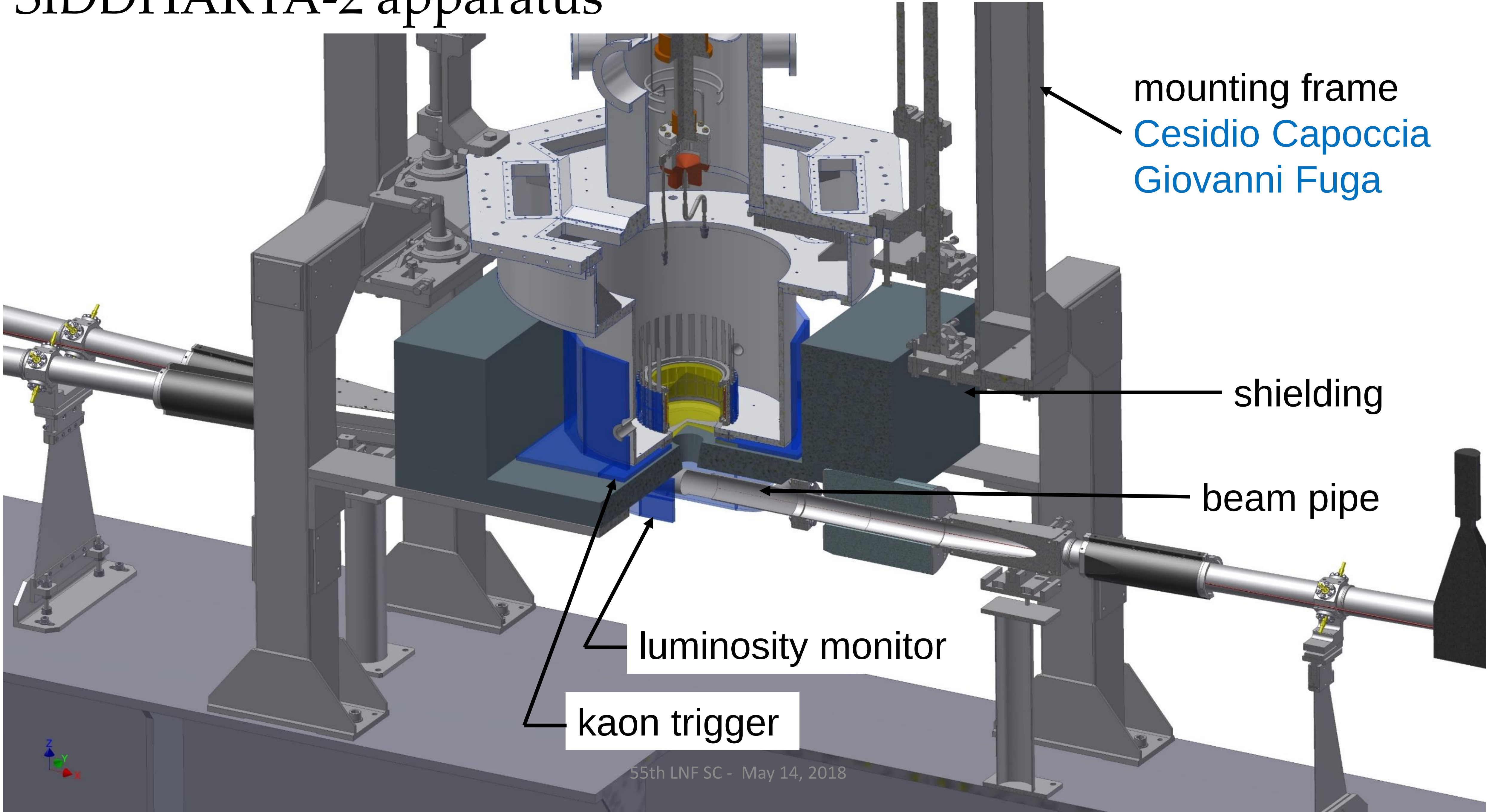
SIDDHARTA-2 setup

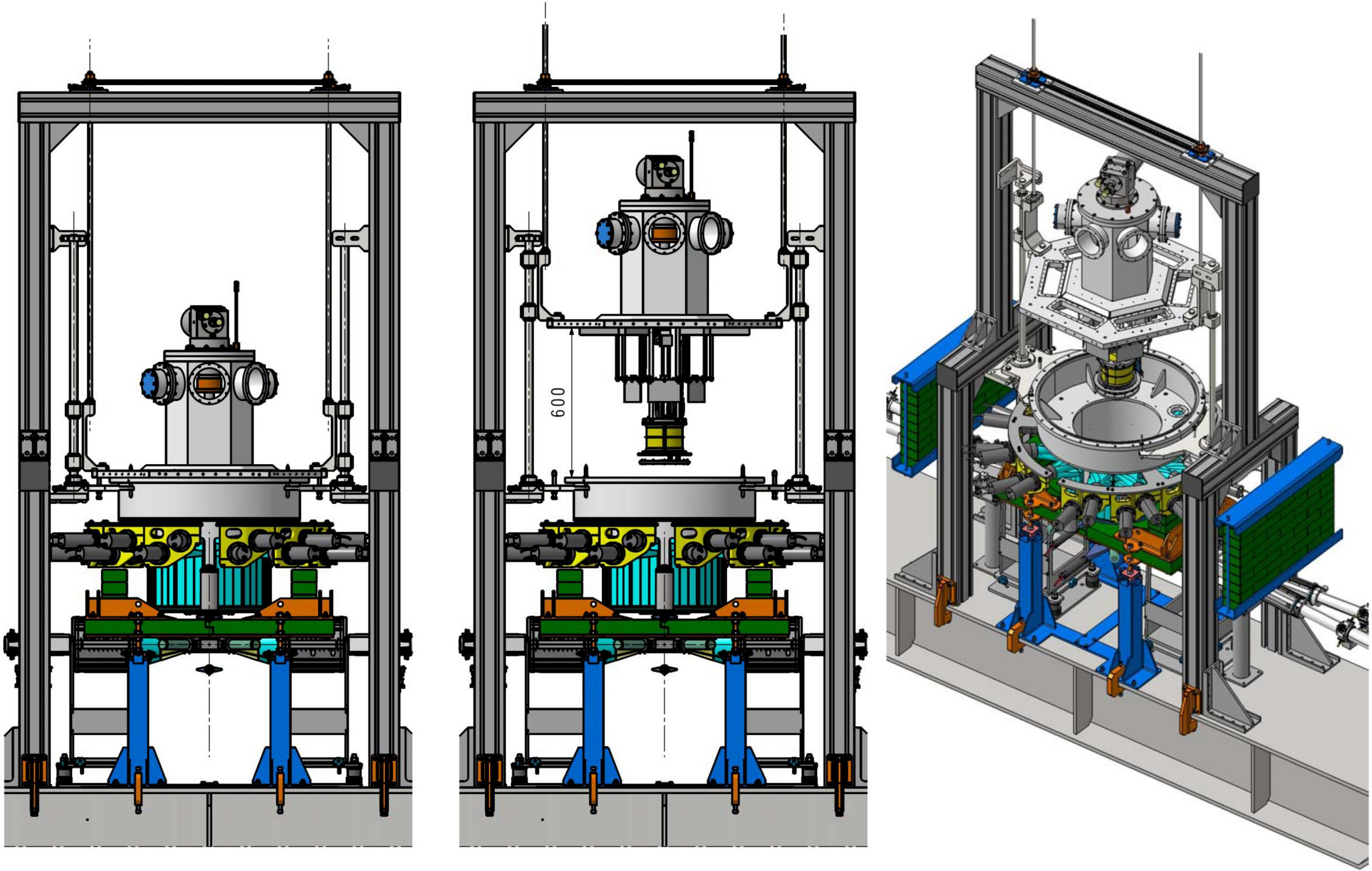
- platform
- cryogenic target
- cryo target – SDD – veto system
- beam pipe
- Silicon Drift Detector array

SIDDHARTA platform reused



SIDDHARTA-2 apparatus

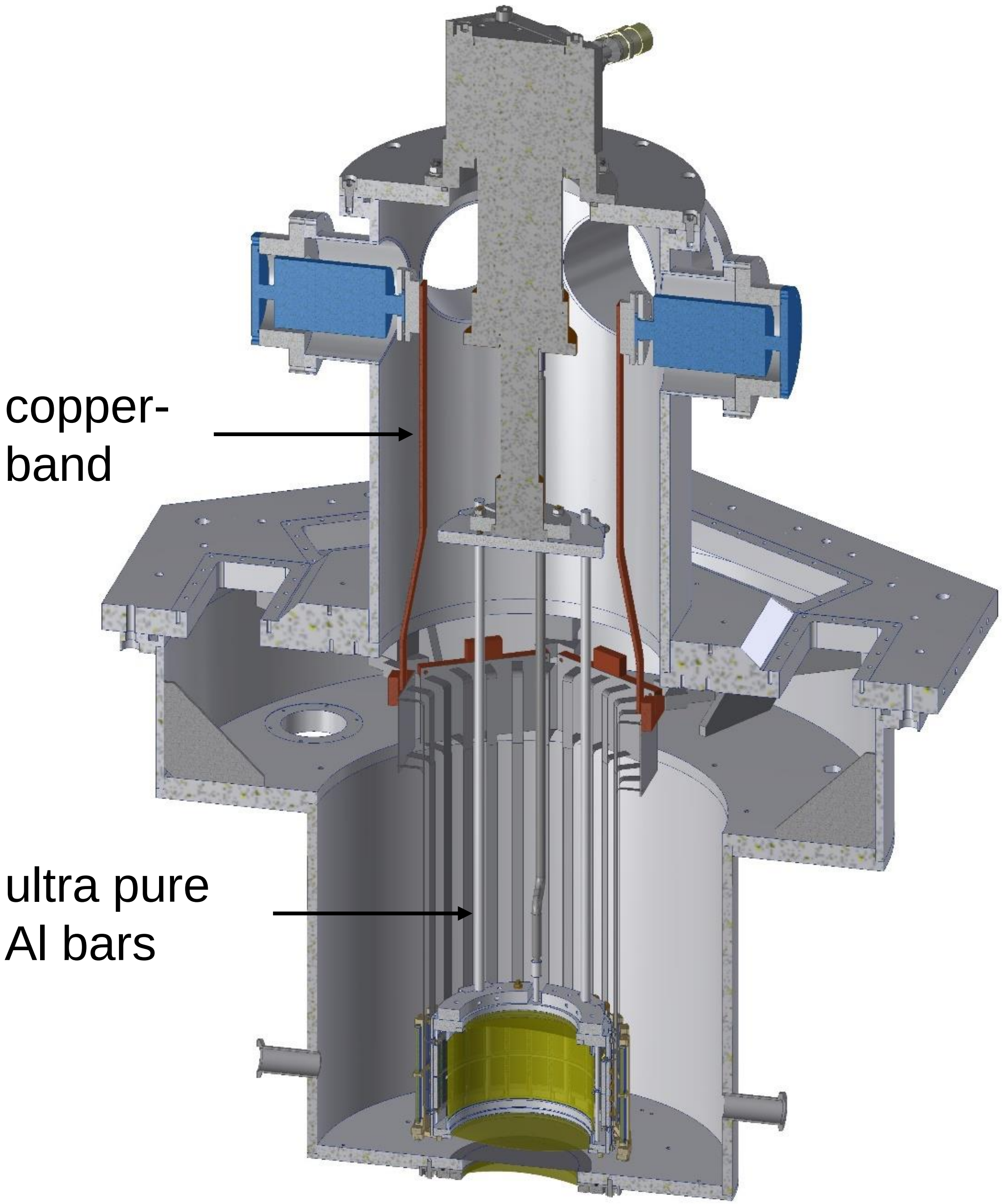



600

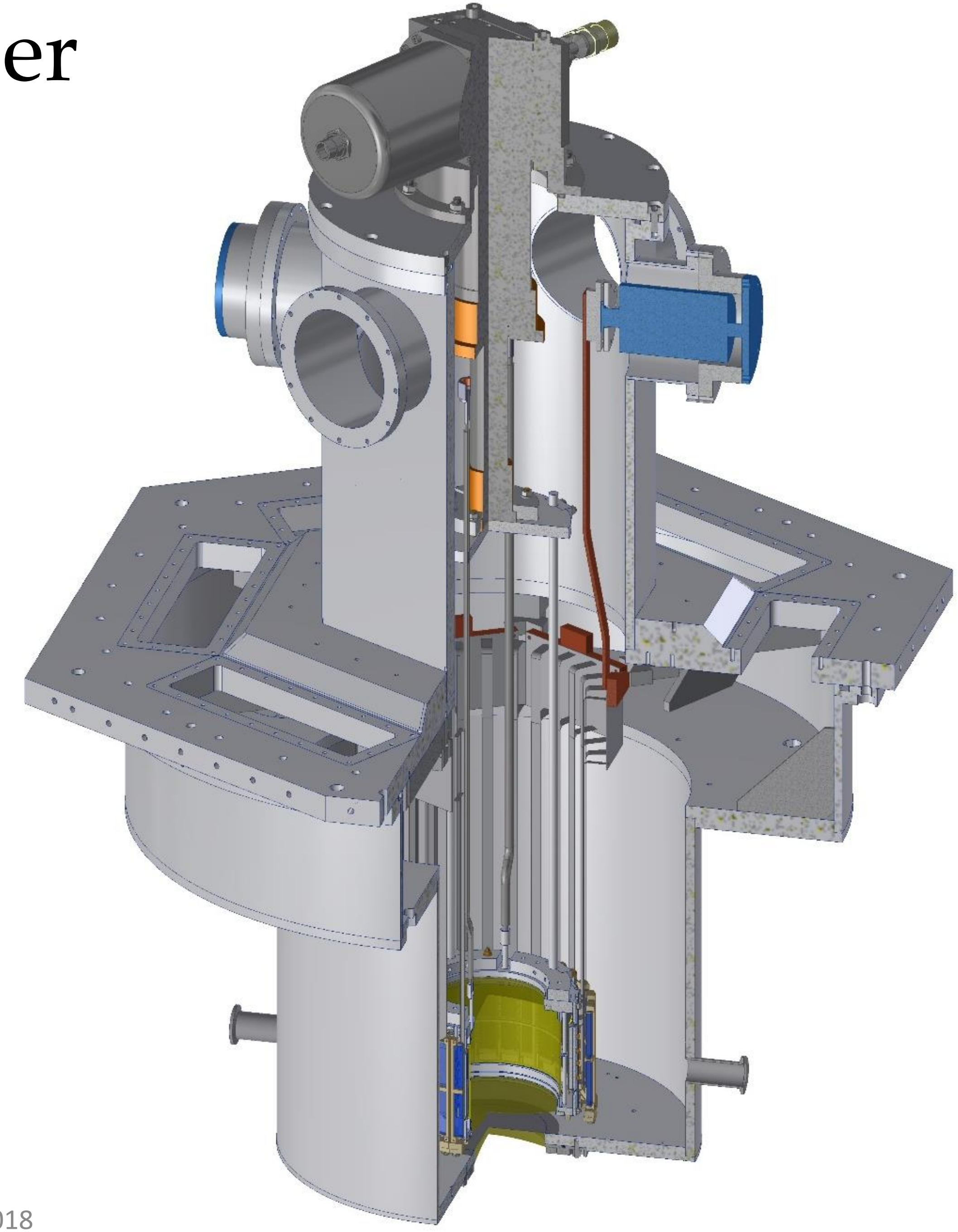
SIDDHARTA-2 cooling

✓ **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
$T_{SDD} = 50$ K

✓ **Line driver boards:**
2 CryoTiger – 30 W @ 120 K
copper-band cooling lines
$T_{LD} = 120$ K

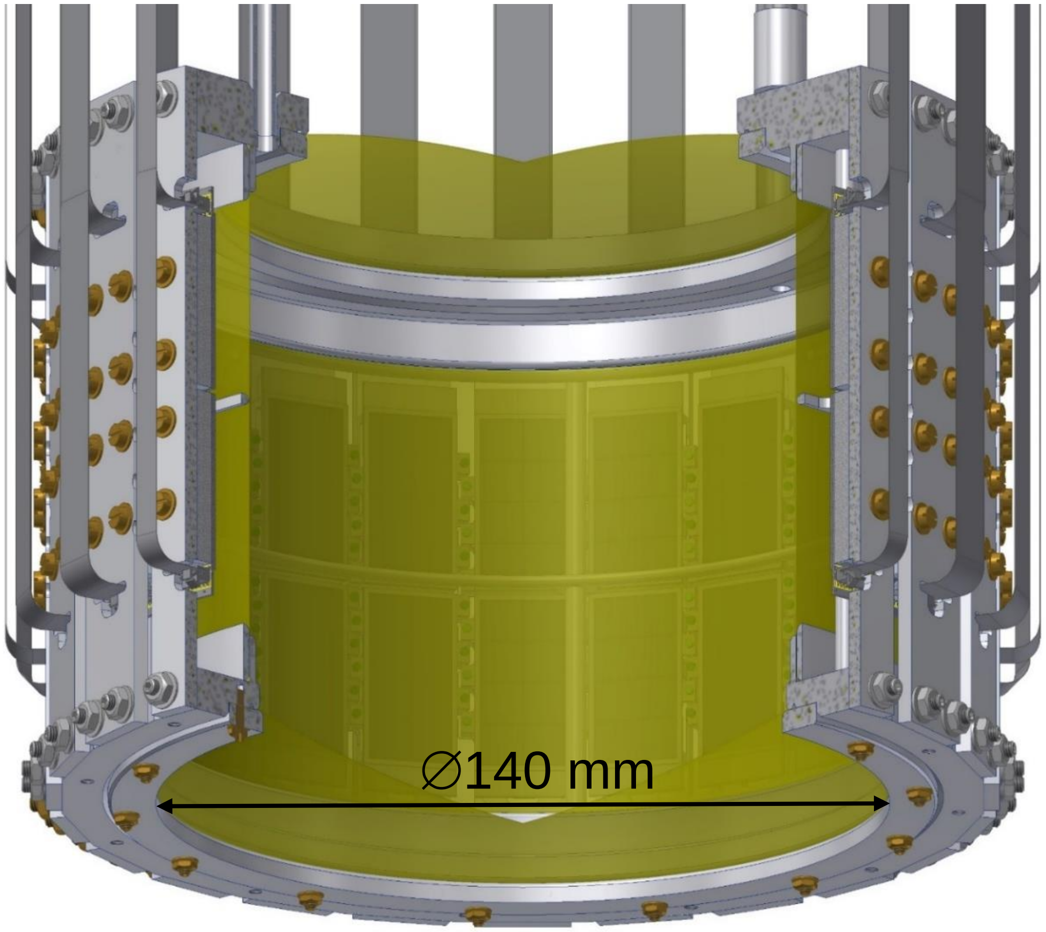


SIDDHARTA-2 vacuum chamber



SIDDHARTA-2 cryogenic target

Working temperature: 30 K
Working pressure : 0.3 MPa



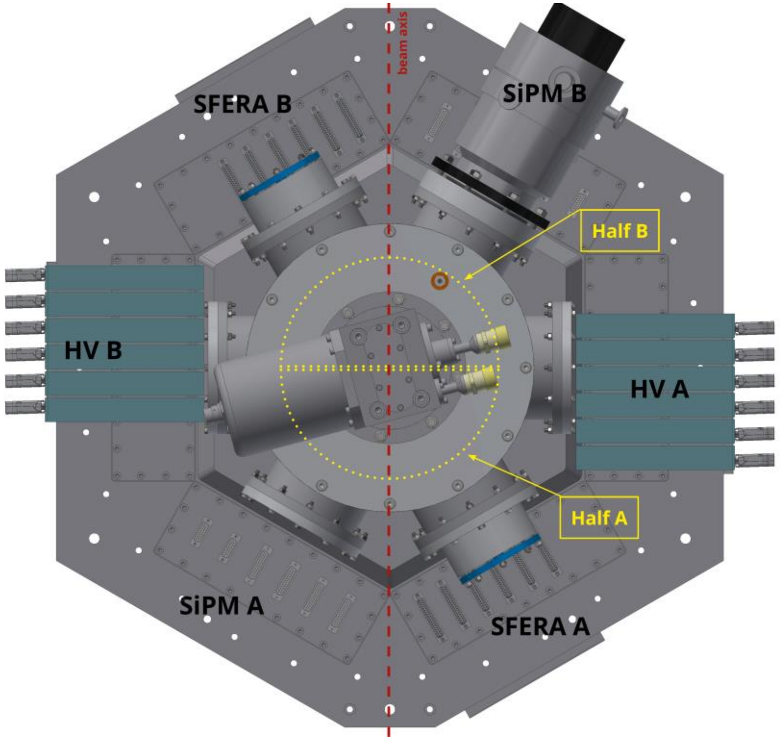
Final test during summer 2017:
Pressurised for 16 days
with P = 0.3 MPa (overP)

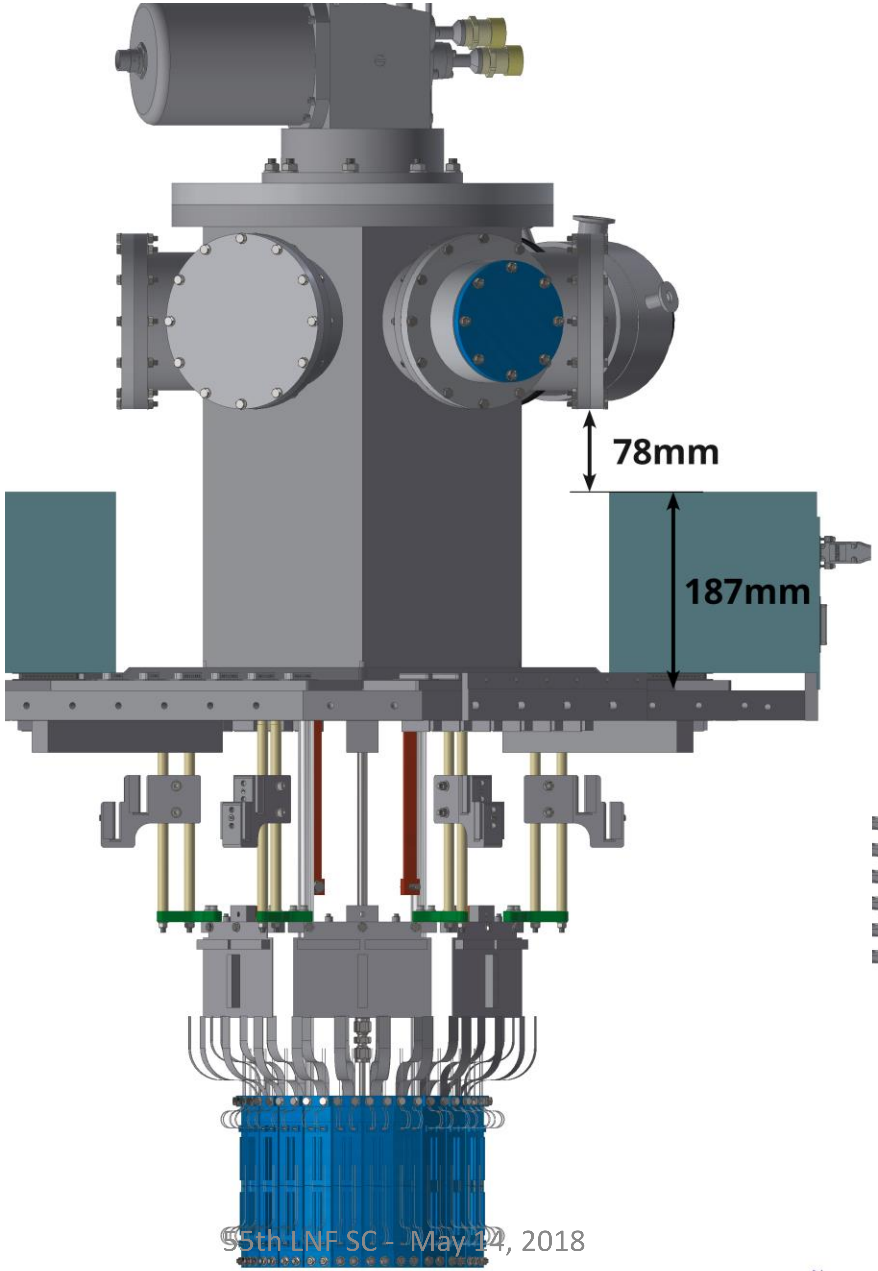
Cooling/pressure test
- 2.5 weeks 30 K / 0.19 MPa
- 3.5 days 30 K / 0.31 MPa

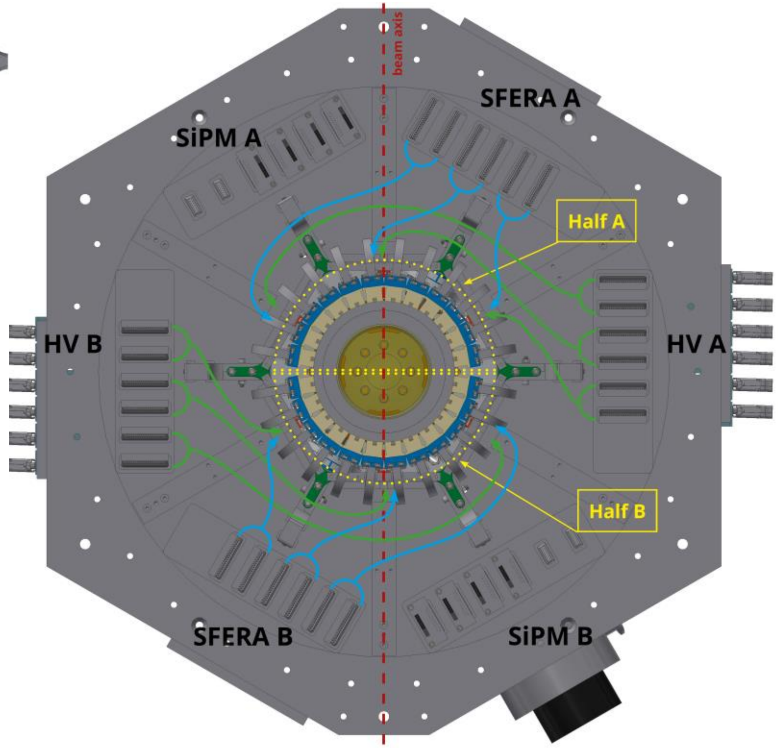
➢ Target cell wall is made of a 2-Kapton layer structure (25 μm + 25 μm + Araldit < 100 μm)

➢ **HP Deuterium generator**

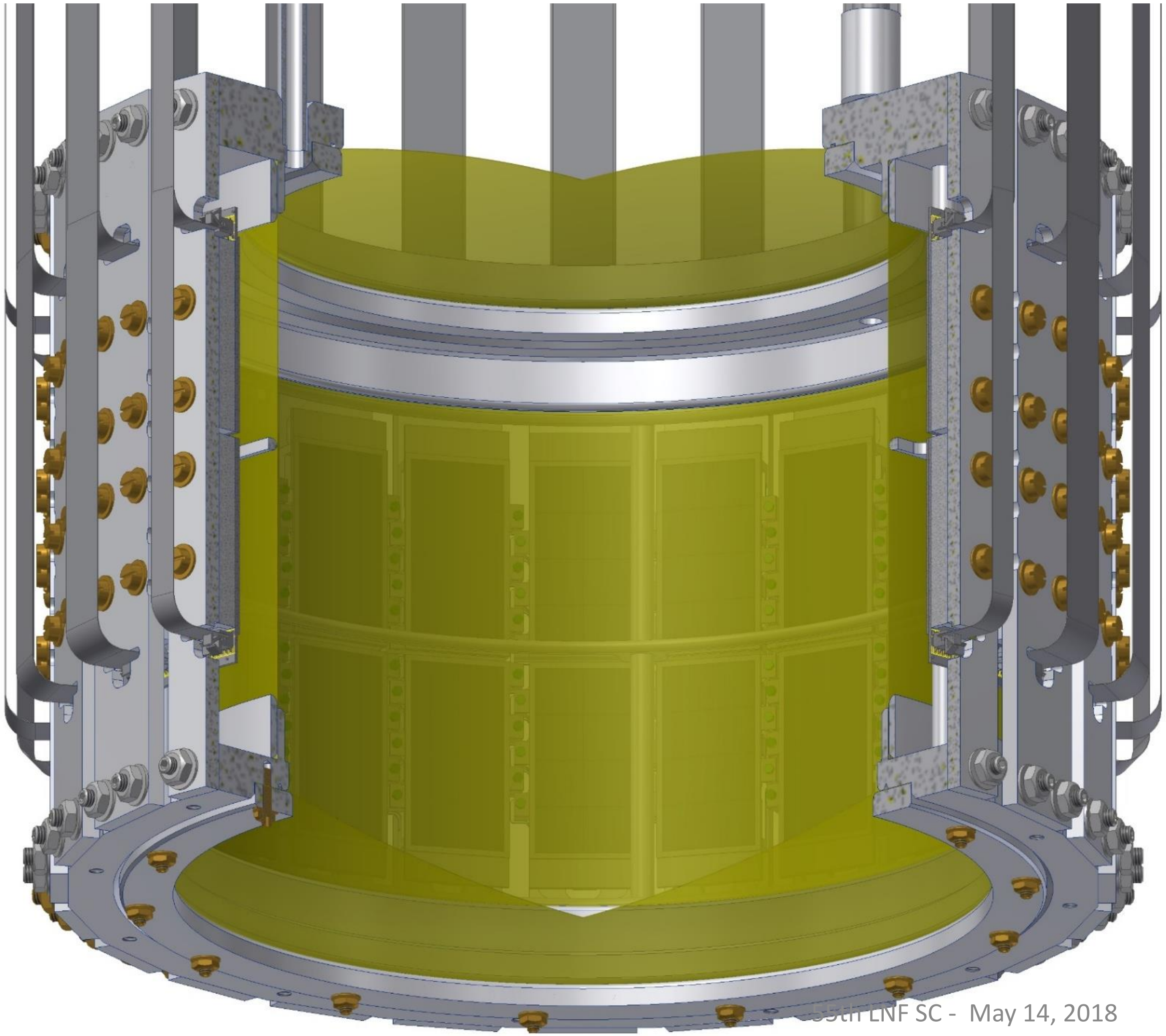
SIDDHARTA-2 apparatus

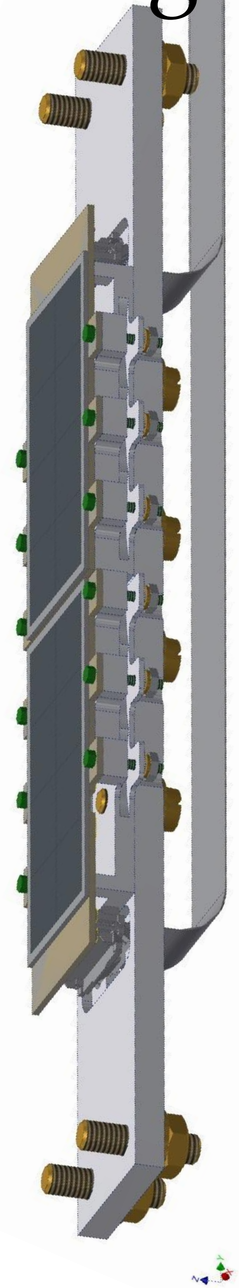






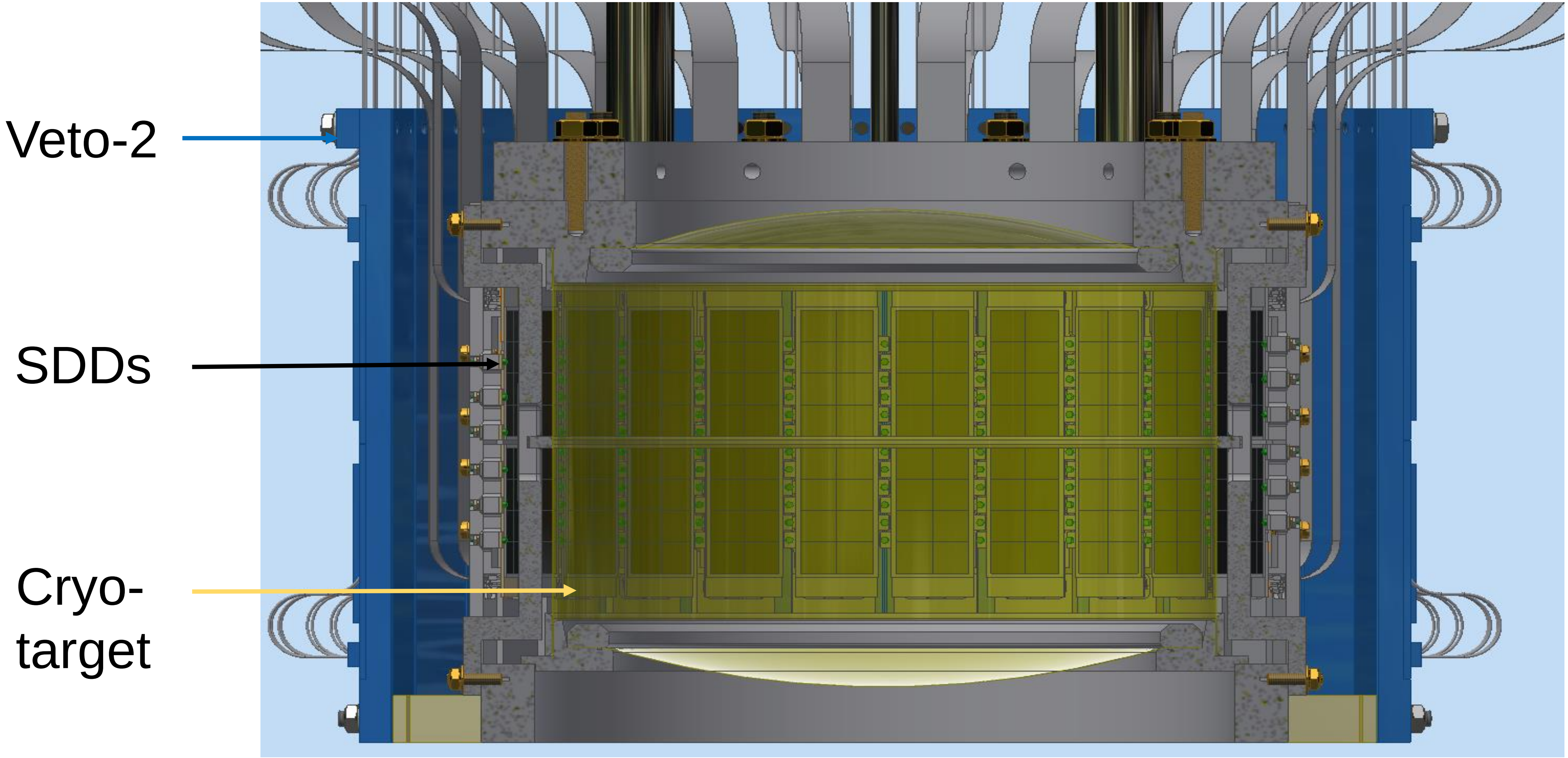
48 SDD arrays around the cryogenic target





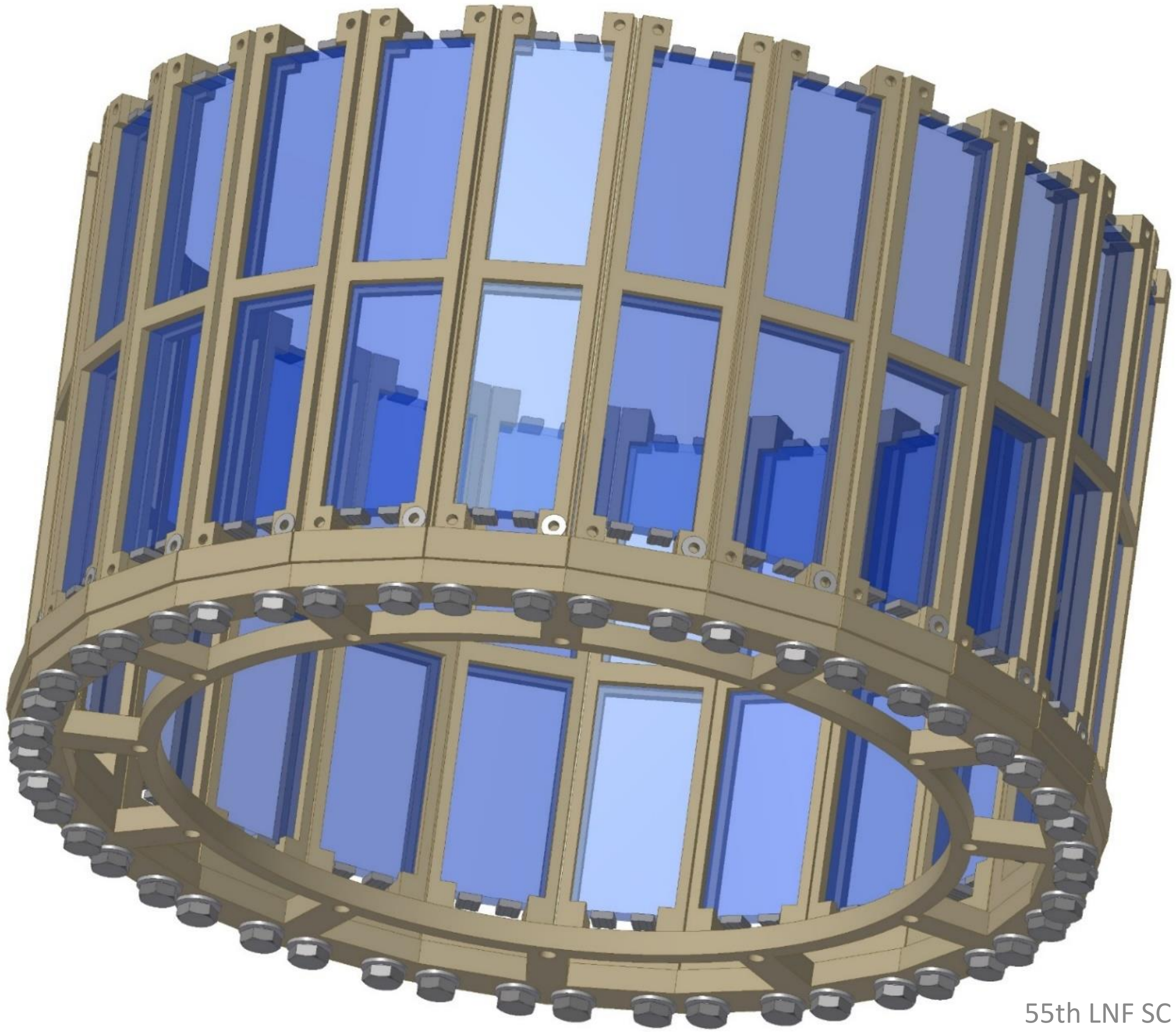
4x2 SDD array

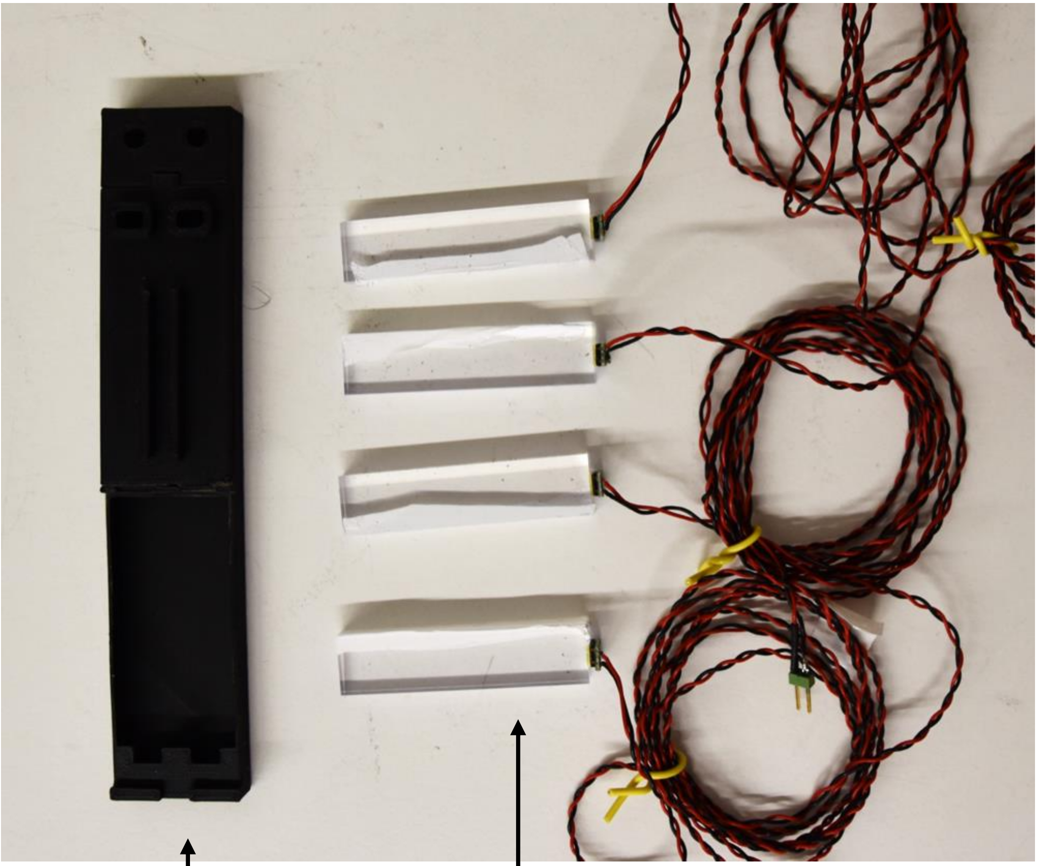
Cryogenic target – SDDs – veto-2 arrangement



The veto-2 system

Veto-2 arrangement

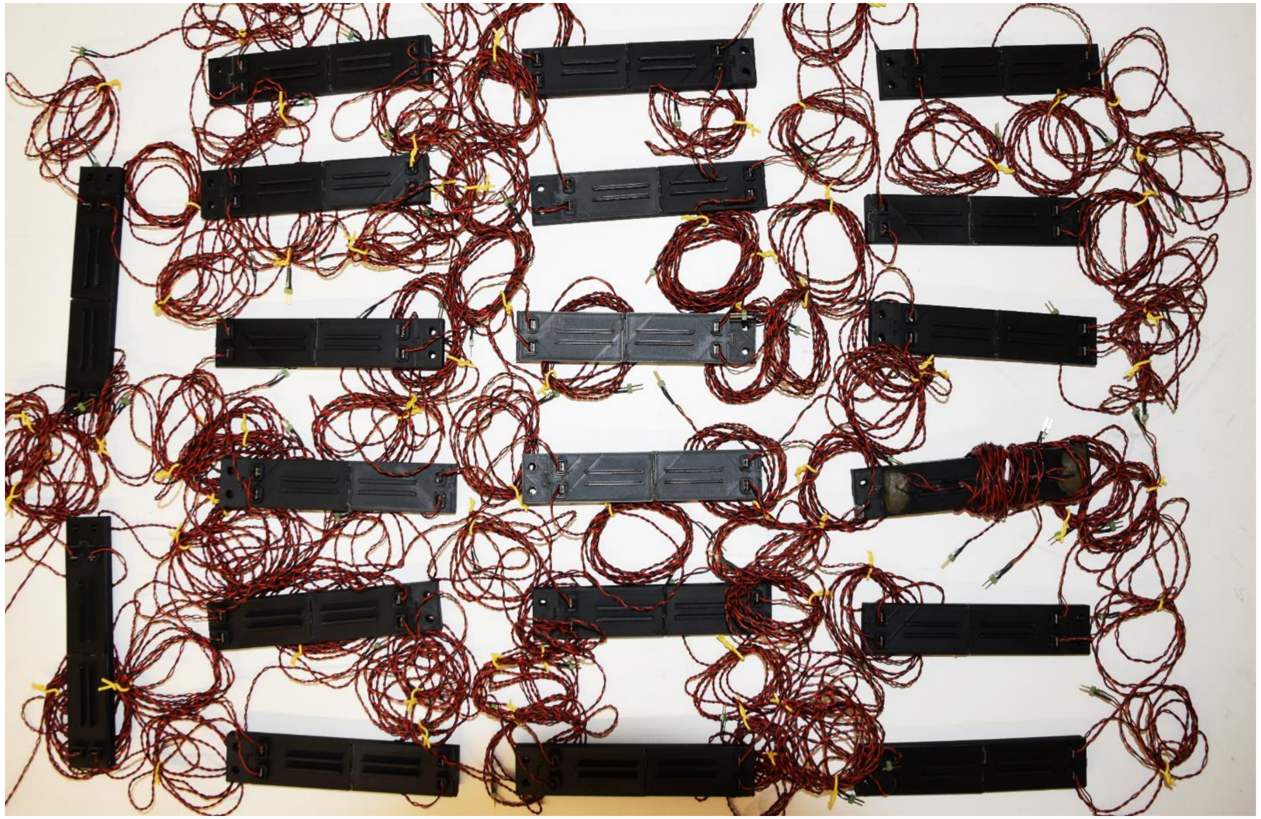


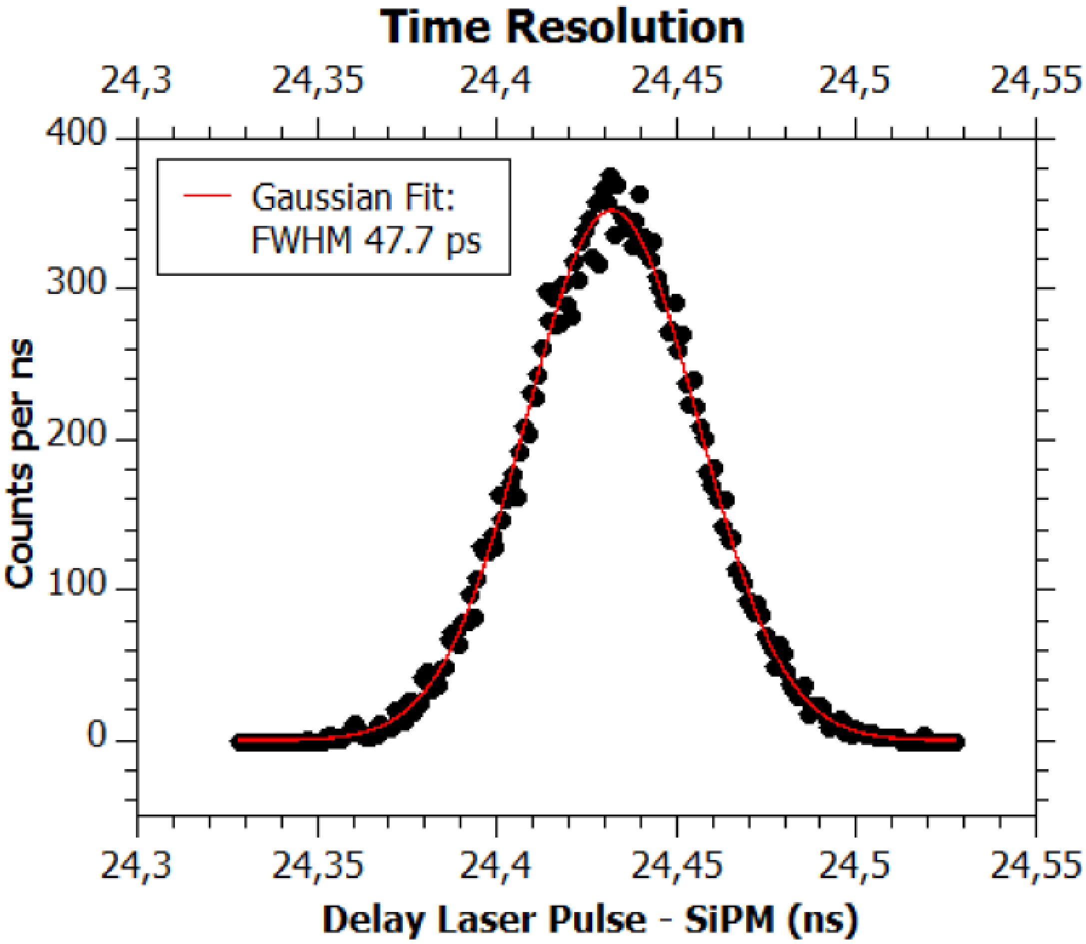


Scintillator mounting box

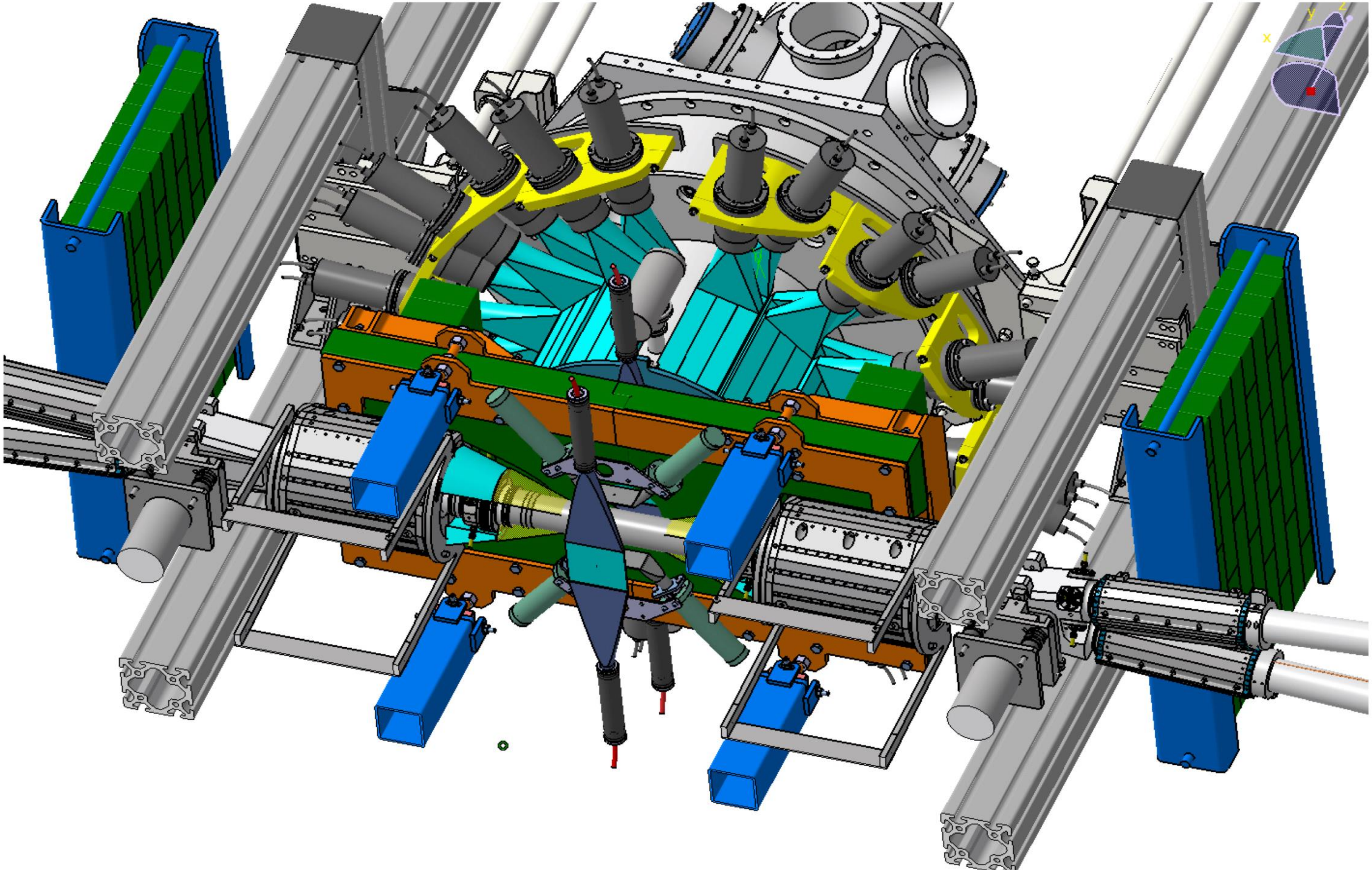
BC-408 scintillator tiles with 4x4 mm^2 SiPM – NUV-Trento

The veto-2 system

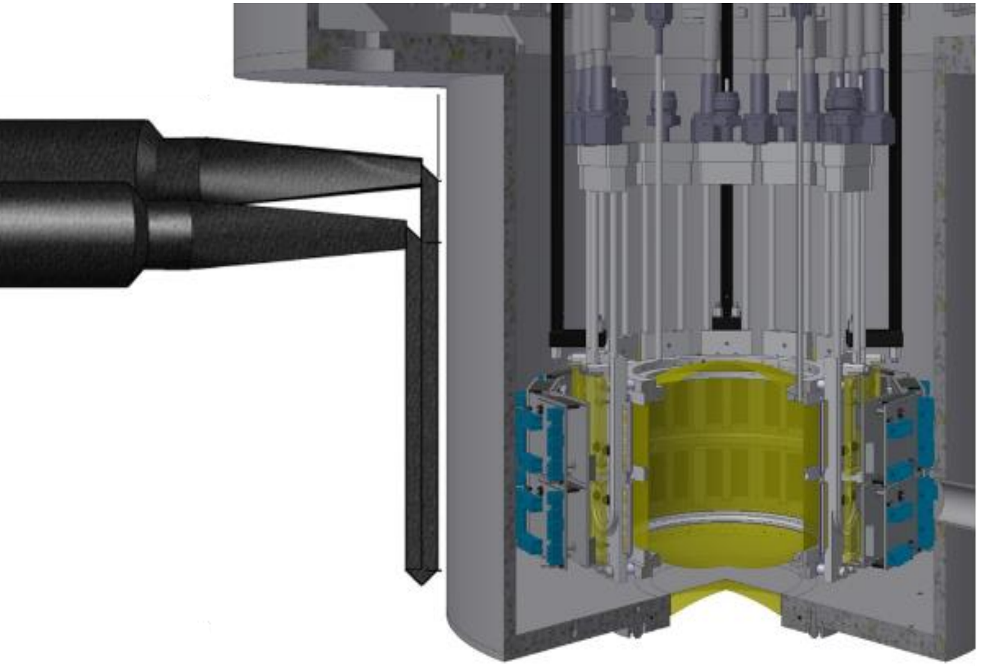


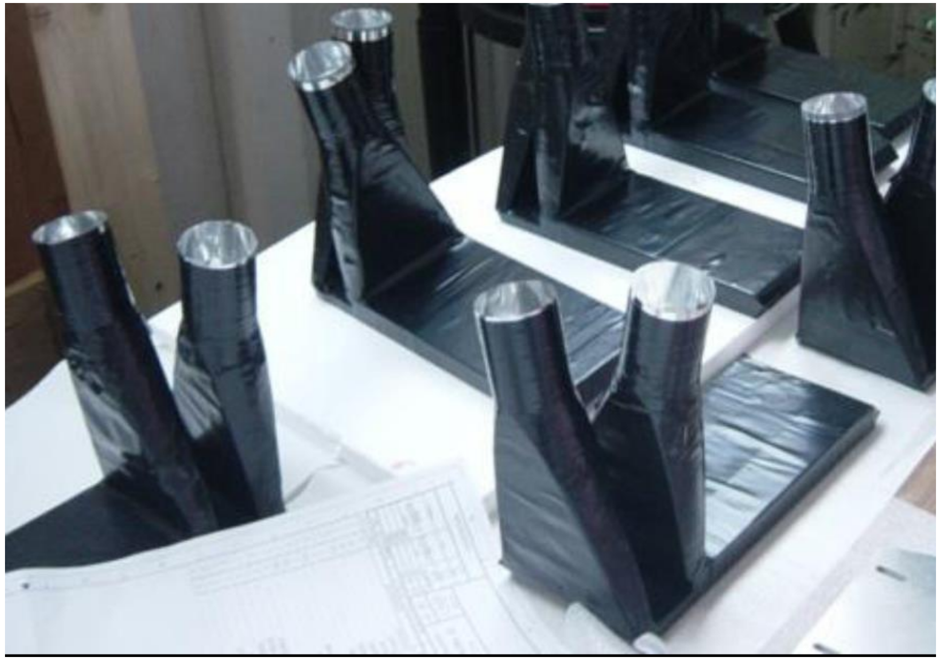


✓ 24 sub-units mounted and tested



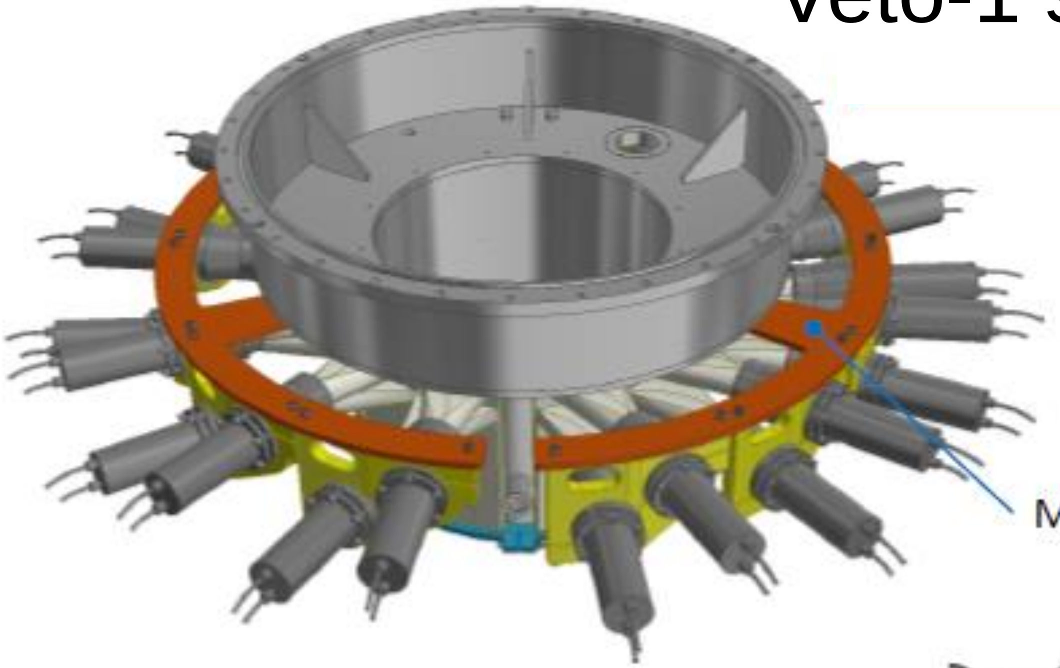
The veto-1 system

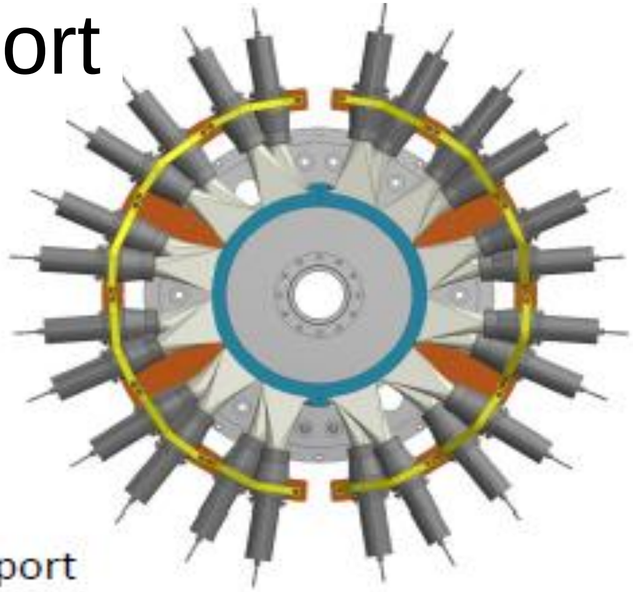


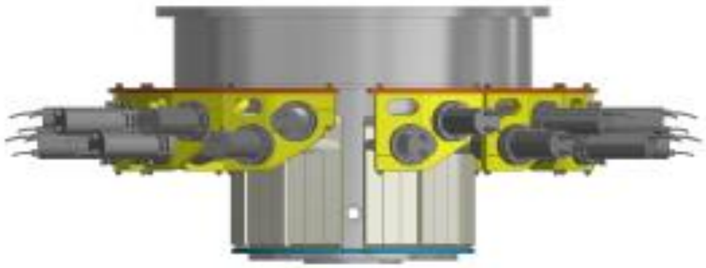


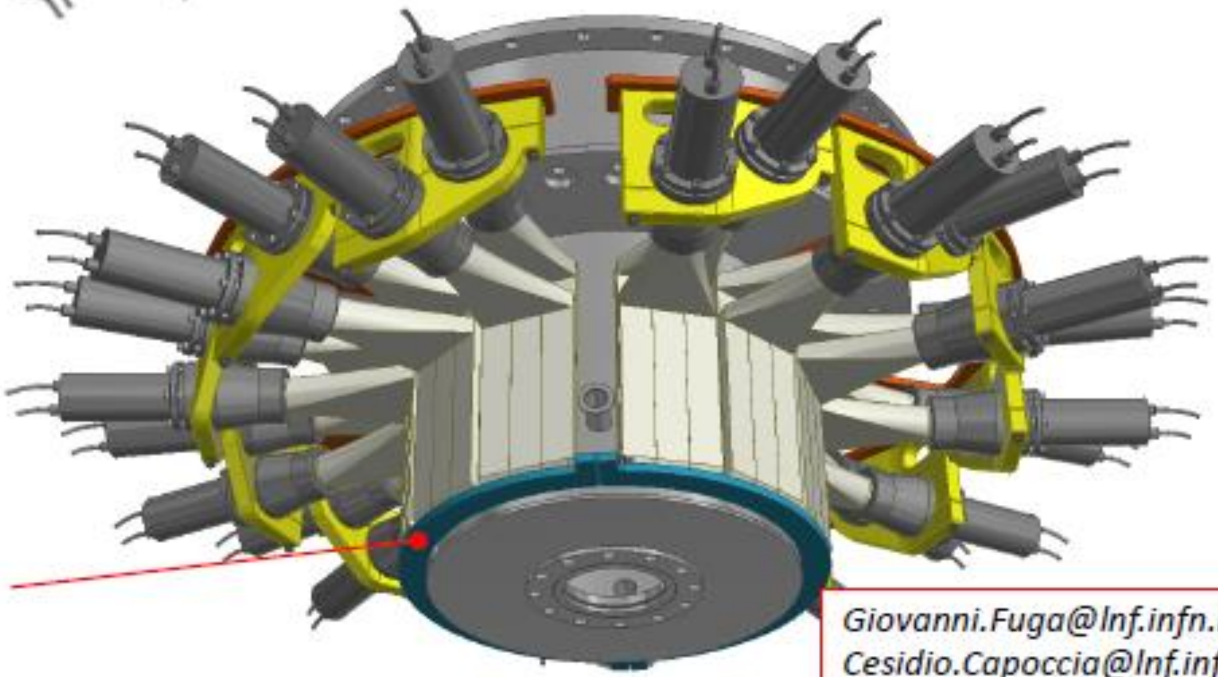
To achieve a good timing resolution, (independent of the "hit" position) < 600 ps (FWHM),the scintillator has to be read out on both side.
Because the available space is limited due to shielding material, the photomultiplier tubes have to be on the same side (a special light-guide mirror design was used).
PAPER

Veto-1 support









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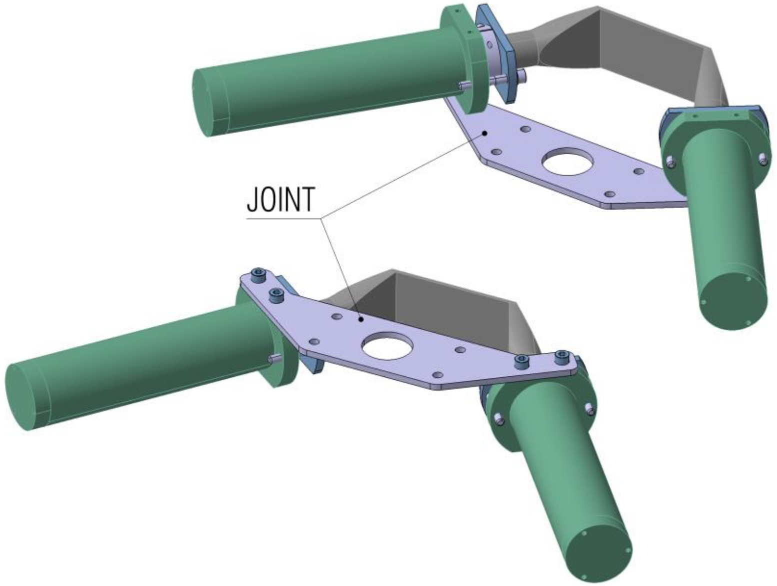
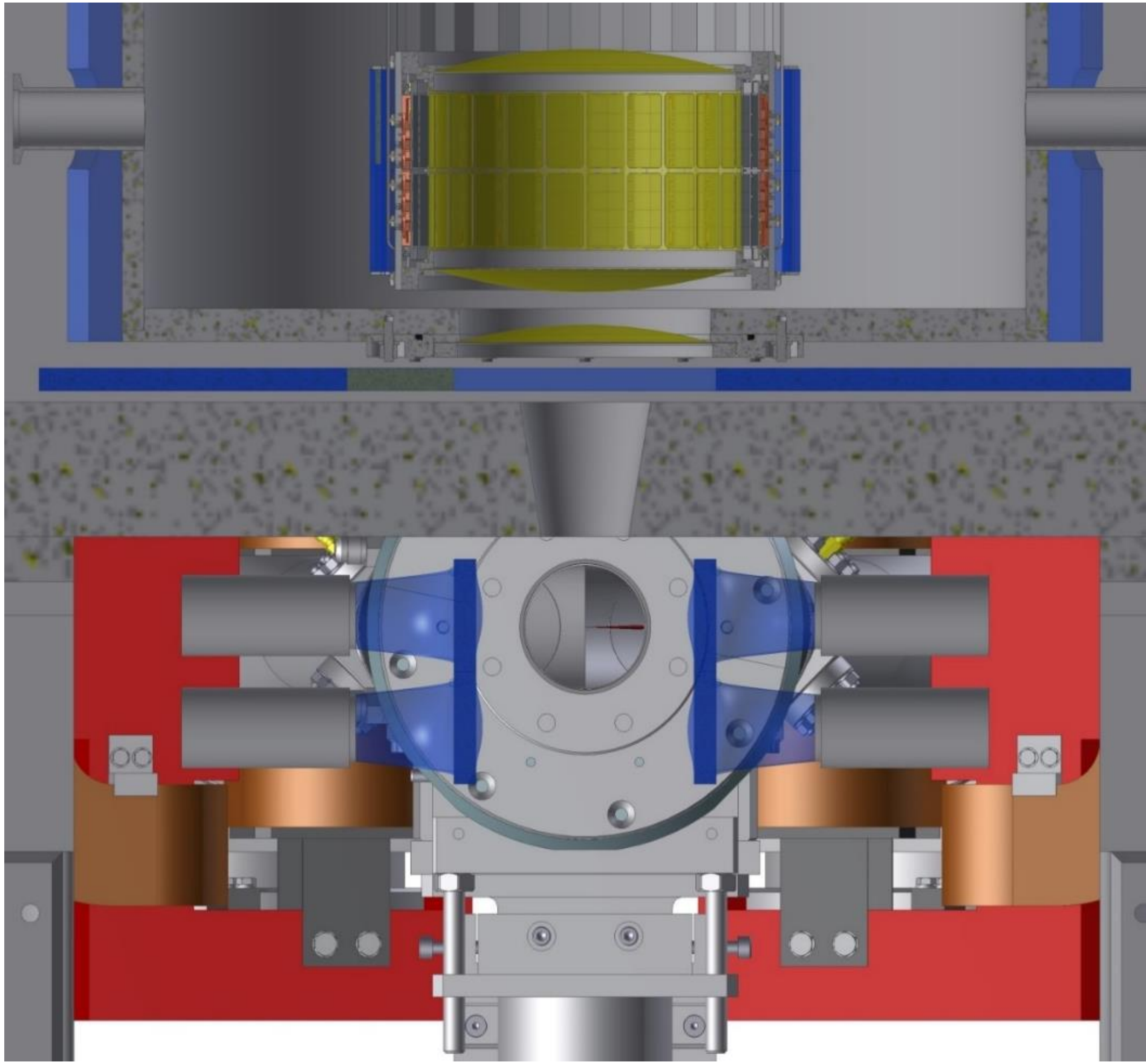
SIDDHARTA-2 - Luminosity monitor (based on kaons)

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 y = ± 4 cm off beam



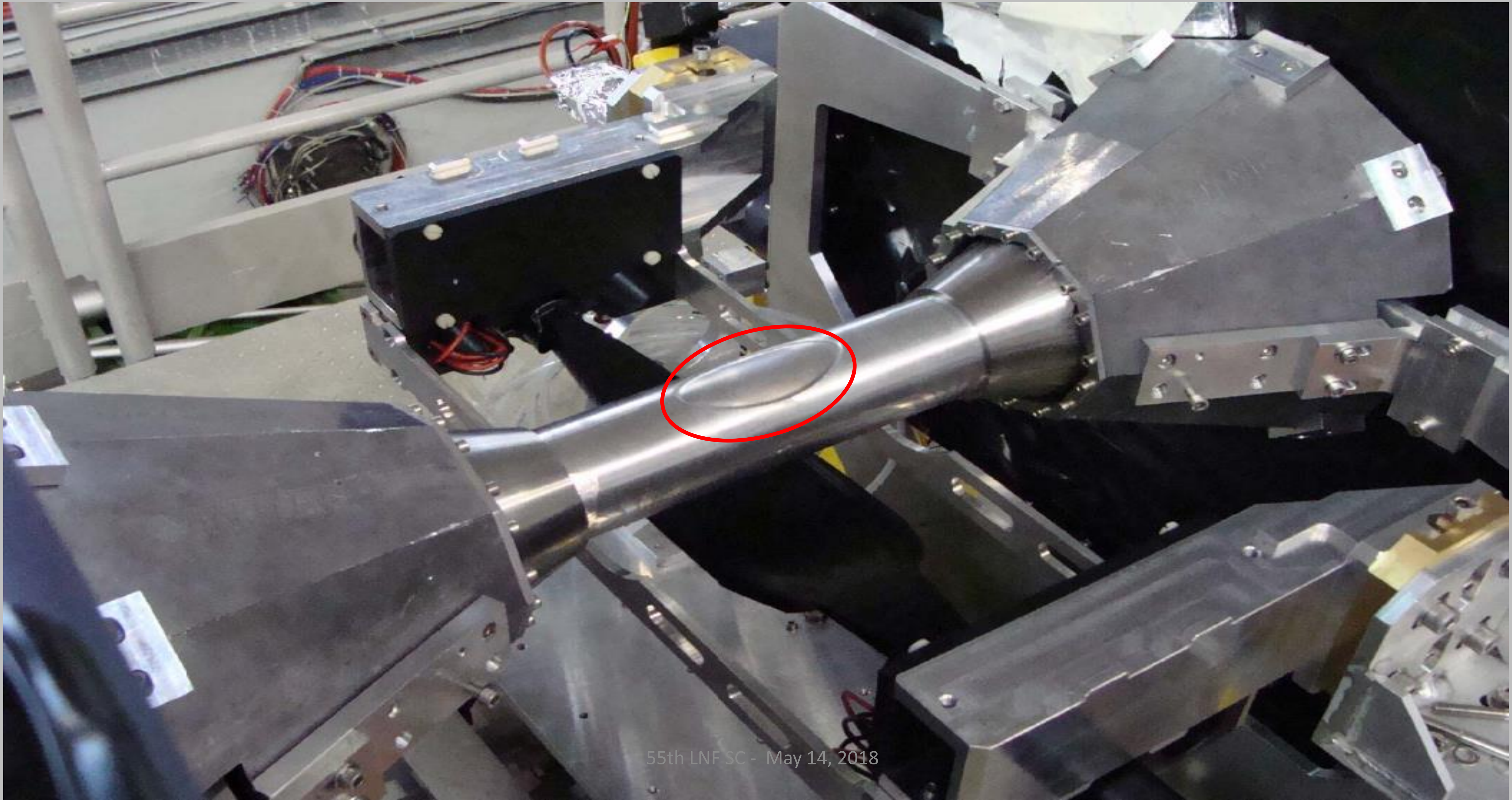


- coincidence rate: 25.7 %
- single rate at boost side: 42.7 %

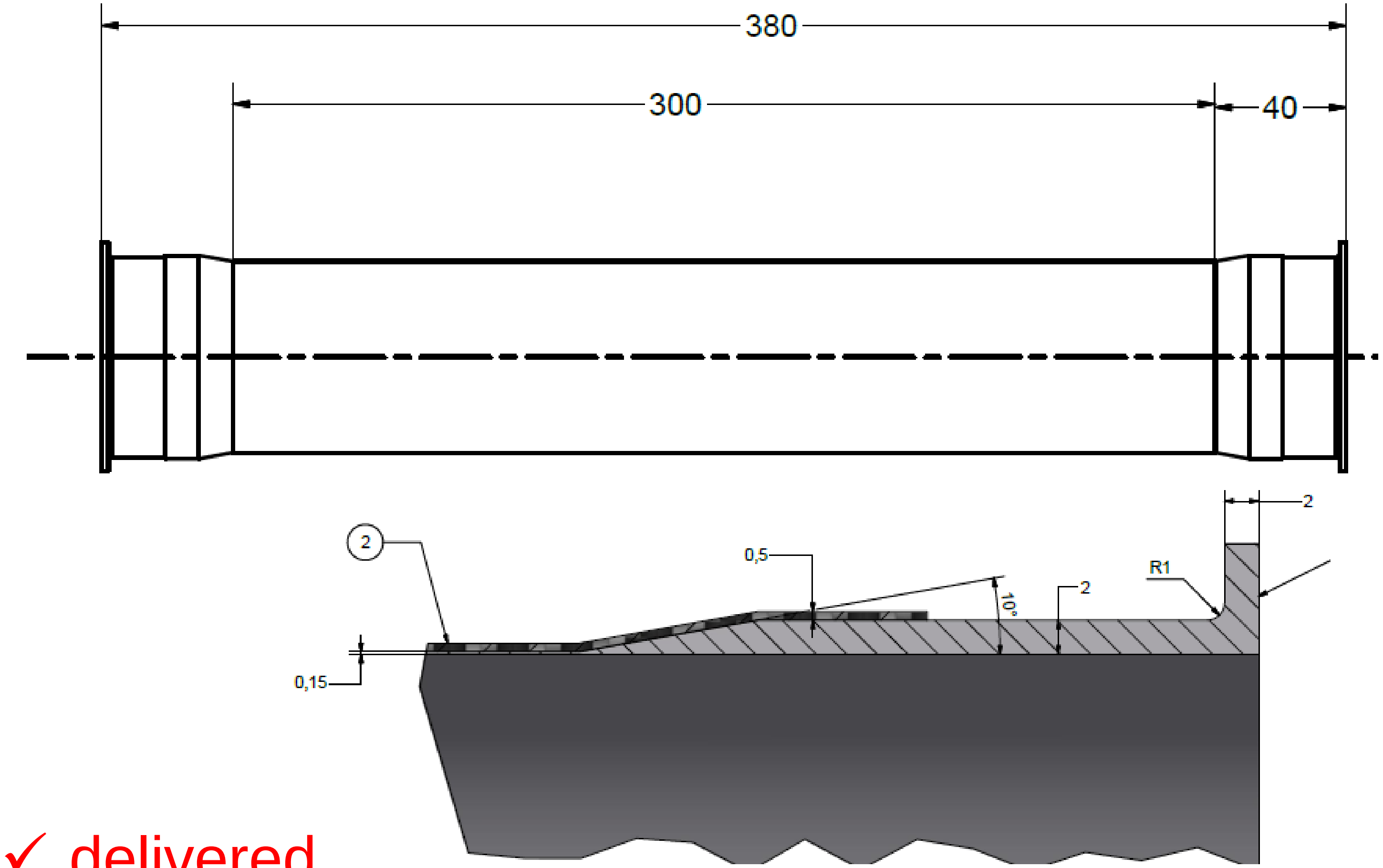
with a luminosity $L = 10^{32}$ and 62 Hz (on boost-side)

in 5 seconds: 310 counts

SIDDHARTA – beam pipe

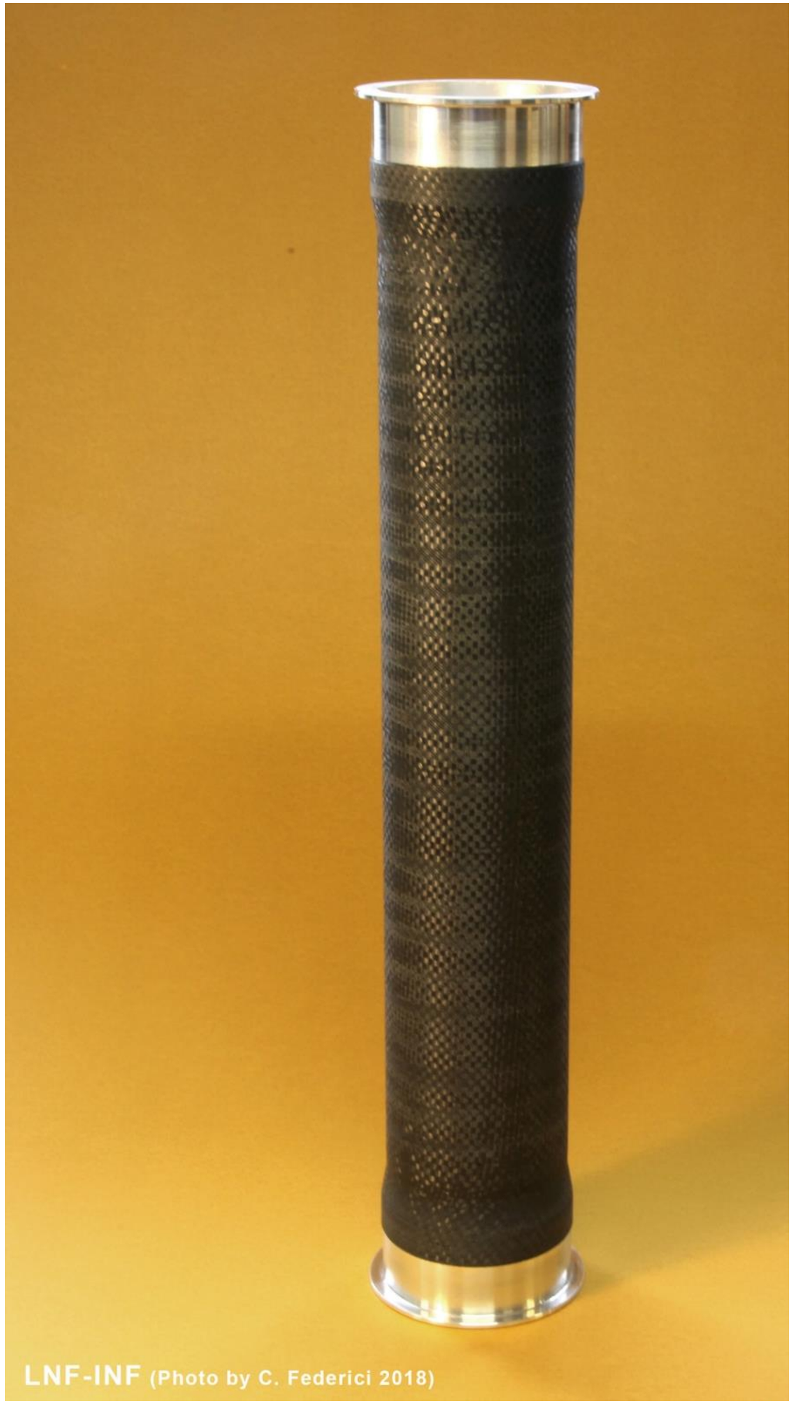


SIDDHARTA-2 beam pipe



✓ delivered

- final inner diameter 57 mm
- Alu thickness 150 µm
- Carbon fibre reinforcement 500µm



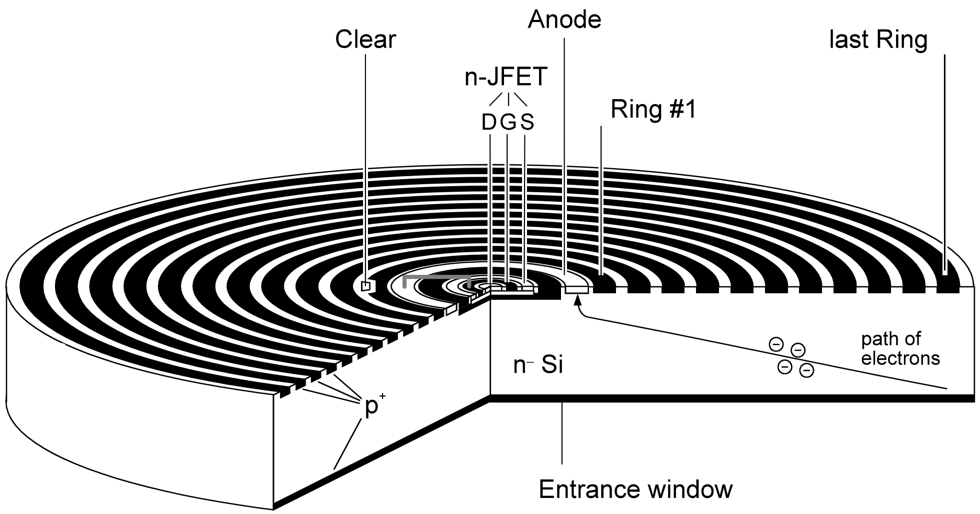
SIDDHARTA-2 setup

- SDD X-ray detector

The “new” Silicon Drift Detector

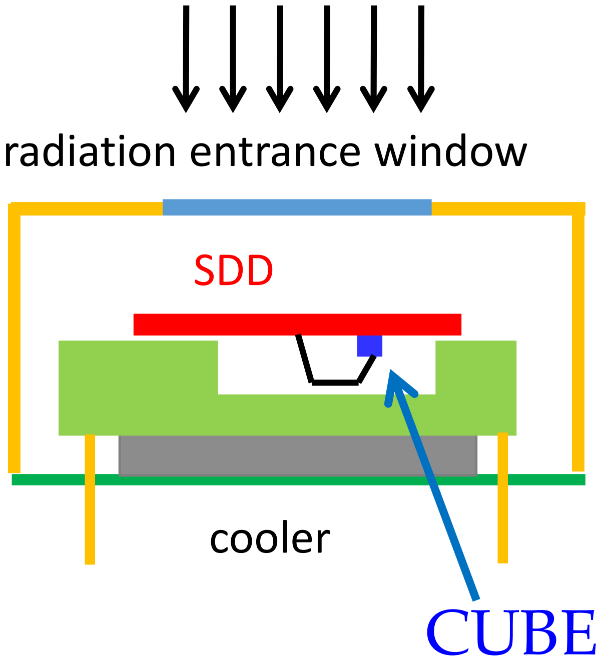
➢ **SIDDHARTA**

- JFET integrated on SDD
- lowest total anode capacitance
- limited JFET performance
- sophisticated SDD+JFET technology



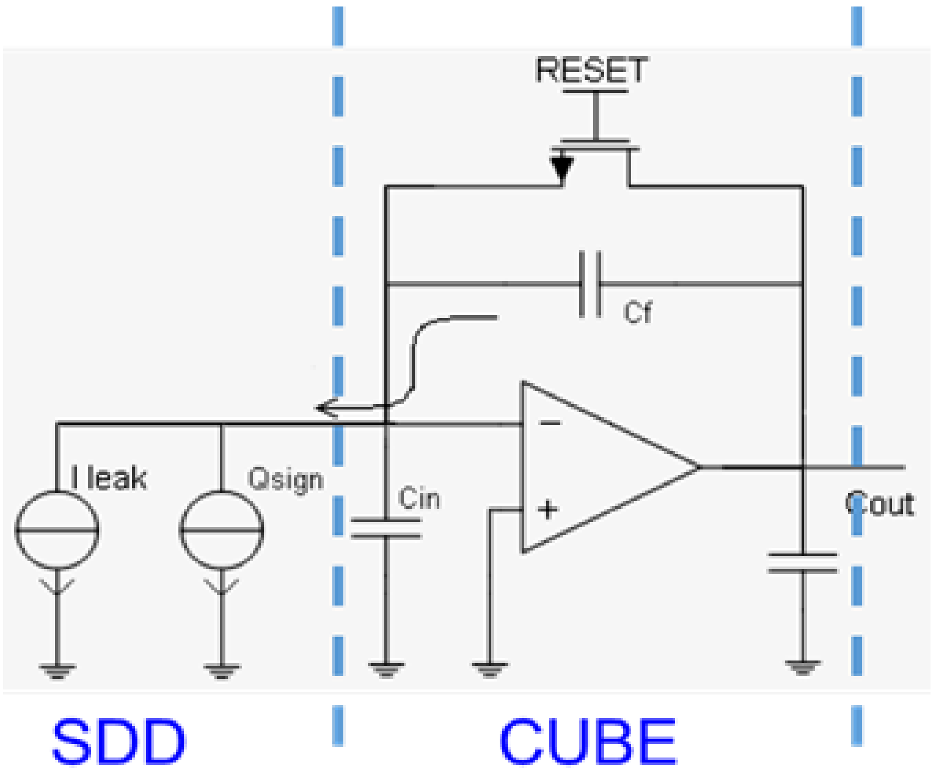
➢ **SIDDHARTA-2**

- external CUBE preamplifier (MOSFET input transistor)
- larger total anode capacitance
- better than FET performances
- standard SDD technology

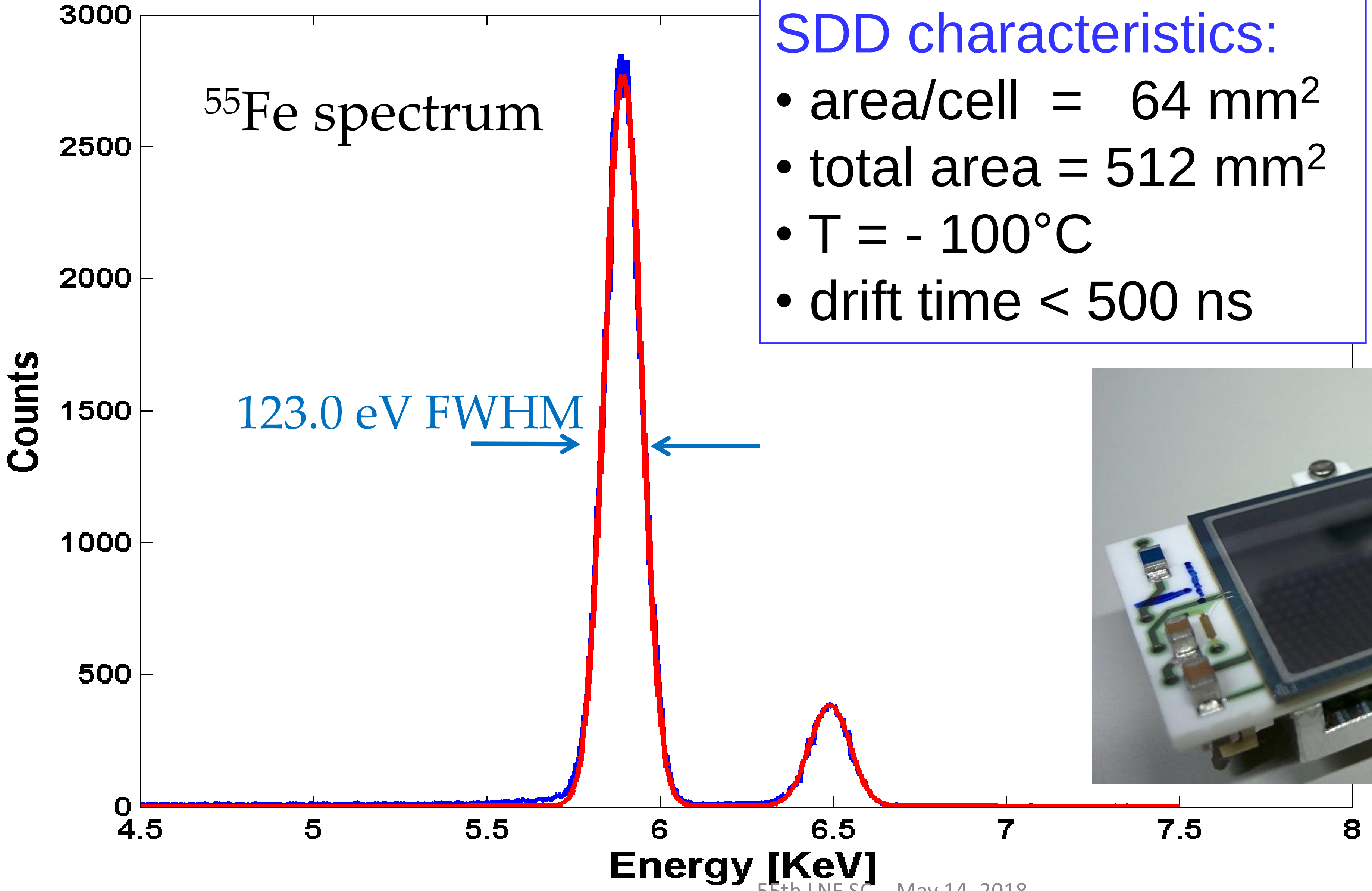


The CUBE preamplifier

- A full CMOS preamplifier is mounted on ceramic board - connected via bonding
- The CUBE replaces the JFET, which was direct implanted on the anode side on the SIDDHARTA type SDDs
- Short bonding lines from CUBE to SDD, no difference in the detector performance
- Advantage, the preamplifier is connected close to the SDD and not only the FET → ASIC of analogue processing can be placed relatively up to ~100 cm away

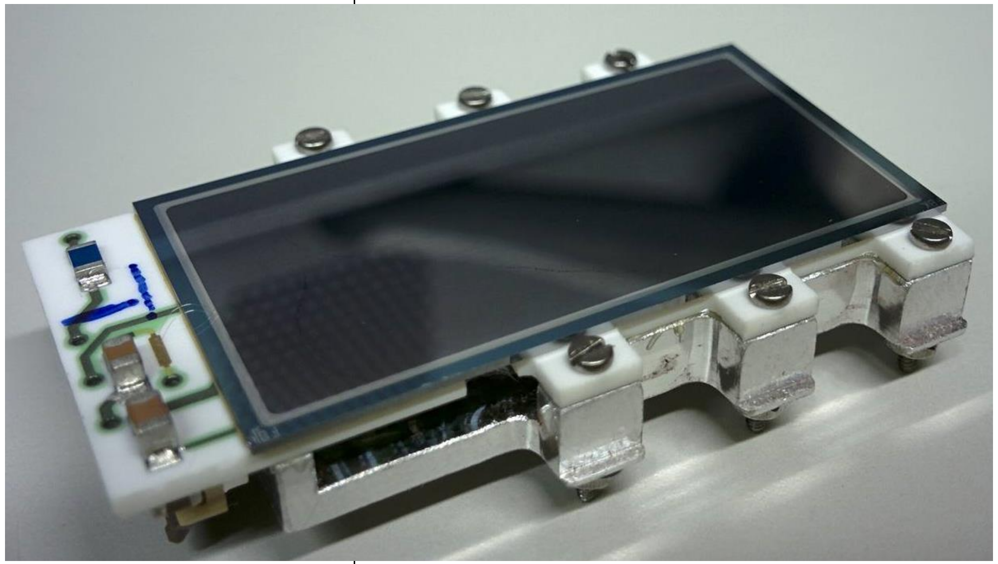


New SDD technology: CUBE preamplifier

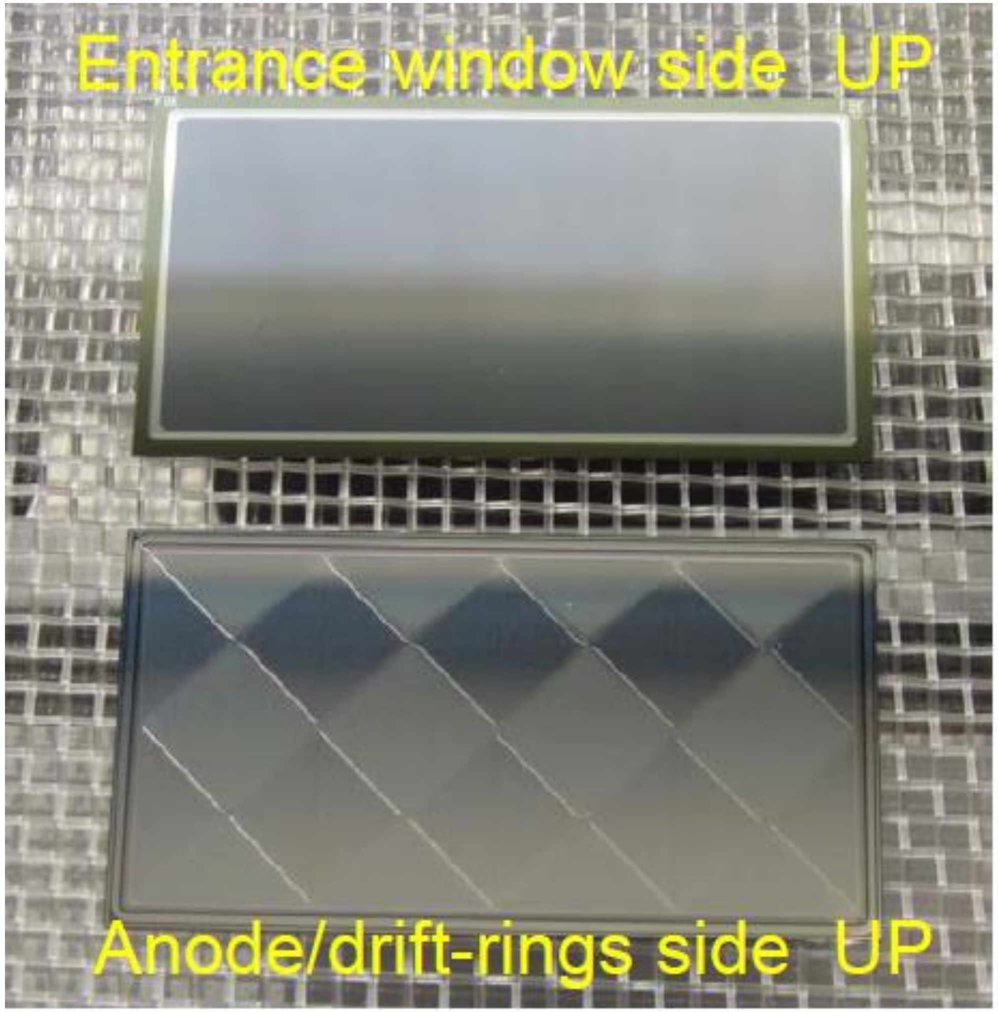


SDD characteristics:

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

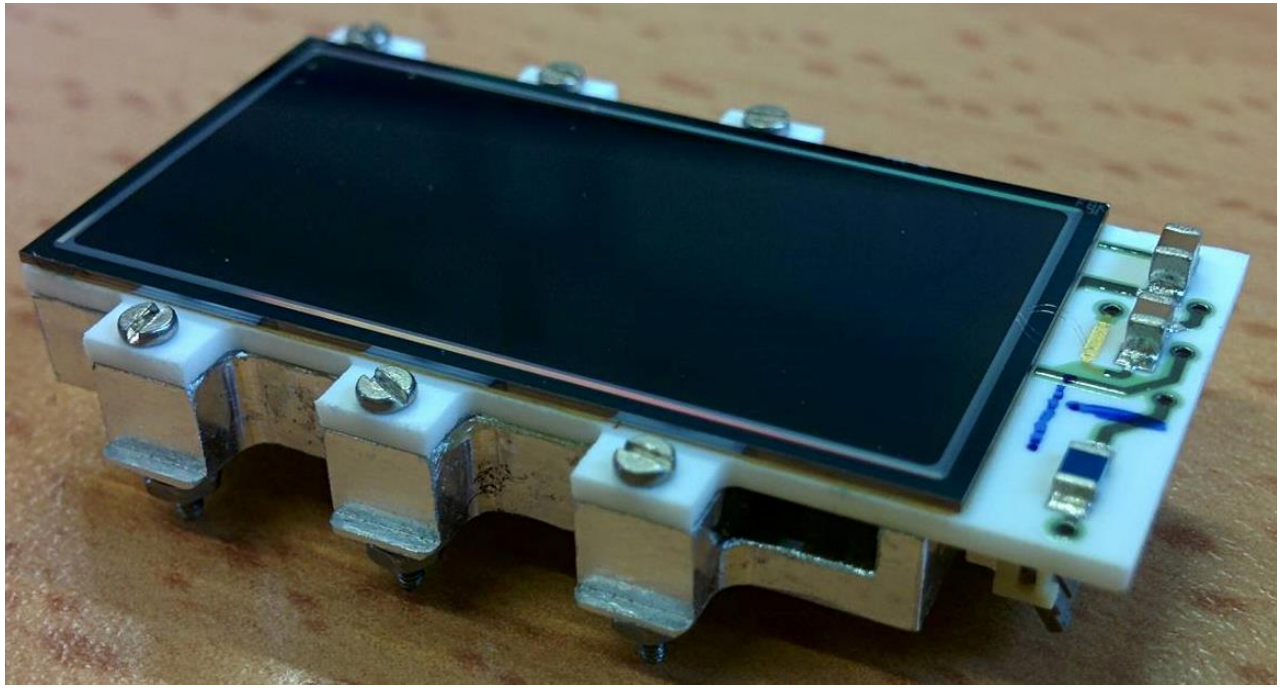


SDD delivery → SDD bonded + mounted



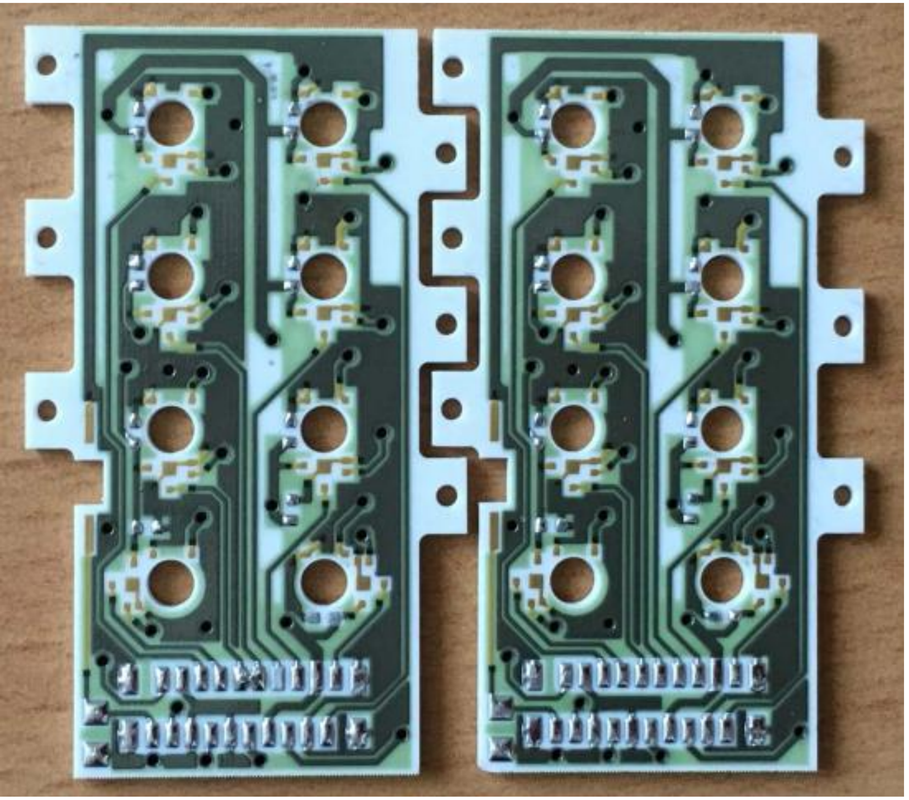
Shipping package

4x2 SDD array - single unit

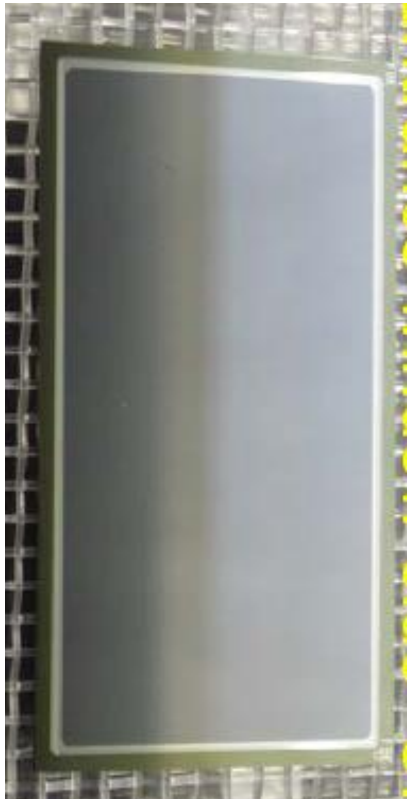


SDD mounting / bonding

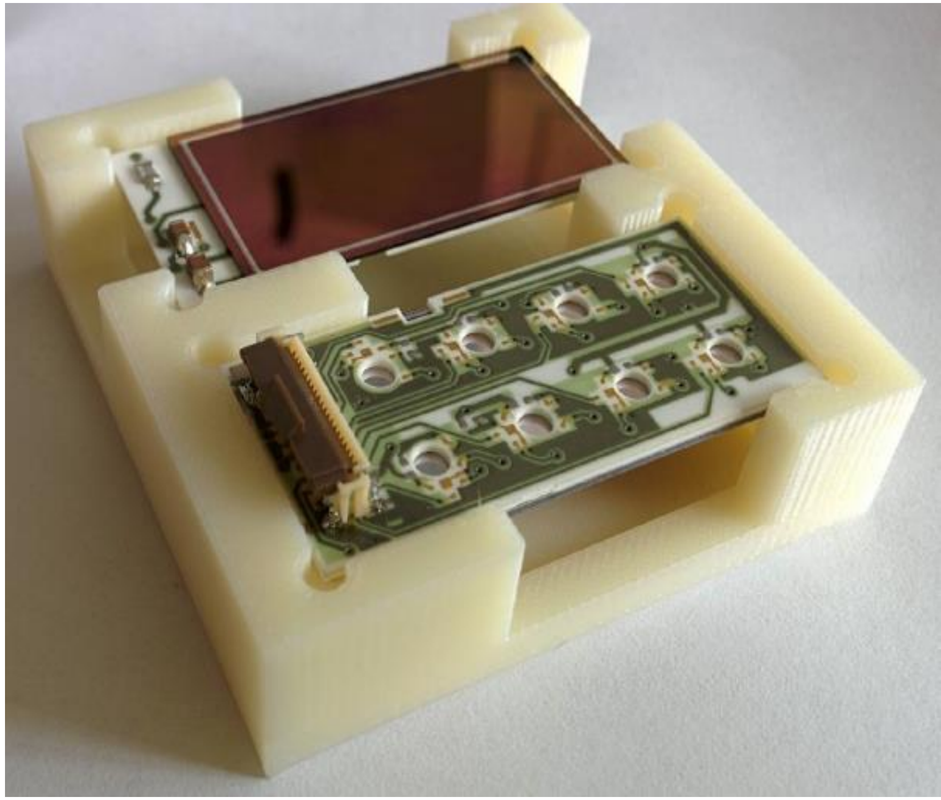
ceramic boards



4x2 SDD chip

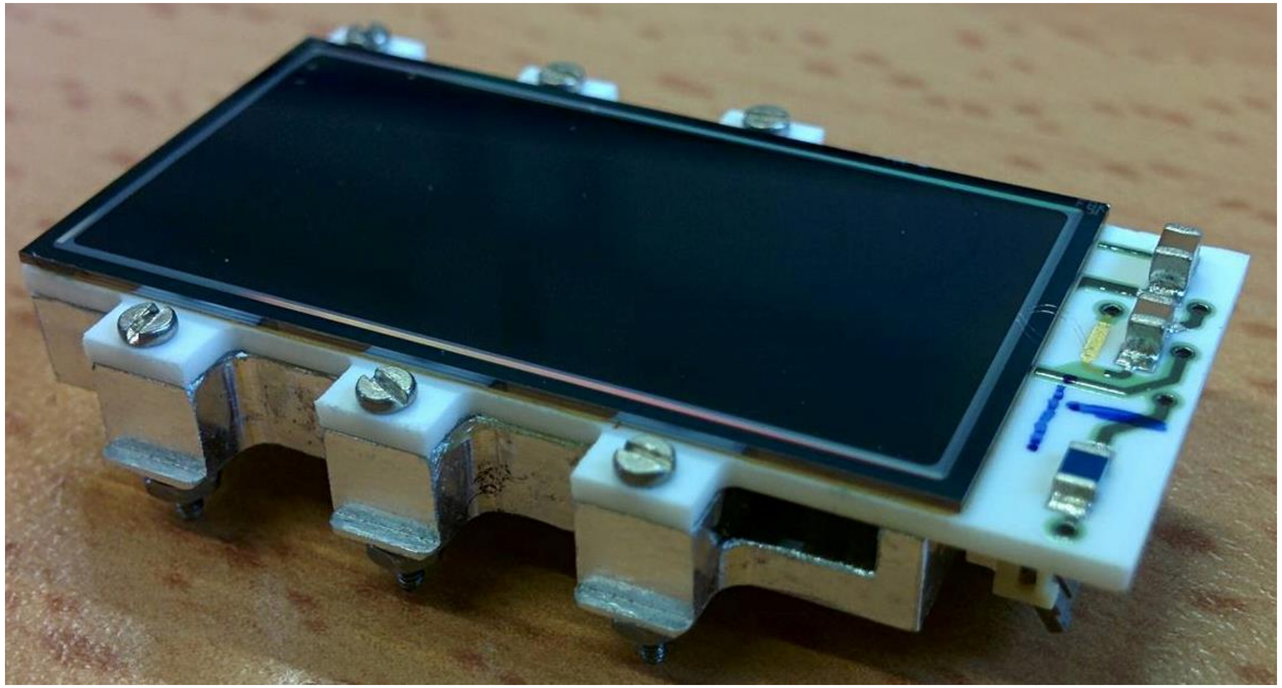


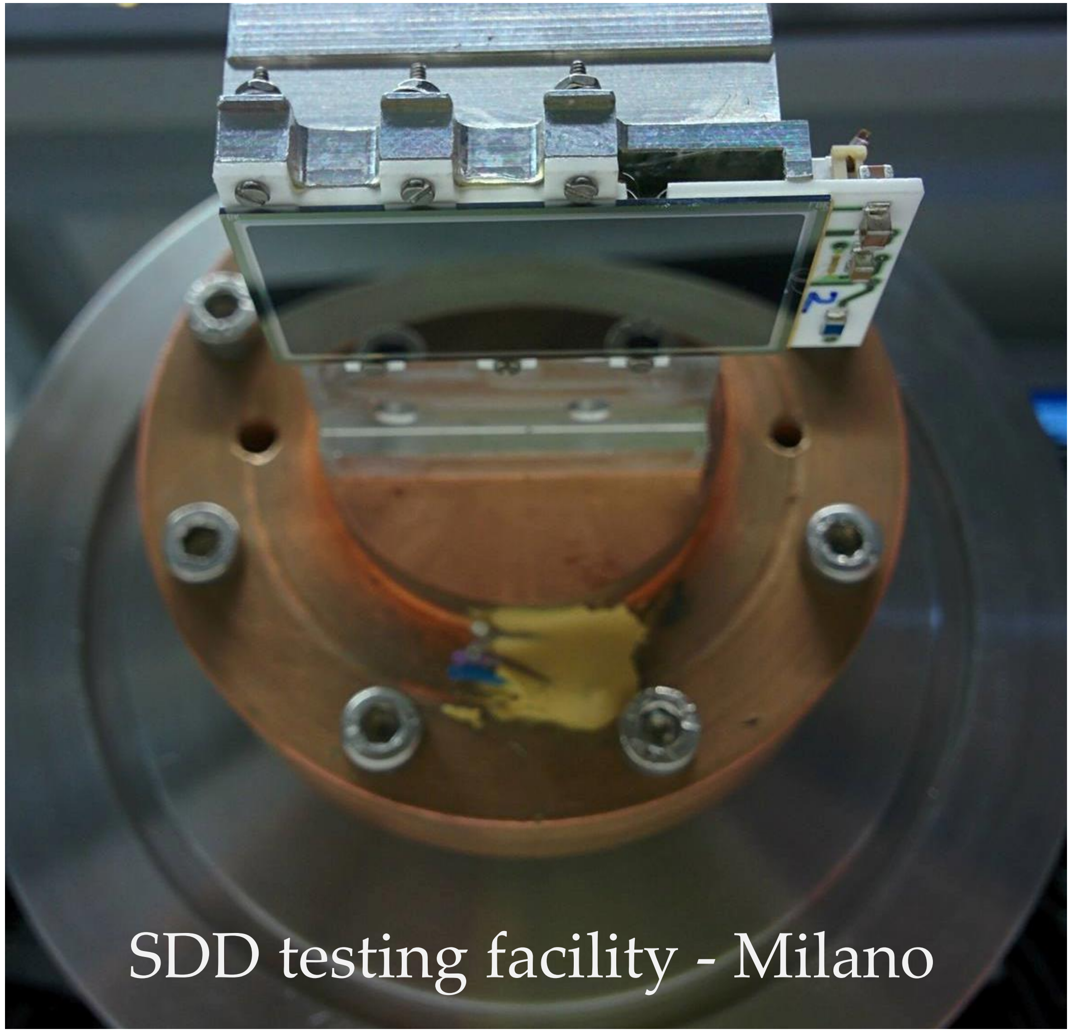
device for gluing and bonding



- mounting and bonding process under control

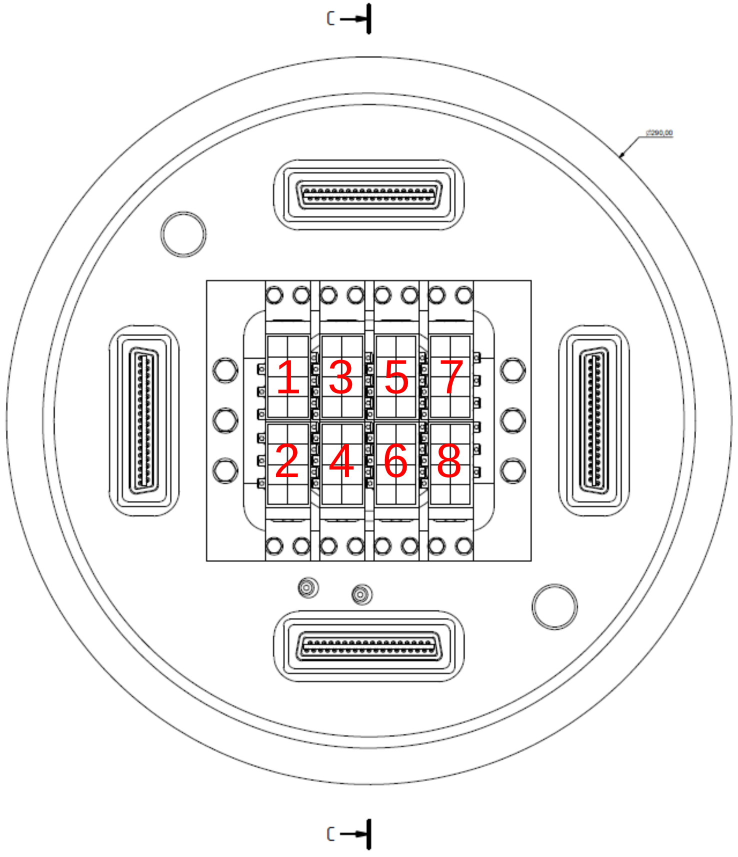
4 x 2 matrix SDD chip - testing

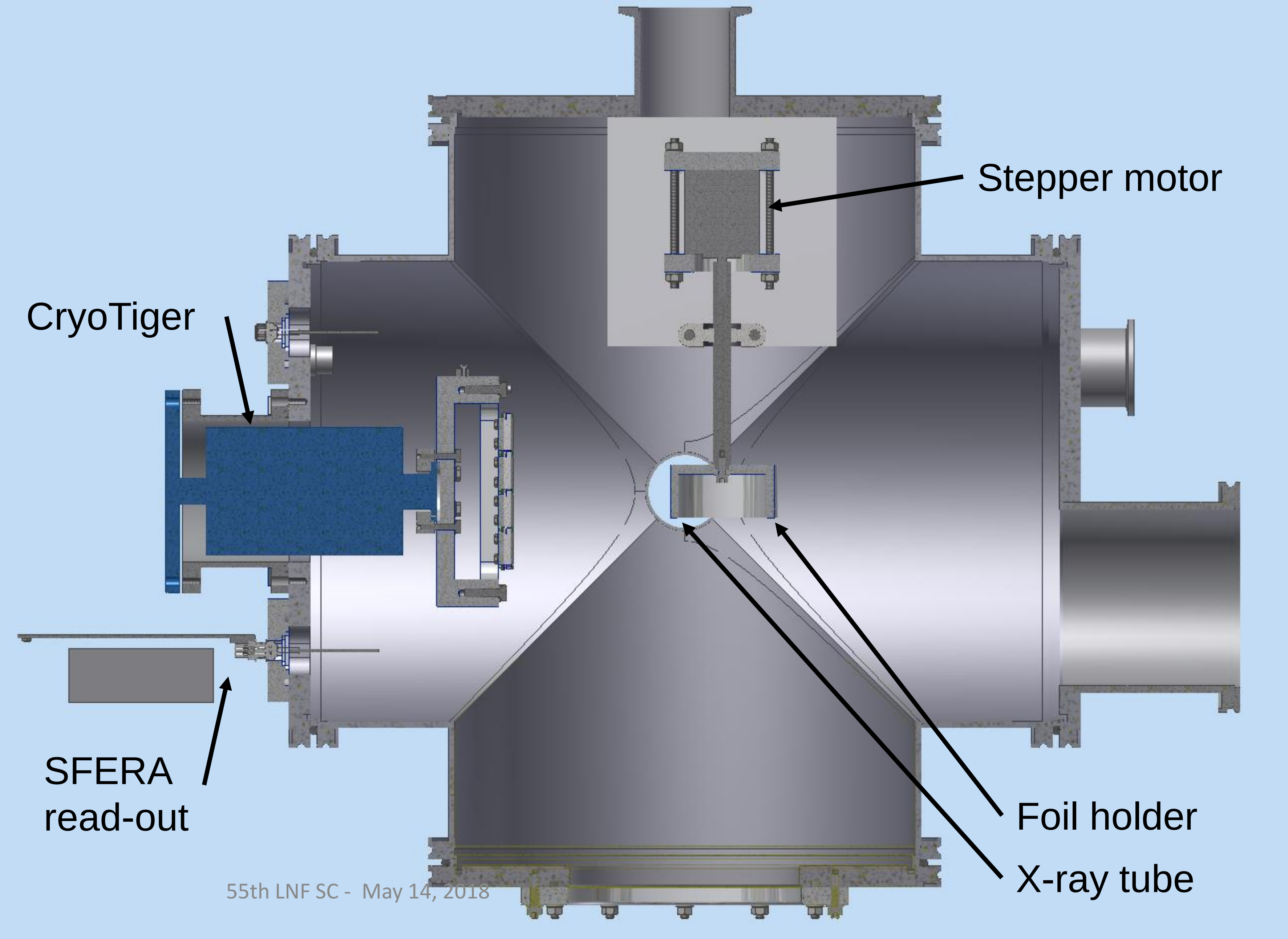




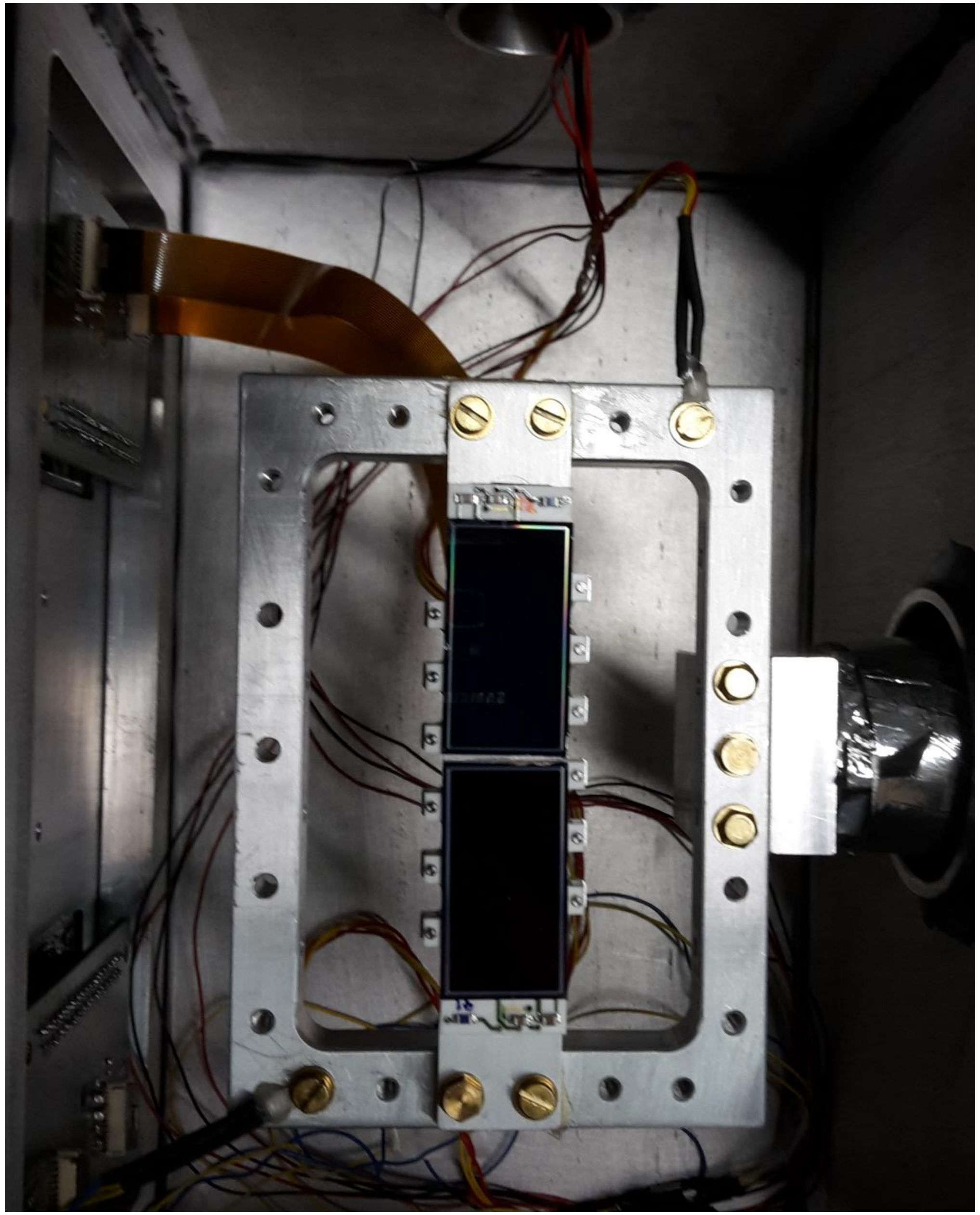
New SDD testing facility - LNF

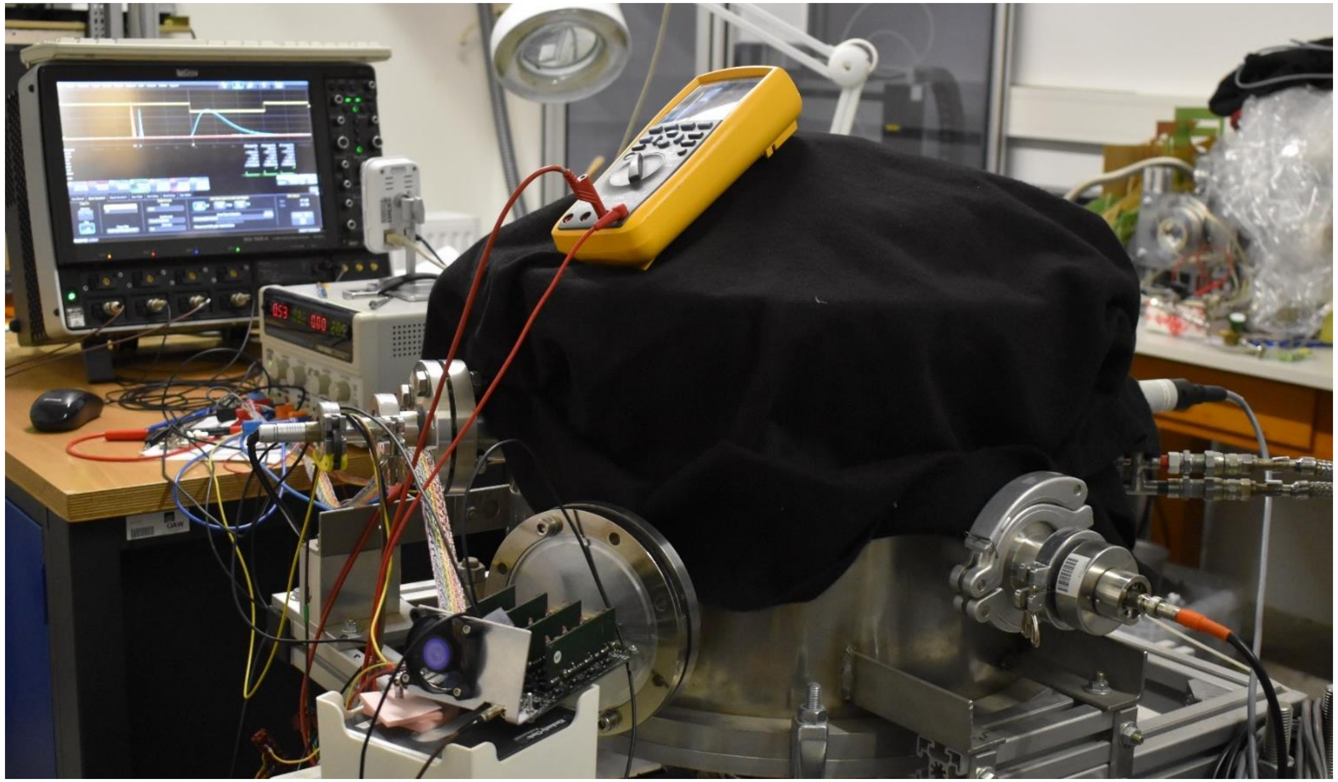
Mounting device for
8 SDD units





SDD testing facility - SMI





SIDDHARTA SDD arrays status end of April 2018

Total delivered SDDs: 54

- 15 more SDDs are ordered

- 46 SDDs assembled/bonded/tested
- 8 SDDs assembled/bonded

- TOT number of working channels **318**/368 (86%)
  - 26 with 8 ch.
  - 11 with 7 ch.
  - 5 with 6 ch.
  - 4 with less than 6 ch.

SIDDHARTA-2 schedule

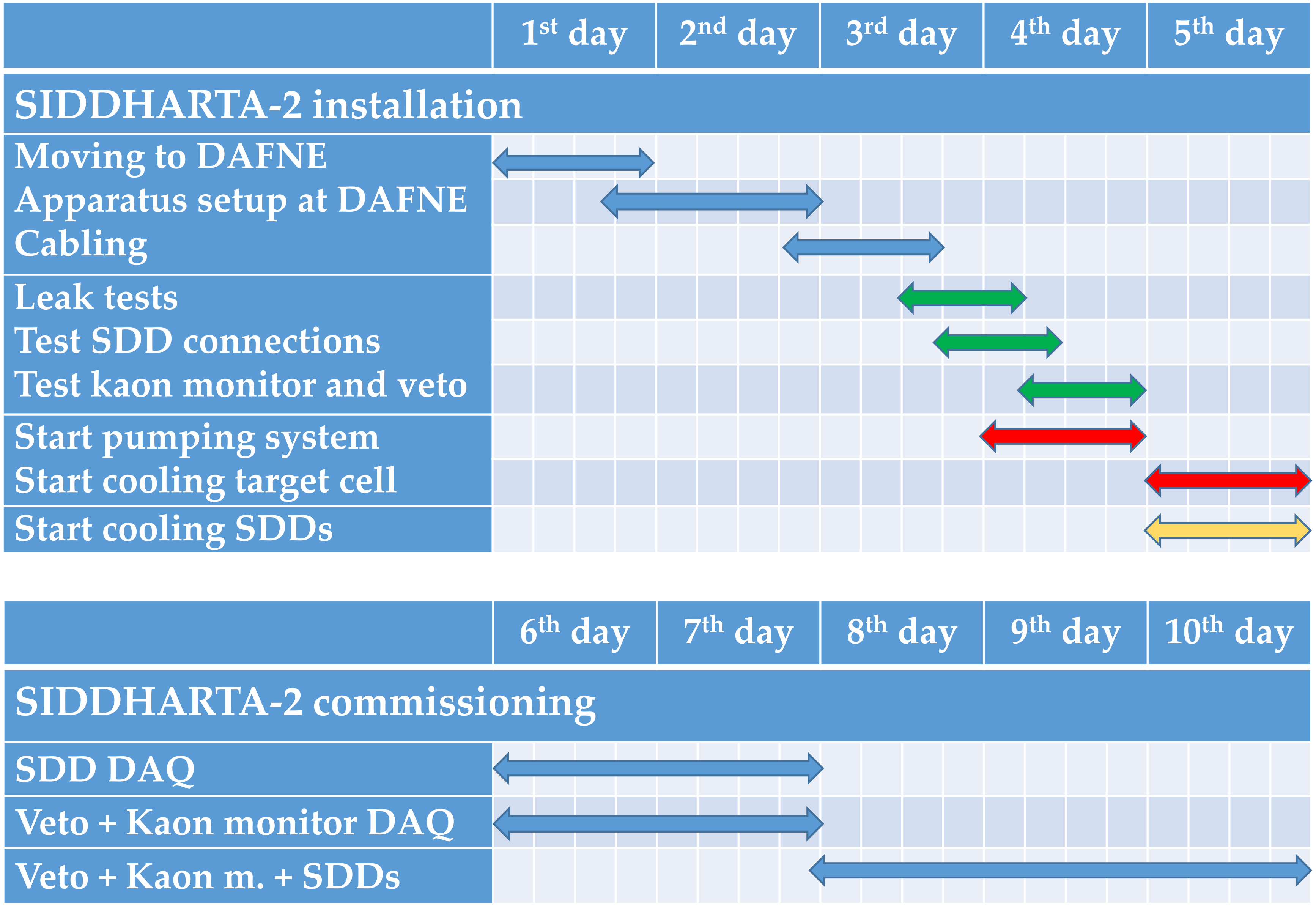
SIDDHARTA-2 schedule (Phase 1: technical run)

- Assembling plan: test setup (1 unit of SDDs) – assembled and tested in laboratory within October 2018

- Installation at DAΦNE: November 2018

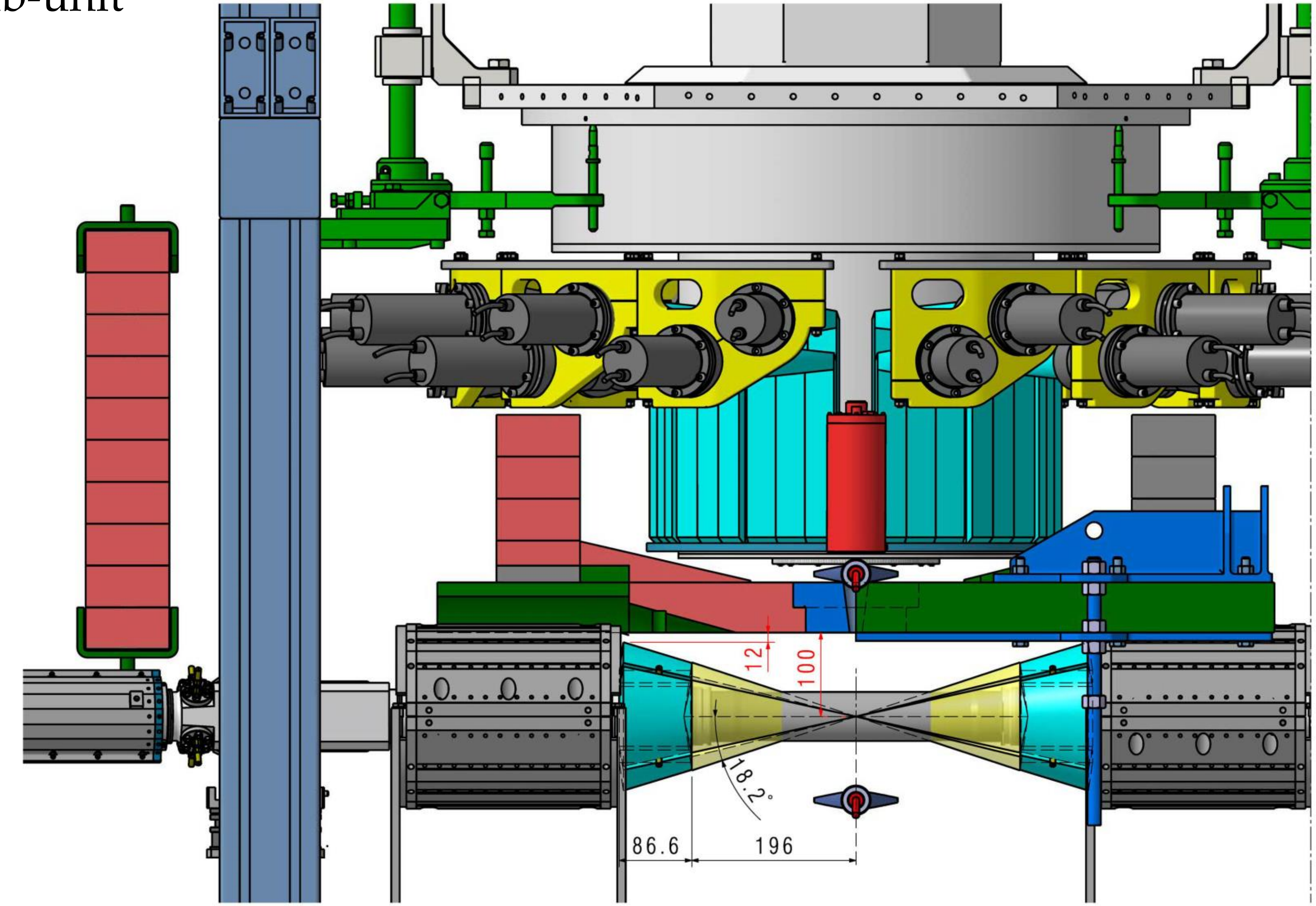
- Test, debug and run

Gantt chart: SIDDHARTA-2 installation at DAΦNE



Technical run – commissioning

- Start end of Nov. 2018
- with full DAΦNE luminosity monitor → SIDDHARTA-2 has to be lifted ~100 mm
- with 8 SDD arrays – 1 DAQ sub-unit
- complete Veto systems
- kaon monitor
- SIDDHARTA luminometer



GOAL:

run with He-4

(same condition as SIDDHARTA)

- to achieve same signal to BG ratio as with SIDDHARTA

SIDDHARTA-2 Technical run

Installation on DAFNE will start November 2018

- **Technical run start has to be confirmed**

  target position 100 mm higher in order to install the DAΦNE luminosity monitor for optimal beam tuning!

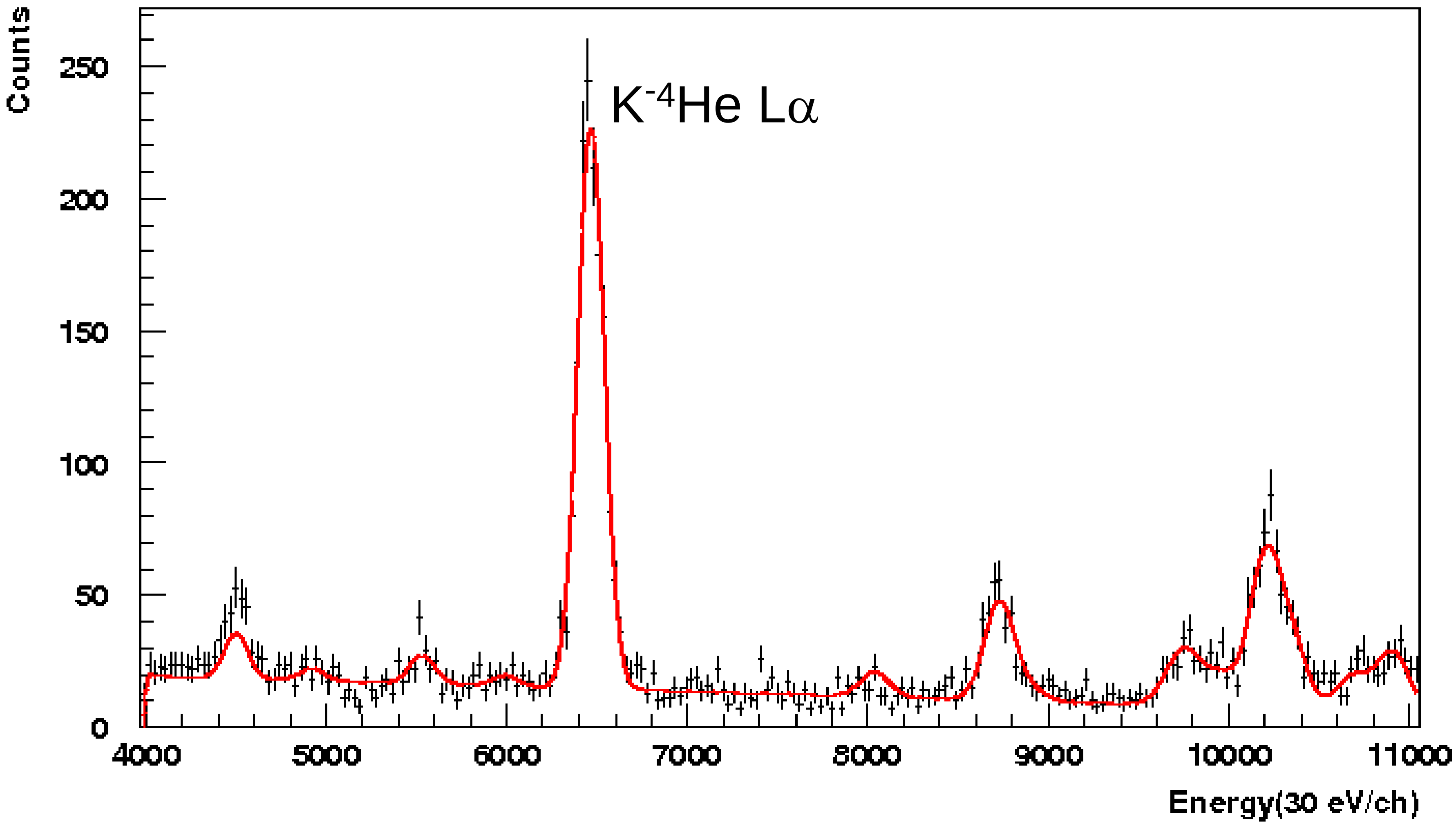
  - with 8 SDDs (one DAQ bus subsystem)
  - with complete Veto I + II
  - with kaon monitor
  - SIDDHARTA-2 luminosity monitor

- **Technical run until 2019**

  as long as similar beam/BG conditions are reached as compared with SIDDHARTA → tested with kaonic helium

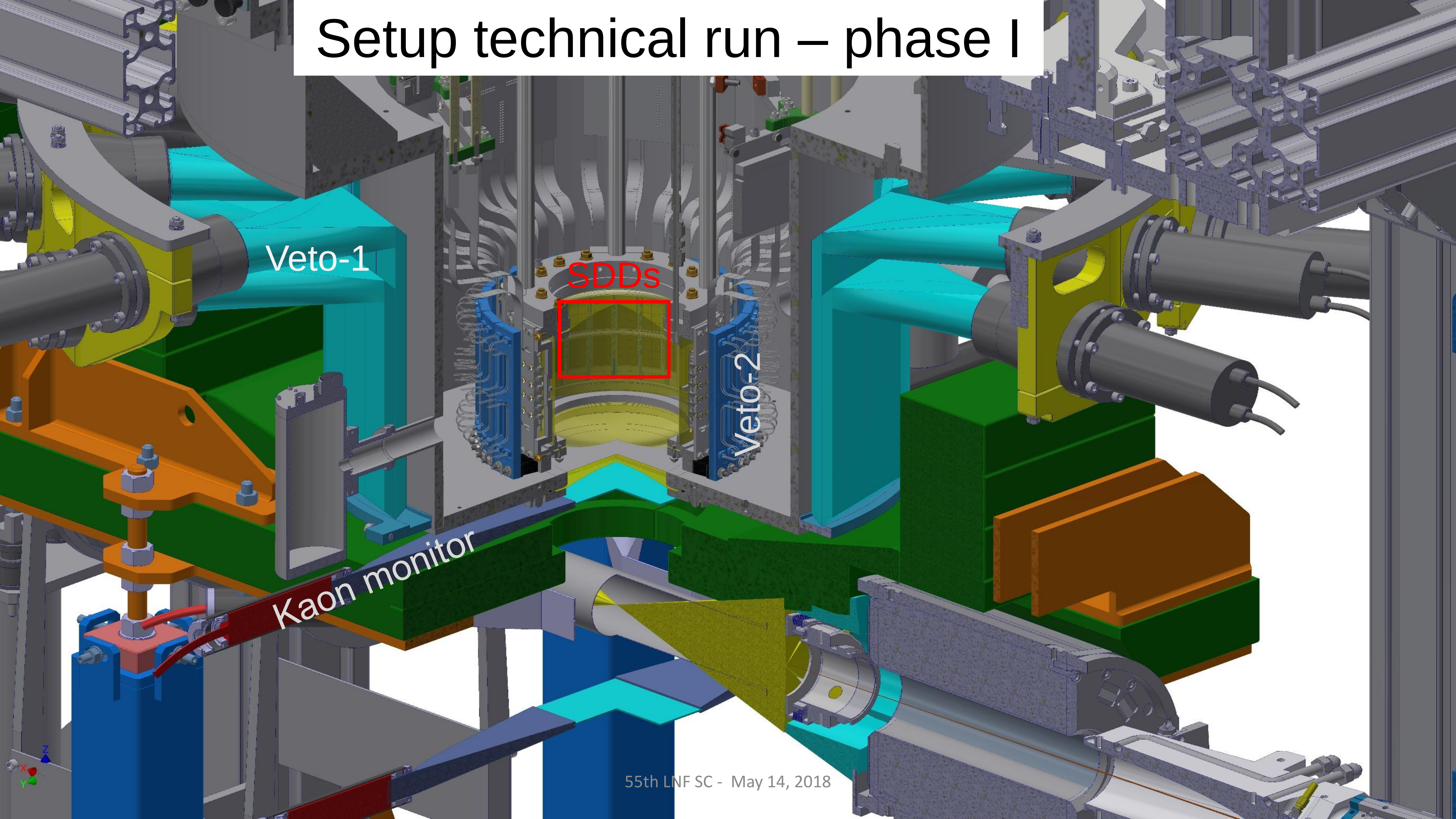
SIDDHARTA result – kaonic helium-4

Available online at www.sciencedirect.com
SciVerse ScienceDirect
Nuclear Physics A 914 (2013) 305–309



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

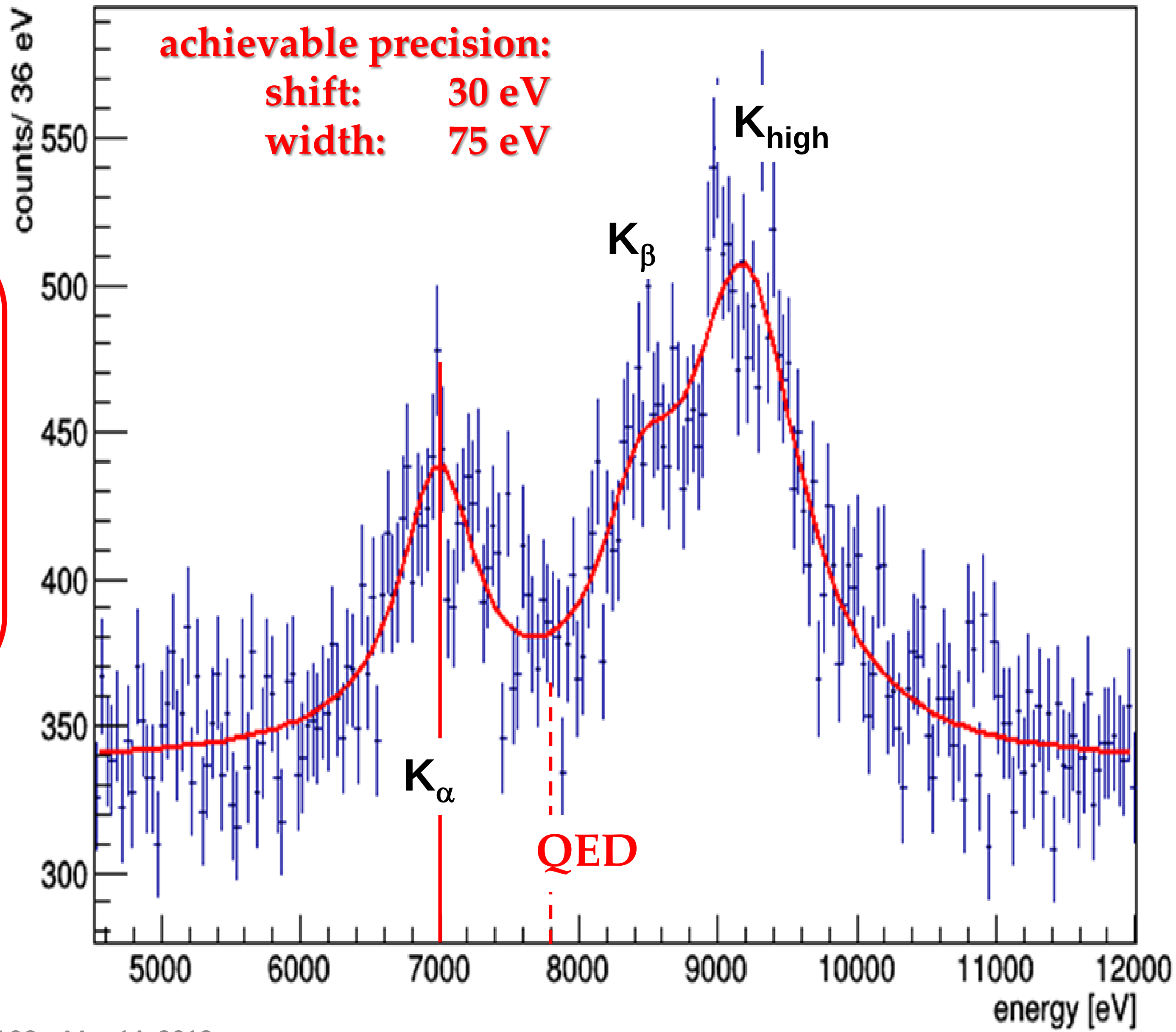
Setup technical run – phase I



SIDDHARTA-2 K-d measurement – phase II

Kaonic deuterium run in 2019:

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) !



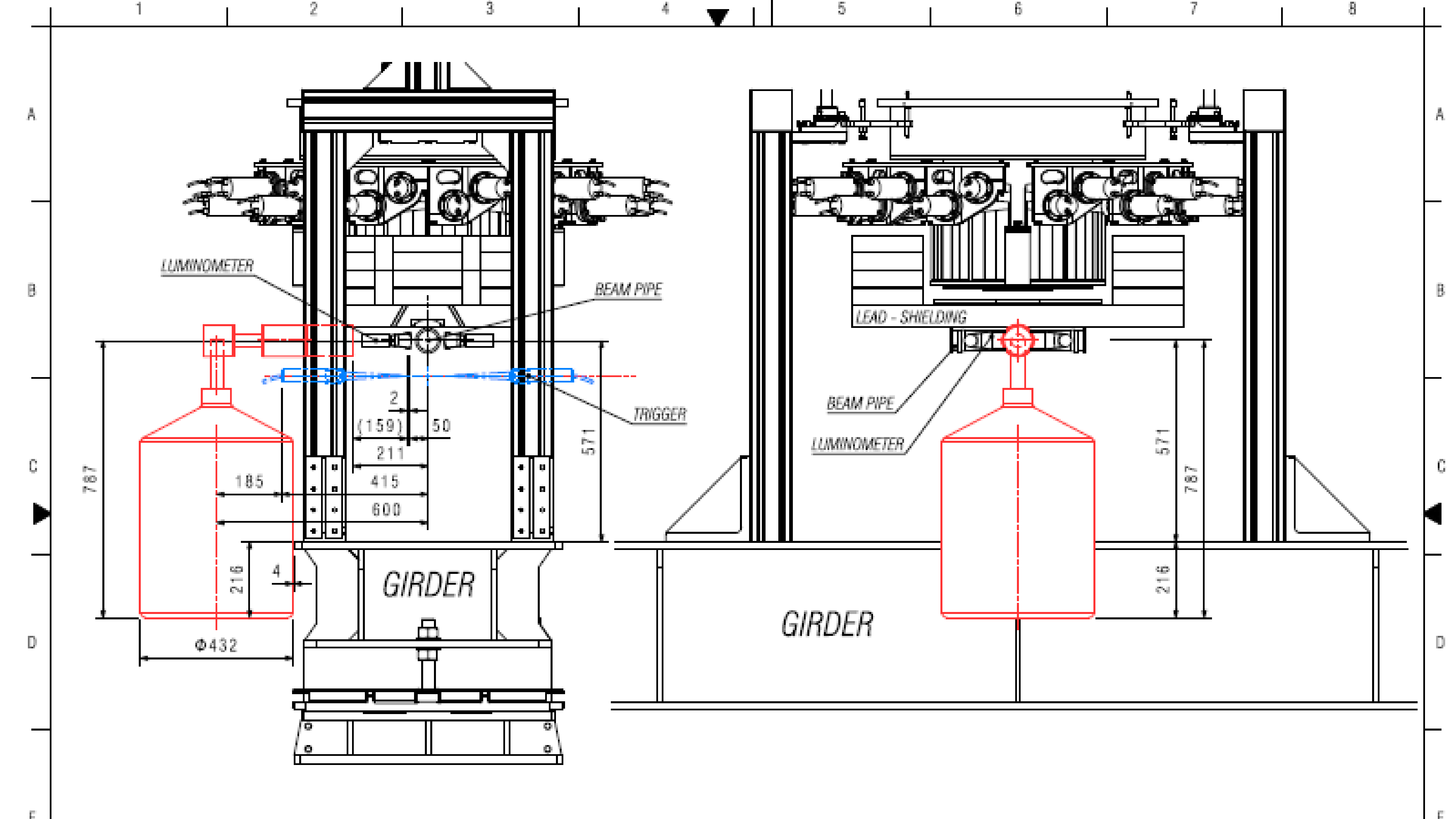
Future programme and perspectives:

- Feasibility studies in parallel with Siddharta-2 (Ge and VOXES)
- Plan for Extension of the 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 ?)**



LUMINOMETER
BEAM PIPE
TRIGGER
2
(159)
50
211
415
600
185
571
787
216
4
Φ432
GIRDER
LEAD - SHIELDING
BEAM PIPE
LUMINOMETER
571
787
216
GIRDER

SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

LNF- INFN, Frascati, Italy
SMI- ÖAW, Vienna, Austria
Politecnico, Milano, Italy
IFIN – HH, Bucharest, Romania
TUM, Munich, Germany, Germany
RIKEN, Japan
Univ. Tokyo, Japan
Victoria Univ., Canada
Univ. Zagreb, Croatia
Helmhotlz Inst. Mainz, Germany
Univ. Jagellonian, Krakow

Personnel issue - SIDDHARTA-2 (1)

Note: SIDDHARTA-2 survived from 2009 until now – it was a difficult task but successfully realized

We have secured the personnel needs to install the SIDDHARA-2 on DAFNE and for the Technical run (if done within April 2019) – all specific tasks are covered, including:

DAQ, SDDs detectors and electronics, veto systems, trigger, luminosity monitor, mechanics, vacuum and cryogenic, shifts for data taking, MCarlo and data analyses)

Personnel issue - SIDDHARTA-2 (2)

Specific Tasks:

LNF-INFN: responsible for DAQ, SDDs, part of readout, trigger, veto1, supports and shielding, slow control, contact with DAFNE; installation, debug, shifts, MCarlo and data analyses

SMI-Vienna: responsible for cryogenic, vacuum, veto2, SDDs, target system, MCarlo; participate in installation, debug, shifts, data analyses

Politecnico Milano: responsible with readout electronics SDD; participate in installation and debug

Jagellonian Univ. Krakow: responsible for luminosity monitor; participate in shifts and data analyses

To the installation and debug, shifts and data analyses participate:

Univ. Zagreb; IFIN-HH; RIKEN and Univ. Tokyo;

Data analyses and interpretation, R&D:

TUM Munich; Helmhotlz Inst. Mainz; Univ. of Victoria

Personnel issue - SIDDHARTA-2 (3)

After April 2019 main part of tasks are covered, however for LNF-INFN there are specific tasks for which support is needed for the dedicated kaonic deuterium run:

- **extension of post-doc position for F. Sirghi: trigger system, contact with DAFNE, data taking**
- **1-2 new post-doc positions: DAQ and SDDs, data taking**
- **new temporary contract: data analyses and MCarlo simulations**
- **support for post-doc fellowship for (experimental) non-italian citizens**

Possible external sources of funding: STRONG-2020 Proposal (under evaluation at EU)

Special thanks to the accelerator,
research and technical division,
to the DAΦNE staff
and to the LNF Director

Thank you !