SIDDHARTA - 2
STATUS REPORT

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for the SIDDHARTA-2 Collaboration

52nd LNF-INFN SCIENTIFIC COMMITTEE
November 21, 2016

CONTENT

Scientific Motivation

SIDDHARTA-2 apparatus – status with time lines:

- vacuum chamber
- cryogenic target
- X-ray detector system + calibration
- veto counters
- luminosity detector

MC simulation

- synchronous – background
- asynchronous – background

Overall time schedule

Beam time request

SIDDHARTA-2 Collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

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

The scientific aim of SIDDHARTA-2

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

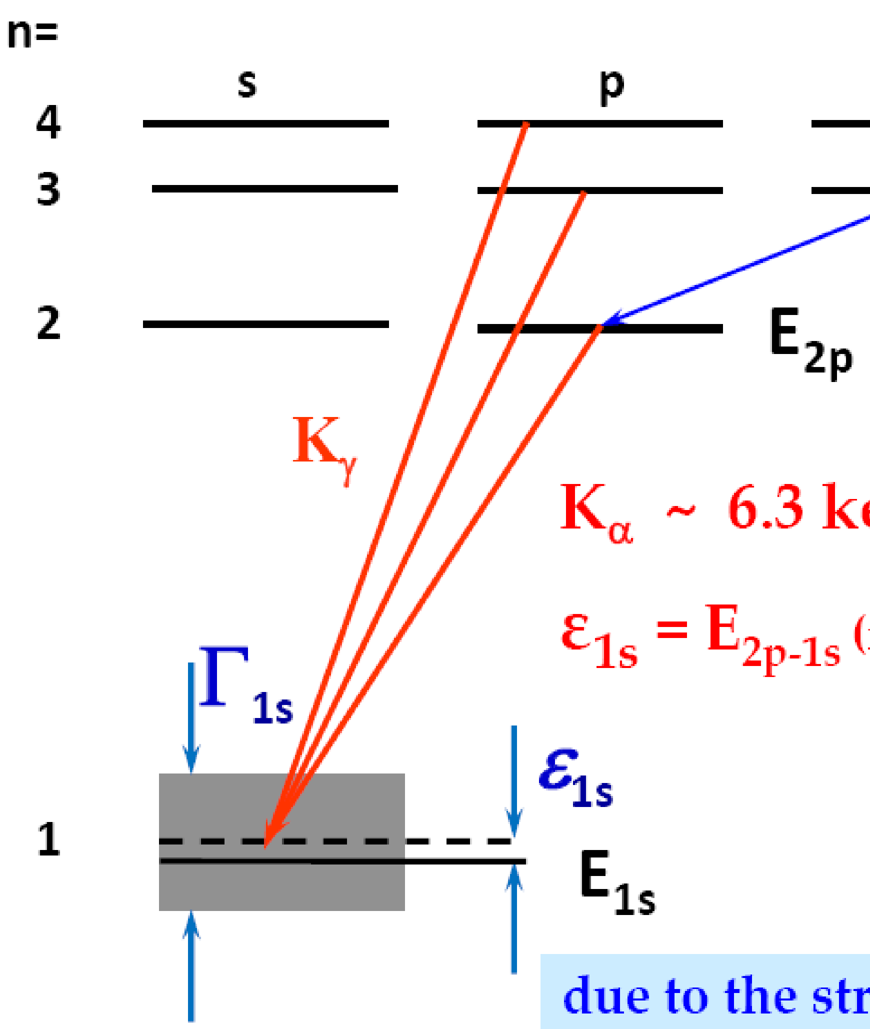
Precision measurement ***of shift*** and ***width***

- of the 1s level of kaonic hydrogen - SIDDHARTA
- *first measurement* of **kaonic deuterium - SIDDHARTA-2**

to extract the antikaon-nucleon isospin dependent scattering lengths

- chiral symmetry breaking, EOS for neutron stars

X-RAY TRANSITIONS TO THE 1s STATE

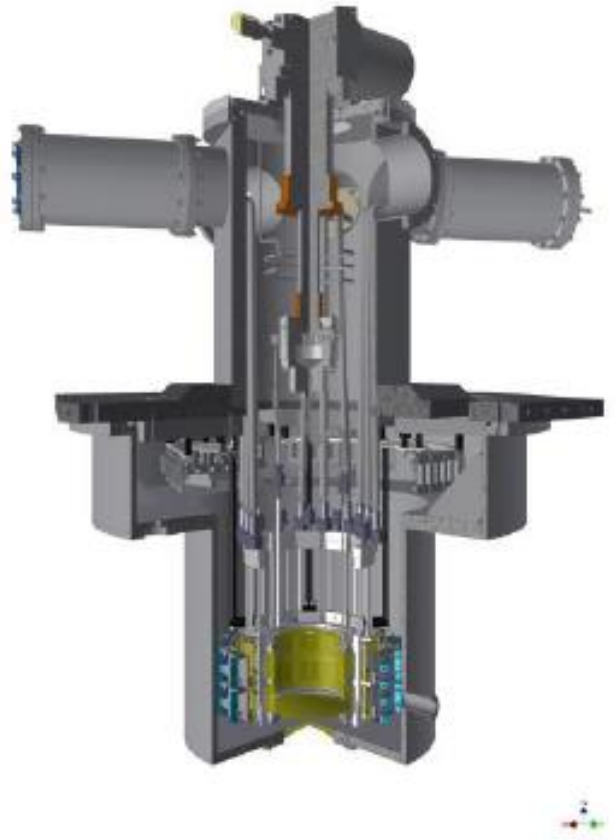


shift and width of states
n > 1 are negligible

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



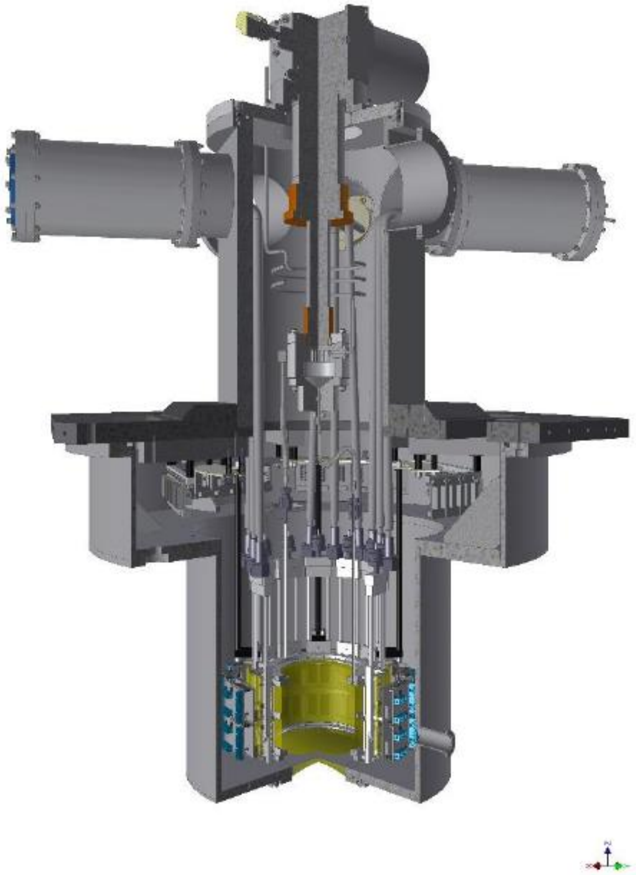
TECHNICAL REPORT

SIDDHARTA-2 – kaonic deuterium measurement

May 2016

The SIDDHARTA-2 Collaboration:

LNF- INFN, Frascati, Italy; SMI- ÖAW, Vienna, Austria; IFIN – HH, Bucharest, Romania; Politecnico and INFN, Milano, Italy; TUM Muenchen, Germany; RIKEN, Japan; Univ. Tokyo, Japan; Victoria Univ., Canada; Univ. Zagreb, Croatia



THE VETO SYSTEM FOR SIDDHARTA - 2 TECHNICAL REPORT

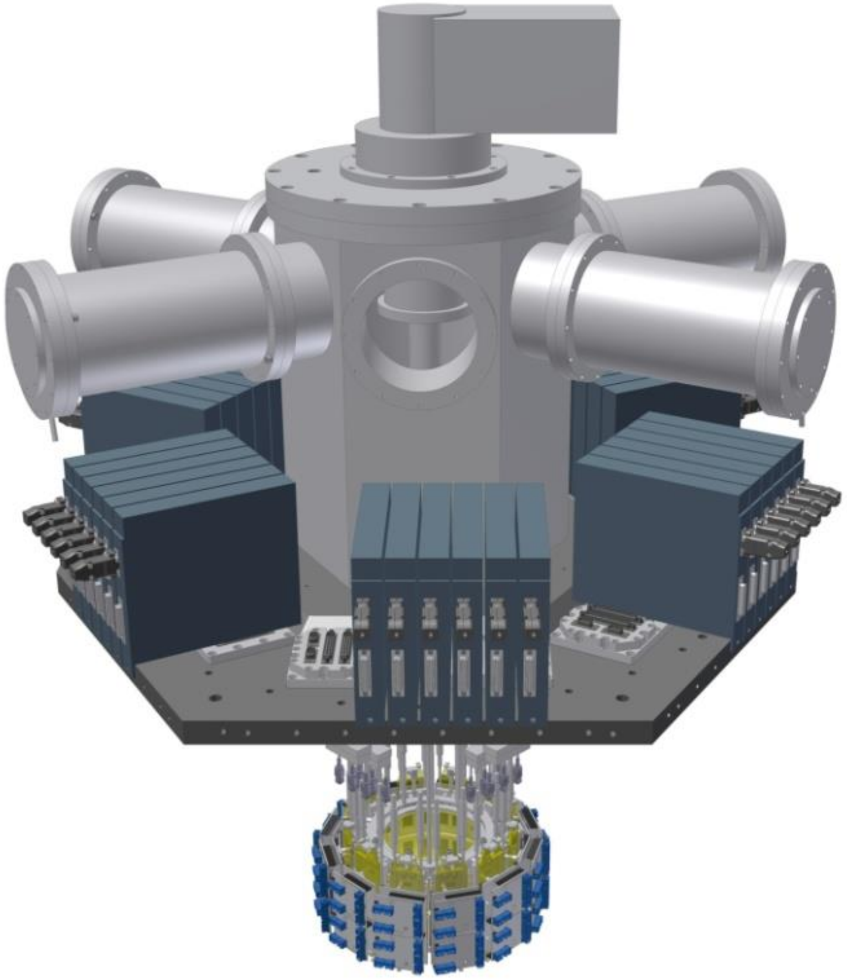
August 2016

SIDDHARTA-2 Collaboration

SIDDHARTA-2

- Cooling systems
- Cryogenic target

The SIDDHARTA-2 vacuum chamber



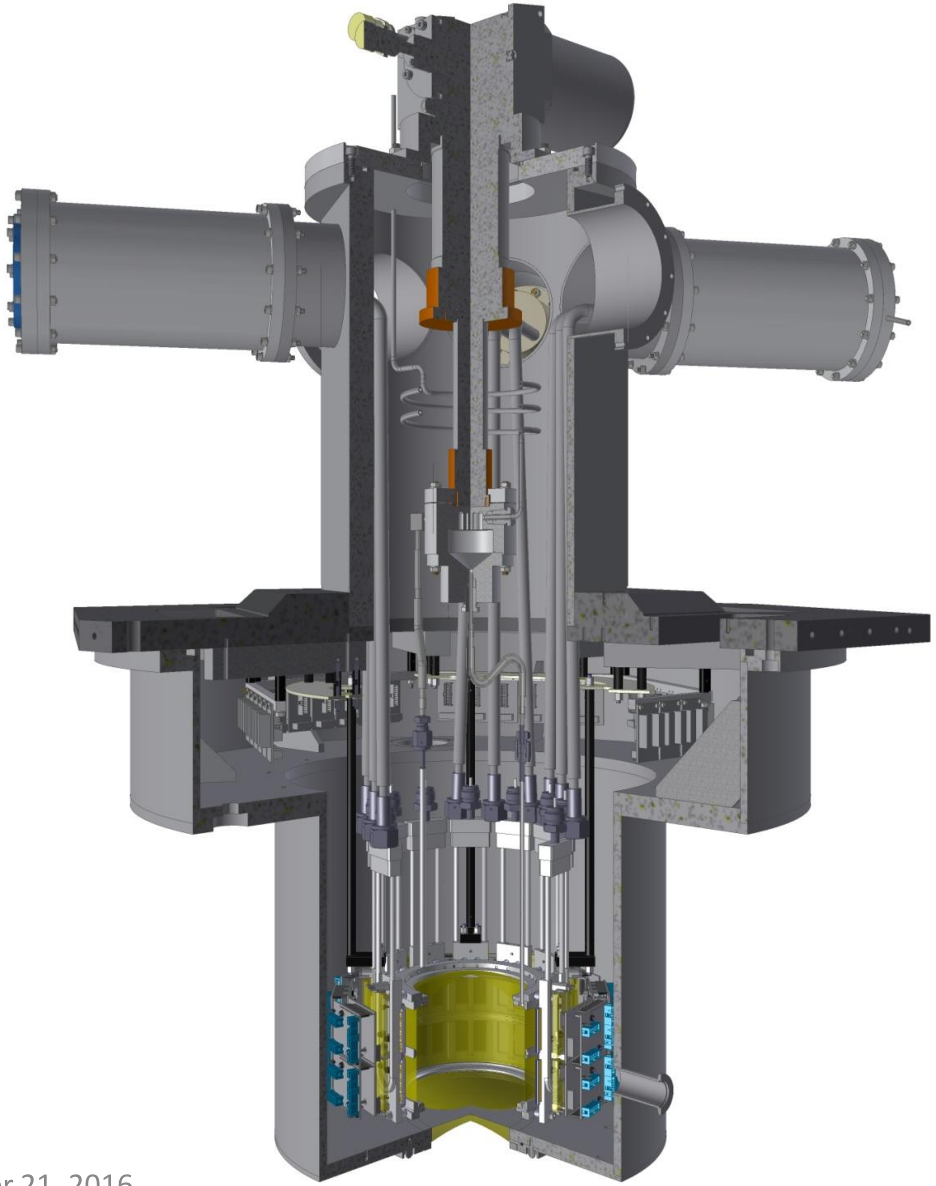
✓ ready and tested

New SIDDHARTA-2 cooling design

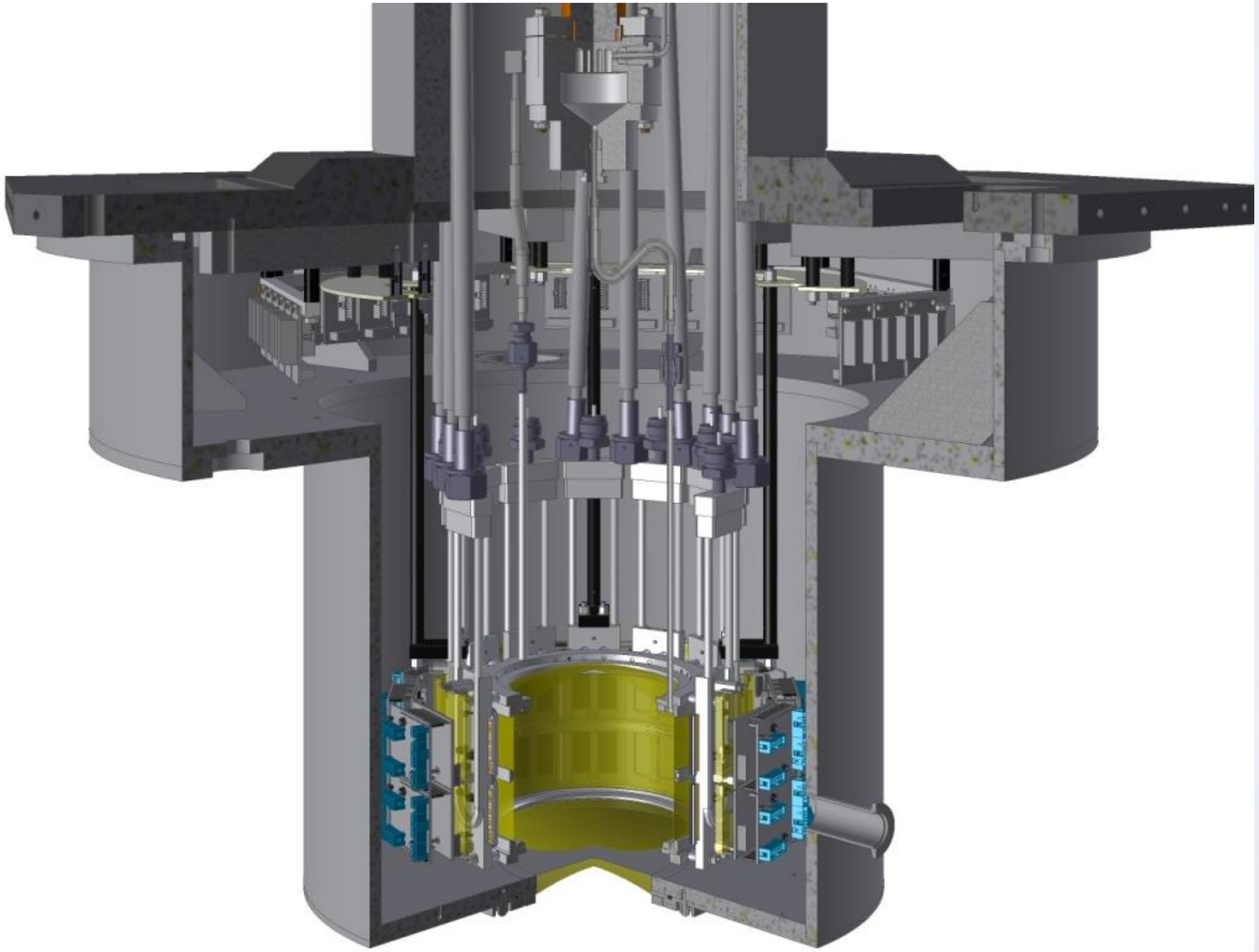
Target cooling:
1 Leybold – 16 W @ 20 K
new target cell
cooling via ultra pure aluminum bars

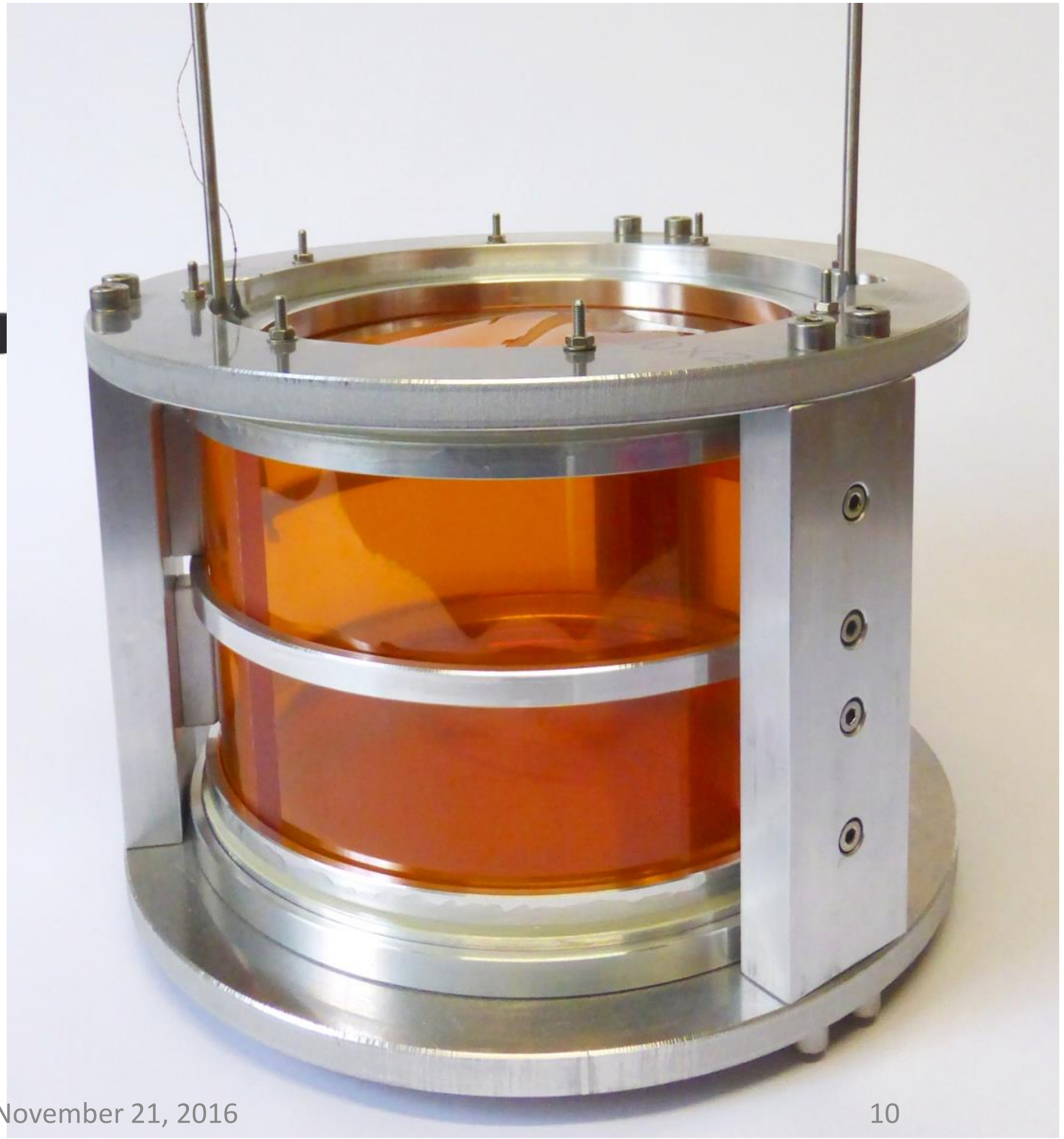
SDD cooling:
4 CryoTiger – 60 W @ 120 K
Liquid argon cooling lines:
SDD cooling to 90 – 110 K

✓ cryo coolers available/tested

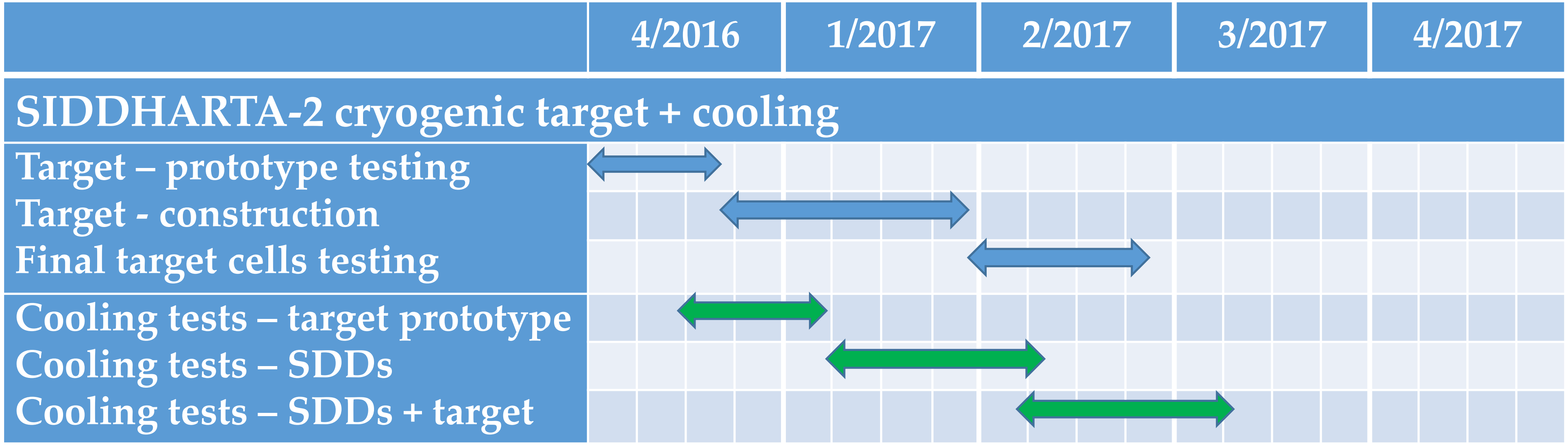


SIDDHARTA-2 target prototype





Gantt chart: SIDDHARTA-2 target



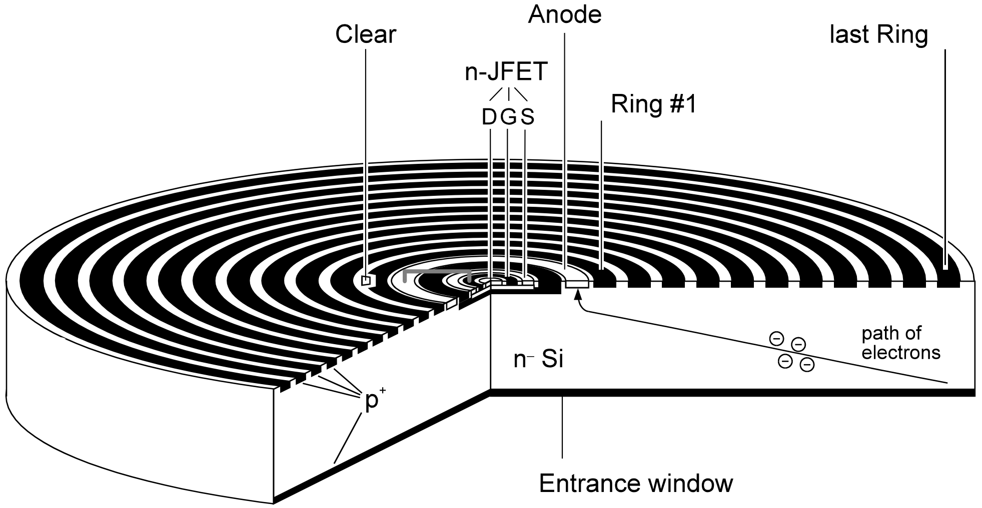
SIDDHARTA-2

- X-ray detectors: SDDs

The “new” Silicon Drift Detector

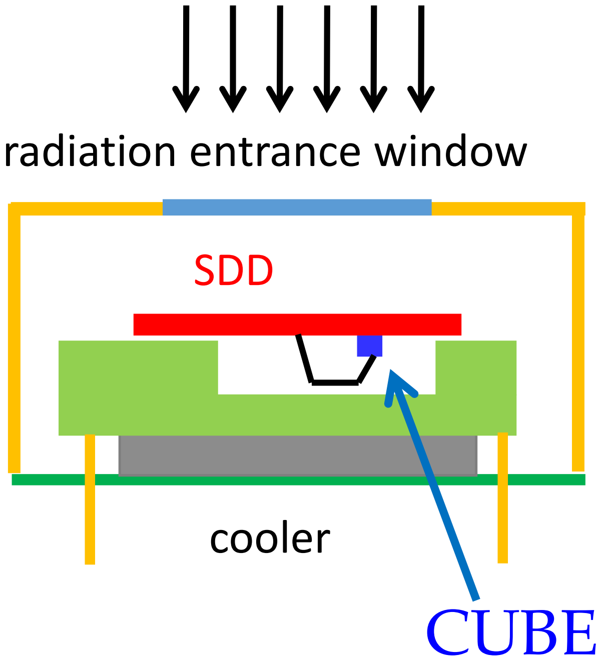
➢ **SIDDHARTA**

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

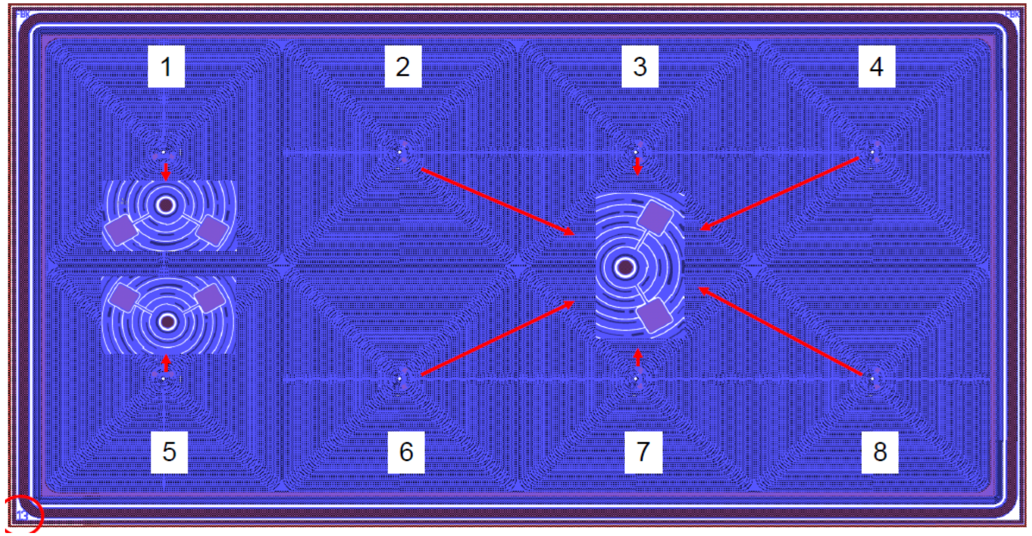


➢ **SIDDHARTA-2**

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

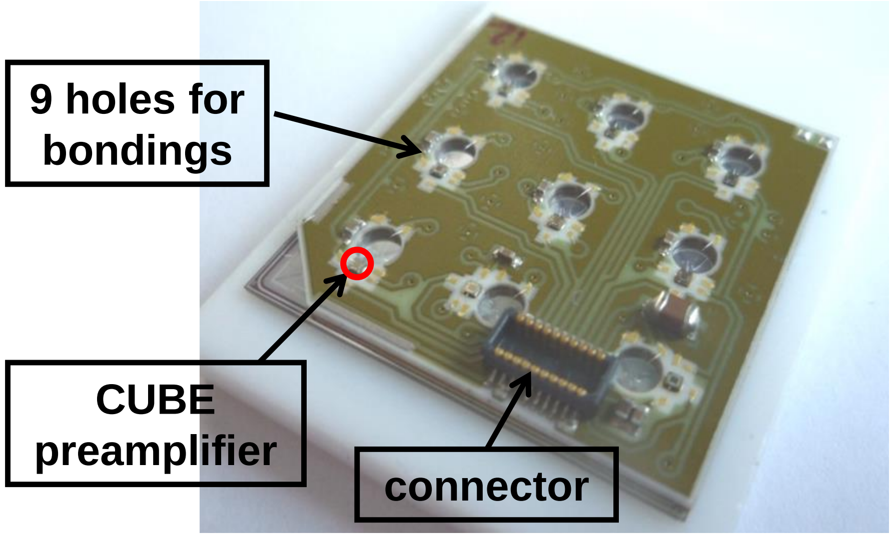


The 4x2 SDDs array for $K^{-}d$



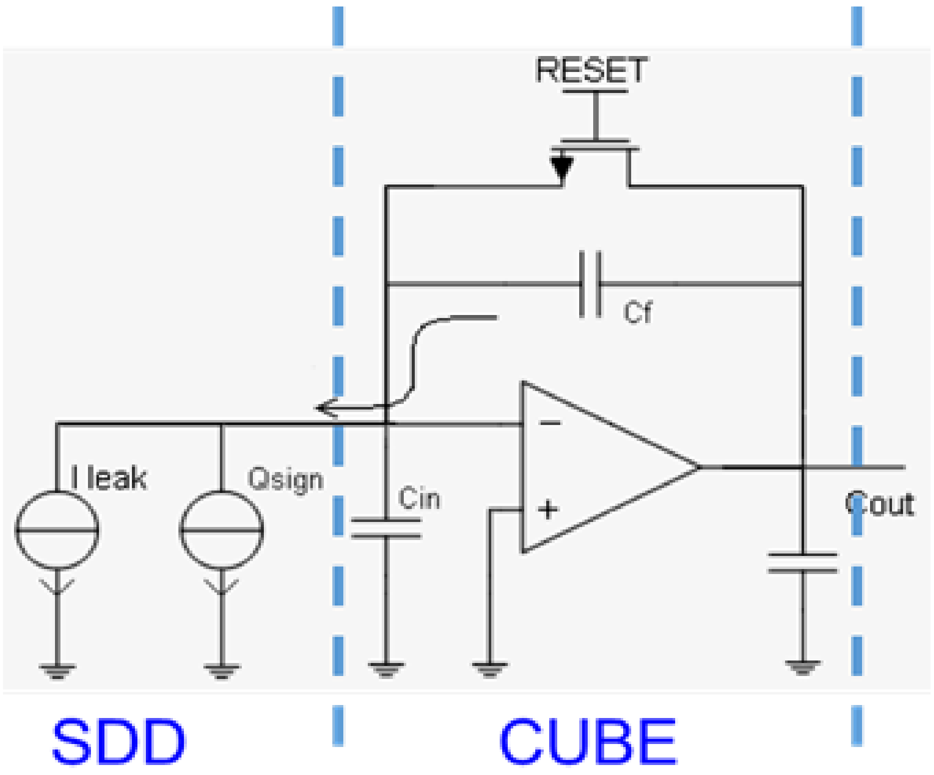
SDD-chip back side with bonding pads

SDD-chip glued to ceramic board, bonded to CUBE preamplifier



The CUBE preamplifier

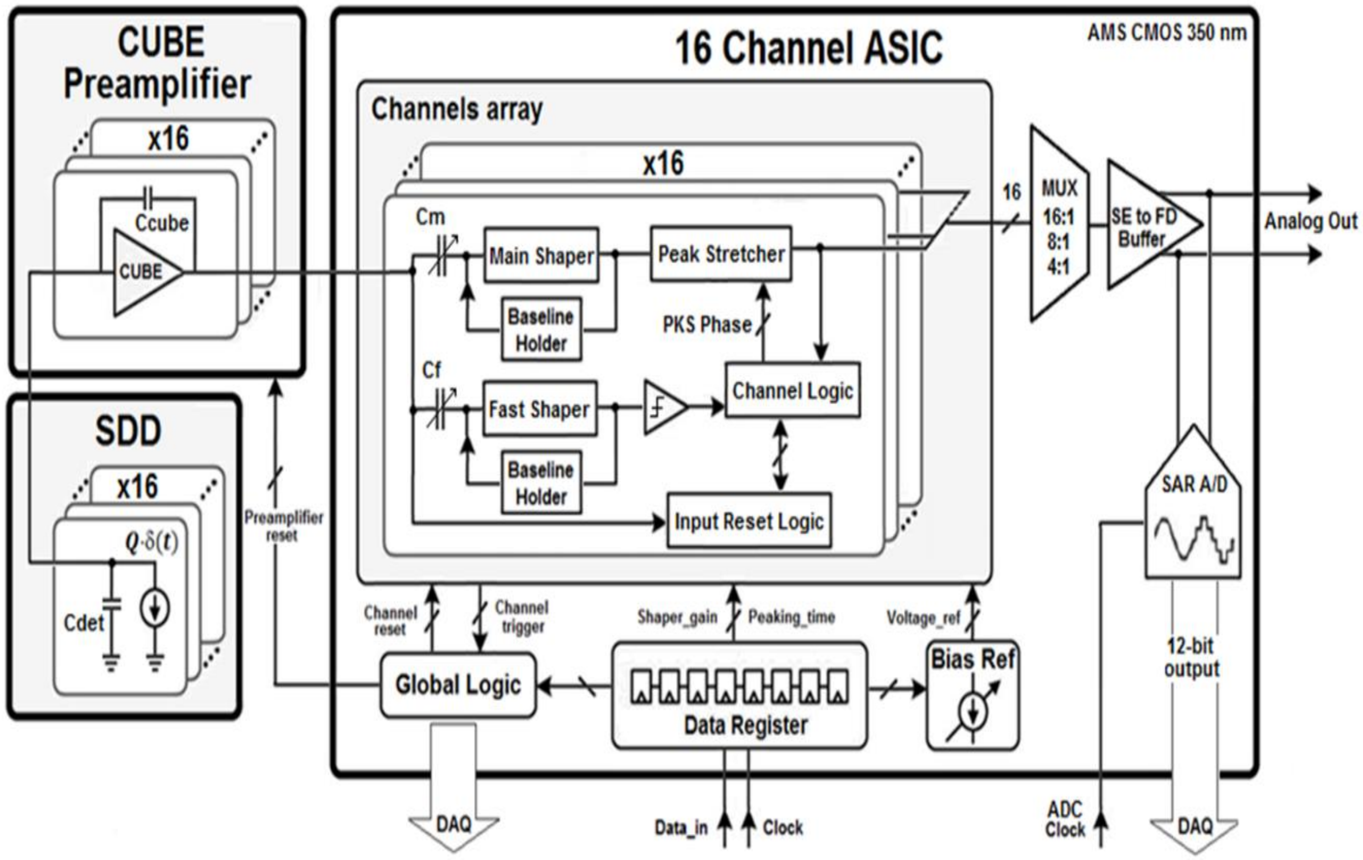
- A full CMOS preamplifier is mounted on ceramic board - connected via bonding
- The CUBE replaces the JFET, which was direct implanted on the anode side on the SIDDHARTA type SDDs
- Short bonding lines from CUBE to SDD, no difference in the detector performance
- Advantage, the preamplifier is connected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



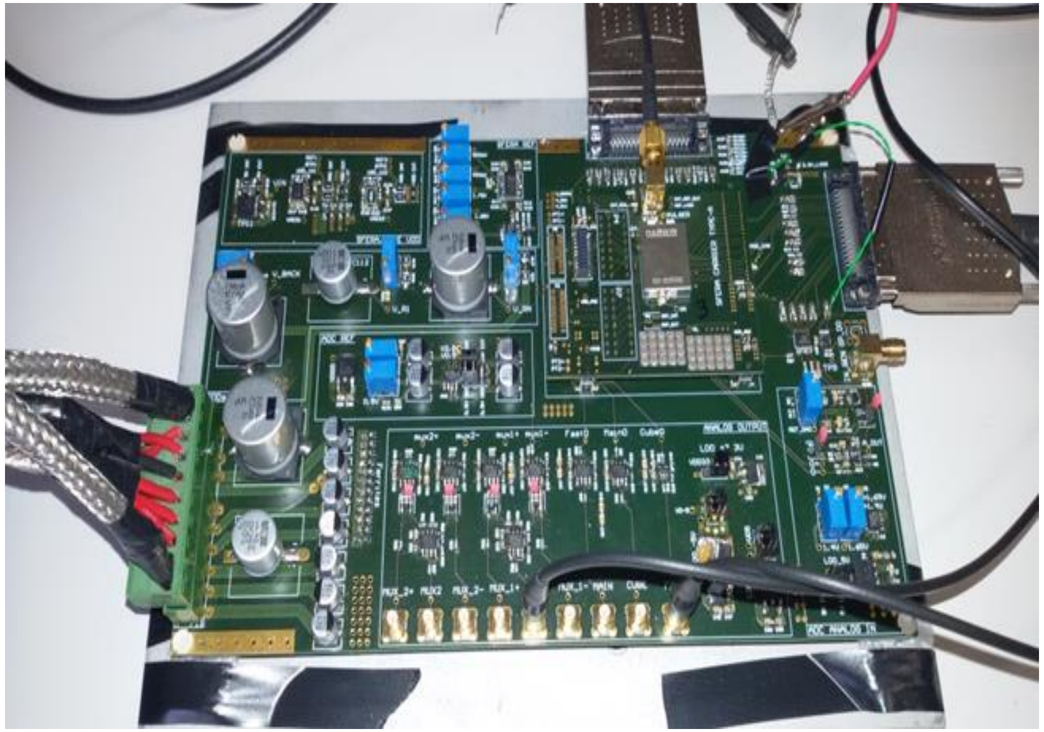
The ASIC - the SFERA-chip

Specifications

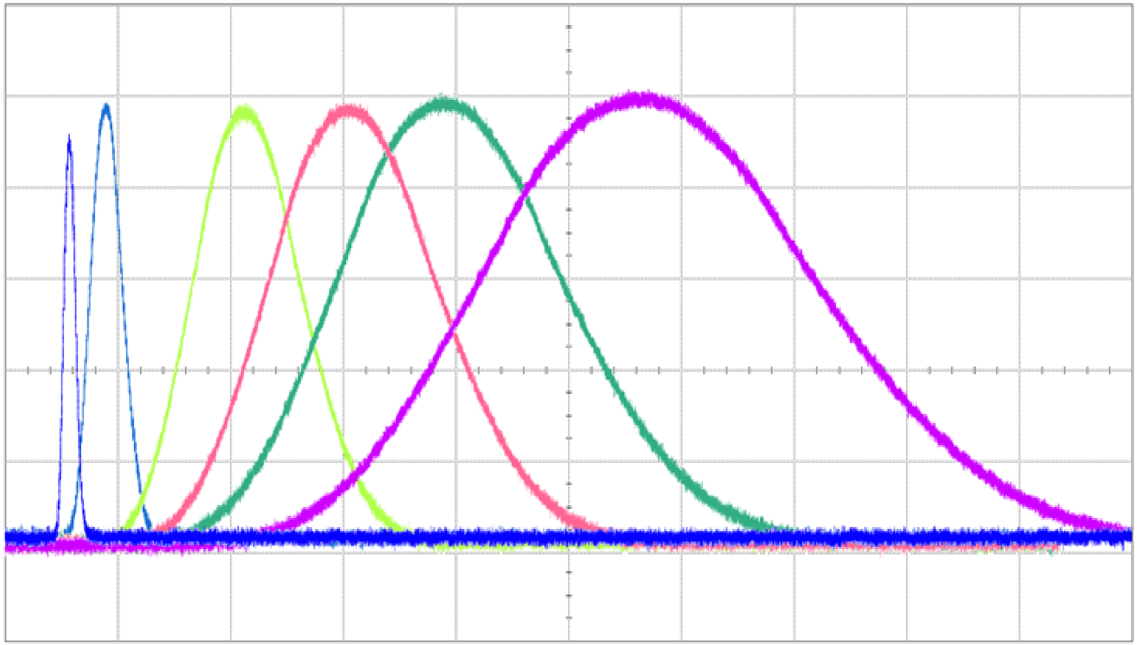
- CMOS AMS 0.35μm technology
- 16 input channels
- shaper amplifier topology: 9^{th} order semi-gaussian
- input dynamic ranges:
  2800 e⁻ (10 keV), 4420 e⁻ (16 keV), 9950 e⁻ (36 keV)
- shaper amplifier peaking times:
  200 ns, 500 ns, 1 μs, 2 μs, 4 μs



The SFERA test board



SA output pulses at different peaking times (0.2, 0.5, 2, 3, 4 and 6 μs)

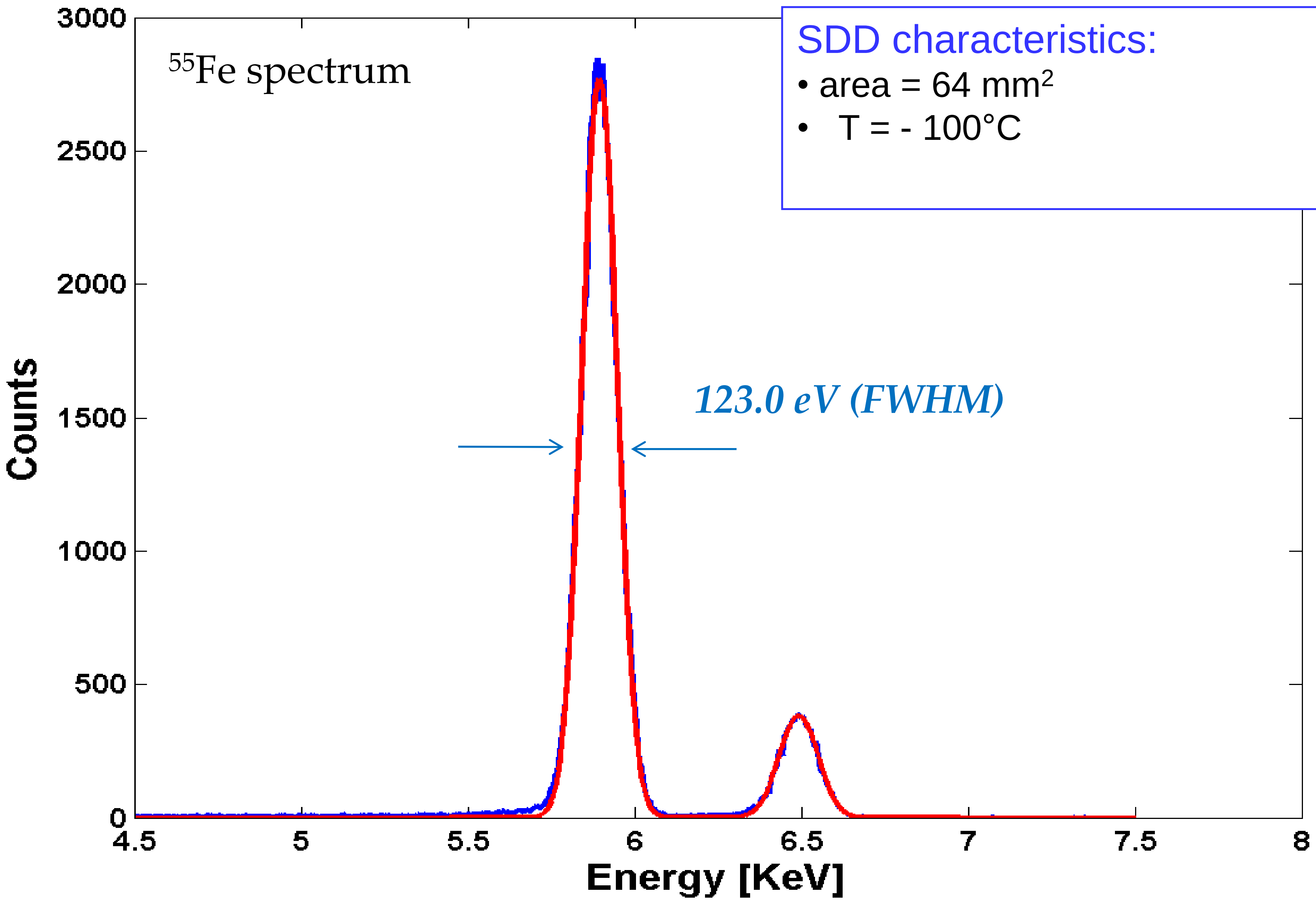


Channel 1: Scale 500 mV/,
Channel 2: Scale 500 mV/,
Channel 3: Scale 500 mV/,
Channel 4: Scale 500 mV/,
Horizontal: Scale 1.00 μs/,

new optimised electronics:

- more robust – allows to work during injection
- fast timing
- stability/linearity improved
- excellent energy resolution

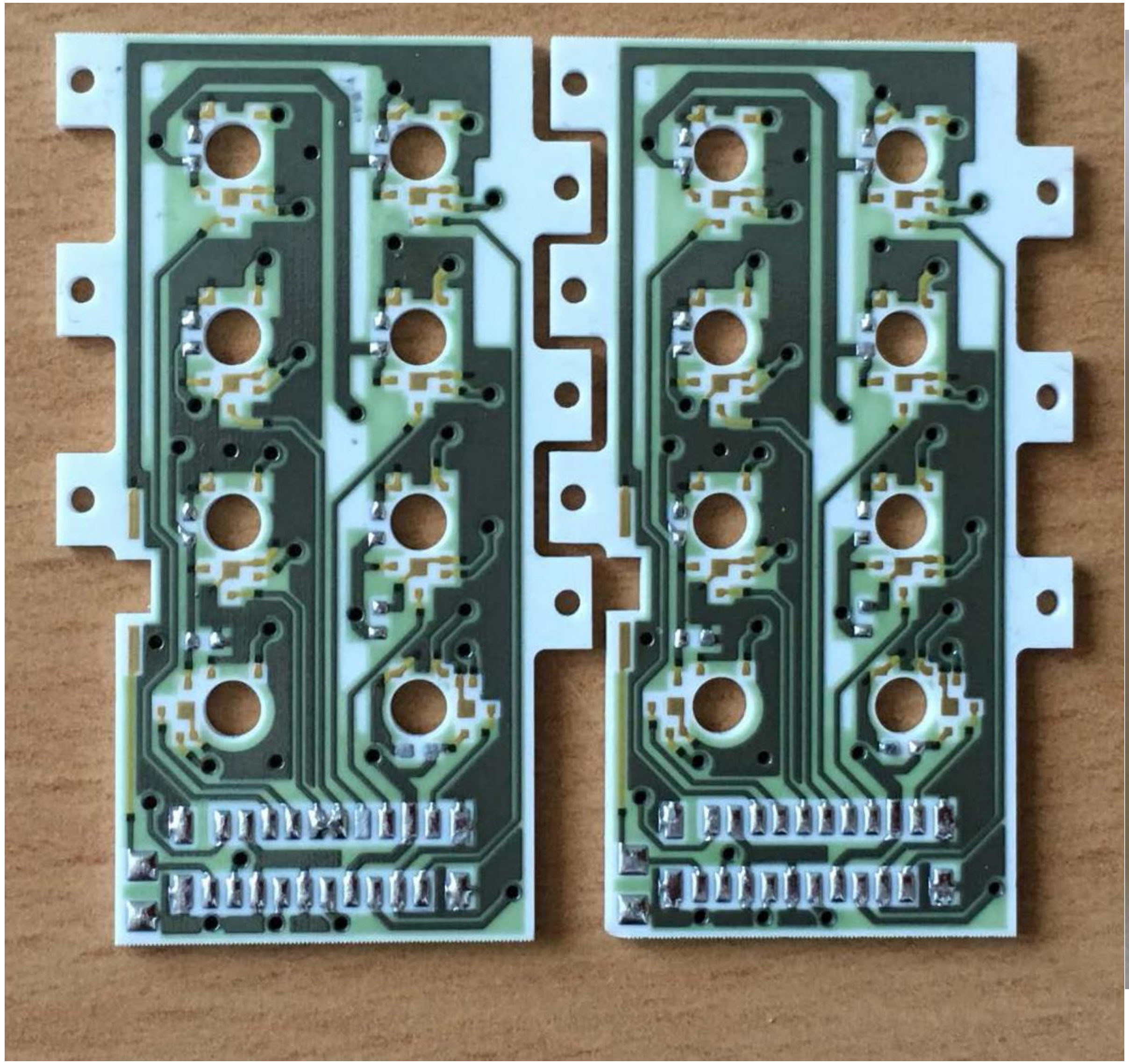
The “new” SDD technology: CUBE + SFERA

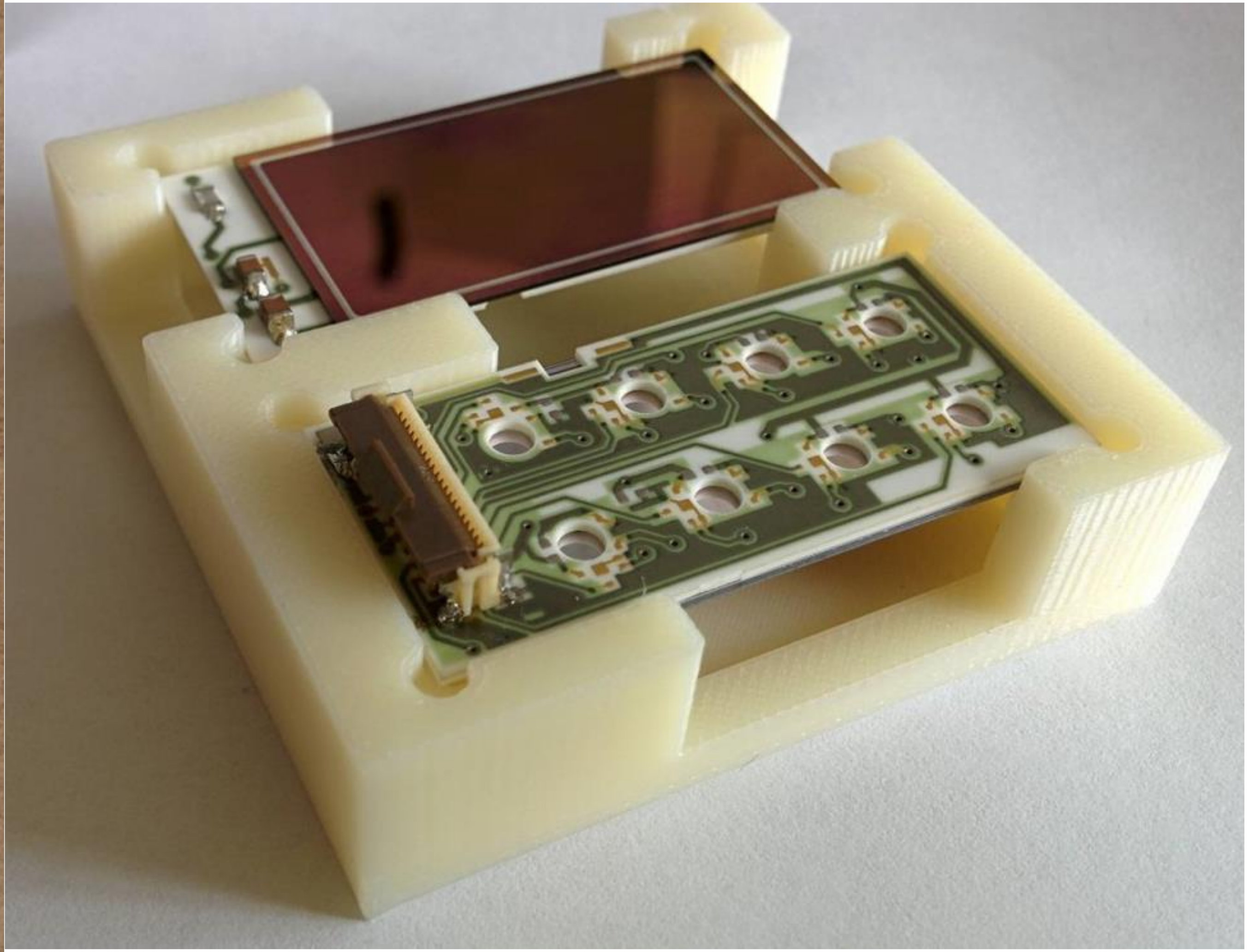


SDD characteristics:

- area = 64 mm^2
- T = - 100°C

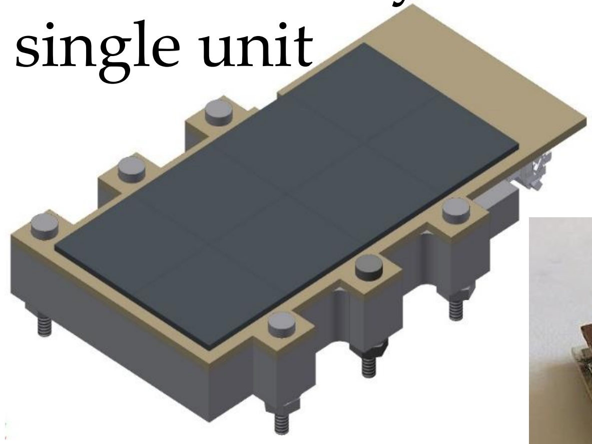
4x2 SDD ceramic + bonding device

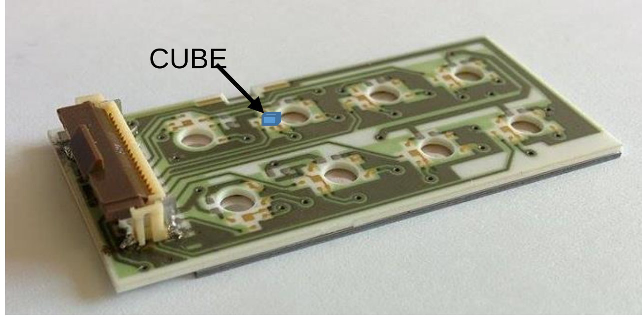




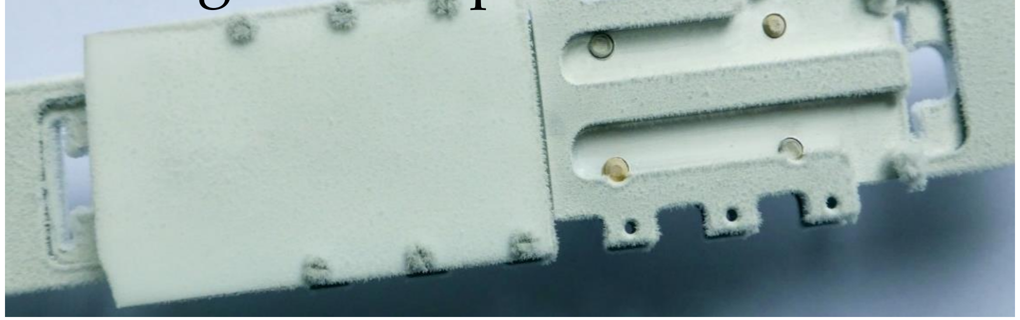
4x2 SDD array – layout + arrangement

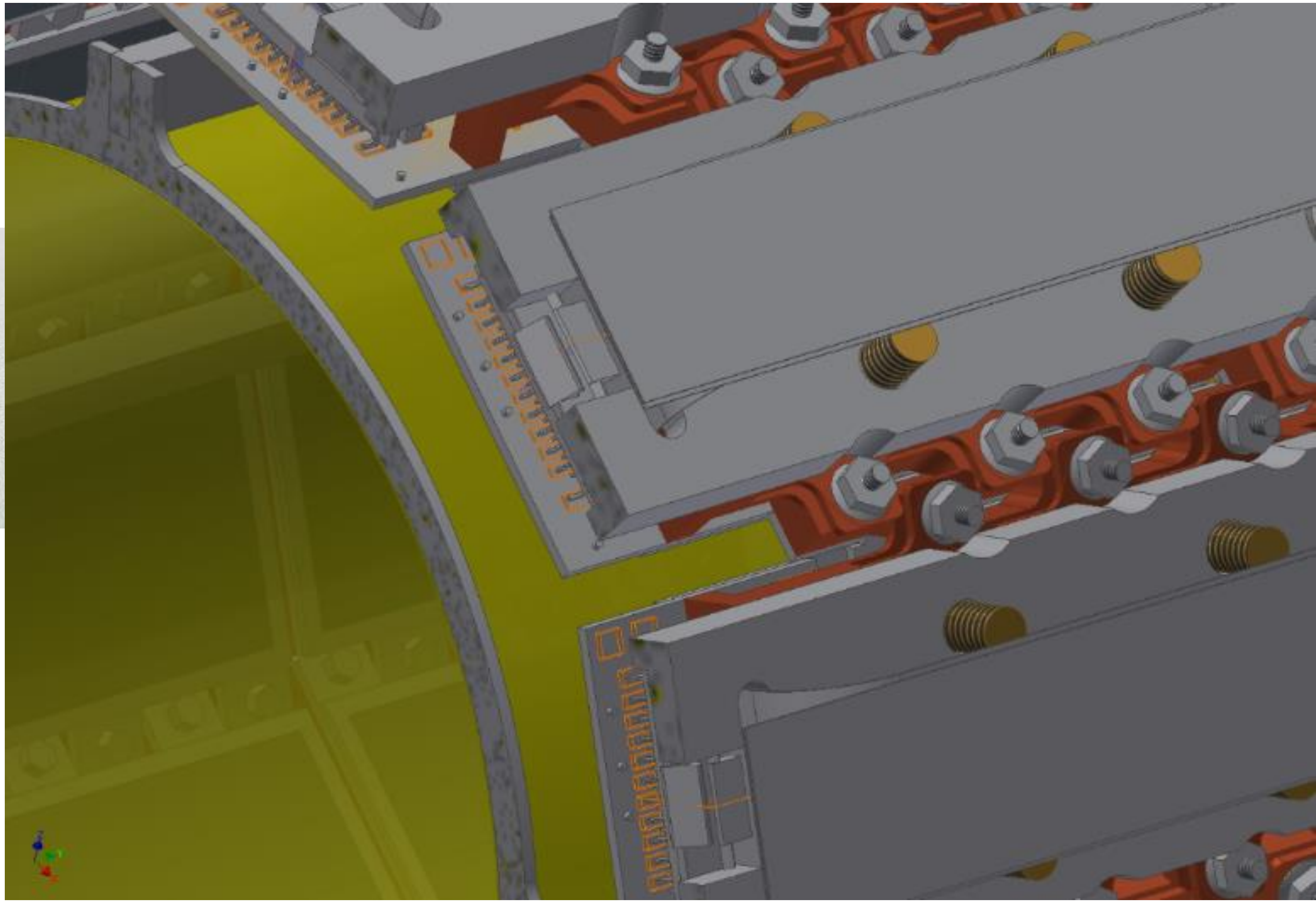
4x2 SDD array
single unit





cooling test – liq.N2





4x2 SDD array cooling test

- 3 cooling cycles
- Cryostat set to 65 K
- Ceramic temperature 73 K
- No visual damage of SDD/ceramic

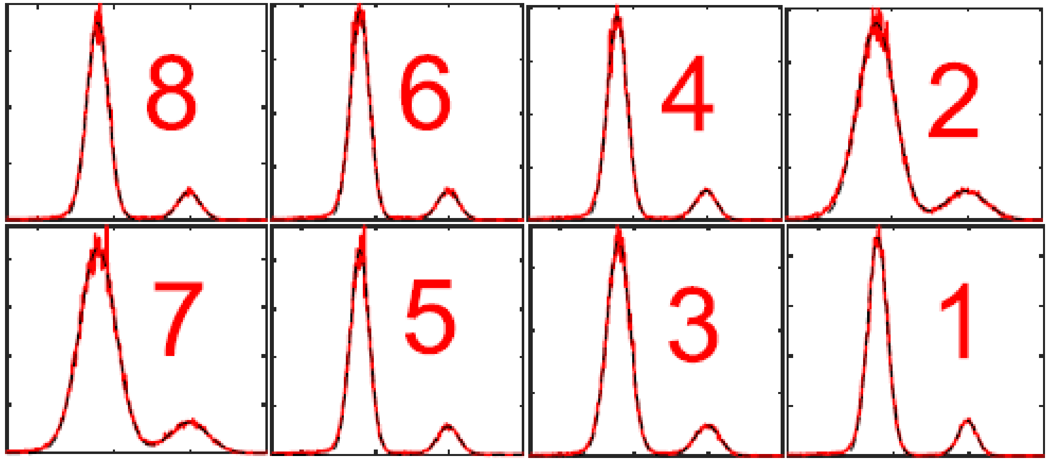


Fig. 5. Eight X-ray spectra acquired by irradiating a 2×4 SDD array with an un-collimated ^{55}Fe X-ray source at a temperature of -30 °C with 3 μs shaping time using.

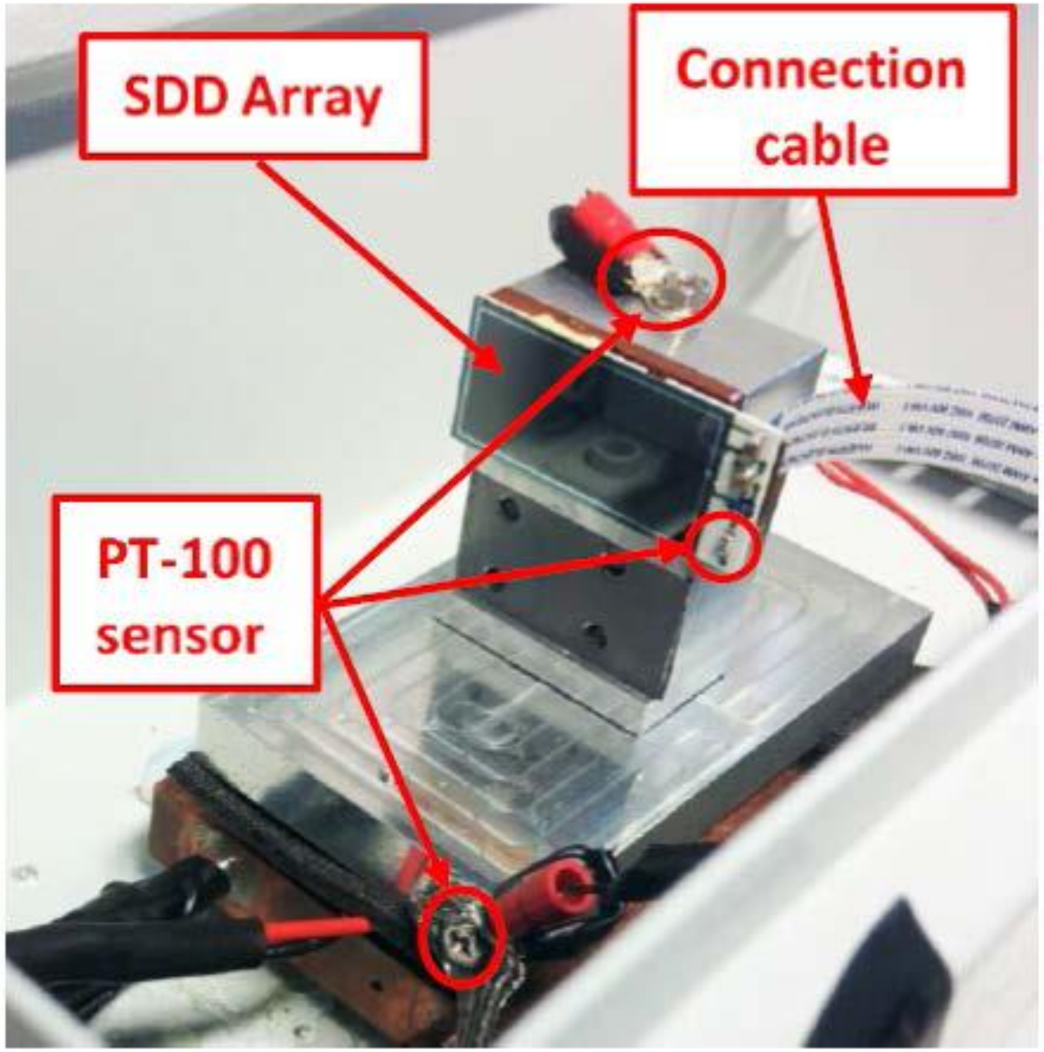
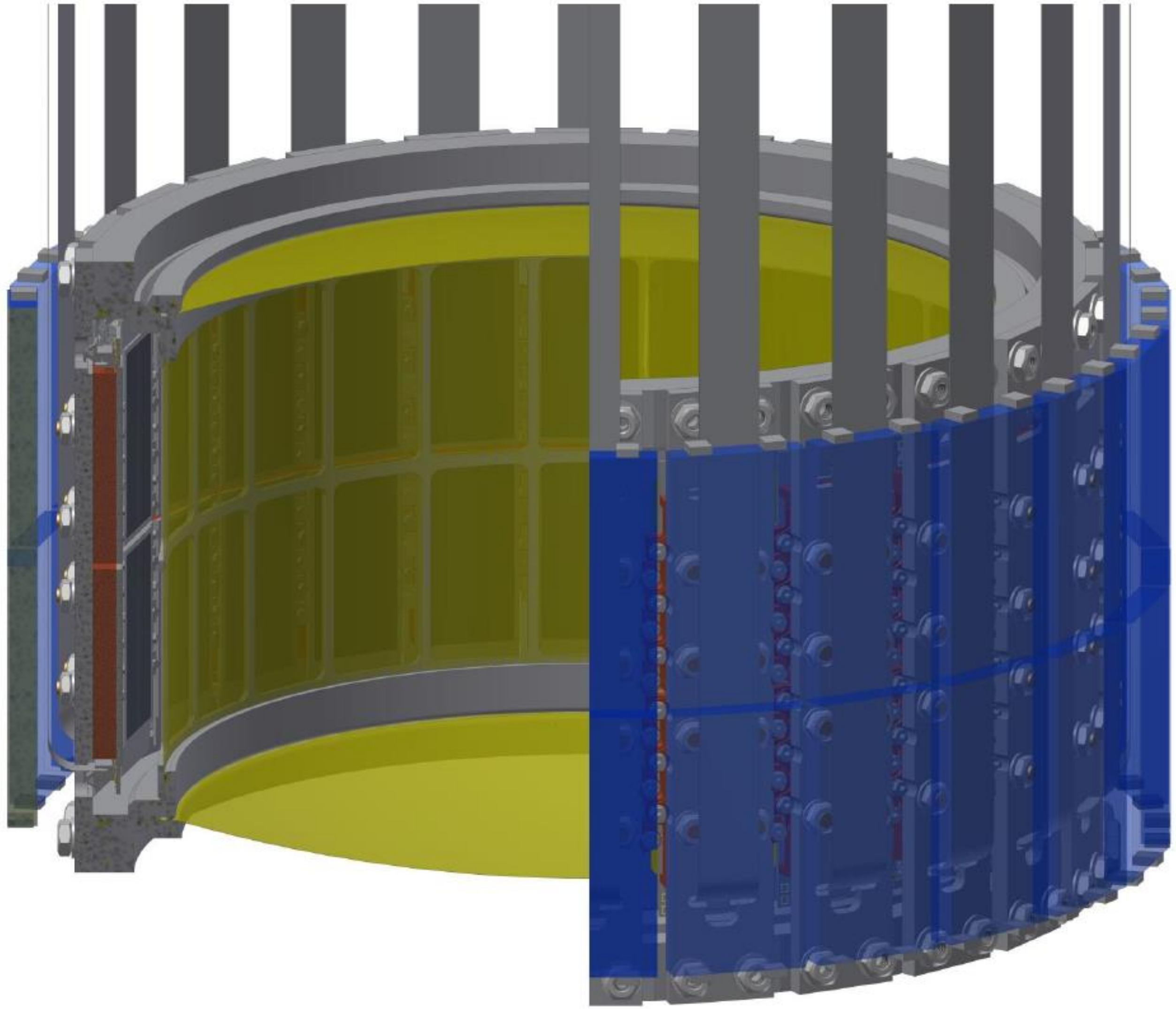
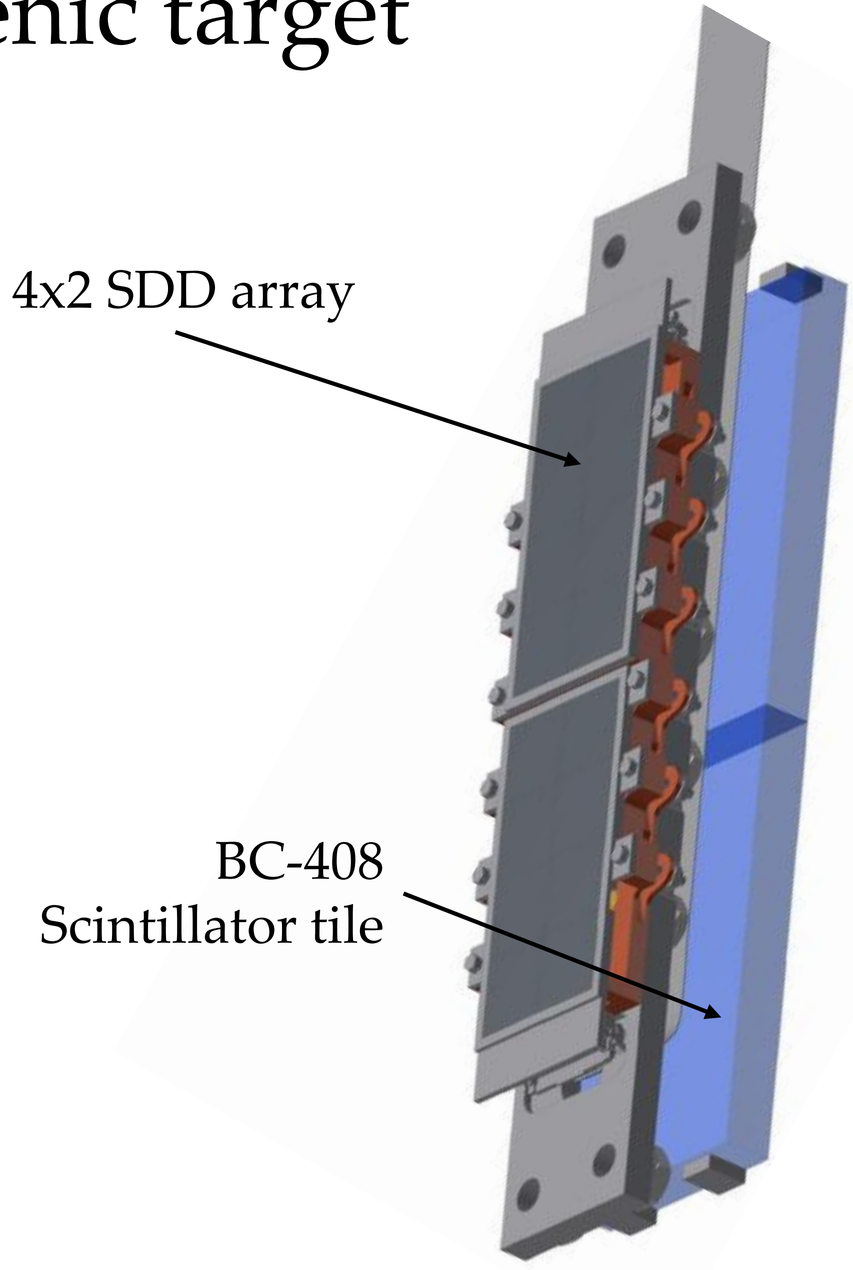


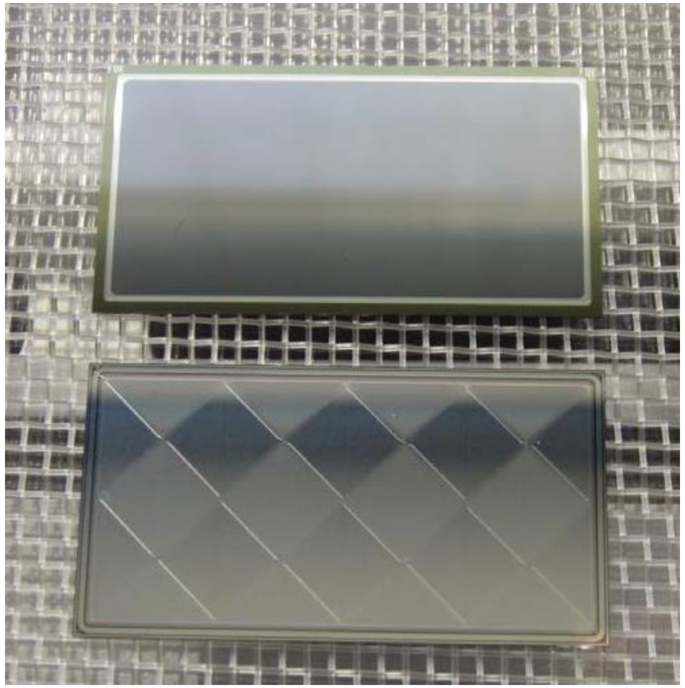
Fig. 4. Experimental setup employing thermoelectric (Peltier) cooling stage to characterize Siddharta-II arrays at a temperature of -30 °C.

4x2 SDD array around the cryogenic target





SDD arrays delivery and qualification



48 SDDs arrays needed

Delivery status:

40 arrays received

16 ordered (to be delivered within January 2017)

Batch	Wafer	Matrix	Q-index
SIDDHARTA1b	W01	1,2	8.080
SIDDHARTA1b	W01	2,1	8.080
SIDDHARTA1b	W01	3,2	8.080
SIDDHARTA1b	W01	3,3	8.530
SIDDHARTA1b	W02	1,4	8.161
SIDDHARTA1b	W02	3,1	8.800
SIDDHARTA1b	W02	3,3	8.530
SIDDHARTA1c	W12	2,1	8.440
SIDDHARTA1c	W17	1,1	8.080

Batch	Wafer	Matrix	Q-index
SIDDHARTA1b	W03	1,4	8.080
SIDDHARTA1b	W03	1,1	8.620
SIDDHARTA1b	W04	3,2	8.260
SIDDHARTA1b	W04	2,1	8.611
SIDDHARTA1b	W04	1,2	8.710
SIDDHARTA1b	W05	3,4	8.710
SIDDHARTA1d	W14	3,1	8.080
SIDDHARTA1d	W14	3,2	8.440
SIDDHARTA1d	W14	2,1	8.521
SIDDHARTA1d	W14	3,3	8.620
SIDDHARTA1d	W15	3,4	8.170
SIDDHARTA1d	W15	3,1	8.251
SIDDHARTA1d	W15	3,3	8.260
SIDDHARTA1d	W15	2,1	8.440
SIDDHARTA1d	W19	1,2	8.260
SIDDHARTA1d	W19	3,1	8.260
SIDDHARTA1d	W19	1,1	8.350
SIDDHARTA1d	W19	1,4	8.350

Q-index: N.DGS

N = number of functioning channels (with J_{anode} < 2nA/cm²)

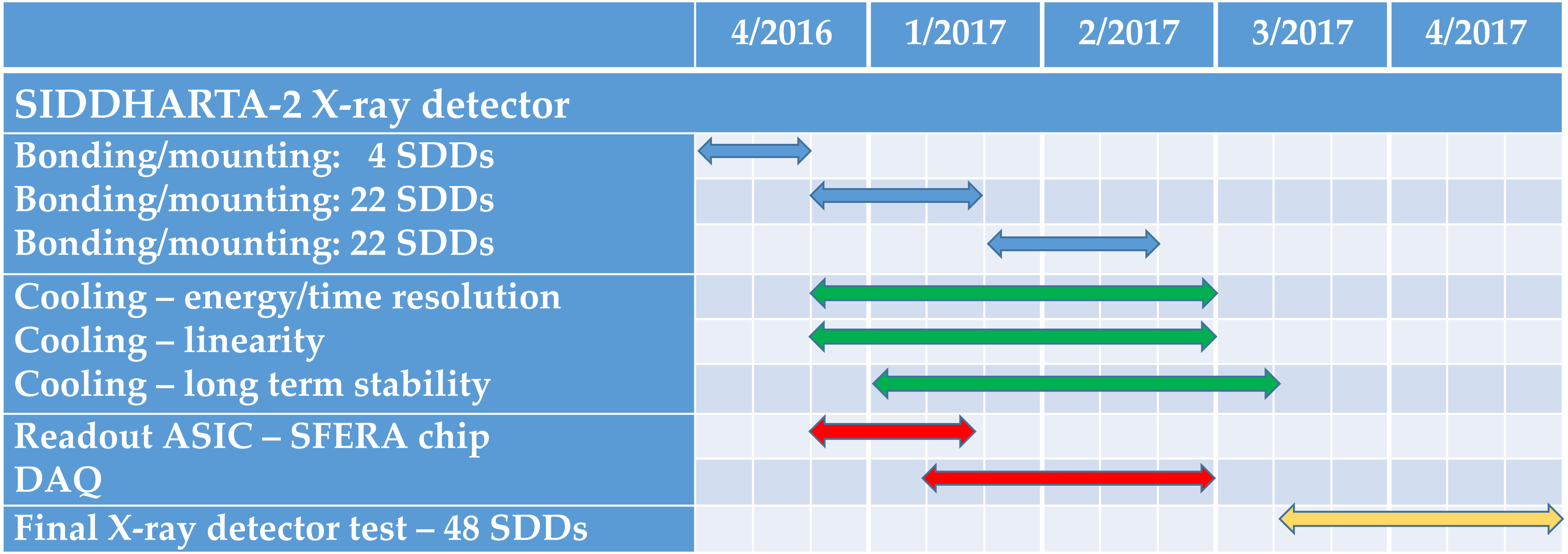
D = number of "diamond" channels (with J_{anode} < 80pA/cm²)

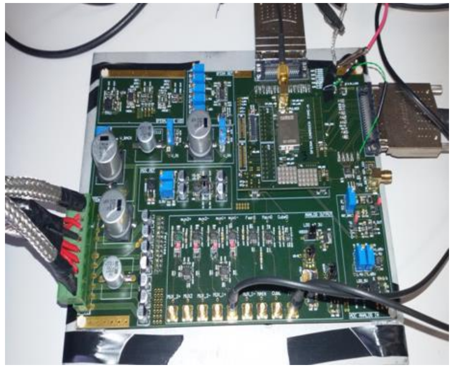
G = number of "gold" channels (with J_{anode} < 250pA/cm²)

S = number of "silver" channels (with J_{anode} < 600pA/cm²)

Table 1: Q-index classification based on anode leakage current density

Gantt chart: SIDDHARTA-2 X-ray detector

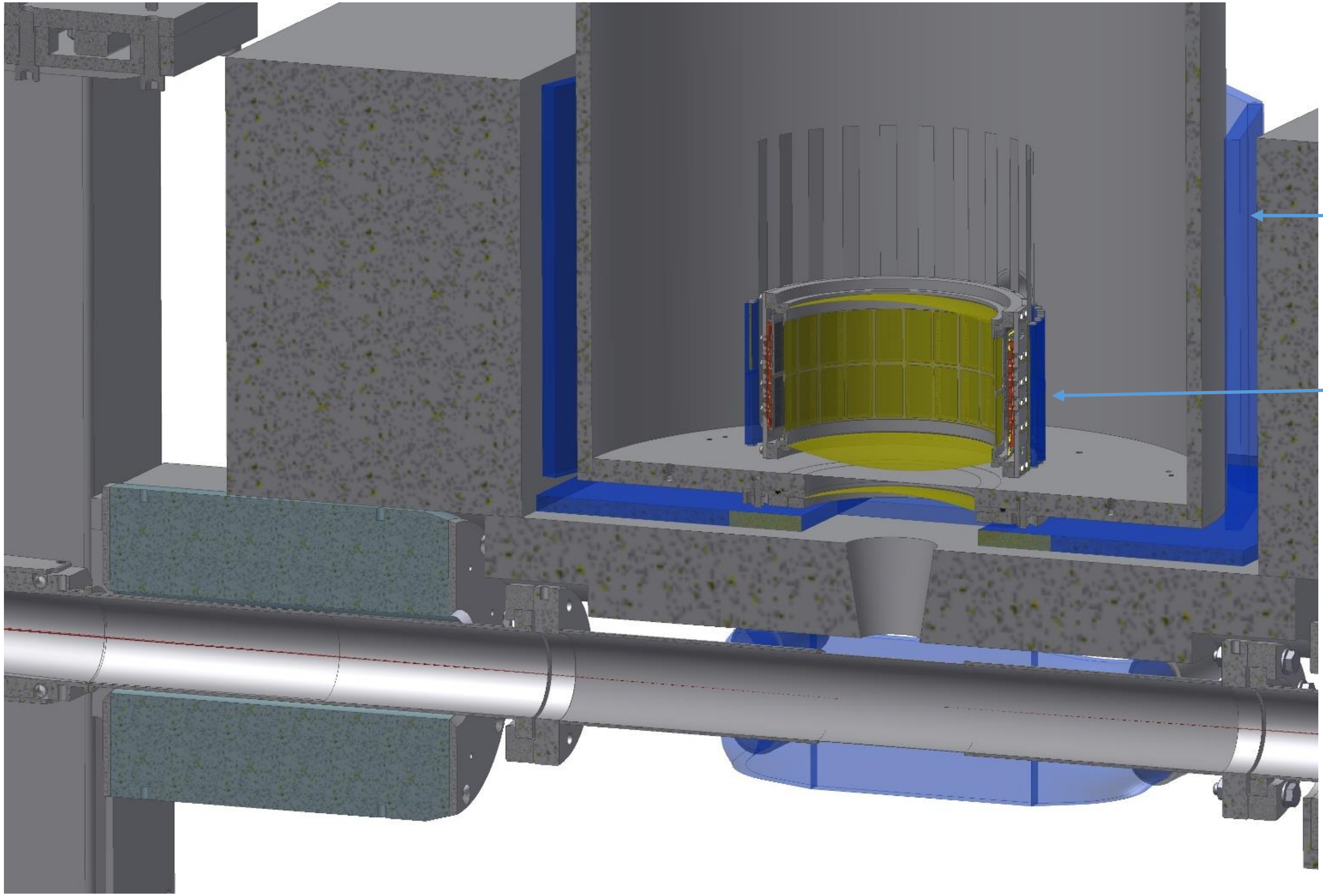




SIDDHARTA-2

- the veto system

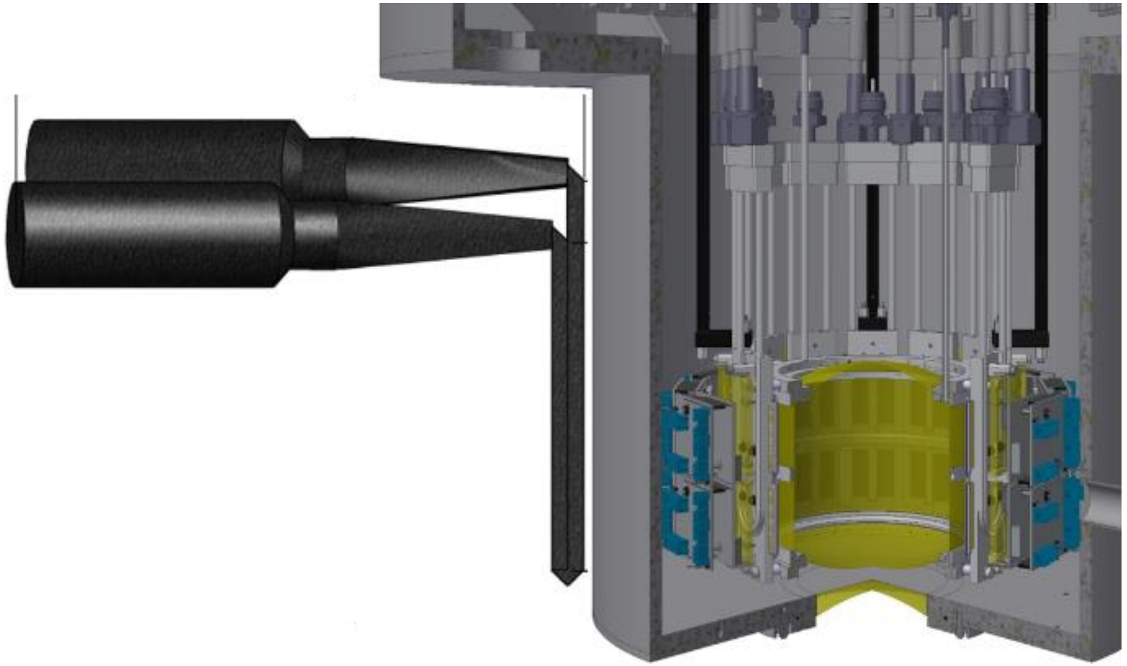
The SIDDHARTA-2 setup – Veto-1 + Veto-2



Veto-1

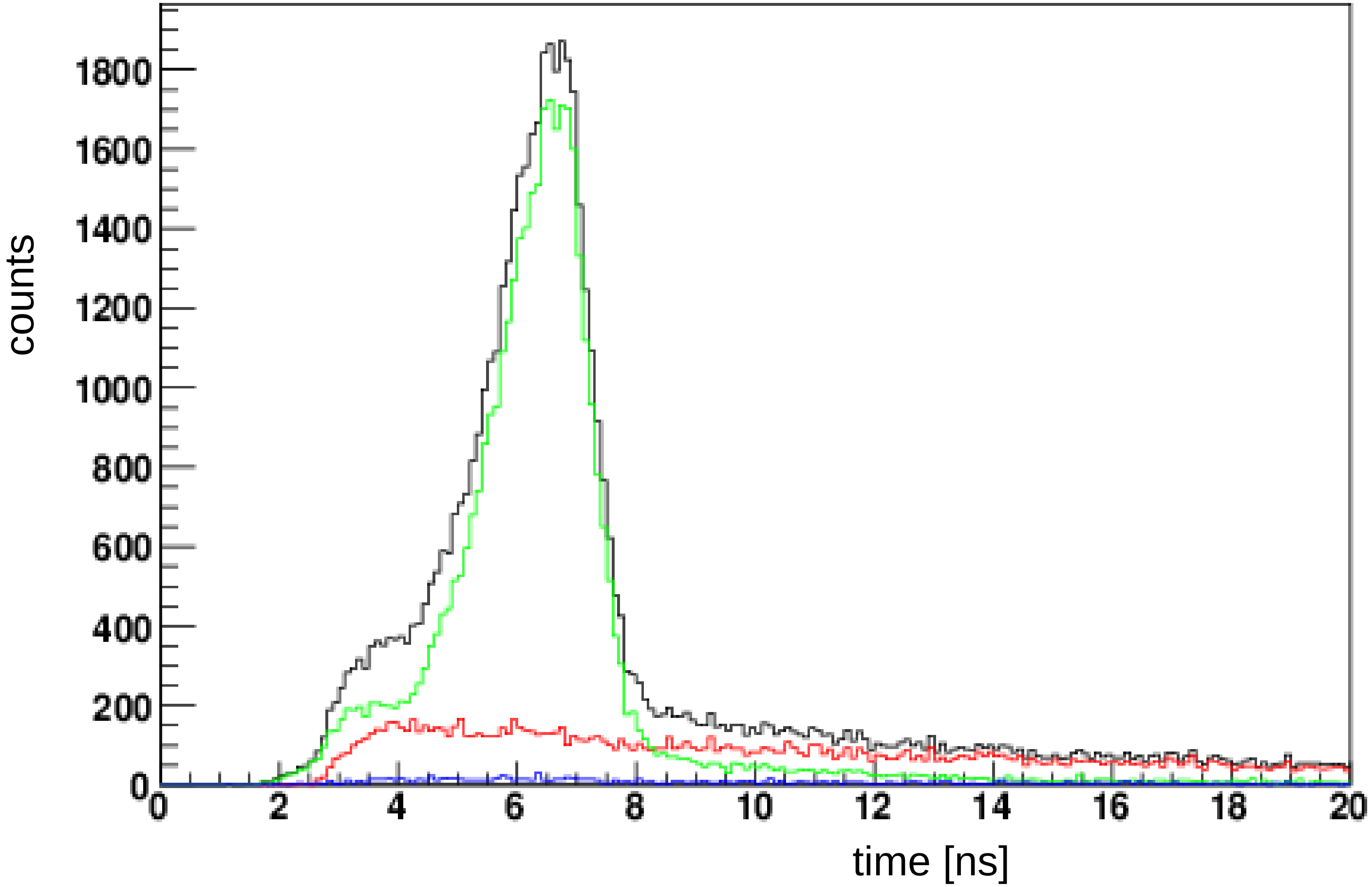
Veto-2

The veto-1 system



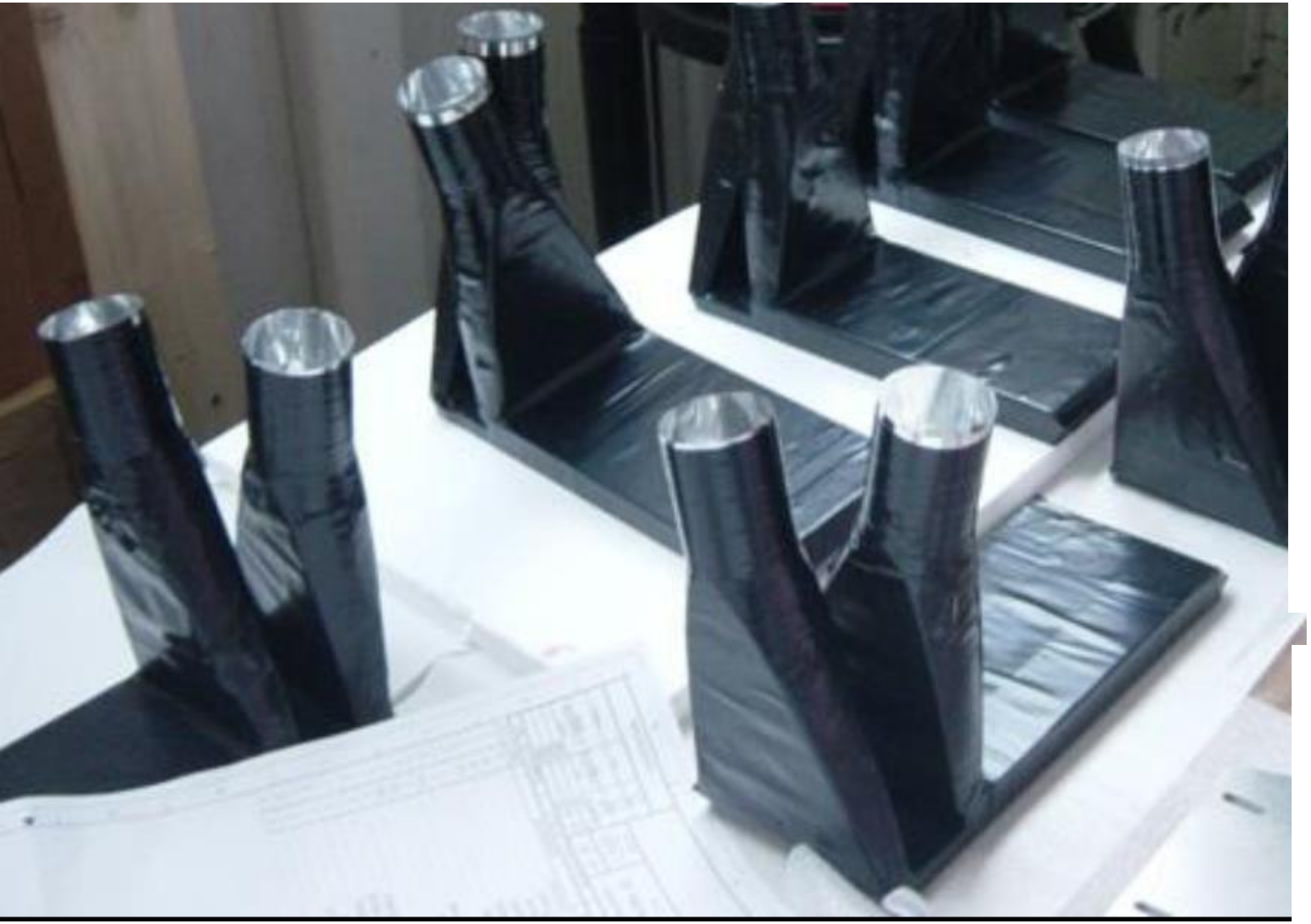
To achieve a good timing resolution, (independent of the "hit" position) < 600 ps (FWHM),the scintillator has to be read out on both side.
Because the available space is limited due to shielding material, the photomultiplier tubes have to be on the same side (a special light-guide mirror design was used).

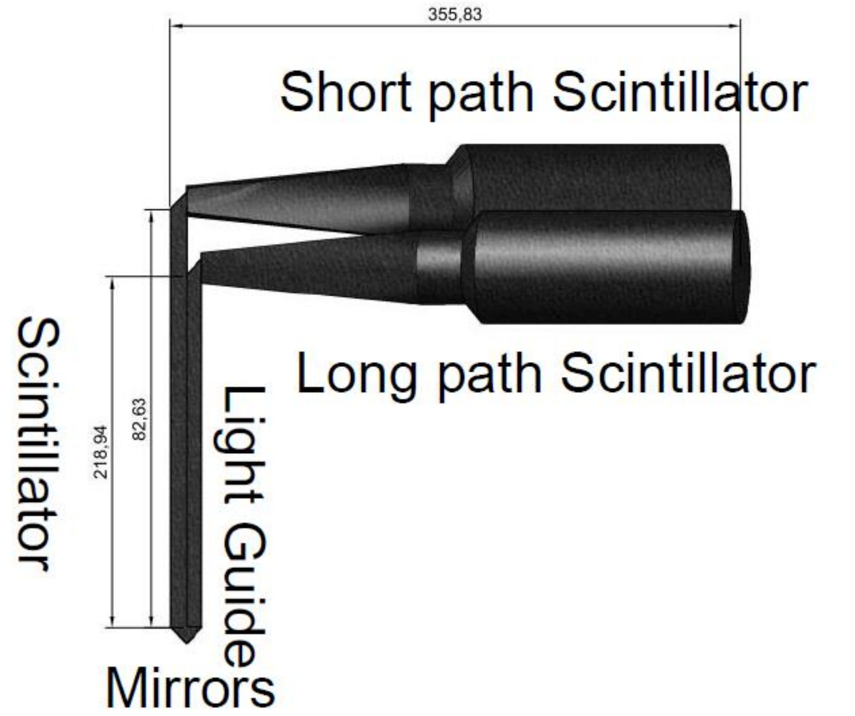
MC simulation veto-1 system



Timing (< ns) of veto-1 scintillators. The peak in green corresponds to particles from K^- absorption on gas nuclei. The red distribution is the time spectrum of events correlated to a K^+; no peak is present because there is no nuclear absorption, the shape follows the K^+ decay. In blue, the bottom kaon detector detects neither a K^+ nor a K^-.

The veto-1 system





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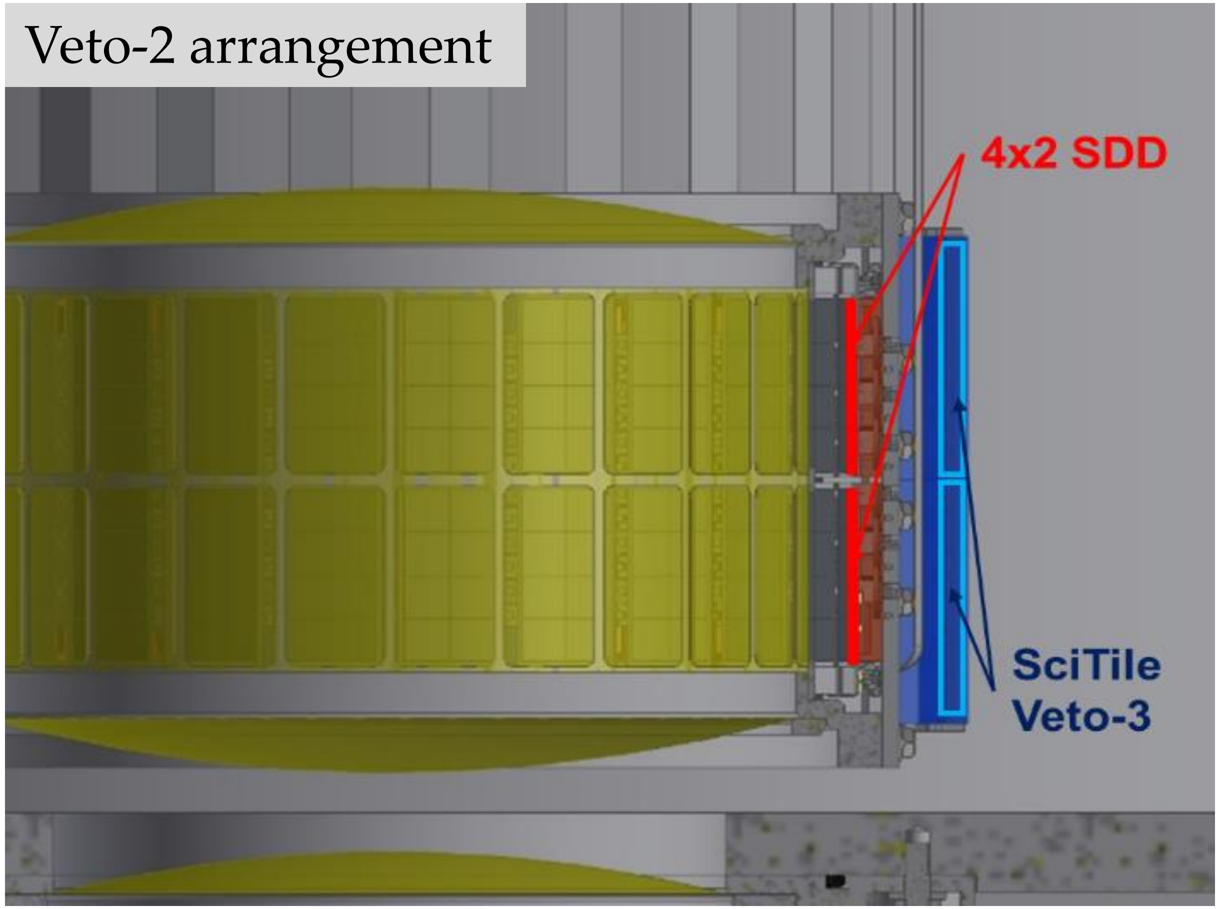
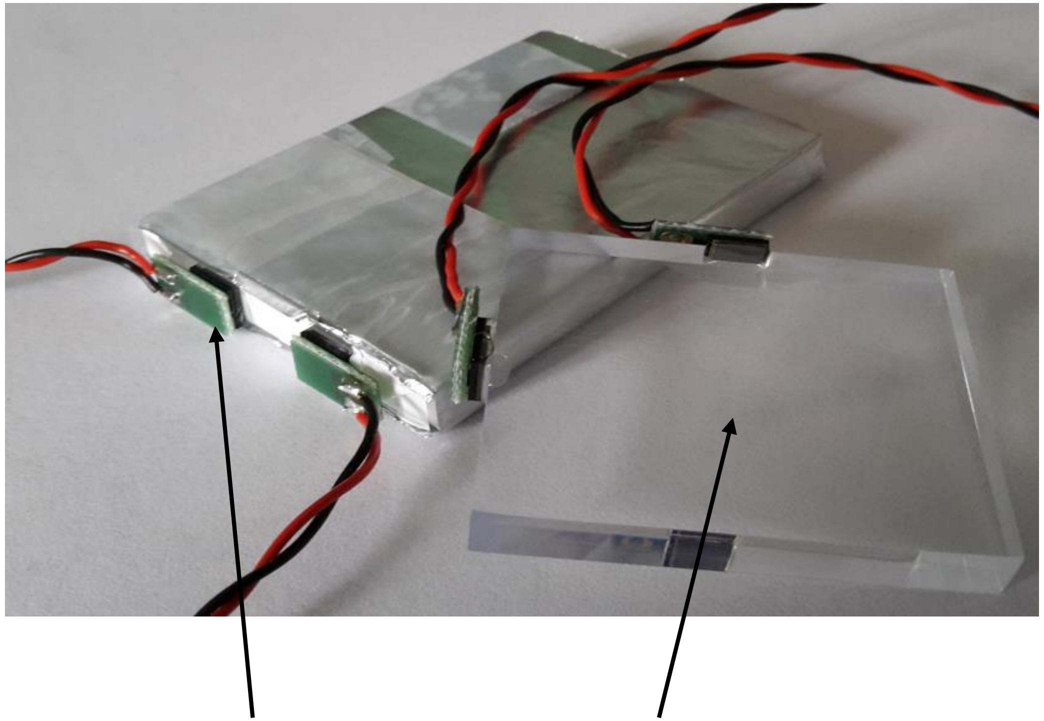
TECHNICAL REPORT

Characterization of the SIDDHARTA-2 second level trigger detector prototype based on scintillators coupled to a prism reflector light guide

The veto-2 system

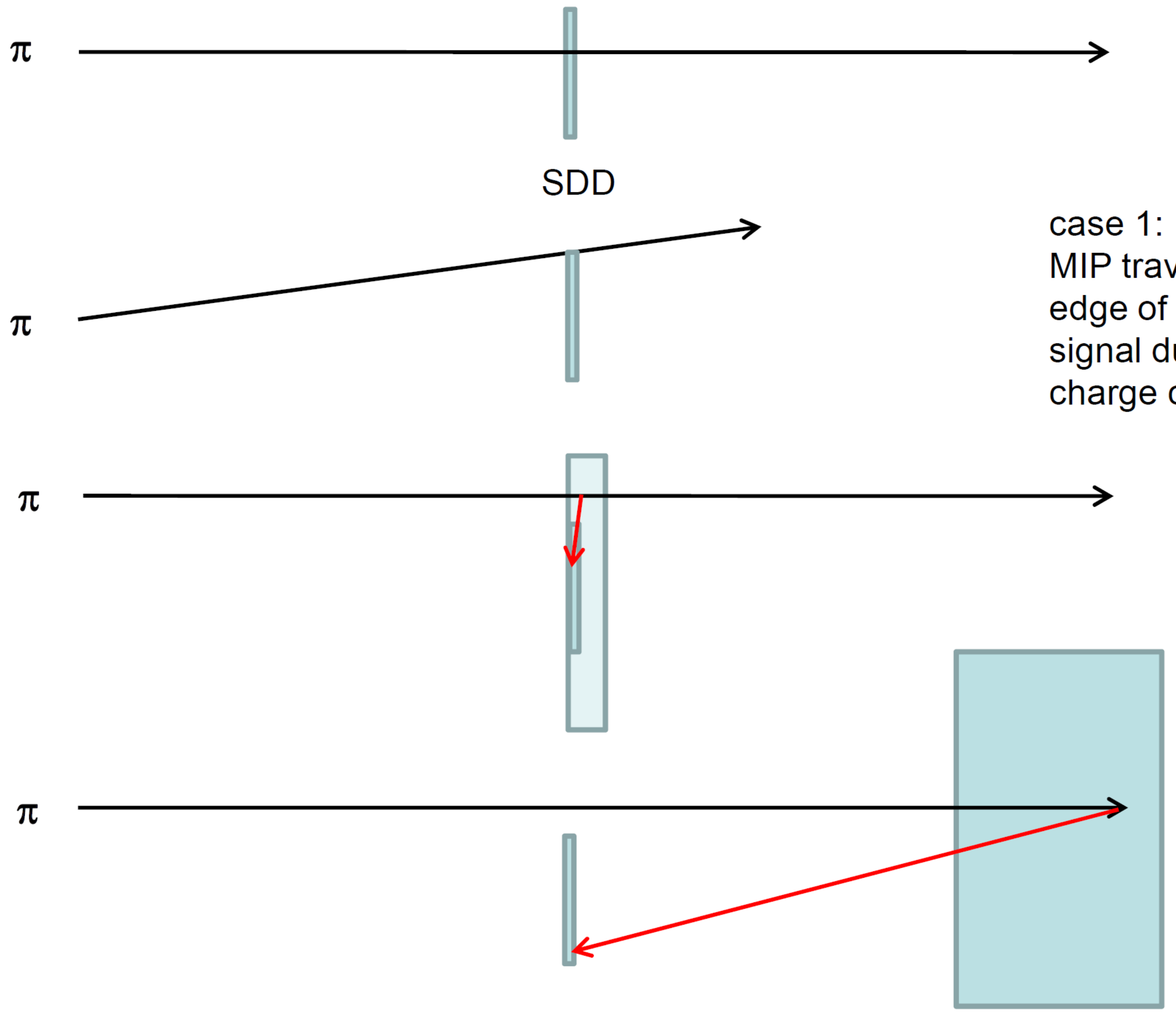




SiPM – 4x4 NUV-Trento

BC-408 scintillator tile

Charged particle veto – veto2



case 0:
MIP traversing SDD in some distance of the edge
=> large signal > 150 keV

case 1:
MIP traversing SDD at the edge of active area.. small signal due to incomplete charge collection

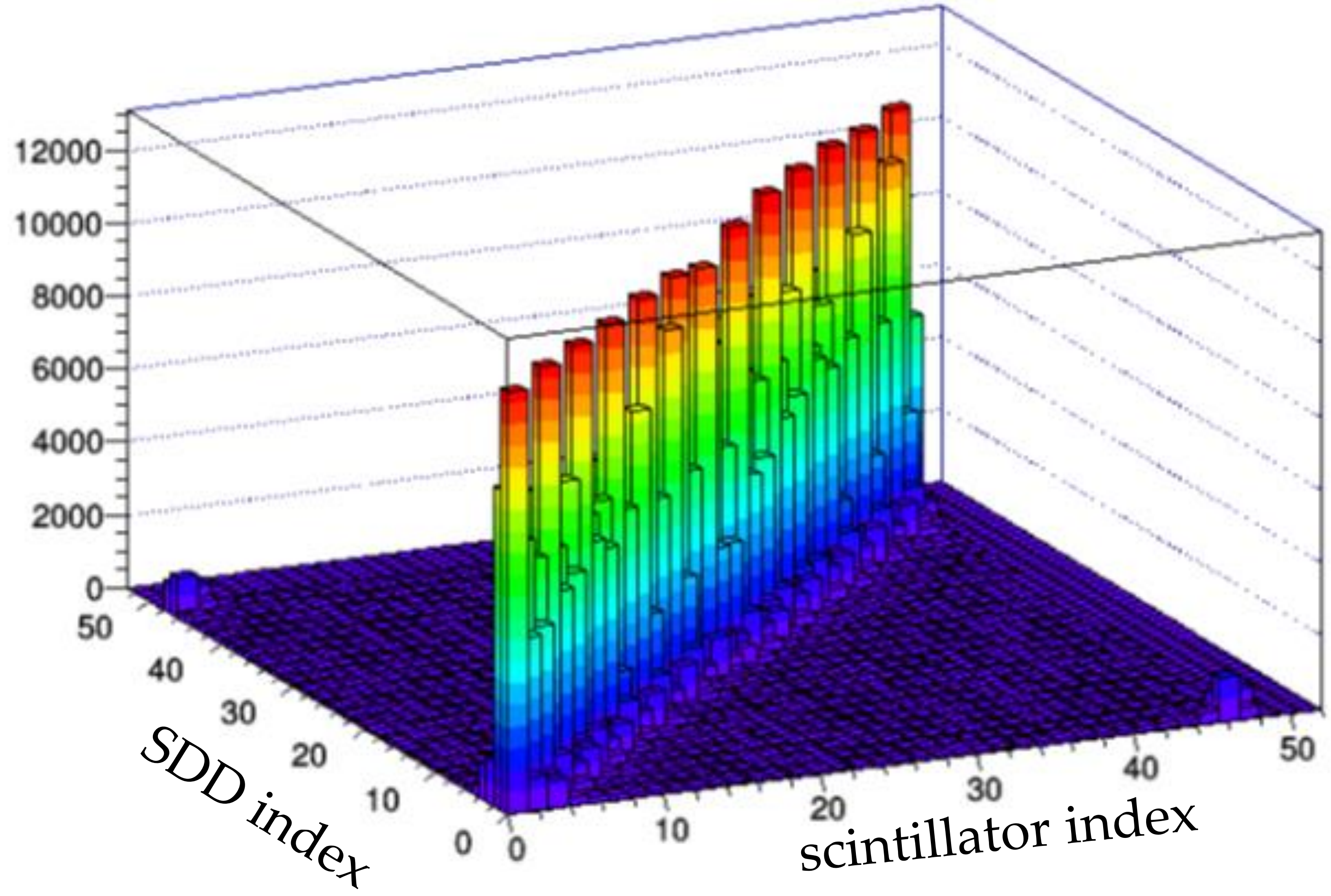
case 2:
„knock on electron“ („delta-ray“) produced nearby

case 3:
X ray or e from a secondary produced somewhere in the setup

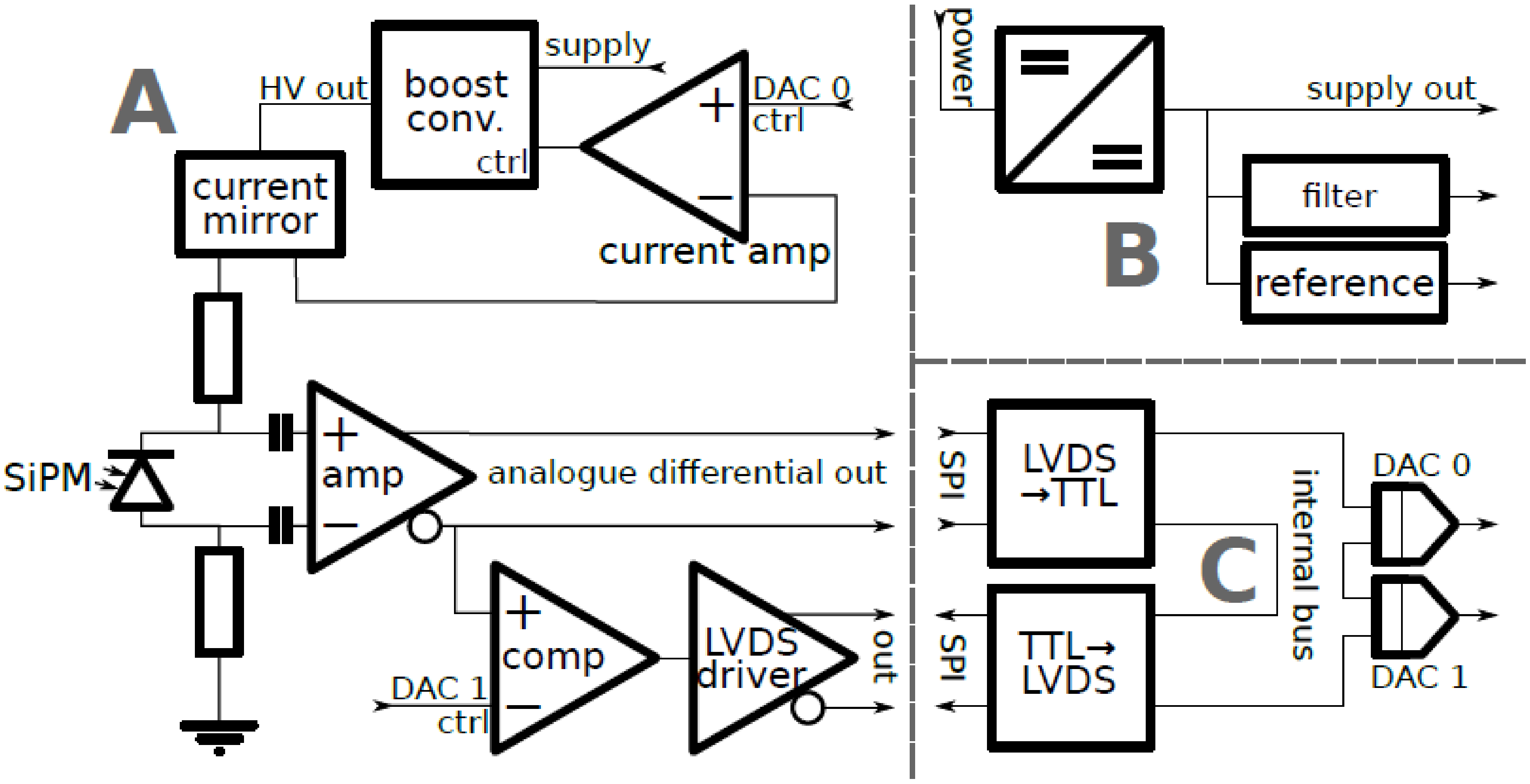
K^-N reaction products	Subsequent decay mode	Finally produced particles	Branching ratio (%)
$\Sigma^+ \pi^-$	$\Sigma^+ \rightarrow \pi^0\ p;\ \ \pi^0 \rightarrow 2\gamma$	$\pi^-\ 2\gamma\ p$	11.1
$\Sigma^+ \pi^-$	$\Sigma^+ \rightarrow \pi^+\ n$	$\pi^- \pi^+\ n$	11.1
$\Sigma^- \pi^+$	$\Sigma^- \rightarrow \pi^-\ n$	$\pi^- \pi^+\ n$	10.0
$\Sigma^0 \pi^0$	$\Sigma^0 \rightarrow \Lambda\ \gamma;\ \ \Lambda \rightarrow \pi^-\ p$	$\pi^-\ 3\gamma\ p$	7.6
$\Sigma^0 \pi^0$	$\Sigma^0 \rightarrow \Lambda\ \gamma;\ \ \Lambda \rightarrow \pi^0\ n;\ \ \pi^0 \rightarrow 2\gamma$	$5\gamma\ n$	7.6
$\Lambda \pi^-$	$\Lambda \rightarrow \pi^-\ p$	$2\pi^-\ p$	14.2
$\Lambda \pi^-$	$\Lambda \rightarrow \pi^0\ n;\ \ \pi^0 \rightarrow 2\gamma,\ \pi^0 \rightarrow 2\gamma$	$\pi^-\ 4\gamma\ n$	14.2
$\Sigma^0 \pi^-$	$\Sigma^0 \rightarrow \Lambda\ \gamma;\ \ \Lambda \rightarrow \pi^-\ p$	$2\pi^-\ p$	5.4
$\Sigma^0 \pi^-$	$\Sigma^0 \rightarrow \Lambda\ \gamma;\ \ \Lambda \rightarrow \pi^0\ n$	$\pi^-\ 2\gamma\ n$	5.4
$\Sigma^- \pi^0$	$\Sigma^- \rightarrow \pi^-\ n$	$\pi^-\ 2\gamma\ n$	10.8

K^- decay	Branching ratio (%)
$\mu^- \nu_\mu$	63.5
$\pi^- \pi^0$	21.2
$\pi^-\ \pi^{-+} \pi^0$	5.6
$\pi^0 e^- \nu_e$	4.8
$\pi^0 \mu^- \nu_\mu$	3.2

MC simulation: Correlation between SDDs and back-mounted scintillators for charged particles



SIPM read-out: Intelligent front-end electronics for silicon photo detectors - IFES

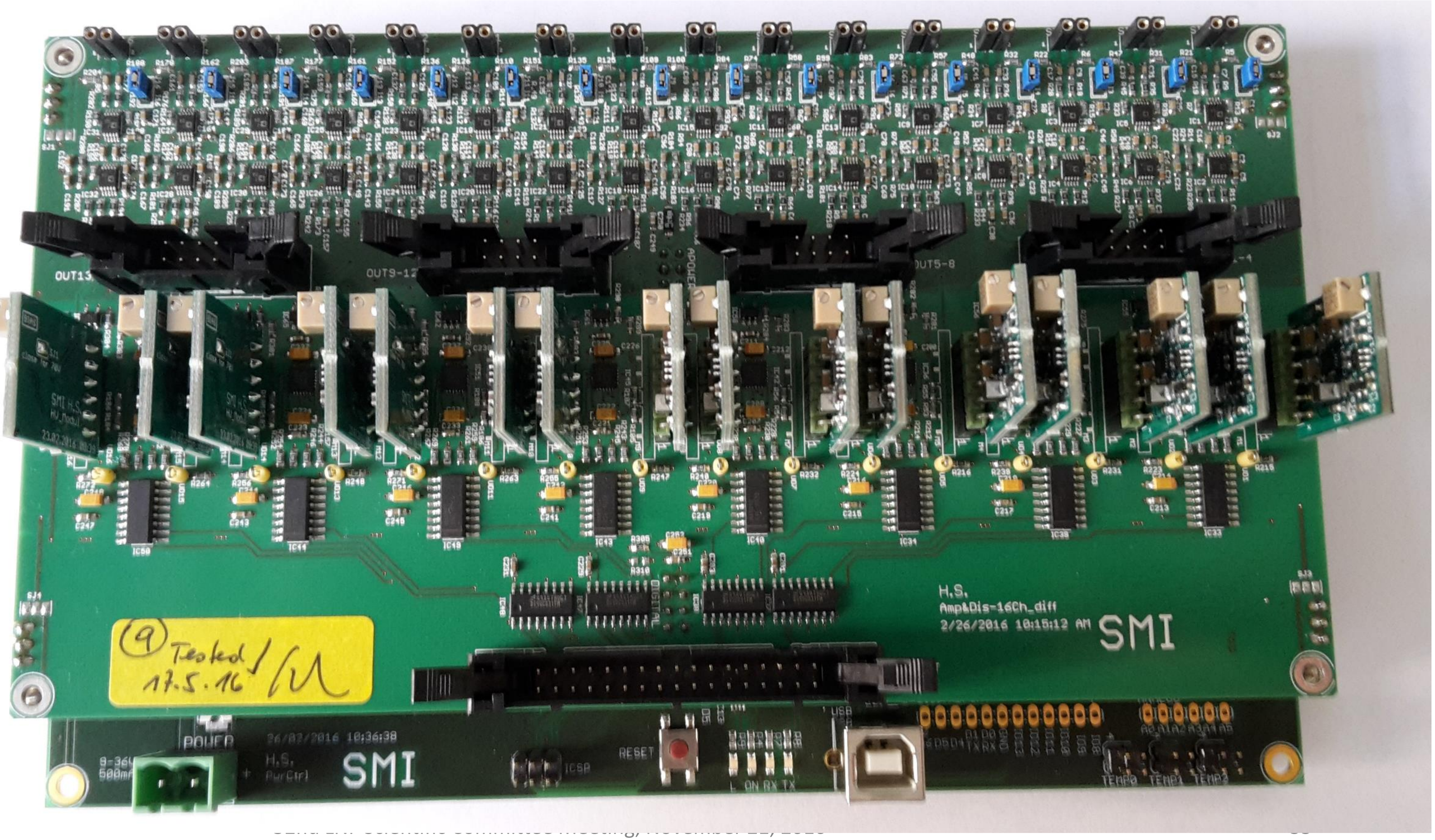


SiPM read-out: the IFES board

Analogue differential out

Bias voltage boards

LVDS digital ToT output

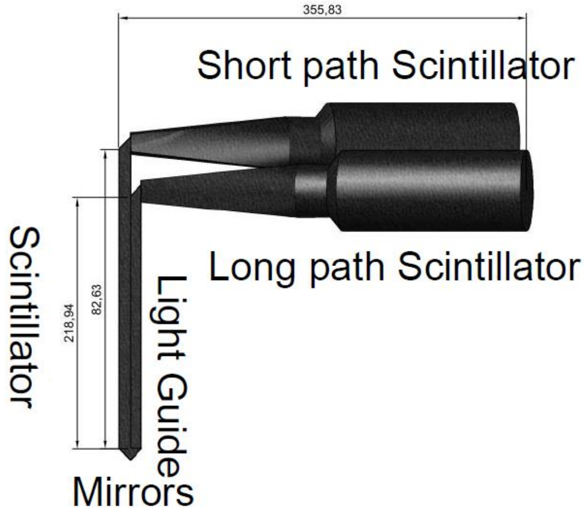


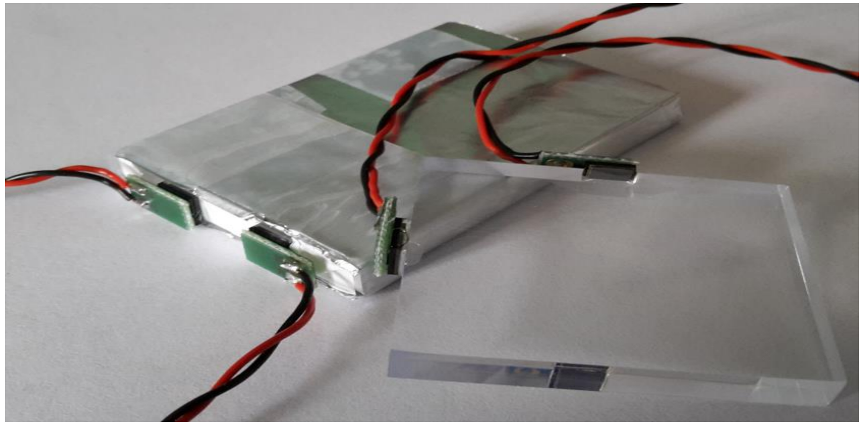
Veto-1 and veto-2 are an essential part of the SIDDHARTA-2 apparatus. A signal to background enhancement by a factor ~ 3 will be achieved.

Veto-1 also will be used to optimize the kaons stopping distribution inside the target.

Gantt chart: SIDDHARTA-2 veto systems

	4/2016	1/2017	2/2017	3/2017	4/2017
SIDDHARTA-2 veto systems					
Veto-1 – final tests					
Veto-2 – construction phase					
Veto-2 – final tests					
Kaon trigger - construction					
Kaon trigger – final tests					





SIDDHARTA-2

- A new dedicated Al-beam pipe with carbon fibre reinforcement
- Luminosity monitor (Luminometer)

DAΦNE – SIDDHARTA-2 + KLOE-2 meetings

- installation of the SIDDHARTA-2 in the actual KLOE region (same as SIDDHARTA)

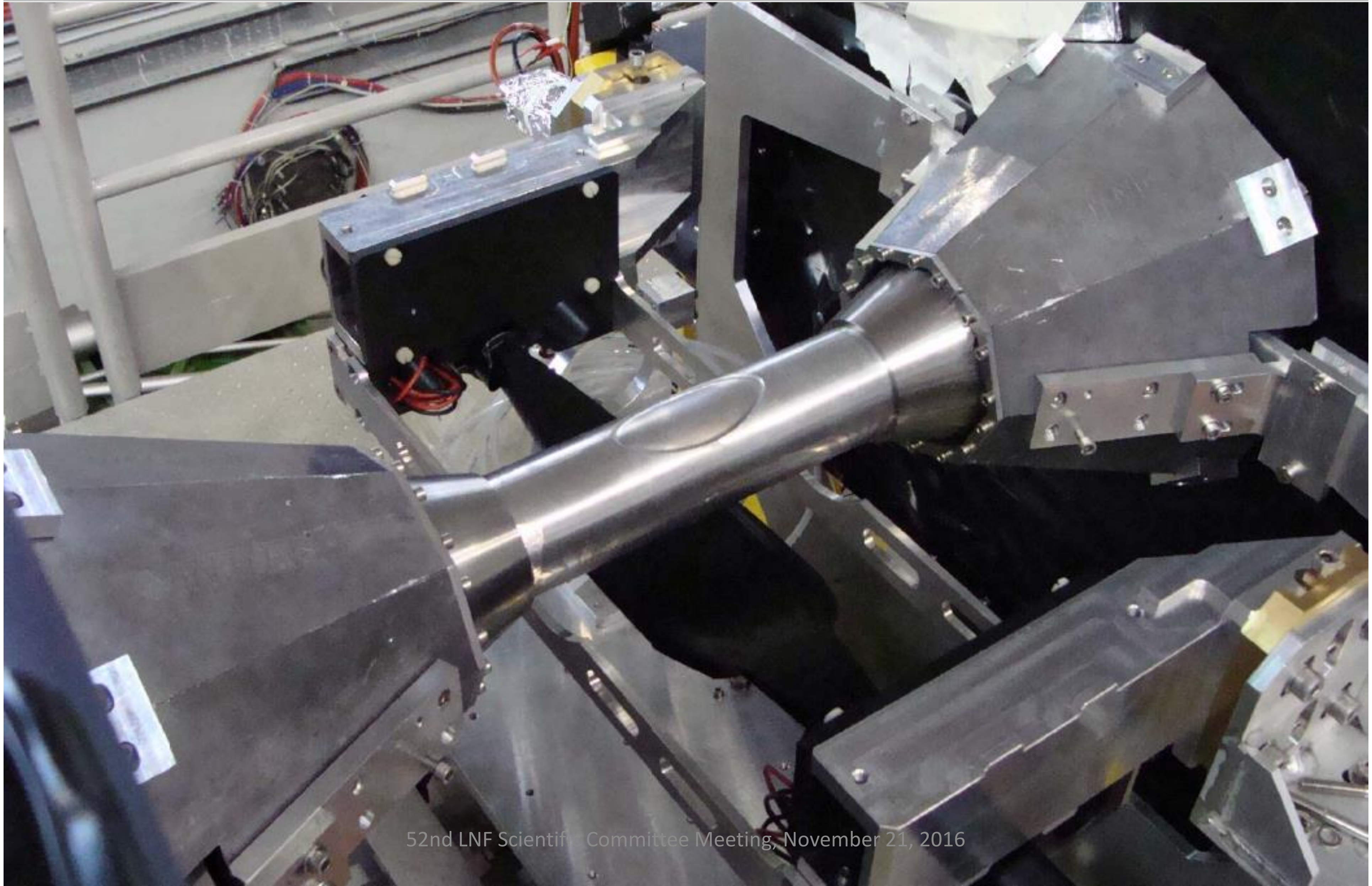
- DAFNE team checked the existence of beam pipe elements and of the platform of SIDDHARTA – done (OK)

- beam pipe: a new Al-beam pipe (with carbon fibre) necessary

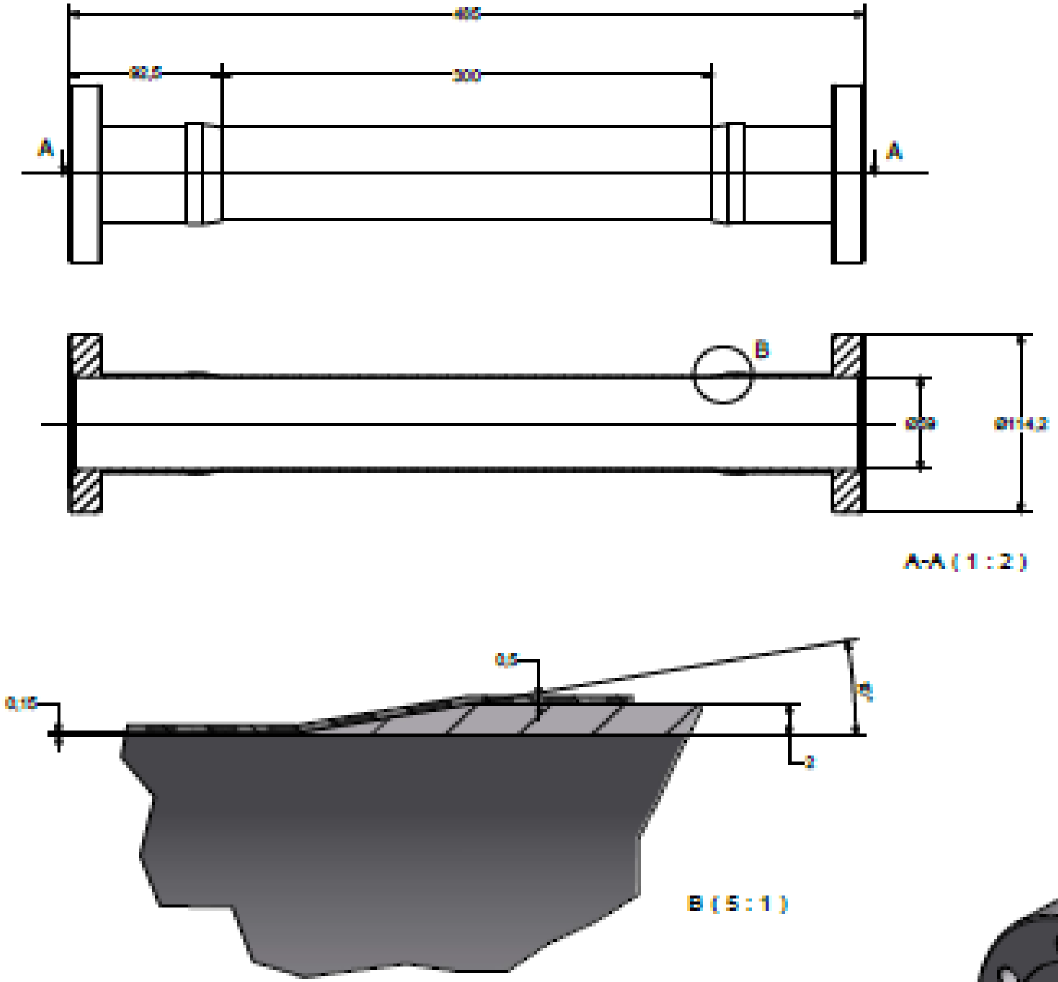
- Luminometer necessary

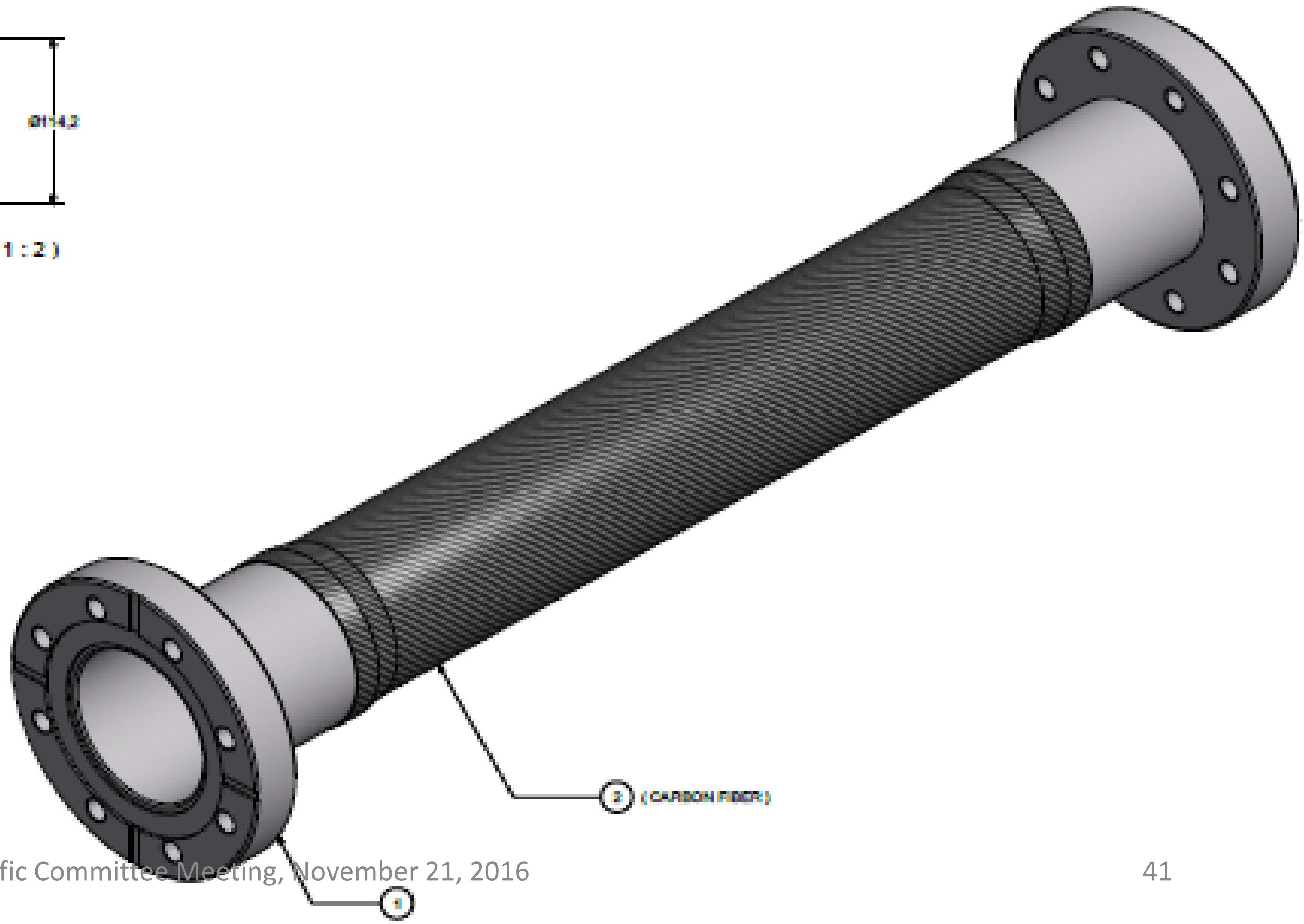
- study feasibility of rolling out KLOE2 as a block – new quadrupole magnets

SIDDHARTA interaction region

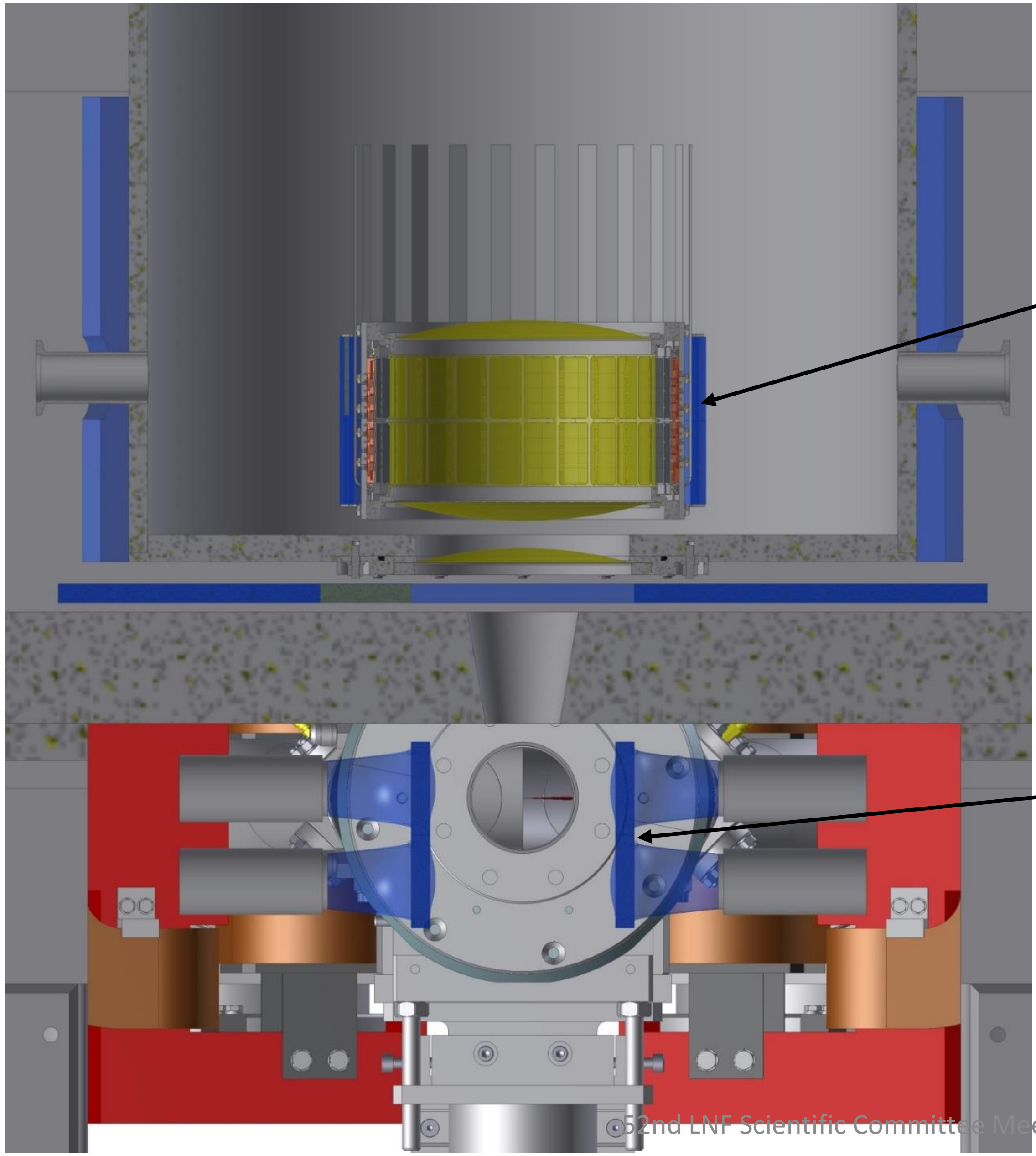


SIDDHARTA-2 beam pipe financed by INFN





SIDDHARTA-2 - Luminosity monitor



Cryo-target surrounded by SDDs with veto-2

Luminosity monitor "Luminometer"

SIDDHARTA-2 - Luminosity monitor (based on kaons)

Size: 8 x 8 cm^2 both side of the beam pipe
distance $y = \pm 4$ cm off beam
made of 2 pieces 8 x 4 cm^2

- **Coincidence rate: 25.7 % per charged kaon pair**
  single rate at the boost-side: 42.7 %
  single rate at the antiboost-side: 32.3 %

$L = 10^{32} \rightarrow$ 37 Hz (coincidence) / 62 Hz on boost-side

5 seconds:

185 counts (7%) / 310 counts (5.7%)

DEAR experiment – proof of luminometer concept:

In summary, the configuration selected for the Kaon Monitor consists of two fast NE104 scintillator slabs, each 2 mm thick. Both scintillators are 8 cm high (y-axis) and 15 cm long (z-axis) and are placed back-to-back at IP2, on the two sides of the beam pipe, with the longest side parallel to it and are referred as the "inner" and the "outer" scintillator with respect to the center of the machine. The slabs are perpendicular to the

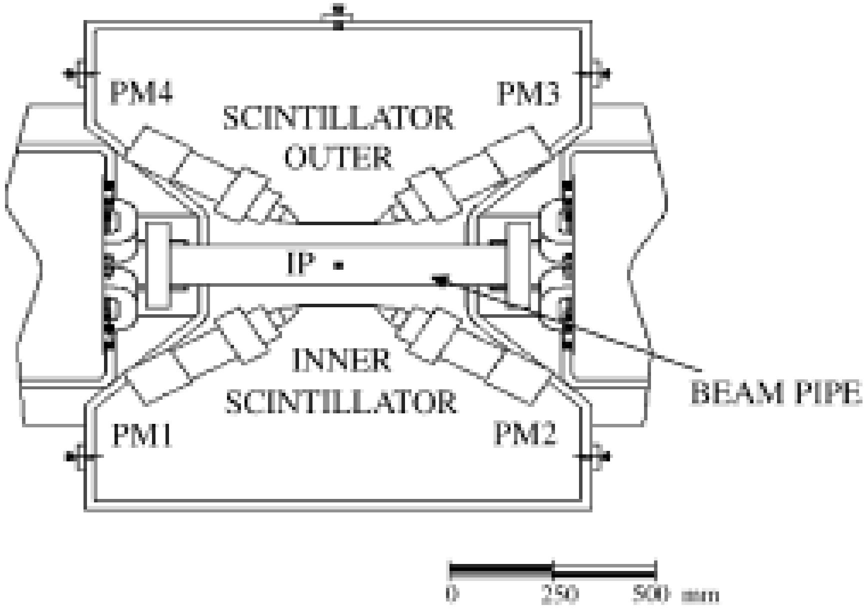


Fig. 1. The Kaon Monitor experimental setup in the DEAR region at the DAΦNE interaction point (IP).

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
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The DEAR Kaon Monitor at DAΦNE

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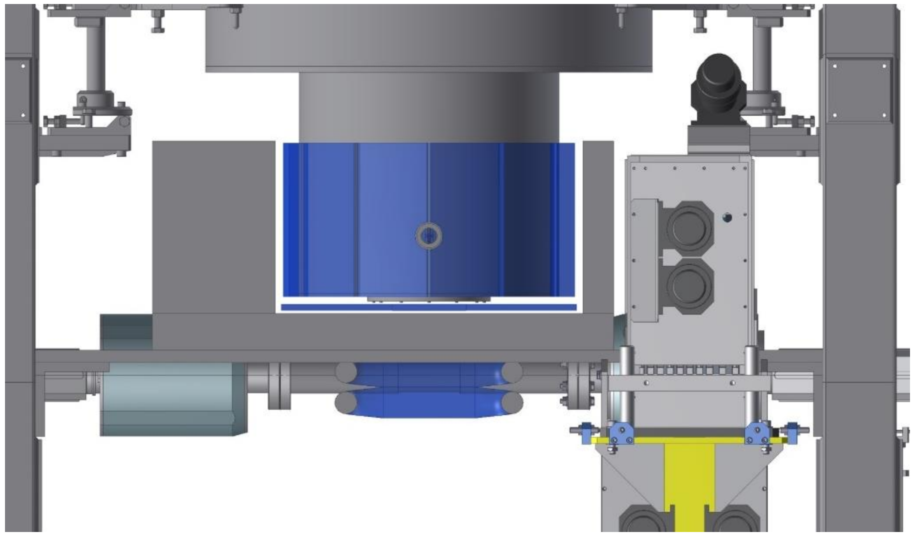
F. Sirghi[a], J. Zmeskal[e]

Gantt chart: SIDDHARTA-2 beam pipe + luminosity monitor

	4/2016	1/2017	2/2017	3/2017	4/2017
SIDDHARTA-2 beam pipe + luminosity monitor					
Beam pipe – final design	↔				
Beam pipe – construction	↔	↔			
Beam pipe – final tests			↔		
Luminosity monitor – construction		↔			
Luminosity monitor – final tests			↔		

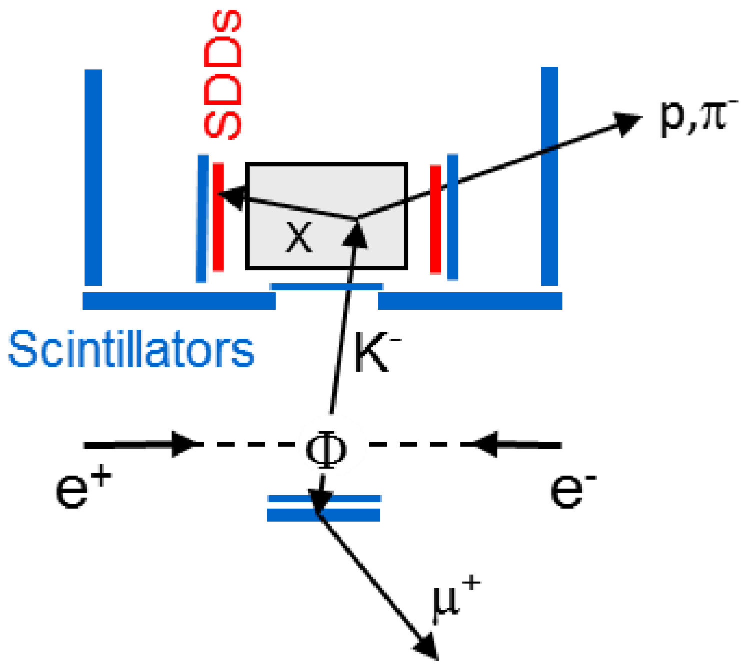


SIDDHARTA-2

- Geant4 MC simulation

MC simulation – SIDDHARTA-2

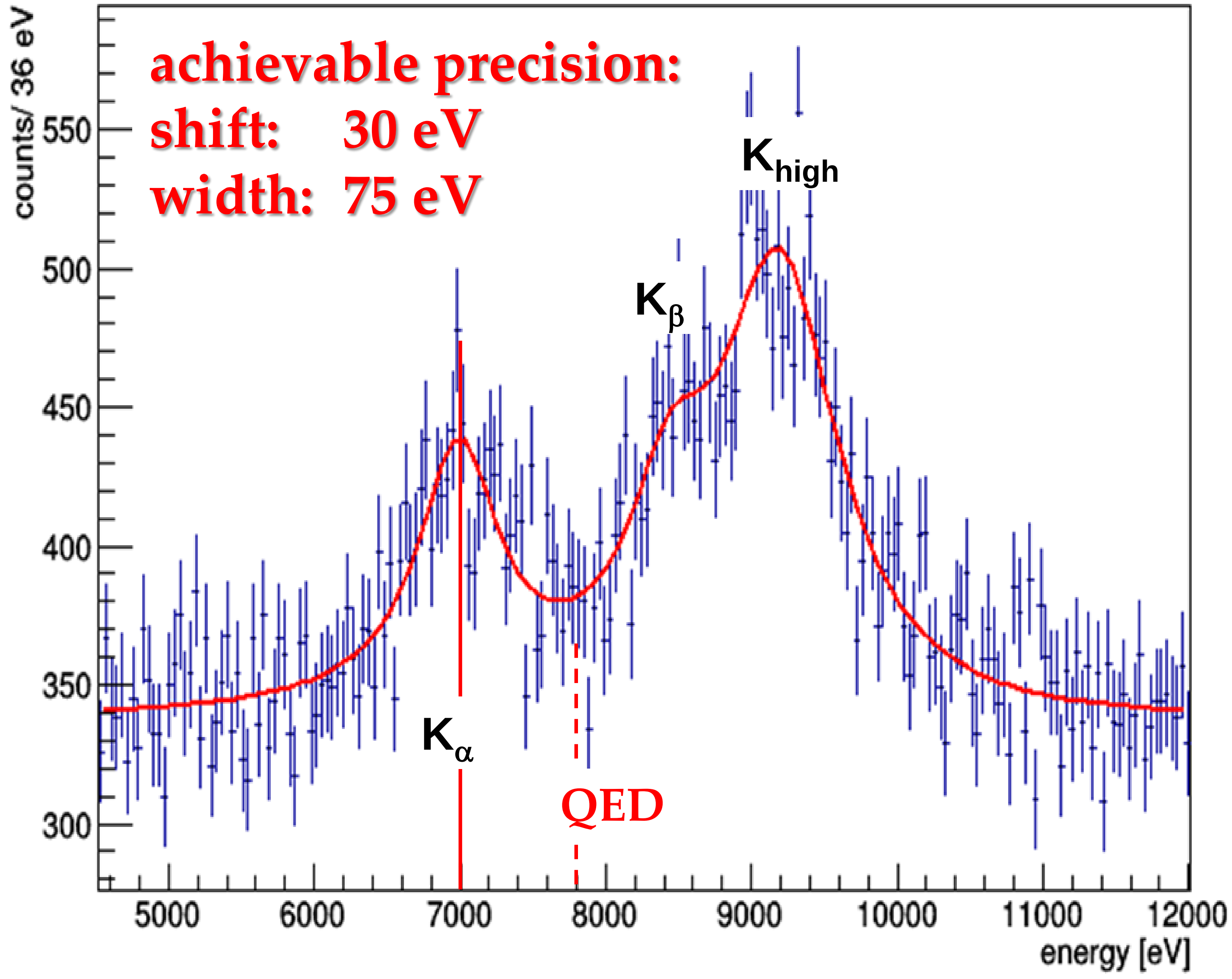
The following main improvements are included in the final GEANT 4 simulation for the SIDDHARTA-2 experiment at DAΦNE, LNF-INFN:



- 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)

	Signal to background	Kα events
SIDDHARTA	1:100	1280
from SIDDHARTA to SIDDHARTA-2		
Improved setup: Cryogenic target new SDDs	1:18	5210
Trigger 1	1:12	3865
Veto-1	1:8.5	3074
Veto-2	1:4.4	2686
K+ discrimination	1:3.1	2664
Drift time 400 ns	1:3.0	2664
SIDDHARTA-2 final Monte Carlo results		
SIDDHARTA-2	1:3.0	2664

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

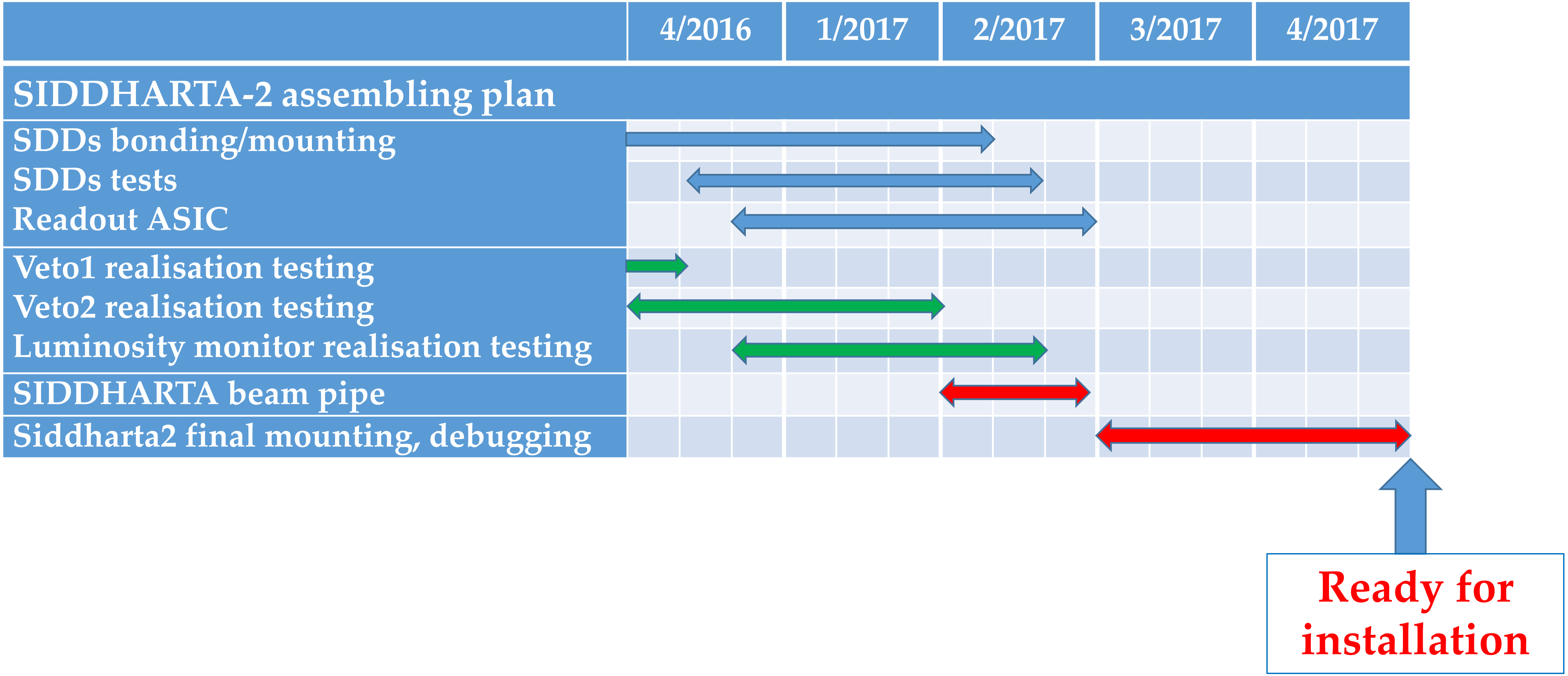
Kα yield: 0.1 %
yield ratio as in K⁻p
S/B ~ 1 : 3

- charged particle veto
- asynchronous BG

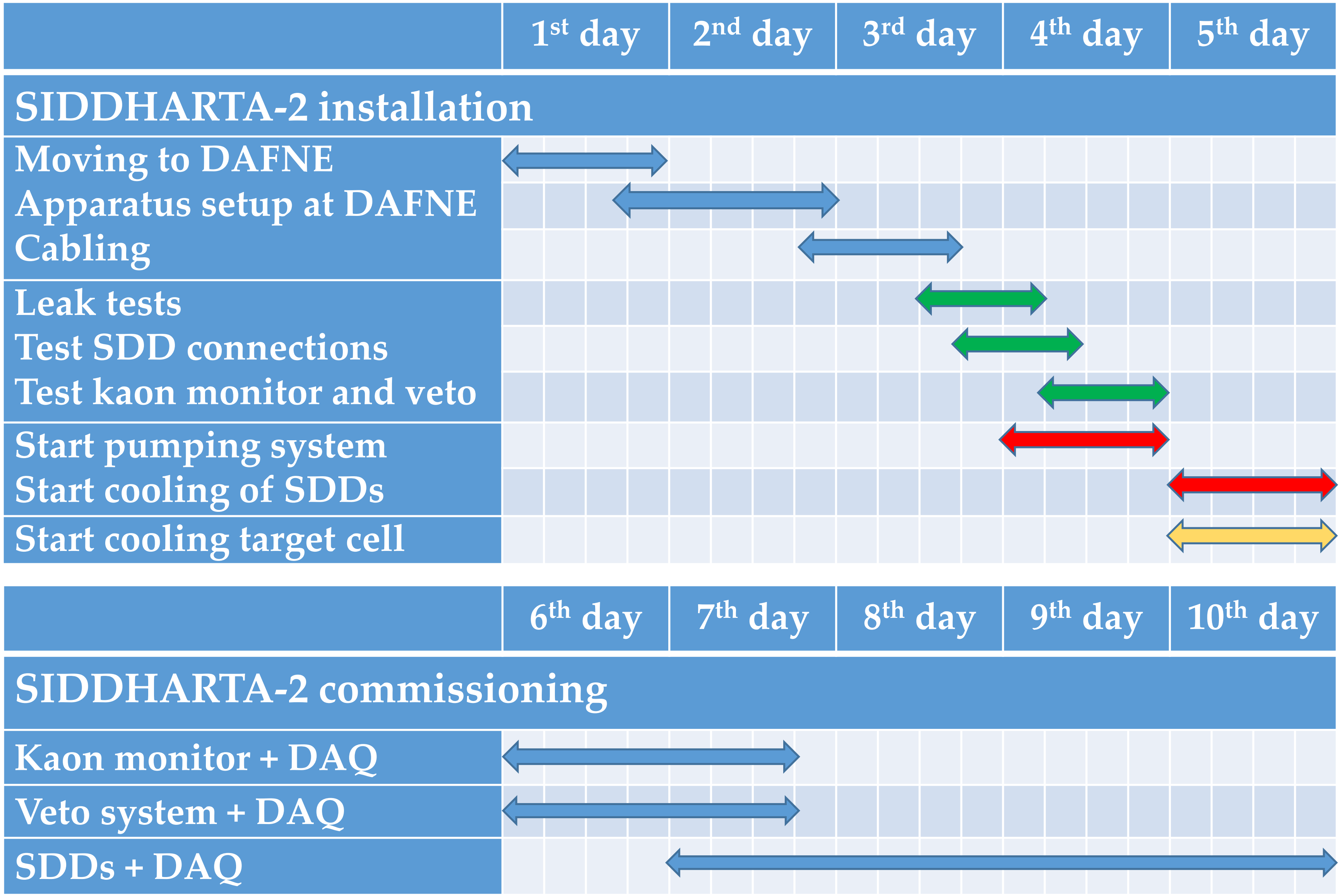
SIDDHARTA-2

- Assembling plan
- Installation at DAΦNE
- Beam time request

Gantt chart: SIDDHARTA-2 assembling

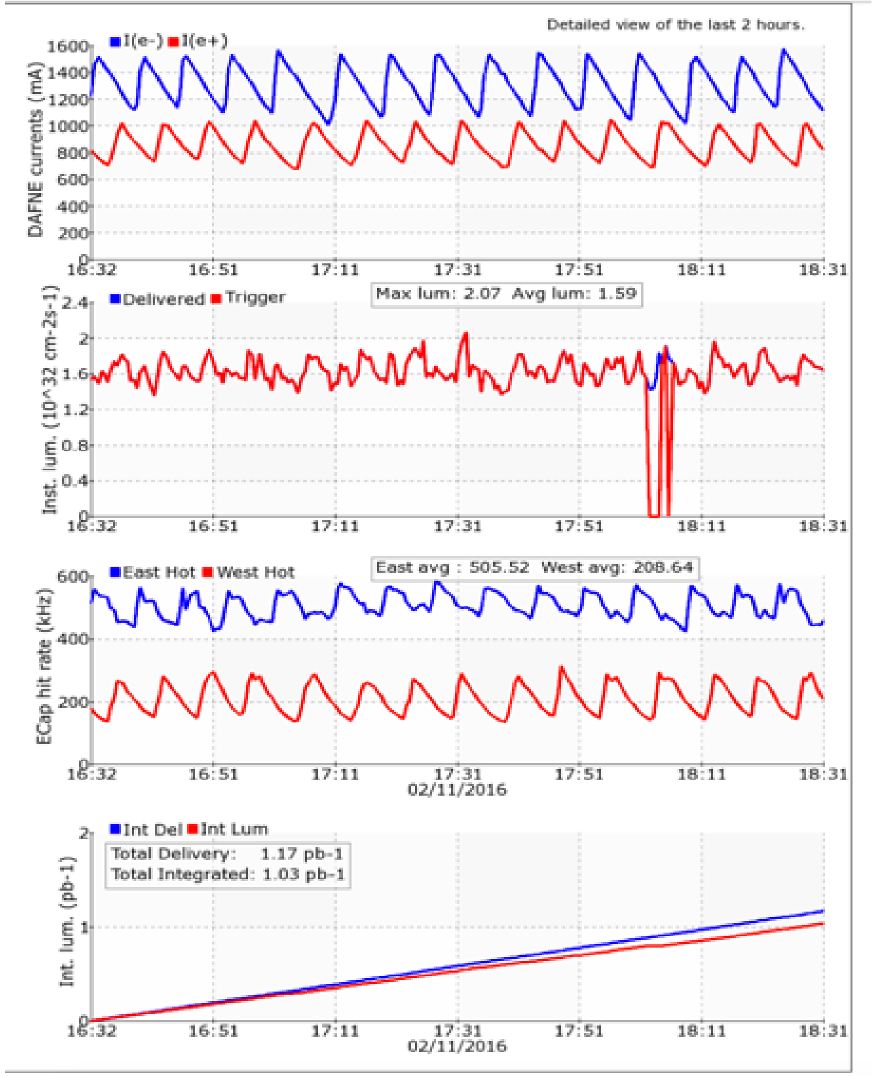


Gantt chart: SIDDHARTA-2 installation at DAΦNE



SIDDHARTA-2 on DAΦNE

DAΦNE two hours luminosity plot



The new SDD X-ray detector system will allow to run in "topping up" mode (*)

- **80% duty cycle (0.4 pb^{-1}/h)**
- Possible due to CUBE preamplifier technology

(*) if background conditions are similar to the SIDDHARTA ones

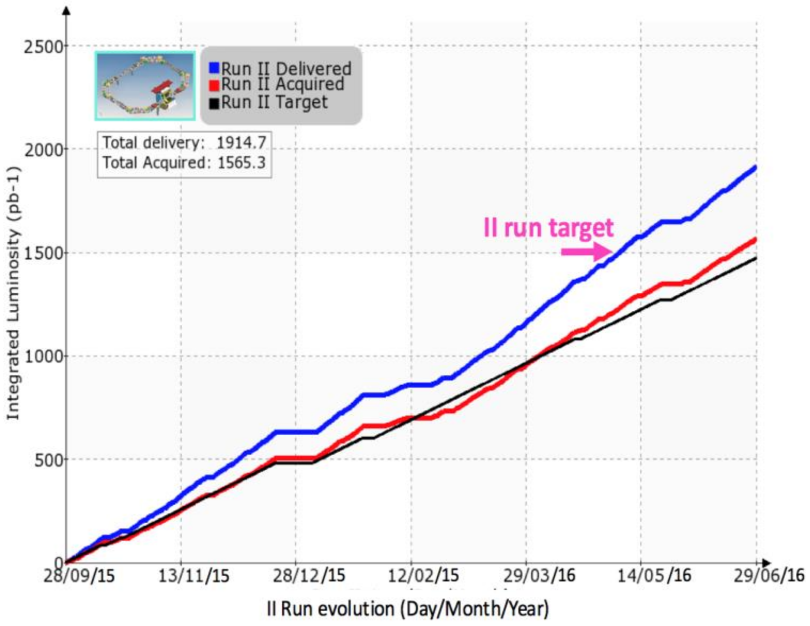
SIDDHARTA-2 requests

200 pb^{-1},   to optimize the SIDDHARTA-2 apparatus

800 pb^{-1}, to perform the first measurement of the strong interaction induced

- energy shift and the width - for the konic deuterium ground state, which is a fundamental measurement in low-energy strangeness physics (QCD).

In running conditions similar to KLOE2 that means about 8 months of data taking (starting after machine optimization)



Financial support for SIDDHARTA-2 key-persons!

SIDDHARTA-2 future perspectives

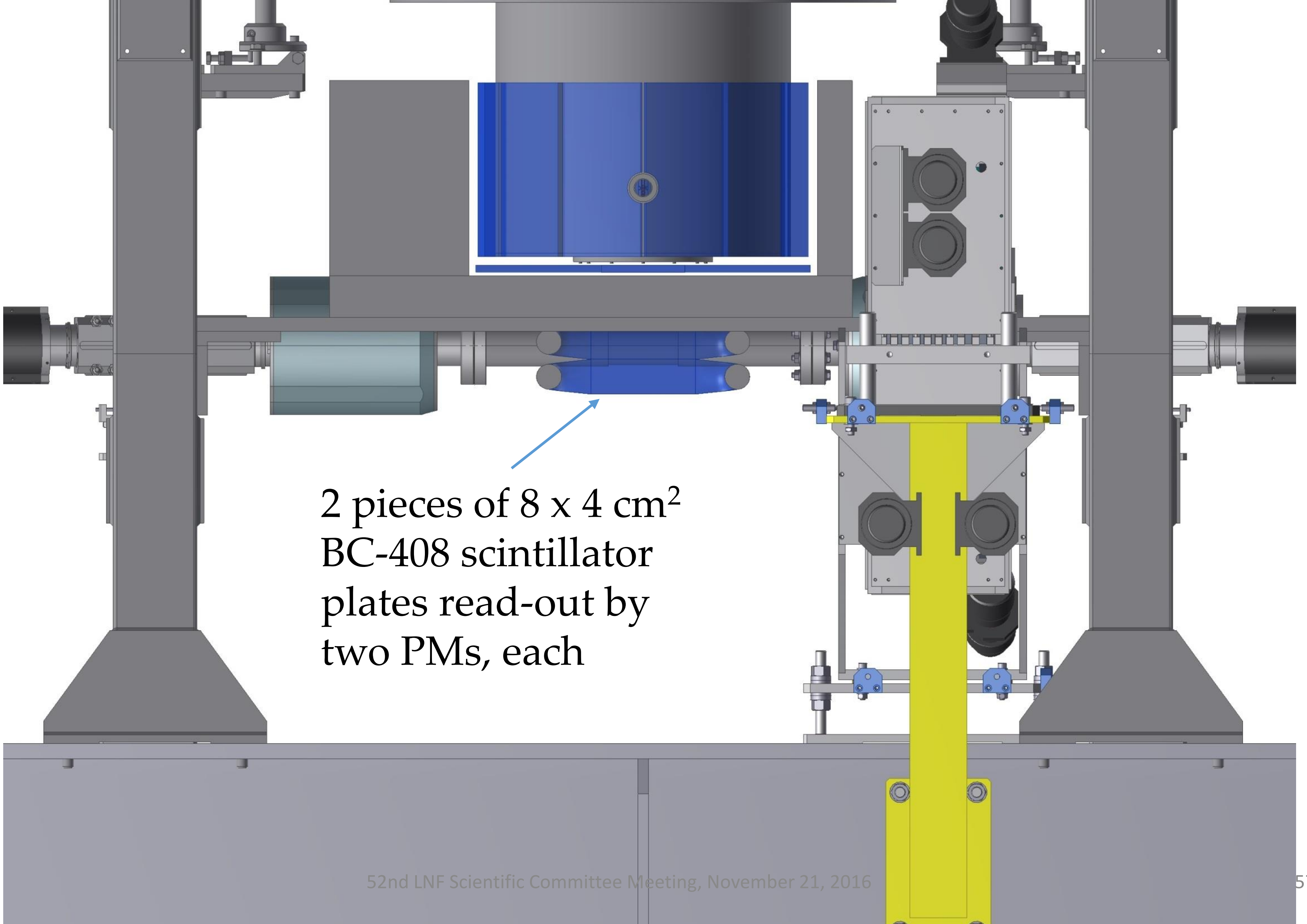
- **Kaonic helium transitions to the 1s level**
- **Kaon mass - precision measurement at the level < 7 keV**

- **Other light kaonic atoms (K^-O, K^-C,…)**
- **Heavier kaonic atoms (K^-Si, K^-Pb…)**
- **Radiative kaon capture – Λ(1405) study**

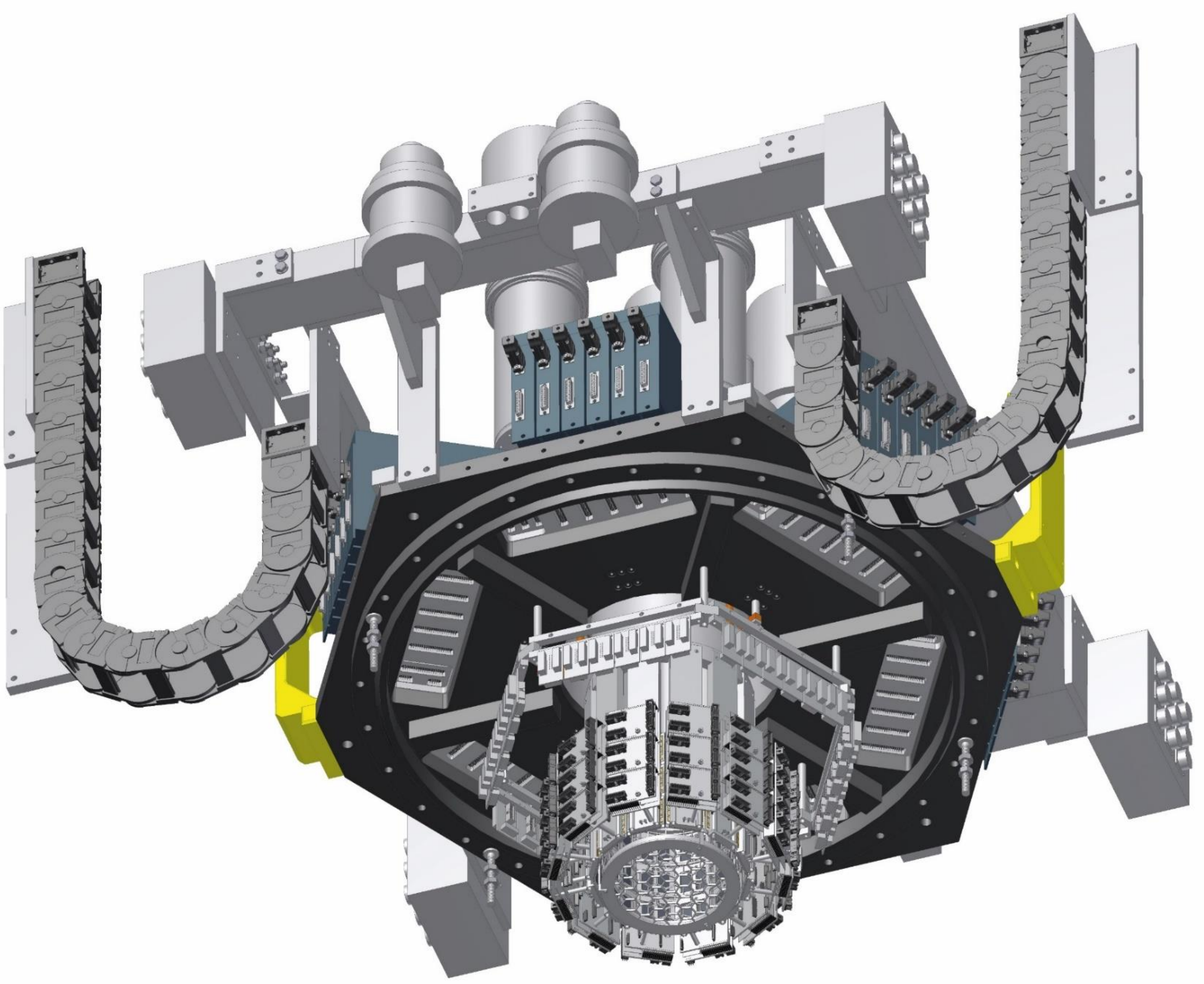
➢ **Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)**

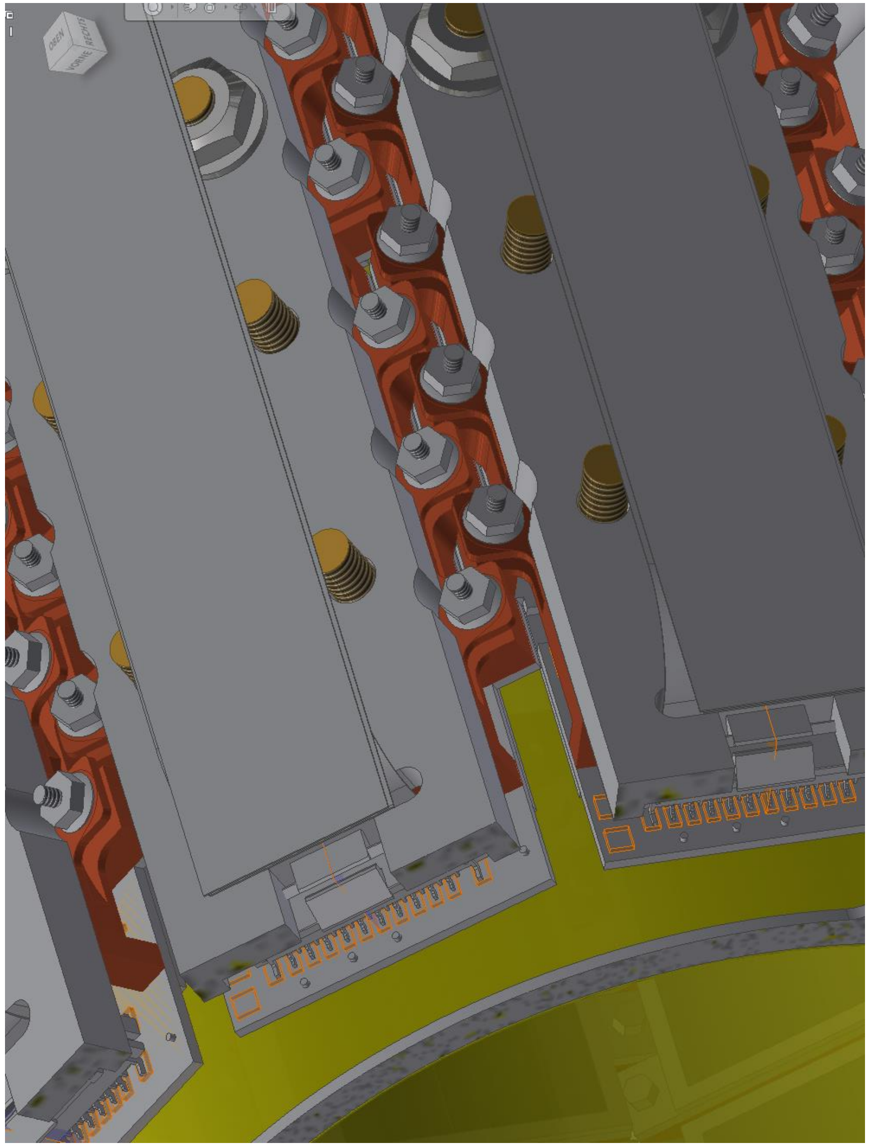
Thank you !

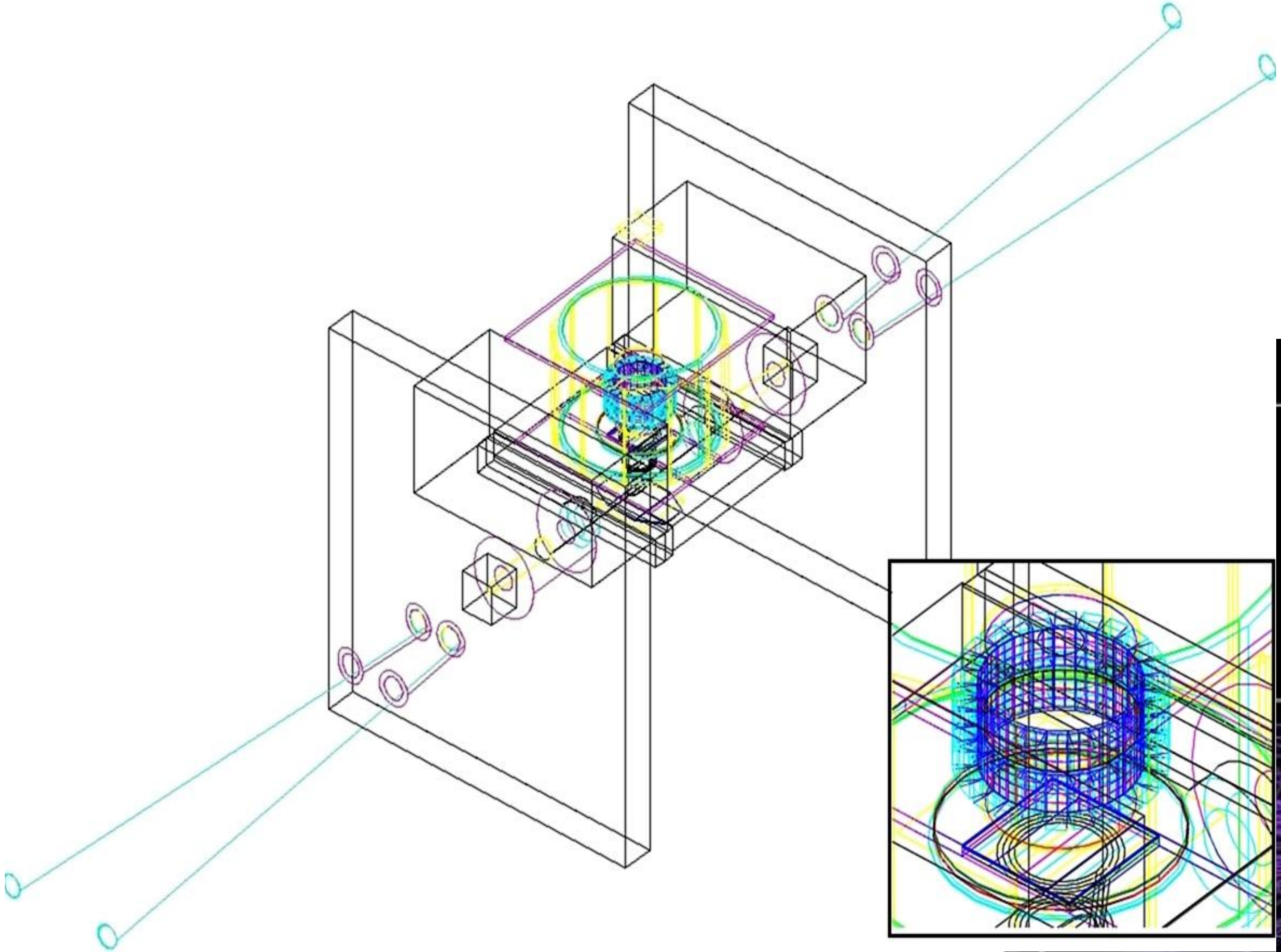
Special thanks to the accelerator division, in particular to the DAΦNE staff
and to
the KLOE-2 collaboration

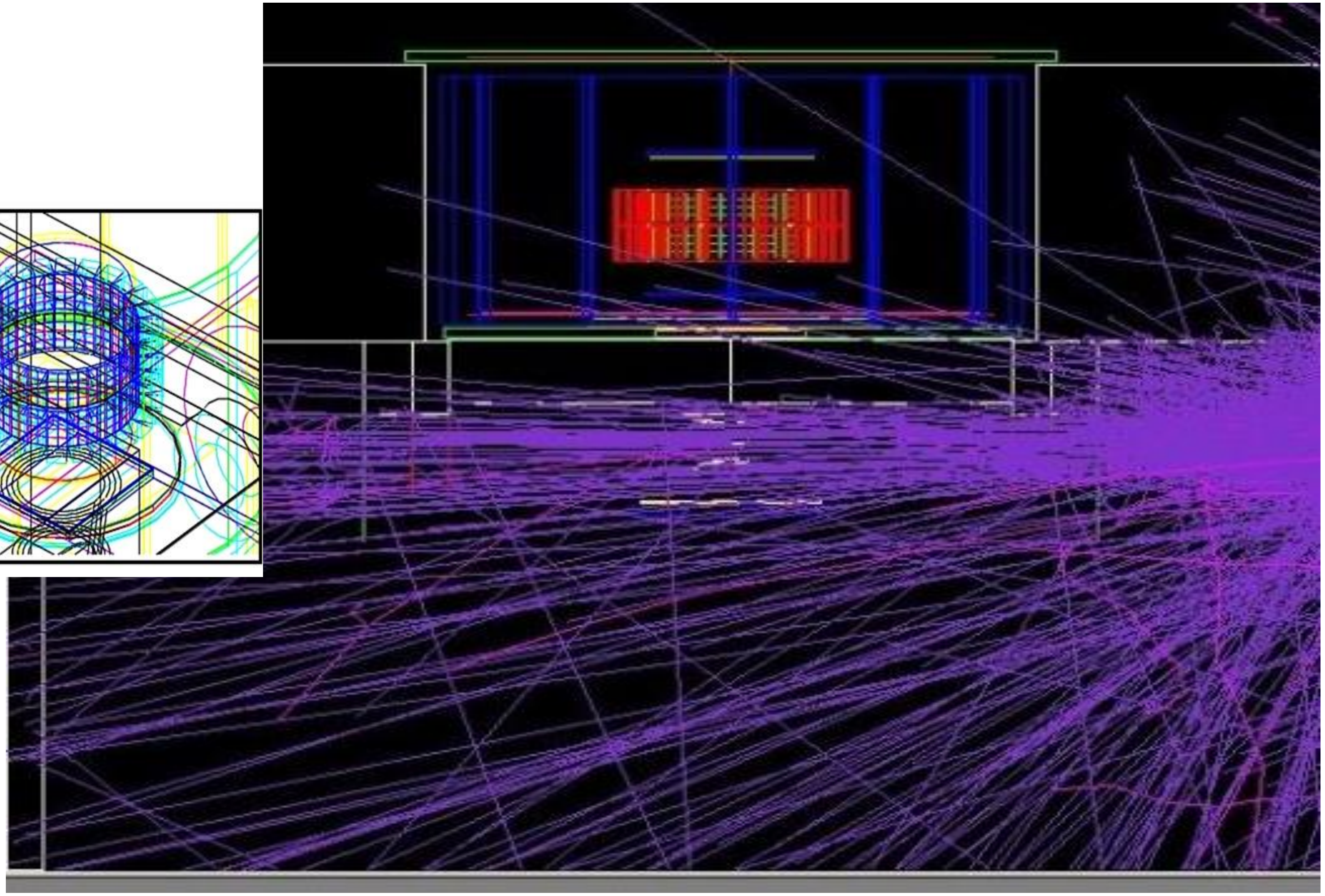

2 pieces of 8 x 4 cm^2
BC-408 scintillator
plates read-out by
two PMs, each

SIDDHARTA-2 cryogenic target cell + X-ray detector









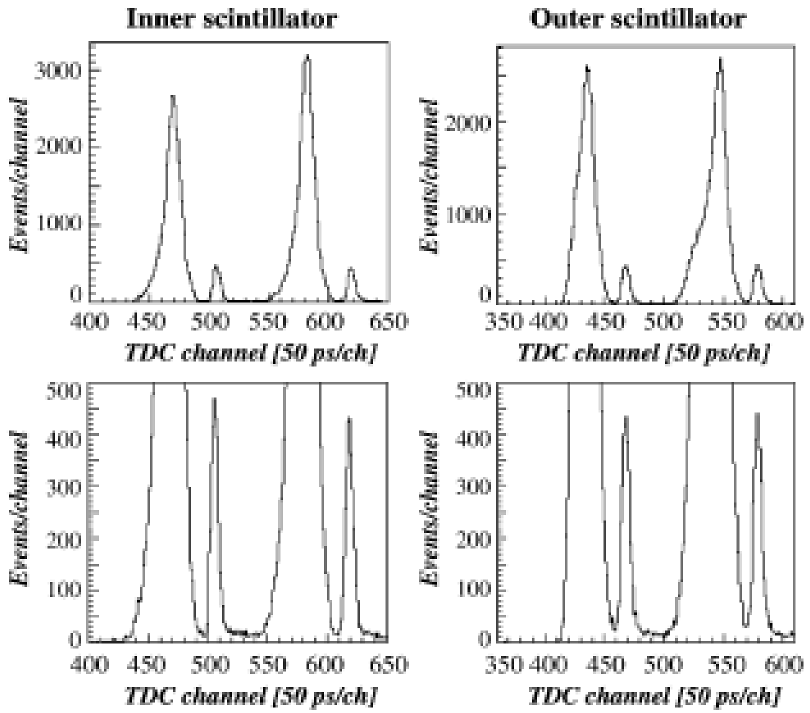


Fig. 5. The TDC spectra of the inner and the outer Kaon Monitor scintillators. The lower spectra are a zoom of the upper ones.

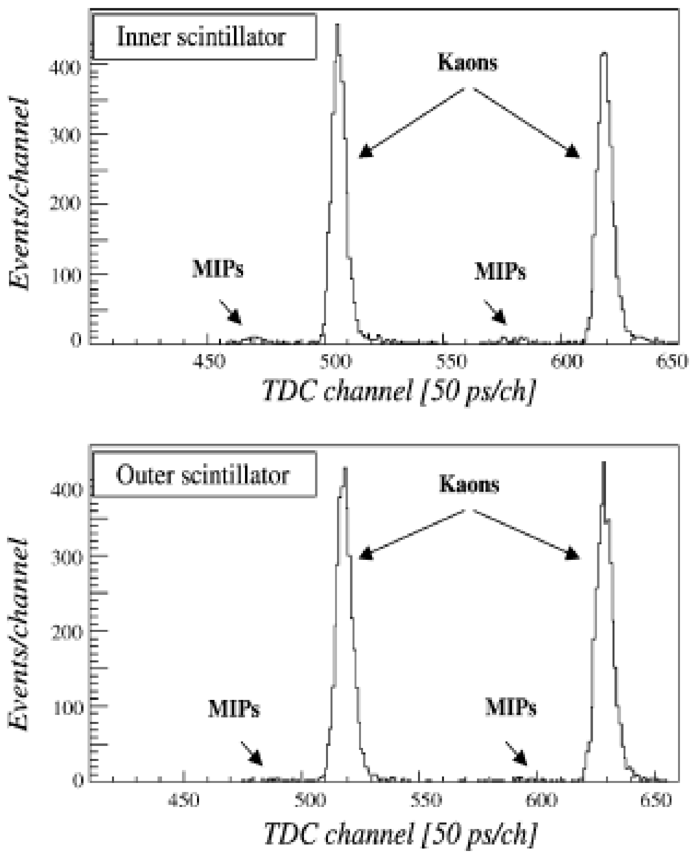


Fig. 7. The TDC spectra of the inner and outer Kaon Monitor scintillators corresponding to kaon window selections in the time spectra of the other slab. It is worth noting that the higher MIPs contamination of the inner slab (upper plot), is related to the threefold higher single counting rate of the outer slab with respect to the inner one.

$$\mathscr{L} = 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}, \quad R = 1.4\ \mathrm{Hz}.$$