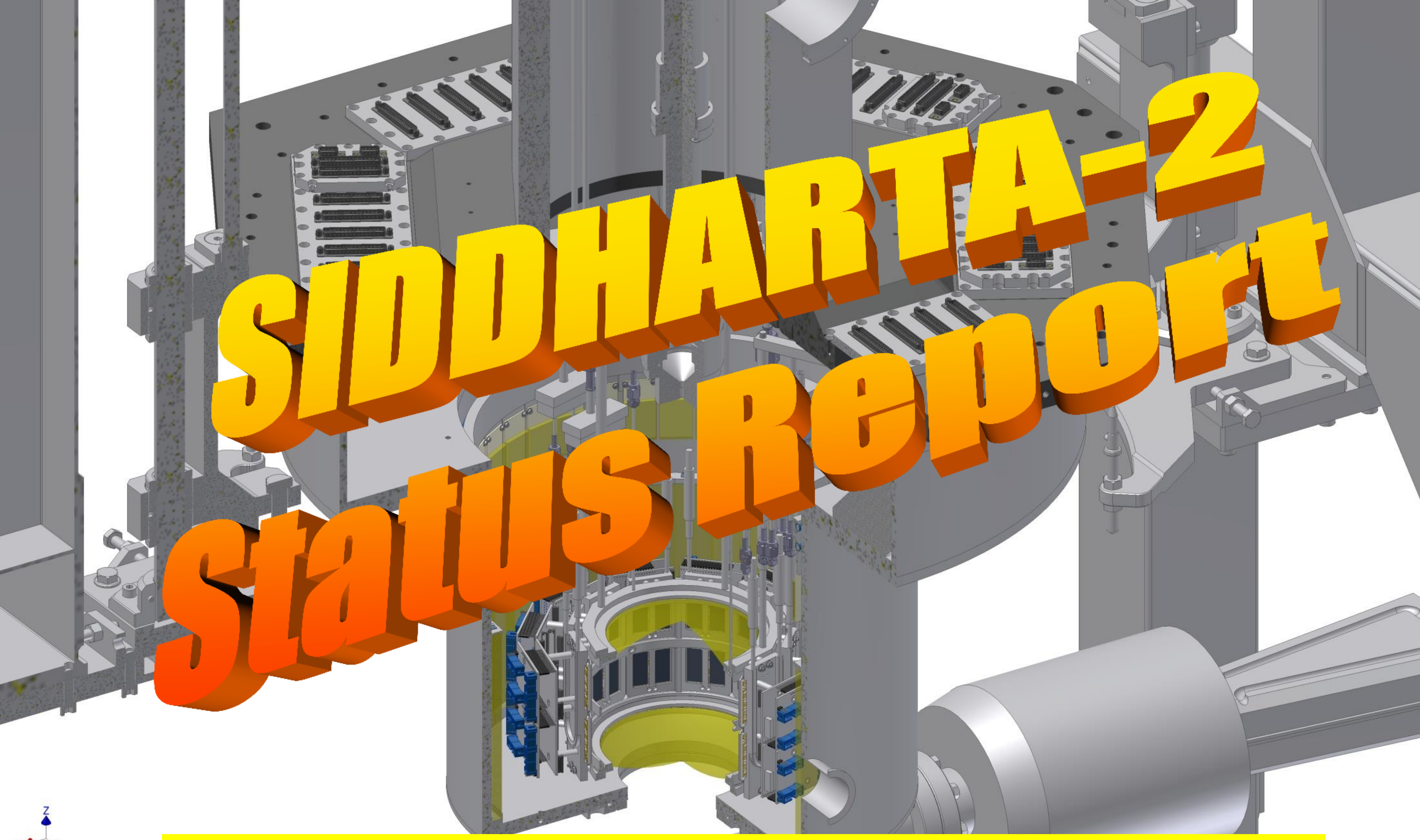
SIDDHARTA-2 Status Report



Catalina Curceanu, LNF-INFN

On behalf of the SIDDHARTA-2 Collaboration

LNF – SC, 23rd November2015

SIDDHARTA-2

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**
- **MPE and TUM, Munchen, Germany, Germany**
- **PNSensors, Munich, Germany**
- **RIKEN, Japan**
- **Univ. Tokyo, Japan**
- **Victoria Univ., Canada**
- **Univ. Zagreb, Croatia**

Content

- *Reminder: SIDDHARTA-2 Scientific case – kaonic deuterium*
- *Status of the experiment*
- *Future perspectives*
- *Requests to the SC-LNF*

The scientific aim of SIDDHARTA & SIDDHARTA-2

To perform precision measurements of kaonic atoms X-ray transitions -> unique info about the <u>QCD in non-perturbative regime in the strangeness sector</u> <u>not obtainable otherwise</u>

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

-> of the 1s level of **kaonic hydrogen (SIDDHARTA)** and

-> the *first measurement* of **kaonic deuterium (SIDDHARTA-2)**

to extract the antikaon-nucleon isospin dependent scattering lengths (-> chiral symmetry breaking)

To the LNF-INFN Director, Dr. Umberto Dosselli

To the Director of the LNF Accelerator Division, Dr. Pantaleo Raimondi

July 2011

Support letter for the SIDDHARTA-2 scientific case

We are writing this document to express our strong support to the scientific line presently pursued at the DAΦNE Accelerator by the SIDDHARTA-2 Collaboration. DAΦNE represented since its birth a unique facility for the study of the low-energy kaon-nucleon/nuclei interaction, for obtaining key-experimental results promoting the understanding of low-energy QCD in the strangeness sector, not accessible in any other way.

This successful history was pioneered by the DEAR experiment, which performed the measurements of kaonic hydrogen and nitrogen. The DEAR results certainly represented a step forward in understanding low-energy QCD.

This success was then continued by the SIDDHARTA experiment, which combined the excellent kaon beam delivered by DAΦNE with new techniques for precision X-ray measurements, by using a large array of high resolution Silicon Drift Detectors for the first time in triggered mode on an accelerator. The kaonic hydrogen precision measurement performed by SIDDHARTA, together with the kaonic helium 3 and 4 ones, represent the best measurements ever performed in this sector.

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These results are already actively used by several theory groups working in the field of low-energy QCD. The deduced antikaon-proton scattering length serves as a basic constraint in effective field theories investigating the interplay of spontaneous and explicit chiral symmetry breaking in QCD with strange quarks.

In order to reach a breakthrough in the field and to complete the picture, the kaonic hydrogen result must be complemented with a measurement of kaonic deuterium. This would allow extracting the complete set of isospin-dependent antikaon-nucleon scattering lengths in combination with a proper theoretical treatment of deuteron binding and absorption. Establishing accurate values for both the antikaon-proton and antikaon-neutron scattering lengths is not only providing essential input for chiral SU(3) effective field theory. It is also the prerequisite for explorations of antikaon-nuclear systems that are under very active discussion, from the quest for antikaon-nuclear clusters to the role of strangeness in the core of neutron stars.

We strongly support the proposal put forward by the SIDDHARTA-2 Collaboration, namely the measurement of kaonic deuterium X-ray transitions, as being one of the most important measurements in the strangeness sector of low-energy QCD. There is not any other beam of comparable quality available in a foreseeable future in order to perform this very challenging and important measurement. At the same time, the expertise of the SIDDHARTA-2 Collaboration is well recognized and represents the best guarantee of success.

We plead the LNF Director and INFN management to find a way to assure the realization of this measurement which is expected to bring further worldwide scientific acknowledgement to DAΦNE and INFN.

Univ. Prof. Dr. Manfried Faber
Technische Universität Wien, Austria

Prof. Eli Friedman
The Hebrew University of Jerusalem, Israel

Prof. Paolo Gensini
Sezione di Lecce, INFN, Italy

Prof. Dr. Ing. Paul Kienle
Excellence Cluster Universe, Technische Universität München, Germany

Dr. Jiri Mares
Jiri Mares Nuclear Physics Institute Rez/Prague, Czech Republic

Prof. Dr. Ulf-G. Meissner
Helmholtz Institut für Strahlen und Kernphysik, Bonn, Germany

PD Dr. Akaki Rusetsky
Helmholtz Institut für Strahlen und Kernphysik, Bonn, Germany

Prof. Ryoichi Seki
California State University, USA

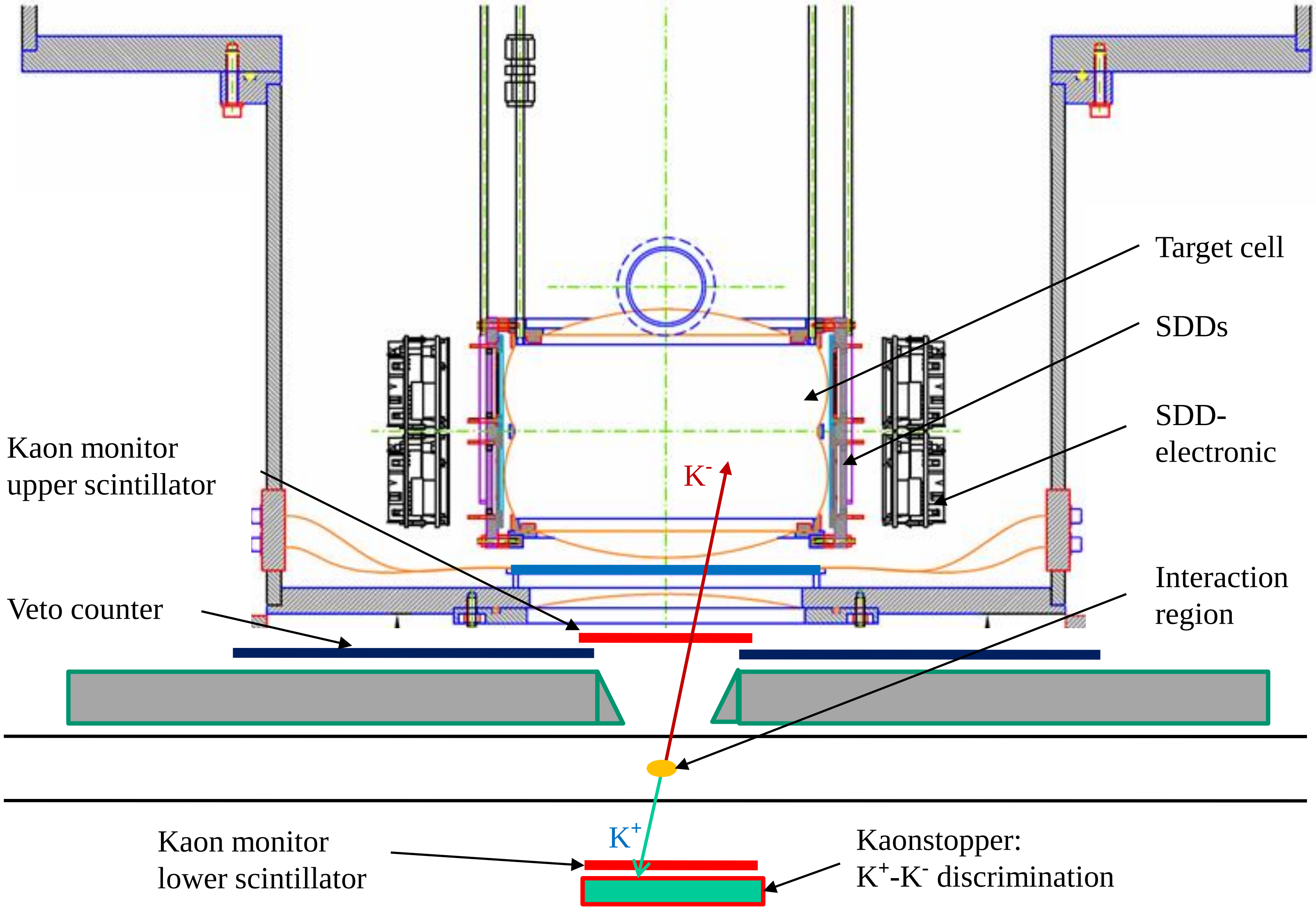
Prof. Dr. Wolfram Weise
Technische Universität München, Germany

Prof. Slawomir Wycech
Soltan Institute for Nuclear Studies, Warsaw, Poland

Prof. Dr. Toshimitsu Yamazaki
The University of Tokyo and RIKEN, Japan

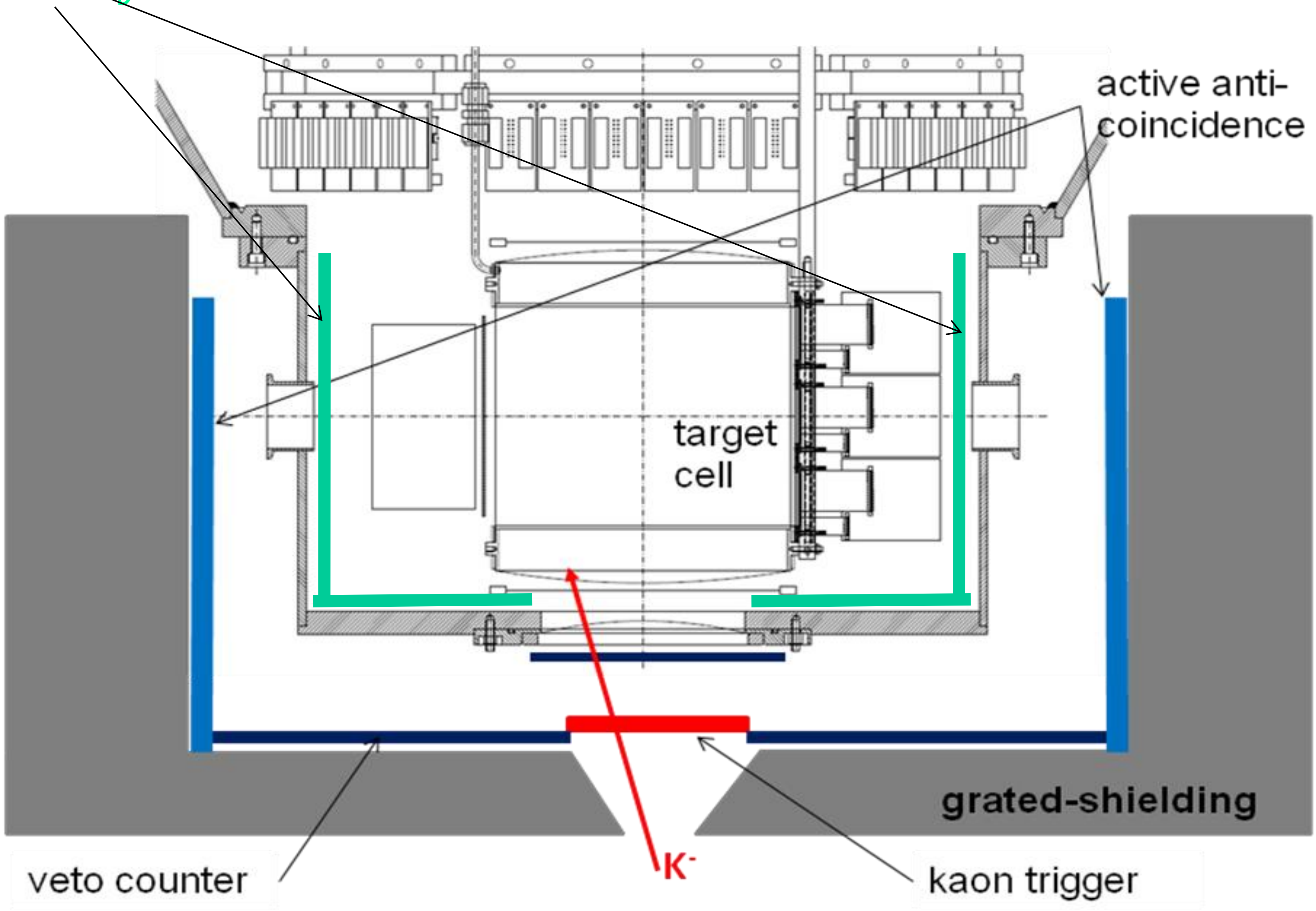
The SIDDHARTA-2 setup

- **new target cell**
- **new vacuum chamber**
- **new cooling system**
- **a veto system**
- **improved trigger scheme**
- **K^+ induced backg. veto**
- **new shielding structure**
- **New SDDs (FBK)**



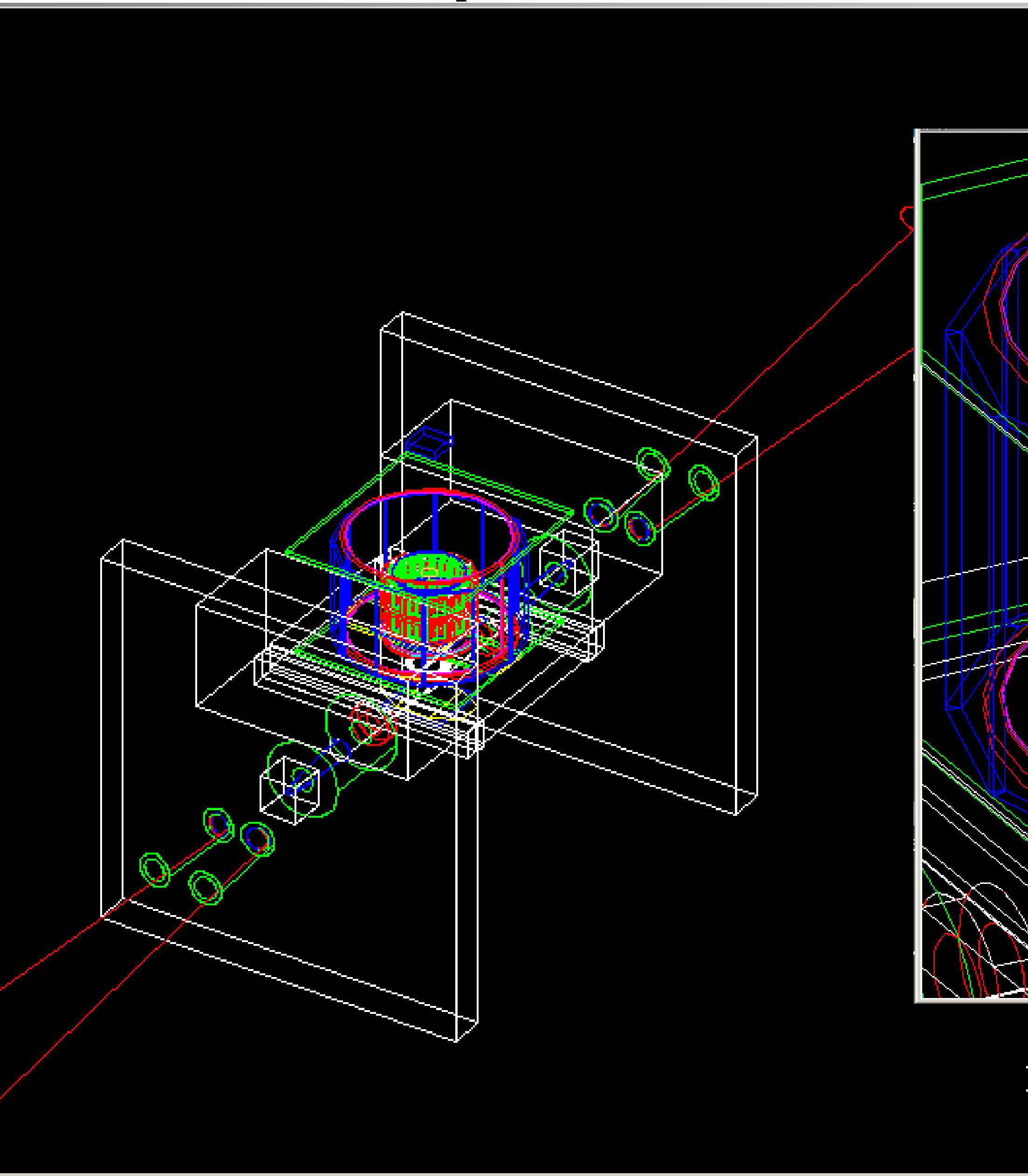
Target cell
SDDs
SDD-
electronic
Kaon monitor
upper scintillator
K-
Veto counter
Interaction
region
K+
Kaon monitor
lower scintillator
Kaonstopper:
K+-K- discrimination

Veto2 system

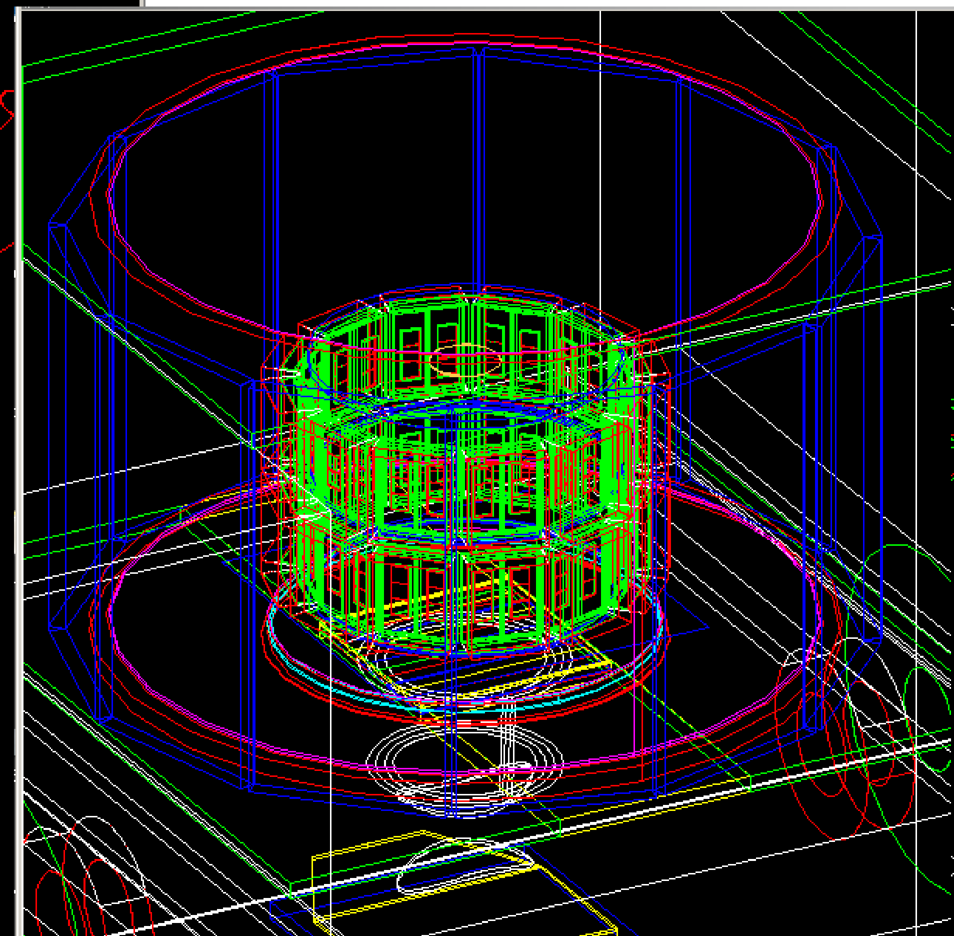


SIDDHARTA 2 (GEANT4 MC, M. Iliescu & C. Berucci)

SIDDHARTA2 setup



Setup detail



MC simulation - summary
gain factors w.r. to SIDDHARTA

	new geometry & gas density	timing resolution	$K^{\pm}$ dis-crimination	del'd anti-coinc.	prompt anti-coinc.	total impr. factor
Signal	**2.5**		**0.8**			**2.0**
kaonic X-rays wall stops	**20**					**20**
continuous background /Signal /keV	**3.8** ratio of gasstops vs. decay+wallstops		**2** events due to decay of K^{+} removed		**2** charged particle veto	**15.2**
beam background (asynchron)	**4.8** less trigger per signal	**1.5** smaller coincidence gate		**3** „active shielding"		**21.6**

New SDDs: another factor 2

SIDDHARTA2

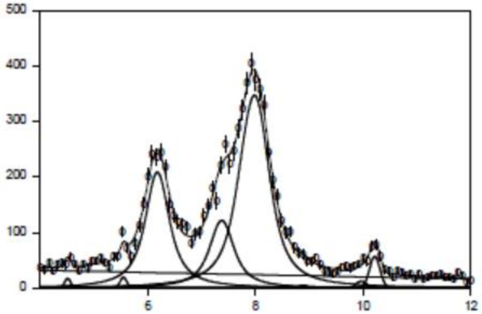
100 cm^2 SDDs from SIDDHARTA
active area / module = 22%
time window = 500 ns (was 800 ns at SIDDHARTA)

200 cm^2 new SDDs
active area / module = 64%
time window = 20 ns (backplane signal pickup)

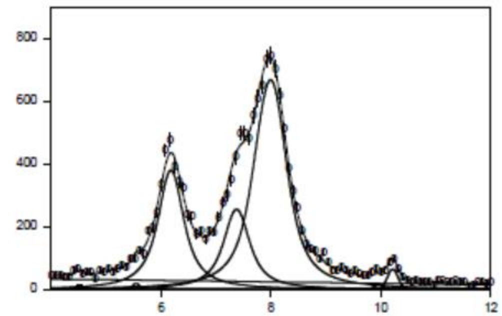
- efficiency doubled
- beam-background 1/25
- total background 1/2

100 pb^{-1} hydrogen

K_α peak 2000 events
S/B 7:1 (was 1:3 in SIDDHARTA last dataset)
sigma(shift) = 10 eV sigma(width) = 22 eV

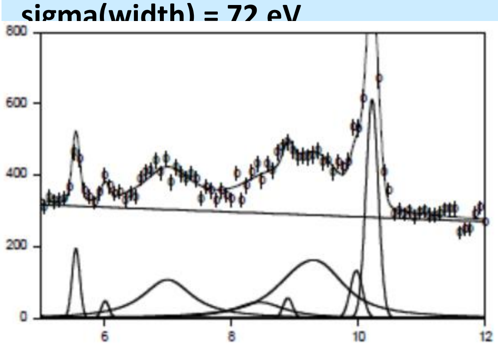


K_α peak 4000 events
S/B 14:1
sigma(shift) = 7 eV sigma(width) = 13 eV

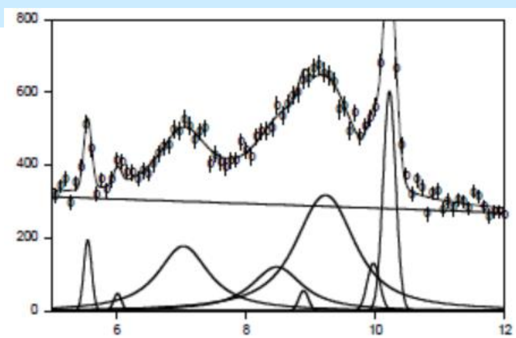


800 pb^{-1} deuterium

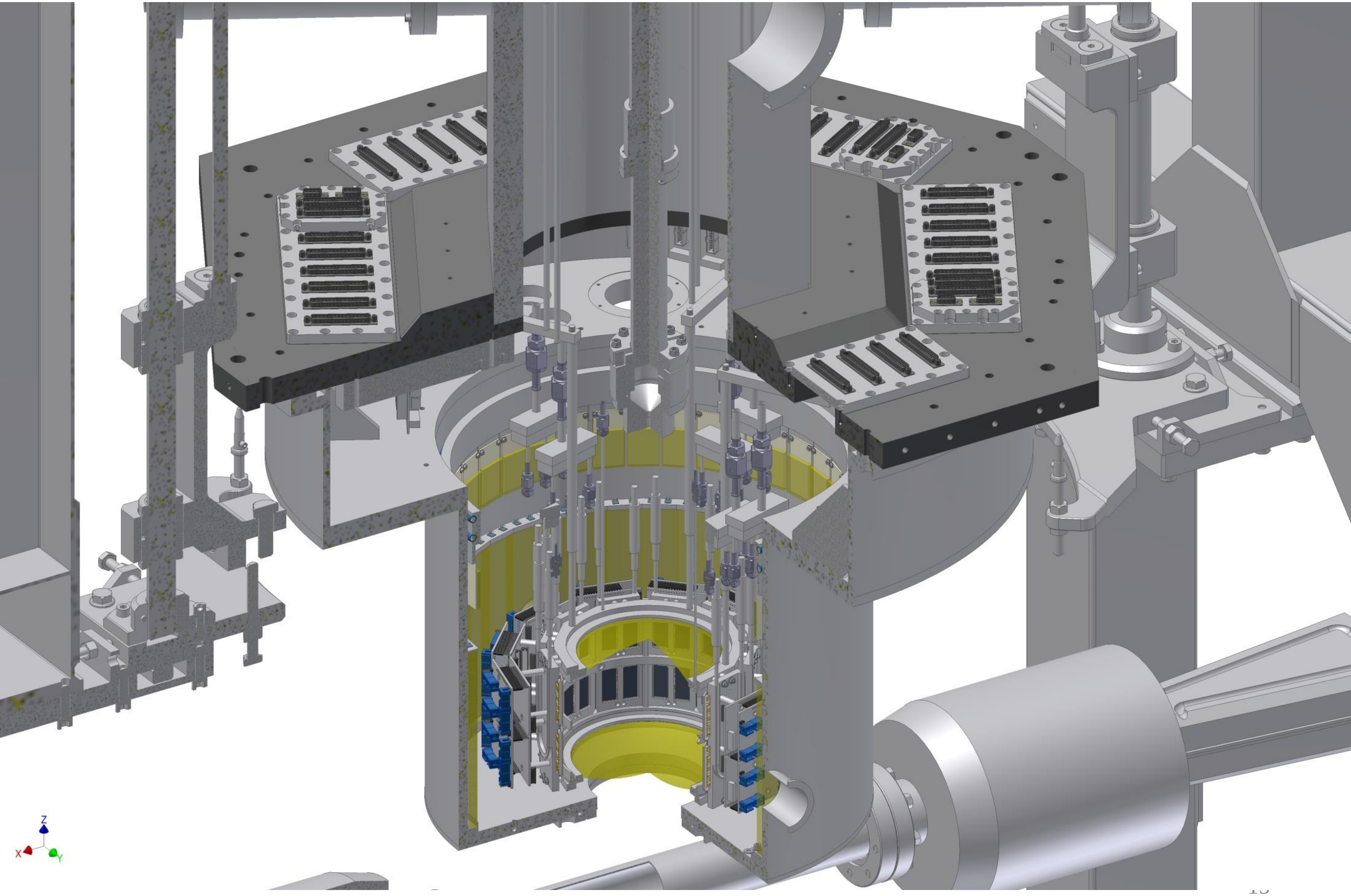
K_α peak 1500 events
S/B 1:3
sigma(shift) = 38 eV sigma(width) = 125 eV



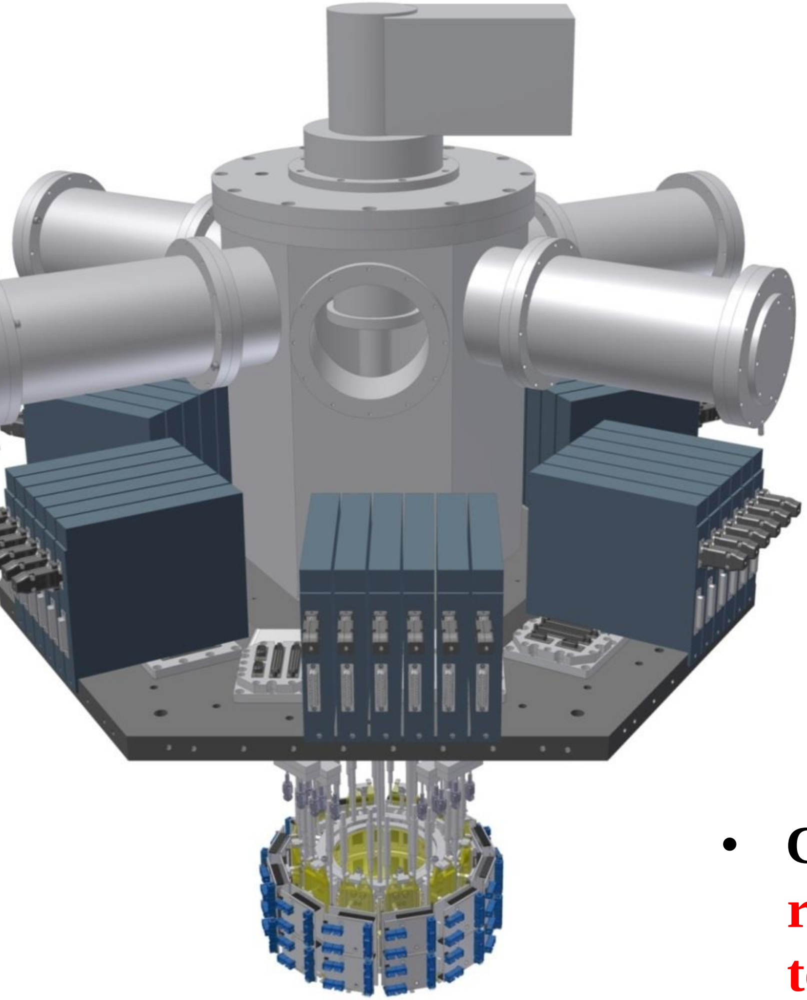
K_α peak 3000 events
S/B 1:1.5
sigma(shift) = 27 eV
sigma(width) = 72 eV



SIDDHARTA-2 setup



SIDDHARTA-2 setup:

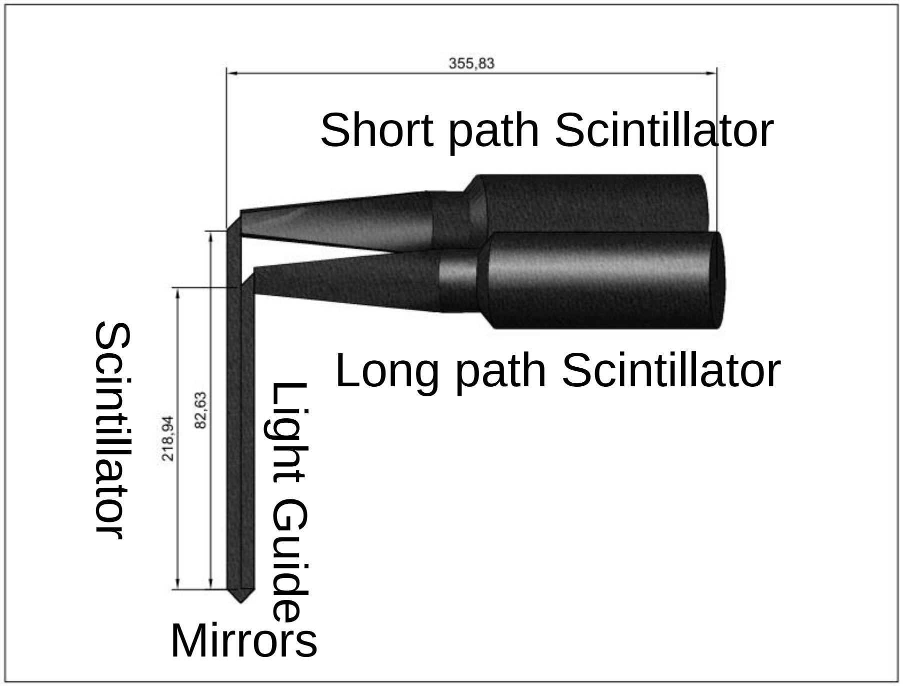


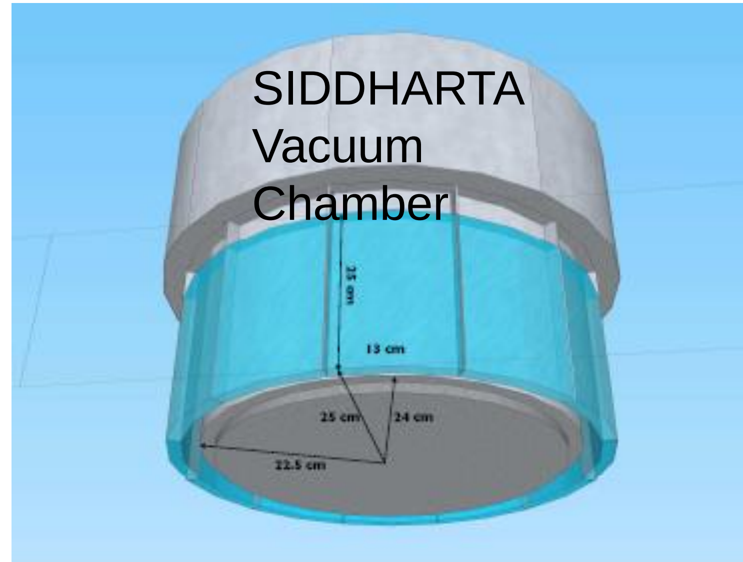
- **Vacuum chamber**
  ready and tested

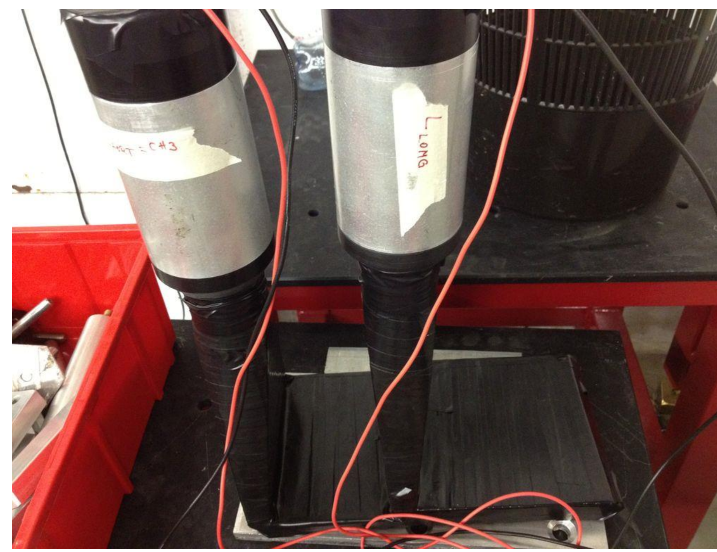
- **Cryogenic target**
  ready and cooling tests were successful

Veto system: construction and tests (PSI)

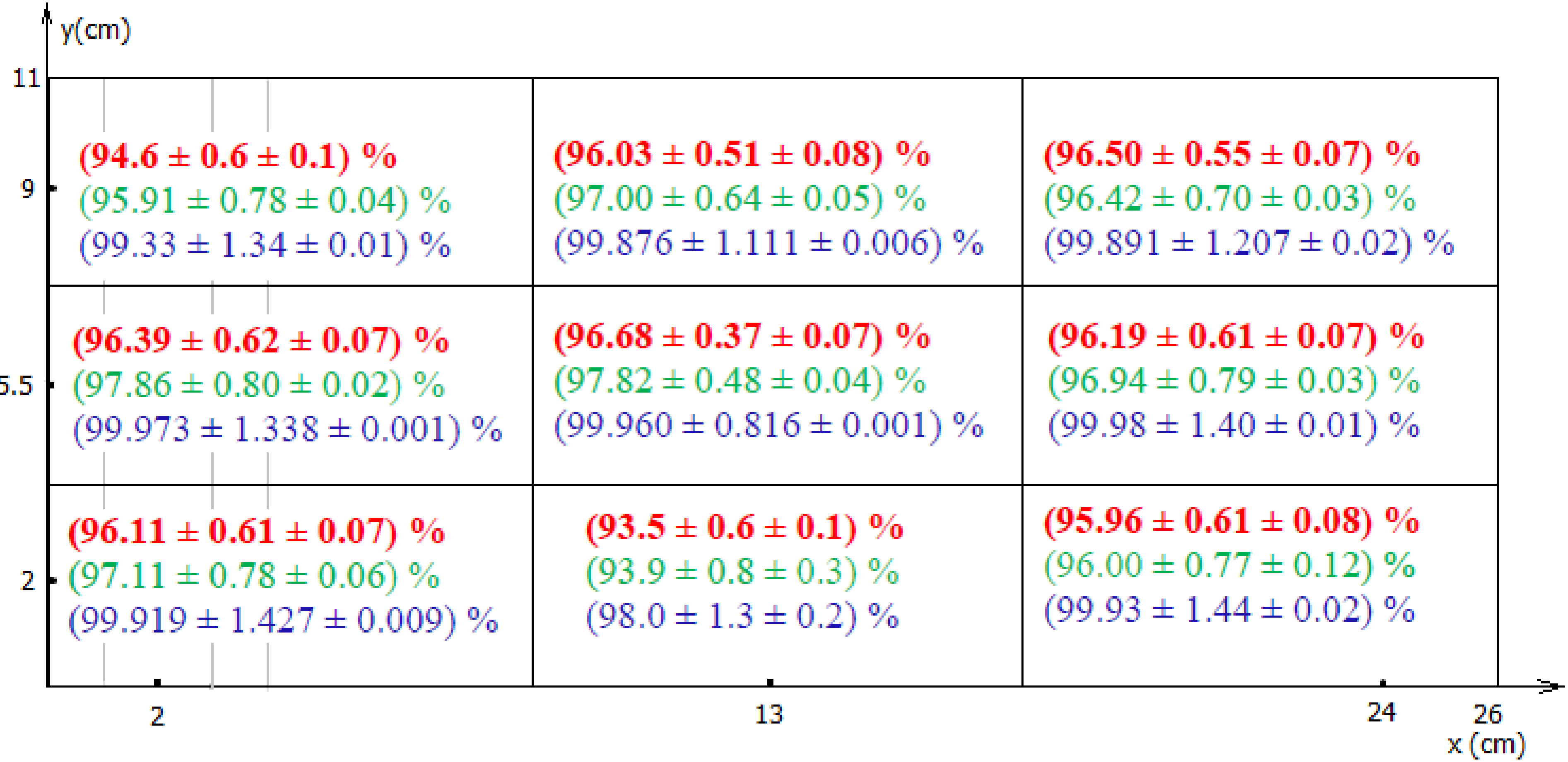
A multi – reflection Scintillator for the VETO system of the SIDDHARTA experiment







Which are the difference between
Long and Short?
How much is their efficiency?
How much is the time resolution?
Is this compatible with the 2 ns peak?



Measured efficiencies (MT) for the 170 MeV/c momentum pions (red) muons (green) and electrons (blue).

Jinst
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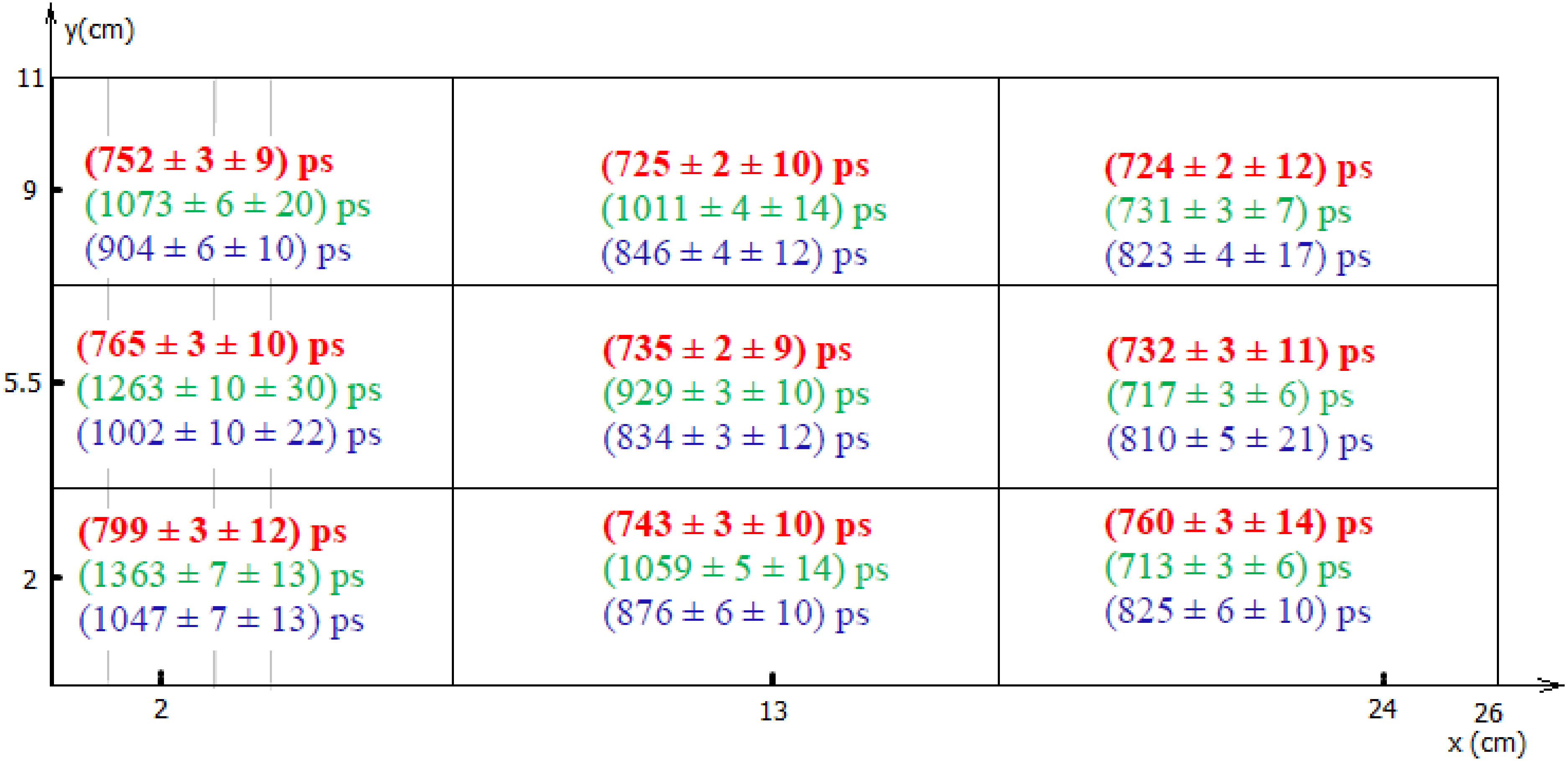
TECHNICAL REPORT

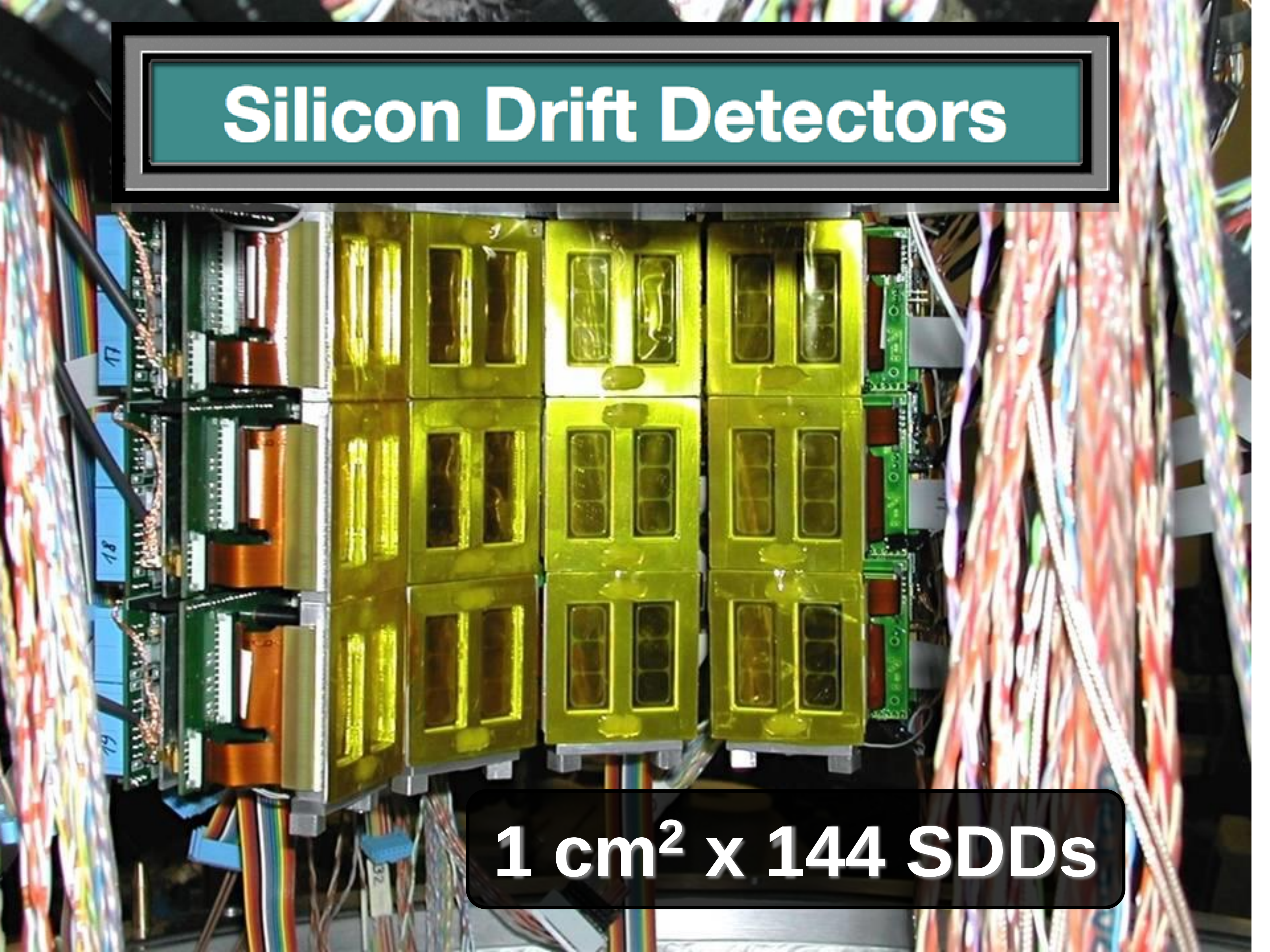
Characterization of the SIDDHARTA-2 second level trigger detector prototype based on scintillators coupled to a prism reflector light guide



Measured mean time resolutions (FWHM) for 170 MeV/c momentum pions (red), muons (green) and electrons (blue).

New SDD detectors

Silicon Drift Detectors



1 cm^2 x 144 SDDs

New development of SDDs by Politecnico & FBK

- **Started in 2011 within a project supported by ESA**
- **Considered very suitable for the upgrade of the Siddharta-2 apparatus, with preliminary evaluation on prototypes in 2012/2013**

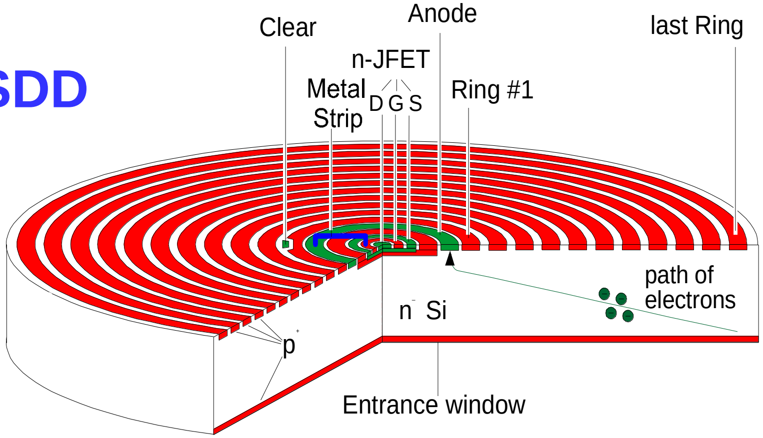
- **Key features of the new technological approach:**

1) process of SDD detectors WITHOUT <u>JFET integrated on the SDD itself</u> (as used on current SIDDHARTA apparatus).
advantages:
- simplicity
- much lower production costs (much less techn. steps)
- faster production times (3-4 months vs. one year)
- much lower dependence of settings/performances on bias voltages than with the present detectors
- less sensitivity to latch-up during beam injection

2) SDD readout based on a new charge preamplifier "Cube" (recently developed at Politecnico di Milano):
- allows high performances in X-ray spectroscopy still using 'conventional' SDD technology (W/O integrated JFET)

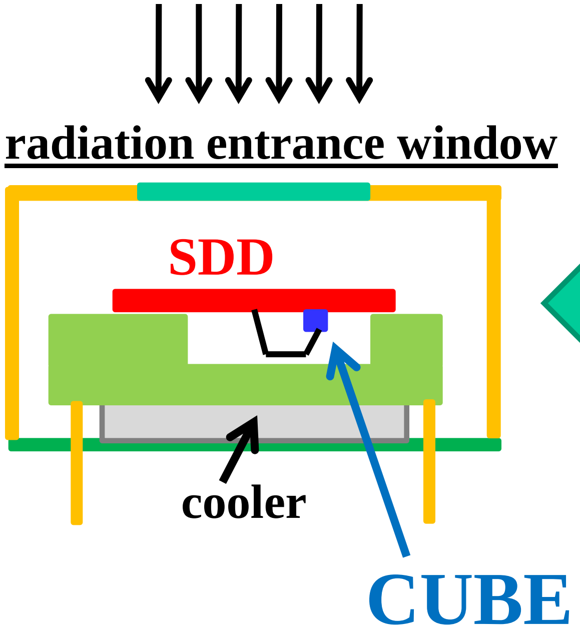
Front-end readout strategy

- **JFET integrated on the SDD**
  - **lowest total anode capacitance**
  - **limited JFET performances (gm, 1/f)**
  - **sophisticated SDD+JFET technology**



Now in Siddharta

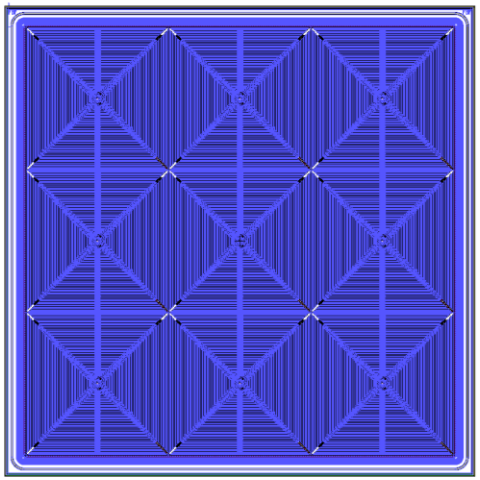
- **external CUBE preamplifier (MOSFET input transistor)**
  - **larger total anode capacitance**
  - **better FET performances**
  - **standard SDD technology**



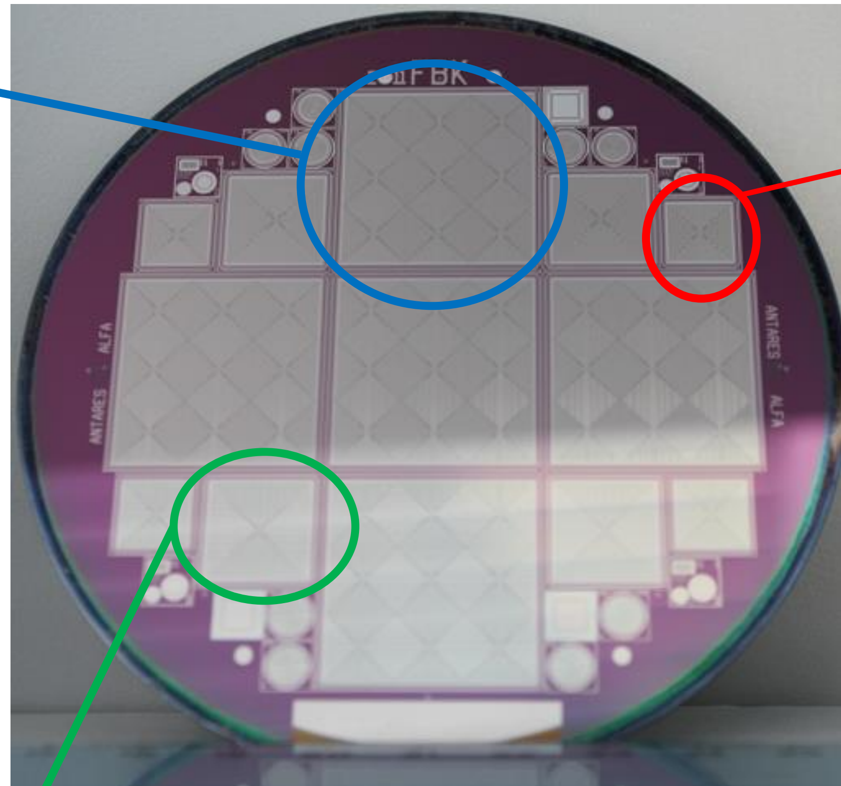
Proposed for Siddharta-2

Present layouts of SDDs developed in the Polimi-FBK collaboration

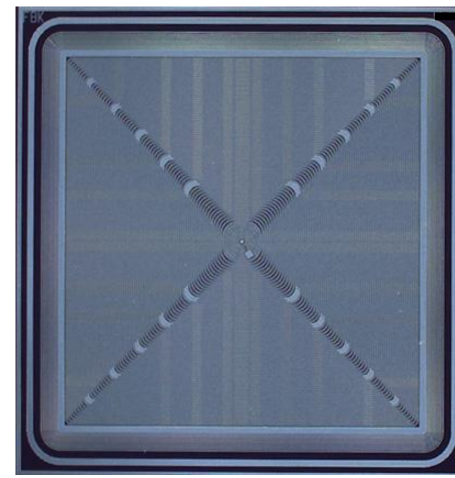
Array: 9 SDDs (8 x 8 mm² each)



26mm



8 x 8 mm² single SDD

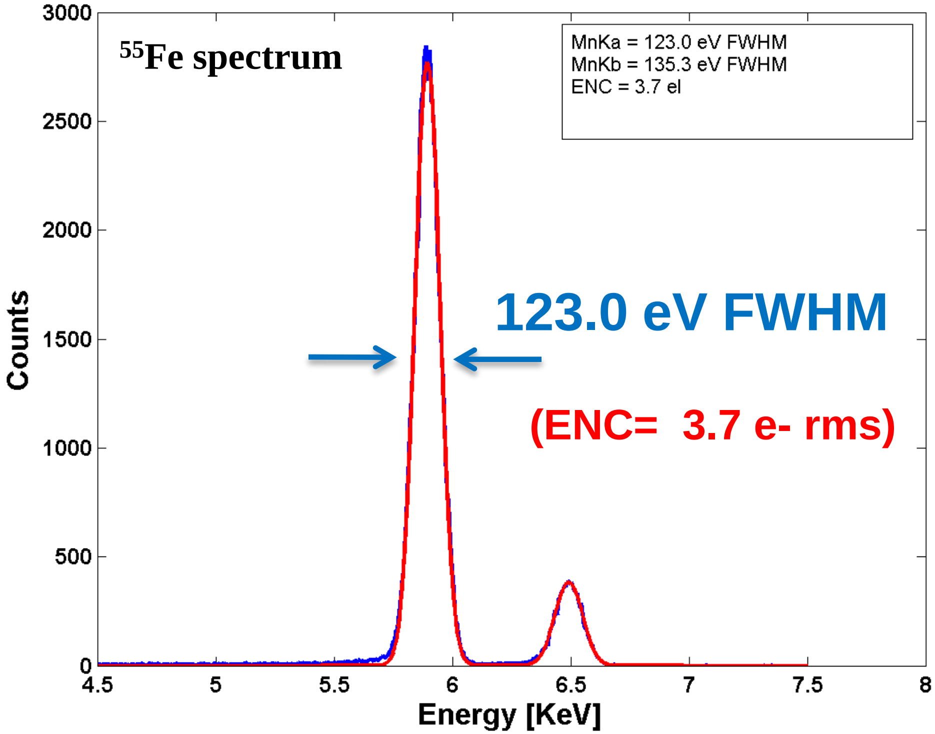


12 x 12 mm single SDD

FBK production:

- **4” wafer**
- **6” wafer upgrade just finished**

Best performances of new SDD technology and CUBE preamplifier

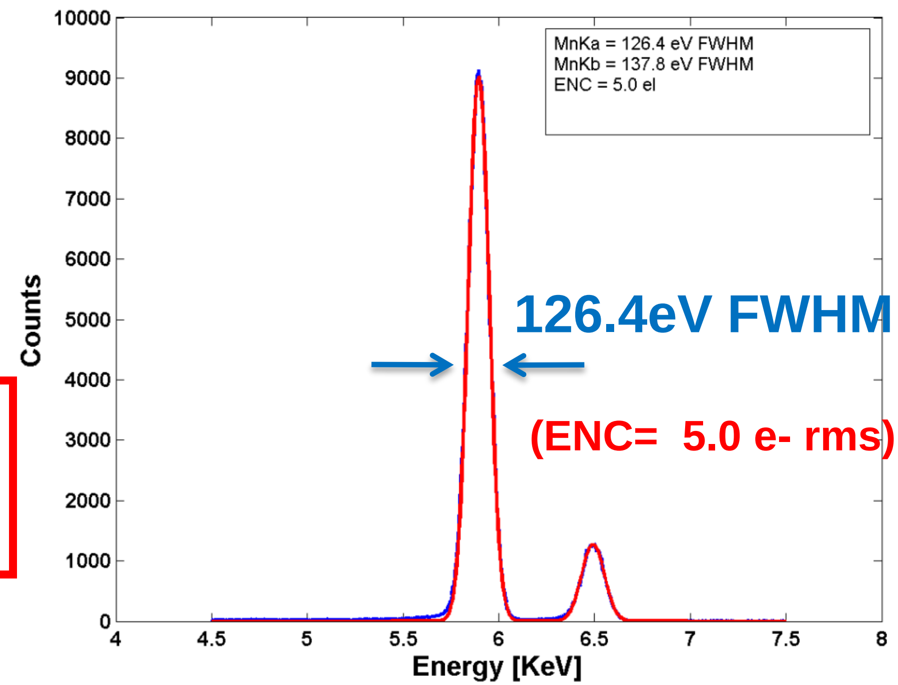


SDD characteristics:

- **Area = 10mm^2**
- **T= -40°C**

1.0 μs shaping time (optimum)

250ns shaping time

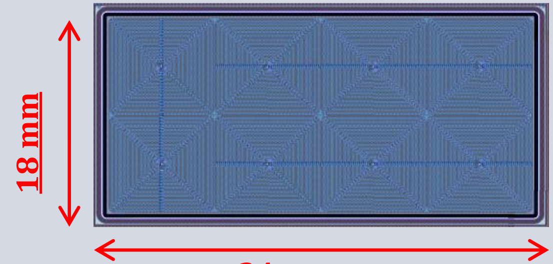


best resolution ever obtained with a SDD (even with integrated JFET) at this short shaping time

Development of arrays of Silicon Drift Detectors for the SIDDHARTA experiment

In the framework of the INFN-SIDDHARTA experiment a new SDD array has been developed. This array is characterized by eight independent elements organized in a 4 x 2 format (square SDD). Each channel is connected to a CUBE preamplifier.

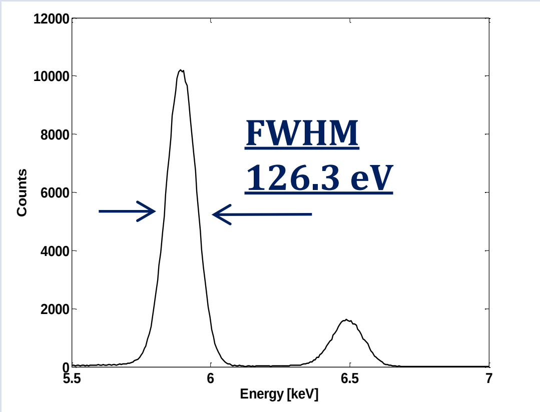
Layout and picture of the SDD array.



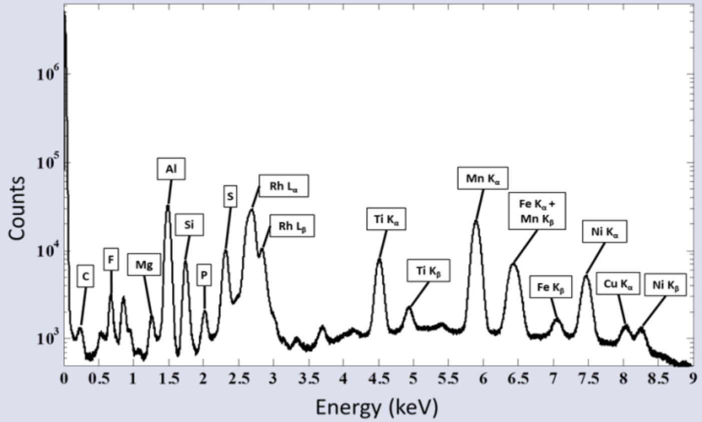
Layout of the front side

Picture of the detector mounted in a proper carrier (back side view)

Spectroscopic measurements with the single square shaped SDD (8 x 8 mm^2 active area):

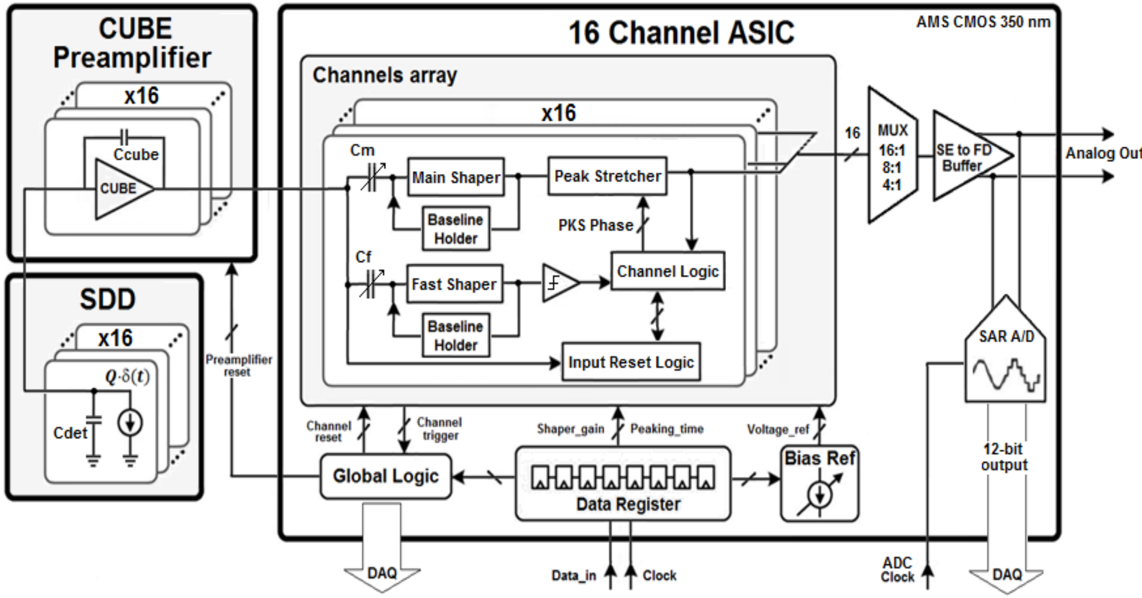


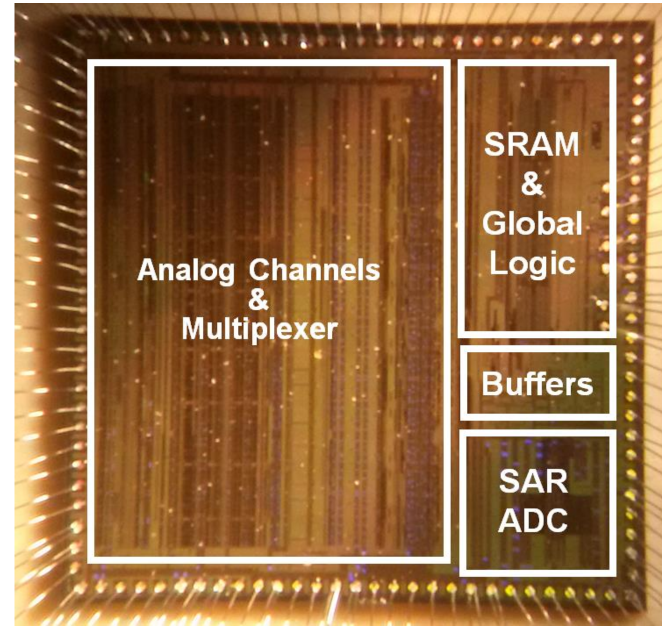
^{55}Fe spectra at 150K. Shaping time 1 µs.

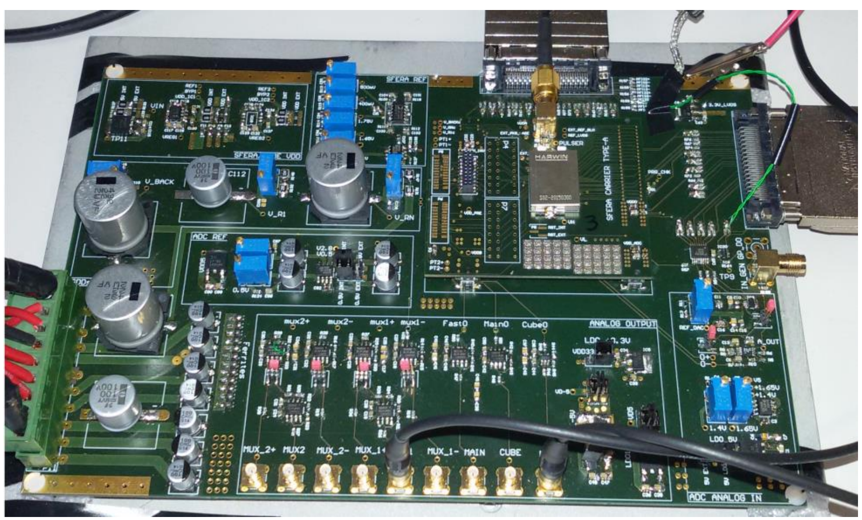


Low energy X-ray lines measured with a 8 x 8 mm^2 detector.

Siddharta Front-end

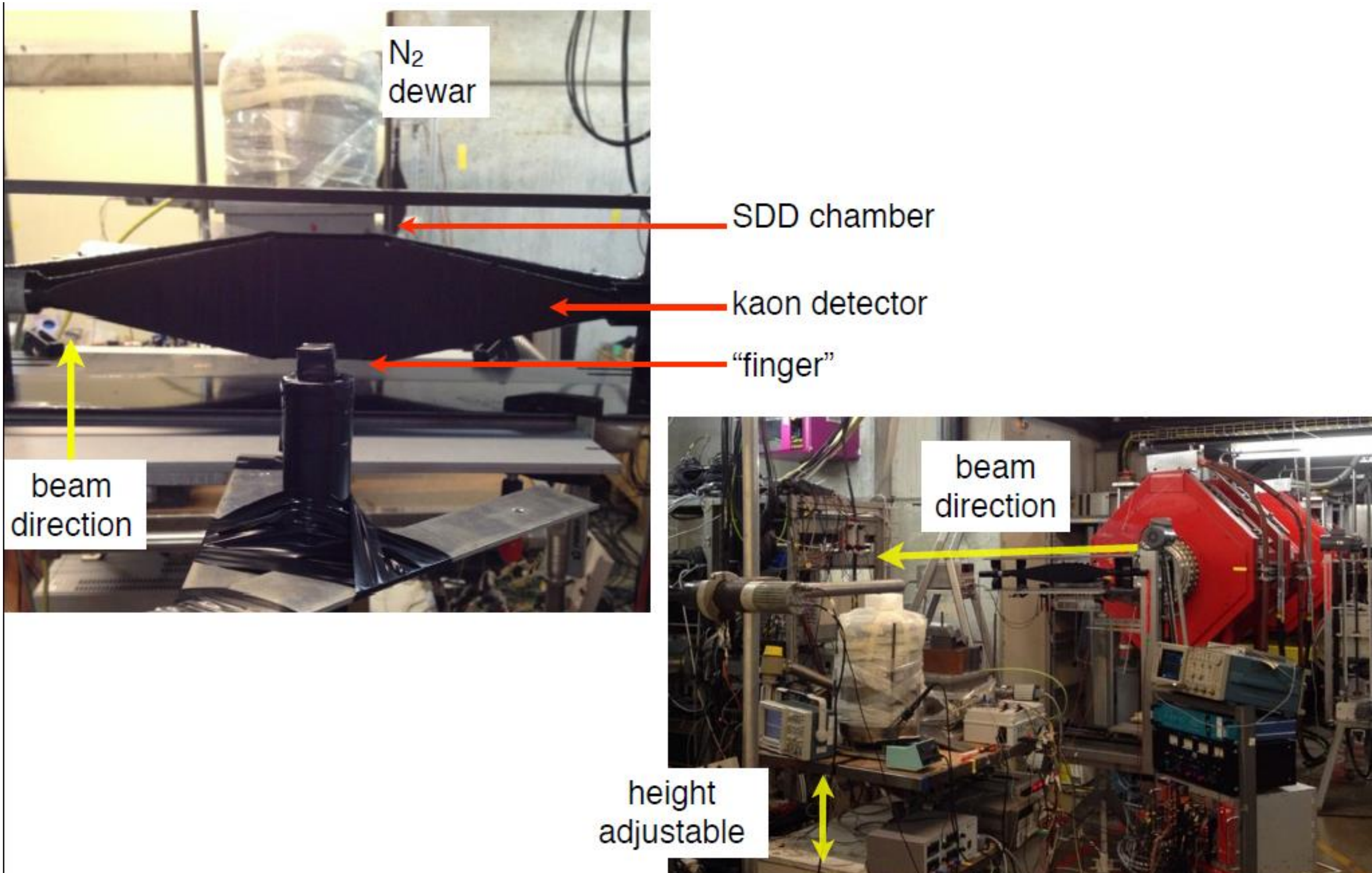






Siddharta ASIC block-diagram (top left), die photograph (top right) and characterization printed circuit boards (bottom left).

CUBE-SDD setup installed on PiM1 beamline at PSI



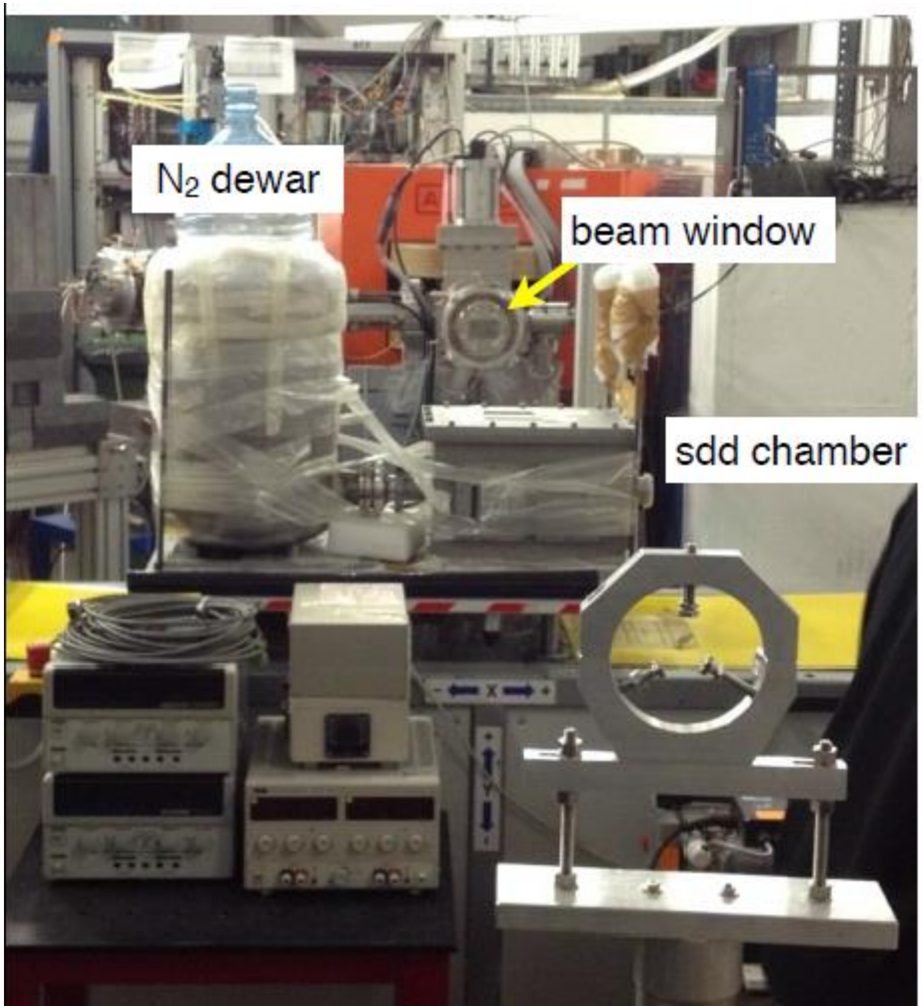
CUBE-SDD response under pion beam

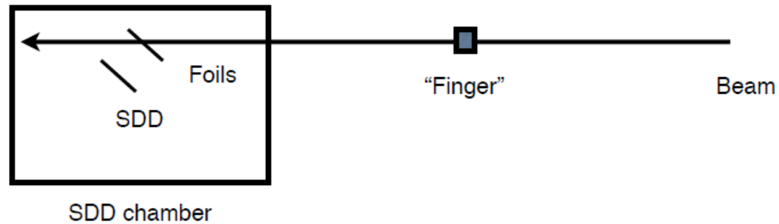
170 MeV/c, -158 C, with Fe-55 source

Worst expected case

overall sdd hit rate [Hz]	X-ray rate [Hz]	FWHM@6 keV [eV]	Mn Ka1 position [ch] (error < 0.1)
28	24	132.9 +- 0.2	376.9
65	48	131.9 +- 0.2	376.6
152	107	132.1 +- 0.2	376.4
290	200	*138.7 +- 0.2*	376.5
870	570	133.7 +- 0.3	376.5
1630	1050	138.7 +- 0.3	376.1
2370	1470	140.3 +- 0.3	376.5

CUBE-SDD setup installed on BTF at LNF





Measurements performed:

-gain & resolution stability under various X-ray rates

-timing performance of the new SDDs and temperature dependence

CUBE-SDD stability under various X-ray rates

Worst expected case

DAQ rate [Hz]	FWHM@6 keV [eV]	Cu Ka1 position [ch] (error < 0.1)	Br Ka1 deviation [eV]
100	133.89 +- 0.06	864.4	- 2.0 +- 2.5
400	137.48 +- 0.03	864.4	- 2.3 +- 1.3
800	138.99 +- 0.03	863.4	0.8 +- 1.3
1k	137.13 +- 0.03	862.7	-3.9 +- 1.3
2k	139.51 +- 0.03	862.4	- 1.5 +- 1.3
3k	139.59 +- 0.03	863.3	- 3.2 +- 1.4
6k	140.95 +- 0.03	863.2	- 2.2 +- 1.0
8k	142.60 +- 0.03	862.7	- 0.9 +- 1.0

SDDs status

- **All SDD arrays (200 cm^2) were ordered**
  half were delivered within summer 2015
  half will be delivered within spring 2016

- **Readout electronics will be ready within spring 2015**

- **SDDs will be fully mounted and characterized within early summer 2016**

SIDDHARTA-2 timescale :

1) **SIDDHARTA2 with “SIDDHARTA-like” SDDs ready to be mounted on DAΦNE anytime**

2) **SIDDHARTA2 with the new SDDs ready to enter on DAΦNE in the second half on 2016**

-

SIDDHARTA-2 - Kd measurement request:

We require an integrated luminosity of *800 pb^{-1},* to perform the first measurement of the strong interaction induced parameters - the energy displacement and the width - for the konic deuterium ground state, which is a fundamental measurement in low-energy strangeness physics (QCD).

SIDDHARTA2 future perspectives

1) Kaonic deuterium measurement - 1st measurement: and R&D for other measurements

2) Kaonic helium transitions to the 1s level – 2nd measurement, R&D

3) Other light kaonic atoms (KO, KC,…)

4) Heavier kaonic atoms measurement (Si, Pb…)

5) Kaon radiative capture – Λ(1405) study

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

7) Kaon mass precision measurement at the level of <7 keV (kaon mass puzzle)

Considerations and requests

It is worthy to recall that the exotic kaonic atoms scientific line on the – unique in the world for this type of research – DAΦNE facility, has been opened more than 15 years ago and it is **worldwide recognized as one of the most important lines in the strangeness sector of non-perturbative QCD**.

This is confirmed by the letter of eminent scientists supporting the deuterium case.

This is proved by the results of DEAR and SIDDHARTA, which have become **benchmarks for theory groups working in effective field theories, in particular chiral perturbation theory, and in astrophysics**.

Therefore we demand:

1) to have a clear schedule for running SIDDHARTA-2 on DAΦNE

2) to have a link scientists and a link engineer from the DAΦNE team with whom we can interact in the view of the installation

3) to have stronger support from LNF and INFN (man-power included) to finalize and run the experiment