New beam position detectors for NA61/SHINE experiment

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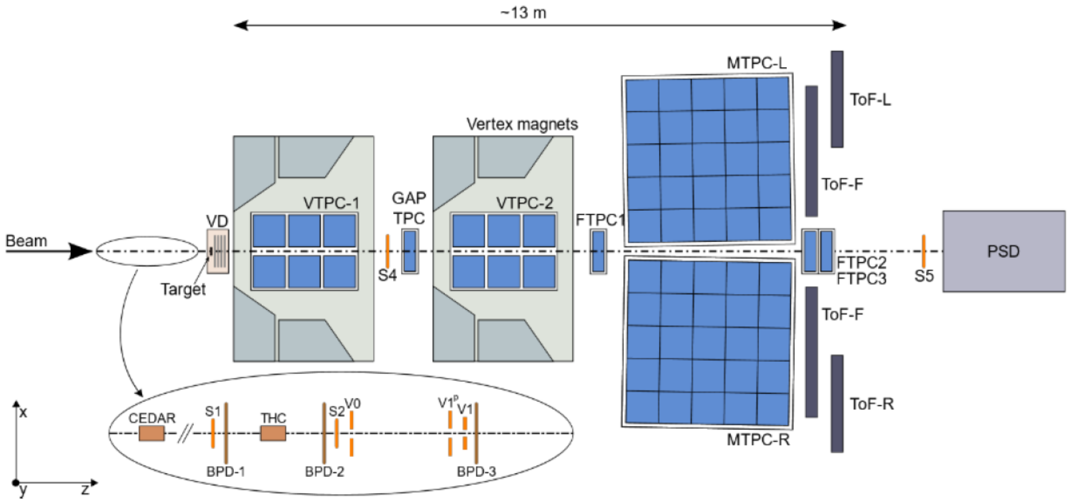
for the NA61/SHINE collaboration

NA61/SHINE experiment at CERN SPS



NA61/SHINE facility: arXiv:1401.4699

- hadron beams (π, K, p) @ 13-400 GeV/c
- ions beams (Be, Ar, Xe, Pb) @ 13*A*-150*A* GeV/c

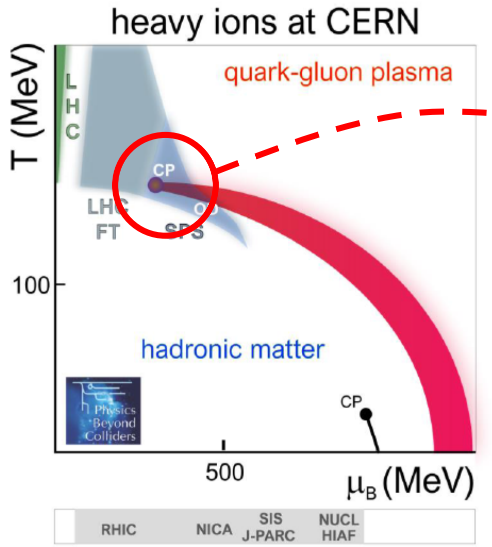
NA61/SHINE research programme

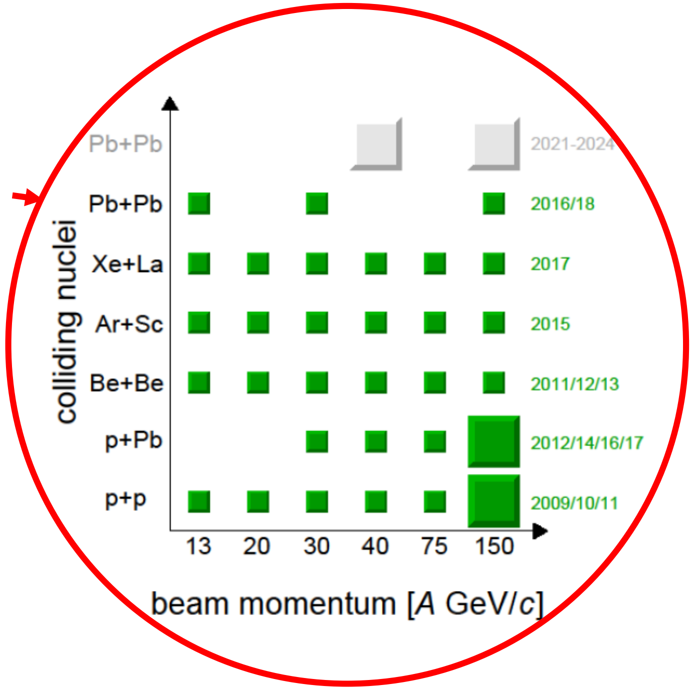
Strong interactions physics:

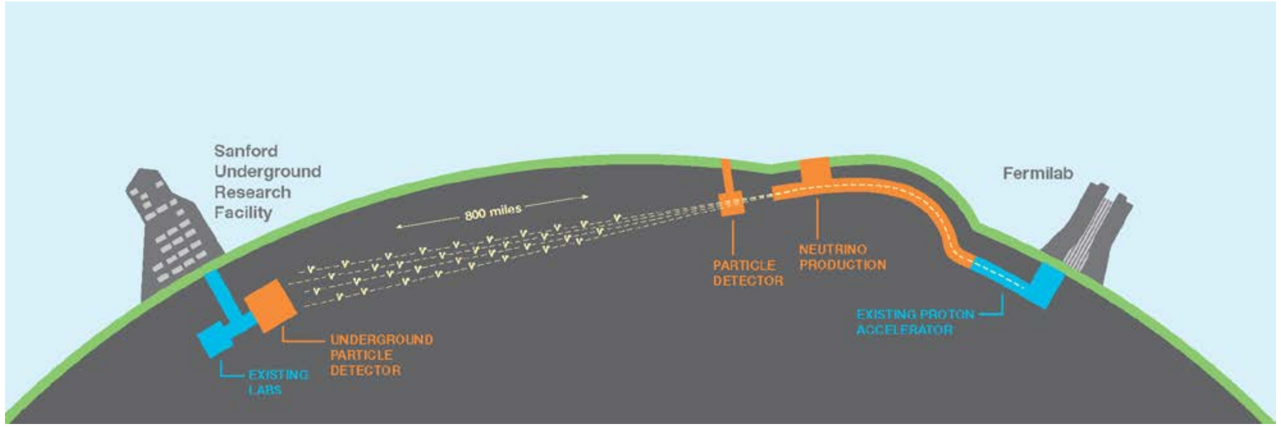
- study of the properties of the onset of deconfinement
- search for the critical point of the strongly interacting matter

as well as

- measurement of hadron production for neutrino programmes
- measurement of nuclear fragmentation cross-sections for cosmic-ray physics



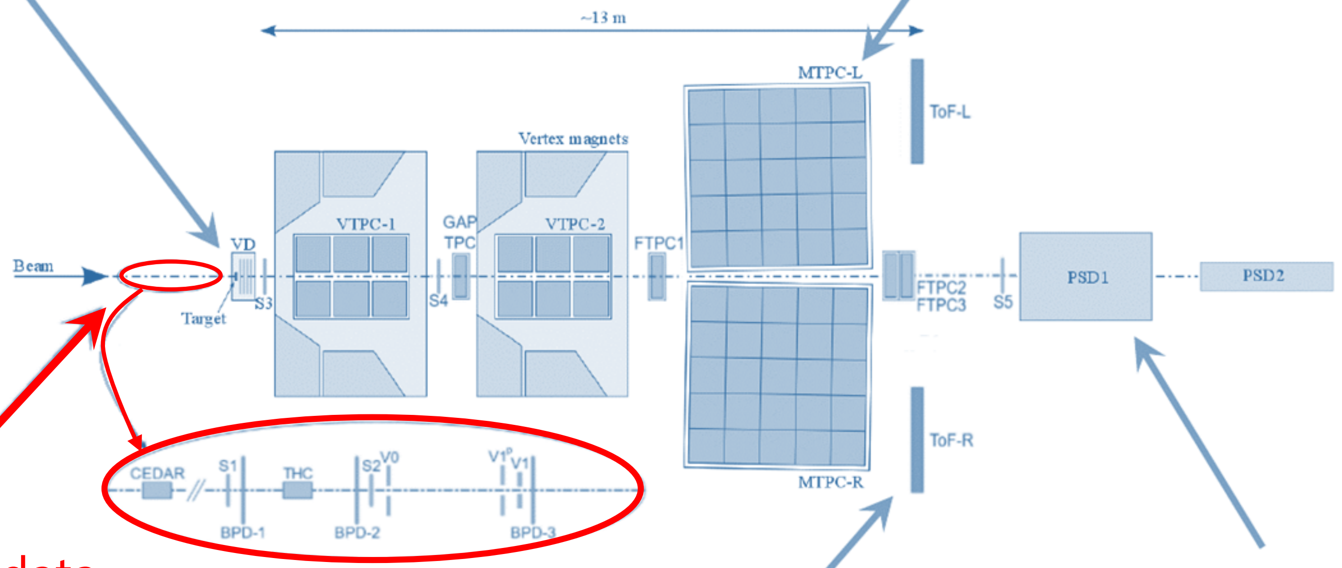




Upgrade of NA61/SHINE detector during LS2

Construction of Vertex Detector (VD)
for D^0, $\overline{D^0}$ decay reconstruction

Replacement of the TPC
read-out electronics
to increase data rate to 1 kHz

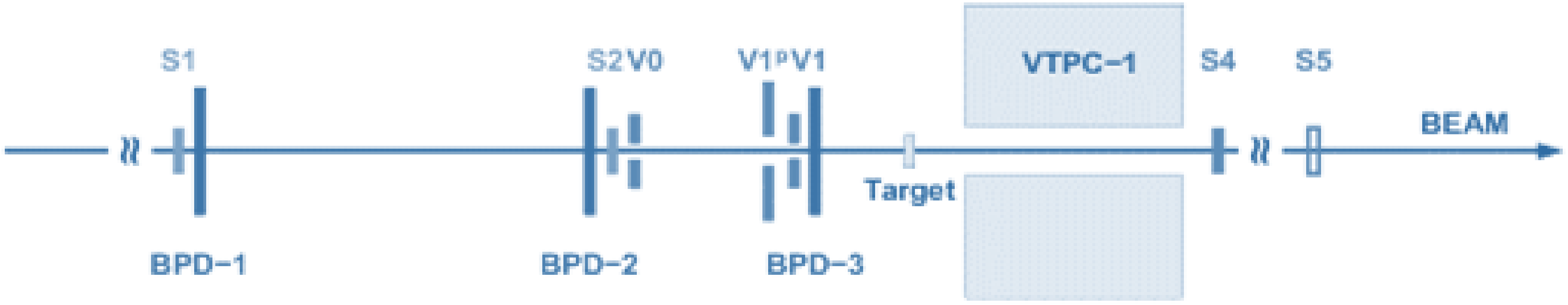


New trigger and data
acquisition system, including
Beam Position Detectors

New Time-of-Flight
detectors

Upgrade of Projectile
Spectator Detector

Beam Position Detectors at NA61/SHINE

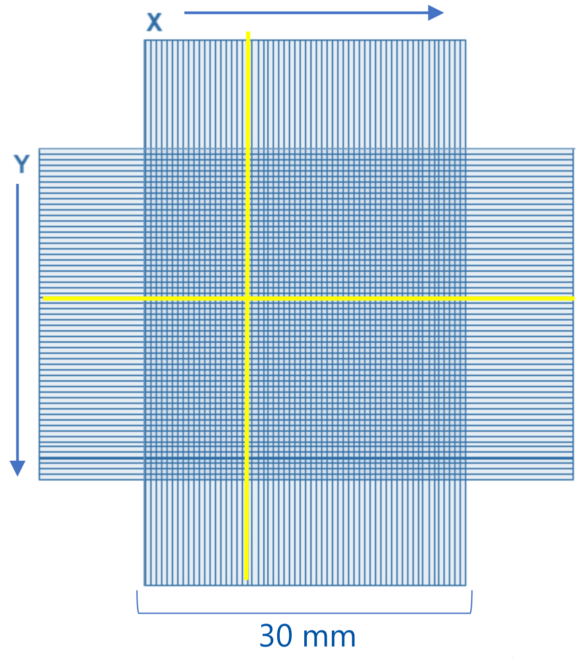


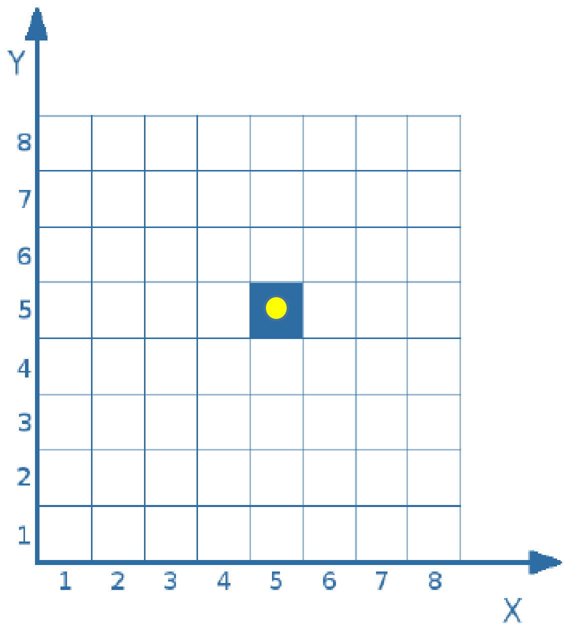
Beam Position Detectors (BPD-1,2,3) provide position and charge measurement of the incoming beam particles during the data taking.

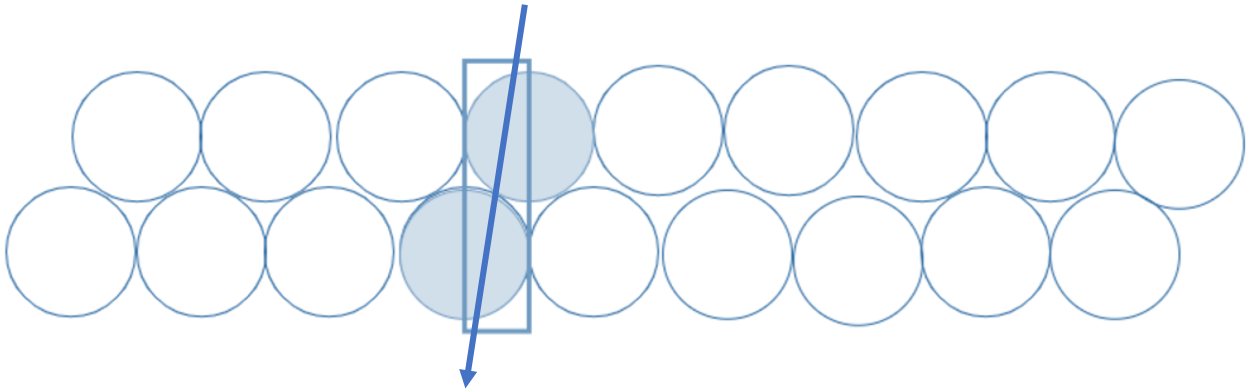
The upgrade of BPDs is necessary

- to work efficiently both with hadron and heavy ion beams with beam intensity on the level of 100 kHz
- to minimize the detector material on the beamline

First solution: scintillating fiber detector





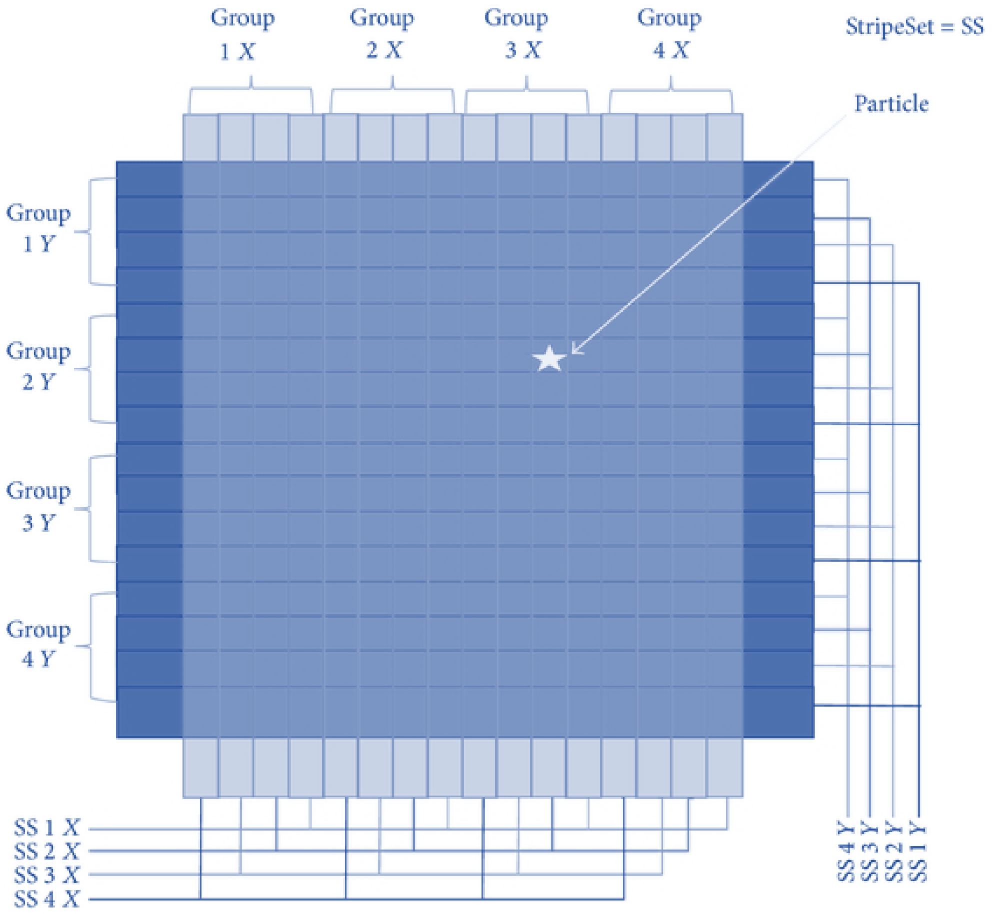


- two perpendicularly arranged ribbons to measure the position in XY plane
- each ribbon consists of two layers of green-emitting round scintillating fibers Ø250 μm (Saint-Gobain BCF-60)
- the layers are shifted by 125 μm
- readout is done by multianode photomultiplier (Hamamatsu H9500)

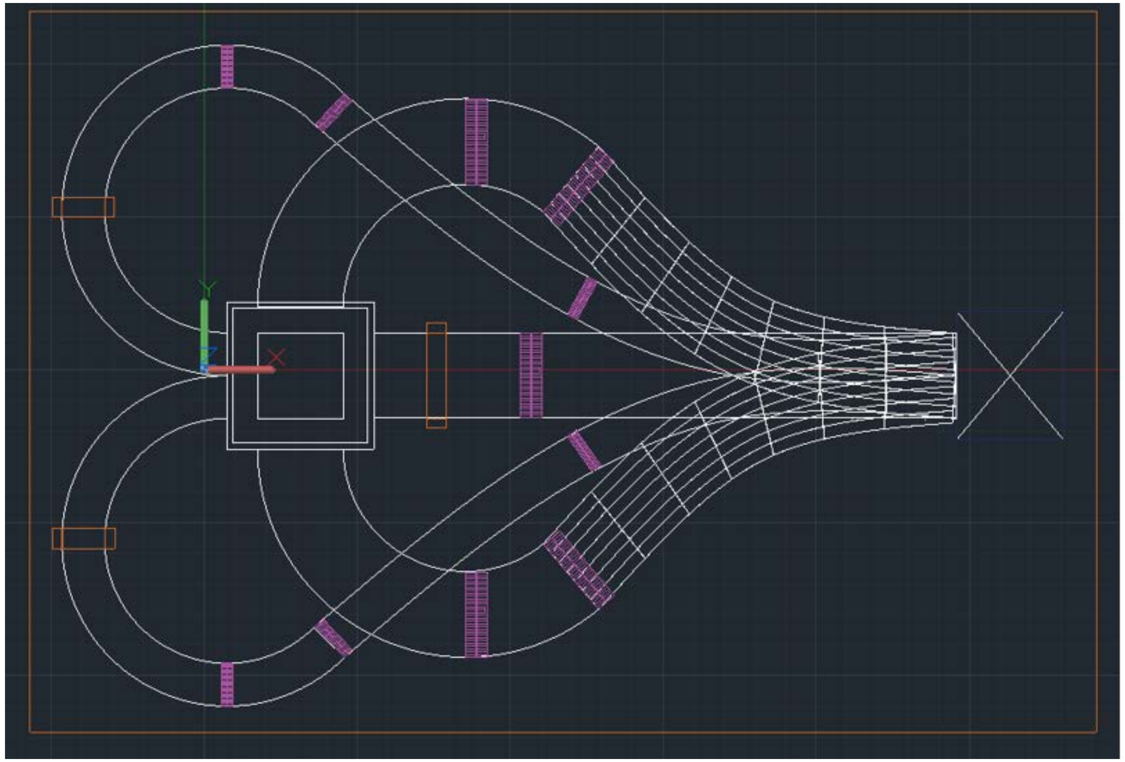
First solution: scintillating fiber detector

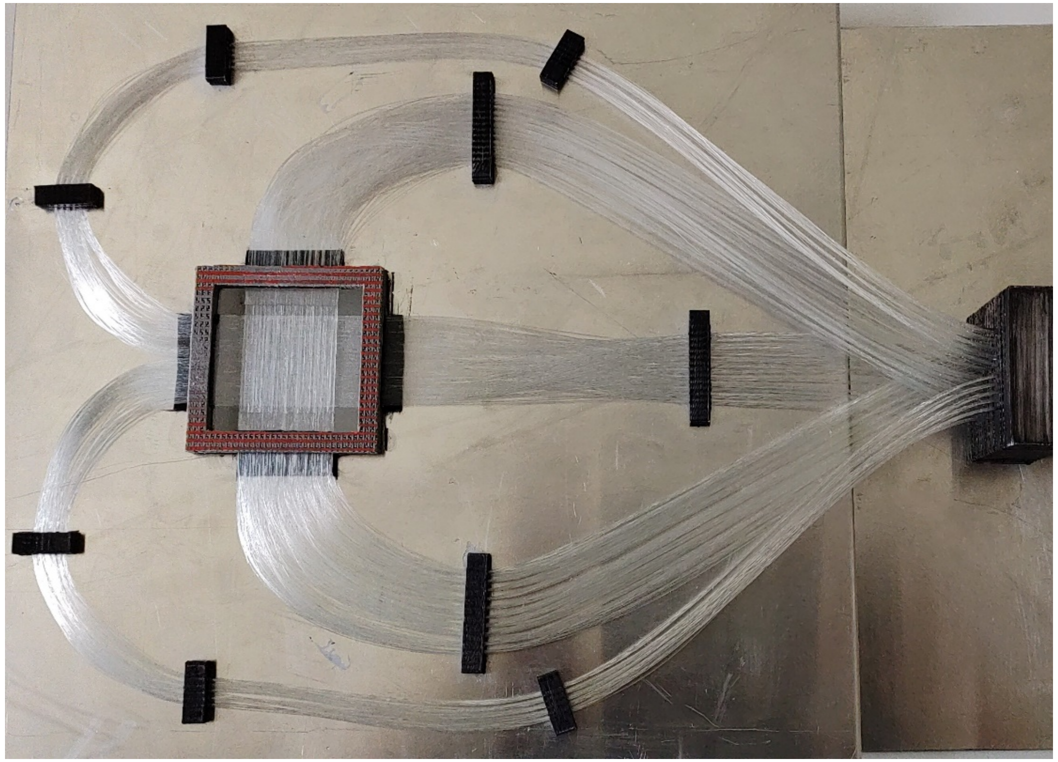
D. Lo Presti *et al* 2013 *JINST* **8** P04015 (INFN patent)

- for classic fiber-by-fiber readout from both ends of each ribbon 120 x 4 x 2 = 960 ch. is necessary
- grouping of scintillating fibers was applied in order to reduce number of used channels on the PMT
- at one end of the ribbon fibers are read together in groups of 12 contiguous fibers
- at other end of the ribbon the 1st (2nd and so on) fiber of each group are read together as set
- beam particle crossing the ribbon generates signal at both ends allowing to identify precise position
- with grouping method only **88 ch.** instead 960 ch. for single XY detector!



First solution: scintillating fibre detector



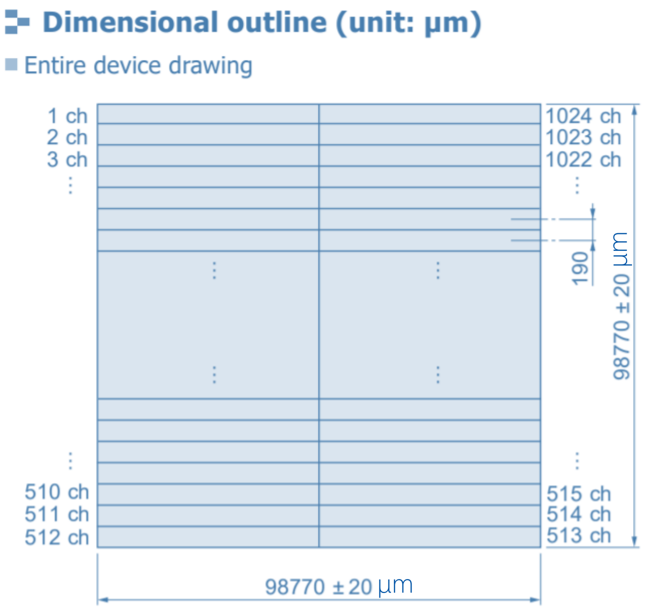


The prototype of the detector has been manufactured and tests are in progress

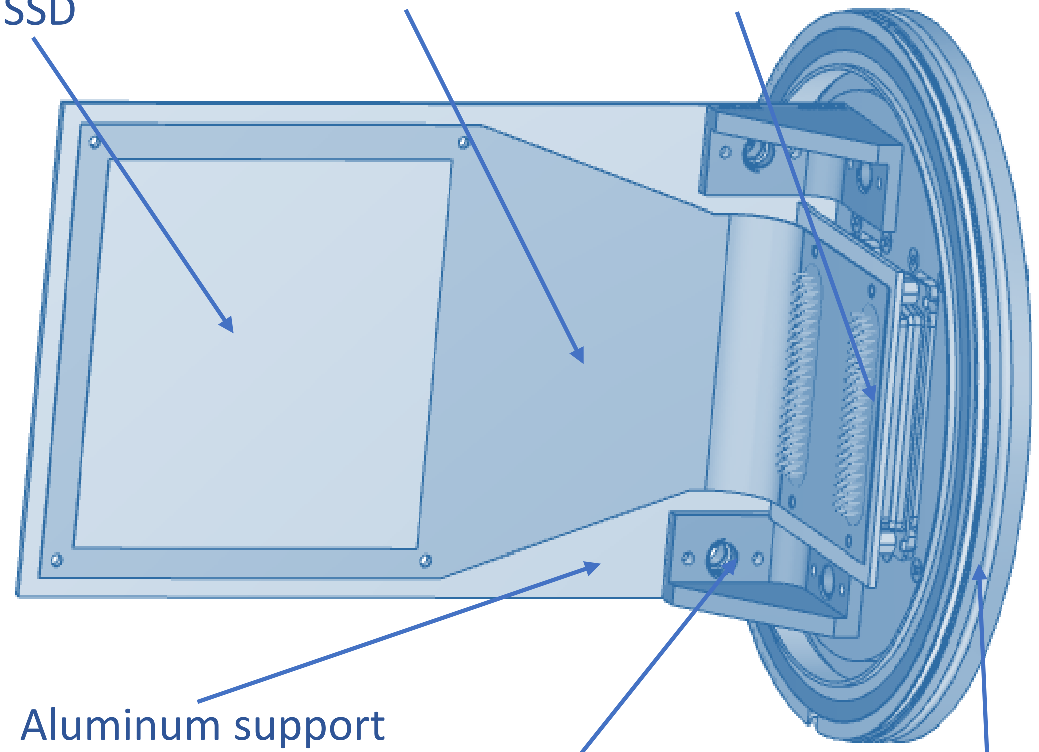
Second solution: single-sided silicon strip detector

Single layer (one axis):

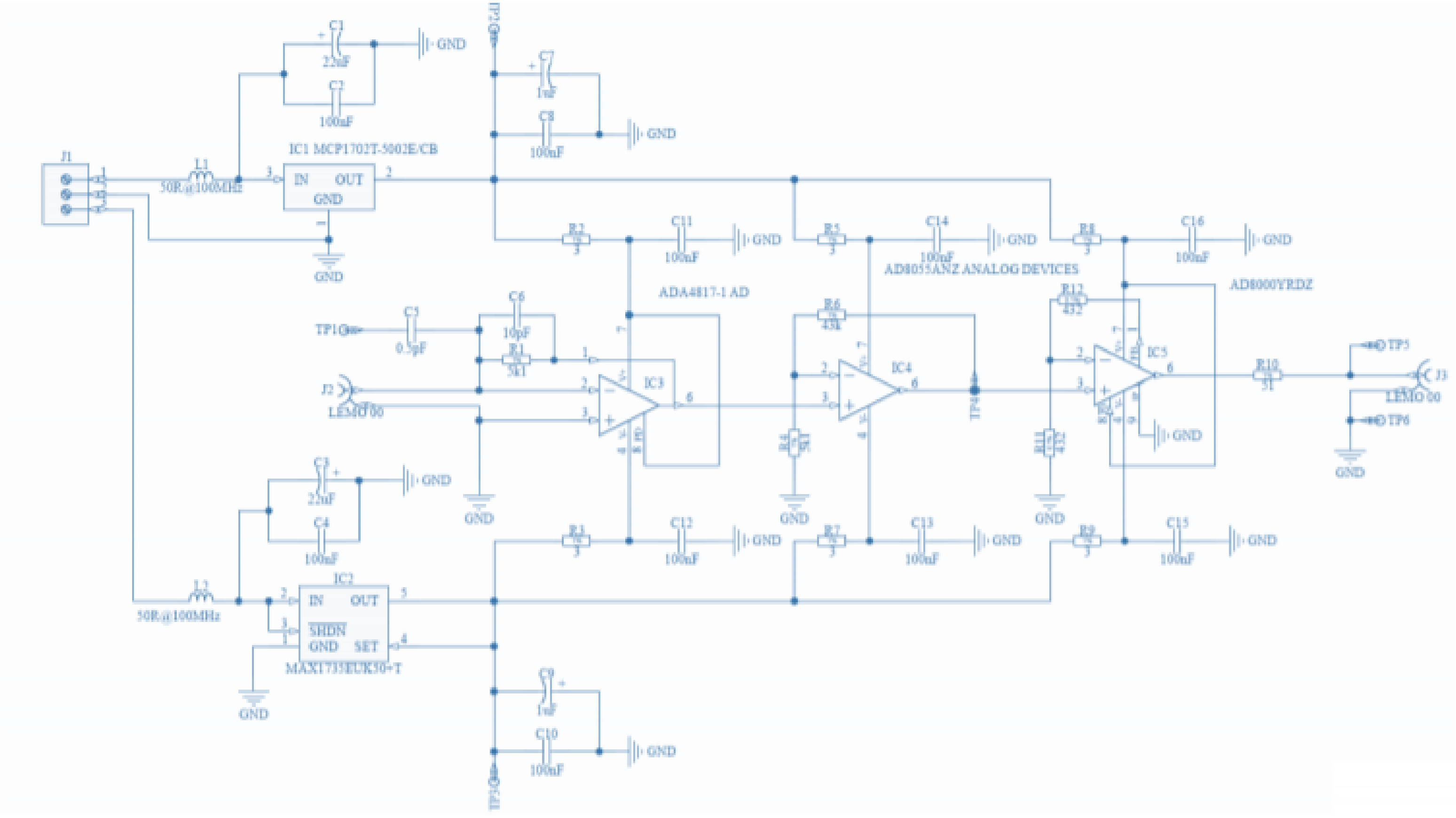
- single-sided SSD (Hamamatsu S13804)



- flex PCB
- mechanical frame
- 2 high density connectors Xavax 104
- 2 high density feedthrough Xavax 104



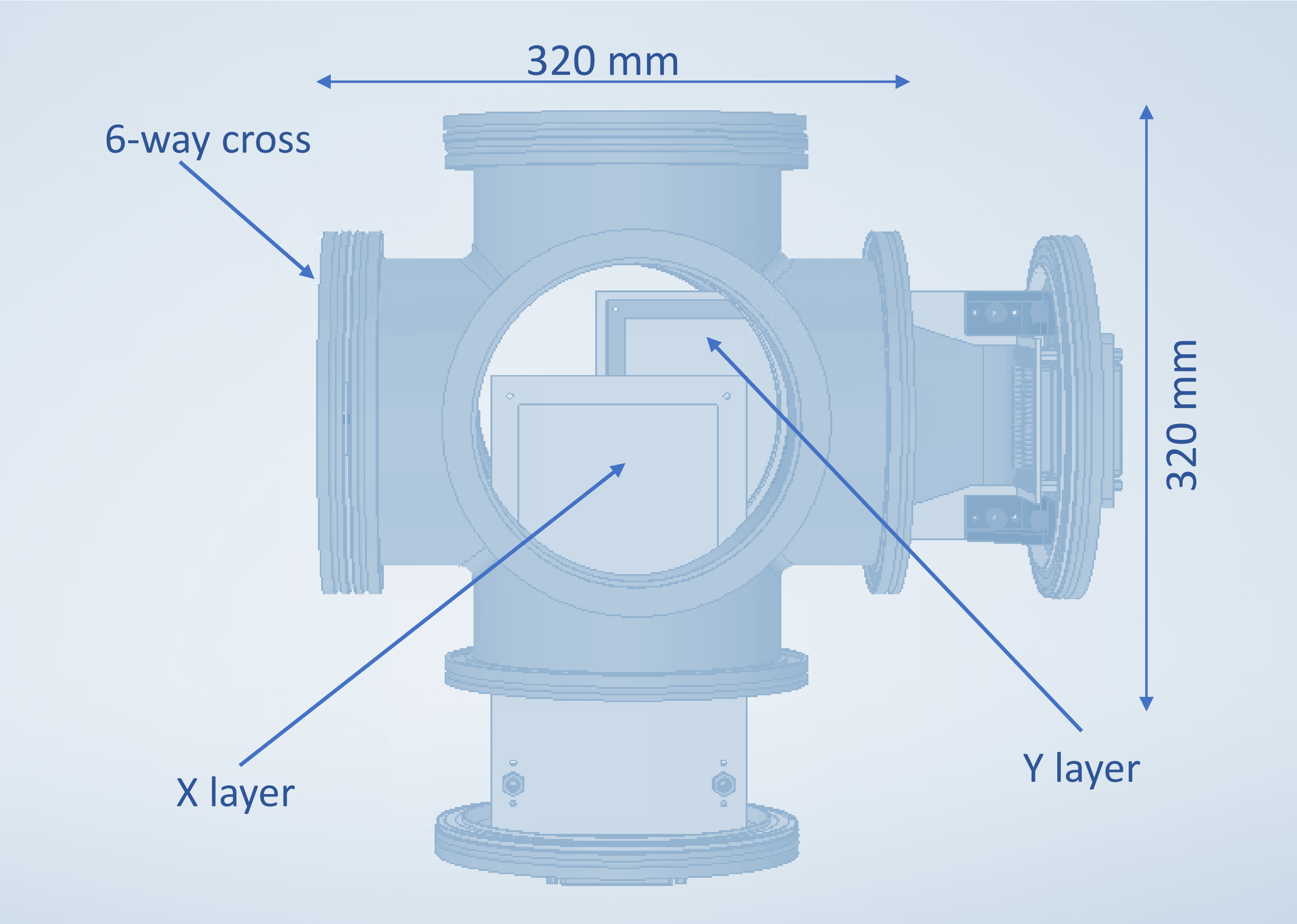
Second solution: single-sided silicon strip detector



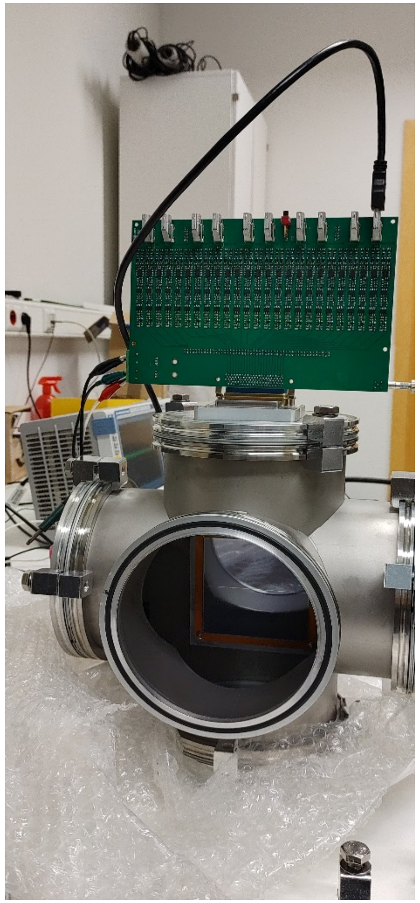
- there is no ready solution for readout and amplifiers on market
- a new set of electronics was designed with off-the-shelf components only
- prototype was fitted with scale-changing circuitry to operate at both hadron and heavy ion beams

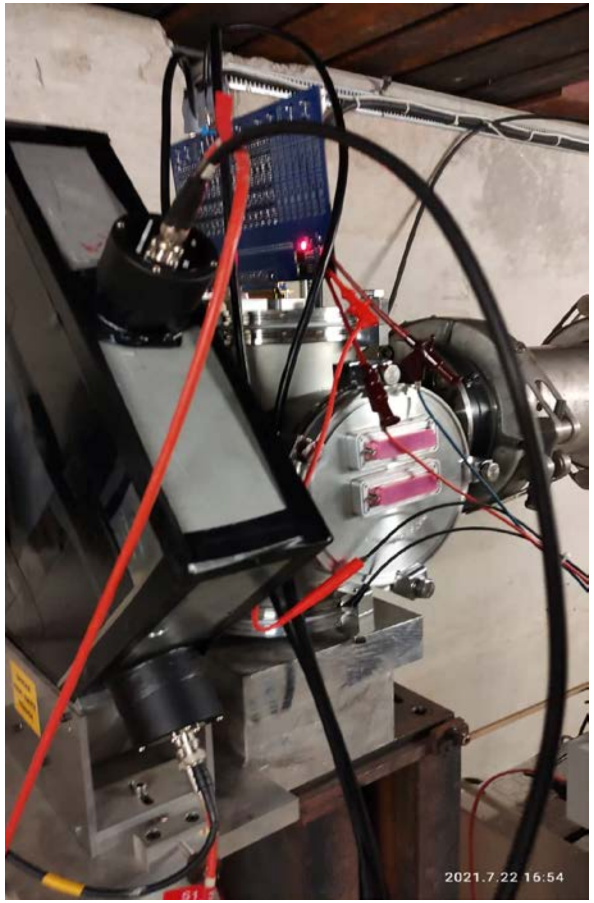
Second solution: single-sided silicon strip detector

- beam installation:
  - 6-way cross
  - 2 layers inserted: one from top and one from side
  - connected to the beamline (detector operates in the vacuum)
- mounting fixtures are offset, so the beam would hit the middle detector's sensitive area (200 center channels)
- amplifiers outside of the vacuum for hadron and heavy ion beams
- HDMI connection to the readout



Second solution: single-sided silicon strip detector

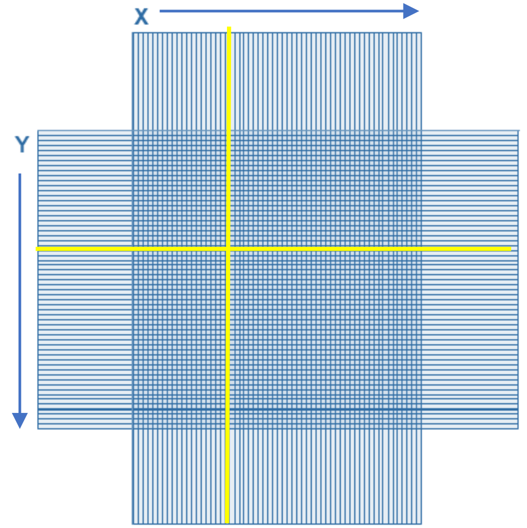


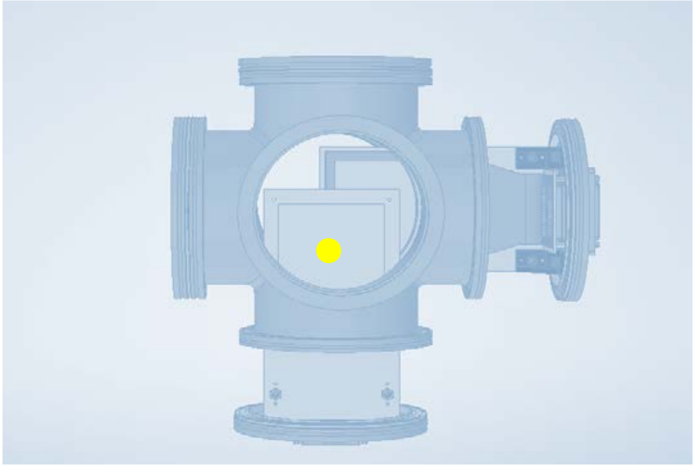


The detector has been manufactured and first data was taken during the test period at CERN and is currently analyzed

Summary

- the development of new beam position detectors is a crucial part of the upgrade of NA61/SHINE detector
- two new kinds of beam position detectors are prepared and being currently tested:
  - scintillating fiber detector with a multi-anode photomultiplier readout, which is built of two perpendicularly arranged ribbons, each consisting of two shifted layers of green-emitting scintillating fibers with a diameter of 250 μm
  - detector based on the single-sided silicon strip detector (Hamamatsu S13804) with custom-made readout electronics





Thank you for your attention!

All comments and questions are very welcomed:
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Backup

Fibers properties

Features/Benefits

Flexibility to conform to the surface shape, yielding geometries superior to those of other types of detectors. Examples are detectors for monitoring pipes or barrels.

Specifications

Fiber Type	Emission Color	Emission Peak, nm	Decay Time, ns	# of Photons per MeV**	Characteristics/ Applications
BCF-10	blue	432	2.7	~8000	General purpose; optimized for diameters >250µm
BCF-12	blue	435	3.2	~8000	Improved transmission for use in long lengths
BCF-20	green	492	2.7	~8000	Fast green scintillator
BCF-60	green	530	7	~7100	3HF formulation for radiation hardness
BCF-91A	green	494	12	n/a	Shifts blue to green
BCF-92	green	492	2.7	n/a	Fast blue to green shifter
BCF-98	n/a	n/a	n/a	n/a	Clear waveguide

** For Minimum Ionizing Particle (MIP), corrected for PMT sensitivity

PMT properties I

GENERAL

Parameter		H9500	H9500-03	Unit
Spectral Response		300 to 650	185 to 650	nm
Peak Wavelength		400		nm
Photocathode Material		Bialkali		—
Window	Material	Borosilicate glass	UV glass	—
	Thickness	1.5		mm
Dynode	Structure	Metal channel dynode		—
	Number of Stages	12		—
Number of Anode Pixels		256 (16 × 16 matrix)		—
Pixel Size / Pitch at Center		2.8 × 2.8 / 3.04		mm
Effective Area		49 × 49		mm
Dimensional Outline (W × H × D)		52 × 52 × 33.3		mm
Packing Density (Effective Area / External Size)		89		%
Weight		177		g
Operating Ambient Temperature		0 to +50		°C
Storage Temperature		-15 to +50		°C

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter	H9500	H9500-03	Unit
Supply Voltage (Between Anode to Cathode)	-1100		V
Average Anode Output Current in Total	100		µA
Divider Current at -1100 V	180		µA

PMT properties II

CHARACTERISTICS (at 25 °C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous Ⓐ	50	60	—	μA/lm
	Blue Sensitivity Index (CS 5-58) Ⓑ	8.0	9.5	—	—
Quantum Efficiency at 420 nm		—	24	—	%
Anode Sensitivity	Luminous Ⓒ	—	90	—	A/lm
Gain Ⓒ		0.5×10^6	1.5×10^6	—	—
Anode Dark Current per Channel Ⓓ		—	0.02	—	nA
Anode Dark Current in Total Ⓓ		—	5	30	nA
Time Response Ⓔ	Rise Time Ⓕ	—	0.8	—	ns
	Transit Time Ⓖ	—	6	—	ns
	Transit Time Spread (FWHM) Ⓗ	—	0.4	—	ns
Pulse Linearity per Channel (±2 % deviation)		—	0.2	—	mA
Anode Uniformity (Condition Figure 3)		—	1: 3	1: 5	—
Cross-talk Ⓙ		—	5	—	%

NOTES

Ⓐ:The light source is a tungsten filament lamp operated at a distribution temperature of 2856 K. Supply voltage is 150 volts between the cathode and all other electrodes connected together as anode.

Ⓑ:The value is cathode output current when a blue filter(corning CS 5-58 polished to 1/2 stock thickness) is interposed between the light source and the tube under the same condition as Note Ⓐ.

Ⓒ:Measured with the same light source as Note Ⓐ and with the anode-to-cathode supply voltage and voltage distribution ratio shown in Table 1 below.

Ⓓ:Measured with the same supply voltage and voltage distribution ratio as Note Ⓒ after 30 minutes storage in darkness.

Ⓔ:Those are test data when a signal from a central channel of 256 anodes is used, while all photocathode are illuminated by pulsed light source.

Ⓕ:The rise time is the time for the output pulse to rise from 10 % to 90 % of the peak amplitude when the whole photocathode is illuminated by a delta function light pulse.

Ⓖ:The electron transit time is the interval between the arrival of delta function light pulse at the entrance window of the tube and the time when the anode output reaches the peak amplitude. In measurement, the whole photocathode is illuminated.

Ⓗ:Also called transit time jitter. This is the fluctuation in electron transit time between individual pulses in the single photoelectron event, and defined as the FWHM of the frequency distribution of electron transit time.

Ⓙ:Supply Voltage: -1000 V Light Source: Tungsten filament lamp + blue filter (corning CS 5-58 polished to 1/2 stock thickness)
Aperture Size: Approx. 2 mm × 2 mm
One anode is illuminated through the aperture and the output of the adjacent anodes are calculated as relative value, with 100 % being equal to the output of the illuminated anode. The cross-talk is the relative value of the adjacent anodes expressed in %.

SSD properties I

Structure

Parameter	Specification	Unit
Type	PolySi-bias AC-readout	-
Si thickness	320 ± 15	μm
Si crystal plane direction	<100>	-
Chip size	(98770 ± 20) × (98770 ± 20)	μm
Active area	97280 × 97280	μm
Strip layout	512 ch × 2 columns	-
Number of strips	1024	ch
Strip pitch	190	μm
Strip implant width	80	μm
Strip readout Al width	90	μm
Readout pad size	165 × 100 × 2	μm

Electrical and optical characteristics (Ta=25 °C)

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Breakdown voltage	V_{BR}		200	-	-	V
Dark current	I_D	V_R=200 V	-	-	3	μA
Full depletion voltage	Vfd		-	-	100	V
Defective strip rate	-		-	-	5	%
PolySi resistor	Rpoly		5	10	15	MΩ

SSD properties II