Common R&D project to upgrade the COMPASS Polarized Target with the Recoil Detector (PT with RD). (To be submitted to the CERN EP Department R&D on experimental technologies)

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Conveners: J. Friedrich, I. Savin.

1. Introduction: possible application of the COMPASS PT with RD

In 2016-17 the COMPASS collaboration has collected the data to study the exclusive Deep inelastic Virtual Compton Scattering (DVCS) process using the μ+ and μ beams and the 2.5 m long liquid hydrogen target surrounded by two concentric rings of scintillating counters (CAMERA). CAMERA detects recoil particles identity of which (PID) is determined using the time of flight technique (TOF). These data permit to measure the spin independent (unpolarised) part of the Generalized Parton Distributions (GPD) functions called as GPD H. To solve the long standing proton spin crisis, additionally to the GPD H one needs to know the spin-dependent (polarised) part of GPD called as GPD E. For this purpose one needs to use the polarised target equipped with Recoil Detectors (RDs). Present COMPASS polarised target (PT) and CAMERA cannot be used for this purpose because all low energy recoil particles absorbed in the materials surrounding the PT target cells.

The COMPASS Polarised Target, equipped with Recoil Detector (PT with RD), can be used for the following studies:

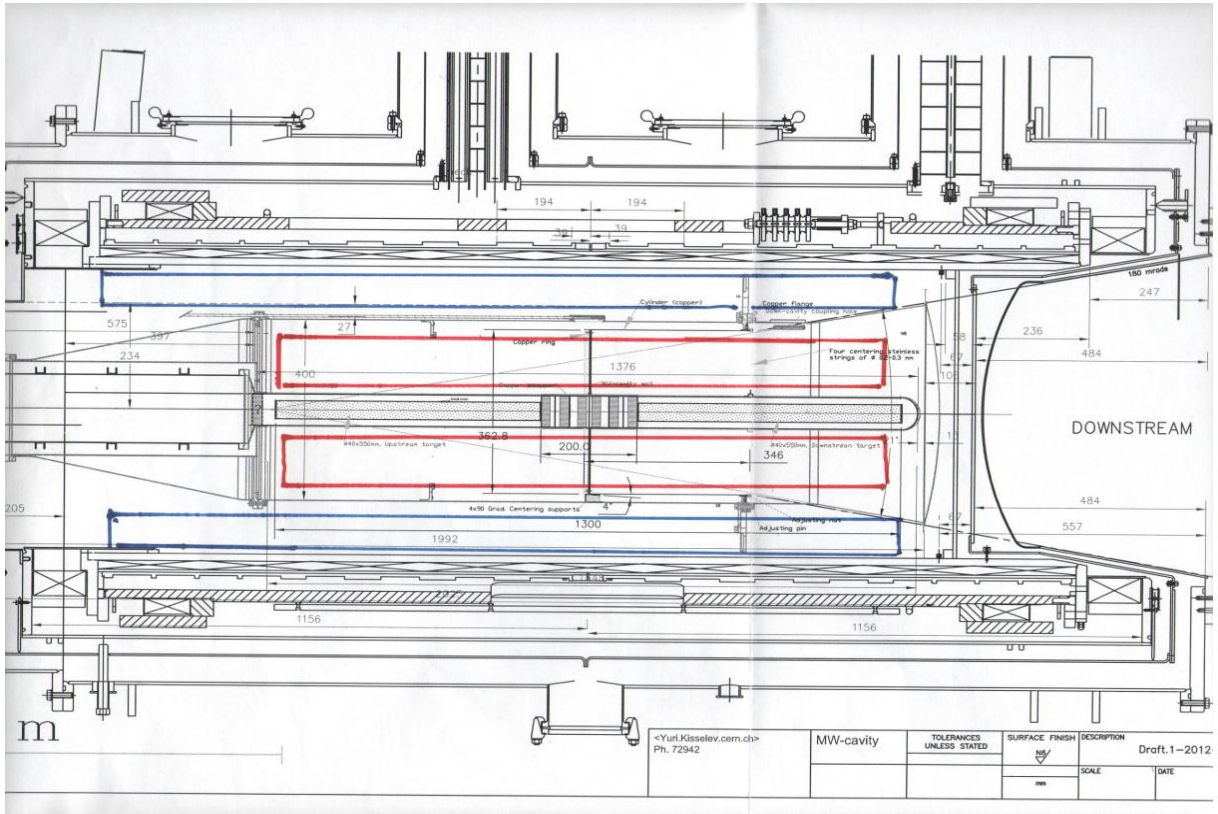
- exclusive DVCS mechanism, in the muon beam;

- J/Ψ production with its subsequent decays in the lepton pairs;

- Exclusive DY mechanism in the pion beam .

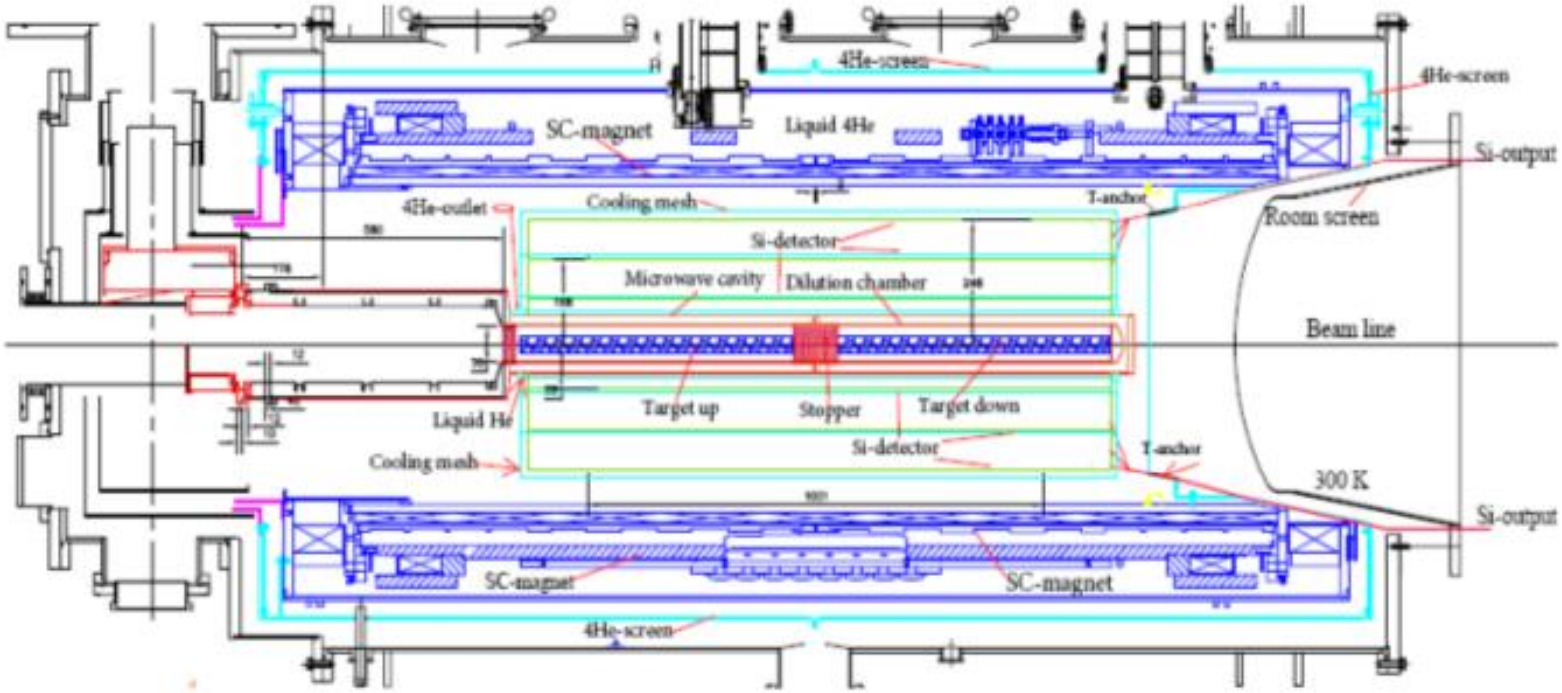
2. COMPASS Polarised Target. Status and modification.

Considering the drawing of the COMPASS PT magnet, used for the DY studies , one can see that inside its volume there are free zones marked red and blue. The red zone dimension (inside of the MW-cavity volume) is about 108 mm along the radius while the blue one is about 66 mm. Both can be used by detectors capable to work in the environments of: (i) a magnetic field (longitudinal or transversal) of about 0.5-2 T, (ii) a low temperature of about 5 – 10 K ° , (iii) a presence of the micro-wave (MW) field (temporary) and (iv) a vacuum of about 10 -6 mm Hg. Note that the red free zones are inside of the MW cavity. The best detectors capable to work in such environments could be the Silicon ones. Options for the Silicon (SiFi) are to be considered.

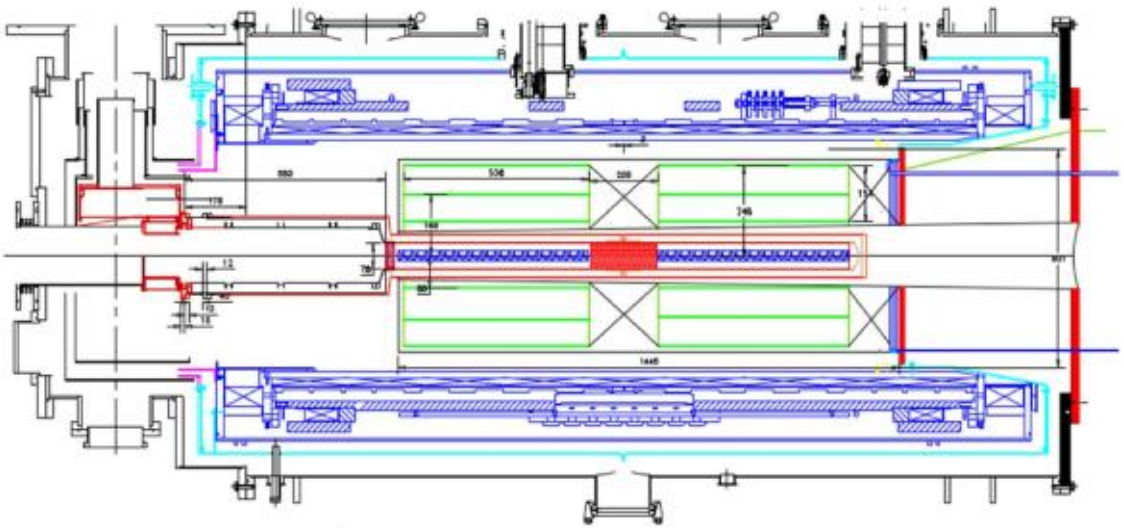


2. COMPASS Polarised Target. Status and modification.

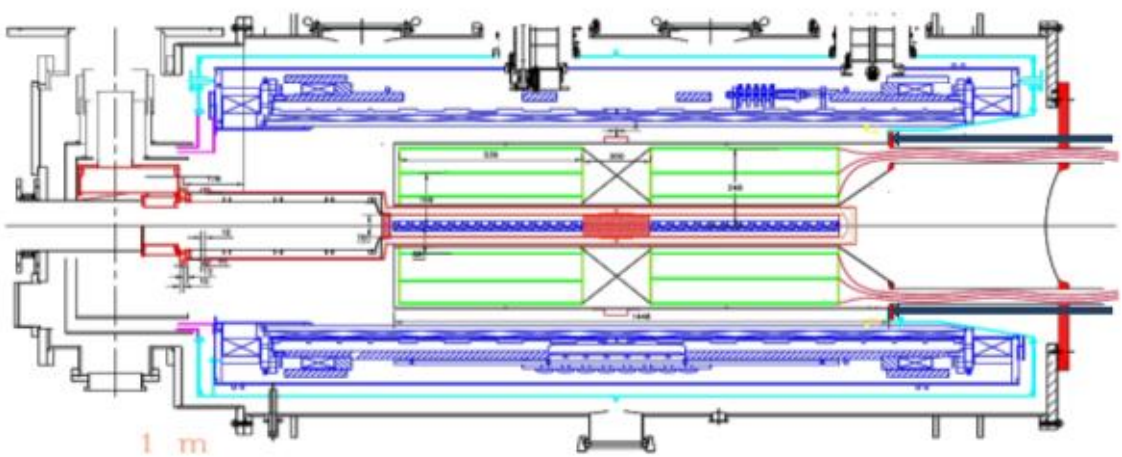
New design of the MW cavity. It is assumed that the shape of the cavity is modified and the rest of the inner target magnet volume is decupled from it but have the same vacuum. The cylindrical part of the cavity, supported by plastic rings, can be made of the 0.2-0.4 mm thick copper foil to avoid distortion of the MW field by a presence of Silicon detectors. The MW cavity is cooled by the circulating flow of ^{4}He. A part of this flow cools also a mesh surrounding the Silicon detectors volume and keeping it at the uniform temperature. This prevents decrepitating of Silicon and takes a heat of the Silicon readout electronics. Thermal isolation of the detector's volume also should be considered. Extraction of the power from the Silicon and its readout electronics can be one of the R&D subjects. The radial dimension of the free space (detector space) in this case is 180 mm. The red lines marked by "Si-output" show one of possible places for input-output connections and places of their contacts (T- anchor) with the He screen. Possibility to have the second place for i/o in the upstream flange is to be considered. Green lines show three layers of the Silicon detectors.



2. COMPASS Polarised Target. Status and modification.



The version of the modified MW-cavity is presented in Figure left. In this option, the silicone detectors are located in the separate blocks. These blocks can be assembled outside of the target. They can be warmed up to about 70 K and protected by heat shields from the helium environment of the target volume with a temperature of about 5K. Similar version with the modified forward flange is shown in Figure below.



The last modification is preferable:
(i) it does not limit the acceptance in the forward direction,
(ii) the length of cables will be minimised,
(iii) “worm” chips can be fixed on the outside surface of the flange at the room temperature,
(iv) lengths of the target cells can be increased up to 75 cm each. (The 3-cells option is to be considered).

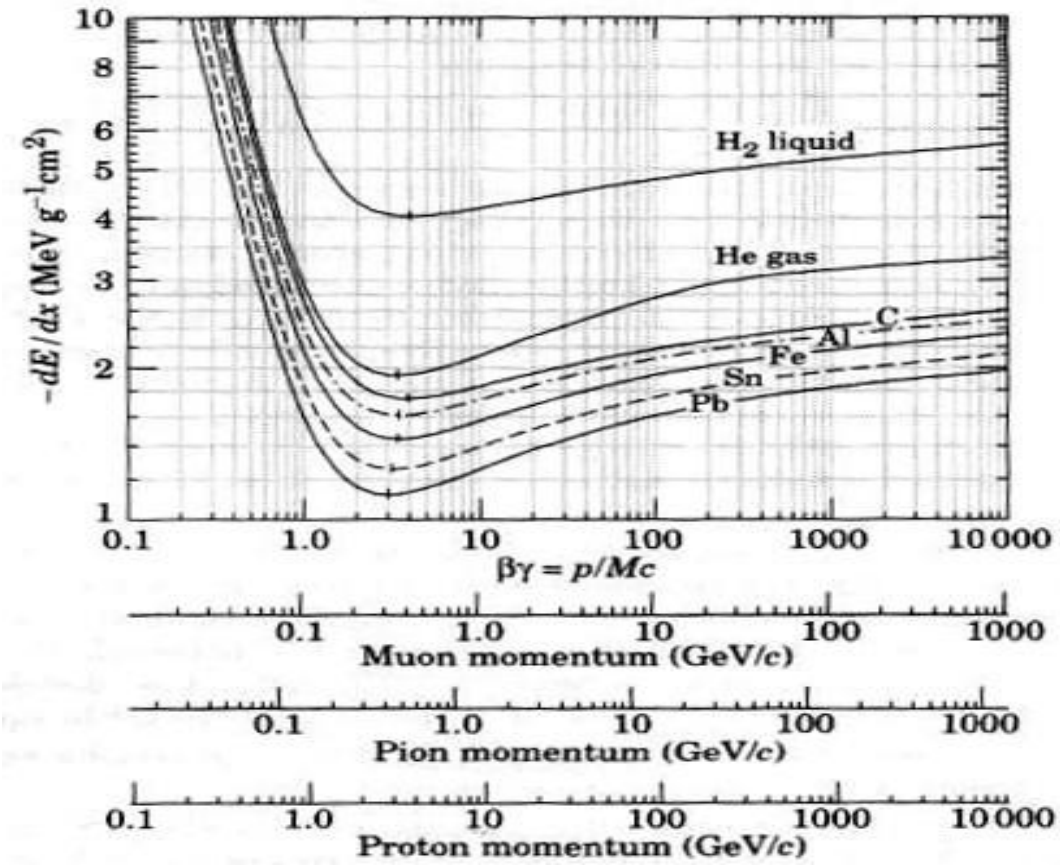
3. PID inside the COMPASS PT magnet

In order to use the dE/dx technique for PID distinguishing protons, kaons and pions, detectors should be able to measure:
(i)space coordinates of the recoil particles with a precision of about 1 mm at least in 3 space points,
(ii) momentum of each recoil particle in the region of about 100-1000 MeV/c (preliminary estimation by MC) with a precision of about 5-10% and
(iii) dE/dx for each recoil particle with precision of about 10%.

Momentum of the particle is determined from reconstruction of its trajectory in the magnetic field which needs at least three space points. The fourth point (redundant) along this trajectory will be a vertex of an event to be used for improvement of resolutions. Feasibility of such characteristics is to be confirmed by MC studies.

For estimations of the required precisions of the momentum and (dE/dx) (p) measurements, one needs to use the (dE/dx) (p) rates in the Si for π, K and p. Note, that for this type of PID, the time of flight technique is not required at all.

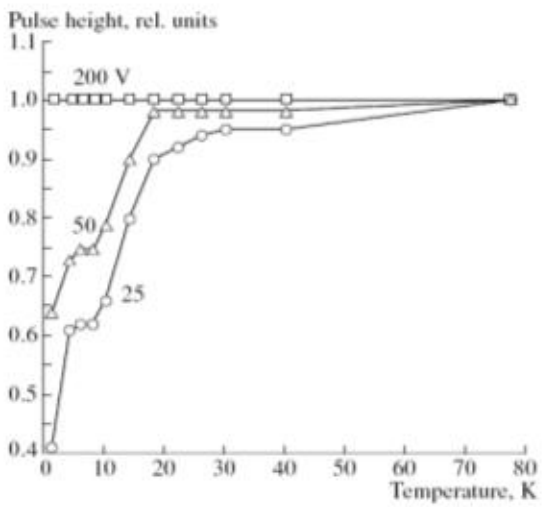
3. PID inside the COMPASS PT magnet

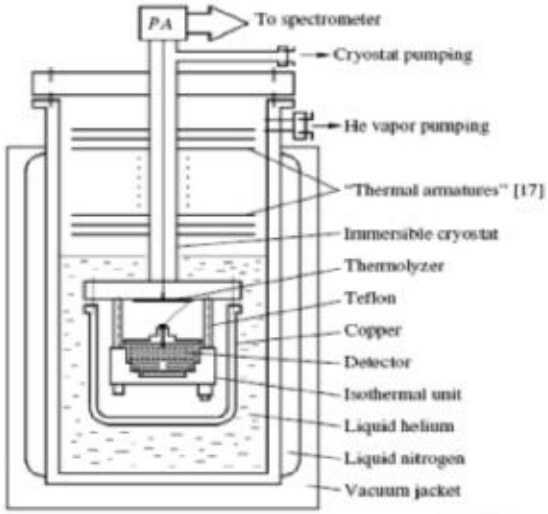


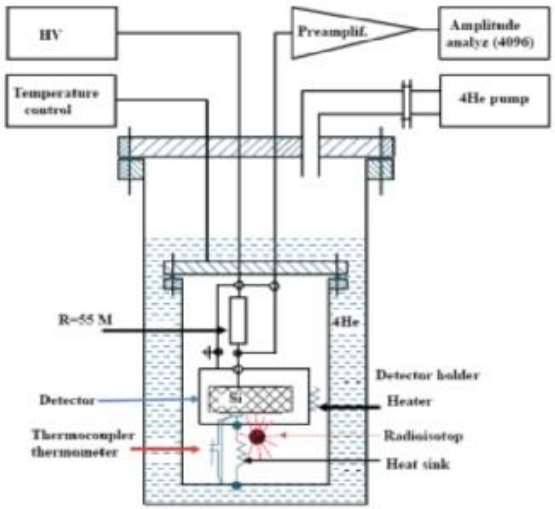
Mean energy losses in various atomic elements as a function of βγ.

4.Silicon detector at low temperature.

Performance of silicon detectors is studied in a number of papers (see [1] and references therein). An example of the pulse height dependence on temperature for the n-Si detectors is shown in Figures below.







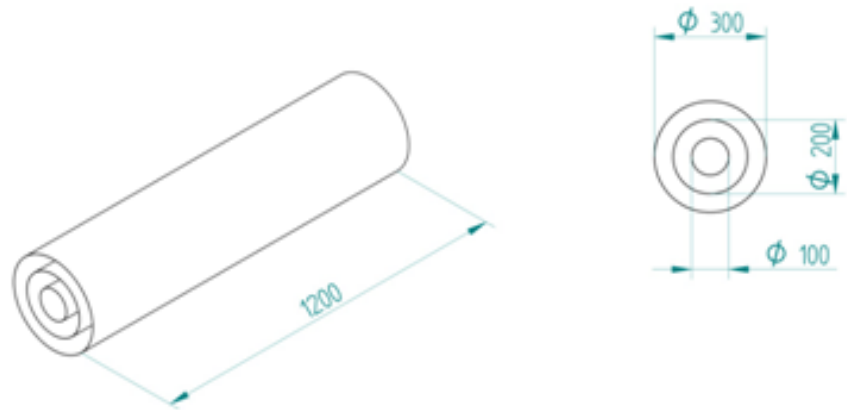
Stable performance of this and other type of detectors at the temperature up to 1K ° requires higher working voltages.

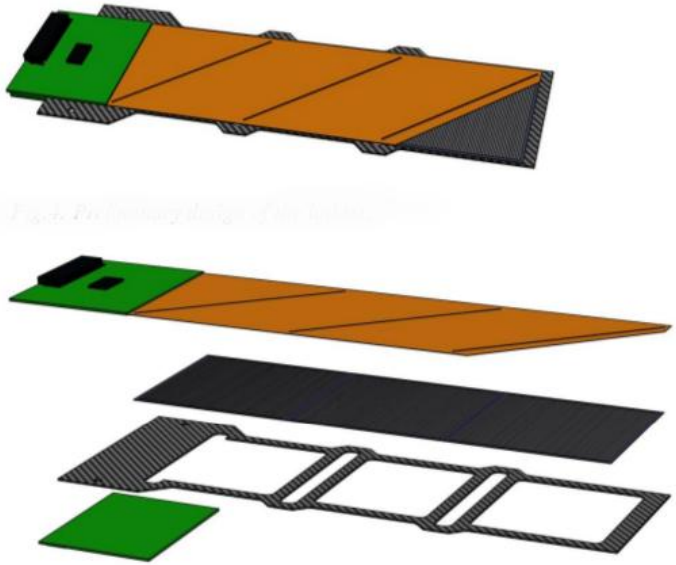
[1] K.N. Gusev et al., A study of the performance characteristics of silicon and germanium semiconductor detectors at temperatures below 77K, Instruments and Experimental Techniques, 2007, Vol.50, No.2, pp 202.

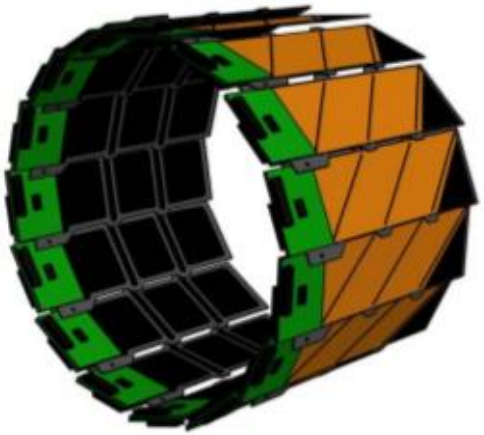
4.Silicon detector structure.

Possible structure of the detector layers is shown in Figure below. The structure should be sub-divided in two parts, each of which is to be placed over one of the target cell. The length and position of the layers along the target is a subject of the acceptance-wise optimizations.

Each layer contains a number of ladders. The ladder supporting the double-sided Silicon strip detectors, 63x63 mm each, with a ~ 0.5 mm pitch should be made of a low-Z material



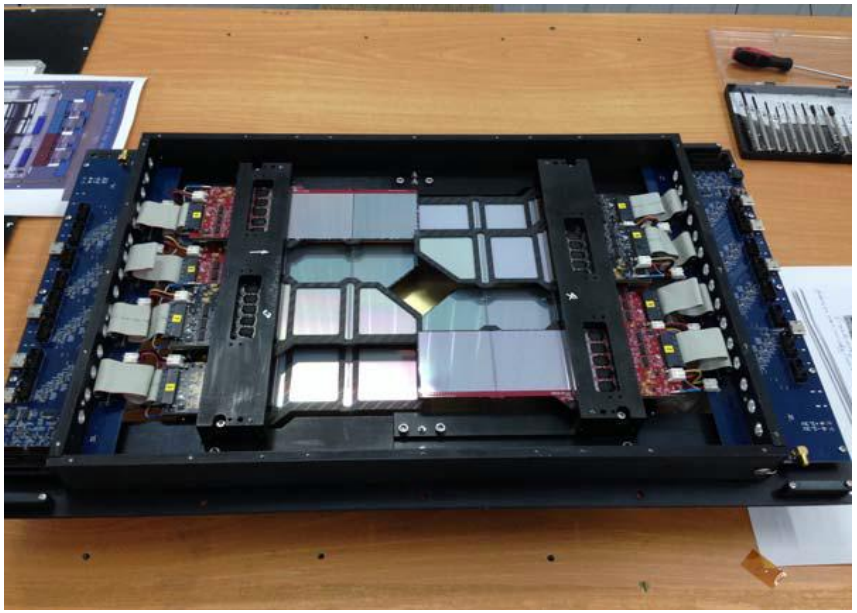




Proposal on Si-detector – next talk

4.Silicon detector structure.

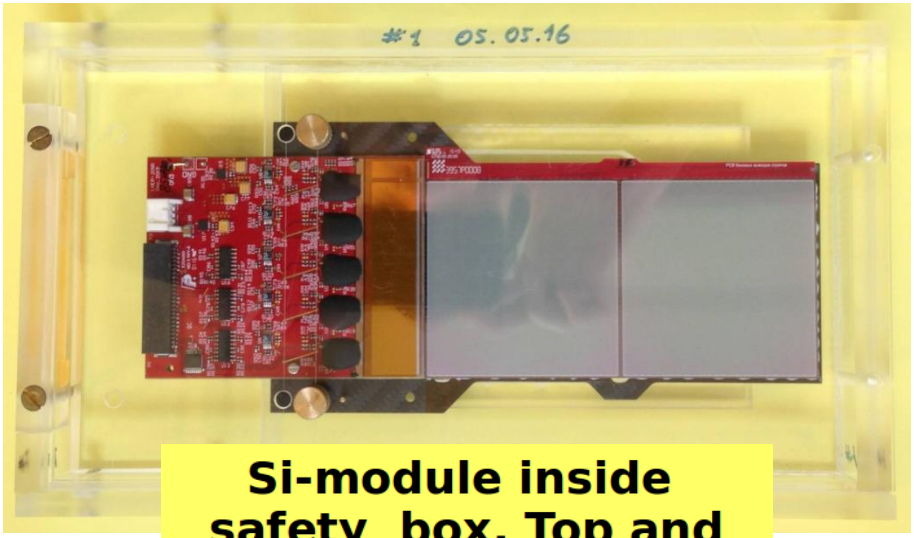
The possible design of recoil tracker system based on Double-Sided Silicon Detectors is proposed. A coordinate plane consists of 10240 measuring channels, pitch adapter and readout electronics. Each element was tested and assembled into a coordinate plane. The first tests of the plane with ^{106}Ru source were carried out before installation for the BM@N experiment (JINR,LHEP).



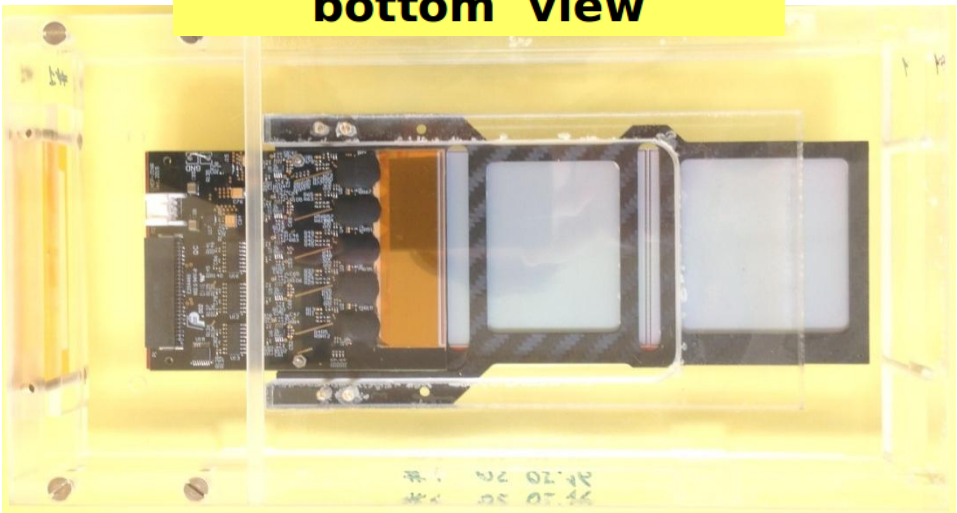
The details can be found in talk given be
A. Nagaytsev, DAQFEET, Prague, Nov 2017

The coordinate plane consist of 8 detector modules with 10240 strips (measuring channels) is assembled on a mechanical frame and placed in a box which is light and electromagnetic shielding. In the center of the plane the inner 4 modules form have a square hole with a side of 50 mm, intended for the beam pipe. All electrical signals – control, information, low voltage (LV), detector bias (HV) are transmitted to the modules and received from the modules through short micro cables to two cross-boards. Each of two cross-boards is responsible for upper and lower half of the coordinate plane of 4 modules by 5120 strips. Analog signals from the output of multiplexer of each chip are transmitted from the cross-board by cable length about 20 m to the inputs of analog-to-digital converters (ADC).

4.Silicon detector structure.



Si-module inside safety box. Top and bottom view



The module consists of two square snape silicon microstrip detector, two electronics read-out cards (one on each side of the detector) and a mechanical frame for precise module positioning, assembling of detectors and read-out cards. Each side of detector has strips, which are continuation of each other, are electrically connected by ultrasonic bonding. DSSD have two types of geometry – square and pentagon. Dimensions of silicon detectors are 63 × 63 mm2, the sensitive area of detectors is 61 × 61 mm2, and the thickness of detectors is 300 μm. Detectors are made on four inch FZ n-type conductivity silicon wafers with resistivity ρ>8kΩ × cm. The total dark current of detectors is < 1μA/120V, full depletion voltage is 40V. Each detector has 640 p+ strips with 0° and 640n+ strips located at an angle of 2.5°. The pitch of p+ strips is 95 μm and the pitch n+ is 103 μm. The capacity of each strip (bulk + interstrip) is 8 pF.

5. Subject of the Common R&D Project

The aims of the present R&D project are as follows:
- to study the engineering problems connected with a detector's insertion inside the inner volume of the target;
- tests of the silicon detectors in the environment close to that of the present PT, consideration of alternatives to silicon detectors;
- tests of the Silicon detectors and associated electronics in the environment close to that of the present PT.
- tests of the Silicon detectors can be performed partially in the laboratory using the specialized set-up and partially in a beam.

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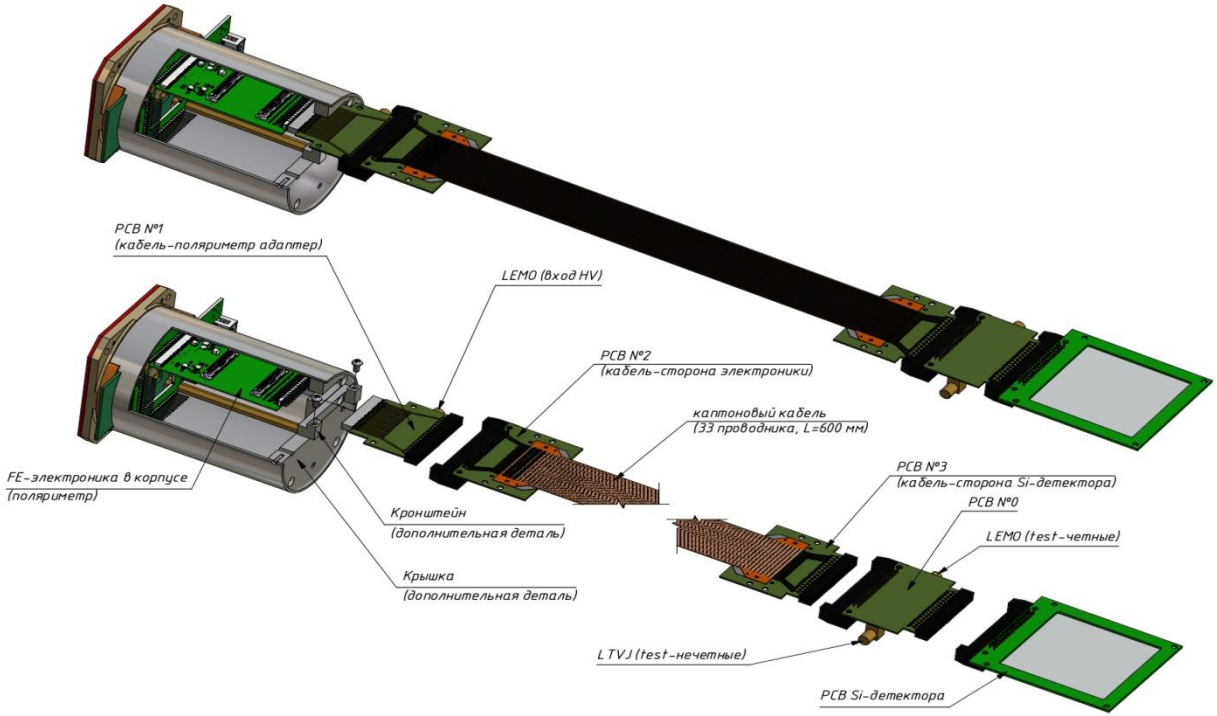
The list of measurements with the test set-up, first of all should include:
- responses and resolutions of commercially available Silicon detectors,
- operation of the FE-electronics (preamplifiers) and cables in the environment close to that of the PT,
- tests of materials which will be used in mechanical supports of Silicon detectors,
- tests of the kapton multilayer flexible buses (KMFB) of different length at different temperatures.

5. Subject of the Common R&D Project

The Dubna, Prague and Munich groups with the participation of the MSU and Ukrainian groups will perform preliminary test of the silicon detectors connected by cables (KMFB) to readout electronics. The set up for these tests is under preparations at Dubna.

The preliminary tests will be performed at the room temperature using the KMFB of different length up to 120 cm. Tests at the cryogenic temperatures are under discussions.



5. Subject of the Common R&D Project

Tests of the Silicon detectors to be used in RD can be performed partially in the laboratory using the specialized set-up and partially in a beam. The Silicon detector samples, together with input/output systems, placed inside the cooler, can be tested with this set-up up to 4 K°. The design of the set-up with the cryogenic cooler does not need the external helium system. Tests of the selected Silicon detectors can be performed at the test beams either at CERN or at Dubna.

5. Subject of the Common R&D Project

Assuming the R&D project helps to solve all technical problems, the suggested obligations of the participating Institutions concerning the final design of the PT with RD for the COMPASS-like experiments beyond 2020 could be as following.

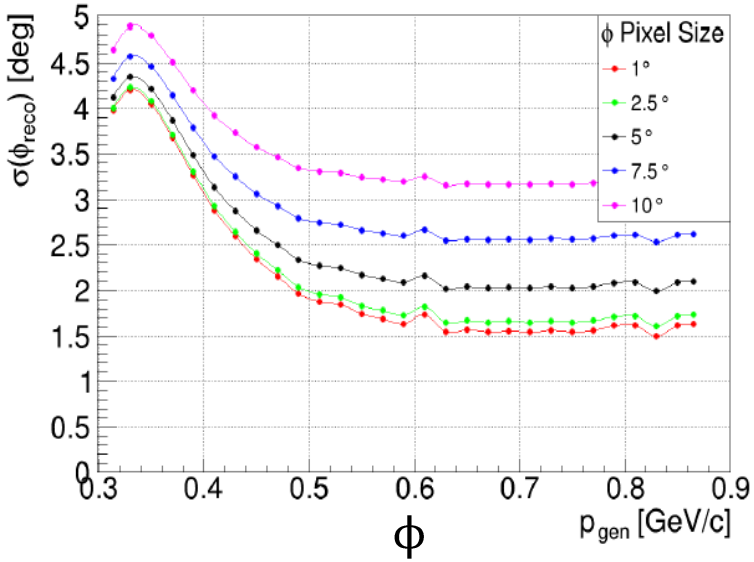
- **The CERN, Japan and Illinois groups with participation of the Dubna and Saclay groups will finally suggest the scheme of the inner target volume modifications.**
  CERN will supply drawings, manufacturing of details and assembling.
- **The Dubna, Prague and Munich groups with the participation of the MSU and Ukrainian groups will design the Silicon based RD.**
- **The Bonn group will consider the alternative RD-design based on SiFi.**
- **The Munich group with participation of the Prague group will develop the data acquisition (DAQ) system.**
- **Front-end-electronics (FEE) could be developed and produced by the Warsaw (TU) with participation of the Dubna. Participation of the Torino group is also welcomed.**
- **The Mainz group will develop (update) the trigger system.**
- **The Lisbon group will develop (update) the online control (Slow control) of data.**

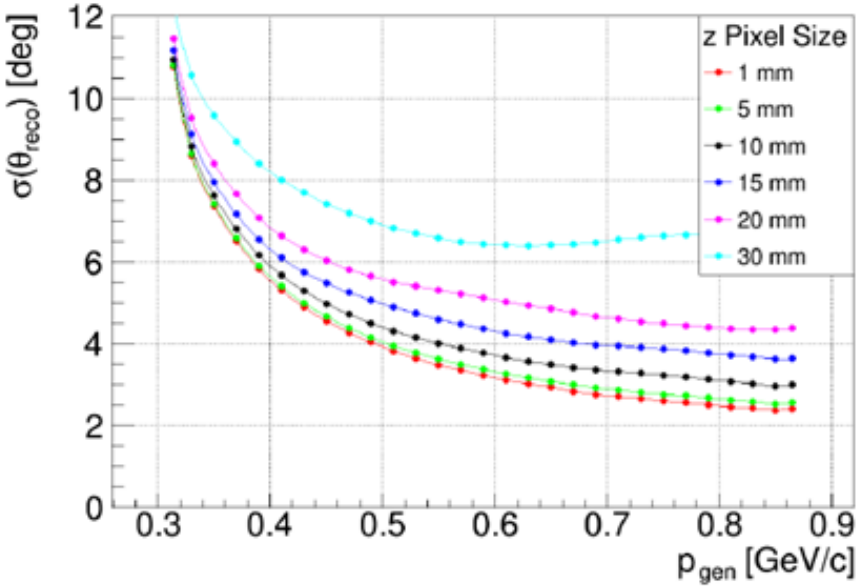
Equipment	Responsibility***	
	Main Team	**In cooperation with**
Target volume reconstruction	CERN, Japan, Illinois	Dubna, Saclay
Si-Recoil Detector and cabling	Dubna, Munich, Prague	LTU(Kharkov**), MSU
Triggers	Mainz	
FEE	Warsaw (TU)	Trieste, Torino, Dubna
DAQ	Munich	Prague
Slow control	Lisbon	Saclay
Tests and maintenance	Dubna, Japan	Illinois, Munich, CERN
Software *	Freiburg, Dubna	Warsaw, Saclay

6. MC studies

Simulations have been performed at Freiburg using the TGEANT package for the two-layer geometry. Two plots given below show that there will be no problems with the angle reconstruction of the recoil particles.

"Silicon RPD Simulations with TGEANT", T. Szameitat
Physikalisches Institut Albert-Ludwigs-Universit at Freiburg, August 2016



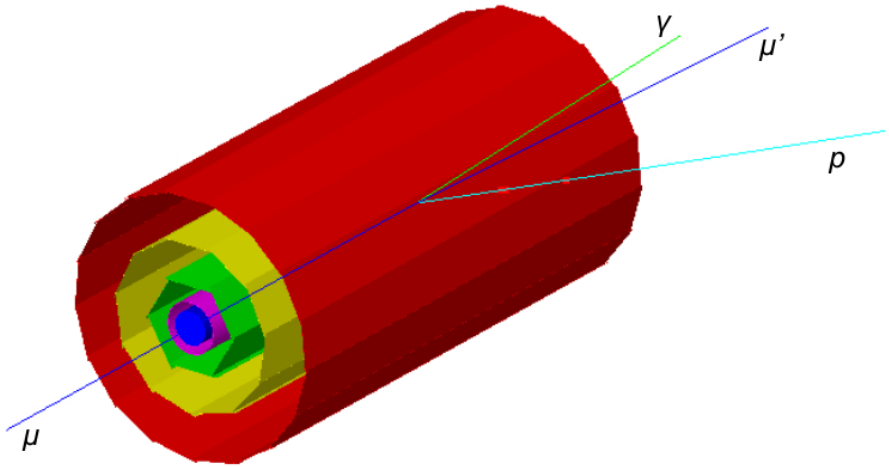


Reconstruction of - (left) and θ- angles as a function of momentum for various pixel sizes.

6. MC studies

R.Akhunzyanov JINR Dubna, January 2017

3-layer Silicon Recoil Detector



Target: r = 20 mm

Microwave cavity:
r = 30 mm, d = 0.6 mm

Inner layer: 6 ladders,
r = 49 mm, d = 0.1 mm

Middle layer: 11 ladders,
r = 97 mm, d = 0.1 mm

Outer layer: 17 ladders,
r = 152 mm, d = 0.3 mm

Ladder width = 63 mm,
length = 600 mm

B = 0.5 Tl

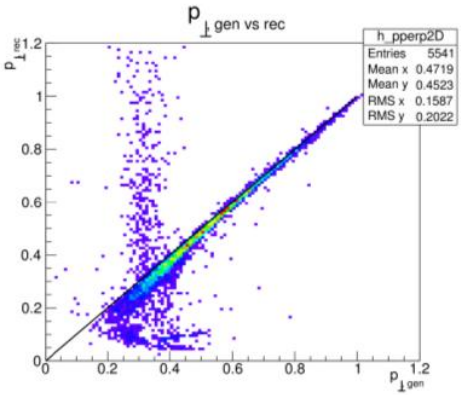
Simulation of a DVCS event in TGEANT

Default HEPGen settings were used.

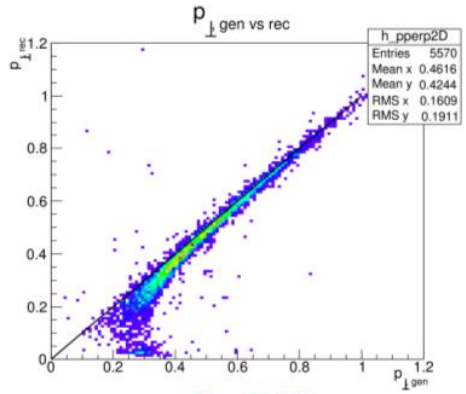
6. MC studies

Momentum reconstruction

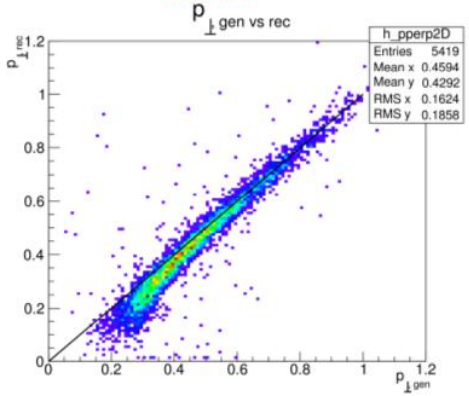
B = 5 T



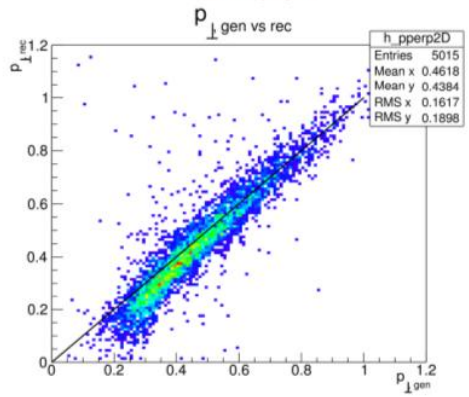
B = 2 T

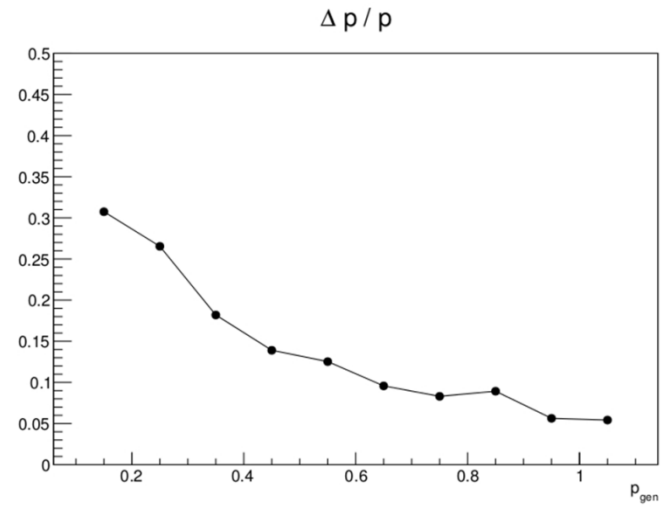


B = 1 T



B = 0.5 T





Preliminary MC simulations show feasibility of the PID inside the PT volume

Conclusions

We ask the TB:

- to support this project,

- to recommend presentation this project at the next meeting of the collaboration,

- to recommend submission of the project to the CERN EP department R&D workshop,

- after determining the work plan and the responsibility of the groups, recommend to present the project at the session of the CB to be considered as a COMPASS common project,

- to recommend to present this R&D for approval at the COMPASS Institutions.

Backup slides

1. Introduction: possible application of the COMPASS PT with RD

One of the major goals of the forthcoming worldwide GPD physics programs will be the precise mapping of the GPDs H and E, which enter in the "Ji sum rule" and provide access to the total parton angular mometum:

$$J^f(Q^2) = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x\left[H^f(x,\xi,t)+E^f(x,\xi,t)\right]$$

$$\frac{1}{2} = \sum_{q=u,d,s} J^q(Q^2) + J^g(Q^2)$$

While some information on the GPD H is already provided by the existing data, the GPD E is basically unknown. The most promising DVCS observables that are sensitive to E are the transverse target spin asymmetry in the case of proton targets, and the longitudinal beam spin asymmetry with neutron targets.

By employing a transversely polarized proton target, COMPASS has the possibility to access the GPD E through the measurement of the transverse target spin dependent DVCS cross-sections.

Since at COMPASS both beam and target are polarized, the relevant observables for accessing the GPD E are represented by the transverse beam charge & spin difference and sum of the m p mg p cross section, respectively defined as follows:

$$\mathscr{D}_{CS,T} \equiv \left(d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S) - d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S+\pi)\right) - \left(d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S) - d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S+\pi)\right).$$

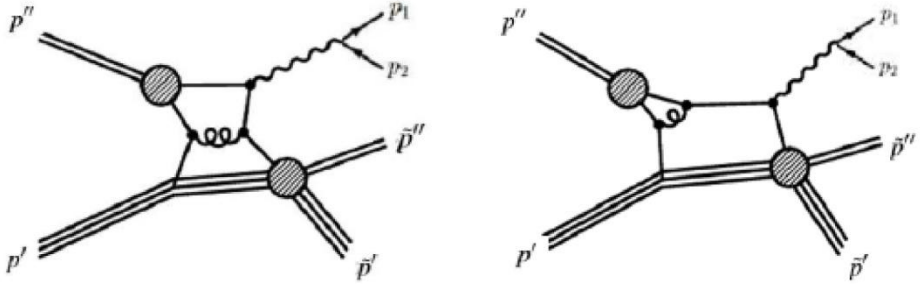
$$\mathscr{S}_{CS,T} \equiv \left(d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S) - d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S+\pi)\right) + \left(d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S) - d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S+\pi)\right).$$

$$\mathscr{A}^D_{CS,T} = \frac{\mathscr{D}_{CS,T}}{\Sigma_{unpol}} \text{ and } \mathscr{A}^S_{CS,T} = \frac{\mathscr{S}_{CS,T}}{\Sigma_{unpol}}.$$

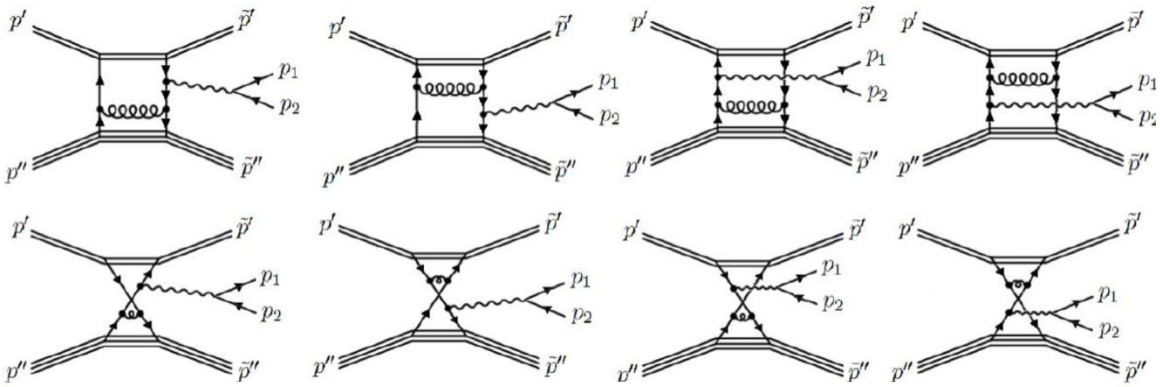
1. Introduction: possible application of the COMPASS PT with RD

A.A.Pivovarov, O.V.Teryaev (JINR,Dubna), QCD mechanisms of (semi)exclusive Drell-Yan processes,Published in AIP Conf. Proc. 1654 (2015) 070008.

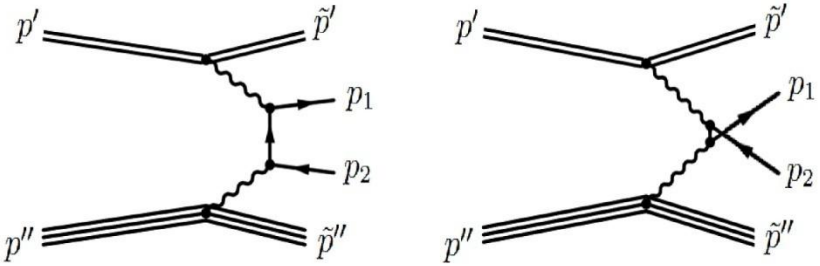
The exclusive DY formalism of the lepton pair's production in pion-nucleon interactions can be represented by a combination of two mechanisms: (i) a classical mechanism and (ii) so called GPD·GPD-mechanism.



The classical mechanism of the DY pair's production in pion-nucleon interactions.



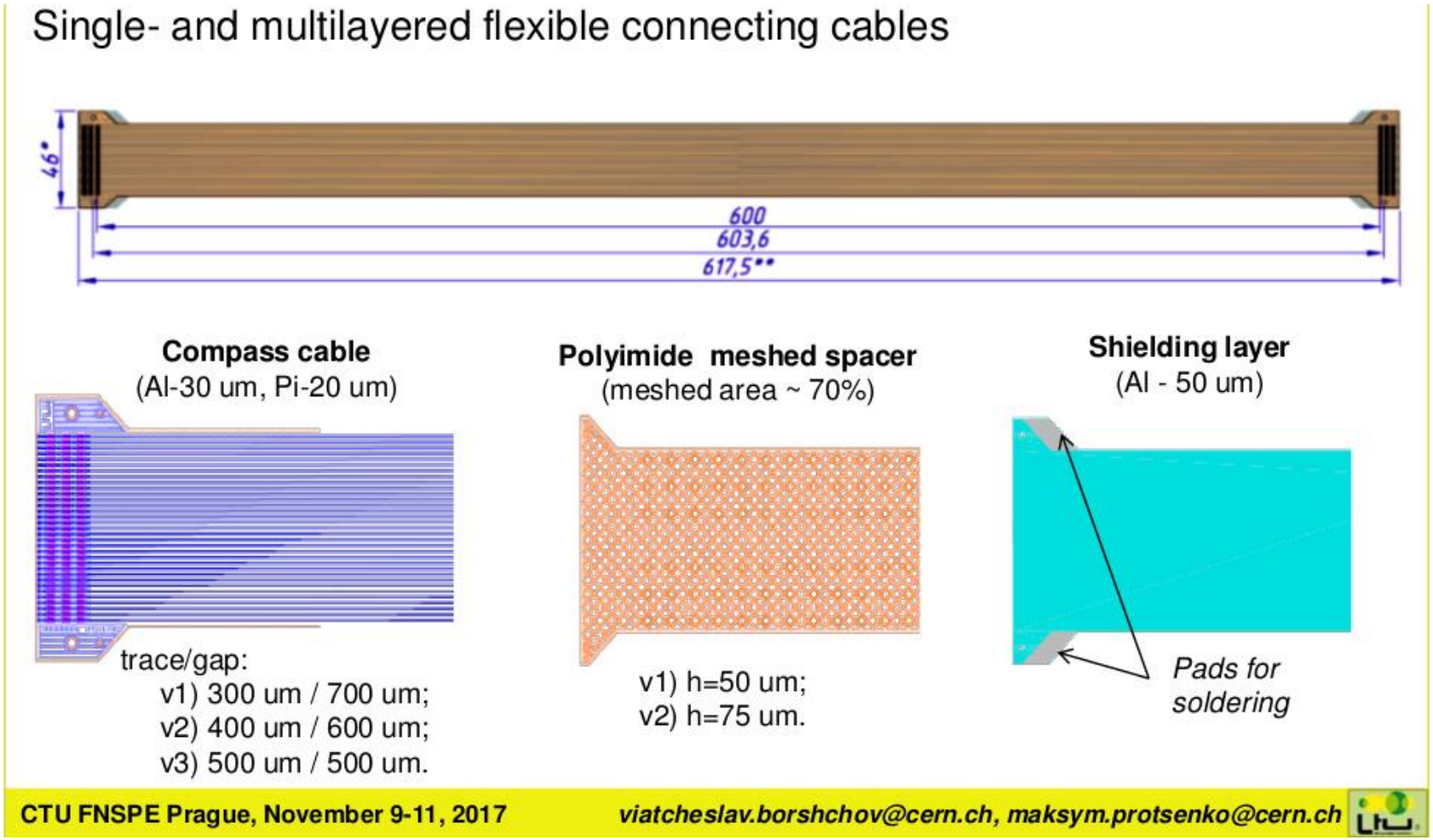
GPD·GPD-mechanism of the DY lepton pair's production in pion-nucleon interactions.



The EM-diagrams which can interfere with those shown in Figure above.

5. Subjects of the Common R&D Project

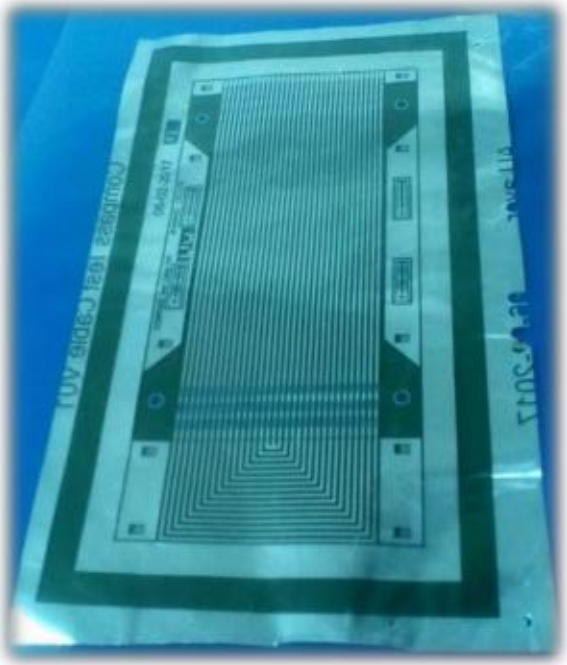
The KMFB are used for the Silicon detector input-output connections in a number of experiments (f. e. NOMAD, PANDA and CBM). They are commercially available. Examples of the KMFB are shown in Fig. 11 (http://www.thinflex.com.tw).



5. Subjects of the Common R&D Project

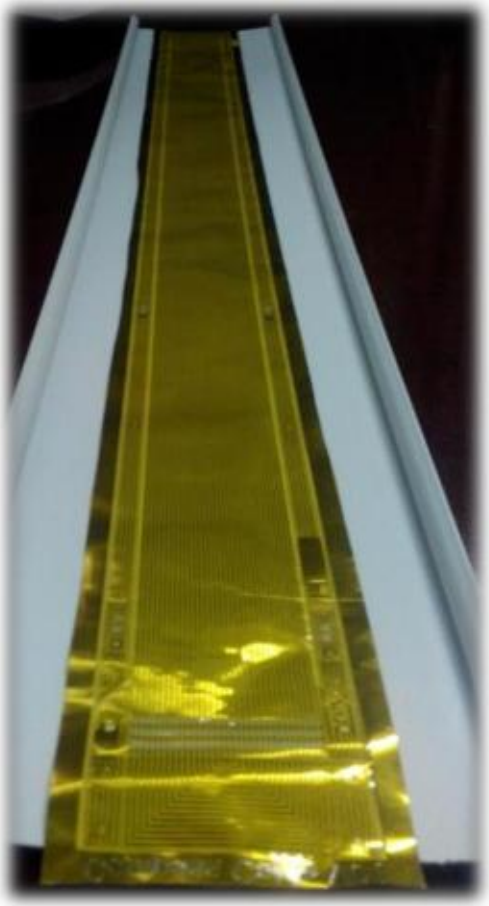
Technological test cable

(~ 15 cm long)



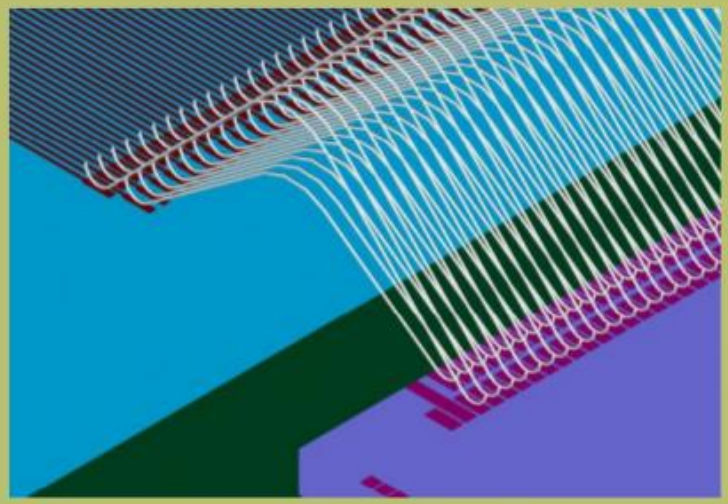
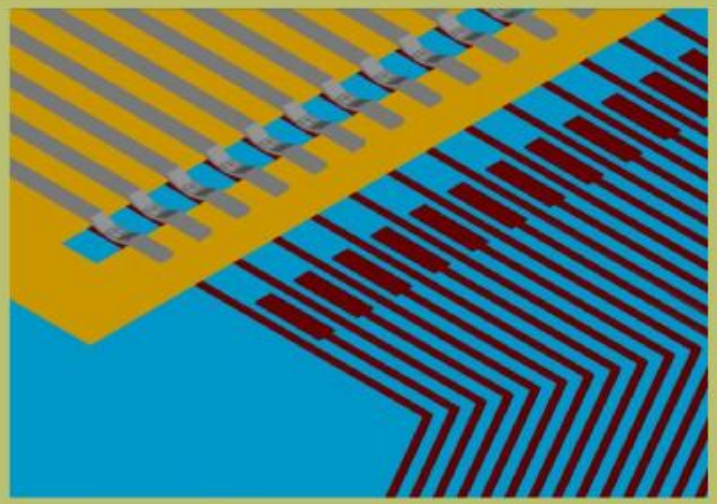
Cable prototype

(~ 65 cm long)



The details can be found in talk given be M. Protsenko, DAQFEET, Prague, Nov 2017

5. Subjects of the Common R&D Project

Wires	SpTAB
	
Wire-welding to the aluminum-polyimide flexible board (FDI-A-50 - aluminum thickness is 30 um) is possible	SpTAB of the aluminum-polyimide flexible board (FDI-A-50 - aluminum thickness is 30 um, width of trace is 100 um) to PCB contact pads is possible

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The details can be found in talk given be M. Protsenko, DAQFEET, Prague, Nov 2017