Letter of Intent on the Common R&D project to upgrade the COMPASS Polarized Target with Recoil Detectors.

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Conveners: J. Friedrich, I. Savin.

Contents

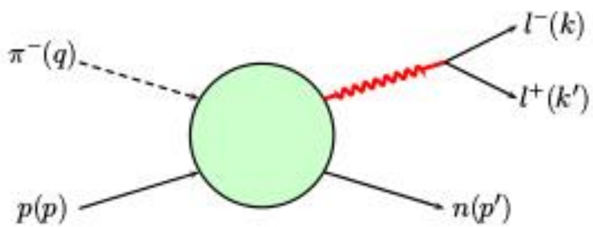
1. Introduction.

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

- via the exclusive DVCS mechanism, in the muon beam;
- via the Exclusive DY mechanism in the pion beam .

For Exclusive reactions, A_{LL} initial and final state particles and their characteristics should be known. At COMPASS, the best Exclusive DY reaction would be

$$\pi + p \rightarrow l^+ \; l^- \; \pi^+$$



Measurements of the Exclusive DVCS at COMPASS can be performed using the μ^+ and μ^- beams and existing set-up including ECAL0 and the PT equipped with RD.

2. Physics Motivations.

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:

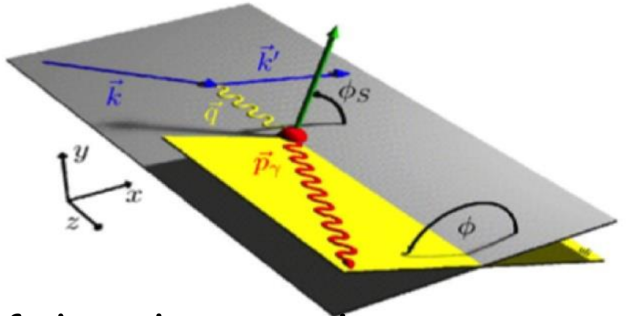
$$\mathscr{D}_{CS,T} \equiv \left(d\sigma^{\stackrel{+}{\leftarrow}}(\phi,\phi_S) - d\sigma^{\stackrel{+}{\leftarrow}}(\phi,\phi_S+\pi)\right) - \left(d\sigma^{\stackrel{-}{\rightarrow}}(\phi,\phi_S) - d\sigma^{\stackrel{-}{\rightarrow}}(\phi,\phi_S+\pi)\right).$$

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

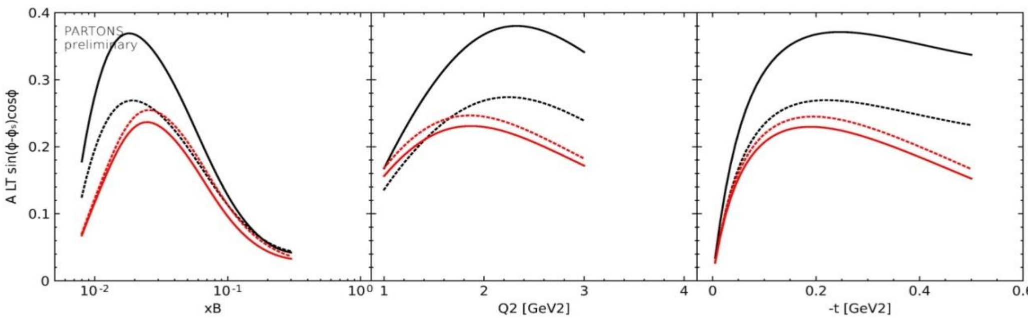
$$\mathscr{A}^{D}_{CS,T} = \frac{\mathscr{D}_{CS,T}}{\Sigma_{unpol}} \text{ and } \mathscr{A}^{S}_{CS,T} = \frac{\mathscr{S}_{CS,T}}{\Sigma_{unpol}}.$$

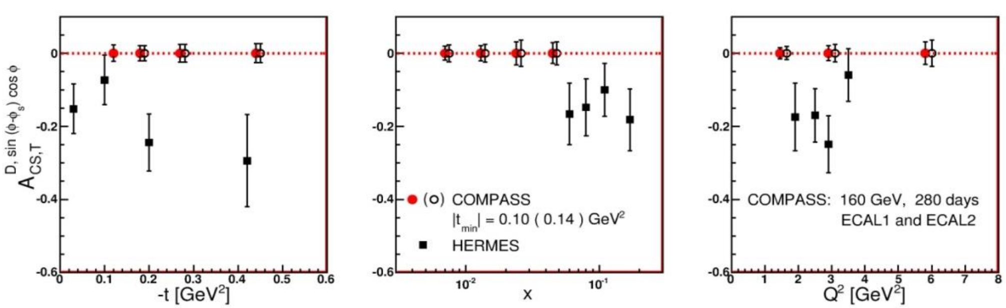
LoI 2022++ muon beam

2. Physics Motivations. GPD E



Definition of the relevant angles in the DVCS on a transversely polarized target.





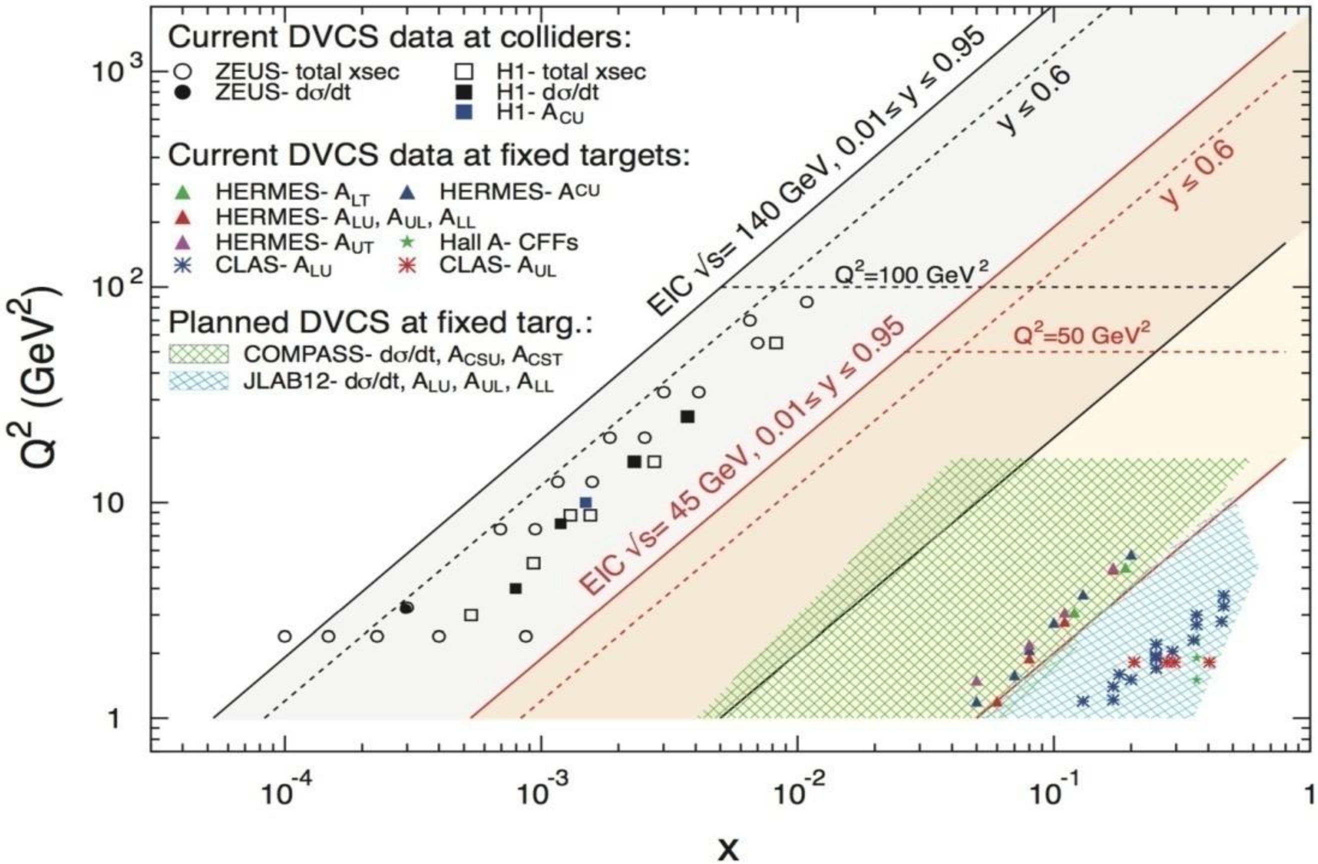
LoI 2022++ muon beam

Estimation of the amplitude of the [sin(φ-φ$_S$)cos(φ)] modulation in the COMPASS kinematics, based on predictions from the VGG (red) and GK [(black) models at leading order (solid lines) and with the additional assumption of E = 0 (dashed lines). The estimates have been obtained in the context of the PARTONS framework.

Expected statistical accuracy of $A^{D[\sin(\varphi-\varphi_S)\cos(\varphi)]}_{CS,T}$ as a function of -t, x_B and Q_2 from a measurement in 140 days with the COMPASS spectrometer, using a 160 GeV muon beam and a transversely polarized NH_3 target. Solid and open circles correspond to a minimum detectable |t| of 0.10 GeV² and 0.14 GeV², respectively. Also shown is the asymmetry $A^{\sin(\varphi-\varphi s)\cos\varphi}_{U,T}$ measured at HERMES.

The COMPASS data could therefore provide a measurement of the [sin(φ-φ$_S$)cos(φ)] modulation with a statistical accuracy of approximately 2.5% in the so far uncharted region of $5\ 10^3 < x_B < 5\ 10^2$.

2. Physics Motivations.



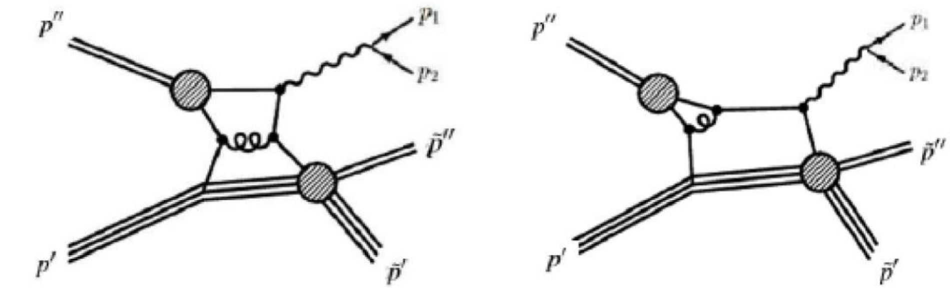
Overview of the existing and planned measurements of DVCS in both fixed-target and collider mode.

LoI 2022++ muon beam

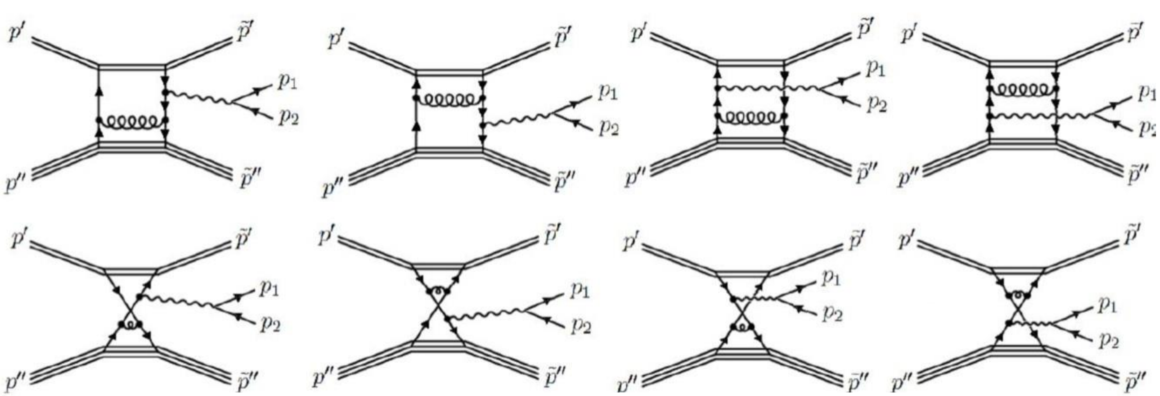
2. Physics Motivations. Exclusive DY

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

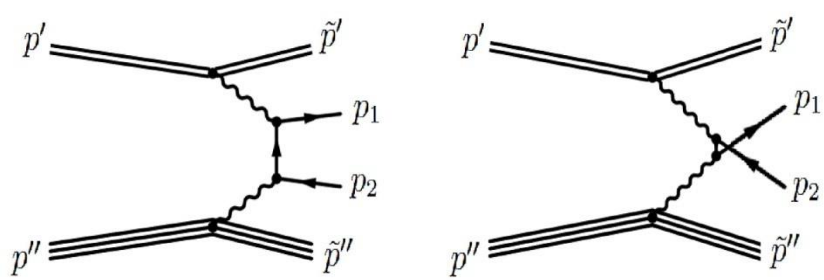
The exclusive DY formalism of the lepton pair's production in pion-nucleon interactions can be represented by a combination of two mechanisms: (i) a classical mechanism and (ii) so called GPD·GPD-mechanism.



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.

2. Physics Motivations. Exclusive DY

Exclusive dimuon production in 2008 πp Data, *Guskov Alexey, JINR, Dubna, presented in COMPASS AM, 18.06.2015*

Event selection

- 2008 π-p diffraction data of W33, W35, W37, W39
- 2 muons in the best primary vertex. Track is treated as muon if it pass >70 X_0
- Vertex: -70 cm<Z<-28 cm , R<1.8 cm
- DT0 trigger
- Exactly 3 outgoing tracks in the best primary vertex
- Negative pion in the best primary vertex
- Exactly 1 recoil proton in RPD
- No neutral clusters in ECAL1,2 with E>2 GeV and |t|<5 ns
- No tracks with momentum with |t|<15 ns
- Energy balance |ΔE|<6 GeV
- P_T balance P_T<0.15 GeV/c

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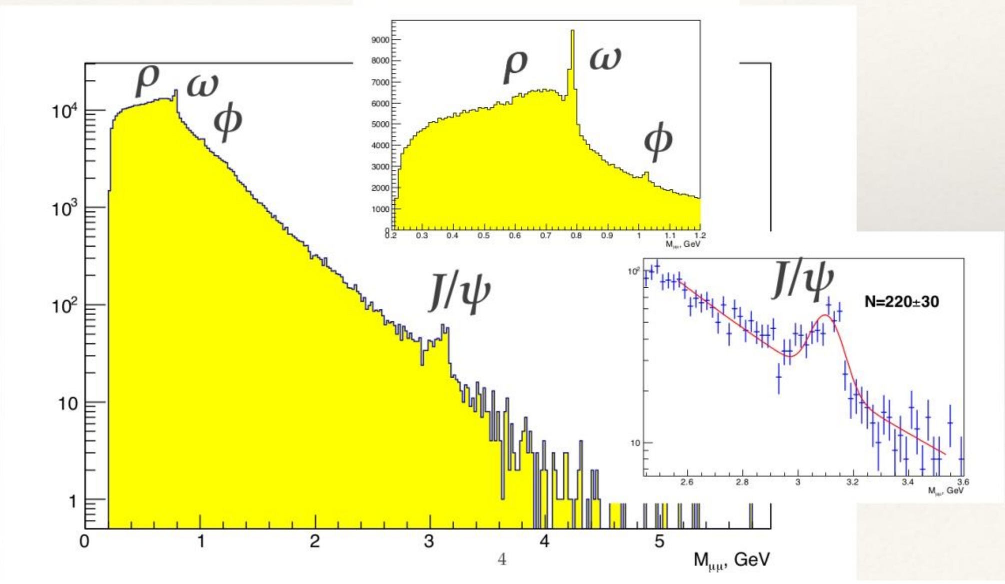
Dimuon mass spectrum



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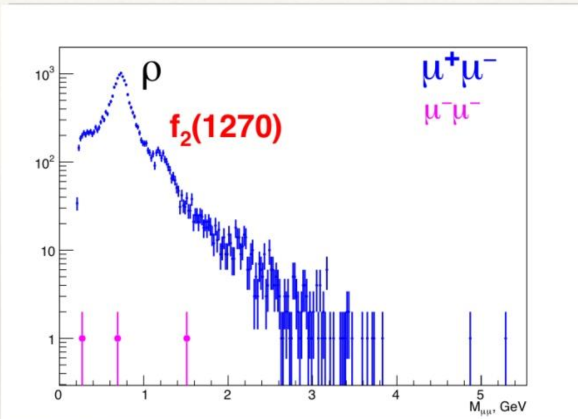
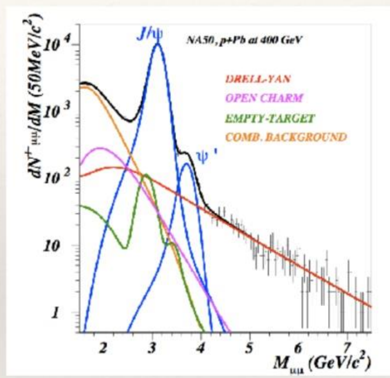
2. Physics Motivations. Exclusive DY

Exclusive dimuon production in 2008 πp Data, *Guskov Alexey, JINR, Dubna, presented in COMPASS AM, 18.06.2015*

Esclusive μμπ−p events: $M_{\mu\mu}$





1) still strong background from π+π− channel
2) no visible signal of exclusive J/ψ production
3) no combinatorial background

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Cut flow

Selection	+/−	+/+	−/−
W33+W35+W37+W39		8×10^9	
2 μ form BPV in the target	504 000	71 600	315 000
DT0 trigger	493 000	69 700	309 000
Exactly 3 outgoing particles in BPV	105 000	1 338	77 700
Scattered negative pion in PBV	100 000	1283	3 010
Exactly one recoil proton in RPD	76 800	749	1 864
No additional neutral clusters in ECALs	34 200	107	316
No additional tracks	30 100	30	100
Exclusivity cut |ΔE|<6 GeV	21 300	4	25
P_t<0.15 GeV/c	18 700	0	3
$M_{\mu\mu}$>2 GeV	313	0	0
$M_{\mu\mu}$>4 GeV	2	0	0

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Cross section

Φ = 49475 spills × 2.5×10^7 π/spill = 1.2×10^{12} π

Target: 40 cm of LH_2, d=0.071 g/cm³

σ[pbn]= 0.5×N/A

$\sigma_{DY}(\pi p)_{M>4\,GeV}$= 150 pb, K=2, $\sigma_{DY}\sim1/M^5$

Total cross section: $\sigma_{DY}(\pi p)_{M>2\,GeV} \approx 10$ nb

Exclusive cross section: $\sigma_{DY}(\pi p)_{M>2\,GeV} \approx 0.16/A$ nb

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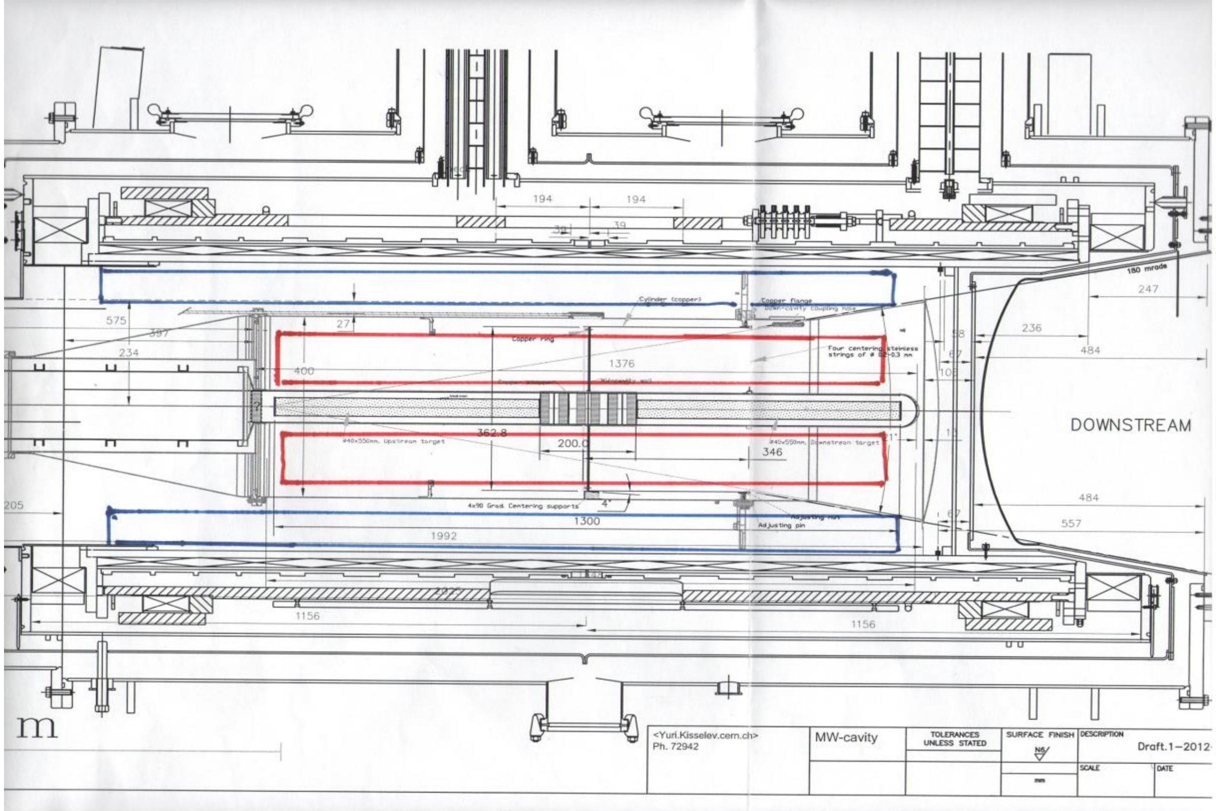
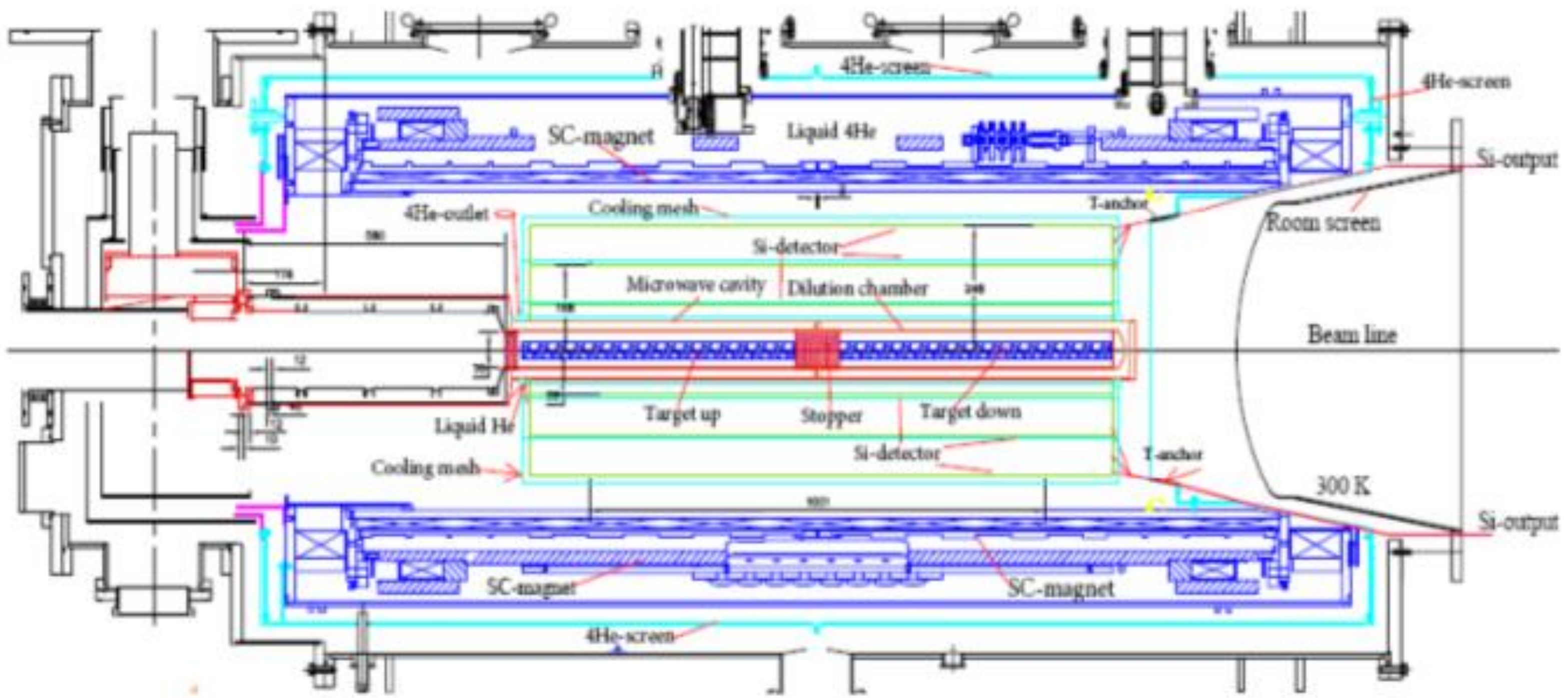
3. COMPASS Polarised Target. Status and modification.

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.

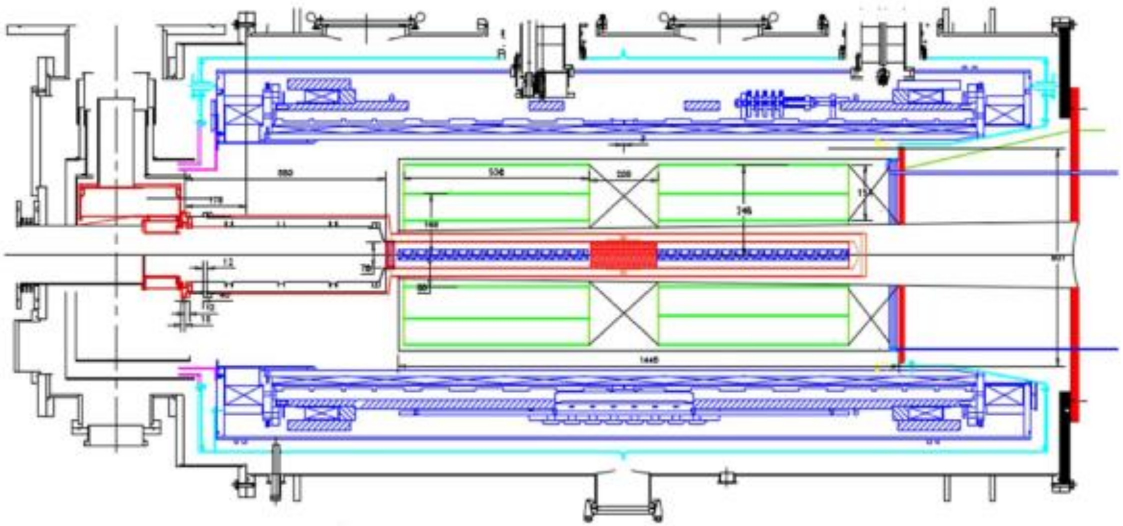


3. COMPASS Polarised Target.
Status and modification.

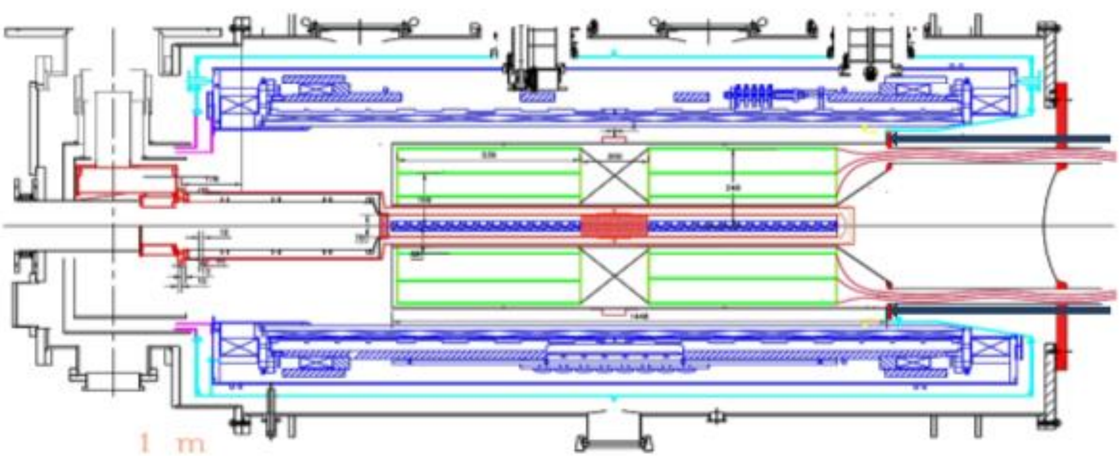
New design of the MW cavity. It is assumed that the shape of the cavity is modified and the rest of the inner target magnet volume is decupled from it but have the same vacuum. The cylindrical part of the cavity, supported by plastic rings, can be made of the 0.2-0.4 mm thick copper foil to avoid distortion 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.



3. 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.

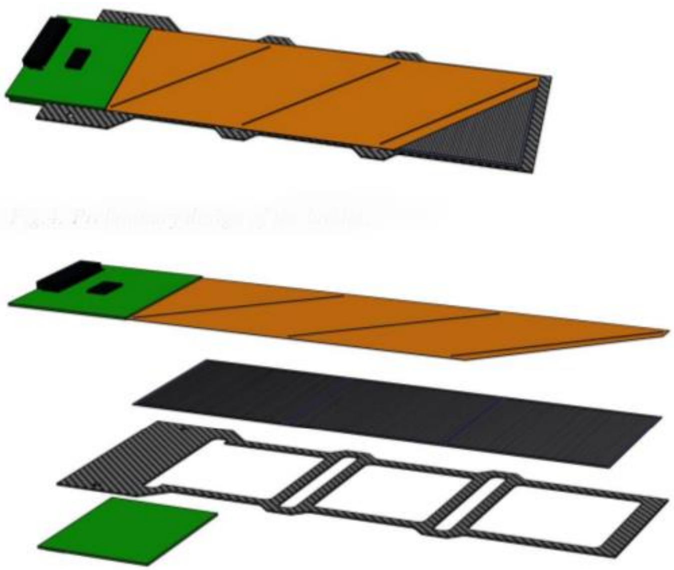


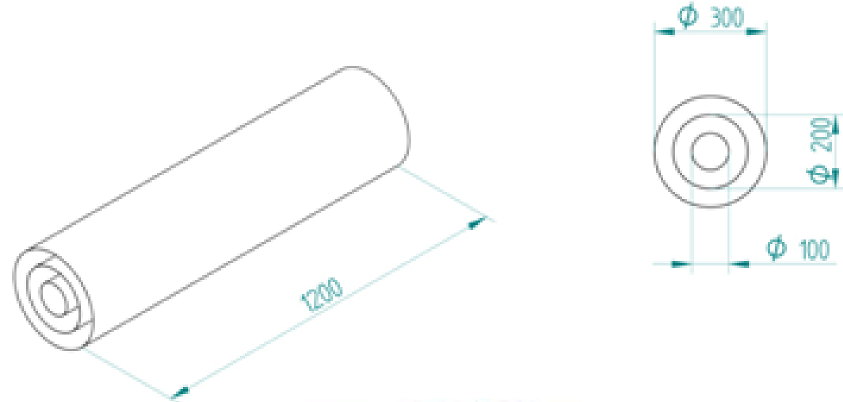
The last modification is preferable:
(i) it does not limit the acceptance in the forward direction,
(ii) the length of cables will be minimised,
(iii) "worm" chips can be fixed on the outside surface of the flange at the room temperature,
(iv) lengths of the target cells can be increased up to 75 cm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

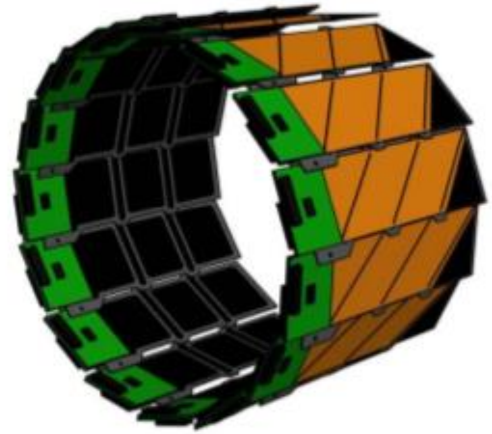
4.Silicon detector at low temperature.

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



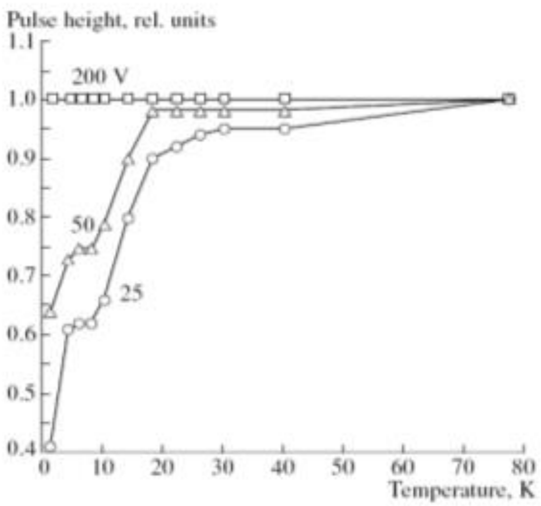


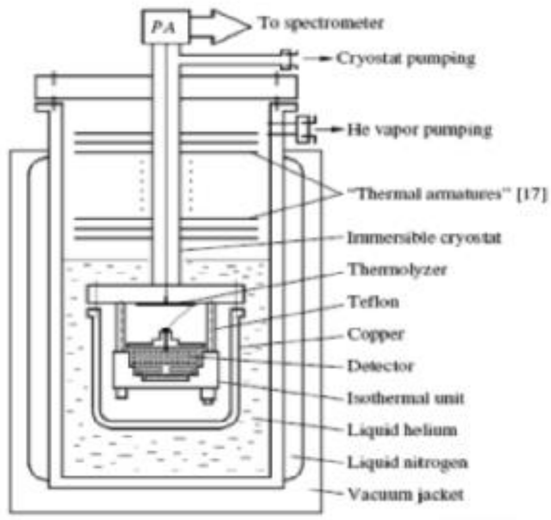


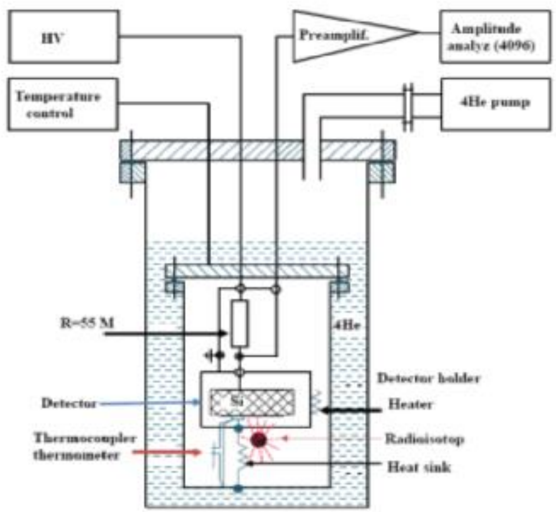
Proposal on Si-detector – next talk

4.Silicon detector 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.

5. MC studies

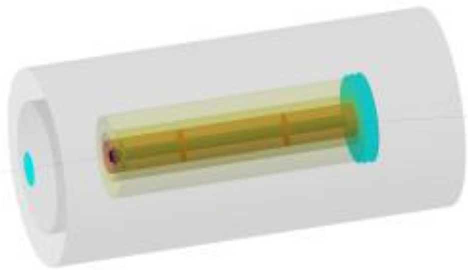
"Silicon RPD Simulations with TGEANT", T. Szameitat
Physikalisches Institut Albert-Ludwigs-Universit at Freiburg, August 2016

Setup

Proton has to traverse:

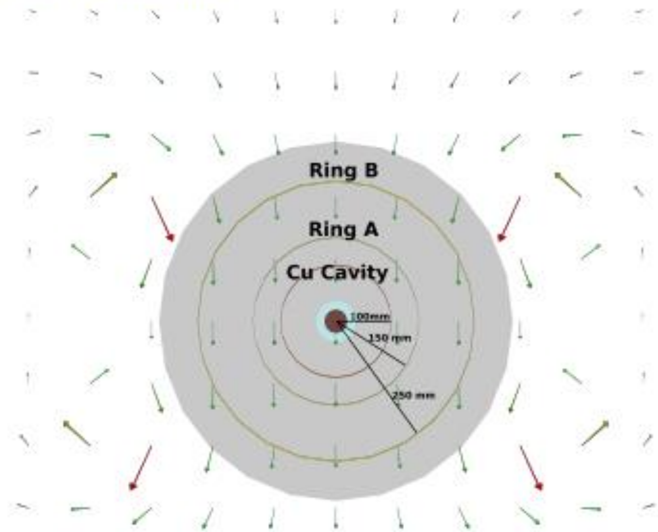
- 20 mm NH3 (⋆)
- 0.6 mm PCTFE
- 14.2 mm LHe
- 0.85 mm Kevlar
- 0.55 mm LHe
- 0.6 mm Epoxy
- 0.6 mm Cu cavity (⋆)
- 300 μm Silicon Ring A (⋆)
- 1000 μm Silicon Ring B (⋆)

(⋆): modified in the MC



Silicon ring A and B (yellow)
Cu cavity (red)
NH3 Target cells inside LHe (blue)
No readout electronics
No mechanical structure

Front View: Field Map



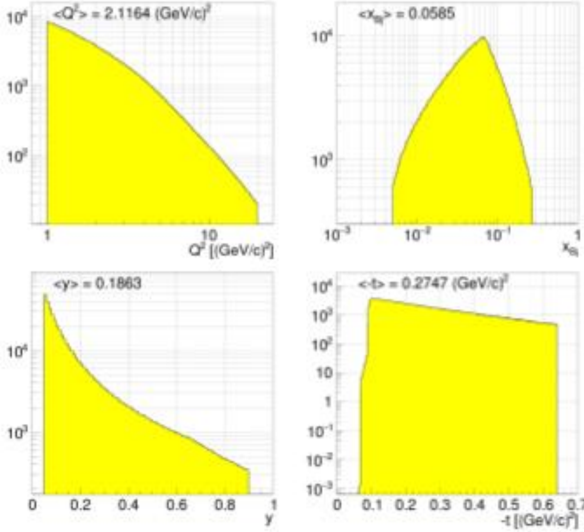
5. MC studies

Kinematics for a Target Radius of 20 mm

$p_{min} = 306$ MeV/c
$-t_{min} = 0.0912$ (GeV/c)^2

Minimum defined as a detection probability of 20%

Kinematic variables from generator

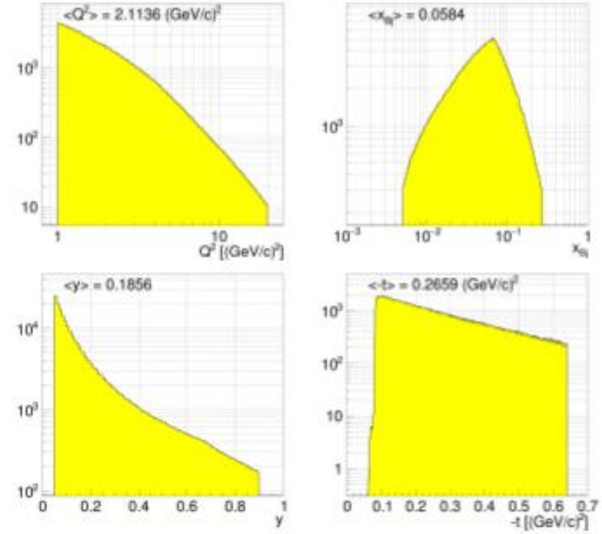


Kinematics for a Target Radius of 15 mm

$p_{min} = 288$ MeV/c
$-t_{min} = 0.0811$ (GeV/c)^2

Minimum defined as a detection probability of 20%

Kinematic variables from generator

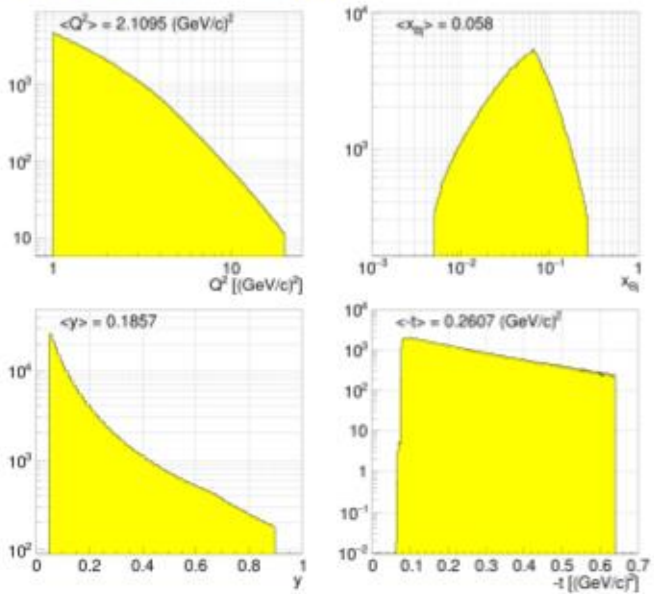


Kinematics for a Target Radius of 10 mm

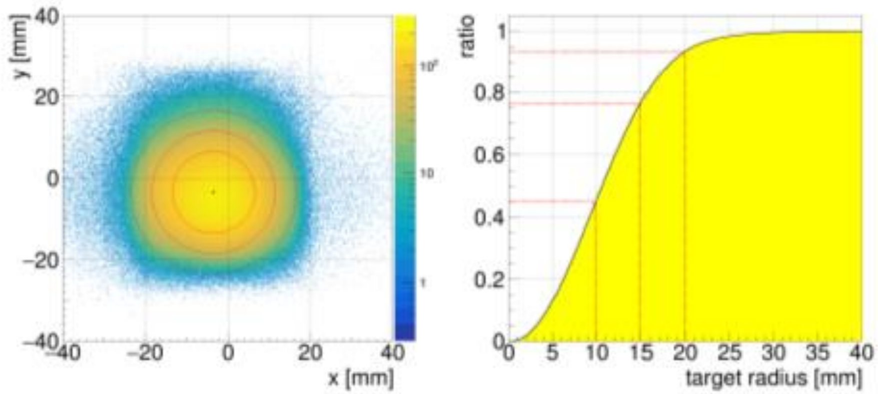
$p_{min} = 278$ MeV/c
$-t_{min} = 0.0756$ (GeV/c)^2

Minimum defined as a detection probability of 20%

Kinematic variables from generator



Luminosity as a Function of the Target Radius



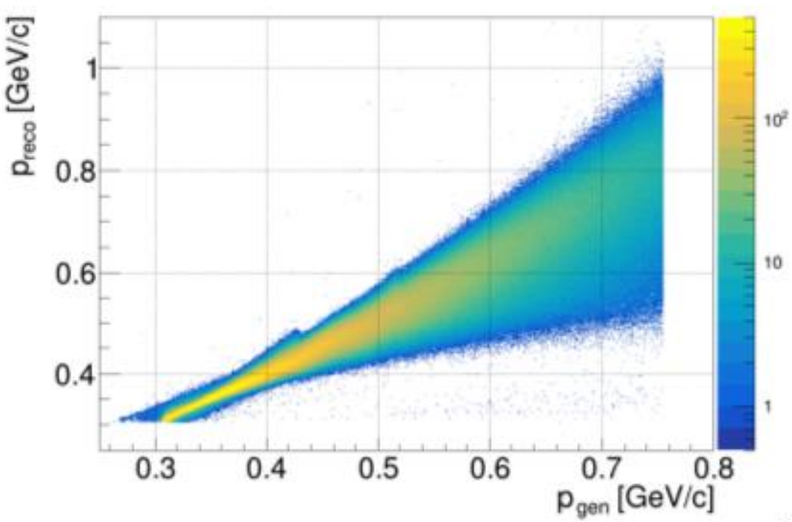
5. MC studies

Momentum Reconstruction Method

1. Pixelate Ring A and Ring B
2. Calulate $\theta = \tan^{-1}(\frac{r_B - r_A}{z_{B,pixel} - z_{A,pixel}})$
3. Use theoretical curve for measured θ
4. Find closest distance of measured E_A and E_B to calculated curve
5. Momentum is already known for this point on the curve

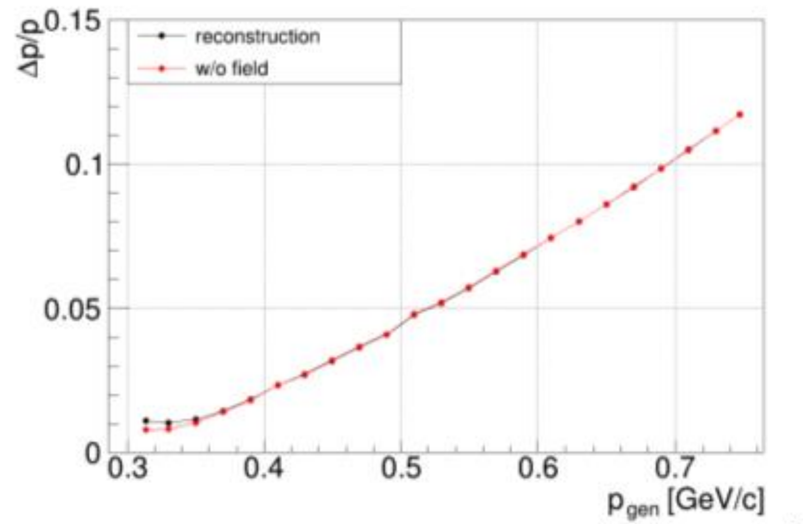
Momentum Reconstruction Method

Reference: 20 mm NH3, 0.6 mm Cu, 300 µm Ring A, 1000 µm Ring B



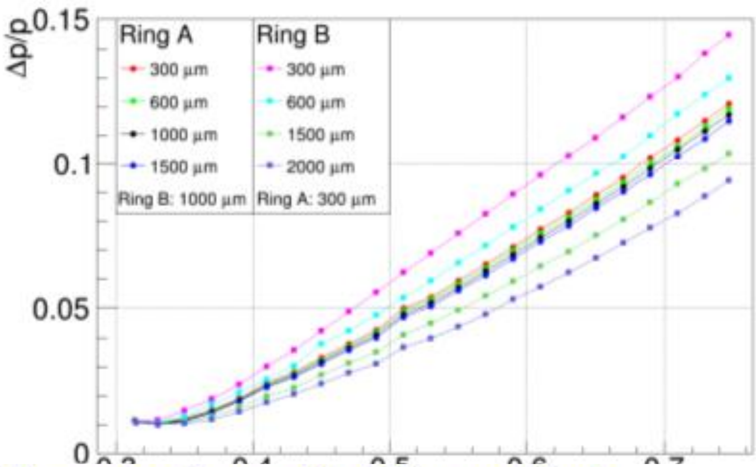
Momentum Reconstruction: w/ and w/o field

Reference: 20 mm NH3, 0.6 mm Cu, 300 µm Ring A, 1000 µm Ring B

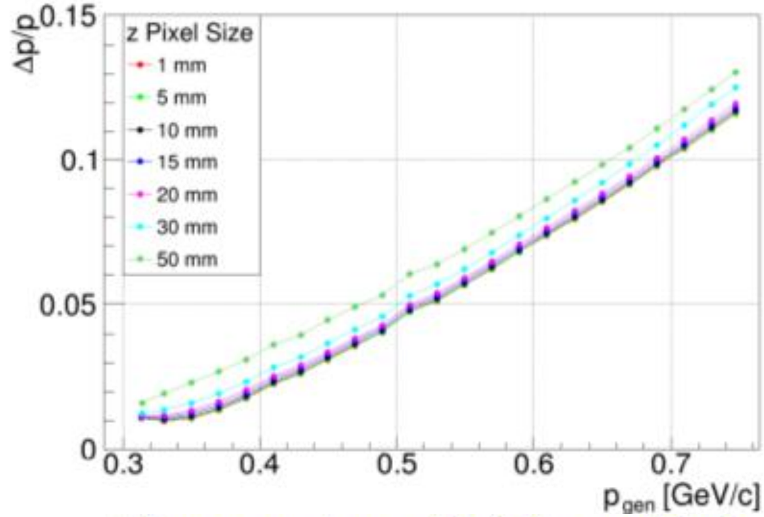


5. MC studies

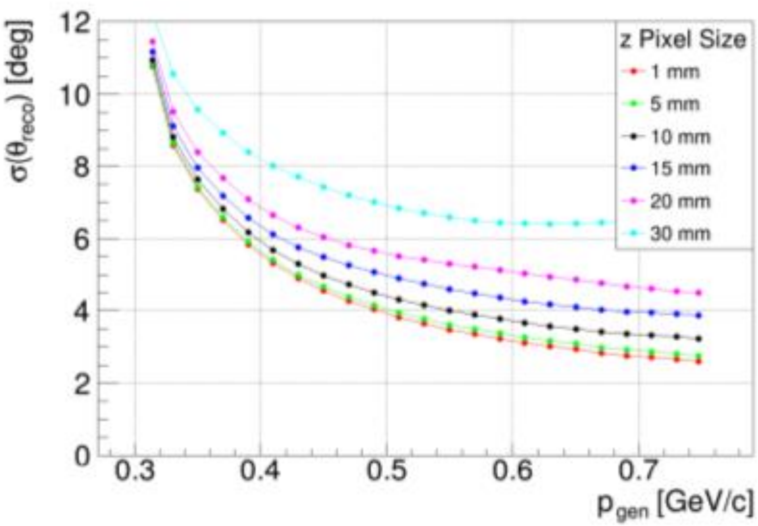
Momentum Reconstruction: Ring A&B modified



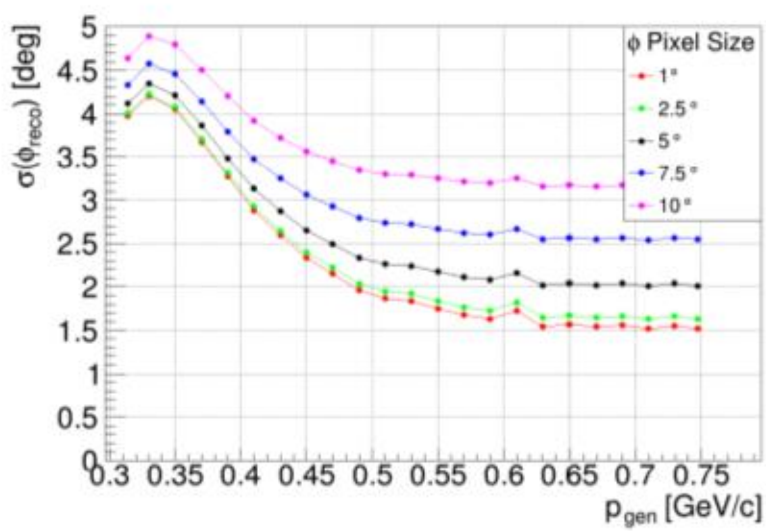
Momentum Reconstruction: z Pixel Size modified



θ Reconstruction: z Pixel Size modified



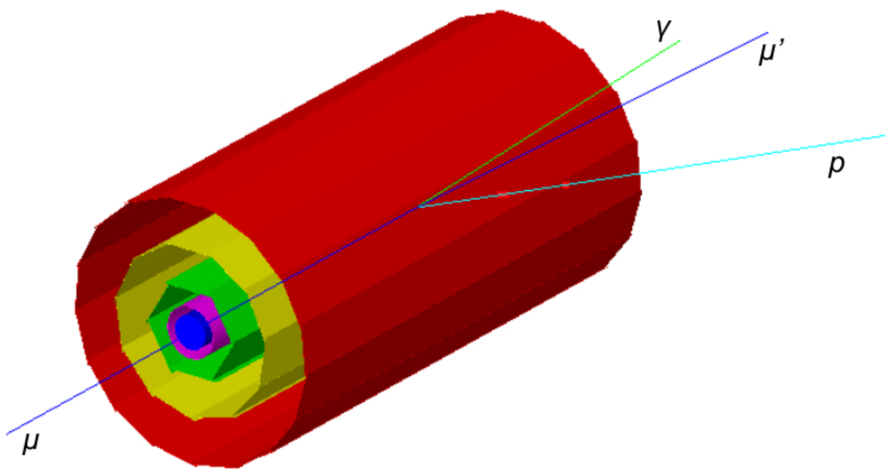
ϕ Reconstruction: ϕ Pixel Size modified



5. 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

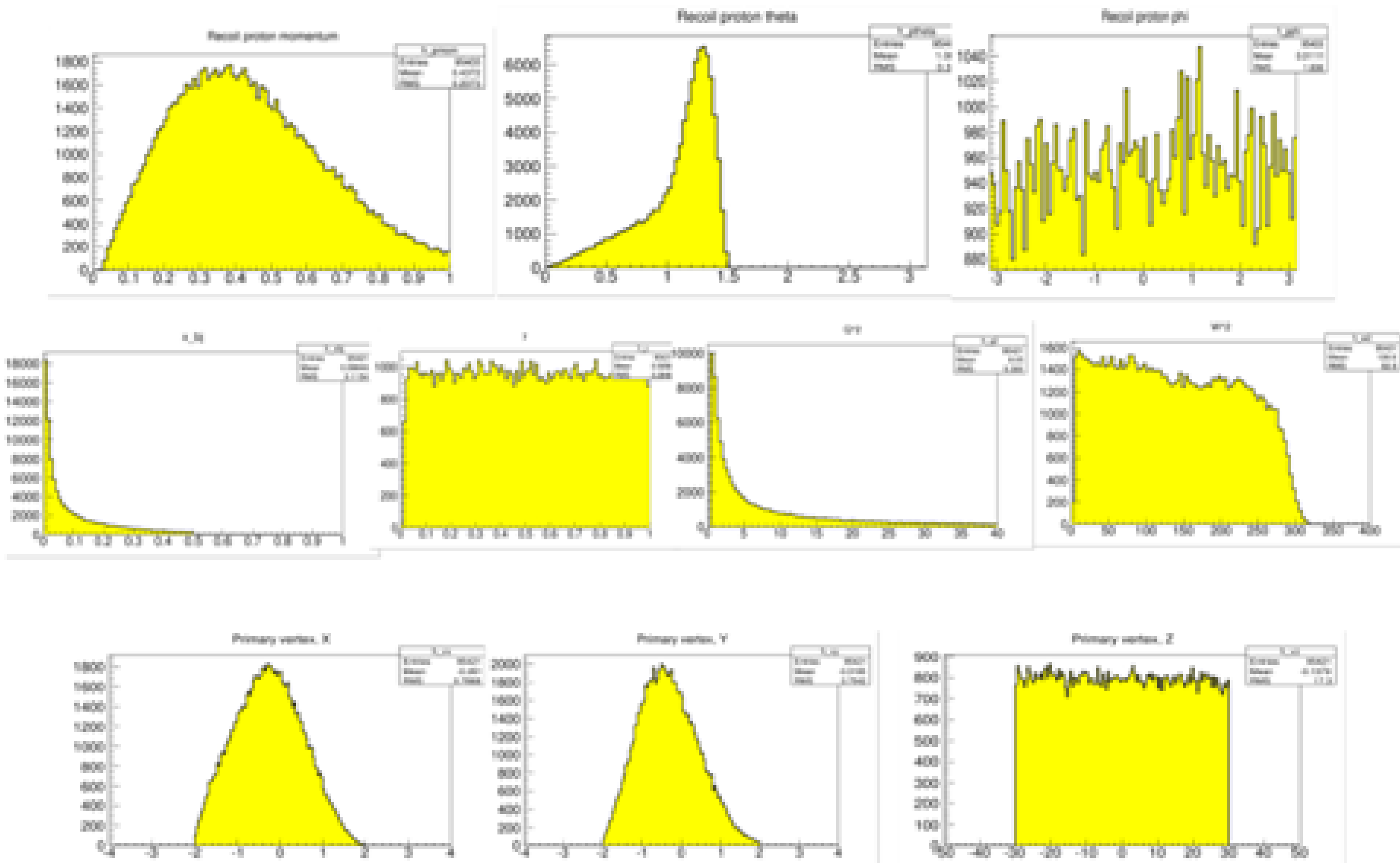
B = 0.5 Tl

Simulation of a DVCS event in TGEANT

Default HEPGen settings were used.

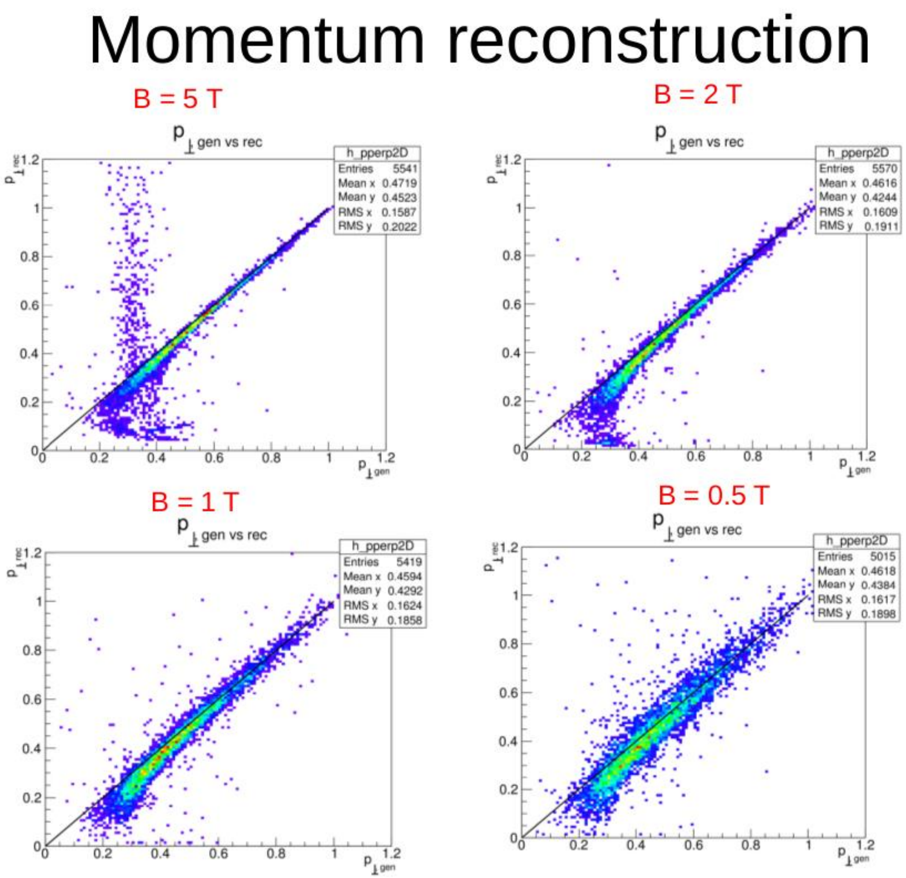
5. MC studies

Generated variables

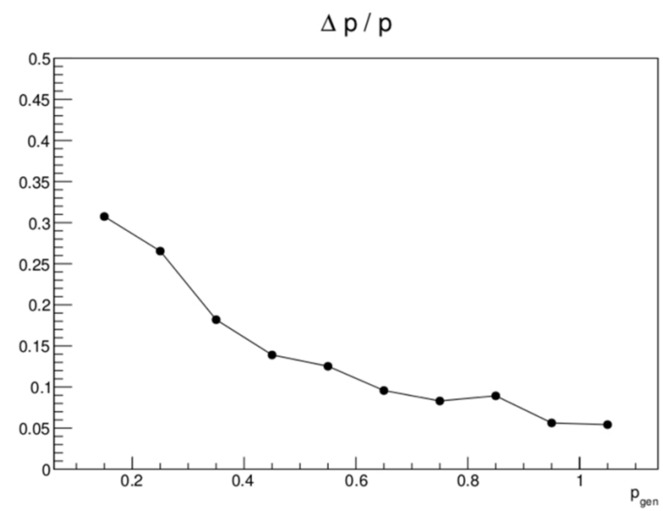


5. MC studies

Proton trajectory radius was determined by three geometrical points, further on the known formula the momentum was calculated. Comparison of the received values of a momentum of the protons and generated ones is shown in the figure.



The coordinate resolution of the silicone detector and a transversal component of a magnetic field are not considered yet. Beforehand, only the geometry of the block of detectors yields the permission to 10-15% on a momentum for the main kinematic measuring range.



6. Possible Common R&D project

The aims of the present R&D project are as follows:

(1) to study the engineering problems connected with a detector's insertion inside the inner volume of the target;
(2) tests of the silicon detectors in the environment close to that of the present PT, consideration of alternatives to silicon detectors;
(3) tests of the Silicon detectors and associated electronics in the environment close to that of the present PT.
(4) tests of the Silicon detectors can be performed partially in the laboratory using the specialized set-up and partially in a beam.

MC studies are very important.

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