A possible layout of the Spin Physics Detector with toroidal magnet.

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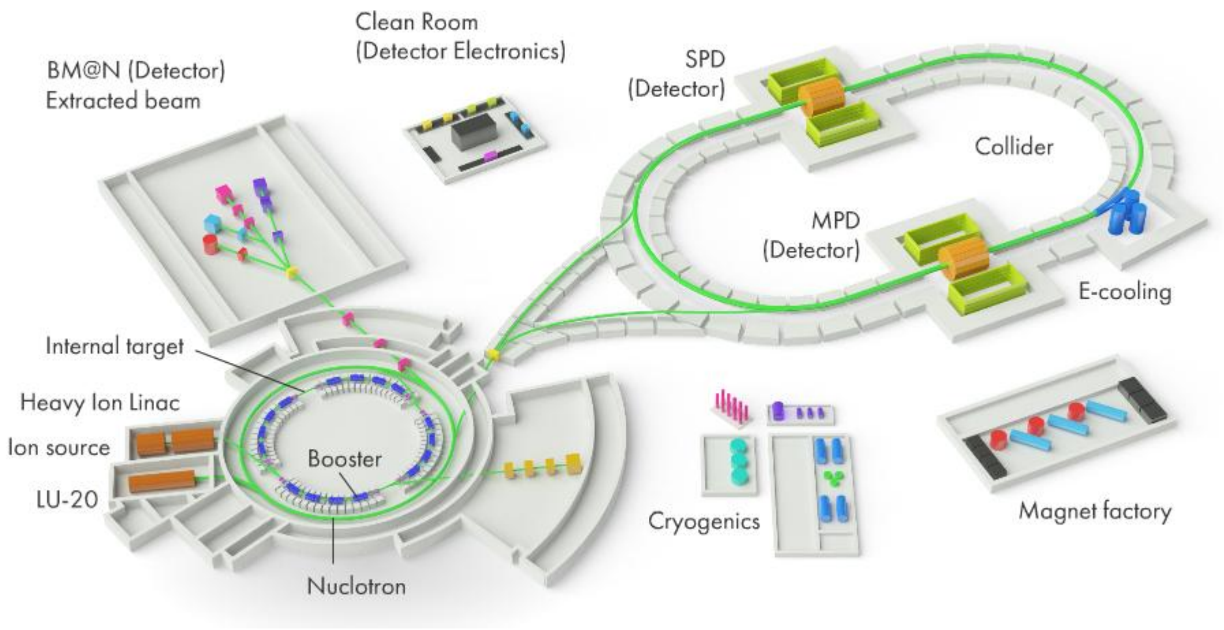
«Spin Physics Experiments at NICA-SPD with polarized proton and deuteron beams», EPJ Web Conf. 85 (2015) 02039, Aug 2014

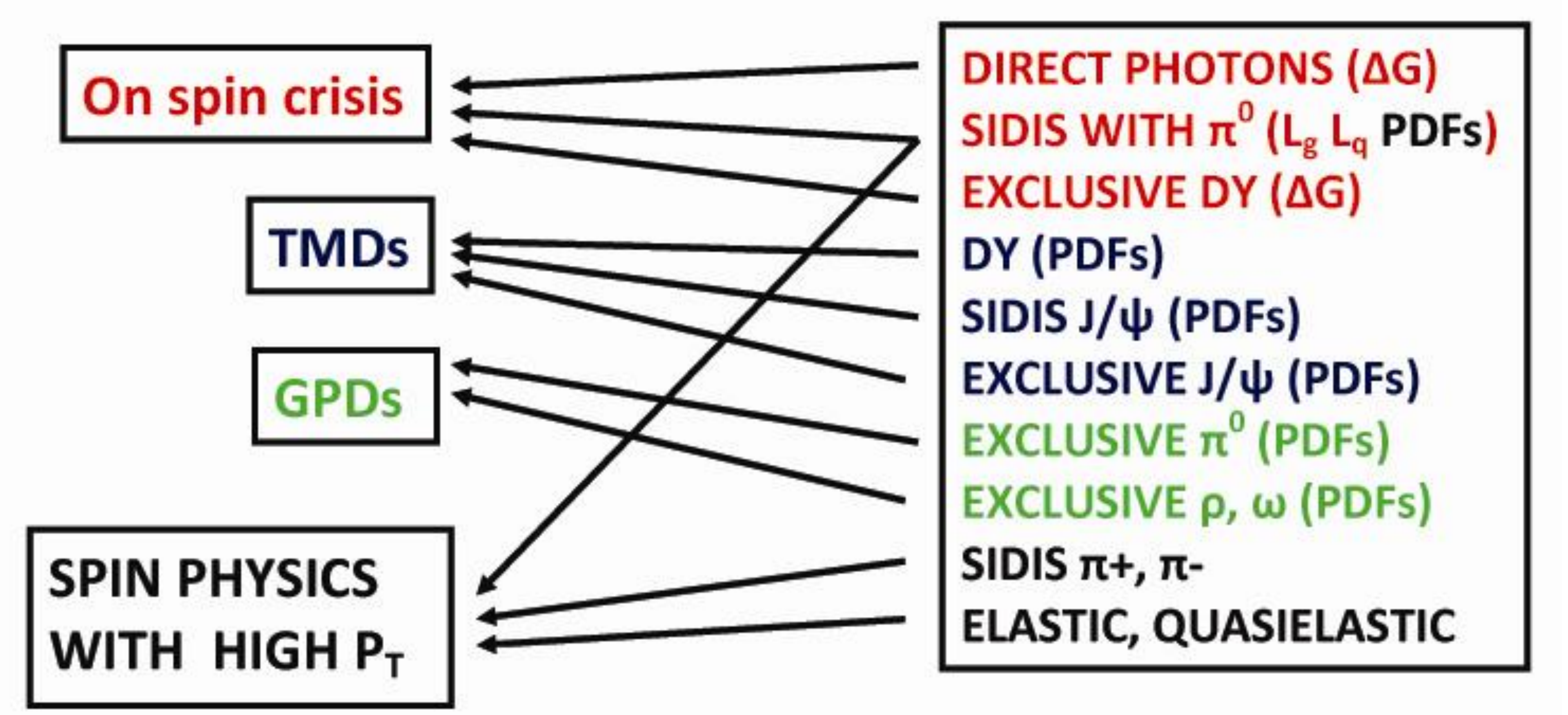
Talks and proceedings:
SPIN-Praha-2013, 2014
DSPIN-2013
SPIN 2012- Dubna, Russia
SPIN 2014 -Beijing, China



Main tasks and measurements.

Possible main tasks:

- **Transverse Momentum Distributions (TMDs).**
- **Generalized Parton Distributions (GPDs).**
- **Spin effects in reactions with high p_T .**



On spin crisis

TMDs

GPDs

SPIN PHYSICS
WITH HIGH P_T

DIRECT PHOTONS (ΔG)
SIDIS WITH π^0 (L_g L_q PDFs)
EXCLUSIVE DY (ΔG)
DY (PDFs)
SIDIS J/ψ (PDFs)
EXCLUSIVE J/ψ (PDFs)
EXCLUSIVE π^0 (PDFs)
EXCLUSIVE ρ, ω (PDFs)
SIDIS π+, π-
ELASTIC, QUASIELASTIC

Requirements to the SPD.

Required characteristics of the experimental setup:

- Geometry close to 4π,
- high-precision (better than 50 μm) and fast vertex detector,
- a tracking system that provides high accuracy (~200 μm) along the track,
- DAQ- data taking rate for luminosity> 10^{32},
- minimum of material,
- measurement of neutral (π^0 etc) secondary particles,
- Identification of charged particles with efficiency close to 100%,
- fast and modern trigger system,
- Modularity and availability to the elements of the installation, which will allow to upgrade and modify detectors for new research.

Requirements to the SPD.

Tracking detectors:

- Vertex detector - several coordinate silicon layers with resolution on the order of 30 µm;
- central and end track detectors - several groups of layers of stroy tubes;
- In addition, you can use the space between the windings of the toroidal a magnet for drift chambers. Track resolution ~ 300 µm.

Trigger detectors:

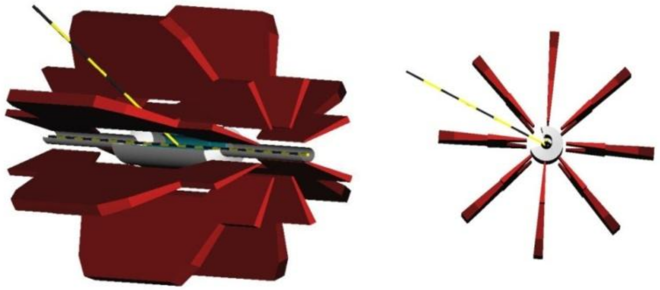
- signals from the electromagnetic calorimeter (“shashlyk” - as for COMPASS);
- scintillation plates.

It is necessary to organize different types of triggers.

PID detectors:

- Time-of-flight system from - RPC planes;
- electromagnetic calorimeter;
- muon system.

Toroid vs Solenoid



Toroid

One can consist of 8 superconducting coils symmetrically placed around the beam axis. Preliminary studies show that the use of superconducting coils.

Disadvantages:

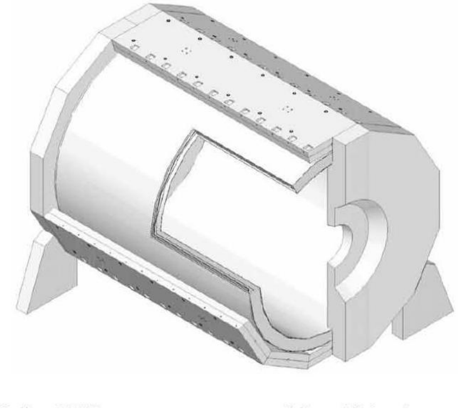
A high non- uniformity field

Lost acceptance

Advantages:

No field in beam pipe.

Compact spectrometer



Solenoid:

The maximum magnetic field of ~1T over a length of about 3.2m and a diameter of 1.8m. The field homogeneity is foreseen to be better than 1% over the volume of the vertex detector and central tracker.

Disadvantages:

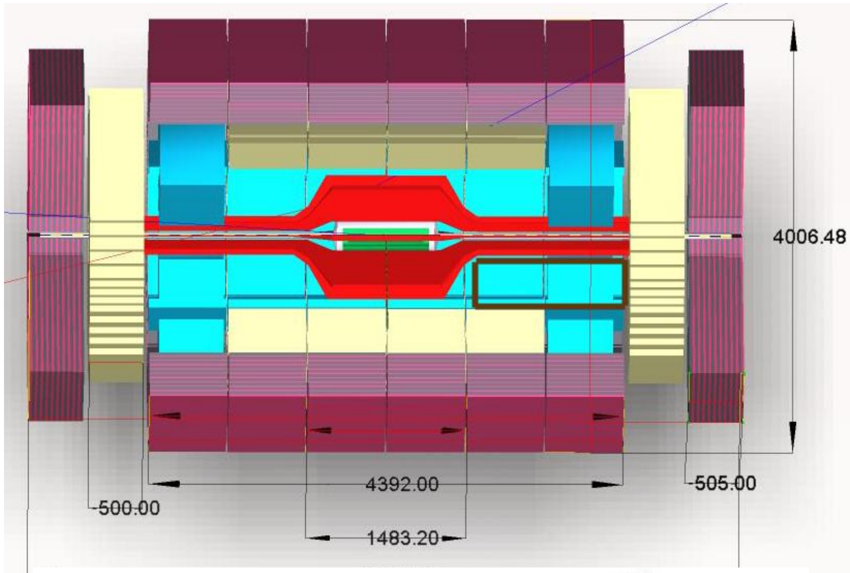
Need to have the special magnetic shield for transverse polarized beams. Soleniod influence on beam polarization. (see talk “Ion polarization control in MPD and SPD detectors of the NICA collider”, A/Kovalenko et al, IPAC 2015

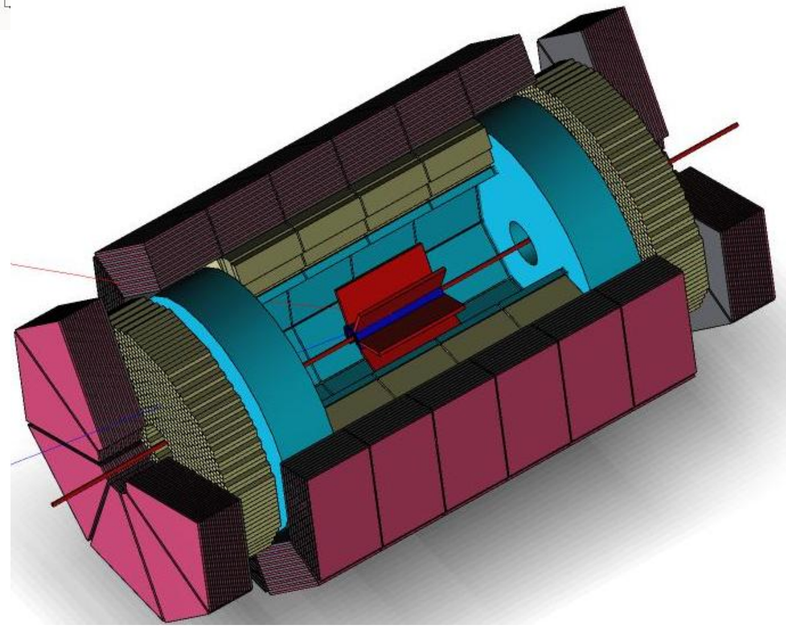
Advantages:

Acceptance

Uniformity of field

Possible layout of the SPD. Toroid.



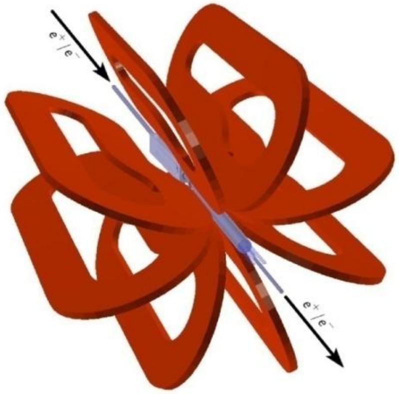


The toriod magnet can consist of 8 superconducting coils symmetrically placed around the beam axis . A support ring upstream (downstream) of the coils hosts the supply lines for electric power and for liquid helium. At the downstream end, a hexagonal plate compensates the magnetic forces to hold the coils in place. The field lines of ideal toroid magnet are always perpendicular to the particles originating from the beam intersection point. Since the field intensity increases inversely proportional to the radial distance: greater bending power is available for particles scattering at smaller angles and having higher momenta. These properties help to design a compact spectrometer that keeps the investment costs for the detector tolerable. The production of such a magnet requires insertion of the coils into the tracking volume occupying a part of the azimuthal acceptance.

Two options are possible:
“warm” and “cold” .

Toroidal magnets for PAX and Olympus

Olympus Toroidal Magnet

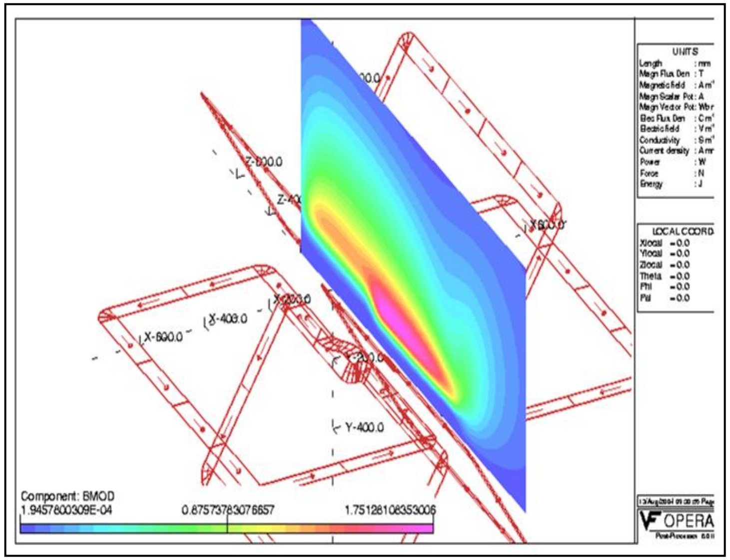


The magnet was designed and assembled at MIT(USA), BLAST experiment.

- **8 copper coils (26 turns each);**
- **acceptance 75%**
- **Max current 6.7 kA;**
- **Max field 0.28 T**
- **Length : 4m**
- **Radial size: 2.5 m**

Olympus Collaboration,
“TDR for Olympus experiment”,
July 7 2010,DESY

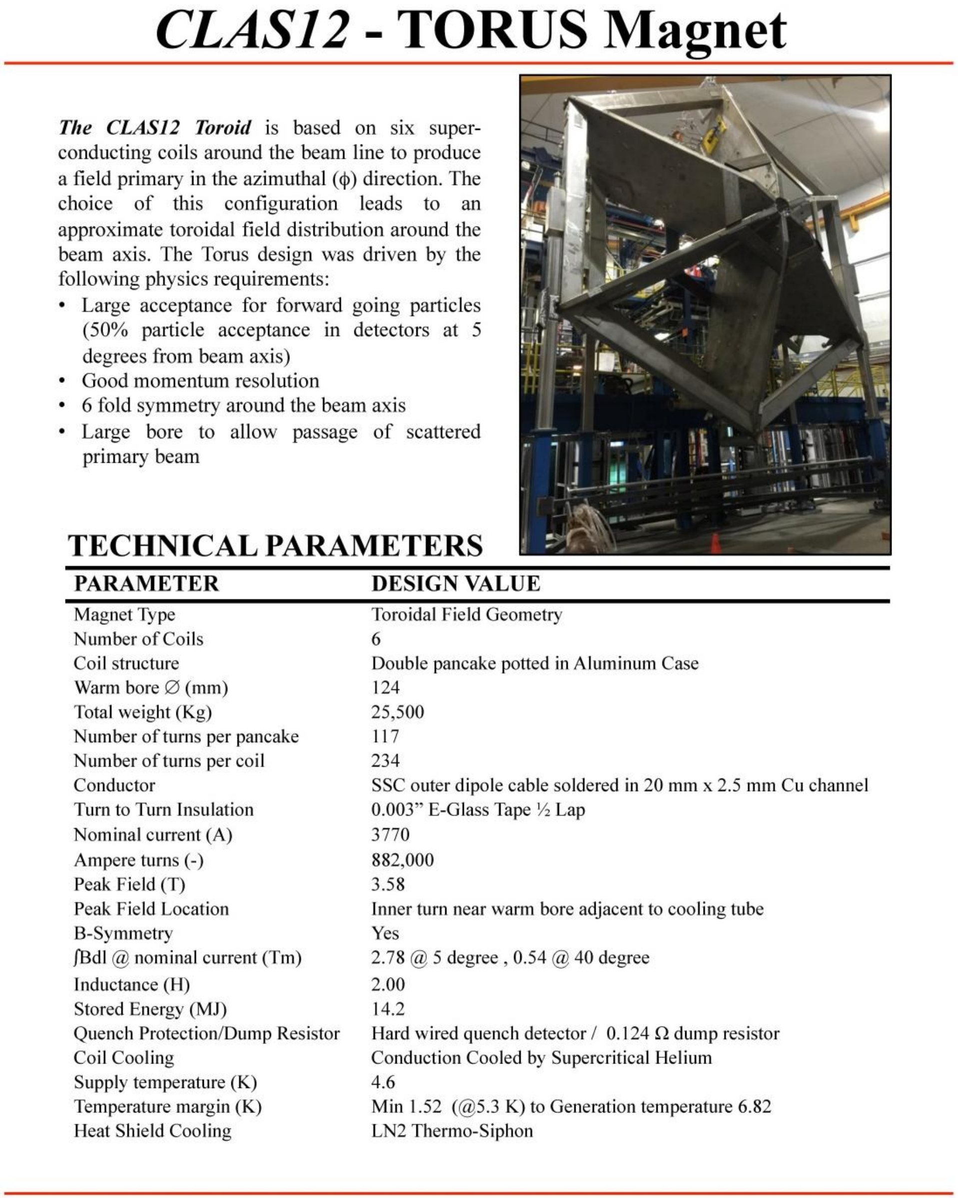
PAX Toroidal Magnet



- **800 x 600 mm coils**
- **3 x 50 mm section (1450 A/mm²)**
- **average integrated field: 0.6 Tm**
- **free acceptance > 80 %**

Technical Proposal for Antiproton—Proton Scattering Experiments with Polarization (PAX Collaboration), Jülich, April 2005

CLAS12 Toroidal magnet



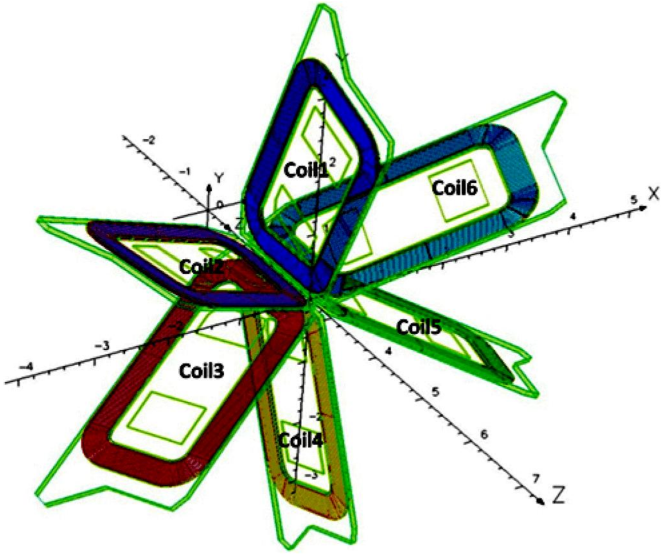
CLAS12 - TORUS Magnet

The CLAS12 Toroid is based on six superconducting coils around the beam line to produce a field primary in the azimuthal (ϕ) direction. The choice of this configuration leads to an approximate toroidal field distribution around the beam axis. The Torus design was driven by the following physics requirements:

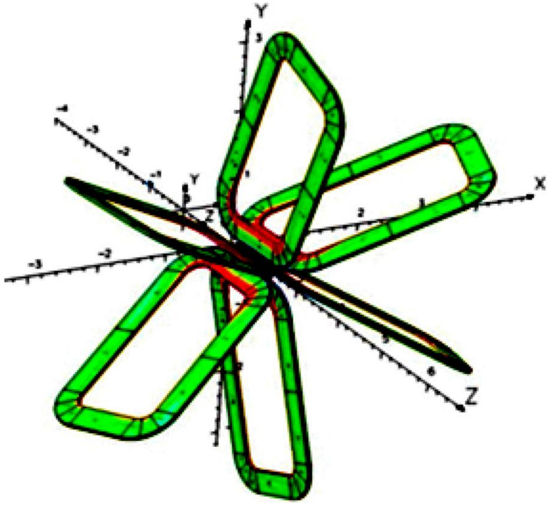
- Large acceptance for forward going particles (50% particle acceptance in detectors at 5 degrees from beam axis)
- Good momentum resolution
- 6 fold symmetry around the beam axis
- Large bore to allow passage of scattered primary beam

TECHNICAL PARAMETERS

PARAMETER	DESIGN VALUE
Magnet Type	Toroidal Field Geometry
Number of Coils	6
Coil structure	Double pancake potted in Aluminum Case
Warm bore ∅ (mm)	124
Total weight (Kg)	25,500
Number of turns per pancake	117
Number of turns per coil	234
Conductor	SSC outer dipole cable soldered in 20 mm x 2.5 mm Cu channel
Turn to Turn Insulation	0.003” E-Glass Tape ½ Lap
Nominal current (A)	3770
Ampere turns (-)	882,000
Peak Field (T)	3.58
Peak Field Location	Inner turn near warm bore adjacent to cooling tube
B-Symmetry	Yes
∫Bdl @ nominal current (Tm)	2.78 @ 5 degree , 0.54 @ 40 degree
Inductance (H)	2.00
Stored Energy (MJ)	14.2
Quench Protection/Dump Resistor	Hard wired quench detector / 0.124 Ω dump resistor
Coil Cooling	Conduction Cooled by Supercritical Helium
Supply temperature (K)	4.6
Temperature margin (K)	Min 1.52 (@5.3 K) to Generation temperature 6.82
Heat Shield Cooling	LN2 Thermo-Siphon



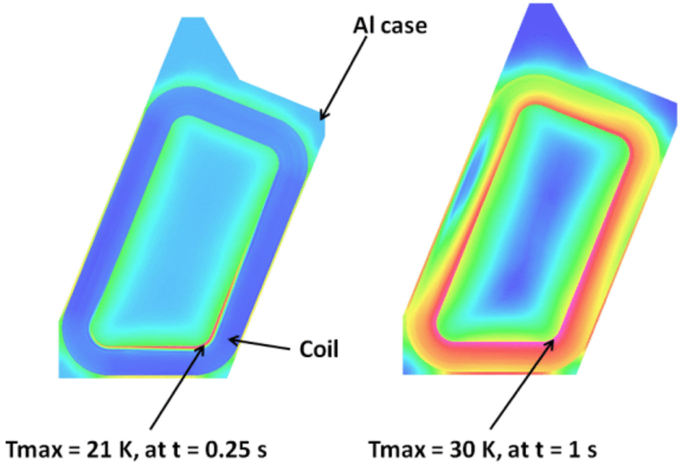
Superconducting magnet system (dimensions in m).



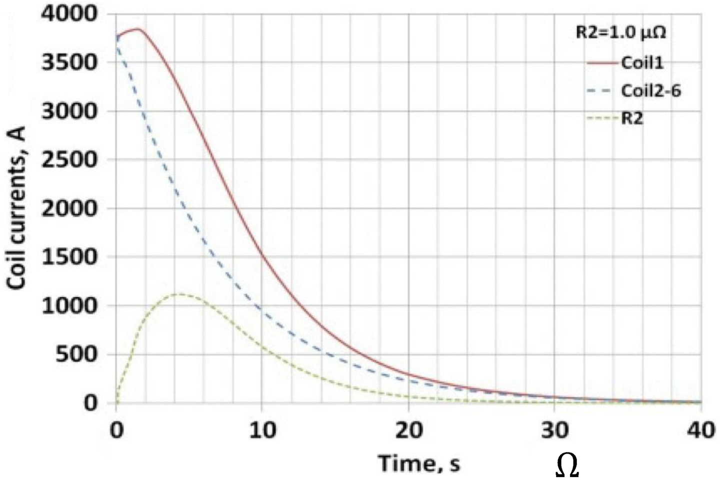
Magnetic flux density map (Bmax=3.6 T) at 3770 A (nominal).

CLAS12 Toroidal magnet

The JLAB Torus magnet system consists of six superconducting trapezoidal racetrack-type coils assembled in a toroidal configuration. These coils are wound with SSC-36 Nb-Ti superconductor and have the peak magnetic field of 3.6 T. The first coil manufacturing based on the JLAB design began at FNAL. The large magnet system dimensions (8 m diameter and 14 MJ of stored energy) dictate the need for quench protection. Each coil is placed in an aluminum case mounted inside a cryostat and cooled by 4.6 K supercritical helium gas flowing through a copper tube attached to the coil ID. The large coil dimensions and small cryostat thickness drove the design to challenging technical solutions, suggesting that Lorentz forces due to transport currents and eddy currents during quench and various failure scenarios are analyzed. The paper covers the magnet system quench analysis using the OPERA3d Quench code.



Cold mass temperature at (left) 0.25 s and (right) 1.0 s after the quench.

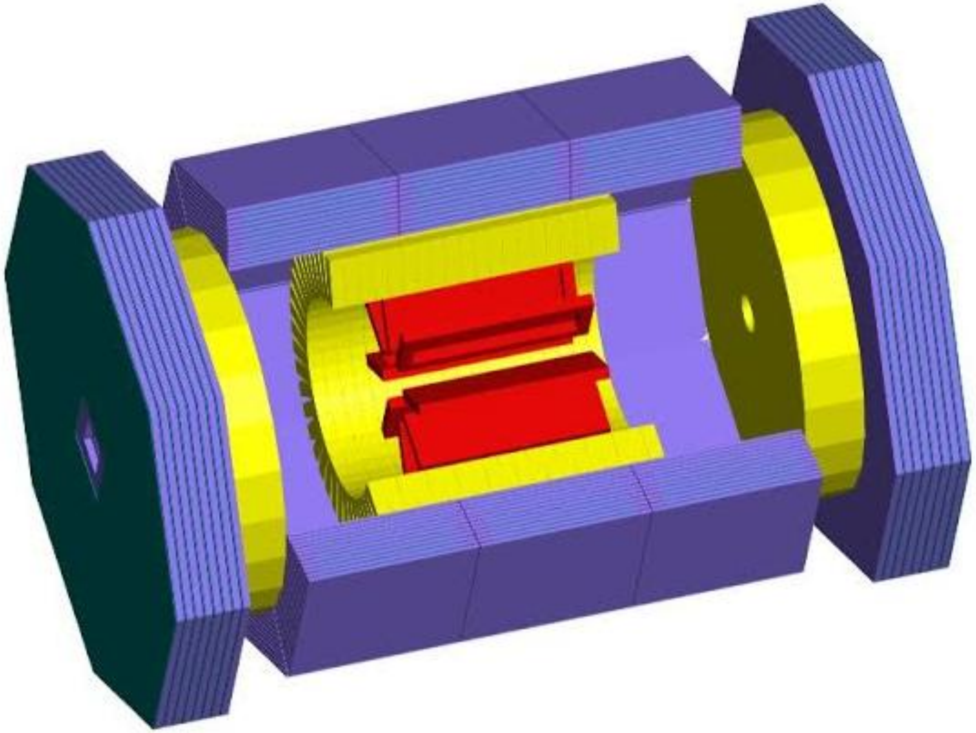


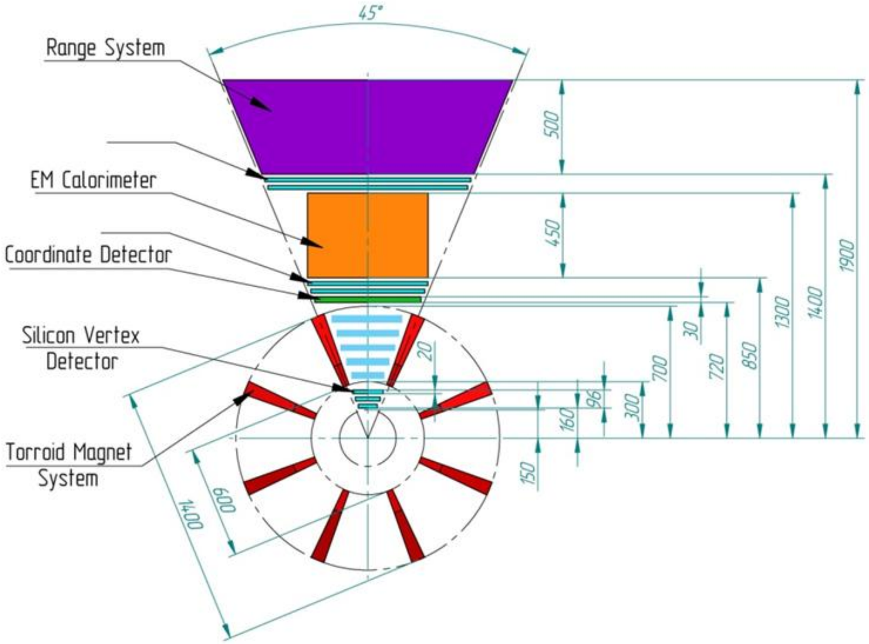
Ω μΩ

Single coil short currents. R1=0.124 , R2=1.0

Possible layout of the SPD.

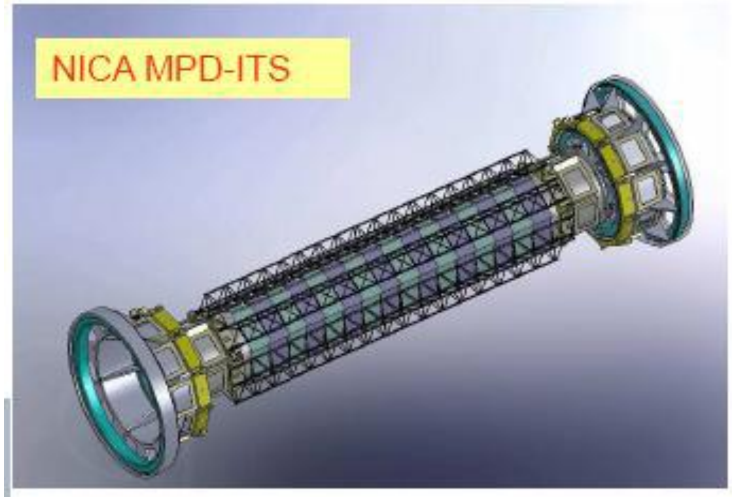
The setup can consist of 3 main parts: a barrel and two endcups.
The length of the installation is about 6 m, the diameter is up to 4 m.

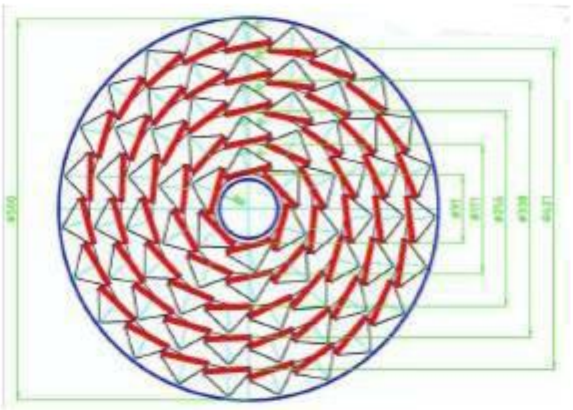




The basic detectors of the setup are shown:
Red - a toroidal magnet,
Yellow - electromagnetic calorimeter,
Muon system - highlighted in blue..

Possible layout of the SPD. Vertex





Silicon Microvertex Detector

The most obvious technology for the vertex detector (VD) is a silicon one.

It is approved for the MPD VD.

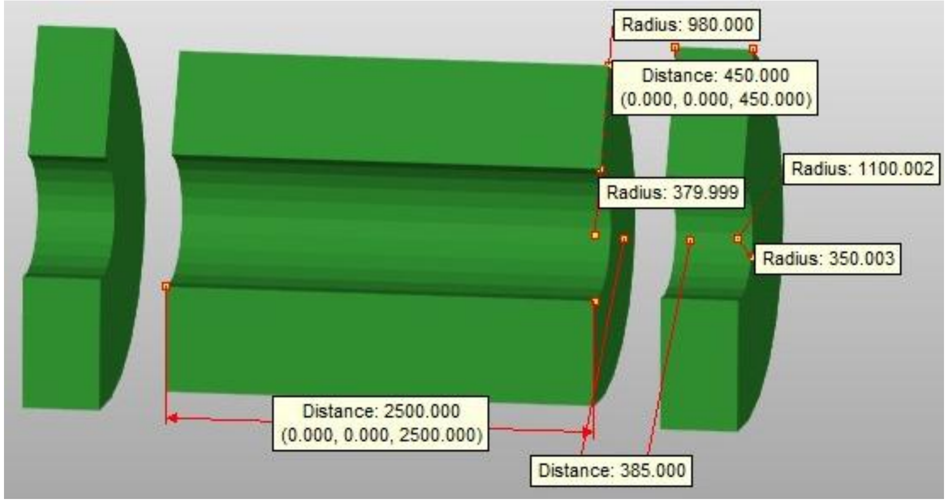
Outside the beam pipe.

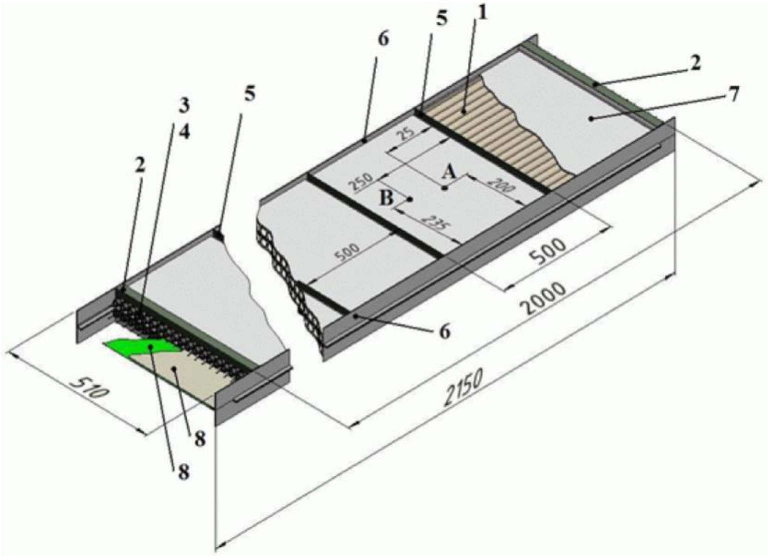
Several layers of double sided silicon strips can provide a precise vertex reconstruction and tracking of the particles before they reach the general SPD tracking system.

The design should use a small number of silicon layers to minimize the radiation length of the material. With a pitch of 50-100 µm it is possible to reach the spatial resolution of 20-30 µm. Such a spatial resolution would provide 50-80 µm for precision of the vertex reconstruction.

This permits to reject the secondary decay vertexes.

Possible layout of the SPD. Straw





The straw tubes can be selected to be the main detector of SPD Tracking System. This choice is due to the following properties of the staws tubes:

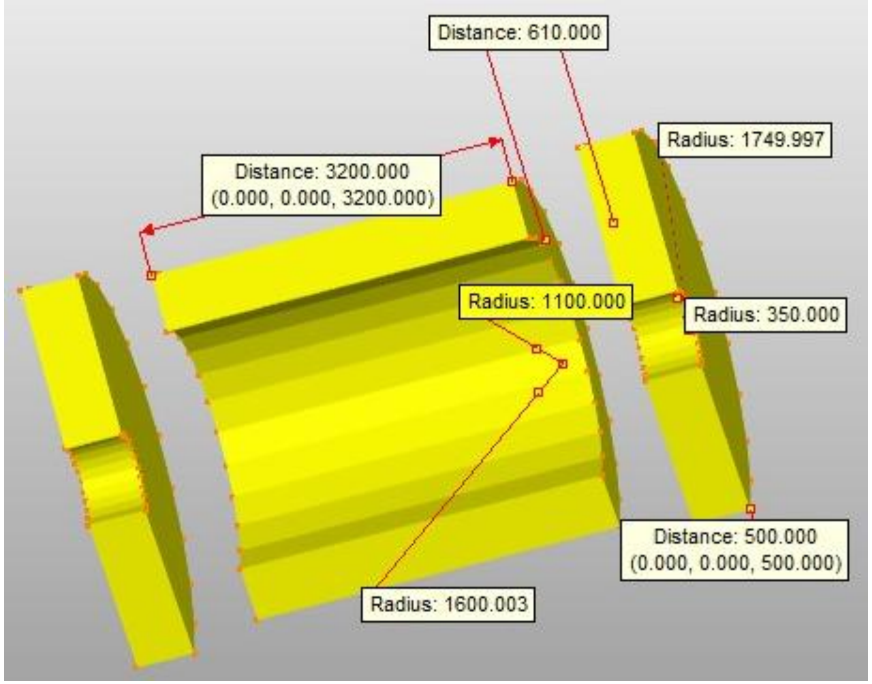
-the minimun of material for the tracks of the secondary particles (X_0 ~ 0.1);

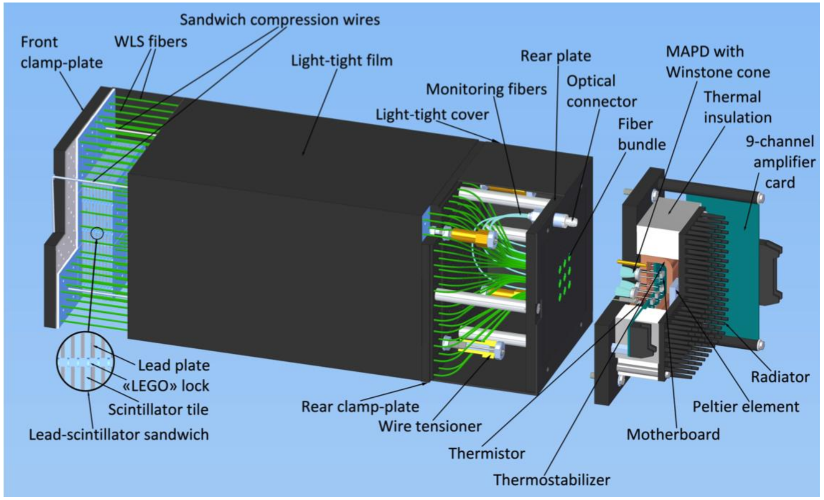
- the time (~ 200-300 ns) and spatial
  (track resolution ~ 100 µm);
- expected particle rates
  (DAQ rates ~ 100 Khz);
- the developed production sites
  (also in JINR,Dubna).

The one the main point of straw system development is the requiremets of the minimization of material budget. To meet this requirement it is planned to use the thin-walled tubes.

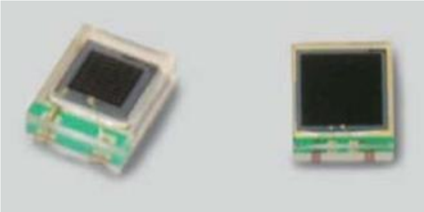
•V.A.Baranov et al, Instrum.Exp.Tech. 55 (2012) 26-28
•Bazylev S.N. et al., JINR Preprint P13-2010-60
•Davkov K.I. et al., JINR Preprint P13-2012-93
•NA-62 Collaboration, Technical Design Document,
NA62-10-07, December 2010

Possible layout of the SPD. ECAL.

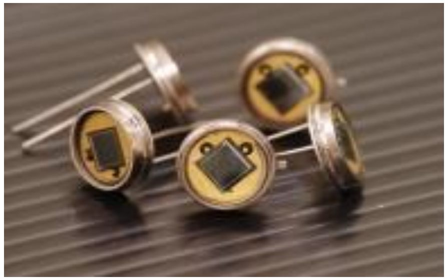




Photon energy range 0.1- 10GeV.
Taking into account the space limitation in the barrel region, the total length of module of the ECAL should be less than 50 cm.
The required energy resolution <10.0%/√E (GeV).
The latest version of the electromagnetic calorimeter (ECAL) modules, developed at JINR for the COMPASS-II experiment at CERN, can be good candidates for ECAL at SPD. These ”shashlyk” type of modules utilise new photon detectors Avalanche Multichannel Photon Detectors (AMPD).AMPD can work in the strong magnetic Field (in case solenoid magnet).

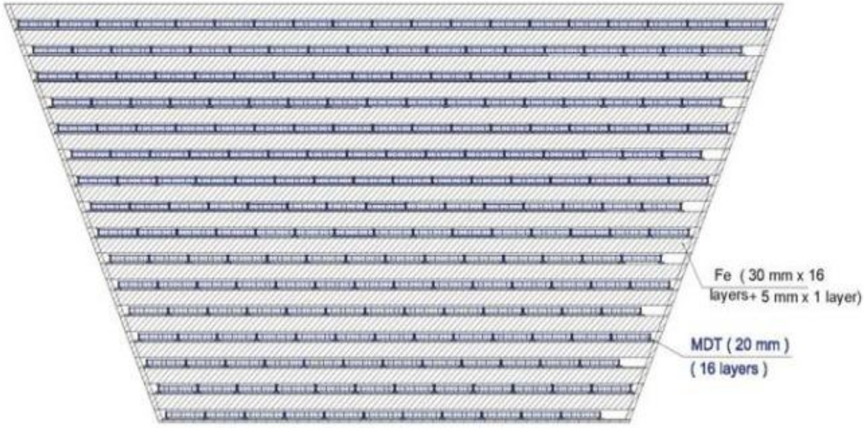


Surface mount type



Custom made

Possible layout of the SPD. Range system.

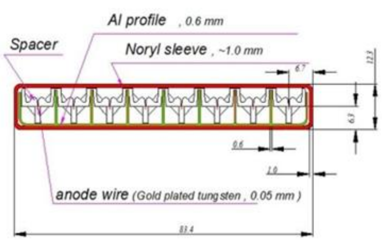


The system of MDT layers with Fe layers called by Range System (RS) is used in SPD as moun detector and main element of Particle Identification System.

It can provide the clean (>95%) muon identification for muon momenta grater than 1 GeV.

The combination of responses from EM calorimeter and RS can be used for the identification of pions and protons in the wide energy range.
RS provides good coordinate accuracy.

MDT cross-section

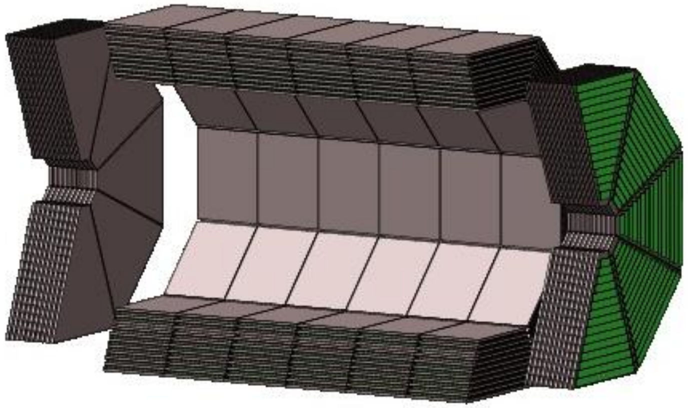


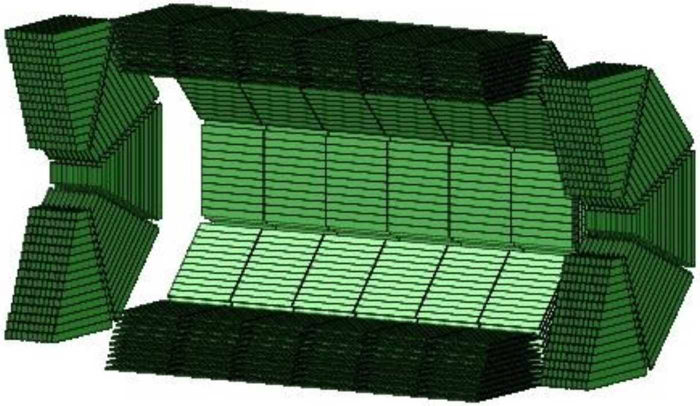
Plots are from “ Muon TDR for PANDA ”, PANDA Collab., November 2011

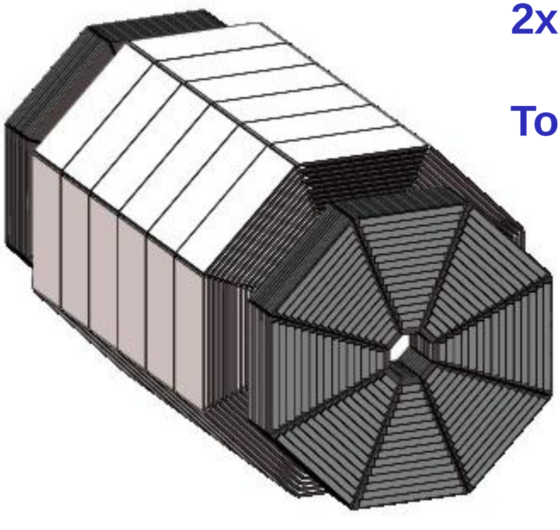
V.Abazov et al.,
Instrum.Exp.Tech.53:648-652,2010,
Prib.Tekh.Eksp.5:32-36,2010.

DLNP group, leader G.Alexeev

Possible layout of the SPD.
Range system.







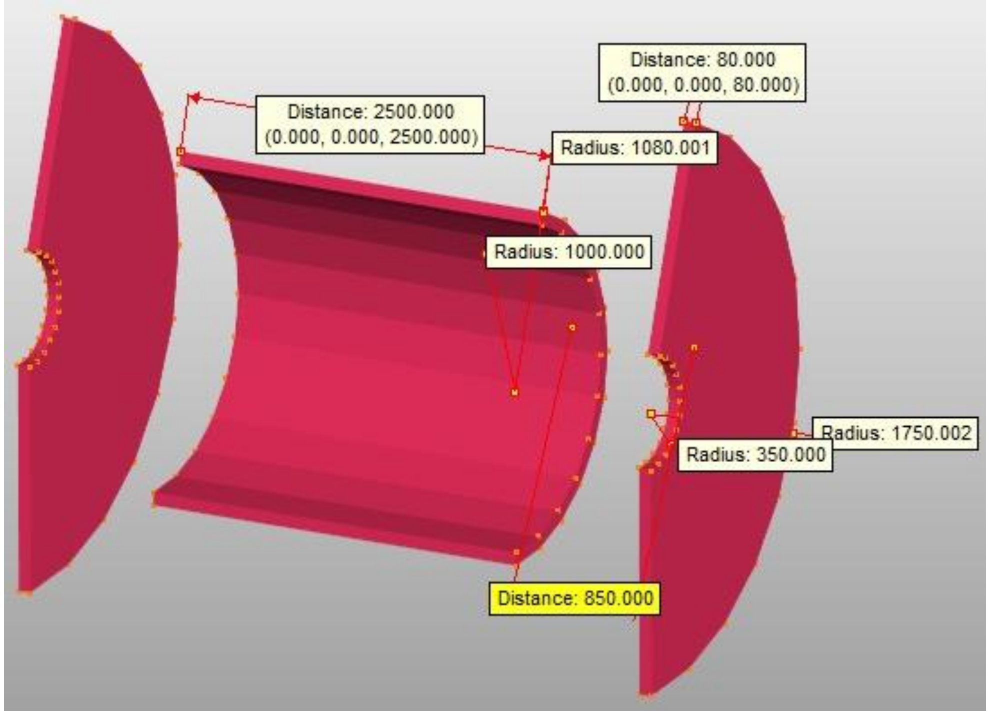
The Range System consists of two parts:
Barrel and two End cups.

The preliminary sizes of RS are as follows:
about 6.8 m along beam line and 3.7 m in diameter.

The RS designed with consists of 4140 MDT units for barell, 2x1200 units for End-cups.

Total: 6540 ch.

Possible layout of the SPD. Trigger and DAQ



The main task of the trigger system is to provide separation of a particular reaction from all reactions occurred in collisions.

Each of them will be pre-scaled with:

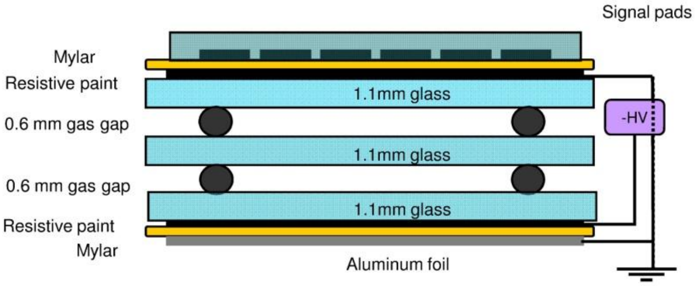
- **two muons (or electrons/positrons) in final states;**
- **various types of hadrons in final states (π+/-, K, p, …);**
- **photons (π^0, ω, η…);**
- **other reactions.**

RPC are proposed to be used as main trigger detector.

Also Hodoscopes of scintillating counters can be used for triggering.

They can be located before and after RS (or mounted in the last layers of RS) and before RPC.

The ECAL modules will also be used in the trigger system.



- **No wires;**
- **High efficiency;**
- **Fast response;**
- **Position measurement;**
- **Low production cost;**
- **Large surface**

RPC developed in the 1980’s.

Applied in many experiments:

ATLAS ans CMS (moun systems)
ALICE (TOF and moun system)
PHENIX (TOF, muon system);
OPERA (neutrino detector)

Possible layout of the SPD. Trigger and DAQ

Trigger logic could have two-level structure.

Dedicated hardware processors may be used at Level 1 which receives signals from the scintillation hodoscopes, EM calorimeter and the Range System. Using FPGA technology and look-up memories it is possible to organize flexible and efficient triggering.

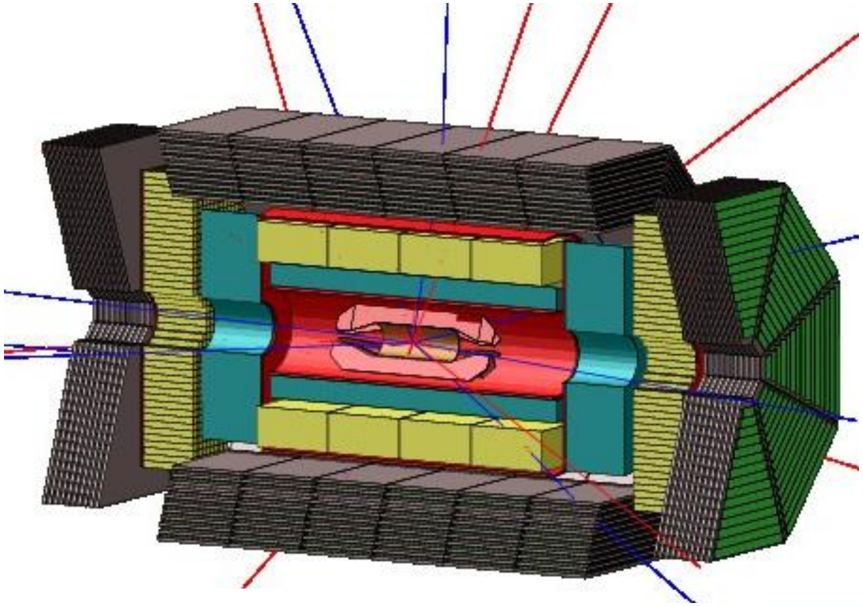
Local and total energy deposit in the calorimeter, multiplicity in the hodoscopes and information from the range system provide primary event selection.

At Level 2 more time consuming operations could be done. These include search for tracks in the Drift Chambers and the Range System, check of track matching with EM calorimeter hits etc.

Information from the silicon detectors could also be employed (if needed) at this stage.
Simulations of physics processes with use of real geometry, detector granularity and resolutions are planned in order to develop trigger scheme and selection algorithms.

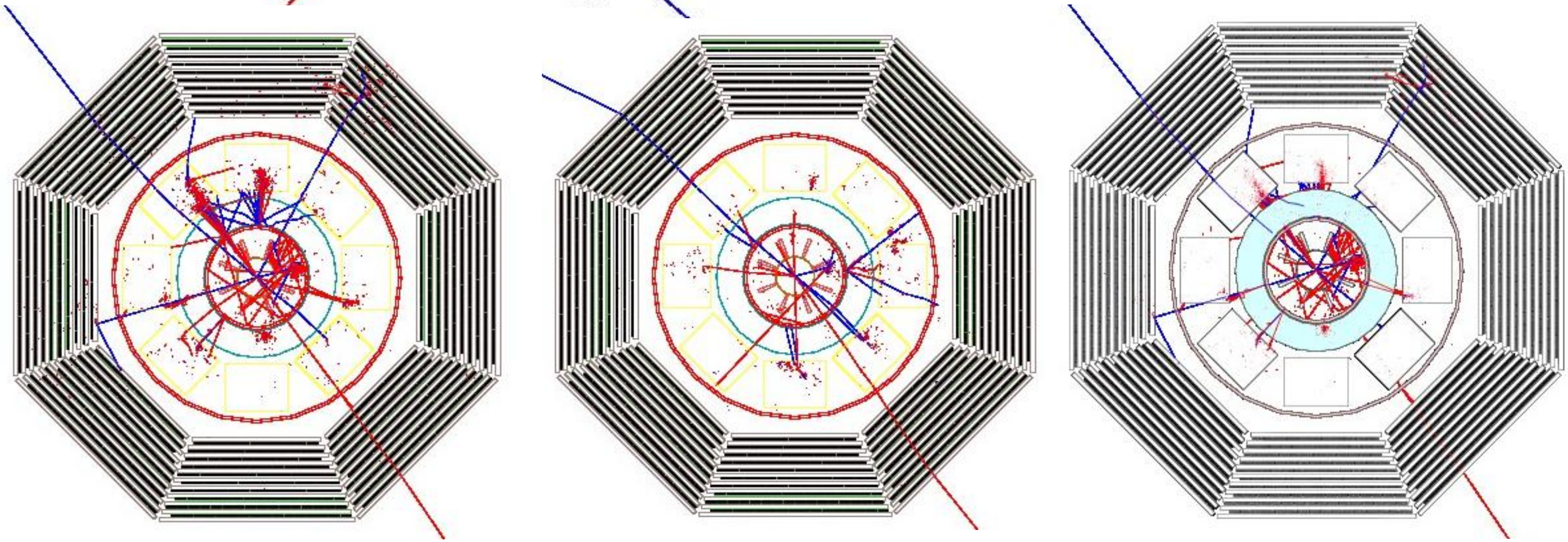
(prepared by A.Kulikov)

Possible layout of the SPD. Event simulation.

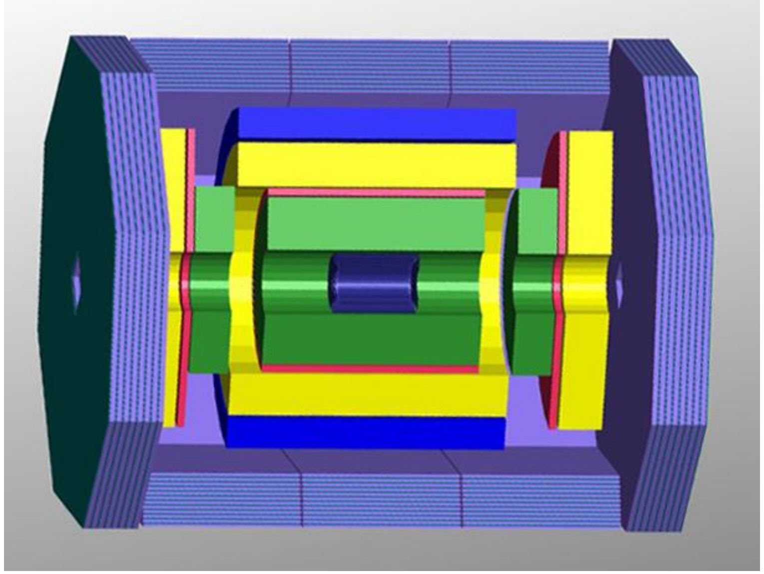


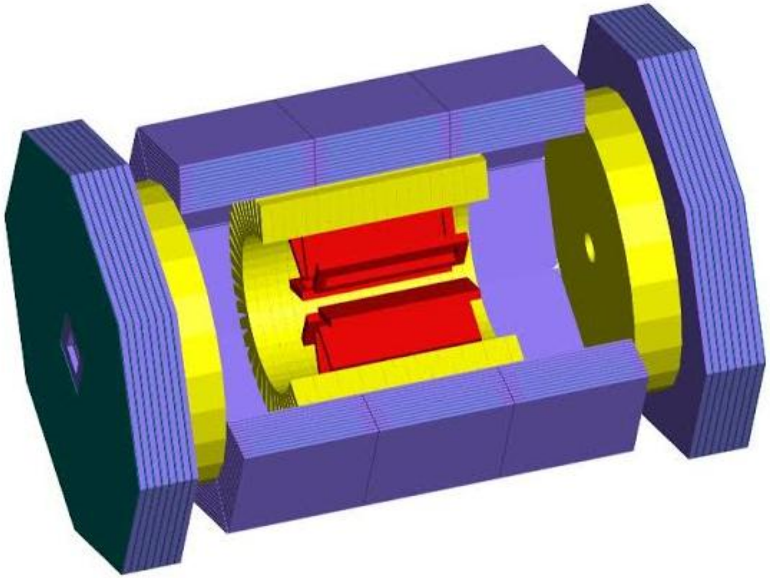
Simulation of MMT-DY in SPD

- for pp beams with E=12.6 GeV;
- pure MMT-DY events;
- PYTHIA generator was used;
- VC, DC, EMC,RS have to be fired.

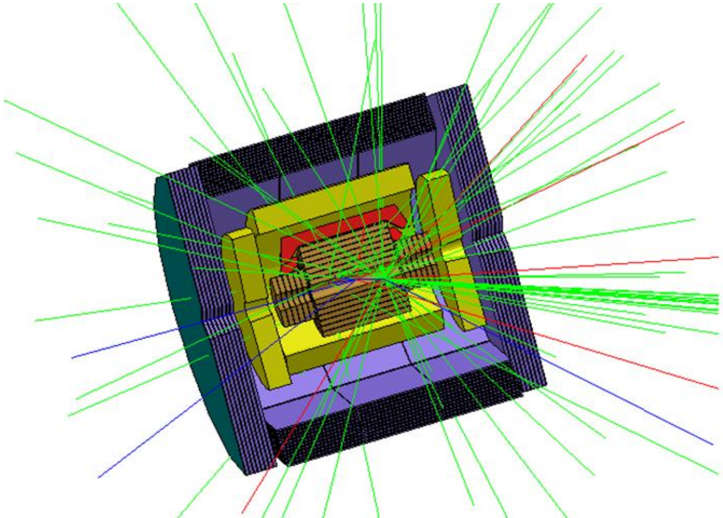


OUTLOOK

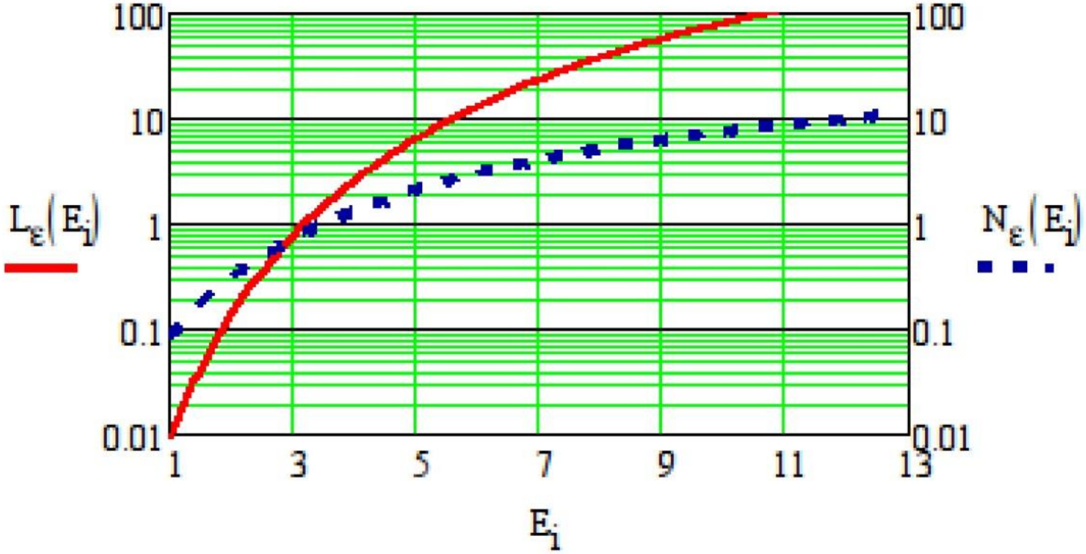




One needs to perform special R&D and MC studies to find the best solution on the SPD magnet system.



NICA Collider Luminosity in pp Collisions



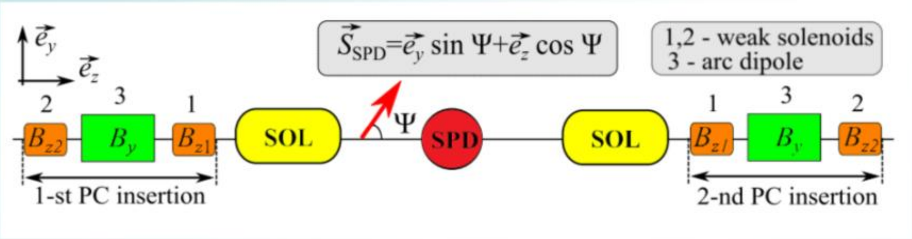
Energy in GeV. Luminosity in 10^{30} cm^{-2}s^{-1}.

(from A.D.Kovalenko's talk)

ION POLARIZATION CONTROL IN THE MPD AND SPD DETECTORS OF THE NICA COLLIDER

A.D. Kovalenko, A.V. Butenko, V.D. Kekelidze, V.A. Mikhaylov,
JINR, Dubna, Russia
A.M. Kondratenko, M.A. Kondratenko,
STL “Zaryad”, Novosibirsk, Russia
Yu.N. Filatov, MIPT, Moscow, Russia

Polarization control in SPD (MPD)



$$\varphi_{z1} = \pi\nu \frac{\sin(\varphi_y - \Psi)}{\sin\varphi_y} \qquad \varphi_{z2} = \pi\nu \frac{\sin\Psi}{\sin\varphi_y}$$

ν is spin tune

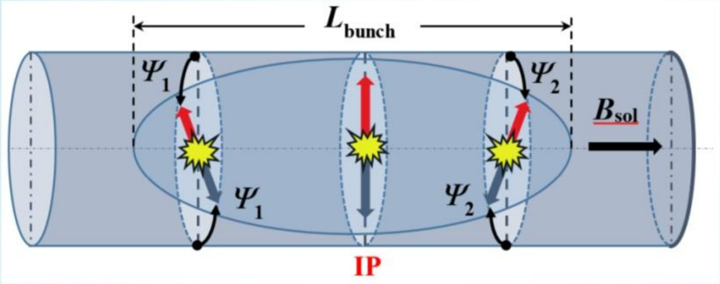
$\varphi_{zi} = (1+G)\frac{(B_{\|}L)_i}{B\rho}$ are the spin rotation angles in the solenoids

$\varphi_y = \gamma G\alpha$ is the spin rotation angle between the weak solenoids

α is the orbit rotation angle between the solenoids

MPD solenoid influence on polarization in MPD detector

Due to momentum spread, the particle collisions could be occurred at any point along a bunch length.

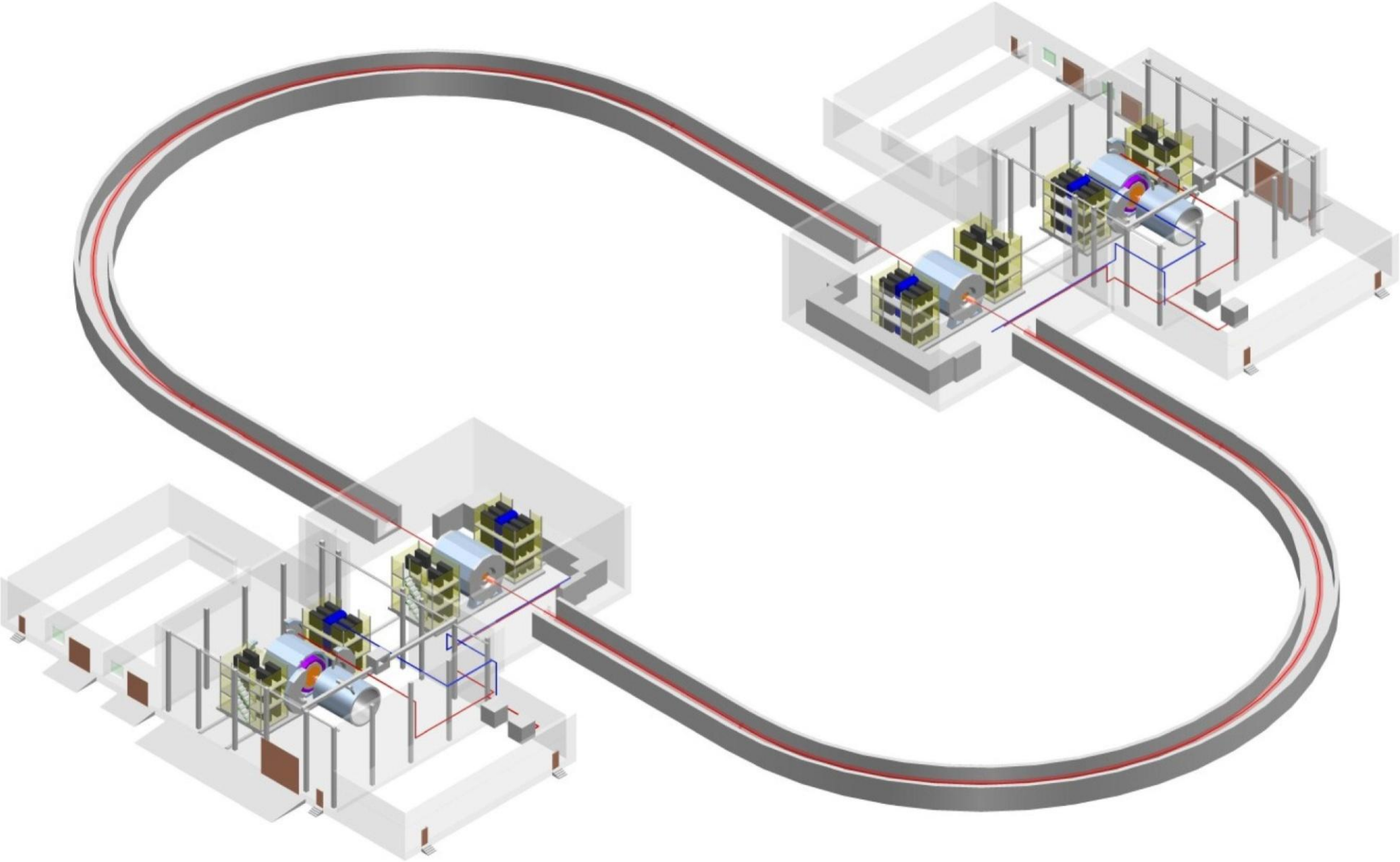


L_{MPD}=7.5 m, L_{bunch}=0,5 m.

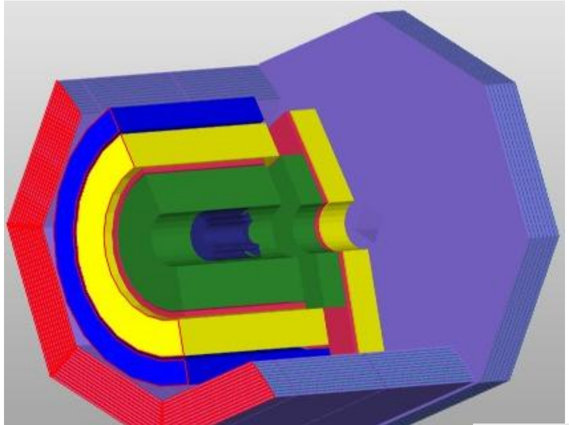
Relative orientation of the spins will be the same at any point of the particles collisions within the detector.

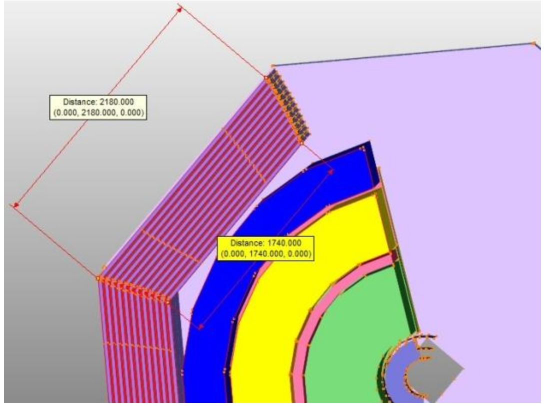
$$\Psi_d[\text{grad}] = 15\frac{B_{sol}[\text{T}]\,L[\text{m}]}{p[\text{GeV}/c]}, \quad \Psi_p[\text{grad}] = 48\frac{B_{sol}[\text{T}]\,L[\text{m}]}{p[\text{GeV}/c]}$$

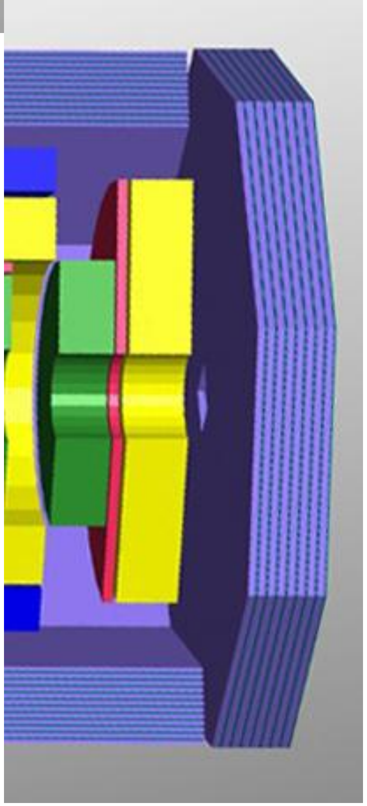
p, GeV/c	B_{sol}, T	L, m	Ψ_d	Ψ_p
2	0.6	4 (MPD edge)	18°	58°
13.5	0.6	4 (MPD edge)	2.7°	8.5°
2	0.6	0.25 (bunch edge)	1.1°	3.6°
13.5	0.6	0.25(bunch edge)	0.17°	0.53°



Possible layout of the SPD. Solenoid







Barrel, detector's positions :

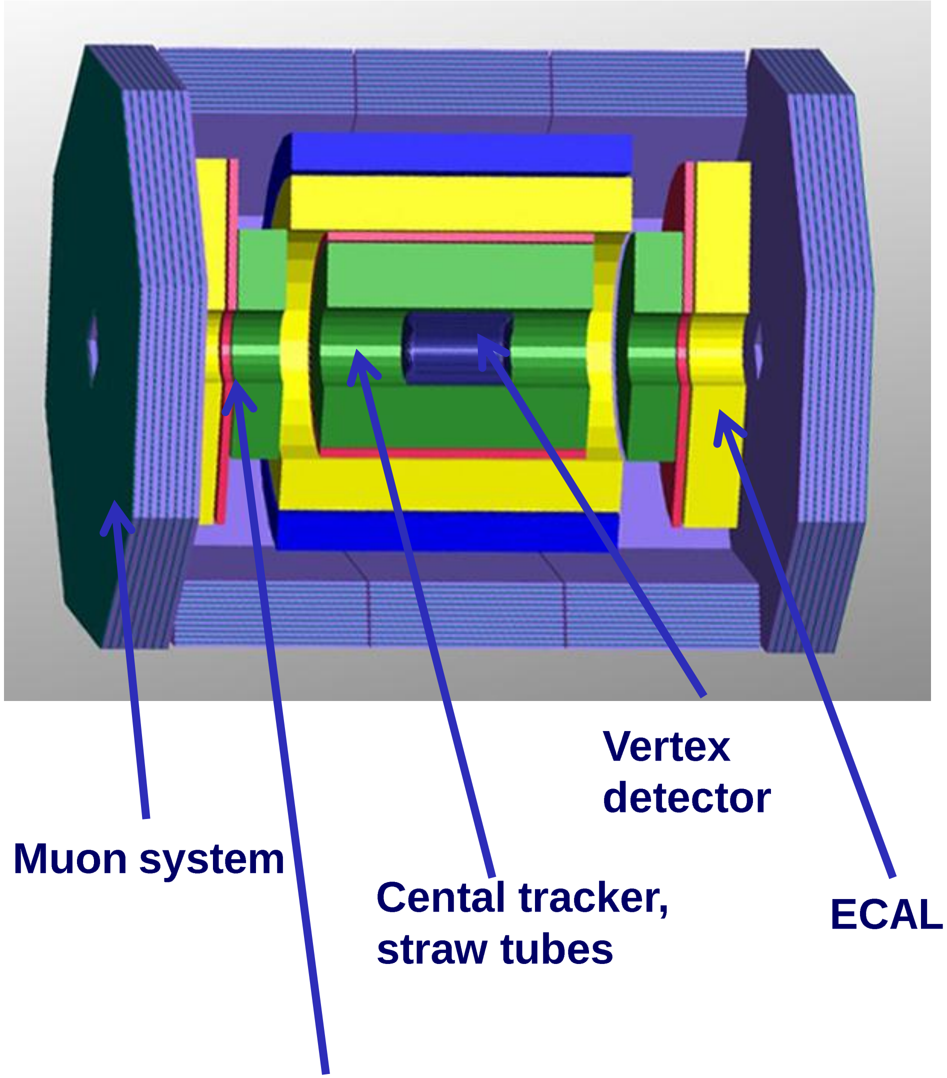
in radius lenght
0.16 - 0.34 -> VD -> 1 m (+-0.5m)
0.38 - 0.98 -> Straw -> 2.3 m
1.00 - 1.08 -> TOF/RPC -> 2.3 m
1.10 - 1.60 -> ECal -> 3.2 m
1.65 - 2.00 -> Solenoid -> 3.2 m**
2.05 - 2.65 -> RS -> ~ 5.50 m

Endcap:

	thickness,m	inradius, m	Z,m
RS(Fw/Bw):	0.56, each		
Straw :	0.45	0.35-1.1	+/- 1.86
TOF/RPC:	0.08	0.35-1.7	+/- 2.14
ECAL:	0.50	0.35-1.75	+- 2.46

** additional space in case of toroid magnet

Possible layout of the SPD.



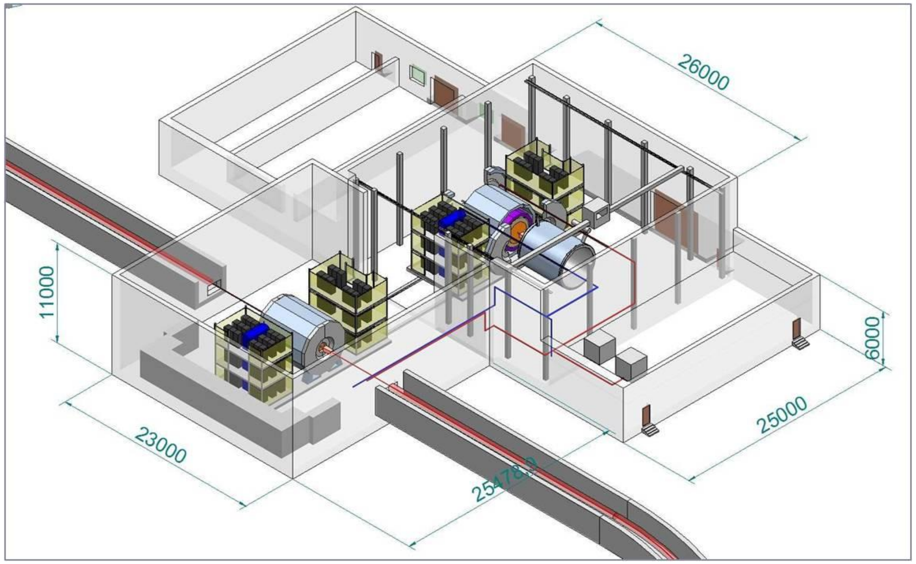
Muon system

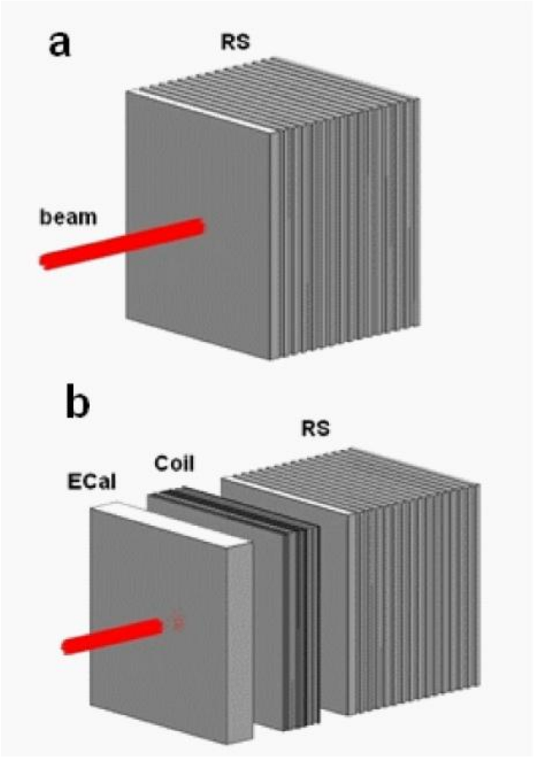
RPC/TOF

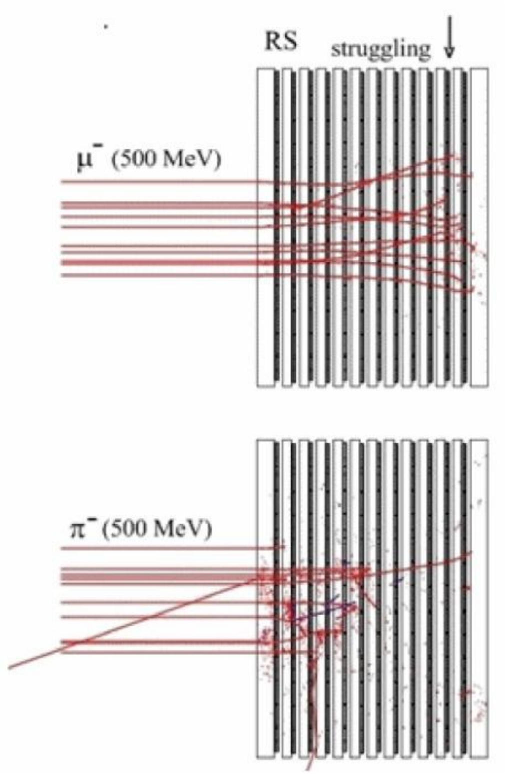
Cental tracker, straw tubes

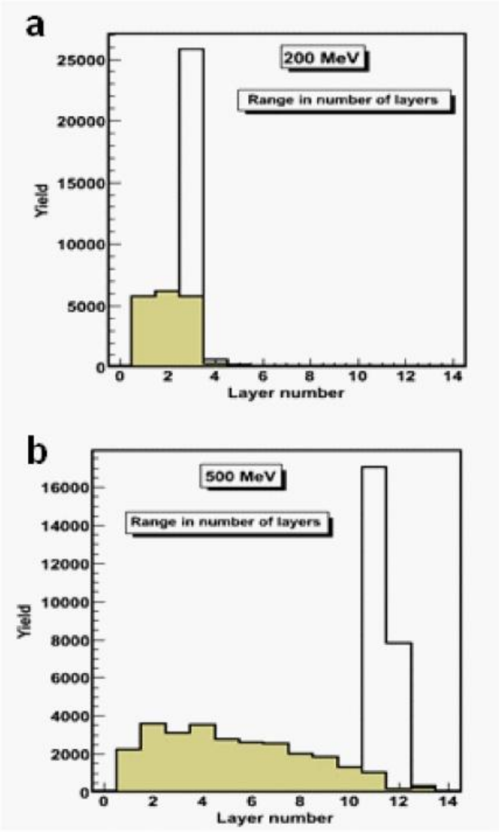
Vertex detector

ECAL

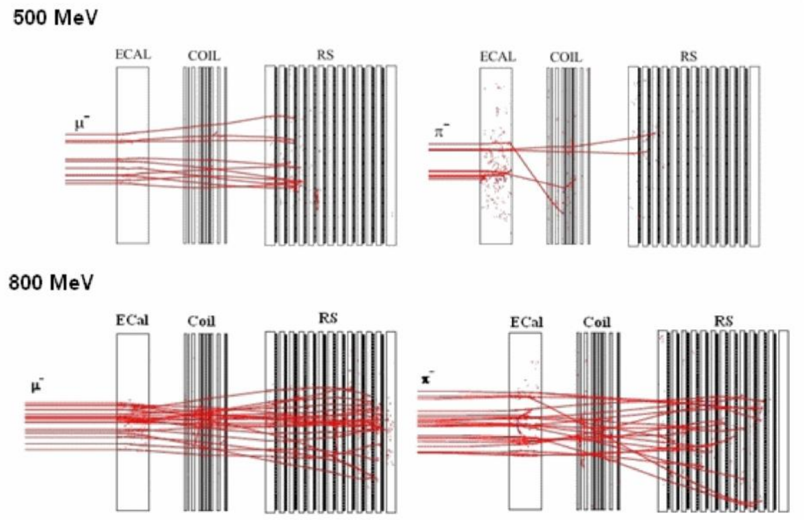


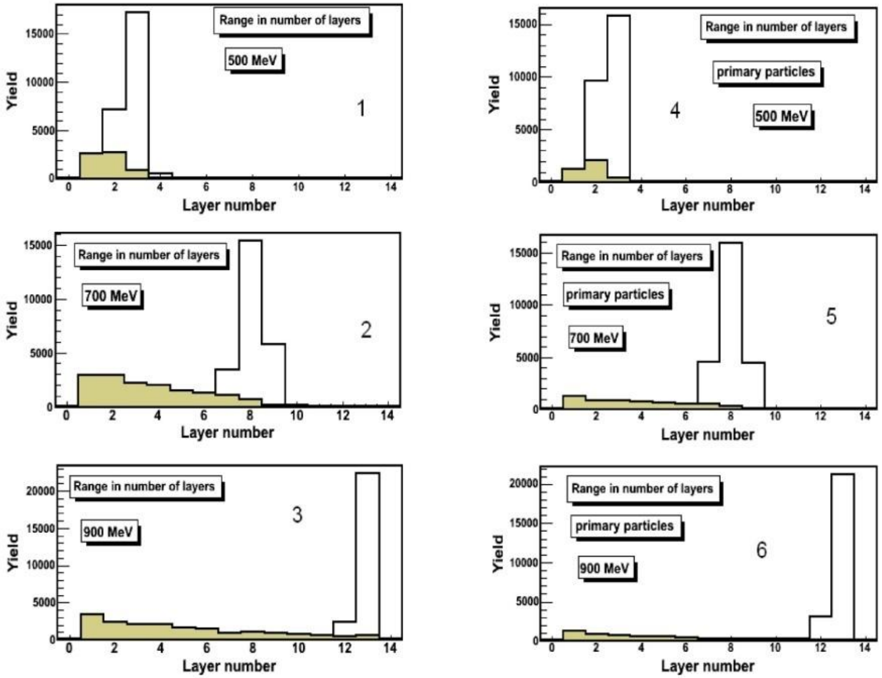


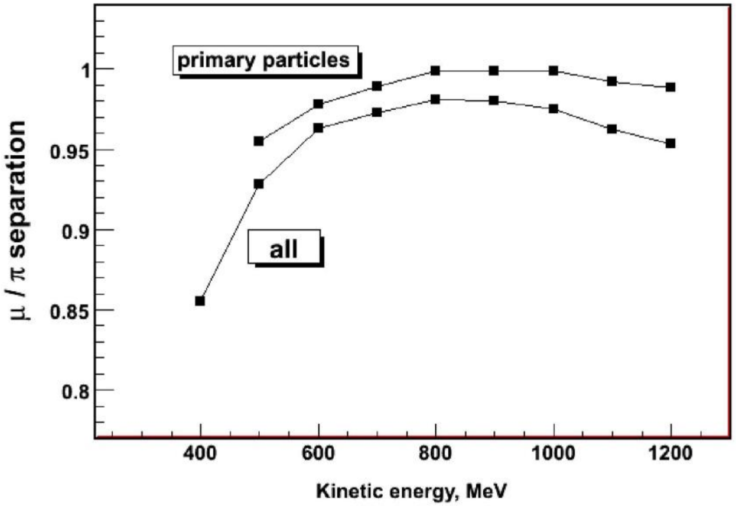




Plots are from “ Muon TDR for PANDA ”, PANDA Collab., November 2011







Estimated μ/π for E>1 GeV is more than 96%

Plots are from “ Muon TDR for PANDA ”, PANDA Collab., November 2011

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