DETECTOR FOR LINEAR COLLIDER

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Abstract

We summarize here our vision on detector for future linear collider. Absence of magnetic yoke allows construction of easy adjustable universal detector. Tanks to usage of multiplet in final focus optics, this detector is also able to register secondary particles under extremely small angles, what is required for running collisions with polarized beams.

1. Introduction

Program for detector development for future linear collider was under discussion during preparation of the Document [1]. It is likely, that such detector can weight within thousands of tons. Mostly of this weight associated with magnetic yoke serving as a flux return for superconducting solenoid. This solenoid generates a longitudinal field, which helps in identification of particle's momenta by measuring the curvature of theirs trajectory[1].

Due to the high cost and uncertainties in program for high-energy physics beyond 0.5 TeV, physical community can afford the only one detector. From the other hand detector for linear collider must be universal, allowing registration of e^+e^-, e^-e^+, gg, $ge^{\pm}$ collisions in separate runs. This dictates a necessity for broad flexibility in design of future detector.

It must take advantages associated with both polarized colliding beams [2].

It was shown recently [3], that yoke is not an unavoidable attribute of future detector. Advantages of this are evident. Internal parts of detector can be made easy accessible in a new design. The same is valid for electronics and cables at the ends. Detector becomes a lightweight unit as a whole. This makes detector more flexible unit for easy upgrade and maintenance.

Modular concept in detector design becomes possible now.

Easy access to the IP might be vital for future photon-photon collider arrangements, as it helps in arrangements of the photon beam optics and it's maintenance.

It is true, that iron is in use as a part of muon identification system. This was done sequentially for utilization of the massive iron of the yoke somehow. Some newest approaches allowing doing the same with toroidal fields of even with Cherenkov ring detectors.

Below the modular detector scheme considered. This scheme meets all requirements.

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[1] Configuration with transverse magnetic field was tested in circular machine VEPP-4, Novosibirsk. Here detector field was a part of bending [9]. However latest design there deals with solenoid also.

2. FF optics

Typical emittances under discussion for future linear collider are within $(ge_x) \approx 3 \cdot 10^{-4} cm \cdot rad$ – radial and $(ge_y) \approx 3 \cdot 10^{-6} cm \cdot rad$ –vertical. Energy spread about $s_e \cong 10^{-3}$ and the bunch length $s_z \cong 5 \quad mm$. The length of the bunch after one stage compression is of the order 500 mm and the number of the particles is about $N \approx 10^{10}$ [1].

For realization the high luminosity the envelope function $b*$ in the interaction point must be of the bunch length value, what is about $s_l \approx b^* \cong 500 mm$. The envelope function value at the distance *s,* calculated *from* the interaction point will be as big as

$$b \cong b^* + \frac{s^2}{b^*} \cong \frac{s^2}{b^*}, \tag{2.1}$$

where we neglected the focusing, arising from the incoming bunch. With such an envelope function value, the transverse dimension $s_{\wedge max}$ will be

$$s_{\perp \max} \cong \sqrt{\frac{(ge)\,b}{g}} \cong \sqrt{(ge)\,\frac{s^2}{gb^*}} = \sqrt{\frac{(ge)}{g\,b^*}} \cdot s\ . \tag{2.2}$$

The last is simply the angular divergence at IP multiplied by the distance s.

For emittance we can take the value $(ge_x) \approx 3 \cdot 10^{-4} cm \cdot rad$, what gives for energy $E \cong 1\,TeV\ (g \cong 2 \cdot 10^6)$ the transverse dimension $s_{\perp \max} \cong 11 \times 10^{-4} cm \cong 11\, mm$ for s= 20 cm. So even 20 sigma margins give the beam size of the order of 500 mm=0.5mm only (and so on). This gives an idea of possible aperture of the closest to IP quadrupole. This first quadrupole prevents the envelope function from growing (in direction of fastest grow, as in reality the envelop functions at IP is different for different coordinates) and directs the beam to the next lens with slightly larger aperture.

So, the focusing of particles towards IP arranged with a multiplet including five-six quadrupoles, rather than doublet in mostly designs. We called these arrangements an ***adiabatic final focus*** [4].

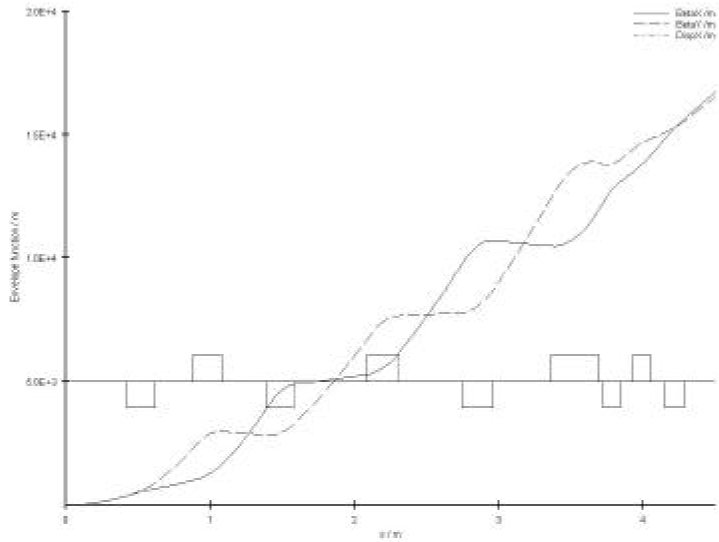

Figure 2.1: Envelope function behavior for the multiplet of lenses around IP. IP supposed to be at *s*=0, left point at abscise axis. Beta-functions for x and y directions at IP in this example is chosen equal the same with values 0.05cm. Beam energy is 1 TeV.

This allows having quads diameter linearly decreasing towards the IP[2]. As the field at the pole or at the wall is fixed by critical current in SC winding or by pole tip saturating field, the gradient increases linearly with decreasing the aperture.
In it's turn this allows having the outer sized of focusing elements linearly decreasing in diameter towards the IP.
As the yoke is eliminated, there is possible now to consider 50-100 kG field.
Meanwhile the solid angle available now can be restricted around $Cos\,J_{\max} \cong 0.995$, allowing measurements of $ds\,/dCos\,J$ in wider margins. So some processes this is important. It is extremely important for measurements with polarized particles.

Crossing angle is not required for TESLA type beam structure, as it is possible to deflect the bunch out of trajectory of incoming bunch.
For screening of beam from magnetic field of main detector solenoid, the anti-solenoid wrapping the lenses can be used here. This will eliminate SR if some crossing angle is used.
Stabilization of doublets is easy now as they might have solid connections.
Real job done with focusing of SLAC beam into ~70nm cross-section [5] indicate, that the dealing with such a small beam size will not be a serious problem.

3. General description of Modular Detector

Basically the detector now is a frame holding a container with SC solenoid, Fig. 3.1, Fig. 3.2. The possibility for lightweight alloy utilization is open. Aluminum and

[2] Real test FF optics described in [3].

titanium alloys are good for this framing. Basically the solenoid is not experiencing strong forces, as the surroundings are non-magnetic.
Advantages of such detector's configuration are evident. Internal parts of detector can be made easy accessible. The same is valid for electronics and cables.
Basically every element now becomes easy replaceable and can be locked in place.
The easy access might be vital for arrangement of gamma-gamma collisions.
As it was mentioned above the cut angle possible now goes to $c_{\max} \equiv CosJ_{\max} \cong 0.995$. Typically, for experiments with polarized particles the back-forward difference of secondary particles decay ratio is the subject of interest. So larger angle available allowing wider cuts margins. Typical c^2 criterion defined as [7]

$$c^2 \cong (X - Y)^2, \qquad (3.1)$$

where

$$X = \int_{c1}^{c2} \frac{ds^{SM}}{dCosJ} dCosJ \, , \; X = \int_{c1}^{c2} \frac{ds^{NEW}}{dCosJ} dCosJ \qquad (3.2)$$

and $ds / dCosJ$ defined for Standard Model and for New one(s).
This analysis with different cut angles is extremely important for measurements with polarized particles.
So that is why all attempts need to be done for increasing the capturing angle.
According to [8] mostly promising might be process asymmetry measurements in the
process $e_L^- e_R^+ \to W^- W^+$, switching off a channel running through real gamma.

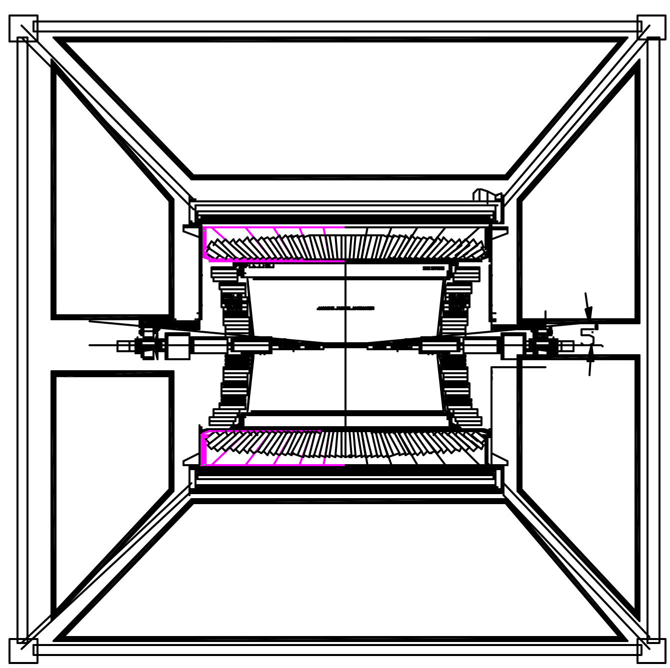

Figure 3.1: Modular detector's cross-section.

Modular detector's cross-section is shown in Fig.3.1. There is no magnetic yoke in this detector. Focusing arranged with the help of multiplet of quadrupoles, rather than a doublet. One can see that in modular detector under discussion the solid angle available for registration is large. This is important for the measurements with both polarized colliding bunches. Back-forward asymmetry in registered secondary particles is important here as it was mentioned above.

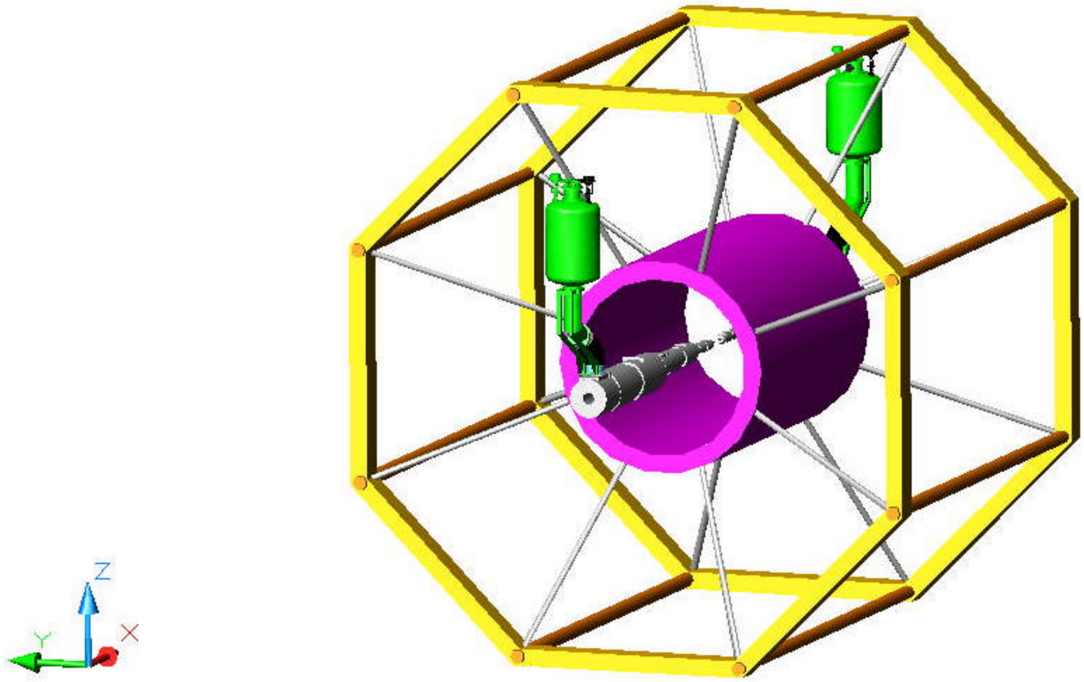

Figure 3.2: 3D view on detector's frame.

3D view on detector's frame is shown in Fig.3.2. Sectors filled with muon identification system. This concept allows easy modular design. The length of solenoid extended for better performance and reduction of stray fields. At the end region solenoid has more tuns, what allows considering this as a solenoid plus Helmholtz coils in the same cryostat. One can see that the diameters of the focusing lenses are decreasing towards the IP.

4. Field inside/outside detector's solenoid

At the present times the all known designs are dealing with solenoidal field (see comment at page 1).

It is well known that the outside field has strictly zero value for (infinitely) long solenoid. Field is homogenous inside the (long) solenoid. Typically field inside real solenoid is dropping 15-25% without iron what can be easily compensated by adding tuns at the end region of solenoid [3]. This configuration can be called as solenoid plus Helmholtz coils type. The field homogeneity is not worsen, than for case with iron yoke presence.

Field outside of solenoid drops rapidly as it was shown in [3]. Basically magnetic field drops as a third power of the distance R,

$$\vec{H} = \frac{3\vec{n}\cdot(\vec{n}\cdot\vec{M}) - \vec{M}}{R^3}, \qquad (4.1)$$

where $\vec{n}$ is unit vector in direction of R, and $\vec{M}$ is the magnetic moment of solenoid,

$$\vec{M} = \frac{1}{2c}\int(\vec{j}\times\vec{r})dV = \frac{pr^2 J}{2c}, \qquad (4.2)$$

J is total current, r is the radius of solenoid. Even at the distance of ~1-2 meters the fields naturally drops to ~0.5kG, where local iron shields can be implemented easily if necessary. Some local shielding far from the solenoid ends can be implemented easily.
Having the field homogenous in region of wire chambers helps in fast reconstruction of the particle's trajectory. The speed of contemporary processors dedicated to this job, allow corrections for the field inhomogeneity to be done in real time, however.

This anti-solenoid maight be added here for possible compensation of coupling and for preventing of SR radiation in the solenoidal field if crossing angle is used.
Mostly of elements of the vacuum chamber around detector, as a rule, made on nonmagnetic materials, such as StSteel and Copper. NEG pumps can support vacuum. IP lenses made with SC wire are nonmagnetic.
It is true that the energy stored in the stray field becomes higher for the case without iron. Making solenoid with extended length helps to avoid this problem.
Small local anti-solenoid installed closer to IP helps in beam dynamics and is an operational part in some working detectors and storage rings.
One can consider the scheme with more coils.
Additional Helmholtz type system of room temperature around whole detector can eliminate the mostly field around.
As the yoke is eliminated, there is possible now to consider very high magnetic field. Say 70-100 kG field might be considerable in a future, not practically possible for detectors with iron yoke.
Here the compensation of coupling introduced by solenoidal field is not so important.

5. Muon identification system

Mostly important components such as vertex detector, wire chamber (or it's analog on functions), calorimeter and some others located at traditional places.
Shower detector requires some material. Nuclear interaction length for iron ~ 131.9 g/cm^2 or ~16.6 cm. For copper the nuclear interaction length goes to 134.9 g/cm^2 or 15 cm respectively.
Other than this traditional possibility, however, is the one with toroidal field with superconducting coils, similar to what developed by ATLAS team [6].
Cherenkov ring detectors have a good potential for doing the same job.

6. References

[1] G. Loew, Editor, *international linear collider technical review committee report,* 1995.

[2] V. Balakin, A. Mikhailichenko, *Conversion System for Generation of Highly Polarized Electrons/Positrons*, BINP 79-85, Novosibirsk, 1979.

[3] A. Mikhailichenko, *Do Detectors need a Yoke?*, (Cornell U., LNS),CBN 01-20, October 6, 2001, 6 pp.

[4] A.A. Mikhailichenko, *The Concept of a Linac Driven by a Traveling Laser Focus*, 7th Advanced Accelerator Concepts Workshop, 12-18 October 1996, Granlibakken Conference Center, Lake Tahoe, CA.

[5] V.E. Balakin, A.V. Aleksandrov, A. Mikhailichenko (Novosibirsk, IYF), K. Floettmann, F. Peters, G.A. Voss (DESY), V. Bharadwaj, M. Halling, J.A. Holt (Fermilab), J. Buon, J. Jeanjean, F. Le Diberder, V. Lepeltier, P. Puzo (Orsay, LAL), G. Heimlinger, R. Settles, U. Stierlin (Munich, Max Planck Inst.), H. Hayano, N. Ishihara, H.Nakayama, K. Oide, T. Shintake, Y. Takeuchi, N. Yamamoto (KEK, Tsukuba), F. Bulos, D. Burke, R. Field, S. Hartman, R. Helm, J.Irwin, R. Iverson, S. Rokni, G.Roy, W. Spence, P. Tenenbaum, S.R. Wagner, D. Walz, S. Williams (SLAC), *Focusing of Sub-Micron Beams for TeV-Scale* e^+, e^- *Colliders,* SLAC-PUB-95-6691, Mar 1995. 4pp. Phys. Rev. Letters, Vol.74 (1995), 2479-2482.

[6] See http://www.usatlas.bnl.gov/ .

[7] A.Likhoded, T.Han, G.Valence, *Study of anomalouse coupling at 500 GeV* e^+e^- *linear collider with polarized beams*, Phys. Rev. D, vol. 53, Number 9, p.4811 (1996).

[8] S.Dawson, G.Valensa, *Signals for parity violation in the electroweak-symmetry-breaking sector*, Phys. Rev. D, Vol.49, Number 5, 2188(1994).

[9] A.E. Blinov, A.E. Bondar, V.R. Groshev, G.M. Kolachev, G.A. Kornyukhin, S.I. Mishnev, A.P. Onuchin, V.S. Panin, V.V. Petrov, I.Ya. Protopopov, A.G. Shamov, V.A. Sidorov, A.N. Skrinsky, V.I. Telnov, Yu.A. Tikhonov, G.M. Tumaikin, A.I. Vorobev, A.A. Zholents, *The interaction region of the VEPP-4 storage ring for the detector with the Transverse field MD-1*,(Novosibirsk, IYF). 1988, in Batavia 1983 Proceedings, High Energy Accelerators, 183-185.