

ILC — ACCELERATOR AND EXPERIMENTS*

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The status of the International Linear Collider and its planned experiments is presented.

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1. Introduction

The Reference Design Report (RDR) has been presented to the International Linear Collider Steering Committee (ILCSC) in August 2007. The report [1] describes the International Linear Collider (ILC) after the first round of design optimisation and a first cost evaluation. This design fulfils the initial basic physics requirements of a future e^+e^- -collider: E_{cm} be adjustable in the range 200–500 GeV, the integrated luminosity amount to 500 fb^{-1} in 4 years, the energy stability and precision be better than 1% and the polarisation of the electron beam surpass 80%. The machine must be compatible with an upgrade into the TeV-region.

The effort for detector design proceeds in parallel with the accelerator and will eventually lead to two proposals. Currently four detector concepts have been studied to support the research of advanced detector components comprehensively. The next phase will be devoted to producing Letters of Intent for actual experimental proposals for the ILC.

2. Features of the reference design

The layout of the ILC has considerably evolved from the *Baseline Design* that originated from a workshop [2] in Snowmass in 2005. The new layout is displayed in Fig. 1, which features a polarised e^- source, an undulator-based e^+ source and 5 GeV e^- and e^+ damping rings (DR) housed in a common tunnel at the center of the ILC complex. The beam subsequently passes a 2-stage bunch compressor prior to injection into the two 11 km long main

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linacs, which are utilising 1.3 GHz SCRF cavities, operating at an average gradient of 31.5 MV/m, with a pulse length of 1.6 ms. A 4.5 km long beam delivery system collides the two beams under an angle of 14 mrad at a single interaction point which can be shared by two detectors. The total footprint is 31 km.

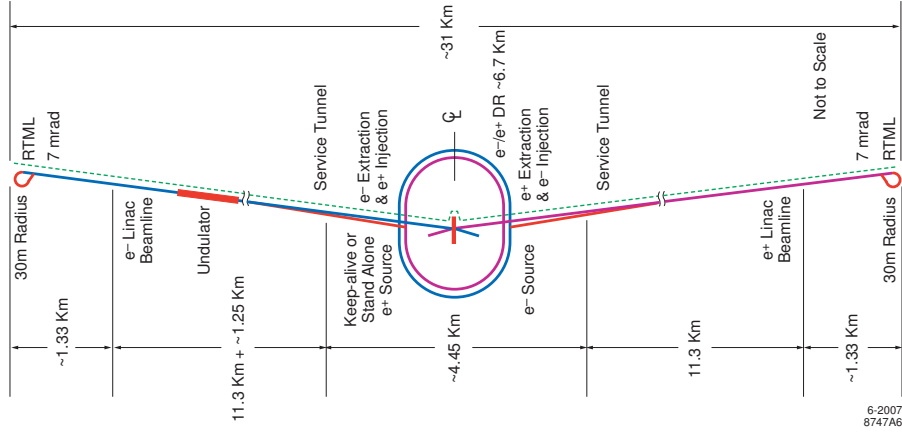


Fig. 1. The layout of the ILC with the central campus and the two linacs.

Electron Source The polarised electron source is located on the positron linac side of the DR (Fig. 2). A laser illuminates a photocathode in a DC gun to produce the beam. Two independent systems provide redundancy. Normal-conducting structures are used for bunching and pre-acceleration to 76 MeV, after which the beam is accelerated to 5 GeV in a SC linac. Before injection into the damping ring, SC solenoids rotate the spin vector into the vertical. A separate SCRF structure is used for energy compression.

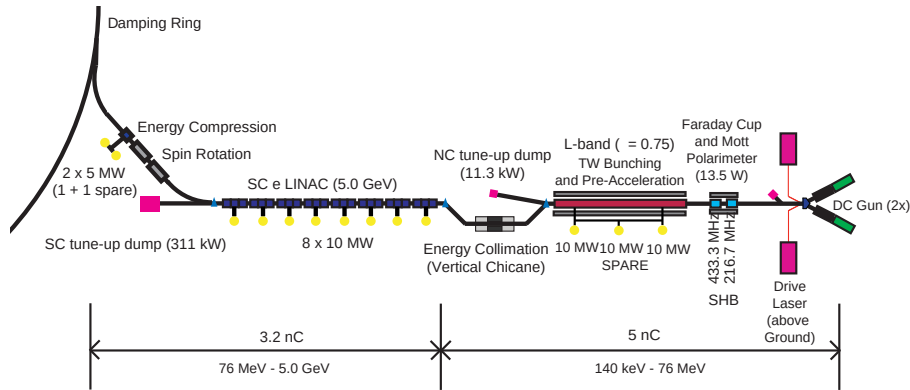


Fig. 2. The Electron Source with the DC gun on the right.

Positron Source The positron source uses photons generated by the electron beam to produce positrons off a thin target (Fig. 3). After acceleration to 150 GeV, the e^- beam is diverted into an offset beamline, transported through a 150 m helical undulator, and returned to the e^- linac. The ~ 10 MeV photons from the undulator are directed onto a rotating $0.4 X_0$ Ti-alloy target ~ 500 m downstream, producing e^- and e^+ pairs. An optical matching device takes this beam into a normal conducting (NC) L-band RF and solenoidal-focusing capture system and accelerates to 125 MeV. The e^- and remaining γ are separated from the e^+ and dumped. The e^+ are accelerated to 400 MeV in a NC L-band linac with solenoidal focusing. The beam is transported 5 km through the rest of the e^- main linac tunnel, brought to the central injector complex, and accelerated to 5 GeV using SCRF. Before injection into the damping ring, SC solenoids rotate the spin vector into the vertical, and a separate SCRF structure compresses the energy. The production process leads to a polarisation of 30%. Beamline space has been reserved for an upgrade to 60%. To allow commissioning and tuning of the e^+ systems while the high-energy e^- beam is not available, a low-intensity auxiliary (or keep-alive) e^+ source is foreseen. This is a conventional e^+ source, which uses a 500 MeV e^- beam impinging on a heavy-metal target to produce $\sim 10\%$ of the nominal positron beam. The keep-alive and primary sources use a common linac to accelerate from 400 MeV to 5 GeV.

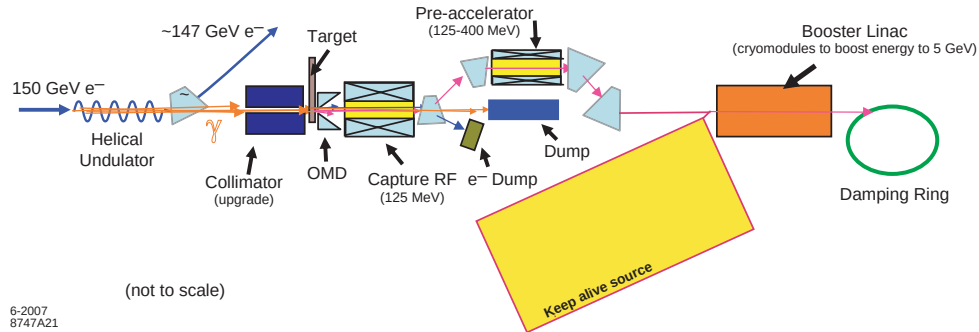


Fig. 3. The Positron Source with the undulator on the left.

Damping Ring The ILC damping ring tunnel houses an electron and a positron ring, each 6.7 km long, operating at a beam energy of 5 GeV. The plane of the DR tunnel is located ~ 10 m higher than that of the beam delivery system. This elevation difference gives adequate shielding to allow operation of the injector, while other systems are open to human access. The damping ring lattice is divided into six arcs and six straight sections. The arcs are composed of TME cells; the straight sections use a FODO lattice. Four of the straight sections contain the RF systems and the SC wigglers.

The remaining two sections are used for beam injection and extraction. Except for the wigglers, all magnets in the ring are normal-conducting. Approximately 200 m of superferric wigglers are used in each DR. The wigglers are 2.5 m long devices, operating at 4.5 K, with a peak field of 1.67 T. The SCRF system is operated cw at 650 MHz, and provides 24 MV for each ring. The frequency is chosen to be half the linac RF frequency to easily accommodate different bunch patterns. The single-cell cavities operate at 4.5 K and are housed in eighteen 3.5 m long cryomodules. The cavities and power sources for this 650 MHz system have to be developed. The large momentum compaction of the lattice helps to maintain single bunch stability. It requires a relatively high RF voltage to achieve the design 9 mm RMS bunch length. The dynamic aperture of the lattice allows the large emittance injected beam to be captured with minimal loss.

Ring to Main Linac The layout of the RTML is identical for both e^- and e^+ (Fig. 4). It consists of a 15 km long 5 GeV transport line with betatron- and energy-collimation systems. A 180° turn-around enables feed-forward beam stabilisation. Spin rotators orient the beam polarisation to the desired direction. The 2-stage bunch compressor reduces the bunch length from several millimeters to a few hundred microns as required at the Interaction Point. The bunch compressor accelerates from 5 to 15 GeV in order to constrain the fractional energy spread associated with bunch compression.

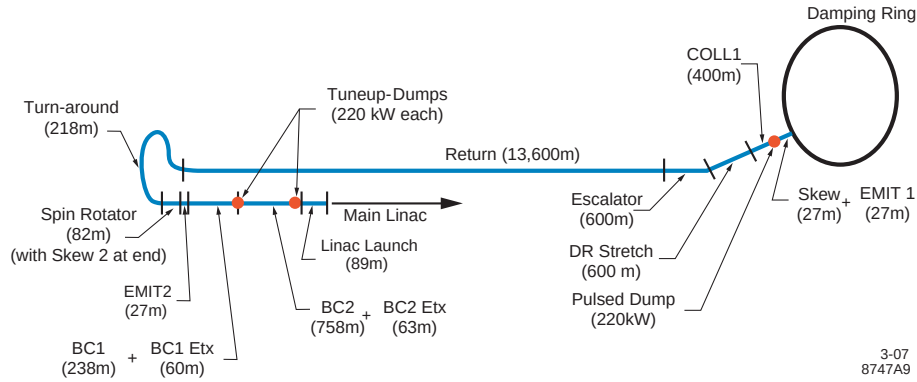


Fig. 4. The Ring to Main Linac section including the long return line.

Main Linacs The main linacs accelerate the beams to 250 GeV at an average gradient of 31.5 MV/m. They are composed of RF units, each formed by three contiguous SCRF cryomodules containing 26 nine-cell cavities, totalling 278 and 282 RF units for the e^+ and e^- linac, respectively. Each unit has a standalone RF source, which includes a conventional pulse-transformer type high-voltage (120 kV) modulator, a 10 MW multi-beam klystron, and

a waveguide system that distributes the RF power to the cavities (*cf.* Fig. 5). It also includes the low-level RF (LLRF) system to regulate the cavity field levels, interlock systems to protect the source components, and the power supplies and support electronics associated with the operation of the source. The cryomodule design is a modification of the type 3 version developed and used at DESY. Within the cryomodes, a 300 mm diameter He gas return pipe serves as a strong back to support the cavities and other beamline components. The middle cryomodule in each RF unit contains a SC quadrupole magnet at the center, a cavity BPM, and SC corrector magnets.

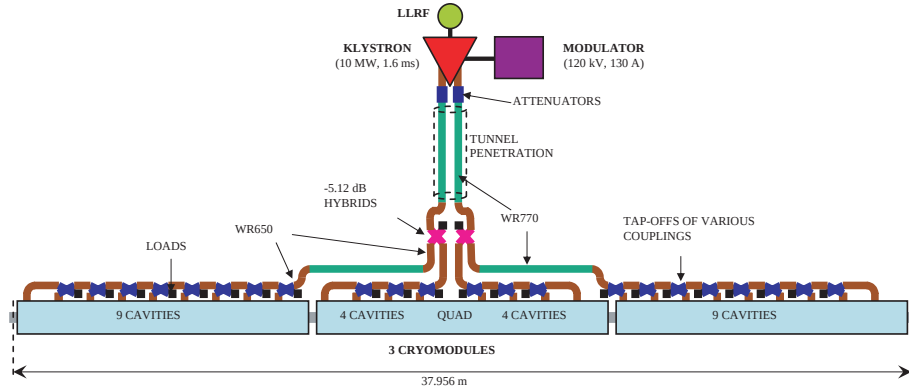


Fig. 5. A full RF section comprising 26 nine-cell cavities.

The quadrupoles establish the magnetic lattice, a weak focusing FODO optics with 80 m (average) β -function. The cryomodes are 12.652 m long, yielding an active-to-actual-length ratio of 73.8%. Every cryomodule also contains a 300 mm long high-order mode beam absorber assembly that removes energy through the 40–80 K cooling system from beam-induced higher-order modes above the cavity cutoff frequency.

To operate the cavities at 2 K, they are immersed in a saturated He II bath, and He gas-cooled shields intercept thermal radiation and conduction at 5–8 K and at 40–80 K. The estimated static and dynamic cryogenic heat loads per RF unit at 2 K are 5.1 and 29 W, respectively. Liquid He for the main linacs and the RTML is supplied from 10 large cryogenic plants, each of which has an installed equivalent cooling power of 20 kW at 4.5 K. The main linacs follow the average Earth's curvature to simplify the liquid He transport. The Main Linac components are housed in two 4.5 m diameter tunnels (*cf.* Fig. 6), an accelerator and a service tunnel. To facilitate maintenance and limit radiation exposure, the RF source is housed mainly in the service tunnel. The tunnels are typically hundreds of meters underground and are connected to the surface through vertical shafts. Each of the main linac includes three shafts, roughly 5 km apart.

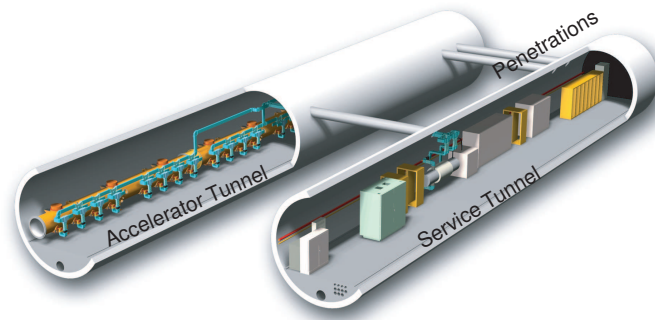


Fig. 6. The two tunnel configuration housing accelerator and services.

Beam Delivery System A single collision point with a 14 mrad total crossing angle provides space for separate extraction lines (Fig. 7) in the BDS. It requires crab cavities to rotate the bunches in the horizontal plane for effective head-on collisions. There are two detectors in a common interaction region (IR) hall in a so-called push-pull configuration. The detectors will be pre-assembled on the surface and then lowered into the IR hall.

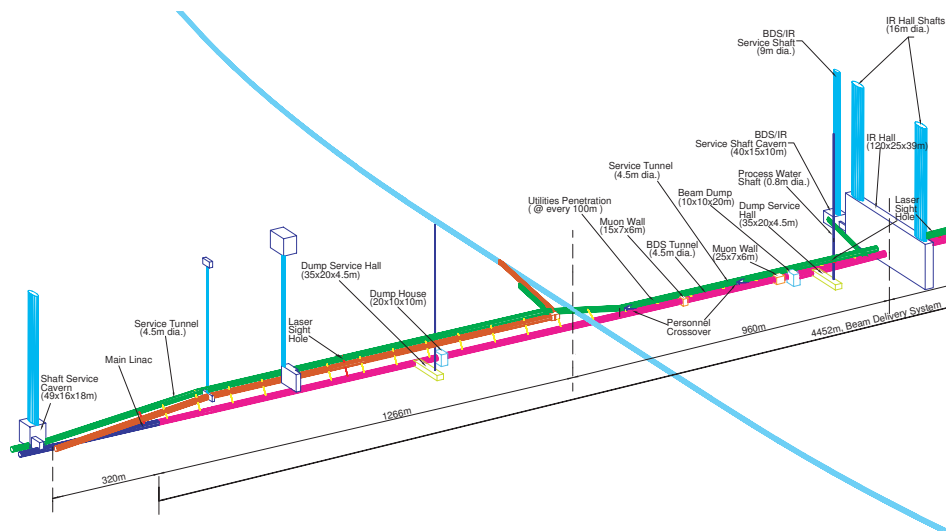


Fig. 7. One half of the Beam Delivery System.

The BDS comprises the post-linac emittance measurement and matching (correction) sections and trajectory feedback, polarimetry and energy diagnostics. A fast pulsed extraction system ejects the beams in case of a fault or dumps the beam when not needed at the IP. A collimation section removes beam halo particles and contains magnetised iron shielding to deflect muons.

The final focus (FF) uses strong, compact SC quadrupoles to focus the beam at the IP, with sextupoles providing local chromaticity correction. The FF quadrupoles closest to the IP are integrated into the detectors. The extraction line has sufficient bandwidth to cleanly transport the heavily disrupted beam to a high-powered water-cooled dump.

3. Detectors

The challenge for the ILC detectors is to optimise the scientific potential from a broad experimental programme aimed at understanding the mechanism of mass generation and electroweak symmetry breaking. This includes the search for supersymmetric particles, and, if found, their detailed study, and the hunt for signs of extra space-time dimensions and quantum gravity. Precision measurements of Standard Model processes may reveal new physics at energy scales beyond direct reach. The detectors must be prepared for the unexpected. Experimental conditions at the ILC provide an ideal environment for the precision study of particle production and decay, and offer the unparalleled cleanliness and well-defined initial conditions conducive to recognising new phenomena. Events are recorded without trigger bias, with detectors, pushing the limits of jet energy, tracker momentum, and vertex resolution. Multi-jet final states and supersymmetry (SUSY) searches put a premium on hermeticity and full solid angle coverage. Although benign by LHC standards, the ILC environment poses challenges of its own. The World Wide Study of Physics and Detectors for Future Linear Colliders has wrestled with these challenges for more than a decade, advancing the technologies for ILC detectors. Different concepts have emerged [3–6], as the rapid collider progress has spurred the experimental community.

3.1. Detector concepts

Four complementary detector concepts are being studied as candidate detectors for the ILC experimental programme. Each concept is designed with an inner vertex detector, a tracking system based on either a gaseous Time Projection Chamber or Si detectors, a calorimeter to reconstruct jets, a muon system, and a forward system of tracking and calorimetry. Table I presents some of the key parameters of the four concepts. GLD, LDC and SiD employ particle flow for jet energy measurements. The 4th concept employs a dual-readout fiber calorimeter and a novel outer muon system.

TABLE I

Some key parameters of the four detector concepts.

Concept	Track det.	Vertex r [mm]	B [T]	Solenoid		ECAL [m]		Det. [m]	
				r [m]	l [m]	r	l	r	l
GLD	TPC/Si	20	3.0	4.0	9.5	2.1	2.8	7.2	7.5
LDC	TPC/Si	16	4.0	3.0	6.6	1.6	2.3	6.0	6.2
SiD	Si	14	5.0	2.5	5.5	1.3	1.3	6.5	5.9
4 th	TPC or drift	15	3.5	3.0	8.0	1.5	1.8	7.2	6.5

SiD The Silicon Detector Concept [3] SiD is based on Si-tracking and a Si-W sampling calorimeter, complemented by a powerful pixel vertex detector, outer hadronic calorimeter, and muon system (Fig. 8). Most SiD sys-

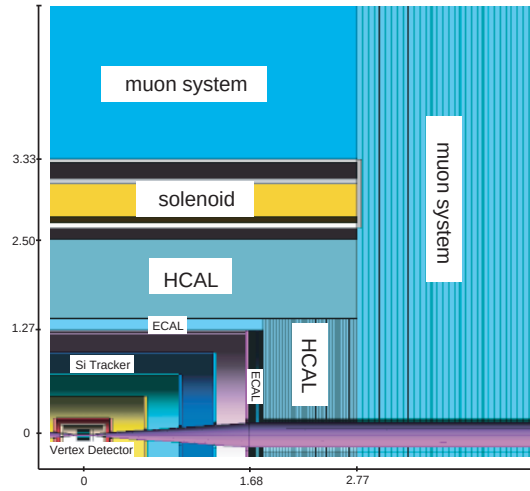


Fig. 8. Illustration of a quadrant of the SiD detector concept.

tems resolve individual bunch crossings. The vertex detector, the tracker and the calorimeter withstand significant radiation bursts. A highly pixellated Si-W electromagnetic calorimeter and a multilayer, highly segmented hadron calorimeter, inside the solenoid, optimise particle flow calorimetry. Cost and performance considerations dictate a 5 T solenoid, at relatively small radius. SiD tracking works as an integrated system, incorporating the vertex detector (5 barrels and 4 endcap layers), the central Si microstrip tracker (5 layers, barrels and endcaps), and the electromagnetic calorimeter. The vertex detector plays a key role in pattern recognition; tracks produced by decays beyond the second layer of the central tracker, but within the ECAL, are captured with a calorimeter-assisted tracking algorithm. The asymptotic

resolution of the combined system is $\sigma_p/p^2 < 2 \times 10^{-5}/\text{GeV}$. The SiD electromagnetic calorimeter consists of layers of tungsten and large-area Si-diode detectors in 1 mm gaps. The hadronic calorimeter sandwich employs Fe absorber plates and resistive plate chambers (RPCs). W-absorber, glass RPCs, GEM foils, Micromegas, and scintillating tiles with Si-photomultipliers are considered options. Muon detectors fill some gaps between iron plates of the flux return and are based on strip-scintillator detectors or RPCs.

LDC The Large Detector Concept [4] LDC is centered on a Time Projection Chamber (TPC) and particle flow calorimetry inside a large volume magnetic field (Fig. 9). The TPC provides up to 200 precise measurements along a track supplemented by Si-detectors measurements. In detail the detector features a 5-layer pixel-vertex detector, extended by a system of Si-strip and pixel detectors, a system of “linking” detectors behind the endplate of the TPC and in between the TPC and the ECAL, granular Si-W electromagnetic and Fe-Scintillator (or gas) hadronic calorimeters, a system of precise and radiation hard calorimetric detectors in the very forward region, a large volume SC solenoid of 4 T and an instrumented iron return yoke.

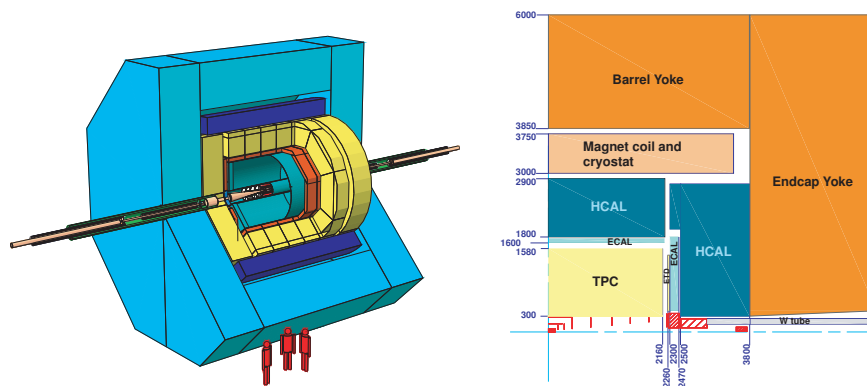


Fig. 9. A 3-D view and a quadrant of the Large Detector Concept, LDC.

GLD The GLD detector concept [5] has a large TPC and finely granulated calorimeter within a large bore solenoid. The highly segmented electromagnetic calorimeter is placed at large radius and based on a W-scintillator sandwich structure followed by a hadron calorimeter with a lead-scintillator sandwich structure (Fig. 10). In the forward direction electromagnetic calorimeters extend the coverage. GLD features a precision Si μ -vertex detector, Si inner and endcap trackers, a beam profile monitor in front of a forward electromagnetic calorimeter, a scintillator strip muon detector interleaved with the iron plates of the return yoke and a solenoidal magnet to generate the 3 T field.

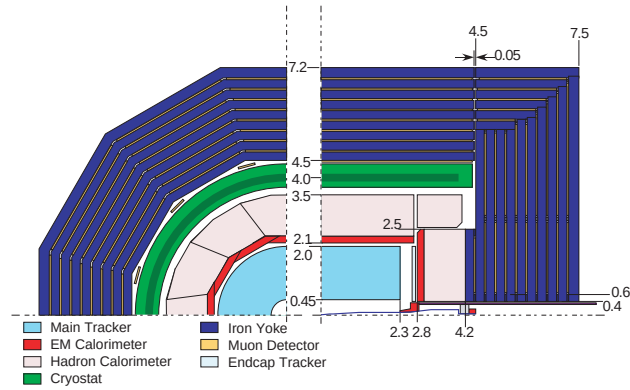


Fig. 10. The GLD detector in $r\phi$ - and rz -views.

Fourth Concept The calorimeter of the 4th detector concept [6] is an augmented fine-grained fiber sampling calorimeter to also measure the neutron content of a shower. The dual-readout scintillation and Cerenkov fibers help to separate hadronic and electromagnetic components. The muon system incorporates a dual-solenoid configuration in which the flux from the inner solenoid is returned through the annulus between inner and outer solenoid (Fig. 11). The magnetic field is confined to a cylinder with negligible fringe fields. This configuration may allow mounting of all beamline elements on a single support to reduce the effect of vibrations at the final focus (FF). The FF elements can be brought close to the vertex chamber for better control of the beam crossing. The iron-free magnetic field configuration supports any crossing angle. The pixel vertex detector follows the SiD design while the TPC resembles those being developed for GLD and LDC.

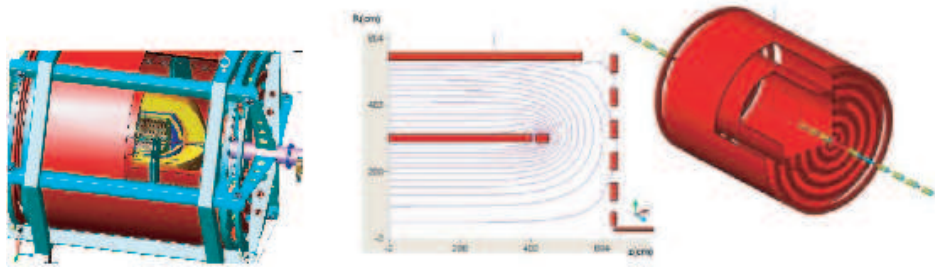


Fig. 11. The 4th detector concept (left). The rz -view shows the B -field (middle) and the “wall of coils” (right).

4. Conclusion

Completion of the RDR constitutes a fine example of international collaboration. It describes the design of a 500 GeV e^+e^- -collider and experiments. It is the basis for future design and cost optimisation that will lead to an engineering plan amenable for political decision in 2010. It is the task of the community and of the GDE to see that the political scenes follows this pace so that the project can be realised without undue delay.

I wish to thank the organisers of “Matter to the Deepest” for hosting this interesting conference in the beautiful forests of Silesia.

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