September 6, 2006

To: Files

From: Nobu Toge

Subject: **Technical Assessment of Extraction Line Magnets for ILC BDS, in Conjunction with the BDS CCR, July, 2006**

Here is a collection of documents which offers the technical assessment of extraction line magnets for ILC BDS in conjunction with the BDS CCR of July 2006.

Most of the technical contents have been prepared by the ILC GDE Magnet Technical System Group members.

Toge removed numerical information which lead to specific cost numbers.

Some follow-up email communications are appended at the end of this package.

E N D

Subject: Here are 4 docs from Mag Systems re 20/2 to 14/14 change

From: **Spencer, Cherrill M.**

To: **N.Toge**

Cc: **Seryi, Andrei , John Tompkins , Brett Parker, Paul Bellomo, Ryuhei Sugahara**

Date: **Mon, 21 Aug 2006 18:04:20 -0700**

Dear Nobu,

The Magnet Systems Group has prepared 4 documents in response to your request to give our technical assessment of changing from 20mr and 2mr crossing angles to 14mr and 14mr from a magnet and power supply point of view.

The attached file called "TechAssessDiffBDSscenarios_Spencer.pdf" assesses the room temperature magnets, I wrote that as the Magnet System person responsible for BDS magnets.

"DesignConstraints2mrExtrLine.pdf" gives a detailed explanation for why the 2mr extraction beamline has the particular magnets it has and why they are placed in certain positions. It was written by the beam optics person who designed the 2mr extraction line : Yuri Nosochkov of SLAC.

"Comparison of SC IR Magnets for the 2 configurations BParker.doc" assesses the differences between the superconducting magnets in the 2 scenarios. It was written by Brett Parker of BNL who has been designing the 20mr and 14 mr superconducting magnets and has spent lots of time thinking about the 2mr s-c magnets.

"ILC BDS 20-2 and 14-14 PS Comparison.doc" describes the power supplies, cables and PS controls in the 2 scenarios. It was written by Paul Bellomo of SLAC who is the PS engineer for all of the ILC.

If you have any questions after you've ploughed through all this information, please contact me and I will arrange to get your questions answered.

Best Regards
Cherrill Spencer, SLAC

Technical assessment of the major differences between the magnets in the 20mrad and 2 mrad crossing angle beamlines, descriptions of problems with the 20/2 case, and assessment of whether changing the crossing angles of the 2 interaction points to both be 14mrad yields any advantages in terms of magnet design, installation, operation and maintenance.

By Cherrill Spencer, SLAC. Member of the ILC Magnet Systems Group responsible for the Beam Delivery System (BDS) magnets. 20th August 2006

Overview of the BDS Magnets

There are about 2548 magnets in the 20/2 BDS system and they are divided into about 68 different styles. If you look at the latest magnet count table you will see 1366 magnets listed in BDS, the large difference between 1366 and 2548 is because a few hundred 12m long, low field, dipoles have been engineered so that each 12m dipole is fabricated as six 2m long dipoles, for ease of construction and installation. The "2548" quantity accounts for each 2m low field dipole.

About 60 of the BDS magnets will be superconducting, there are 26 different styles of superconducting magnets in the BDS; they are all placed within10 meters of the interaction points. Many of the styles sit in concentric layers in the same cryostat and so there are only about 10 separate cryostats containing superconducting magnets in the 20/2 scenario. A technical assessment of these superconducting BDS magnets will be given in a separate document.

This document will just be about the room temperature BDS magnets, of which there are about 2488 of about 42 different styles.

The BDS is one of the more complicated areas of the ILC. Although in quantity of magnets it accounts for only about 13% of all the ILC magnets, it accounts for about 40% of all the different magnet styles.

In order to more easily keep track of the BDS magnets the beam physicists have divided the BDS into 18 separate beamlines, each with their own name. These 18 beamlines are shown schematically in figure 1 below.

The magnets in "EDL2"and "PDL2" are main reason for technical and cost differences between the 20mr and 2mr beamlines. These 2mr "dump" or "extraction" beamlines take away the e- and e+ beams after they have collided at the 2mrad angle IP; they allow some diagnostics to be done on the beams and they send the very disrupted beams into dumps.

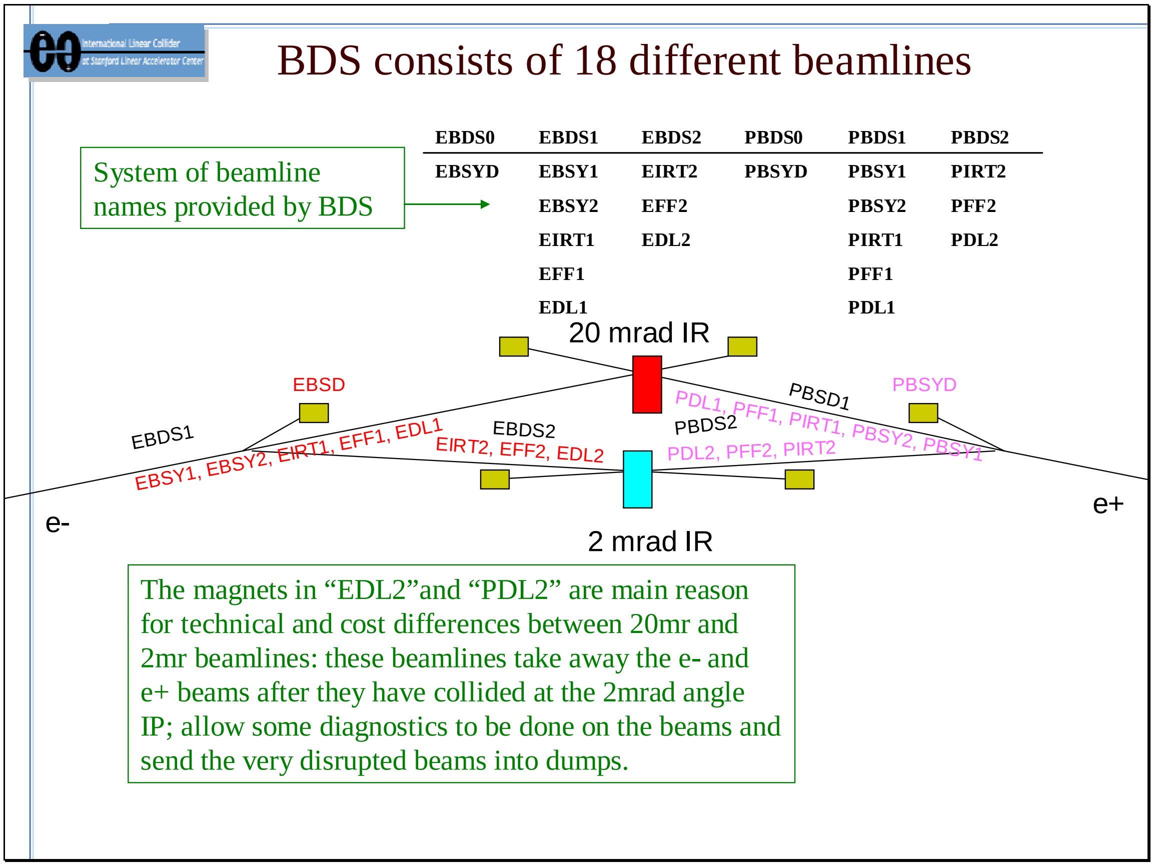


Figure 1

Characteristics of the 2mr extraction lines that influence the magnet requirements

1. High luminosity collisions at IP produce large energy spread of the particles emerging from the IP (larger spread than 20mr IP)
2. Outgoing particles go through 2 quads that are focussing the incoming particles and this bends trajectories of all outgoing particles, especially the lower energy ones. Therefore the beam becomes more spread out than if it didn't pass through the QD0, QF1, SD0 and SF1.
3. Want beam to be as compact as possible when it goes through the 2 diagnostic chicanes, so put some magnets close to the IP to reduce its natural spreading out (if didn't put some quads close to the IP the later quads would have even larger apertures!)
4. Want the dump to have sufficient separation from the incoming beam so need to bend the extracted beam away.
5. Each 500 GeV beam has 18MegaWatts of power, and after the IP it takes up lots of space so need large aperture magnets so few particles hit the beampipe.
6. *Beamstrahlung* photons are produced during the e+e- collisions, they emerge in a well-defined beam and they have about 1 Megawatts of power in the 1TeV case. Cannot stop them so have to let them pass unimpeded.
7. The *beamstrahlung* photons take a straight path and the extracted charged particles' paths are bent through various angles in the 4 magnets mentioned in point 2, so the charged particles and the photons become increasingly separated in the 2mr case. Whereas in the 20 mr case the extracted particles occupy the same physical space as the beamstrahlung photons. It is this difference in the relative positions of the photons and the charged particles between the 2

and 20mr extraction line magnets that accounts for much of the difference in difficulties in engineering the 2 sets of magnets.

8. The other major source of difficulty in engineering the 2mr extraction magnets is the 2 mr crossing angle and placement of the magnets along the incoming and outgoing beamlines- there is very little horizontal space between these 2 beamlines and it turns out there is not enough space to put magnets of the required integrated strength in several places.

The particular set of 2mr extraction line magnets has been chosen to account for all the above facts and also to have as reasonable as possible poletip values, especially for the quadrupoles; and to not be too long, so their coils can be cooled .

Figure 2 below shows the layout of the 2mr incoming and outgoing beamlines “near” the 2mr interaction point. The small red and blue squares indicate the positions of all the magnets and their effective lengths are shown to scale, but NOT their widths.

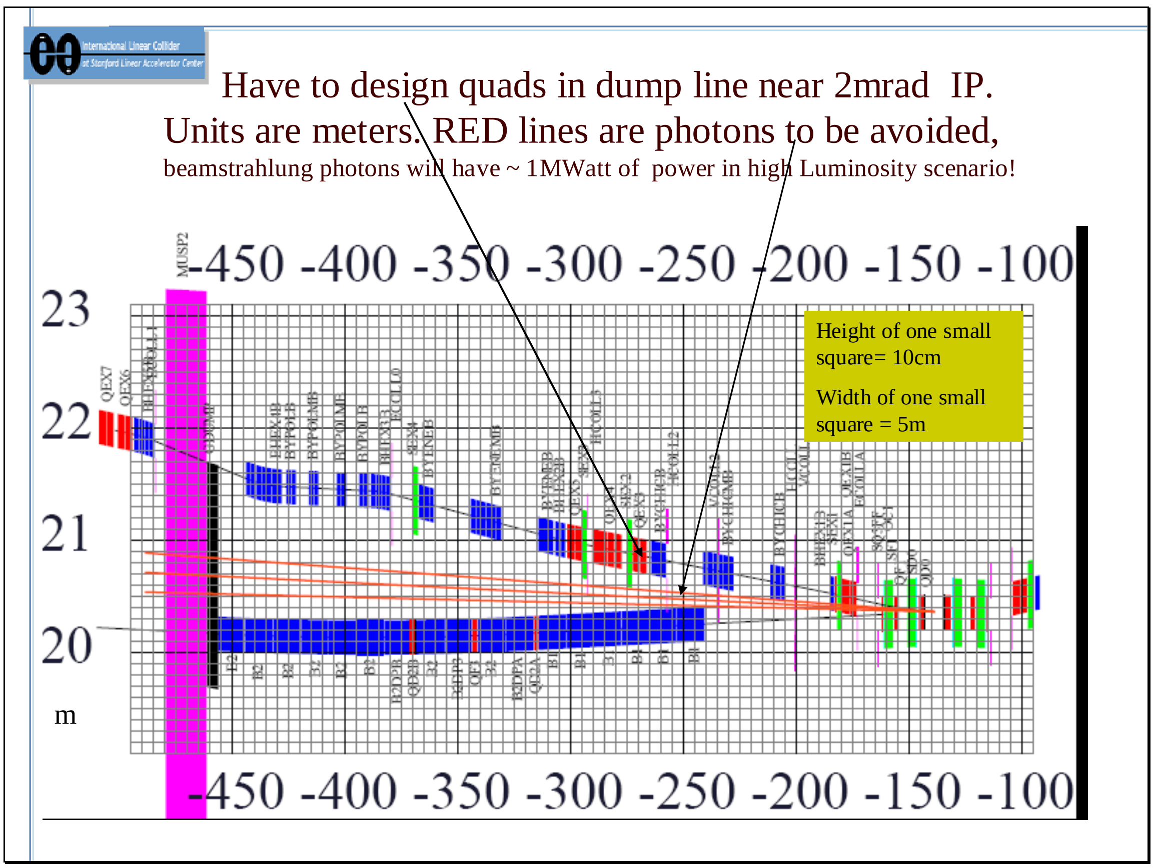


Figure 2

Understanding the magnet requirements

The official BDS “parts list” lists basic parameters for magnets. The BDS lattice designer provides me with several Excel spreadsheets containing most of the magnet parameters the Magnet Systems Group has requested- one line per magnet- at 250GeV/beam. We need to design all BDS magnets to run at 500GeV per beam, so I double the integrated gradients for running with 500GeV beams. In figure 3 below is *sample* of dump line list after 2mr IP, at 250Gev/beam.

Official BDS "parts list" lists basic parameters for magnets- below is *sample* of dump line list after 2mr IP, at 250Gev/beam

Line	Mag Deck		Eff L	Bore	B(pt)	GradKg/m	Int Grad	Beam En	Dist Z
EDL2	QUAD	QEX1A	3 m	0.113 m	6.6432682 Kg	58.78998407	176.37	250	2546.608345
EDL2	QUAD	QEX1B	3	0.127	6.643268199	52.30919842	156.9276	250	2549.908345
EDL2	QUAD	QEX3	3	0.2	6.834936046	34.17468023	102.524	250	2639.608345
EDL2	QUAD	QEX3	3	0.2	6.834936046	34.17468023	102.524	250	2642.908345
EDL2	QUAD	QEX4	3	0.2	-7.418033547	-37.09016773	-111.271	250	2650.708345
EDL2	QUAD	QEX4	3	0.2	-7.418033547	-37.09016773	-111.271	250	2654.008345
EDL2	QUAD	QEX4	3	0.2	-7.418033547	-37.09016773	-111.271	250	2657.308345
EDL2	QUAD	QEX4	3	0.2	-7.418033547	-37.09016773	-111.271	250	2660.608345

Lattice designer provides me with several Excel spreadsheets containing most of the magnet parameters the Magnet Systems Group has requested- one line per magnet- at 250GeV/beam, so I double the integrated gradients for running with 500GeV beams.

Figure 3

Size of apertures of the extraction magnets

The sizes of the bores of the magnets are determined by the beam physicists who run particle tracking programs such as *TURTLE* to find out the tracks of the particles after their collisions, taking into account that many of them have lost some of their energy in the collisions. The range of lost energy is very wide, particles lose as much as 80% of their incoming energy. These low energy particles get bent quite a lot in QD0 and QF1 ; all the particles start to become separated from the beamstrahlung photons. See figure 4 below.

By studying where all the particles are in x and y at every z the beam physicist decides how large each magnet's aperture needs to be. The "bore" in figure 3 is the *radius* of the beam-stay-clear aperture. An additional few mm needs to be added to each specified radius to accomodate the beampipe and possibly some thermal insulation. When I design each BDS magnet I have to increase its aperture to accommodate these items.

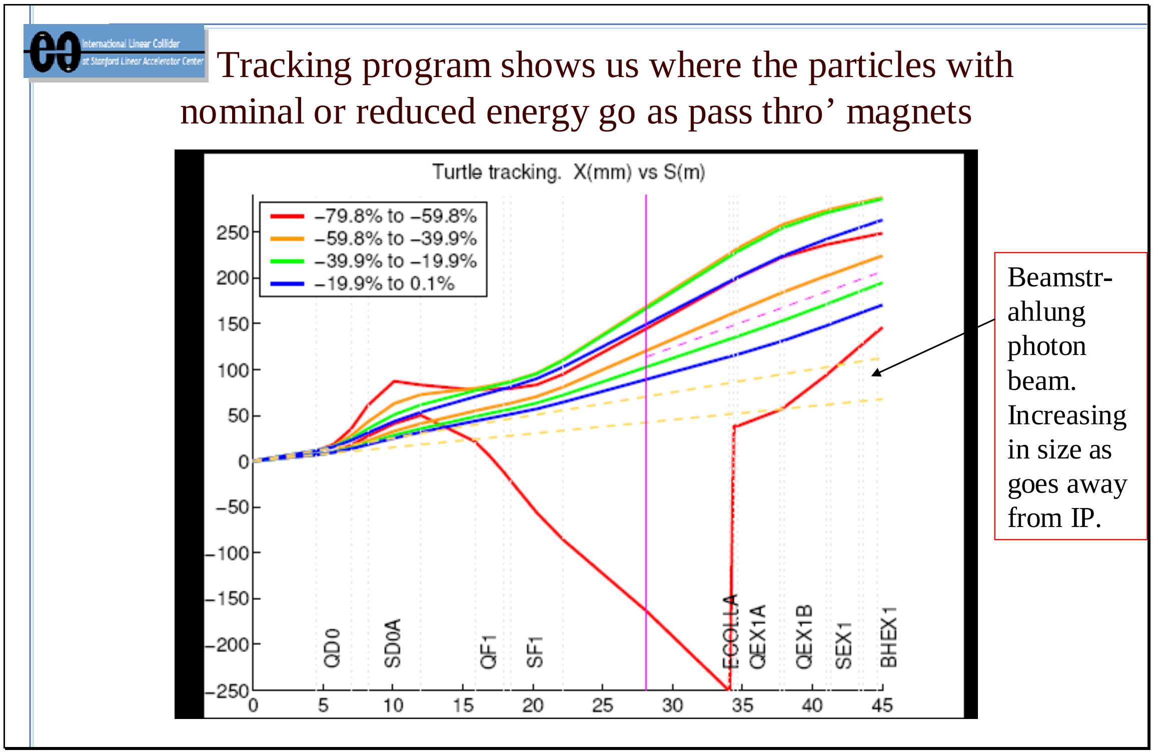


Figure 4

How large a cross-sectional area do the beamstrahlung photons take up?

Other tracking programs model the shape and position of the photons, see figure 5.

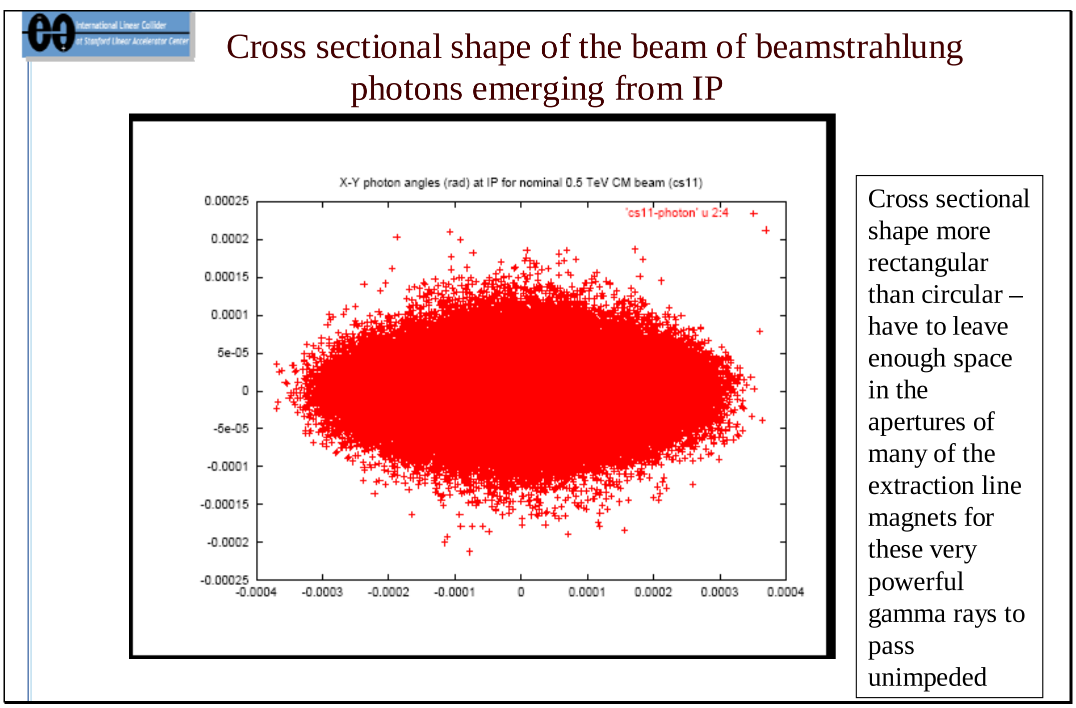


Figure 5

Determining exactly how much space there is to place a magnet : dipole in 2mr extraction

Figure 6 below shows the detail of the beam shape in x and y as it enters the first room-temperature bend magnet in the 2mr extraction line. Also shown is the area taken up with photons and the incoming beam position and an approximate beampipe around it.

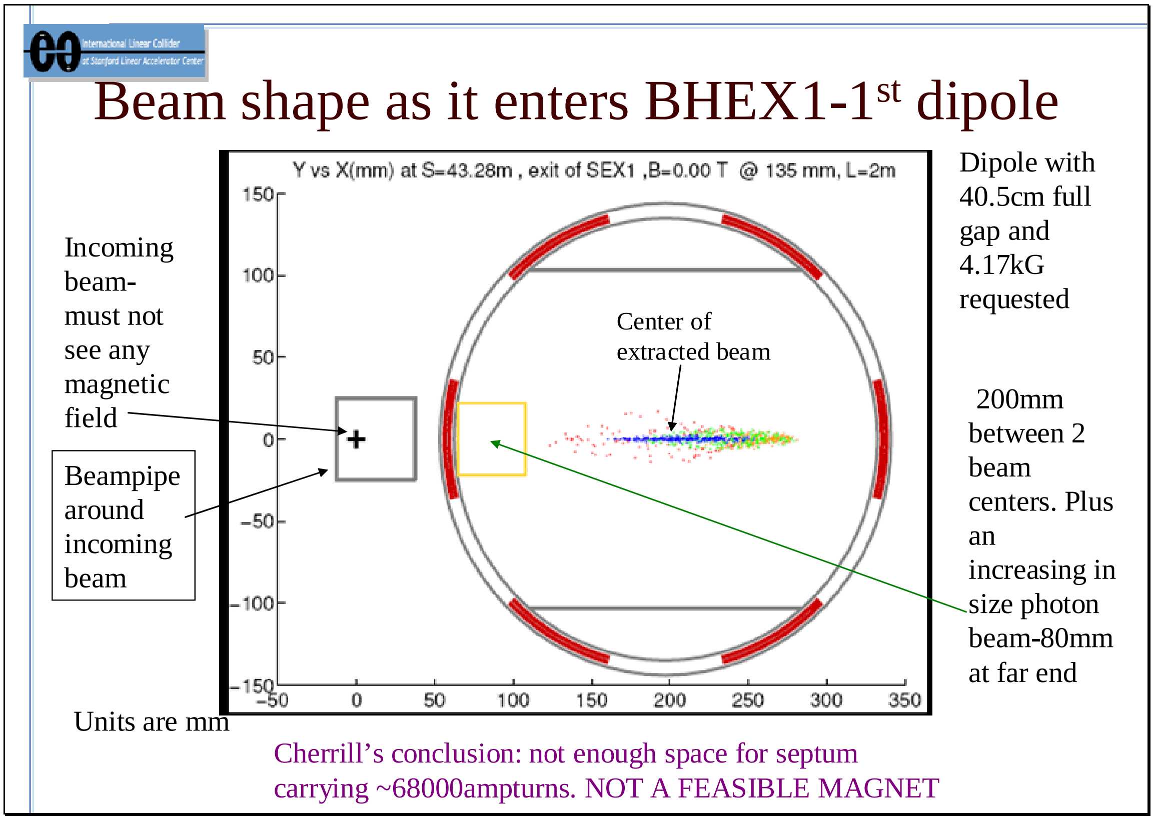


Figure 6

The BHEX1 dipole in the 2mr extraction line has to have a very wide gap in order for the very wide beam not to hit any part of the horizontal bending magnet; at the same time there should be no material sitting in the way of the *beamstrahlung* photons and this severely limits where one can place the electric current (about 68000 ampturns are required) needed to produce the 4.17kG required in the gap. There must be zero field from BHEX1 at the incoming beam. A regular "H" shaped dipole would not work and I couldn't find (in the short time period available to me before the Vancouver LCW06 meeting) a septum dipole layout that could be engineered either. Therefore I declared BHEX1 in the 2mr extraction line to not be feasible.

In contrast, the space available for the first dipole in the 20mr extraction line (called BVEX1E) is much more; it is a vertical bending magnet, its full gap needs to be "only" 17.2cm and so although its field needs to be twice that of the BHEX1, BVEX1E can be engineered as a simple H dipole that fits easily into the 955.5 mm distance between the incoming and outgoing beam centers at the entrance to BVEX1E. Remember that in the 20mr line the *beamstrahlung* photons coming out of the IP are occupying the SAME x-y space as the particle beam and so no special space has to be left for them. In fact my design for the 20mr BVEX1E also fits in the 14mr crossing angle extraction line with no need for any revision, as do all the 20mr extraction line dipoles.

How much room is there for the first room temperature quad in the 2mr extraction line?

Figure 7 below shows the physical circumstances into which the first room temperature quad, QEX1A, in the 2mr extraction line needs to fit, it is closer to the IP than BHEX1 and has even less horizontal space to squeeze in between the incoming and outgoing beams: 150mm at its entrance. Nevertheless its aperture has to be 226mm in diameter and the poletip field 1.328T.

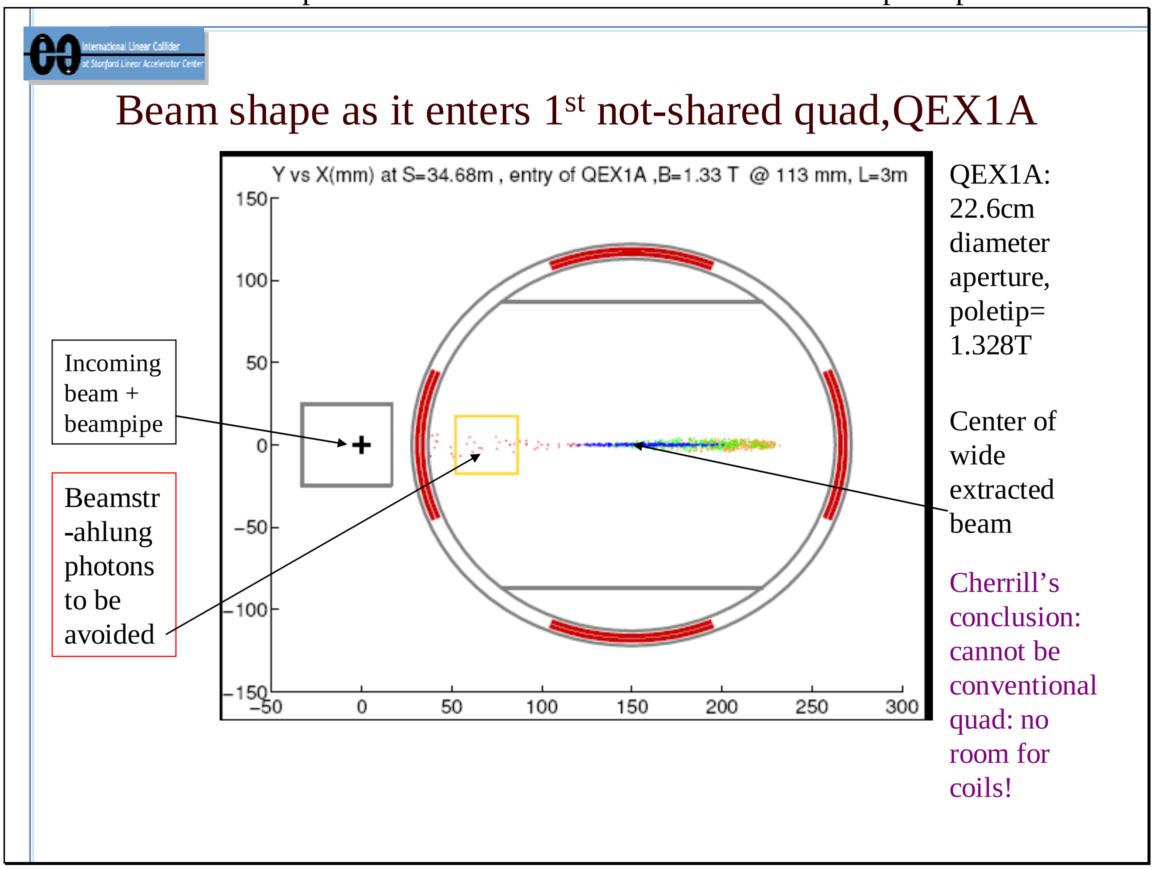


Figure 7

If one designs a conventionally shaped iron-cored quadrupole with a 117mm radius (leaving room for beampipe) and a poletip field of 1.328T and it had all the space it needed, then each coil would need about 63,000 amp turns and the magnet's half-width would be much wider than 120mm. So it is obvious there is not room to put a conventional quadrupole for QEX1A.

So I looked into, what I called a double-Panofsky quad. It would have 2 rectangular shaped openings in its rectangular shaped steel core, one with a quad-shaped field for the extracted beam and the other, smaller, opening for the incoming beam, where there should be ZERO field.

About 17 months ago I did a design of a double Panofsky quad for QEFX1, as it was called back then, the beam optics were a little different from now and I only designed it for 250 GeV beams. That design is shown in Figure 8 below. It appeared to be marginally feasible for the old optics at 250 GeV/beam, but my assessment of such a design for the new optics, with a wider aperture and at 500GeV/beam is that it is not feasible. In the time available to me before the Vancouver LCW06 meeting I had no other ideas for this quadrupole's design. ["Doing a design" involves making a 2D computer model of the magnet using POISSON, choosing a conductor size and designing the cooling circuits to keep the LCW temperature increase below 25ºC.]

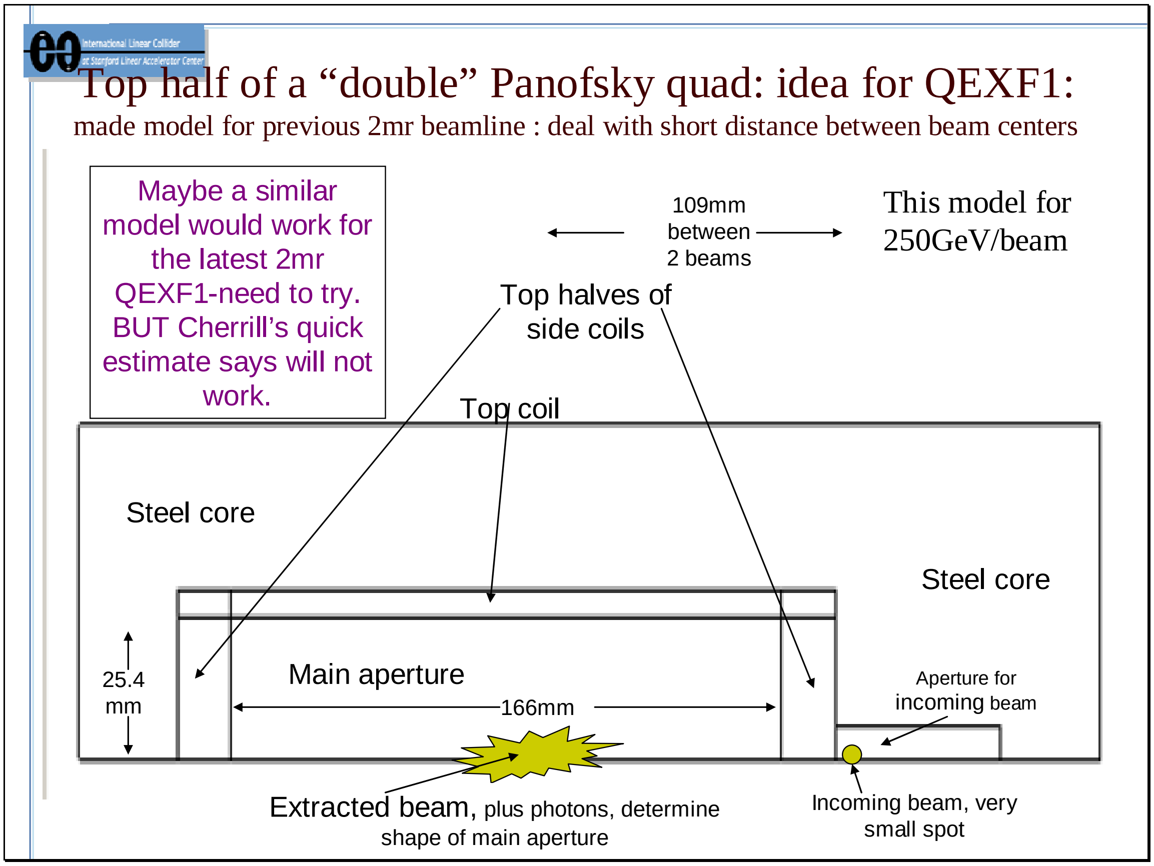


Figure 8

Looking for feasible designs for other 2mr extraction line quadrupoles

Looking again at the layout of the 2mr crossing angle beamlines shown in Figure 2 above, one can see the distance between the incoming and outgoing beams increases as the distance from the IP increases, the next question is, at one point do the 2mr extraction line magnets become feasible, that is, can be engineered to work within our ILC magnet design guidelines?

I tried to find a feasible design for the set of quadrupoles called "QEX4" which had the highest gradient requirement of the 12 quads beyond the QEX1A/B mentioned above. Figure 9 below shows one of my efforts, which had to allow the beamstrahlung photons free passage and not touch the low field dipole called "B1" in the adjacent incoming 2mr beamline. When I did this model I thought the photons occupied a circular cross-section, later I found that the shape is more rectangular, see figure 5 above.

Figure 10 shows the results of a POISSON model of QEX4. The red numbers in the steel core area are the field values at those spots. This model could not achieve the required gradient at 500GeV; it barely achieves the 250GeV gradient.

I tried designs for all the 2mr extraction quads, I determined that 10 were not feasible and 4 were (the last 4 quads, furthest away from the IP). In contrast, ALL the 20mr extraction quadrupoles can be engineered. There are 13 of these room-temperature quads beyond the 3 superconducting quads. The first 5 quads had to be slightly revised in coil shape to fit in the 14mr scenario, the other 8 quads fit on both the 20mr and 14mr beamlines.

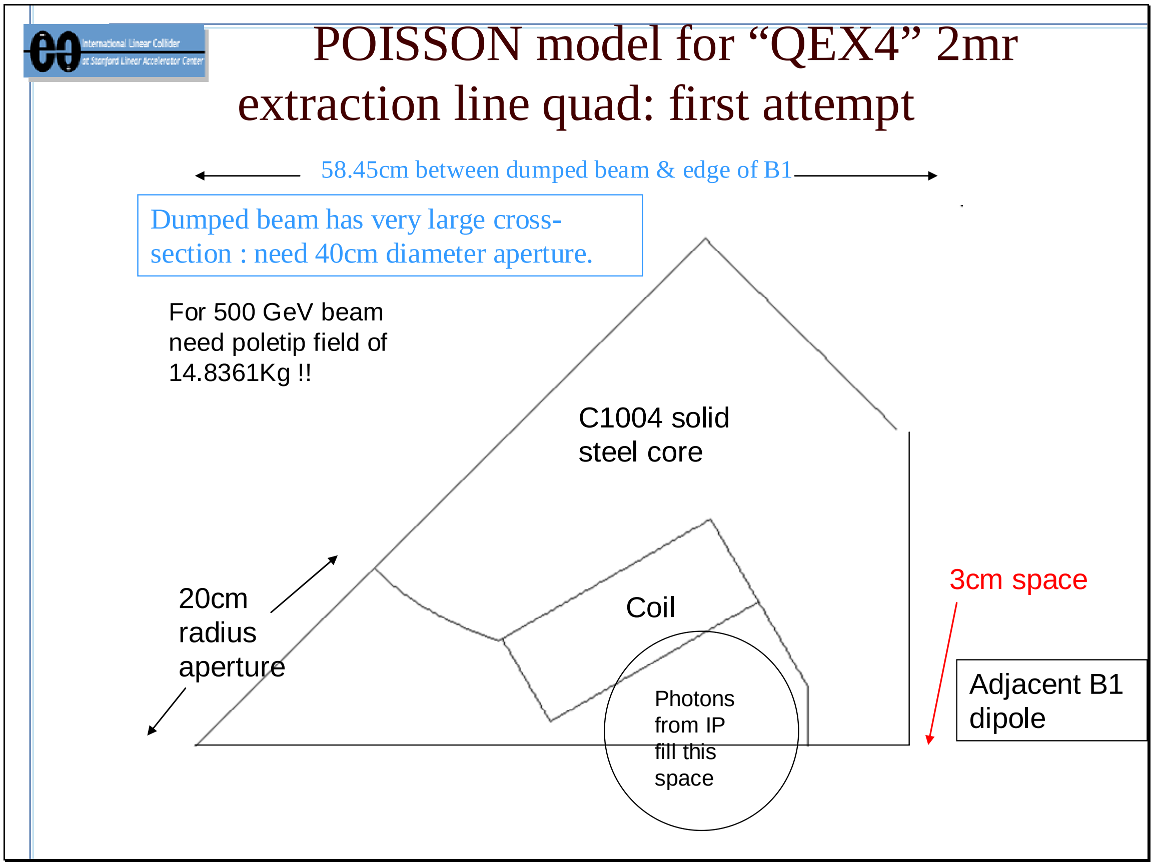


Figure 9

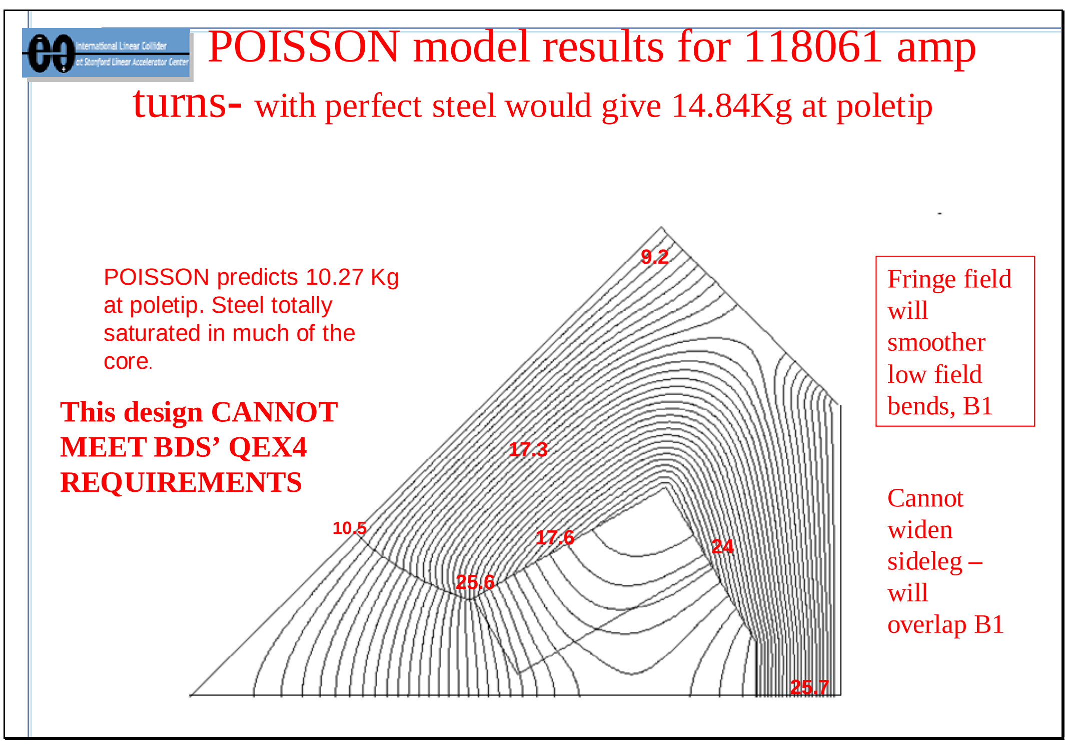


Figure 10

Other efforts to design feasible magnets for the 2mr extraction line

In late June 2006, with the Vancouver meeting approaching and needing to finish my cost-estimating for all the BDS magnets I asked for some other expert magnet engineers to try to design any of the 2mr extraction quads I had deemed “impossible”. Magnet designers at the Efremov Institute in St Petersburg, Russia, at the National Institution of Radiological Science in Chiba-sai, Japan and at Kyoto University, Kyoto, Japan took up my “challenge” and spent a few days each trying to design some of the 2mr extraction quadrupoles. They presented some preliminary designs at the Vancouver LCW06 meeting but none of them were feasible. Their main defects being their coils couldn’t be cooled sufficiently and they created a sizable field in the region where the incoming beam would be. Since the Vancouver meeting most of these people have been on vacation or otherwise not available, so no further design work has happened.

If the BDS area physicists desire that we continue to look for feasible designs for the 2mr extraction magnets then I think some R&D monies will have to be assigned to this task, sufficient to actually build some scaled-down prototypes, to test some of the unusual characteristics these designs are bound to have.

General comparison of the magnets in the 20mr and 2mr beamlines

There is very little difference between the 20mr and 2mr magnets in the incoming lines, they have the same requirements and almost the same quantities. The differences are all in the magnets in the extraction lines and that where I will make some general comparisons of size, LCW needs and cost. The power supply and cable comparison is in another document.

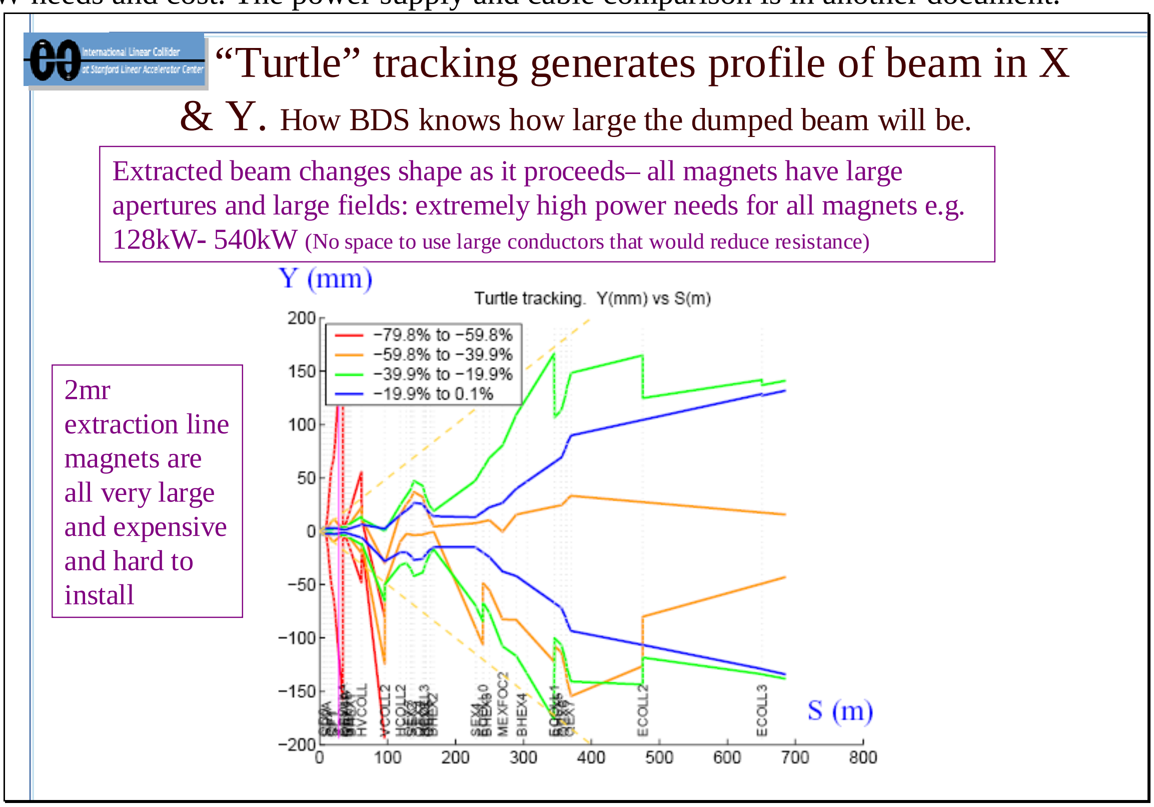


Figure 11 : Overview of the extracted 2mr beam’s Y dimension, leading to very large magnets.

In order to make the comparison tables below I pretended I had no spatial restrictions on the not-feasible magnets and used the magnet weight and cooling water values from the resulting design. In order to develop the current and voltage requirements for the power supplies I did the same thing so every magnet would have an assigned PS, whether it was actually feasible or not.

Comparison of the room-temperature dipoles in the 20mr and 2mr extraction beamlines

Beamline and magnet type	Quantity	M&S costs for this line. (ratio)	Total weight in metric tons	Total cooling water usage in gpm	Tallest dipole in cm
20mr extrac. dipoles	22	1.0	71.54	491	94
2mr extrac. dipoles	60	8.5	635.7	2761	130

Comparison of the room-temperature quads in the 14mr and 2mr extraction beamlines

Beamline and magnet type	Quantity	M&S costs (ratio)	Total weight in metric tons	Total cooling water usage in gpm	Widest quad in cm
14mr extrac. quadrupoles	13	1	32.4	398	52
2mr extrac. quadrupoles	14	10.6	255.6	1246	124

This table uses the 14mr quadrupoles (which have almost the same values as the 20mr quads) to highlight the advantages of using a 14mr crossing angle from a magnet point of view.

Looking over the 2 tables above one can make these general statements, all of which strongly indicate a preference for a 14mr crossing angle over a 2mr crossing angle:

- The 2mr extraction magnets cost about 9 times the 14mr extraction magnets.
- The 2mr extraction magnets weigh about 8.5 times the 14mr extraction magnets, thus their installation will be more costly too.
- The 2mr extraction magnets use about 4.5 times more cooling water than the 14mr extraction magnets, thus the 2mr LCW system would be more costly.
- The 2mr extraction dipoles are much taller than other magnets in the ILC and this has implications for the level of the tunnel floor in the 2mr extraction line (which shares the tunnel with the incoming beamline for some hundreds of meters).

Not possible to use superconducting magnets in any of the extraction beamlines : the high intensity synchrotron radiation, beamstrahlung photons and spread-out beams preclude the use of supercon magnets, even if their cryostats could be made small enough to fit in the tight spaces!

This note gives some explanations and challenges of the 2 mrad extraction optics based on discussion with C. Spencer.

The 2 mrad extraction line is required to transport the extracted e+ (e-) main beam and beamstrahlung photons to dumps with acceptable (small) beam loss in the magnets, provide optics for beam diagnostics with the 2nd focus and two chicanes, and sufficient separation (>3.5 m) between the e+ (e-) dump and the incoming beam line.

There are several factors which complicate the design:

Large energy spread

The IP collision disrupts the incoming beams creating a very large energy spread (which can be 100% to ~20% of nominal energy) and a larger angular spread in the extracted beams. As a result, the particles with very low energy will receive much stronger deflections in the extraction magnets (~1/E) than the nominal energy particles and therefore will tend to increase the beam size along the extraction line.

Shared final focus magnets

The extracted beam has to pass off-center through the aperture of incoming final focus quadrupoles and sextupoles as shown in figure 1. The primary purpose of these magnets is to create a strong focusing on the incoming beam at IP. However, the strong focusing is not desirable for the extracted beam since it causes large deflections for the low energy particles leading to beam size growth. And going off-center in the shared magnets also creates a non-linear dispersion which is not possible to completely correct.

Diagnostic

The diagnostic optics requires strong quadrupoles after the shared magnets to create the 2nd beam focus. This focusing tends to add to the beam size spread due to overfocusing of low energy particles.

Horizontal bending

Horizontal bends are needed to provide the correct orbit angle for diagnostics and achieve enough separation between dump and the incoming line. But the bending creates an orbit spread since different energy particles are bent differently. This spread is not possible to completely compensate due to large energy spread.

Fig. 1: Extracted beam (red) after IP.

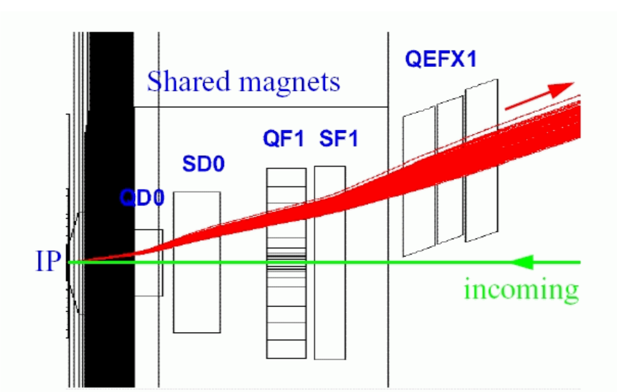
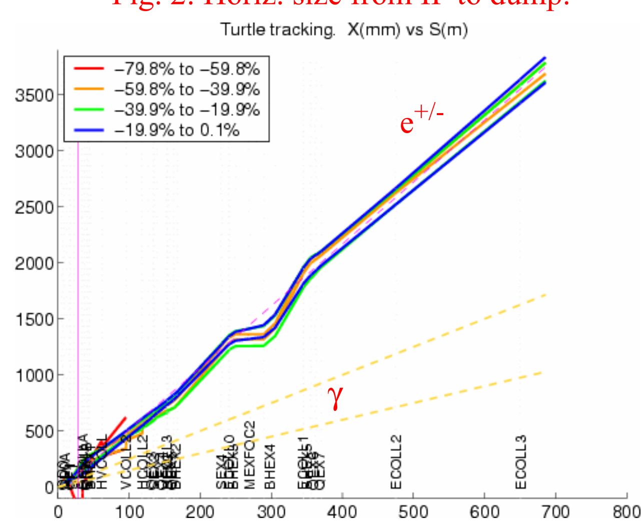


Fig. 2: Horiz. size from IP to dump.



Small separation

Due to the small crossing angle, there is a very small separation between the incoming and extracted beams in the first part of the extraction line. For example, the separation is 150 mm at the first independent extraction quadrupole QEX1A with horizontal half-aperture of 113 mm. The small separation and large aperture make the magnet design difficult.

Beamstrahlung photons

The beamstrahlung photon beam is not bent in the magnet field, therefore it gradually separates from the e+ (e-) beam and follows to a separate dump. In the beginning of beam line, the photon and e+ (e-) beams share the magnets which require a larger aperture to accommodate the two diverging beams.

In summary, the large energy spread is the main source of extracted beam size growth and, consequently, the beam loss which are enhanced by the presence of many magnets needed for diagnostic and proper beam line geometry. Because of the high power (11-18 MW) ILC beam, even a small fraction of lost beam in magnets may be unacceptable.

In the present design, the beam size growth, to certain extent, is minimized by optimizing the final focus quadrupoles and sextupoles and the downstream extraction magnets. Secondly, a set of collimators was included in order to collimate the beam low energy tail as well as to protect magnets from a high loss. As an example, a vertical collimation chicane is included in the beginning of extraction line which deflects the lowest energy particles to high amplitude for collimation at center of the chicane, while the core of the beam is allowed to pass at lower amplitude. For further improvement of the beam transmission, the extraction apertures were chosen relatively large, up to 20 cm radius.

This optics has not been yet optimized for synchrotron radiation. Recent studies at FNAL show a significant power from SR. One way to reduce this power is to lower the field in dipoles and proportionally increase their length.

One of the questions raised by the magnet designers was: Would it be better to move the first independent extraction magnets (such QEX1 quad and following bends) closer to IP and therefore reduce their aperture? The answer is that optically it is possible to move these magnets, however the drawback is that the possible reduction of magnet aperture will be followed by a reduction of horizontal separation between these magnets and incoming beam line. This separation is already very tight (for example, 150 mm at QEX1A), therefore further reduction may be even of more challenge for the magnet design.

The other question was about possible improvements (easier magnets and cost reduction) if there was no extraction diagnostic. The preliminary answer is that without diagnostic there is no need for a secondary strong focusing and there are less constraints on beam line geometry. Therefore it should reduce the number of extraction magnets and likely ease the magnet parameters leading to the reduction of cost. A more precise answer would require an actual design of such optics.

Comparison of Superconducting IR Magnets for the 2/20 mrad and 14/14 mrad IR Configurations

B. Parker, BNL, 21st August 2006

20 vs. 14 mrad

First let's establish that the 20 mrad and 14 mrad crossing angle superconducting magnet solutions are essentially the same. That is, they both use the same set of self-shielded compact superconducting magnet coils and only differ in their respective designs for the inner cold mass containment and outer cryostat housing. The 14 mrad layout is constrained on the inside, i.e. the interface between the incoming and outgoing beamline magnets by not having these elements touch each other and, except for some minor optimization with respect to L* (the distance of the first quadrupole to the IP), this is what sets 14 mrad as the lowest practical crossing angle. So in this respect 20 mrad is a little bit easier since there is more transverse space available between the incoming and outgoing beamlines.

On the other hand the larger beamline separation for 20 mrad compared to 14 makes the interface to the experimental detector slightly more challenging as the extra space between the magnets means that more space is needed for the cryostat that has to go inside the detector. For a fixed detector transverse free space (also must think of opening the detector for installation/access) having less space available for the 20 mrad outer cryostat makes its design more challenging.

So in terms of the IR magnet specifications it is a wash whether the 14 or 20 mrad is more challenging; we only can say that they are different and require slightly different optimization.

What is different between the 20 and 14 mrad magnet layouts is that the 14 mrad crossing angle is small enough that it is possible to use a Detector Integrated Dipole (DID) in its "anti" or reversed polarity sense to minimize the kick given to low energy charged particles coming from the IP and thereby minimize detector background. For the 20 mrad layout, the emittance growth of the incoming coming beam that would occur due to the combined effects of the larger crossing angle and the extra incoming field due to an anti-DID would be unacceptable. This is one definite advantage of 14 with respect to 20 mrad that should be kept in mind but however is not due to magnet design parameters but only due to magnet geometry.

2 vs. 14 mrad

The main difference in going from the 2/20 to the 14/14 mrad configuration occurs in the 2 and 14 mrad crossing angle solutions. Note: a major motivation for developing the self shielded quadrupole solution that made the 14 mrad layout possible was to be able to match the lower (mostly pair) background conditions that preliminary studies by the detector groups indicated might be lower for 2 mrad than for 20 mrad. Again with 14 mrad crossing angle, it is possible to use a reverse polarity (anti) DID to achieve similar pair backgrounds for the 2 and 14 mrad layouts.

However it has recently been realized that the very strong synchrotron radiation (synrad) generated by common near IR magnets in the 2 mrad solution will itself contribute experimental background that is significantly larger than the pair background itself. Thus even in terms of background 14 mrad should win out over 2mr. But this strong synrad has another consequence for the 2 mrad extraction line magnets; it makes it difficult to come up with superconducting version of some of the 2 mrad extraction line magnets, the so called super-septum quadrupole magnets. As discussed elsewhere the 2 mrad geometry with small separation between incoming and outgoing beam and intense beamstrahlung and synrad stay clear zones drives extreme aperture requirements for BDS magnets, often leading to problematic (warm) magnets with large energy and cooling water usage. In principle super-septum magnets might be considered to reduce power consumption except that they would be quite vulnerable to synrad heating and it is not clear if they could be adequately shielded.

As to the IR magnets themselves, it is clear that the large-aperture high-field magnets QD0 and SD0 for 2 mrad are much more challenging than their 14 mrad compact quadrupole equivalents. The 2 mrad QD0 and SD0 magnets require a significant R&D program to come up with a demonstrated design that would meet ILC specific requirements. For their RDR production cost, numbers were scaled from LHC model magnet experience (in terms of tooling, labor etc.) but the ILC requirements differ in many important ways that are hard to address in a manner timely enough to satisfy RDR deadlines. That is QD0 and SD0, unlike the LHC magnets they were scaled from, have to:

- operate in a 3-4 T detector background field (and experience extra 3D coil end forces and reduced conductor margin)
- must have a non-magnetic yoke
- must satisfy tighter detector space constraints (i.e. cannot have outer cryostat, IP side end region or cryogenic support structure too large)
- must have magnetic centers stable or adjustable at better than 100 nm in spite of their not having space for additional correction coils and being quite heavy for mechanical movers.

With the conventional (traditional) magnet construction technology (Rutherford cable in cos(nθ) configuration with collared coils) if one touches even an existing design in a significant way, and the ILC requirements are quite novel, one must produce model magnets in an R&D program to ensure final performance. Magnet R&D can be both time consuming and costly and there is the risk that the design of the production magnets might be considerably different from the existing design.

Note it was also said that the LARP program, to produce large-aperture high-gradient magnets using brittle Nb3Sn conductor technology, is relevant for ILC needs, especially for an energy upgrade. While this is true to some extent (i.e. we are developing a growing experience basis for such magnets) the LARP goals are just that, i.e. targets that we hope to meet after several years of R&D, and not presently existing magnets. (We again must also remember that the ILC magnet requirements differ from those for an LHC Upgrade in important ways so that achieving the LARP R&D goals several years in the future is maybe a necessary but still not a sufficient condition for successful ILC QD0 and SD0 superconducting IR magnet designs.)

We note in passing that short QD0 and SD0/OC0 magnetic test prototypes have already been produced for the compact 14 mrad magnet solution and the QD0 coil has already been shown to meet its main design requirements in the presence of a solenoidal background field and the self-shielding concept has been proven to work as expected. At present there exists on the table an R&D plan addressing the stringent stability requirements with a full length QD0 coil in a cryostat.

One measure of the difference in complexity of the 2 and 14 mrad magnet solutions is that for the RDR the 2 mrad magnet production costs alone were projected to be about 17% higher than those of the 14 mrad magnets. But the difference is qualitatively more: the 14 mrad superconducting layout (for one half-IR) included costs for producing more coils than just QD0 and SD0 but also included QF1 and SD0 as well as the first three magnets in the extraction beamline. Also all these magnets included dedicated correction coils, i.e. dipole, skew-dipole, skew-quadrupole, skew-sextupole and octupole, appropriate to beam alignment and other optics needs. The two 2 mrad magnets QD0 and SD0 had yet to be "dressed" with correctors to this level of detail and these costs will increase the 2 mrad estimate.

The 14 mrad solution, in spite of a lot of attention given to 2 mrad over the course of the last year, is still a more advanced and therefore provides a more complete picture of ILC needs.

Summary

The 14 mrad crossing angle IR magnet solution provides better performance (at least equal if not lower detector background possible thanks to anti-DID and less synrad), greater tuneability/flexibility (thanks to independent coils both main and correction for incoming and outgoing beamlines), less technical risk (ongoing R&D program of coils with actual ILC design parameters and rapid coil production turn around) and reduced cost.

International Linear Collider (IlC)
Beam Delivery System (BDS)
Comparison of Power Systems for
20mr/2mr and 14mr/14mr Magnet Topologies, by Paul Bellomo, SLAC
20th August 2006

Abstract and Conclusions

From a power systems standpoint, there are very large differences between the 20mr/2mr and 14mr/14mr line topologies. The table below summarizes the costs and MVA requirements; the differences can be seen by inspection. The “common” lines transfer the beams from the end of the linac to the point where the beamline splits into 2; either 20/2 or 14/14.

Topology	Magnet Quantity	M& S Cost (Normalized to 20mr)	MVA Requirement
20mr	1,232	1	11.3
2mr	1,262	3.0	60.9
20mr+2mr+common	2,548	4.1	73.5
14mr/14mr+common	2,564	2.1	24.4

The 20mr/2mr Topology

Each of the extraction dipole and quadrupole magnets in the 2mr line requires its own very large 300kW to 600kW power supply. These magnets require currents ranging from 1,500 amperes to 3,500 amperes.

Currents in the order of 1,500A to 3,500A are usually beyond the capability of conventional air-cooled National Electric Code (NEC) rated cables. The Magnet Group has not yet developed a detailed design for the very large and unique conductors required to bring power to each magnet. However, it is clear that the designs are challenging, the implementations unconventional and expensive. The conductors will require water-cooling with all the attendant complexities and high cost.

Although not yet formally tabulated, the vision is that the space, housing and cooling requirements for the 300kW and 600kW power supplies will be very extensive.

The 72.2MVA of power draw requires an extensive and expensive electrical supply system. In addition to the capital equipment expenditure, expect a huge annual electricity usage bill. At $xxx per kilowatt-hour and 24/7 operation for a 6500 hours run, the annual electricity cost is $xxx to run the BDS 20mr-2mr lines.

The tabulations above include only the costs for the power supplies, associated electrical control, cabling, and raceways (presently very rudimentary designs) to the magnet. The table does not include housing, cooling, and AC supply system costs.

The 14mr/14mr Topology

The second 14mr extraction line dipole and quadrupole magnets require significantly less electrical power. The new topology significantly reduces the voltage across and the current in each magnet. The result is a reduction in power dissipation in each magnet and in the entire BDS by almost an order of magnitude.

The lower voltage, current and power requirements in this topology allow for stringing several magnets together electrically, further reducing the quantity and cost of the power systems.

The 14mr/14mr extraction magnet currents range from 500A to 1,000A.The lower operating currents, although not trivial, are more manageable. A single conventional National Electrical Code (NEC) rated cable can carry 500A in a suitable raceway or cable tray. If necessary, several paralleled conductors can carry the 1,000A currents.

Space, housing, cooling reductions follow the reductions in the power supply ratings accompanied by corresponding reductions in system cost. Given the conditions cited above, the annual electricity bill drops to $xxxx to run the BDS 14mr-14mr lines.

Follow-up Email Communications

From: N.Toge
Sent: Tuesday, August 22, 2006 3:21 AM
To: Spencer, Cherrill M.
Cc: Bellomo, Paul; R. Sugahara, CCB
Subject: Re: Here are 4 docs from Mag Systems re 20/2 to 14/14 change

Dear Cherrill,

> The Magnet Systems Group has prepared 4 documents in response to
> your request to give our technical assessment of changing from 20mr
> and 2mr crossing angles to 14mr and 14mr from a magnet and power
> supply point of view.

Thank you very much for producing this substantial set of reports on the BDS Magnet and PS issues. CCB is very happy to chew on them and, if necessary, will get back to you with additional inquiries, as you suggest.

One quick question. Do I understand it correctly that these four documents basically reflect the consensus among five of you (Cherrill, John, Brett, Paul and Ryuhei) at this point of time? I am aware of some folks making the case for some alternative designs of these magnets in question around the time of Vancouver.

Sincerely,

- Nobu Toge

Subject: [CCB-569] RE: Here are 4 docs from Mag Systems re 20/2 to 14/14 change

From: Parker, Brett

Date: Tue, 22 Aug 2006 09:40:32 -0400

> Dear Cherrill,
>
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> you (Cherrill, John, Brett, Paul and Ryuhei) at this point of
> time? I am aware of some folks making the case for some alternative
> designs of these magnets in question around the time of Vancouver.

John/Cherrill, I would like to make the following response to this point and see if (as I expect) you agree.

Around the time of the Vancouver conference there were heroic attempts made to come up with "something" for these magnets since the statement that "some of the 2 mr magnets are unfeasible" was not logically defensible (it is not sufficient to prove a negative statement by demonstration) and actually there was a lot of progress in clarifying the magnet design issues involved. Still even if the ideas for the 2 mr magnets were to be developed further, it is clear that their very challenging requirements will mean that they will be big, relatively costly, use a lot of power and water cooling and will be hard to make them as reliable as the other BDS magnets.

The point is not that there is still work that could be done to improve them further (although we really don't have adequate resources/time to spend on this) but that by the nature of their aperture requirements and relative beamline spacing which arises naturally in the 2 mr layout,

they will always be very challenging magnets that many experienced magnet designers place right at the cusp of feasibility.

- Brett Parker

August 23, 2006

Prof. Nobu Toge
KEK
Tsukuba, Japan

Toge -sama

This note is to accompany the detailed documentation with regard to the BDS Change Configuration Request [CCB-499] sent to the CCB by C. Spencer and P. Bellomo for the Magnet Systems Area Group, as requested. And it attempts to provide a brief discussion of the 2 mrad line design activities just prior to Vancouver, to which you referred in a subsequent email.

The Magnet Systems Area Group fully supports the change from the present 20/2 mrad IR configuration to the proposed 14/14 mrad configuration based only on magnet system considerations. The magnet solutions to the 14 mrad IR are similar to those in the present 20 mrad IR and are not judged to be significantly more difficult or expensive. It should be noted that effort had been invested in a 14 mrad design prior to Snowmass 2005, particularly in the configuration of superconducting magnets at the IP. The 2 mrad line presented many difficulties for magnet solutions due to the limited space between the incoming and disrupted beams. A range of solutions was investigated for the 'problematic' magnets in the 2 mrad line; in all cases, both the estimated capital and operating costs were significantly higher than those of the 14 mrad line magnets. In many cases, the solutions were not judged to be feasible.

As you have noted, there was a great deal of activity just prior to the Vancouver meeting to explore solutions to the most difficult 2 mrad line magnets. I provide a brief summary and assessment of that activity below. We note that the magnet designs and attendant design issues are highly dependent on the details and requirements of the beam line design. No attempt was made to adjust the lattice to make the magnet constraints less challenging.

Pre-Vancouver activity:

The lack of separation between incoming beam and disrupted beams in the 2 mrad beam line (compared with the 20 mrad line) requires special treatment for magnets close to the IR. The large size of the disrupted beam plus 'beamstrahlung' photons requires large magnet apertures to focus and transport the beam to the energy analysis chicane and avoid large backscatter to the detector. The large aperture dictates a magnet geometry in which the magnet steel, in a typical quadrupole, would intersect the (nominally separated) incoming beam. A solution to this spatial problem is to incorporate a shielded region in the magnet steel with appropriate field cancelling windings to reduce the local field and preserve the incoming beam. The combination of focusing strength required for the quadrupole plus the additional steel and correction coils for shielding the incoming beam results in quite large magnets, with significant power and cooling requirements. Very preliminary conceptual designs, focused on QEX1A, were developed which appeared to be able to meet magnetic requirements but with significant powering and cooling issues. These were designated as “feasible” magnets from the standpoint of preliminary field assessments only. Similar difficulties are to be encountered in 9 other quadrupole magnets in this region: QEX1B, QEX3#1, QEX3#2, QEX4#1, QEX4#2, QEX4#3, QEX#4, QEX5#1 and, QEX5#2. Plus the first dipole BHEX1 and 9 other dipoles.

The proposed solutions to this dilemma are very new and have had little time for detailed evaluation. Conventional magnet designs, with attempts to maintain separate magnets for the incoming and disrupted beams had proved to be functionally “impossible”, or at least highly “unfeasible”. Just prior to the Vancouver conference, there were heroic attempts made by several magnet experts at different institutions to develop a conceptual design which combined the magnets for the two lines in one assembly. There was a lot of progress in clarifying the magnet design issues involved and, as stated previously, the magnetic solutions appeared to be “feasible”, if not practical at this early stage. Still even if the ideas for the 2 mrad magnets were to be developed further, it is clear that their very challenging requirements will mean that they will be big, relatively costly, use a lot of power and water cooling and will be hard to make them as reliable as the other BDS magnets.

The point is not that there is still work that could be done to improve them further (although we really don't have adequate resources/time to spend on this) but that by the nature of their aperture requirements and relative beamline spacing which arises naturally in the 2 mr layout, they will always be very challenging magnets that many experienced magnet designers place at the cusp of feasibility.

Best Regards,

- John Tompkins
- For the Magnet Systems Group