Update on e+/e- Timing and Correction

ECFA LC Workshop, May, 2013

Ewan Paterson

The Timing Problem

- **The difference in path-length for e+ from the target, through the DR, the RTML and Linac to the IR and for e- from target to the IR, should ideally be an exact multiple of the DR circumference.**

- **WHY--- If this is not true, there will be very few (if any) bunch patterns of mini-trains in the DR that will satisfy all the DR constraints, have adequate ion clearing gaps over an adequate range of DR operating conditions and have all bunches collide in the IR with sub-millimeter accuracy.**

  There can be solutions for small numbers of bunches that use only small fractions of the DR circumference (less than half) and therefore low luminosity – *not very useful!* – or have 2 e+ rings which alternate fills – *crazy idea!*

- **This is because the electrons collide with the positrons which were produced by electrons on the previous cycle and the only timing variable is the path length travelled by the bunches, through the RTML, Linac and FF ……or is it? Maybe not!**

There are 3 different scales to this E+/- path difference problem!

≈ 100 m — Needs final site and design layout and is required before construction starts.

≈ 1 m — Survey and Alignment above and below ground and used during design, construction, installation and commissioning. Will need some adjustment during commissioning?

≈ 1 mm — Use some fine path length adjustment system? Required during final commissioning and operation. Used daily and might use slow feed forward?

STATUS AS OF LAST WORKSHOP OCT, 2012, Arlington TX

The layout of the accelerator systems required the addition of 100 to 200 meters of path-length to the e+ travel to correct the timing. It was agreed that this would change and will be part of the final layout for the ”real” site. Once the tunnels are constructed it is very difficult to change (without civil construction) the path-length of the beams by more than a few tens of millimeters.

This raises the following questions which are still open :-

a) What is the optimum location for the insert in the final site layout?

b) Is the solution compatible with a staged energy design?

c) To what accuracy will we know the path-length before commissioning with beam and how much and how frequently will it need to be adjusted during commissioning and operation?

Today I will discuss these questions and ideas for solutions!

OVERALL SURVEY ACCURACY at a "GREEN-FIELD" SITE

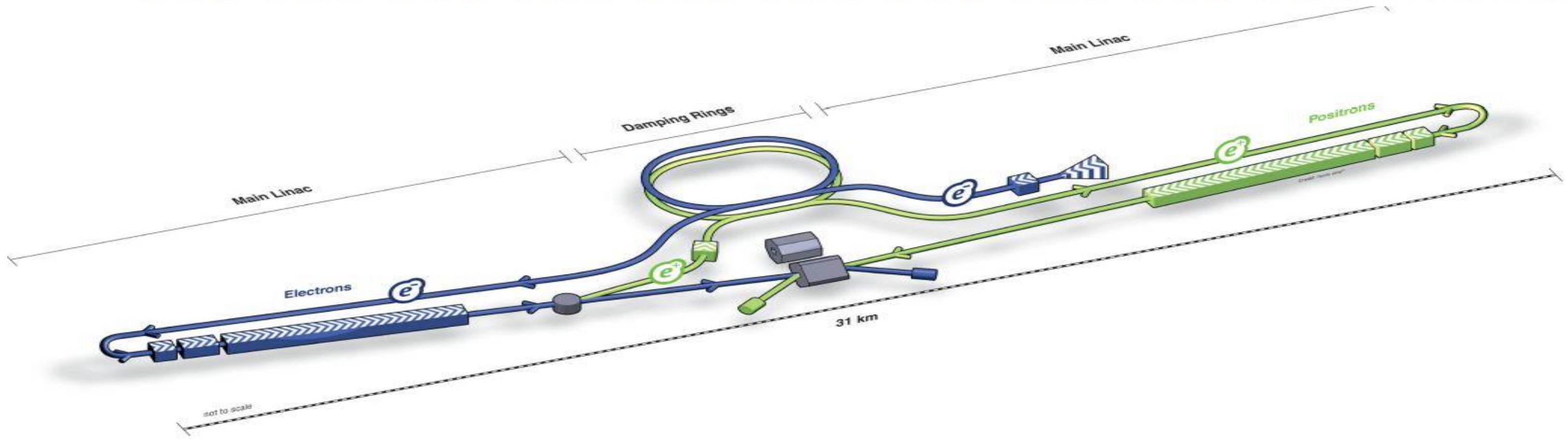


Figure 3.1. Schematic layout of the ILC, indicating all the major subsystems (not to scale).

The following process will need to be repeated before and during construction, throughout commissioning and during operation.

Step 1 :-Set up Geodetic Above Ground Network with many monuments over 30 x 10 km's
Using dual frequency, multi satellite measurements achieve accuracy of ≈ 10x-6 per km
Step 2 :- Transfer to underground construction to guide civil construction
Most difficult step, and dominates distance errors, could be +/- 1 meter over ILC
Step 3 :- Set up 'in tunnel' grid network coupled to above ground network for accelerator systems installation and alignment.
This is a network with very high and adequate transverse accuracy (smooth!)

International Workshops on Accelerator Alignment, Last was (IWAA) 2012 at FNAL

Past Conferences

Stanford Linear Accelerator Center 1989	DESY 1990	CERN 1993
KEK 1995	Argonne National Laboratory • University of Chicago 1997	ESRF 1999
SPring-8 2002	1954-2004 CERN 2004	IWAA 2006
	2008	GEODESY 2010

Latest was IWWA 2012 at FNAL. Where should the next workshop be----- **'Kitakami' or 'Seburi' mountain regions?**

International Workshops on Accelerator Alignment

World's experts meet every 2 years. There is a lot of good information and experience exchanged. However most effort to date has been in improving transverse precision and accuracy over tens to hundreds of meters.

Recent questions --- **How fast are neutrinos?** Has brought new efforts in understanding errors over long distances, above and below ground.

FINDING :- Long distance measurement errors tend to be dominated by systematics in transferring GPS or other Optical System Measurements from Surface networks to Underground networks. Two examples are:-

THE DISTANCE FROM CERN TO LNGS

M. Jones, D. Missiaen, CERN, Geneva, Switzerland
M. Crespi, G. Colosimo, A. Mazzoni, Universita' di Roma "La Sapienza", Rome, Italy
S. Durand, ESGT, Le Mans, France

With new efforts on above and below ground networks, error is now reduced to 0.2 meters

And for MINOS, again after special effort, we have

As reported by the contractor who performed the survey (The Department of Geomatics Engineering from the University of Calgary), the computed accuracies were 0.48 m, 0.20 m and 0.23 m in latitude, longitude and height, respectively, where the 0.48 m on latitude is dominant since the beam points almost North.

Commissioning and Operation of the DR's

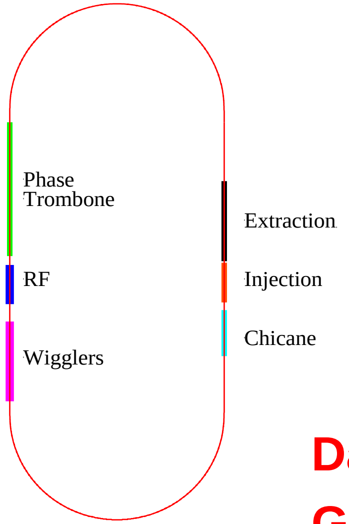
- Injectors and DR's are commissioned with expectation that errors in the circumference (typically ≤ 10*-6 or ≤ +/- 3 mm) are correctable with 100 meter long, circumference chicanes which are part of the present design.

Expected variations are

10*-5 per degree C in tunnel temperature

Example :- It Is 1 mm in Spring 8, annually.

Tunnel and air temperature can be a problem or a nuisance for surveys and timing.



DR is corrected, as required, with it's own chicane so circumference is held constant but not other accelerator systems, such as RTML/LINAC where :-

Daily tidal forces can be ≈ 10*-7 or 0.1 mm

Ground relaxation, water levels, orbit distortions, etc. give small effects on lengths. Each can be in the 0.1 to few mm range.

Commissioning and Operation of RTML,LINAC,FF

- Once two beam operation is established then timing errors can be measured and we should be prepared to correct up to +/- 0.5 to 1 meter of static error from the survey and installation.
- Timing variations due to diurnal, annual and other random effects can be easily measured and could amount to several mm over the 15 km (10*-6) in hours, days, or months but not minutes!. I think?
- Fast changes, minutes or seconds, could come from large orbit oscillations and tuning. 10 mm oscillation down the RTML and back along the Linac changes path by ≈ 1 mm, but a 1 mm oscillation gives only a 10μm change. Only a nuisance??
- Measurement of the e+/e- timing to less than the bunch-length (0.3 mm), using beams in the IR is relatively easy but changing the beam path-length is not!

- **Let's look at correction schemes for these values.**

The Design Layout Correction

- We have, in the past, considered the beginning of the E+ RTML (end of E+ Linac) as the location to insert a long (100-200 m) path-length correction with a tunnel extension.
- This could be pure beam transport (one FODO cell) or filled with additional equipment such as cryomodules in linac line.
- The RTML extension could also be location of a small length adjuster which could look like the +/- 4 mm, 100 m long, circumference chicane in the DR which changes the path by a few mm *OK for slow and small adjustments.* Or a single λ 1 meter offset chicane giving 40 mm change *and requiring mechanical motion and perhaps civil modifications after commissioning !*
- I have no good solution to handle a large +/- 1 meter corrections, if left after installation. *Large chicanes or trombones seem* *impractical?* *One could move the RTML turn-around by half this amount after full commissioning gives the value of the error!* *Ugly?*

We need to consider an alternate approach.

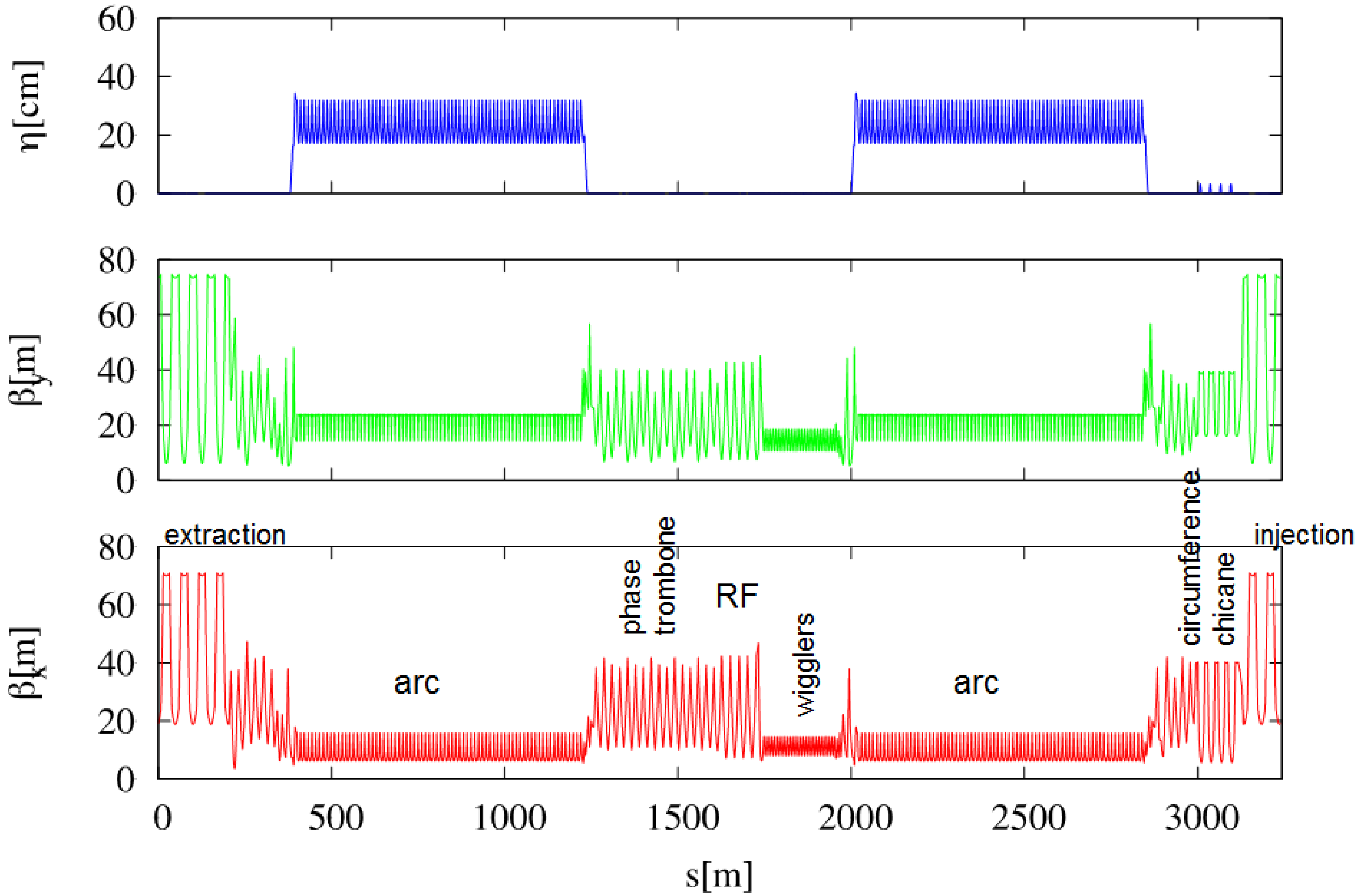
Why not change the DR Circumference rather than length of RTML and LINAC?

- In 10 Hz operation beam is in the DR for 10*4 turns, normally it is 2 x 10*4.
- Injection/Extraction ≈100 turns, during which DR and Linac RF frequencies must be synchronized and locked.
- A damping time is ≈ ≤ 2 x 10*3 turns
- Proposal :- Unlock DR RF of one ring for say 5 x 10*3 turns after some initial damping and change the frequency to change the circumference by +/- 0.1 mm then re-lock RF.
- At extraction time the relative e+/e- path-length has changed by +/- 0.5 meters
- Can this be done with DR hardware and without a penalty in DR performance?

I THINK YES, SEE NEXT SLIDES, BUT NEEDS REVIEW

See D. Rubin's Talk

The DR Lattice



DR Parameters

Parameter	5 Hz Mode: Low Power	5 Hz Mode: High Lumi	10 Hz Mode: Positrons	10 Hz Mode: Electrons
Circumference [km]	3.238		3.238	
Number of bunches	1312	2625	1312	
Particles per bunch [$\times 10^{10}$]	2	2	2	
Maximum beam current [mA]	389	779	389	
Transverse damping time τ_x, τ_y [ms]	23.95		12.86	17.5
Longitudinal damping time τ_z [ms]	12.0		6.4	8.7
Bunch length σ_z [mm]	6.02		6.02	6.01
Energy spread σ_E/E [%]	0.11		0.137	0.12
Momentum compaction factor α_p [$\times 10^{-4}$]	3.3		3.3	
Normalized horizontal emittance $\gamma\epsilon_x$[μm]	5.7		6.4	5.6
Horizontal chromaticity ξ_x	−51.3		−50.9	−51.3
Vertical chromaticity ξ_y	−43.3		−44.1	−43.3
Wiggler Field [T]	1.51		2.16	1.81
Number of Wigglers	54		54	
Energy loss/turn [MeV]	4.5		8.4	6.19
RF Specifications:				
Frequency [MHz]	650		650	
Number of cavities	10†	12	12	
Total voltage [MV]	14.0		22.0	17.9
Voltage per cavity [MV]	1.40	1.17	1.83	1.49
RF synchronous phase [°]	18.5		21.9	20.3
Power per RF coupler [kW]‡	176	294	272	200

† The baseline RF deployment for positrons is 12 cavities to support 5 and 10 Hz modes.
‡ Power/coupler computed as (Max. Current) × (E loss/turn)/(No. cavities).

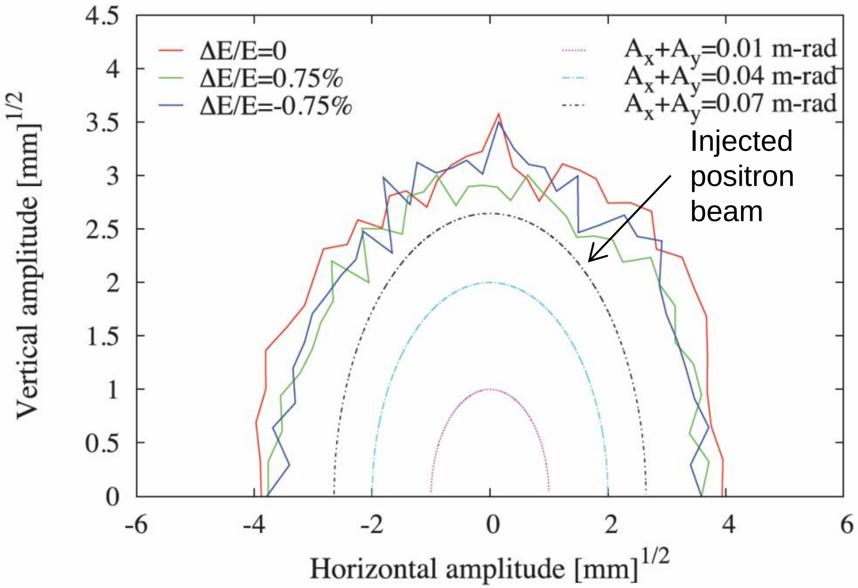
- Three ILC operating modes correspond to four DR configurations
- Two modes utilize a 5 Hz repetition rate: low power baseline (1312 bunches/ring); and high luminosity upgrade (2625 bunches).
- Third operating mode is at 10 Hz, with e- linac operated with alternating pulses: high energy for e+ production followed by low energy for collisions.
- Shorter damping times necessary to achieve the same extracted vertical emittance in half the nominal storage time.

Nonlinear effects

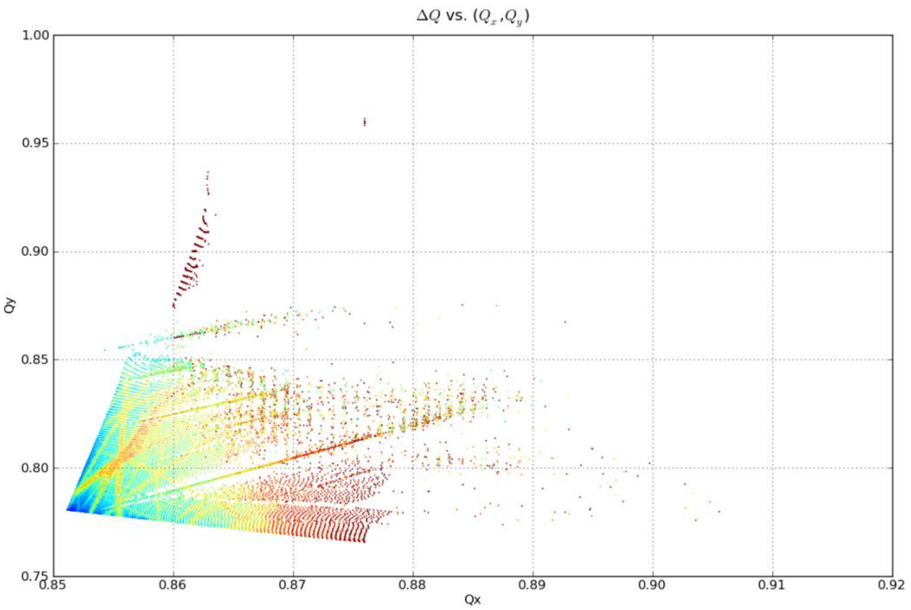
- Magnet misalignments as on previous slide.
- Magnet multipole errors based on PEPII and SPEAR magnet measurements.
- Wiggler nonlinearities based on numerical wiggler field model, checked against Cesr wiggler field measurements.

Type	Unit	Max Field Max KL	Error
Dipoles	mrad	41	2×10^{-4}
Quadrupoles	m^{-1}	0.35	2×10^{-4}
Sextupoles	m^{-2}	1.23	2×10^{-3}
H correctors	mrad	2	5×10^{-3}
V correctors	mrad	2	5×10^{-3}
Skew quads	m^{-1}	0.03	3×10^{-3}
Wigglers		–	3×10^{-3}

Dynamic aperture
with specified magnet misalignments and field errors, and full Taylor map for wiggler nonlinearities



Tune footprint



Summary of E+/- Timing Issues (1)

- **Need to review the optimum design layout, with minimum timing correction, for the final site taking energy staging into account. (Full or half length civil construction ?) Determine length and location of static design path-length correction.**

To maintain constant correction during energy upgrades the RTML/Linac length (including any drift sections) should increase by steps of one half DR circumference, (≈ 1.6 km, 15% of 11 km)

- **Set up surface geodetic network, with monuments, as early as possible. Use during civil construction. Couple to the new underground survey network of monuments using vertical and horizontal shafts and estimate path-length errors. This is most likely a Green Field Site and additional alignment shafts may be worthwhile or even required.**

Repeat often during installation. Remember that systematics such as temperature and humidity are very important . Could be 10*-5 over 10 km, or 0.1 meters but that is only 100 μm per cryomodule.

Summary of E+/- Timing Issues (2)

- During design phase, need to decide on use of DR circumference, Linac tunnel extension with a chicane, or RTML turnaround re-alignment, to correct path-length corrections ≥ 1 meter.
- Decide on use of DR frequency, or a Linac chicane, if built, to correct diurnal , annual and general timing corrections at the ≤ 1 meter level. Check and correct timing in the IR to an accuracy of less than the bunch length during final commissioning and early operation. Study variations and consider slow feedback (forward) corrections and strategies when tuning DR's, RTML/Linac orbits, Compressor phases etc?
- How much timing error (displacement of IR) can we have before detector backgrounds cause problems? This will have to be considered in tuning strategies. Feedback systems will keep the beams in head on collisions but we cannot forget the other dimension and disruption.