Kickers Overview

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ILCDR R&D MiniWorkshop
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Outline

- **Overview**
  - Workshop goals
  - History, Strategy and R&D Overview
- **Technical Issues and Status**
  - Pulsers
  - “Magnets”
  - Insertion Optics
- **Management of R&D**

Workshop Goals for Kickers

- **Technical Status Updates**
  - This afternoon, and tomorrow before coffee
- **Lattice Compatability**
  - Between coffee and lunch tomorrow?
- **Technical review of S3-era kicker R&D plan**
  - After lunch tomorrow?
- **Discussion of EDR deliverables and schedule**
  - Late tomorrow afternoon

Brief LC DR Kicker History

- **SLC**
  - 60 nsec bunch spacing, 1, 2 bunches, thyratrons, ferrite magnets
  - Were considered within state of art at design time, but limited early operation, and were often largest downtime source
  - Were “tamed” by several generations of new magnets, pulsers, control schemes, beampipes, and a dedicated engineering and maintenance-tech team
  - Longer-term problems continued to arise until end of project
- **Pre-ILC**
  - Warm LC: short train in small ring, kicker gap is cheap, so rise, fall times needn’t be super-fast, e+ pre-damping ring reasonably cheap, also relaxes kicker requirements. SLC experience made designers willing to compromise ring design and cost to avoid kicker issues.
  - TESLA: Dog-leg DR, driven by kicker rise & fall times (still assumed to be faster than SLC, but much slower than ILC now).

Brief LC DR Kicker History (2)

- **After the cold ILC decision, we adopted a ring design that requires kickers <u>well beyond</u> the state of the art.**
- **It's hard to see meeting the full requirements with <u>any</u> pulser that has been used for a working accelerator.**
- **We aren't letting kicker technology drive ring design.**
  - Instead, we started a kicker R&D program
- **Results from the R&D program are good enough to pass the giggle test at the RDR level**
  - I wouldn't want to go through a hostile review today!
- **We need to do better than the giggle test for the EDR**
- **And that would still just get us back to where SLC started, with a design that sounds plausible, but still was a constant pain in the @&$!**

Comments on Our Strategy

- I'm not saying any of those decisions weren't right
- I'm not saying I think it's possible to make a kicker system that works for 3 ns bunch spacing.
- I am saying that I don't expect reliable full-spec performance from day 1. There could be lots of down-time, lots of time running with half as many bunches, and a few major system changes.
- There must be enough space in the lattice, and enough rack space in the tunnels, not just for a system that works on paper, but for a do-over or two.
- That includes enough space for an RF-separated region for kickers (although I wouldn't build it for day 1, just keep the option open).

R&D Program Overview

- **Tests of commercial pulsers (Behlke, FID GmbH)**
  - In beam at ATF/2, FNAL photoinjector, DAΦNE (soon)
- **Development of inductive-adder FET pulser**
  - SLAC-LLNL, to be tested at ATF
- **Development of DSRD circuits**
  - SLAC + industry partners
- **Development of stripline structures**
  - Simulation at many sites
  - Building for DAΦNE and ATF/2
- **Reports at DR R&D meetings at Cornell, Frascati, ILCWS at DESY**

Pulser Technology

- **Thyratrons aren't fast enough**
- **FETs can be fast enough, but at low power per device**
  - Engineering of series-parallel combinations is hard
  - Speed-of-light across array is not insignificant
- **Fast Ionization Dynister (FID)**
  - GaAs triggered avalanche device
  - Sub-ns solid-state thyratron
  - Few vendors, expensive, little track record
- **Drift Step Recovery Diode (DSRD)**
  - Non-triggered fast-turn-off device
  - Needs "pump" upstream (FET or FID)
  - "Pump leakage" can be several percent of peak

Kicker Pulsers

- **A fully satisfactory pulser has yet to be demonstrated**
  - RDR text shows ATF test data with FID GmbH pulser that is nearly OK for 6 ns spacing
    - Width is fine, but baseline isn't clean
    - Higher amplitude would be nice
  - Too wide for 3 ns spacing
    - But perhaps close enough if some tricks are used….
- **Kickers and pulsers are a high-priority S3 R&D item**
- **And an EDR work package**

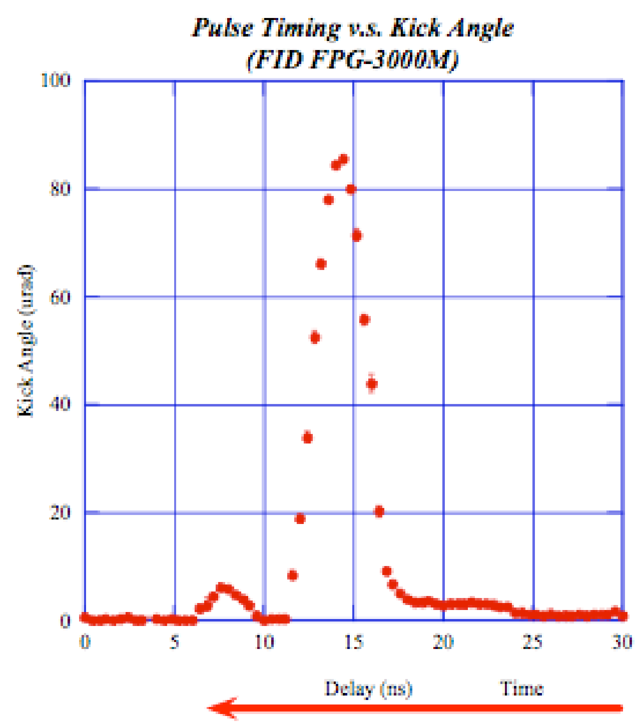
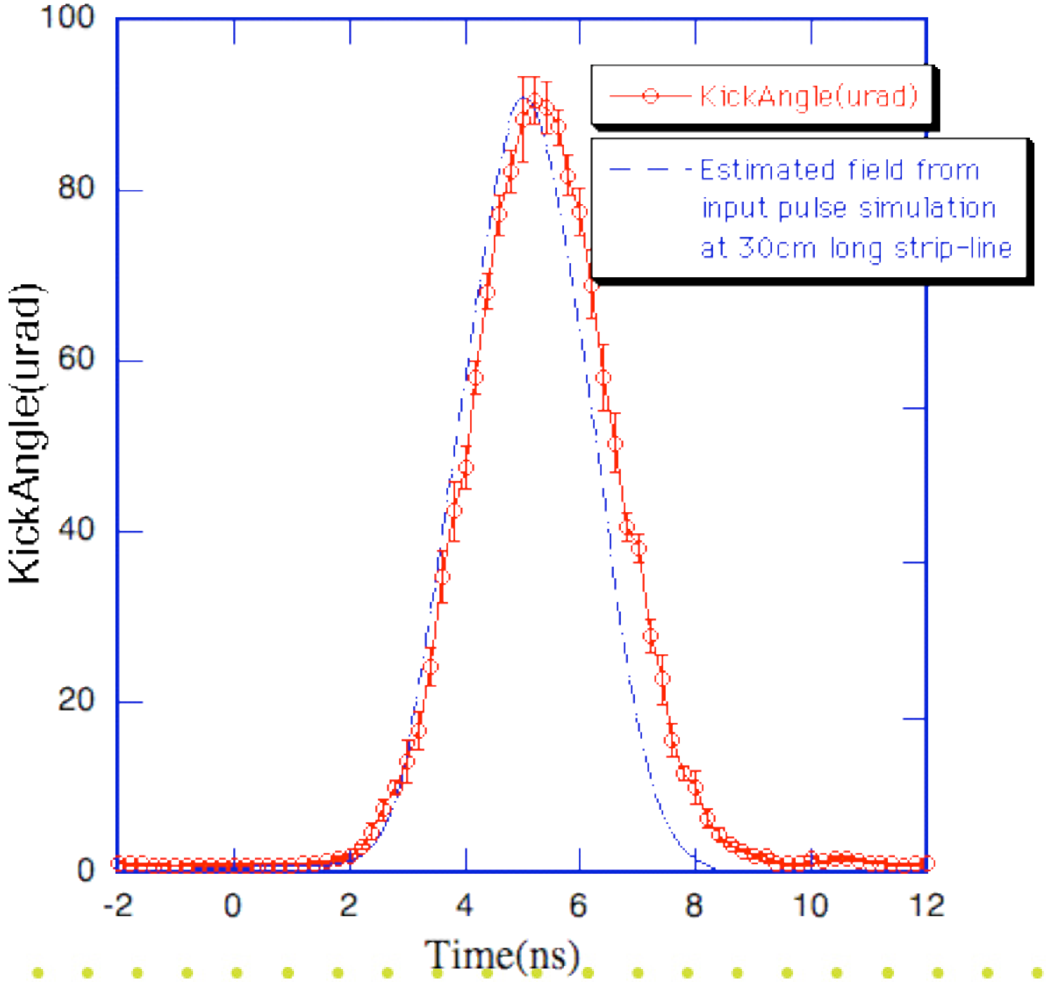


FIGURE 2.4-7. Kick angle vs. time. Note that time increases to the left here.

Performance Update

- **Naito-san's June DESY LCWS07 presentation of KEK results**



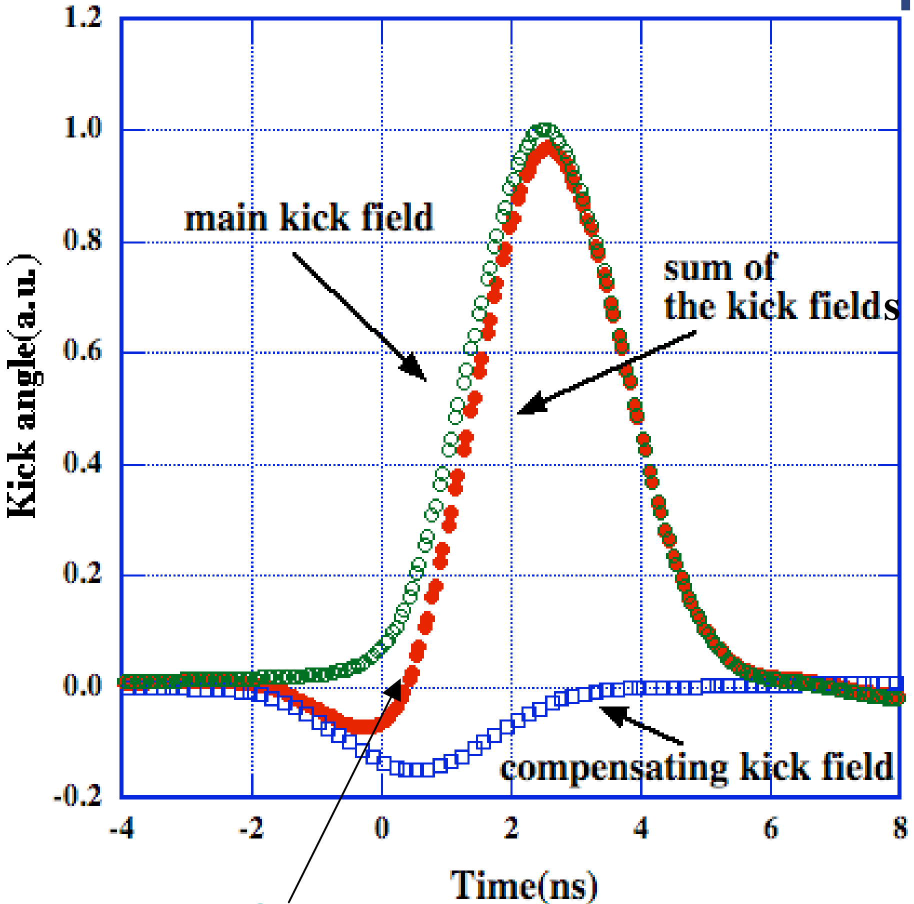
Beam kick profile

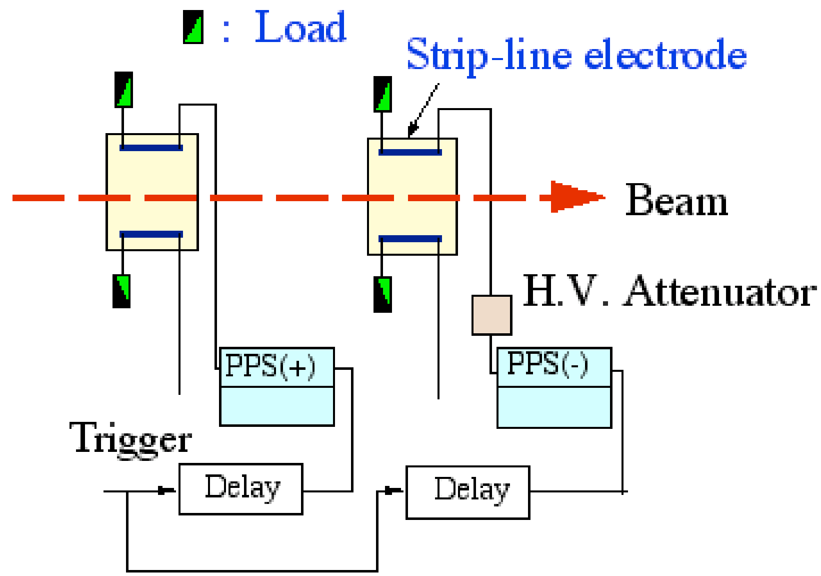
The timing of the kick pulse is scanned for the timing of the beam with 200ps steps. The kick angle is estimated from the beam oscillation amplitude.

Rise time = 3.2ns (1%~100%)
Fall time = 4.0ns (100%~1%)
[goal is sum < 6.15 ns]

Waveform compensator

Naito-san's June DESY LCWS07 presentation of KEK results





Experimental set up

The rise/fall time is improved to 2.2ns and 2.4ns (not at same time in this setup)

Simulation of waveform compensator

Kicker “Magnets”

- **RDR assumption is striplines in vacuum**
  - Pulse direction opposite to beam so E and B add
  - Speed of light propagation
  - No inherent rise-fall-time limitations
- **Field pulse length is electrical pulse plus twice strip length, which must be less than twice bunch spacing**
- **RDR assumes strip length of 30 cm (1 ns)**
  - Electrical pulse width < 10 ns for 6 ns bunch spacing
  - Electrical pulse width < 4 ns for 3 ns bunch spacing
- **“Efficiency optimum” is strip length of half the bunch spacing and electrical pulse equal to bunch spacing**
  - All of pulser energy is used to deflect one bunch

Stripline R&D

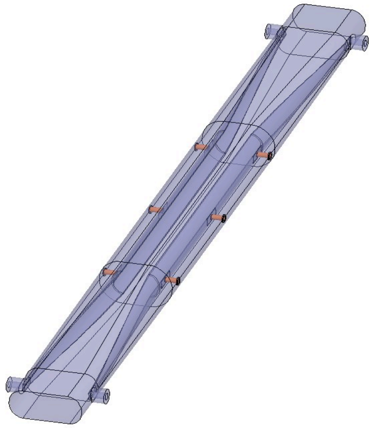
- **Issues**
  - Beam impedance
  - Uniformity of field across aperture (e+ injection)
    Degradation of rise/fall from feedthrus and tapers
  - Packing fraction
  - High voltage on feedthrus
  - Cooling
- **None of these sound un-solvable**
  - Just need to be done right someday

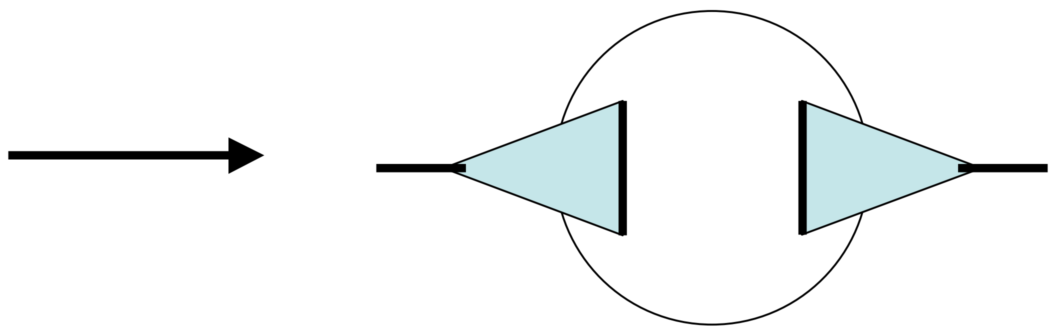
(My) R&D Comments

- With extra pulsers with offset timing, rise and fall time specs for 3 ns bunch spacing seem doable.
- While FID GmbH makes the fastest pulsers, not all their boxes have FIDs in them! Some have had FETs and DSRDs (not that I care, if they do the job).
- DSRDs seem to give “pump leakage” at the few percent level, which is not insignificant for a 100 sigma kick! This needs more attention than it’s getting.
- We may never have tested a device with a FID as the last stage. We should, it may may be great.
- FETs conceivably could work for 6 ns spacing, but it’s hard to see for 3 ns spacing (bipolar avalanche transistor stack vendors seem to do better, why??)

Effective Magnet Length

- **Is product of peak voltage and strip length <u>only</u> for zero-risetime pulse, or zero-length magnet**
  - Guess between 20 and 50% inefficiency
- **Real magnets will have tapers at end of strips, that won't give full kick, but would add to the pulse width**
  - Can we bend them away from the beam path?

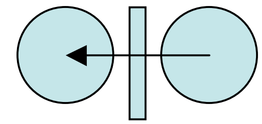




- **Real magnets will have HV cable clearances, flanges, bellows, etc**

Amplitude Requirements

- **Inject high-emittance e+ into center of ring aperture**
  – Move whole beam phase space across septum



$$\Delta x = R_{12}\Delta\theta \geq 2\sqrt{\varepsilon\beta_{sept}} \qquad R_{12} = \sqrt{\beta_{kick}\beta_{sept}}\sin\phi$$

$$\Delta\theta = kE\ell = k\frac{V}{w}\ell \qquad w = 2\sqrt{\varepsilon\beta_{kick}}$$

$$\left[\sqrt{\beta_{kick}\beta_{sept}}\sin\phi\right]\left[k\frac{V}{2\sqrt{\varepsilon\beta_{kick}}}\ell\right] \geq 2\sqrt{\varepsilon\beta_{sept}}$$

$$V\ell\langle\sin\phi\rangle \geq \frac{4}{k}\varepsilon$$

- **Injected e+ emittance --> ≥ 130 kilovolt-meters needed**
- **Less to extract damped e+, or to inject or extract e-**

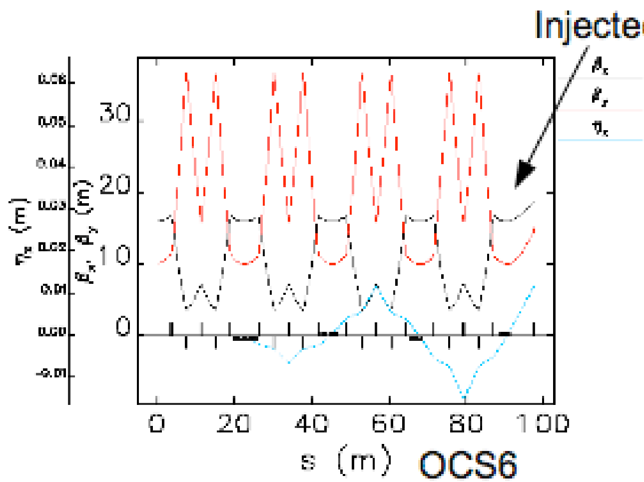
Kicker Beta Optimization

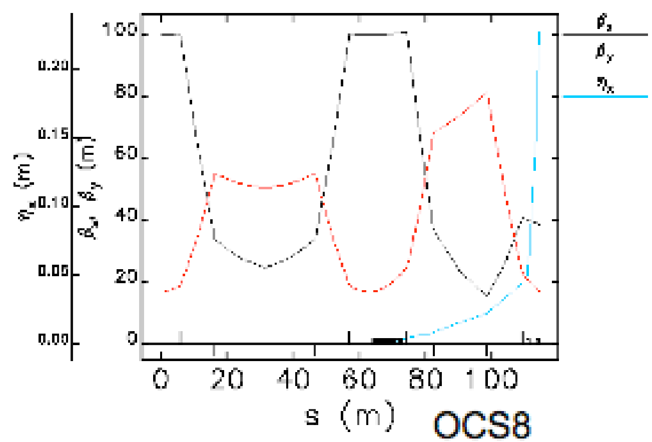
- **To first order, beta at the kicker and septum doesn't affect the kilovolt-meters needed**
- **Septum thickness and stay-clear favors high beta**
- **High beta at kicker means lower E-field for same voltage, which reduces breakdown issues.**
- **Higher beta also means less phase per meter, so there's less loss from the <sin ϕ> term.**
- **There's a length vs pulser-cost tradeoff**
  - If a pulser drives a 50 Ohm cable at V and I, it can drive 4 cables at V/2 and I/2.
  - You get twice as much kick from 4 magnets at V/2 than from one magnet at V (if you have the space….)

Injection/Extraction Straights

- **RDR version has e+ injection kicker broken into several regions 180° of phase apart**
  - Limited the orbit excursion inside the striplines
  - But had large orbit excursions in many quads
- **Proposed OCS8 has single e+ injector region**
  - But higher voltage to reduce excursion inside striplines
  - Still a few quads need special large apertures
- **OCS8 also more completely respects centralization of damping ring, with injection and extraction on opposite sides.**
- **But decks for injection, extraction lines need updating.**

OCS6 (RDR) and OCS8 e+ Injection Region





Design of Injection/Extraction

- Strength of fast strip-line kicker is very weak.
- Need 42 strip-lines in total (30 mm gap, 10 kV pulser).
- They have to be put into separated groups with 180^0 phase advance.
- Extraction line is slightly different from injection line due to damped beam size.

- With 70 mm gap and double the pulser voltage, 23 strip-lines are needed, and can be put into one straight section.
- Extraction line is the same as injection line except using less strip-line kickers.

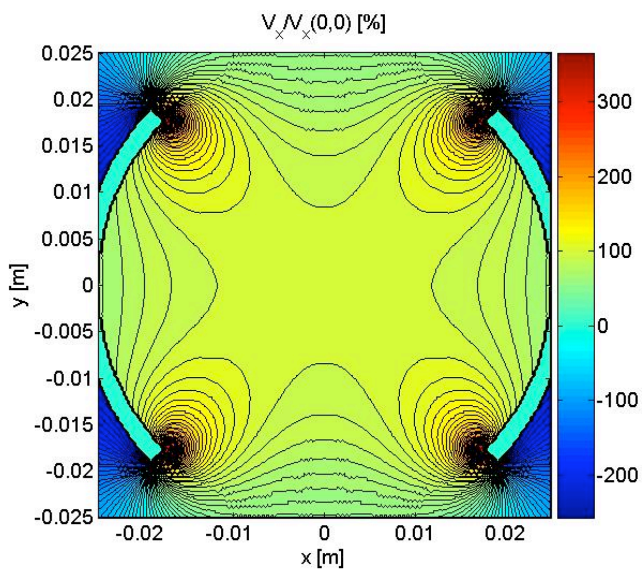
Argonne National Laboratory — Status Report on ILC Damping Ring RDR Lattice — A. Xiao and L. Emery, 10/23/07 6

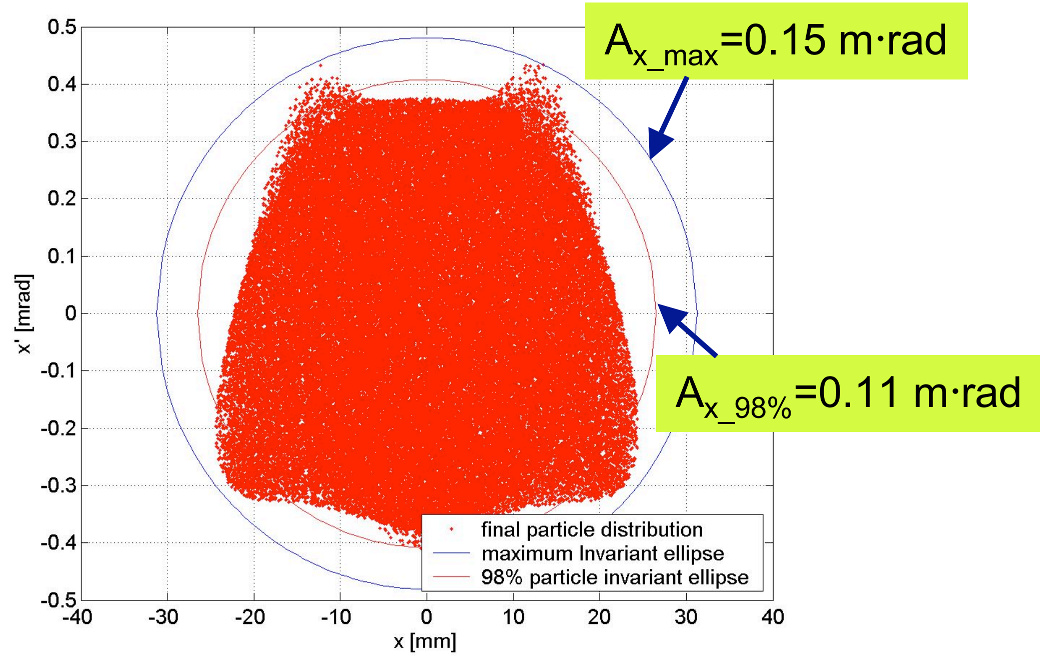
Comments

- **I'd go to fewer, longer cells with more length between for kicker contingency or cost savings and higher beta**
  - Also increases distance between septum and next quad, which makes septum easier
- **It's not obvious to me why the straight section lattice needs to be "OCS-like" rather than FODO.**
- **Optimum for kicking is 90° FODO cell with septum at F, kicker at previous (or next) F, and D halfway between.**
  - Moves F at end of kicker to start of kicker, and single D halfway to septum is (slightly) better than split-D.
- **Lattice folks seem concerned with orbit deflection inside kicker vs stay-clear, resulting in short, high-voltage kicker region, or re-splitting kickers if voltage is lower.**
- **I'd just make downstream kicker units with larger aperture and keep them at one point in a simpler lattice.**

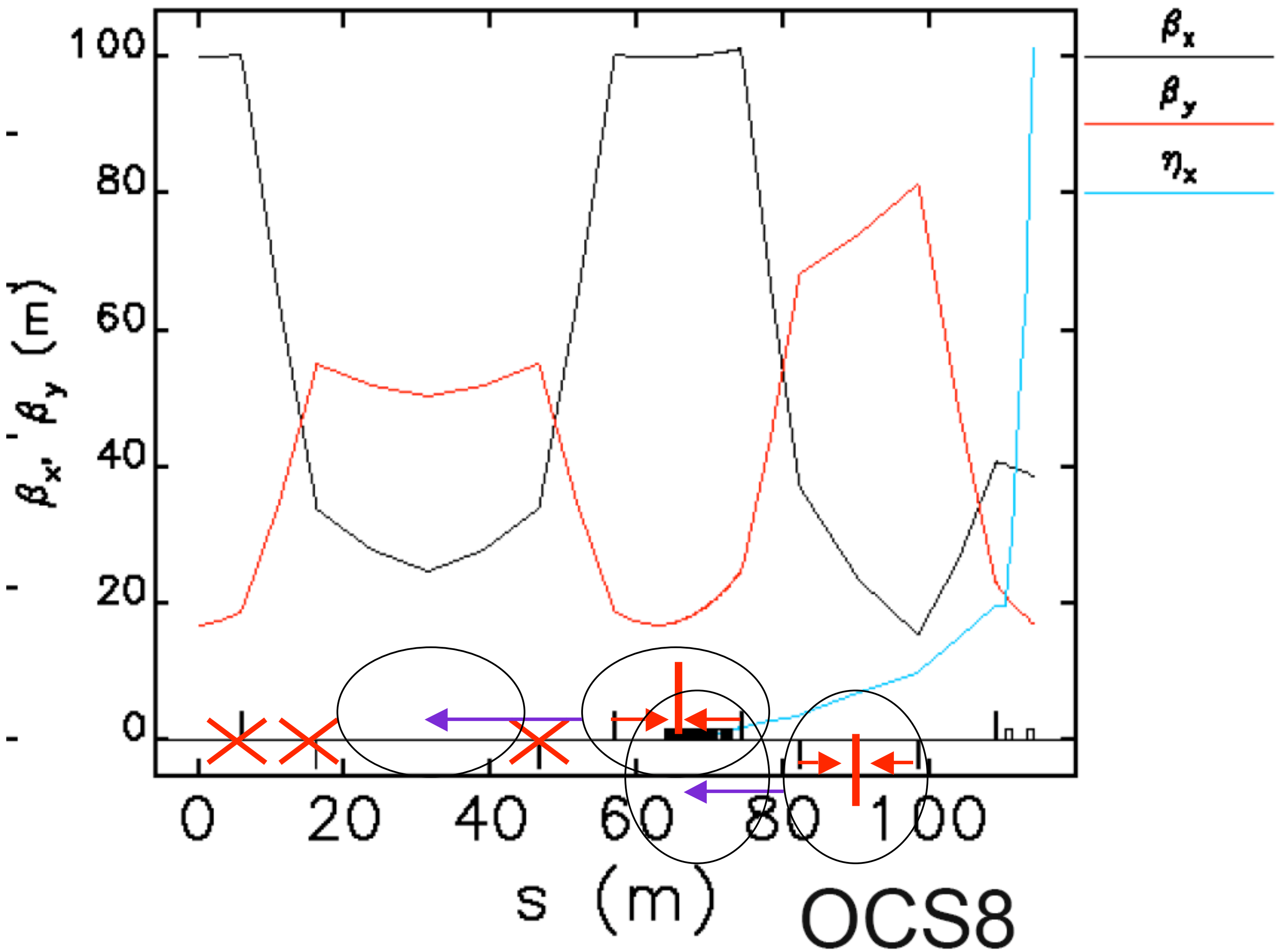
Aperture and Good Field

- **Alesini reported on studies of kicker field non-uniformity and acceptance**
- **My opinion: we must keep this in mind, but far from clear that the electrode geometry is optimized for good field**





Proposal for Discussion



Injection/Extraction Septums

- **RDR version has two pulsed septum magnets (thin and thick) for injection and extraction, similar to APS.**
- **ILC needs long flat top that presents problems**
  - Regulation of flatness, especially for extracted beam
  - Eddy current penetration into stored beam during pulse
- **Lattice isn't very tight, so almost certainly can use DC septums instead, even though they can't be as strong**
- **Should be easier, cheaper, better than pulsed.**
- **Present OCS8 proposal incorporates this**
  - Since septum multipoles tend to be dominated by ends, but proportional to field, longer weaker DC septum units are likely to be better, if there's space for them.

Near-Term Insertion Work

- **Optics and magnet conceptual design for DC septums**
- **Update external injection, extraction lines**
  - Do they belong to the damping ring any more?
- **Revise voltage, apertures, layout of kickers and optics**
  - I'm not sure we're fully optimized
- **Consider adding a kicker upstream of e+ injector**
  - for closed-bump off-axis stacking of e+ from keep-alive source to high intensity during early commissioning
  - Doesn't need to be as strong as on-axis injector
- **Goal is to get this stuff done by end of the year**

History of the Plan(s)

- **I spent some of my sabatical time ('05-'06) on overall ILC kicker and septum issues, as a favor to the magnet tech group, and to BDS group, but not DR focused**
- **Mike Zisman asked me to help organize the Cornell workshop kicker sessions, and I got sucked into S3**
- **Mike Z. and Mark Palmer organized the Americas Regional Team R&D budgets consistent with Cornell**
- **Mike Z. faded away, I had to get back to heavy teaching**
  - Note the underwhelming organization of kicker sessions here
- **The S3 kicker plan is mostly my concept, and hasn't yet been reviewed by the community it affects**
- **EDR plan (proposal-driven) is largely consistent**
- **Flavored by lab priorities more than top-down mgt.**

Cornell Workshop Plan

1. **Inductive Adder Pulser**
2. **DSRD Pulsers (test com'l units, and develop own)**
3. **Collaborate with FID GmbH on pulsers**
4. **Stripline structures**
5. **Beam tests at A0**
6. **Beam tests at ATF**
7. **Beam tests at DAΦNE**
8. **Other pulser technologies (e.g., ferrite shocklines)**
9. **Outside the box (Fourier scheme, RF separator, off-axis injection, slow bump + small fast kick)**

S3 Work Package

ILC Damping Rings R&D Plan

Work Package 3.5.1
Fast Injection/Extraction Kickers

Work Package Coordinator: Thomas Mattison

Potential Investigators

Cornell
Gerry Dugan
Robert Meller
Mark Palmer
David Rubin

FID-GmbH
Vladimir Efanov

FNAL
Marc Ross

KEK
Takashi Natio
Junji Urakawa

LBNL
Stefano de Santis

LLNL
Craig Brooksby
Ed Cook

LNF
David Alesini
Fabio Marcellini

SLAC
Craig Burkhart
Richard Cassel
Anatoly Krasnykh
Ray Larsen

UBC
Tom Mattison

UIUC
George Gollin

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
3.5.1.1	Develop a fast high-power pulser for injection/extraction kickers	Very High
3.5.1.2	Develop physics designs for kicker striplines	High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
3.5.1.1	6.0?	6.0?	6.0?	
3.5.1.2	2.0?	2.0?	2.0?	

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
3.5.1.1	800	800?	800?	
3.5.1.2	200	200?	200?	

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
3.5.1.1	60	60	60	
3.5.1.2	20	20	20	

Facilities

Experimental studies at the ATF have played a vital role in the recent development of kicker technology for the ILC damping rings; work at the ATF will continue to be of great importance as the focus of activities shifts to ATF2 (for studies of issues related to the beam delivery system). Other facilities, such as DAΦNE, and the A0 beamline at FNAL, will also play an important role in development of fast kicker technology.

EDR Work Packages

WP Title	ANL	Cornell	FNAL	SLAC	LBNL	LANL	LLNL	UIUC	UM	CI	DESY	LNF	KEK	IHEP	KNU	Approx Total FTE
Lattice design and acceptance	X	X			X				X			X		X	X	2.6
Orbit, optics and coupling correction	X	X		X	X				X	X		X	X			7.9
Wiggler		X			X											1.9
Instrumentation, diagnostics, controls		X	X		X								X	X		6.9
Impedance & impedance-driven instabs.	X			X	X					X			X	X		3.0
Fast feedback systems				X	X							X				1.5
Electron cloud	X	X	X	X	X	X						X		X	X	8.5
Power systems		X		X												0.3
Other collective effects		X	X	X	X							X		X		1.8
650 MHz RF system		X		X	X											1.2
Magnets and supports					X									X		0.2
Systems integration and availability										X						0.2
Vacuum system				X	X					X		X		X		3.1
Injection and extraction systems		X	X	X	X		X	X				X	X			7.6
Ion effects		X		X	X						X		X	X	X	4.7
Conventional facilities and cryogenics	X		X		X									X		0.2
Global Systems Work Packages																
Survey and alignment	X															0.3
Installation and commissioning plans	X															0.3
Polarisation										X	X					0.3
Approximate Total FTE																52.1

- **Now it's Susanna's turn**

Conclusion

- **Injection/extraction for 3 ns spacing is challenging, not cheap, not yet fully demonstrated, but not obviously implausible**
- **Baseline is FID+DSRD pulsers, vacuum striplines**
  - Probably still need some with offset timing to tweak rise and fall times
- **Lots of R&D ongoing to demonstrate and improve pulsers and striplines**
- **I hope we can reserve lots of kicker contingency space in the insertion optics**
- **We have a(n evolving) plan for further R&D**