Damping Ring Optimization

S. Guiducci

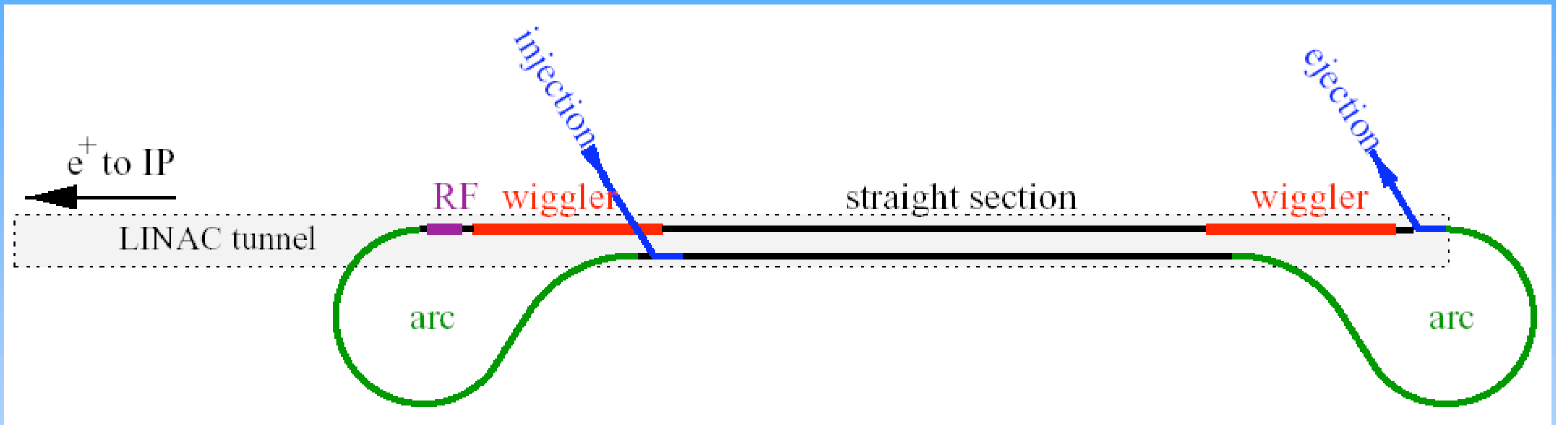
SuperB Workshop

LNF, 16-18 March 2006

ILCDR Nominal Parameters

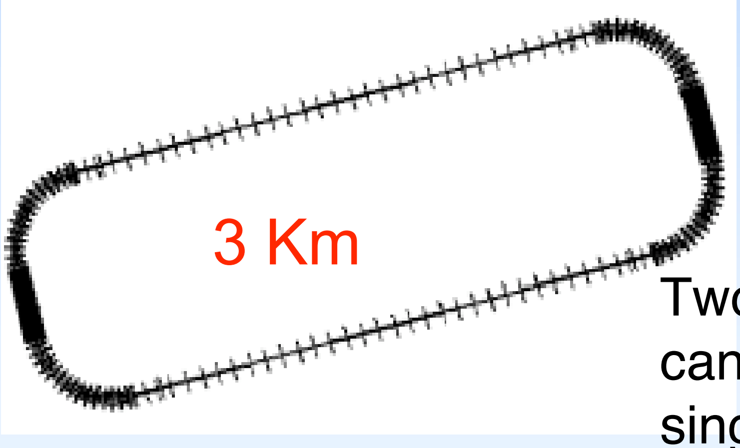
Number of Bunches/train	2820
Bunch charge	$2\ 10^{10}$
Train repetition rate	5 Hz
Injected bunch separation	330 ns
Maximum injected norm. betatron amplitude (e+)	0.09 m-rad
Injected full width energy spread (e+)	1%
injected norm. emittance (e-)	45 μm
Injected full width energy spread (e-)	0.1%
Extracted norm. horizontal emittance	8 μm
Extracted norm. vertical emittance	20 nm
Extracted bunch length	6 mm
Extracted energy spread	$1.4\ 10^{-3}$

Circumference options
from TESLA dogbone 17 Km to 6 & 3 Km

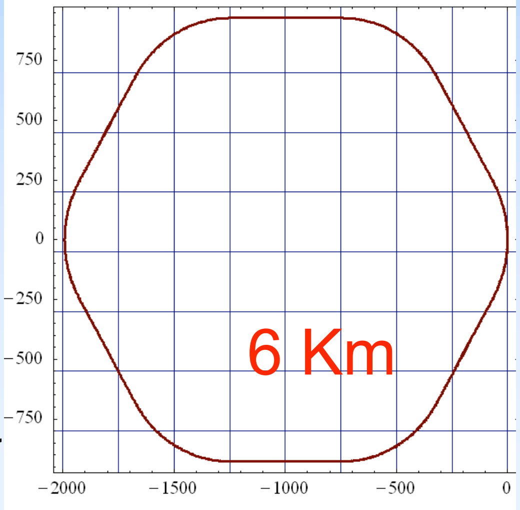


3 or 6 km rings can be built in independent tunnels

“dogbone” straight sections share linac tunnel



Two or more rings can be stacked in a single tunnel



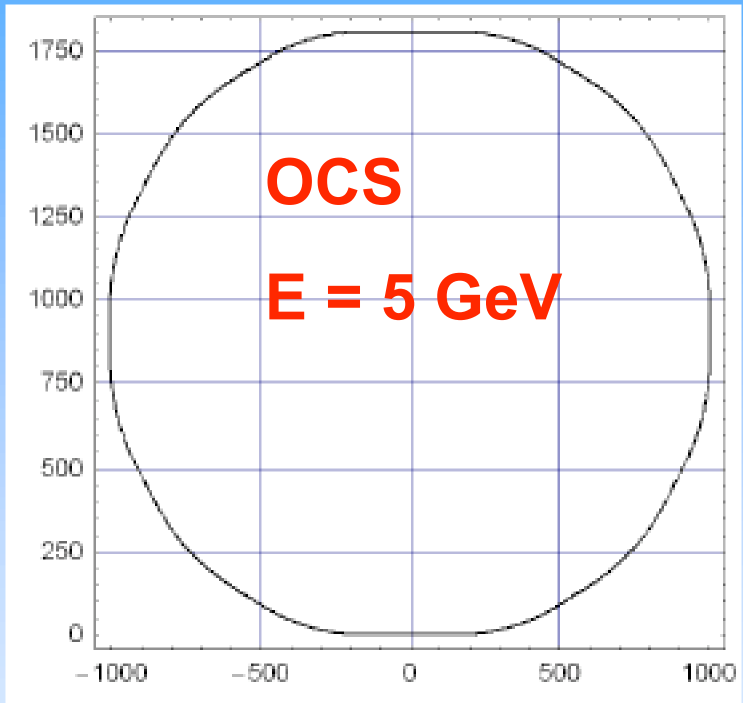
Issues for the circumference choice

- Acceptance
  - achieving a large acceptance is easier in a circular 6 km ring than in a dogbone ring.
- Collective effects
  - Electron-cloud effects make a single 6 km ring unattractive, unless significant progress can be made with mitigation techniques.
  - Space-charge effects will be less problematic in a 6 km than in a 17 km ring
  - The electron ring can consist of a single 6 km ring, assuming that the fill pattern allows a sufficient gap for clearing ions.
- Kickers
  - The injection/extraction kickers are more difficult in a shorter ring. R&D programs are proceeding fast and, it is expected that will demonstrate a solution for a 6 km circumference.

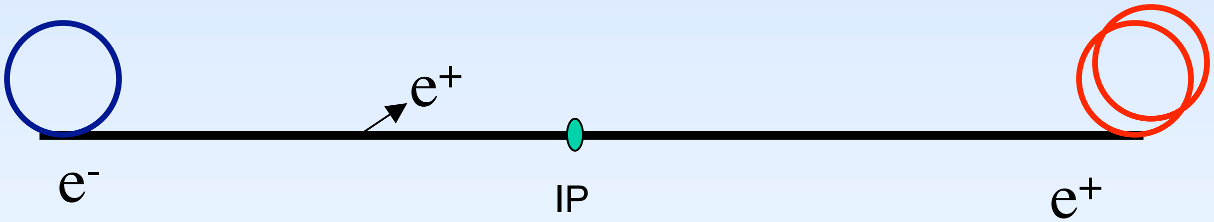
Baseline Configuration

Recommendation

- Positrons: **two** (roughly circular) rings of **~ 6 km** circumference
- Electrons: **one** ~6 km ring



- 2 tunnels at both linac ends
- e^+ rings vertically stacked in 1 tunnel



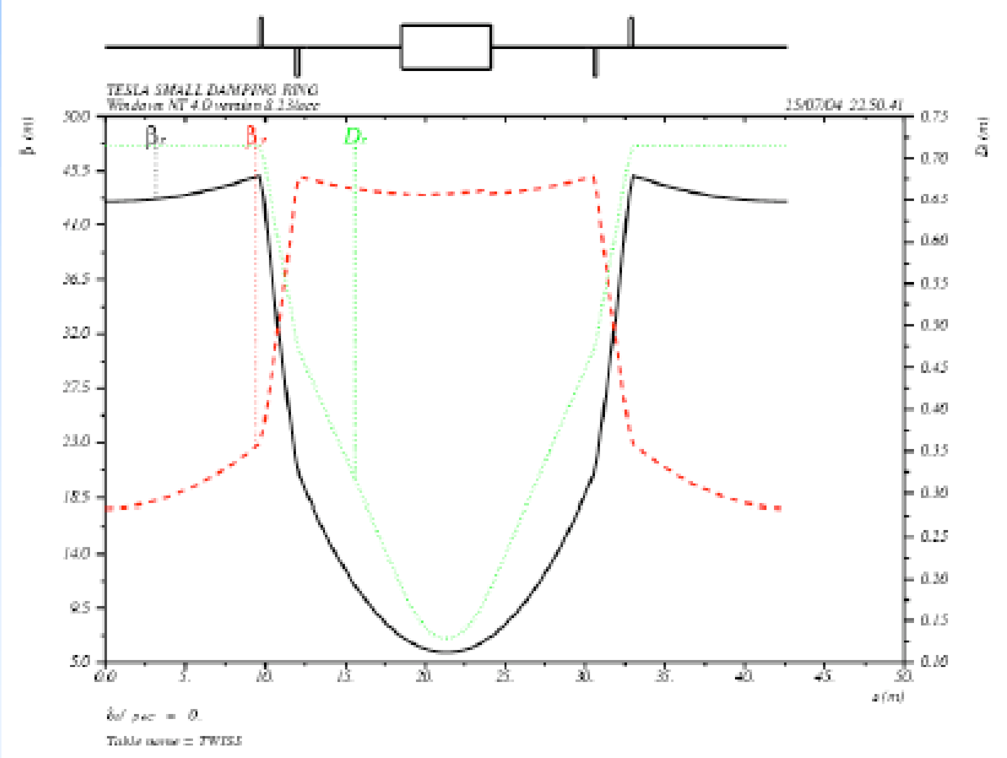
Lattice Description

- The ring is designed with 10-fold symmetry and incorporates 10 long straight sections.
- 8 of the straight sections contain wigglers and RF cavities, the other 2 can accommodate tune adjustment sections, and injection/extraction lines.

•arc cells

-TME cells 40 m long

-72 dipoles 5.6 m long with rather low , 0.2 T, bending field.



DR Parameters

Energy (GeV)	5
Circumference (m)	6114
Bunch number	2820
N particles/bunch	$2x10^{-10}$
Damping time (ms)	22
Emittance $\gamma\varepsilon_x$ (nm)	5600
Emittance $\gamma\varepsilon_x$ (nm)	20
Momentum compaction	$1.62x10^{-4}$
Energy loss/turn (MeV)	9.3
Energy spread	$1.29x10^{-3}$
Bunch length (mm)	6.0
RF Voltage (MV)	19.3
RF frequency (MHz)	650

Low Charge Parameter Set

- It has been proposed to reduce disruption at IP and background in the detector

N	2820	$\Rightarrow$	5640
Charge/bunch	2e10	$\Rightarrow$	1e10
Bunch distance (ns)	6.2	$\Rightarrow$	3.1

Due to the short bunch distance it is more challanging for:

- Kickers

- e-cloud

- Fast ion

Low Charge Parameter Set: kickers

- A rise/fall time less than 3ns has been demonstrated at KEK.
- The stripline length has to be ~0.3 m (instead of 0.6 m for 6ns) ⇒ the kicker angle is halved
- The number of kickers needed to achieve the required angle is doubled
- The kicker repetition frequency is doubled: 6 MHz instead of 3 MHz

Damping time and Emittance

$\tau = 2T_0E/\ U_{0\ ;}$ $\qquad$ $U_0 \propto E^2 \int B^2\ dl$

$U_0 = U_a + U_w;$ $\qquad$ $F_w = U_w/U_a$

$\varepsilon_a \propto E^3\ \text{flat}\ \theta_{bend}{}^3;$ $\qquad$ $\varepsilon_w \propto B_{wig}{}^3\ \lambda^2 <\beta>$

$$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w\ F_w/(1+F_w) \approx \varepsilon_a/F_w\ ; \quad F_w >> 1$$

$$\tau \propto T_0/(E \int B^2 ds)\ ; \quad \varepsilon \propto E/\int B^2 ds$$

Increasing $\int B^2 ds$ wigglers allows to reduce both damping times and beam emittance at the same time

Radiated energy needed to get a given Damping time

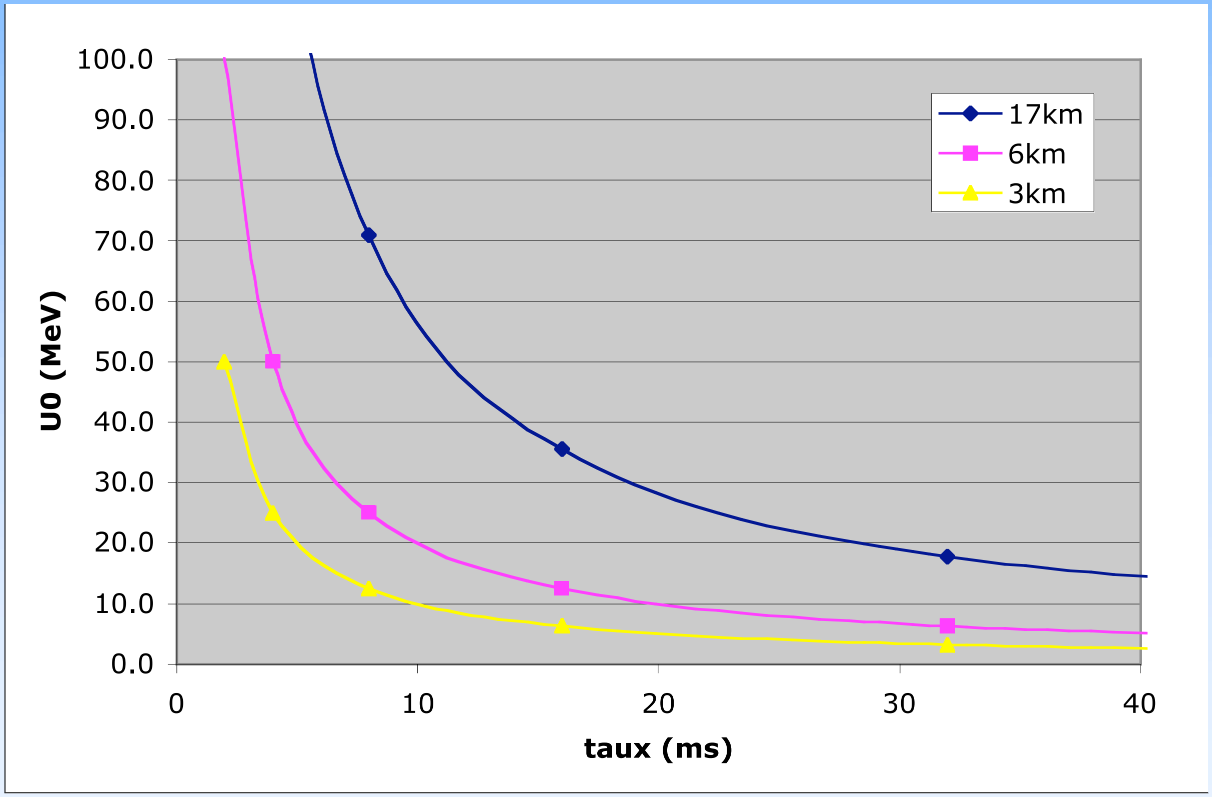
$\tau = 2T_0 E / U_0$

$U_0 = C_q / 2\pi \, E^4 \int 1/\rho^2 \, dl$

$C_q = 88.5e\text{-}5 \text{ Gev-3m}$

$U_0 \propto E^2 \int B^2 \, dl$

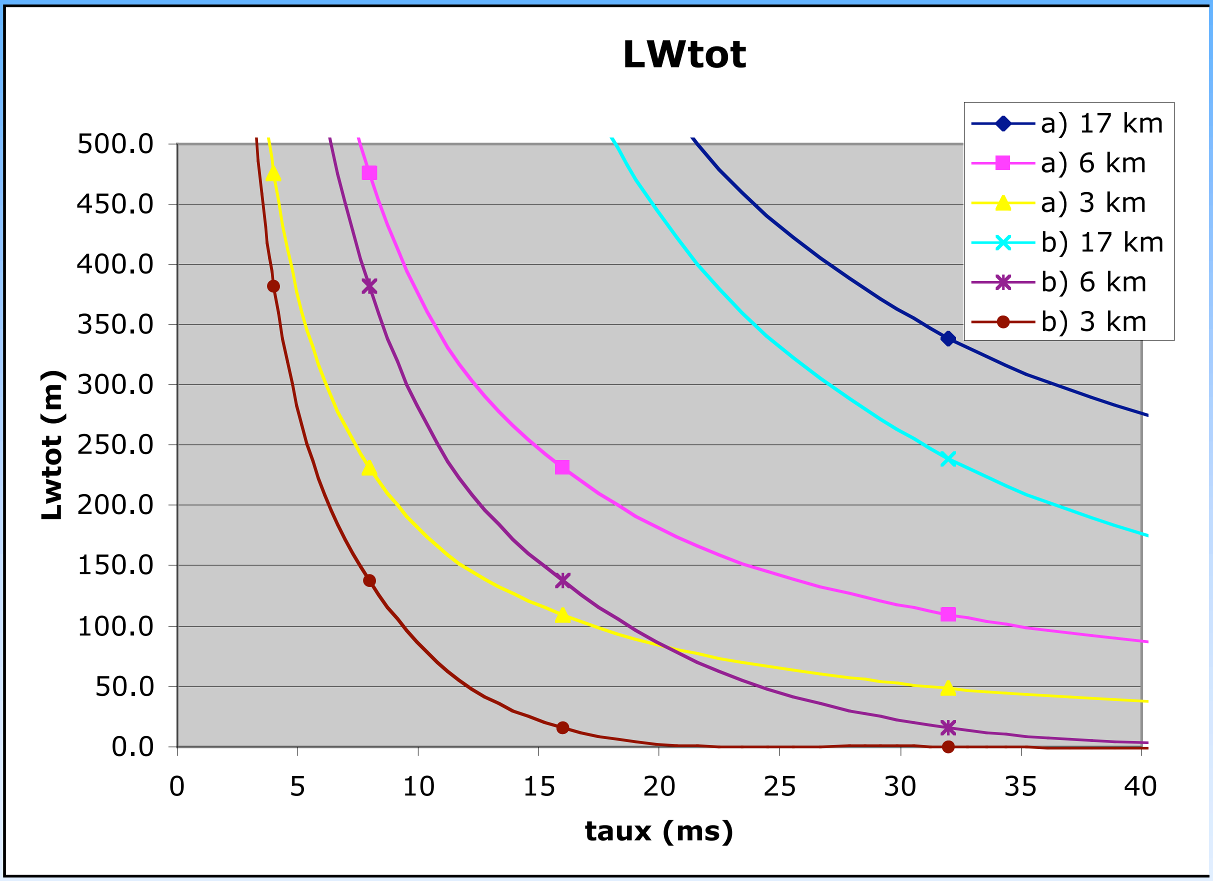
$\tau \propto T_0 / (E \int B^2 \, dl)$



U_0 (MeV)

	τ=28 ms	τ=14 ms
17 km	20.3	40.5
6 km	7.1	14.3
3 km	3.6	7.1

Wiggler length needed to get a given Damping time



L_W (m) - B_{arc} = 0.2

	τ=28 ms	τ=14 ms
17 km	388	783
6 km	127	266
3 km	57	127

L_W (m) - B_{arc} = B_{wig}

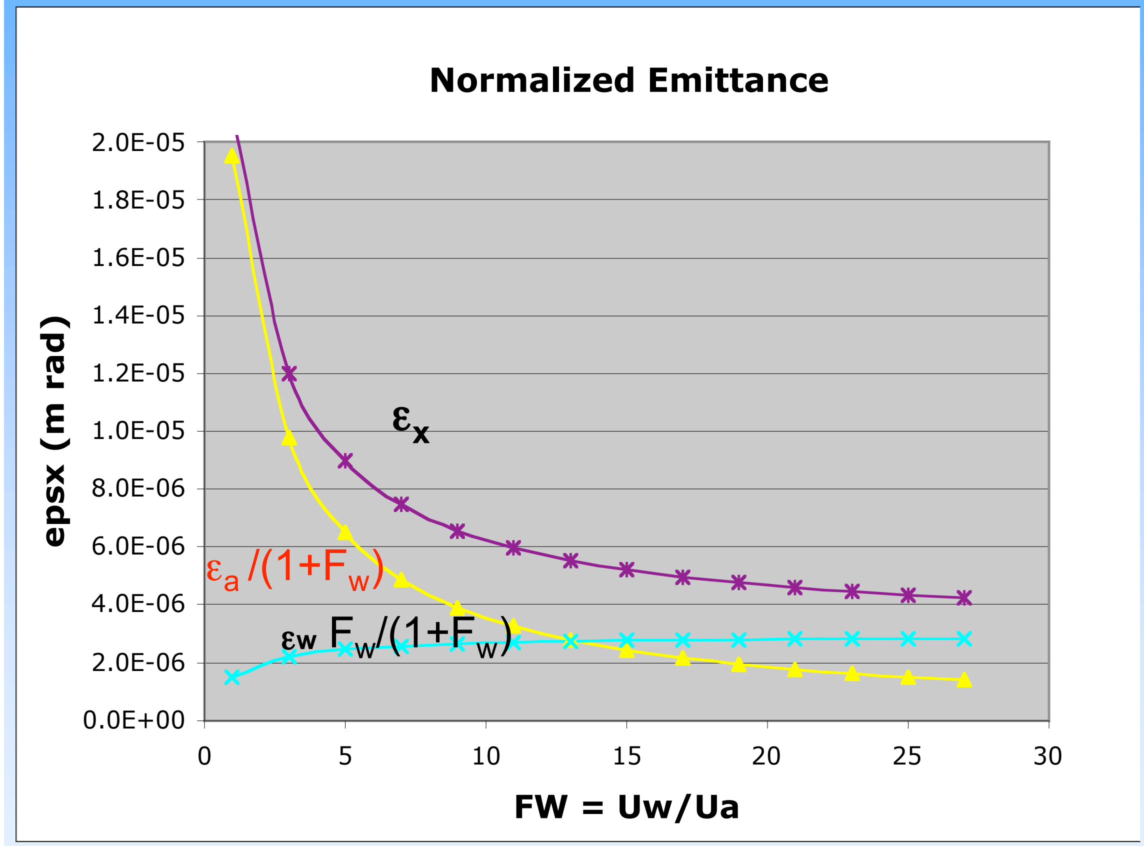
	τ=28 ms	τ=14 ms
17 km	288	684
6 km	32.8	172
3 km	0	32.8

a) B_{arc} = 0.2 T => low field to reduce emittance

b) B_{arc} = B_{wig} = 1.65T (100 m shorter wiggler)

Normalized Emittance

$$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w F_w/(1+F_w)$$



$\varepsilon_a \propto E^3$ flat $\theta_{bend}^{\,3}$

$\varepsilon_w \propto B_{wig}^{\,3} \lambda^2 <\beta>$

$F_w = U_w/U_a$

F_w	13
τ_x (ms)	22
ε_a (m)	3.9e05
$\varepsilon_a/(1+F_w)$ (m)	2.8e06
$\varepsilon_w F_w/(1+F_w)$ (m)	2.7e-6
ε_x (m)	5.5e-6

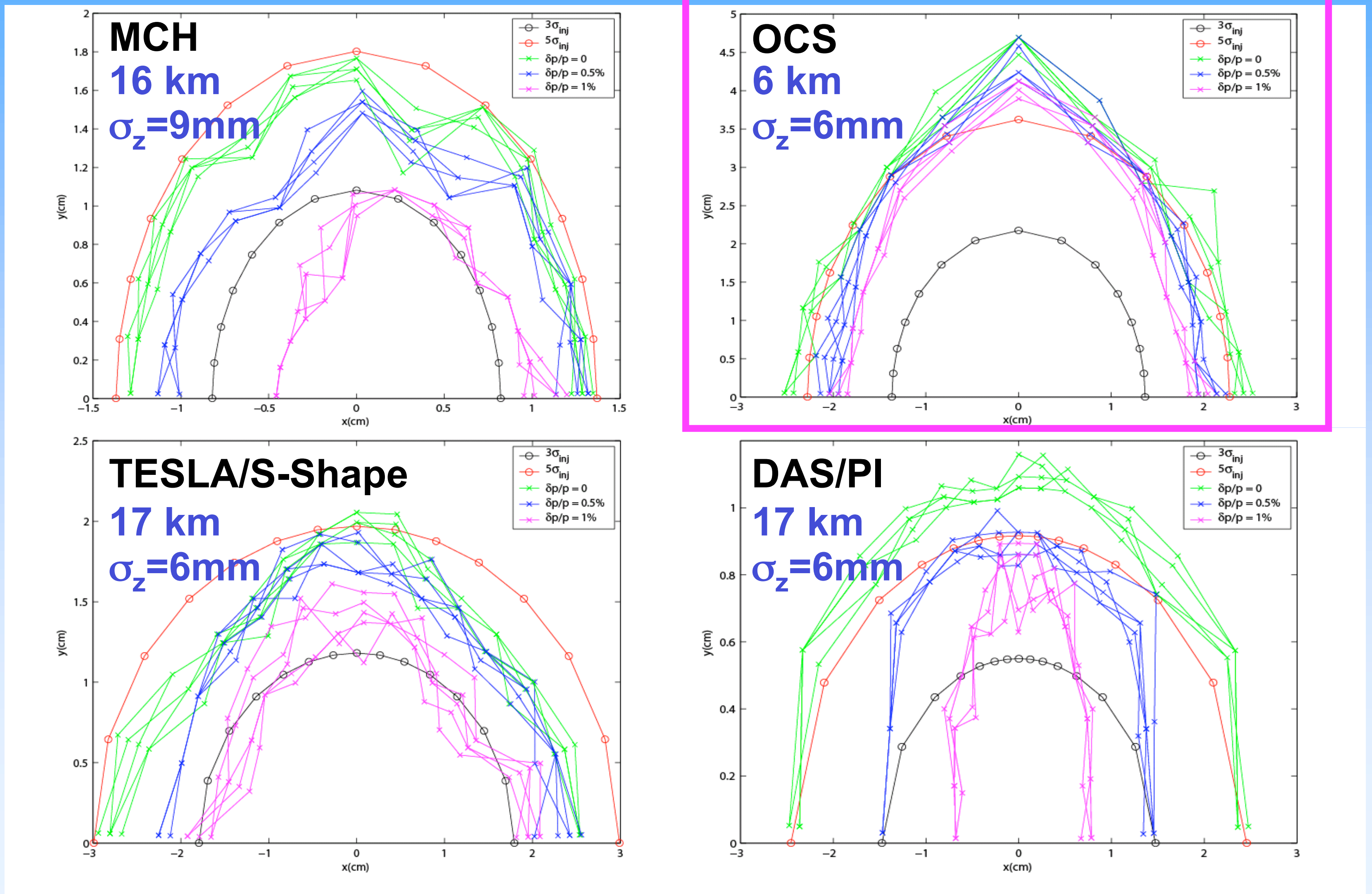
ILC DR Issues

- BD issues - single particle
  - Acceptance
  - Low emittance tuning
- BD issues - collective
  - e-cloud instability
  - Fast ion
  - Other instabilities (microwave, IBS,…)
- Technical issues
  - Kickers
  - Wigglers

ACCEPTANCE

A large acceptance is needed to inject the high emittance positron beam with high efficiency

Dynamic Aperture with Multipole Errors and Single-Mode Wigglers

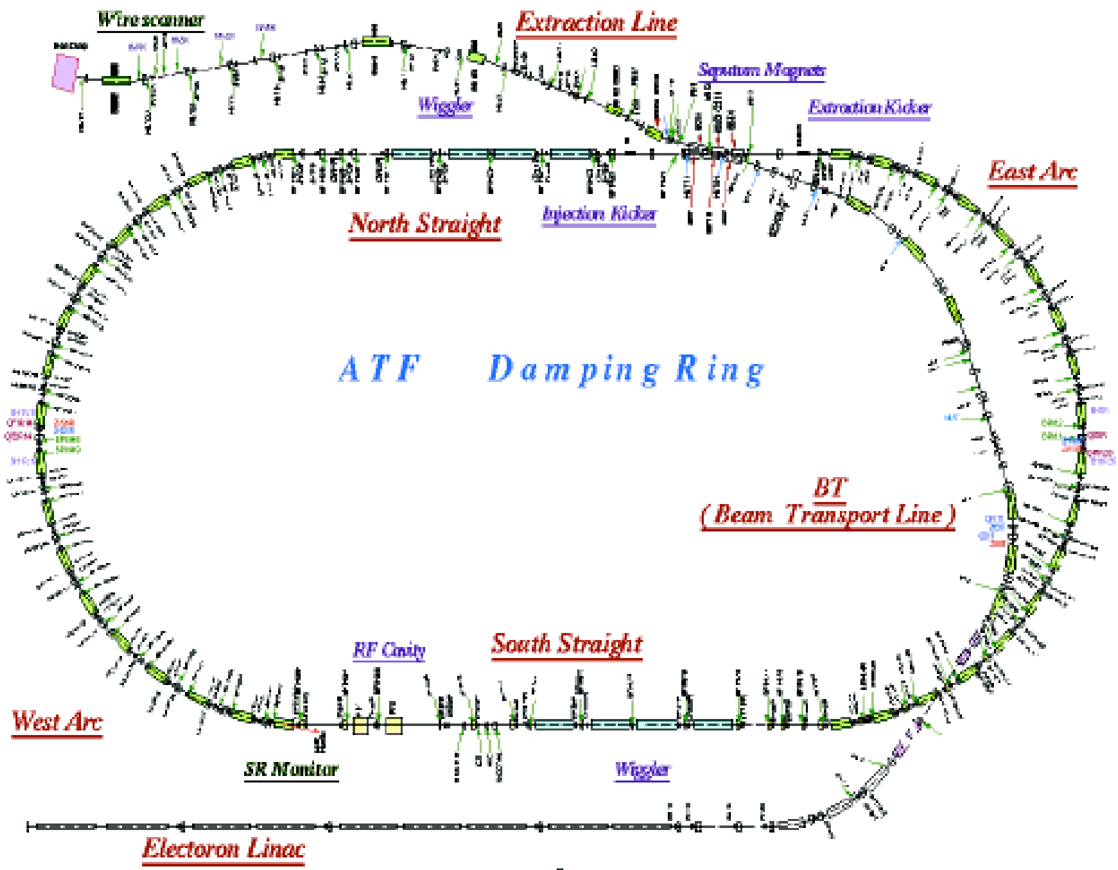


Y. Cai, Y. Ohnishi, I. Reichel, J. Urban, A. Wolski

4 pm vertical emittance demonstrated at ATF - Damping Ring Test Facility (KEK)

- E = 1.28GeV
- N = 2×10^{10} e/bunch
- 1 ~ 20 bunches
- $\varepsilon_{x/y}$ - 1.5nm/4pm
- 20 weeks/year
- 2 weeks/month

DR 2 pm



$\gamma\varepsilon_{x,y}$ smaller than DR requirements!

Develop bpm R&D toward 1-2 pm emittance

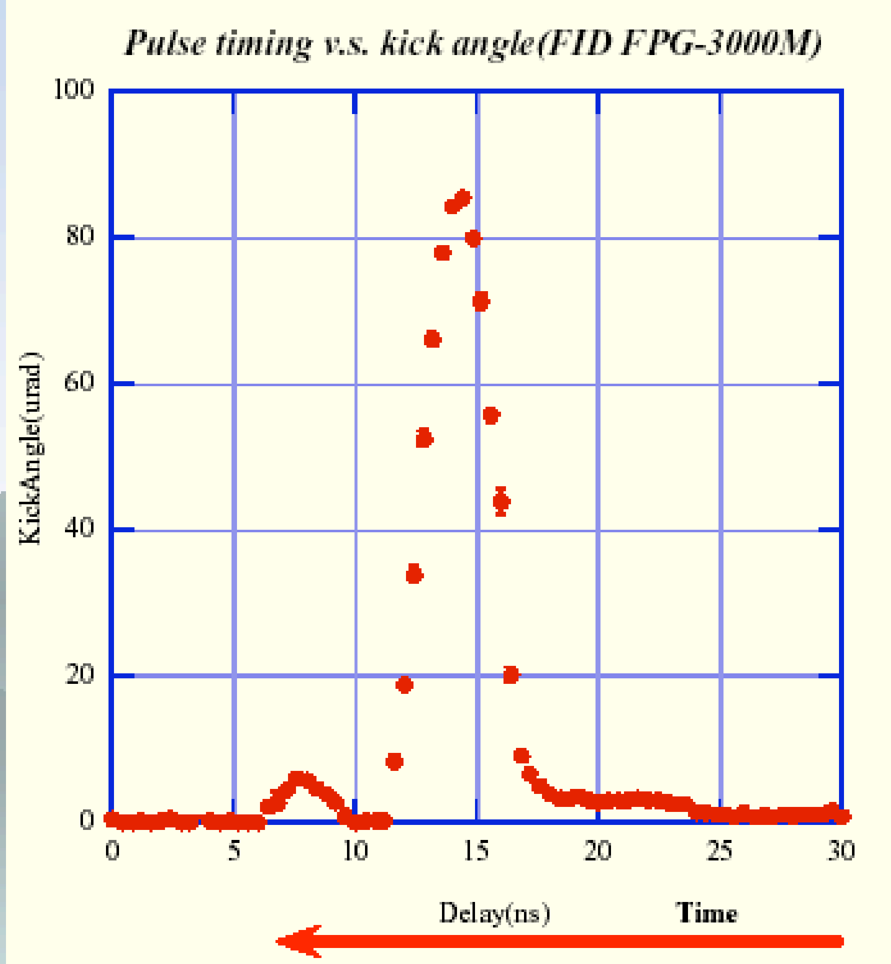
Adequate resolution, low systematic errors

Simple, fast calibration

Strip line kickers and fast pulser

- kickers tested at KEK(1 trasparenza da Junji): 3 ns rise/fall time, 30 cm stripline length, voltage 5KV.
- For the baseline 6ns rise/fall time are needed, the stripline length could be doubled and the required strength would be achieved with ~ 20 kickers.
- By using two power supplies for each kicker the voltage could be 10 KV and only 10 kickers would provide the required strength.
- (more efficient design of the electrode and lower impedence, trasp da Alesini)
- There is a fruitful collaboration between many laboratories on the kickers and pulsers R&D and the performances achieved are rapidly improving.

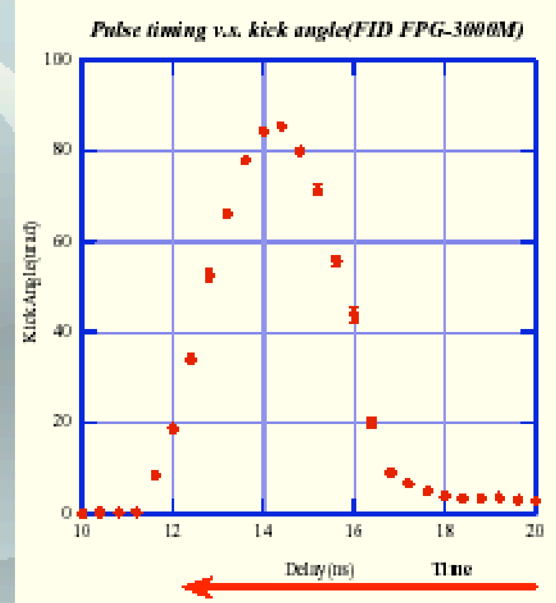
Measurement result of FPG5-3000M



Rise time~3.2ns

Kick angle ~85μrad

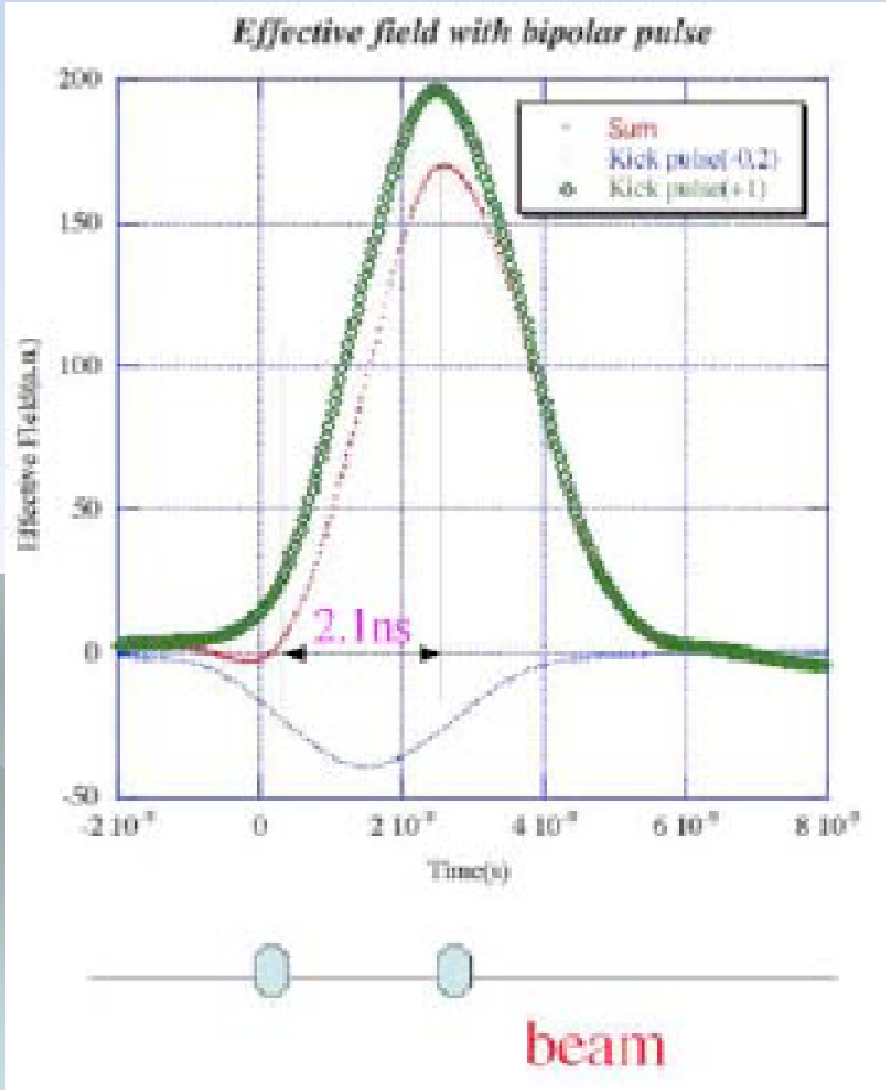
(calc. 94.7μrad)

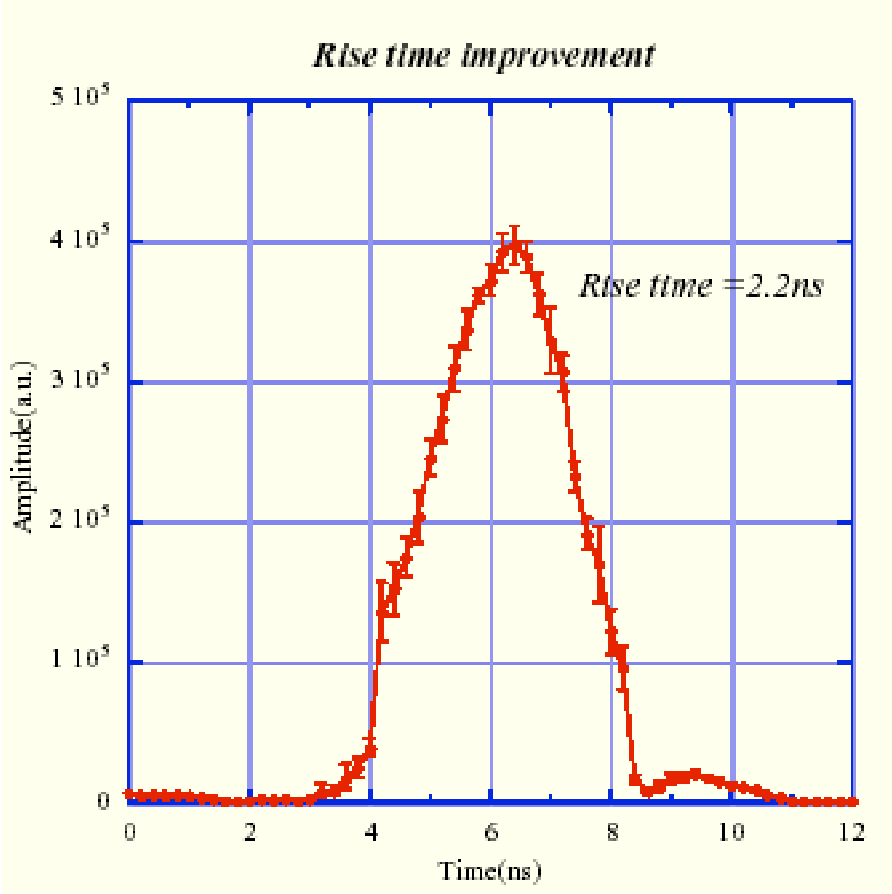


Expanded horizontal scale

J. Urakawa

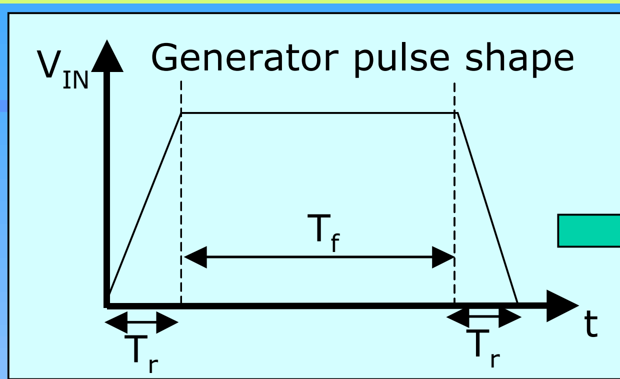
Rise Time improvement by using bipolar pulse

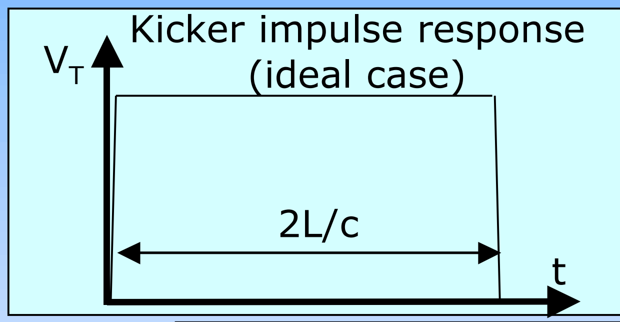


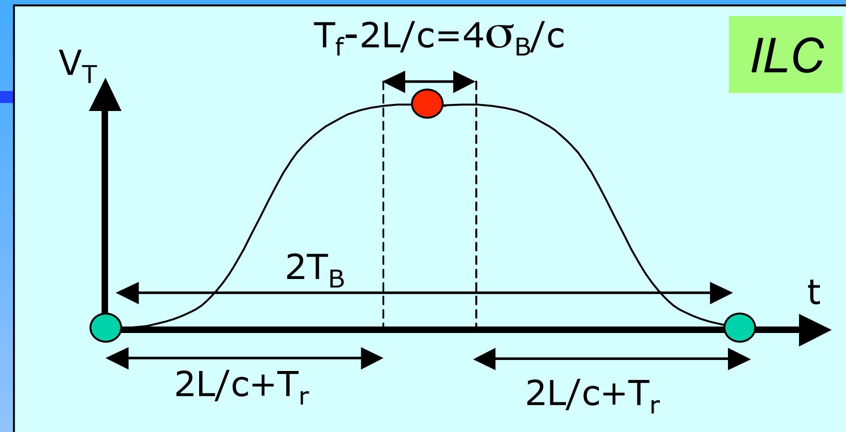


1) General considerations: kicker length and pulse length

L=kicker length
T_r=rise time length
T_f=flat top length
σ_B=bunch length
T_B=bunch spacing

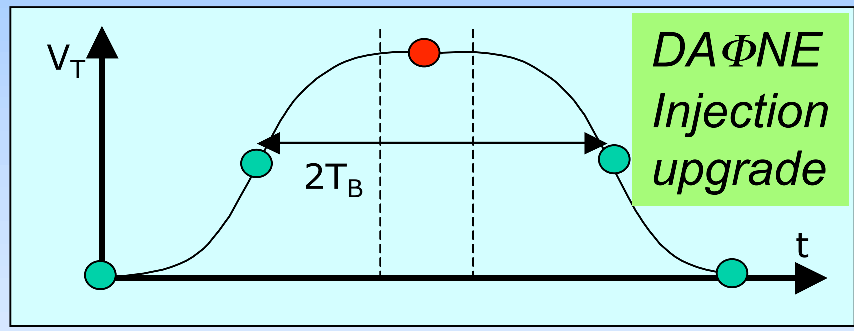






Injected bunch

Stored bunches



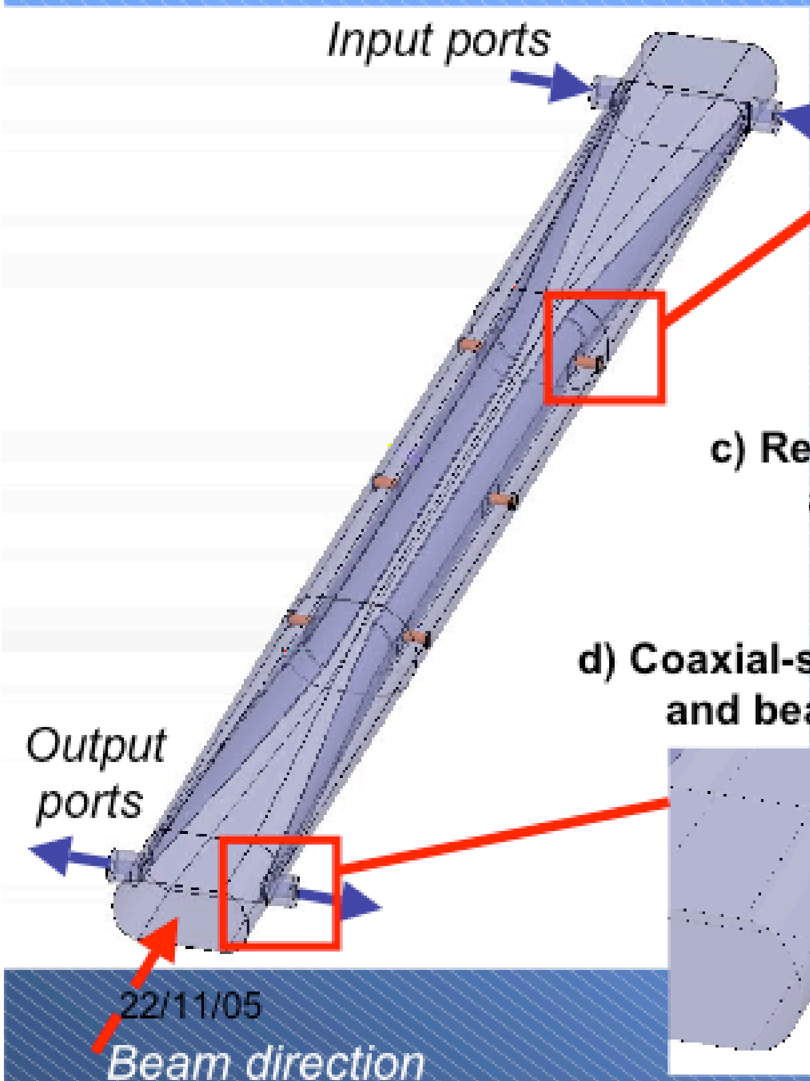
assuming T_r=300ps

	ILC DR	DAΦNE
E [GeV]	5	0.51
T_B [ns]	6.15	2.7
σ_B [mm]	6	35
Defl. [mrad]	0.5	5
L [cm]	87	73
T_f [ns]	5.9	5.3
σ_x [mm] @ septum and kicker	5	2
σ_y [mm] @ septum and kicker	1	1

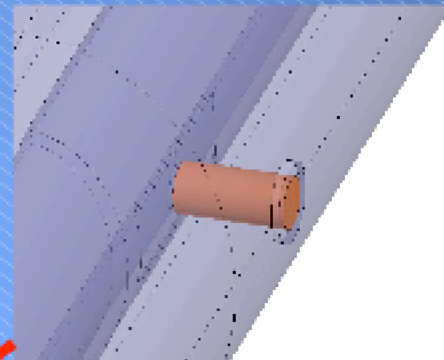
V_T=2.5 MV

D. Alesini, F. Marcellini

3) DAΦNE stripline kickers design: 3D electromagnetic model (1/3)



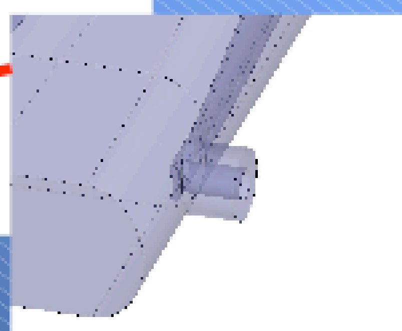
a) Ceramic stand-off effects



b) HOM studies

c) Real deflecting field calculation and frequency response

d) Coaxial-strip transition optimization and beam transfer impedance



Optimization of the whole structure

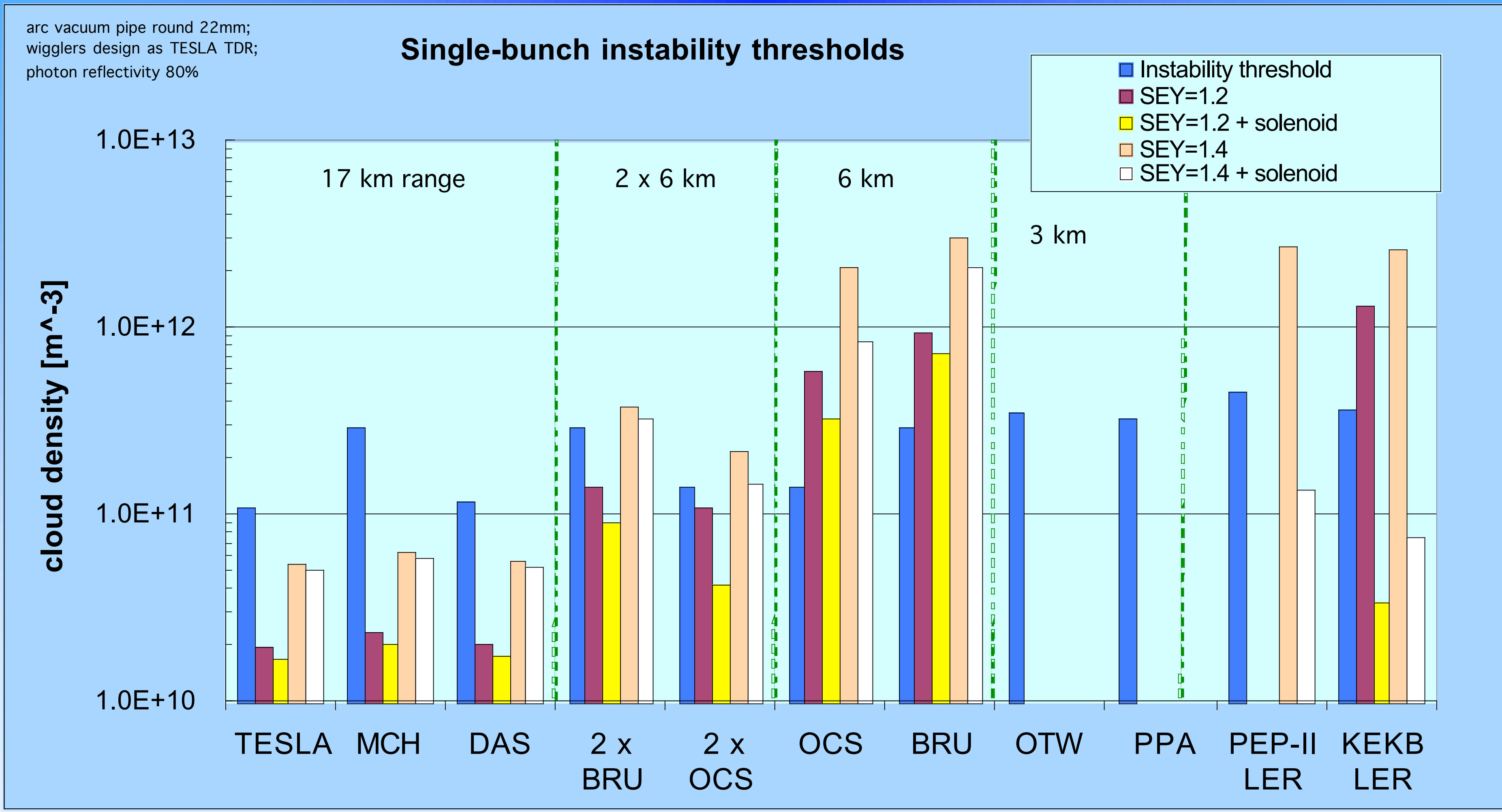
Design completed

D. Alesini, F. Marcellini

Issues Due to Electron Clouds

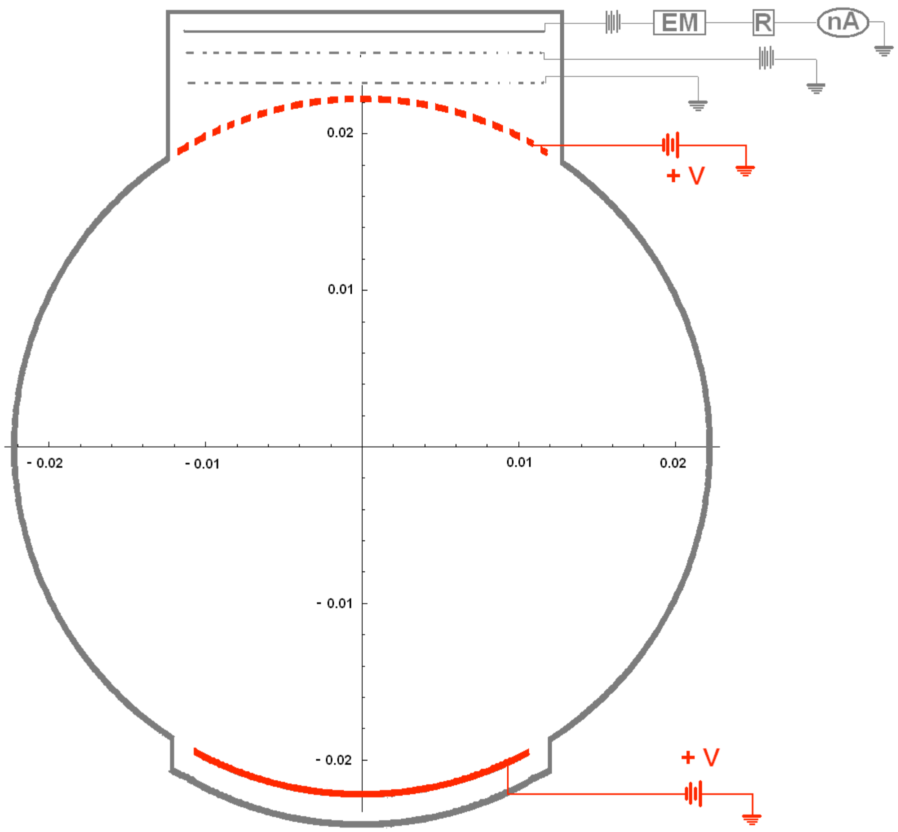
- How electron clouds are generated?
  - Photoelectron build-up
    - Synchrotron radiation
    - Geometry of bending
    - Antechamber
    - Reflectivity
    - Secondary eletrcon yield (SEY)
  - Multipacting of electrons
    - Solenoid wining in straight sections
- What are the effects on the positron beam?
  - Coupled bunch instability
    - Transverse bunch-by-bunch feedback system
  - Single bunch instability
    - Growth of beam size especially in the vertical plane

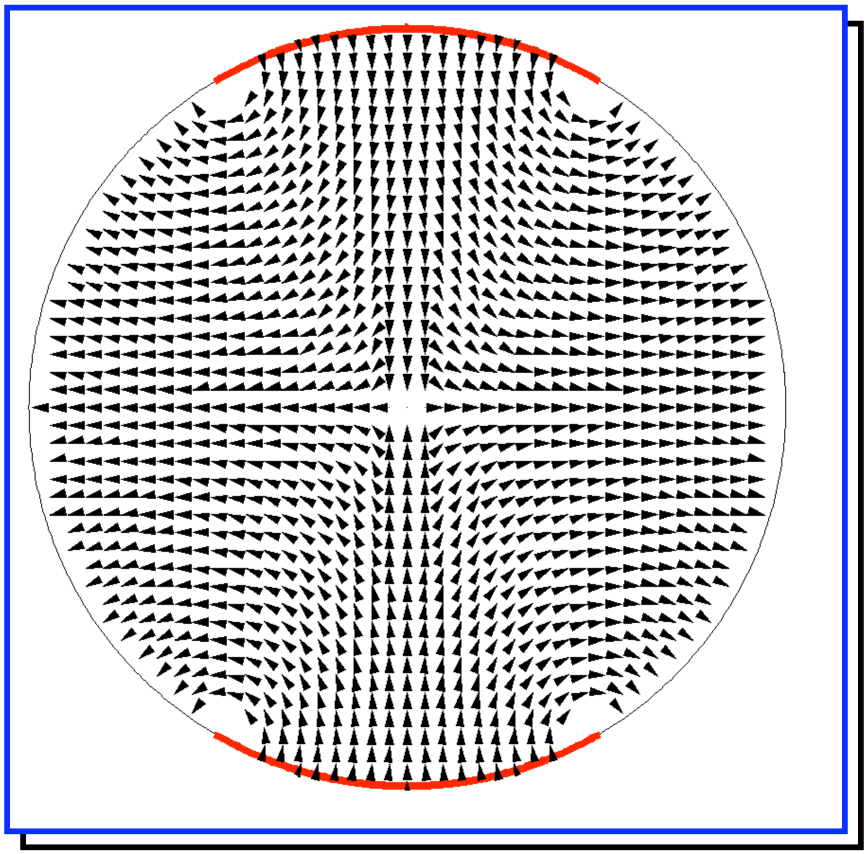
Single bunch instability threshold and simulated electron cloud build-up density



M. Pivi, K. Ohmi, F. Zimmermann, R. Wanzenberg, L. Wang, T. Raubenheimer, C. Vaccarezza, X. Dong

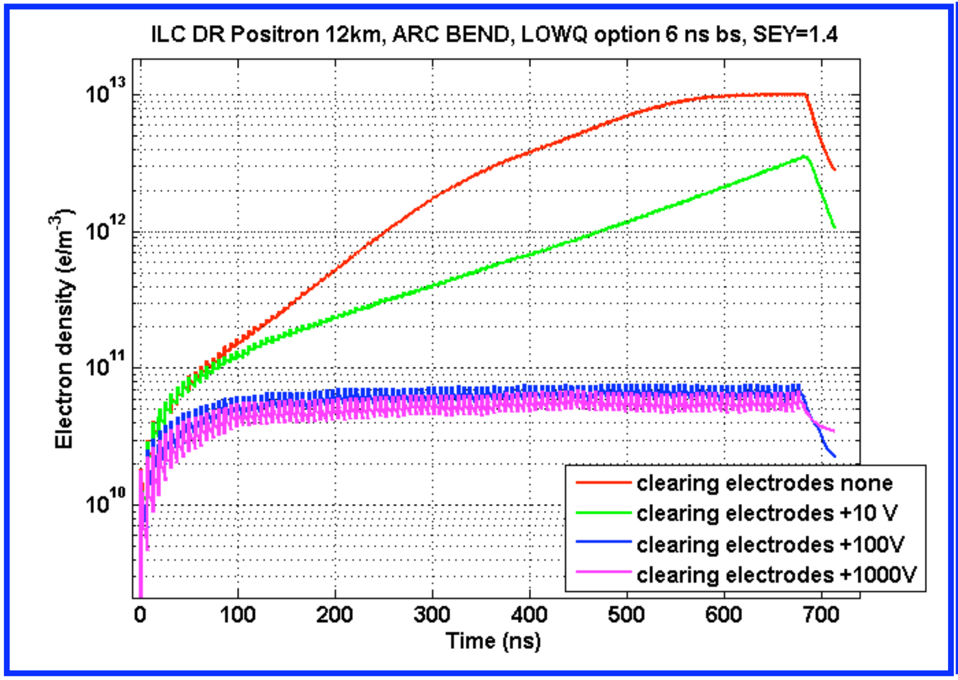
Curved clearing electrodes

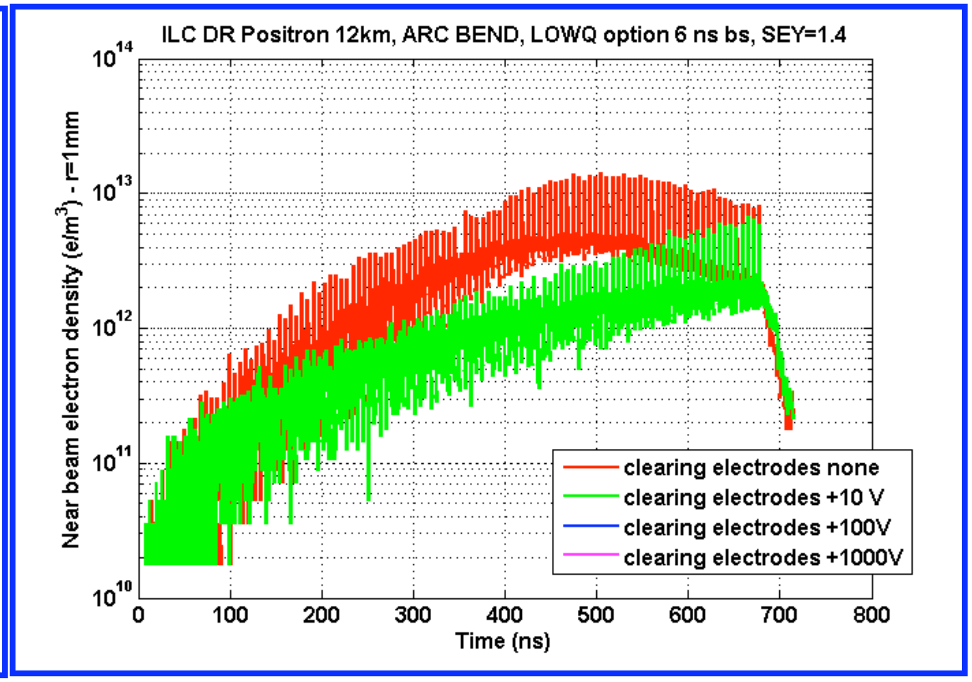




M. Pivi – L. Wang – T. Raubenheimer - P. Raimondi, SLAC

Curved clearing electrodes





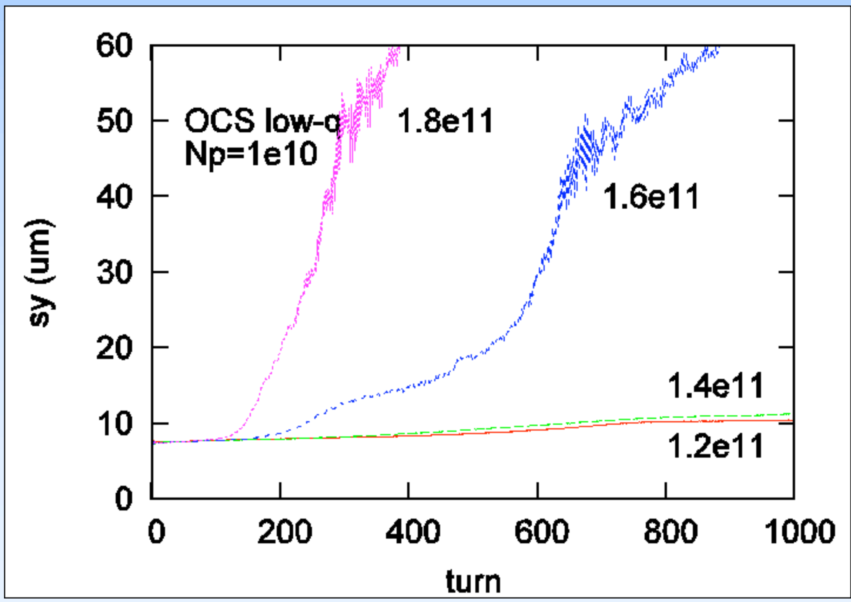
using POSINST

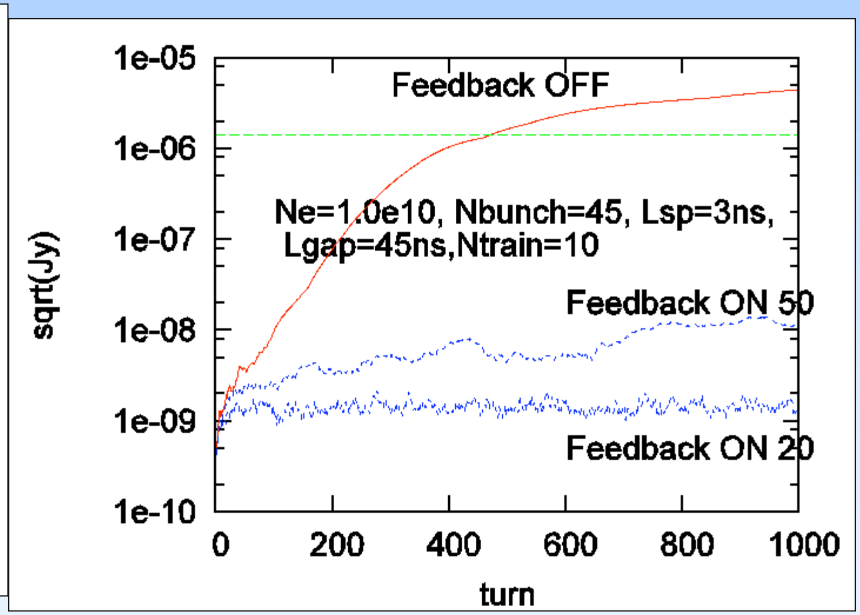
M. Pivi – P. Raimondi, SLAC, Mar 2006

ILC Damping Ring from BCD to CCB-4

Recent results for low Q ($N=1x10^{10}$) K.Ohmi (KEK)

- Ecloud: Threshold of electron cloud, $1.4x10^{11}$ m^{-3}.
- Ion: Feedback system can suppress for 650 MHz (3ns spacing),
- number of bunch in a train 45, and gap between trains 45ns..





ILC Damping Ring from BCD to CCB-5

Recent results for low Q ($N=1\times10^{10}$) L.F. Wang and T. Raubenheimer (SLAC)

Remedy to suppress FII:

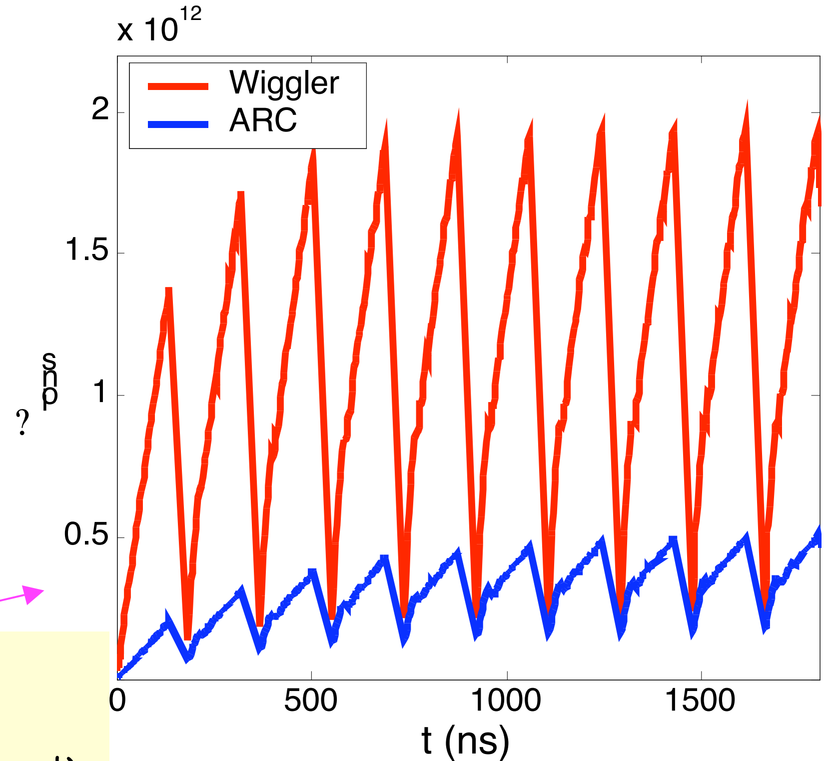
Gaps between bunch trains

Gaps can reduce the ion density by a factor 100 and even more comparing without gaps fill pattern.

Ion reduction factor

$$IRF = \frac{Ion\_cloud_{\min i\_gaps}}{Ion\_cloud_{long\_train}}$$

$$= \frac{1}{N_{train}} \frac{1}{1-\exp(-\tau_{gap}/\tau_{ions})}$$



Low_Q fill pattern
Bunches per minitrain = 45
Gaps between minitrain = 49.23 ns (15 'missing bunches')
Number of bunch train=120
Particles per bunch = 1.04e10
Total number of bunches=5400

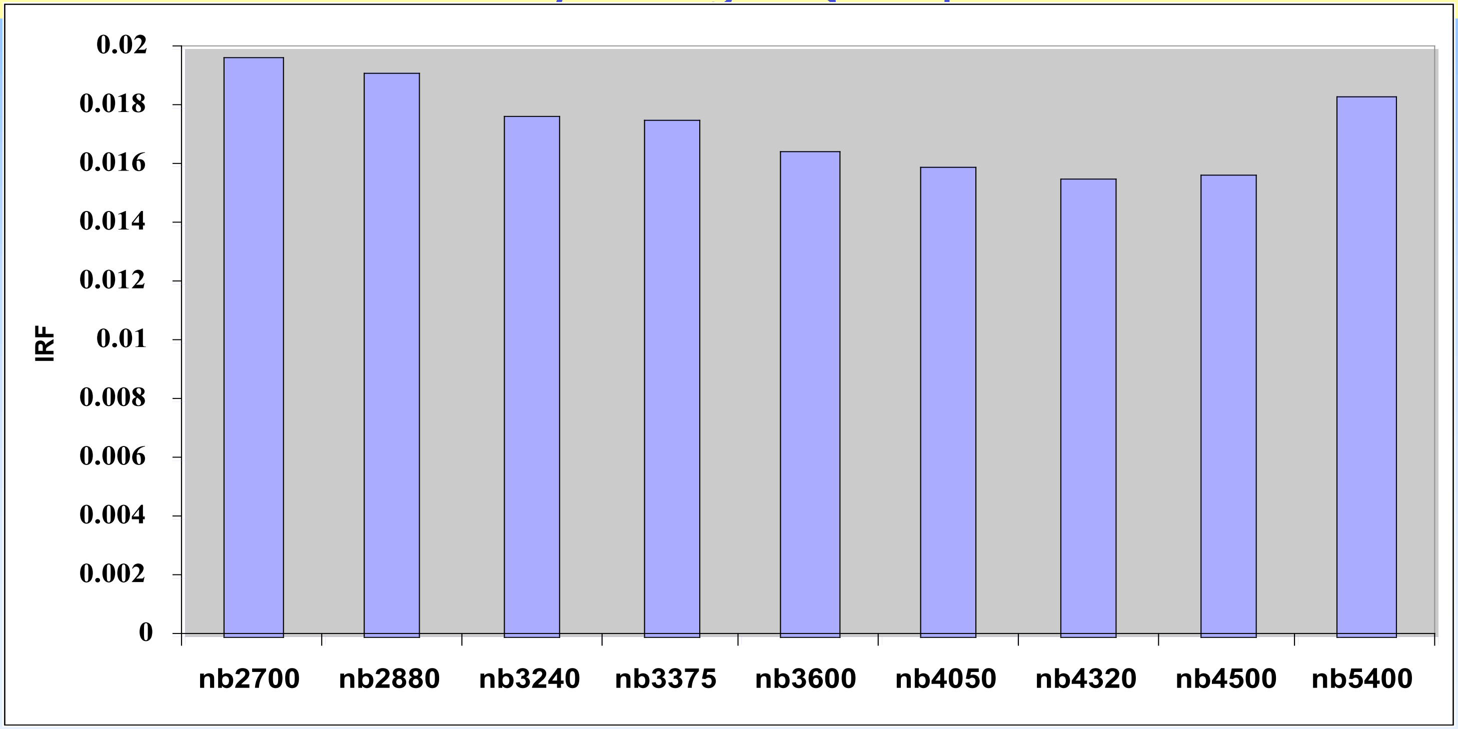
Ion density inside wiggler is reduced by a factor of 100!

ILC Damping Ring from BCD to CCB-6

Recent results for low Q ($N=1\times10^{10}$) L.F. Wang and T. Raubenheimer (SLAC)

Summary of Fill pattern with 650MHz RF

- Optimized Beam Patterns: 4320 bunches, 4500 bunches
- The difference between different fill patters is small: Low-Q has similar ion density as high-Q fill pattern



Ion reduction factor for different fill patterns (ref: http://www.desy.de/~awolski/ILCDR/)

Wigglers

- B_{peak} 1.6 T
- λ_w 0.4 m
- Section length 2.45 m
- Total length 196 m
- Radiated energy 9.3 MeV

- **A high quality field** is needed to achieve the dynamic aperture necessary for good injection efficiency:

- **Physical aperture** A large gap is needed to achieve the necessary acceptance for the large injected positron beam:
  - a full aperture of **at least 32 mm** is highly desirable **for injection efficiency**
  - a full aperture of **at least 46 mm** is highly desirable **to mitigate e-cloud effects**

ILC DR Wiggler Technology

- **Baseline**
- The CESR-c SC wigglers have demonstrated the basic requirements for the ILC damping ring wigglers. They have been chosen since allow a very good field uniformity in a large aperture.
- **Alternatives**
- Hybrid PM wigglers have the advantage that do not require power supplies, cabling, cooling and criogenics. Design with acceptable costs for hybrid wigglers need to be developed, that meet specifications for aperture and field quality.

SuperB: Flat case in multiturn regime

Energy (GeV)	4 - 7	5
Circumference (m)	3000	6114
Bunch number	5000	2820
N particles/bunch	$2x10^{10}$	$2x10^{10}$
Damping time (ms)	10	22
Emittance $\gamma\varepsilon_x$ (nm)	4000	5600
Emittance $\gamma\varepsilon_x$ (nm)	20	20
Bunch length (mm)	4.0	6

Energy

- ILC 5 GeV SuperB 4 - 7 GeV
- Lower energy increases risk for collective effects
- Higher energy makes more difficult to tune for low emittance
- To get the same damping time at lower energy more wigglers and less RF power are needed

$\tau \propto T_0/(E \int B^2\, dl)$

$\varepsilon \propto E/\int B^2 ds$

$U_0 \propto E^2 \int B^2\, dl$

E (GeV)	5	4	7
L_{wig} (m)	160	200	114
$\gamma\varepsilon_x$ (μm)	8	5.1	15.7
U_0 (MeV)	9.3	7.4	13

Conclusion

- Baseline Configuration established for ILC DR
- Reference Design and cost estimate in progress
- R&D on main issues is going on at a global level
- Superb ring very similar, can take advantage of ILC R&D and design work

ATF
Accelerator Test Facility