超低エミッタンスビーム の生成と制御

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Introduction

ATF/ATF2 and ILC

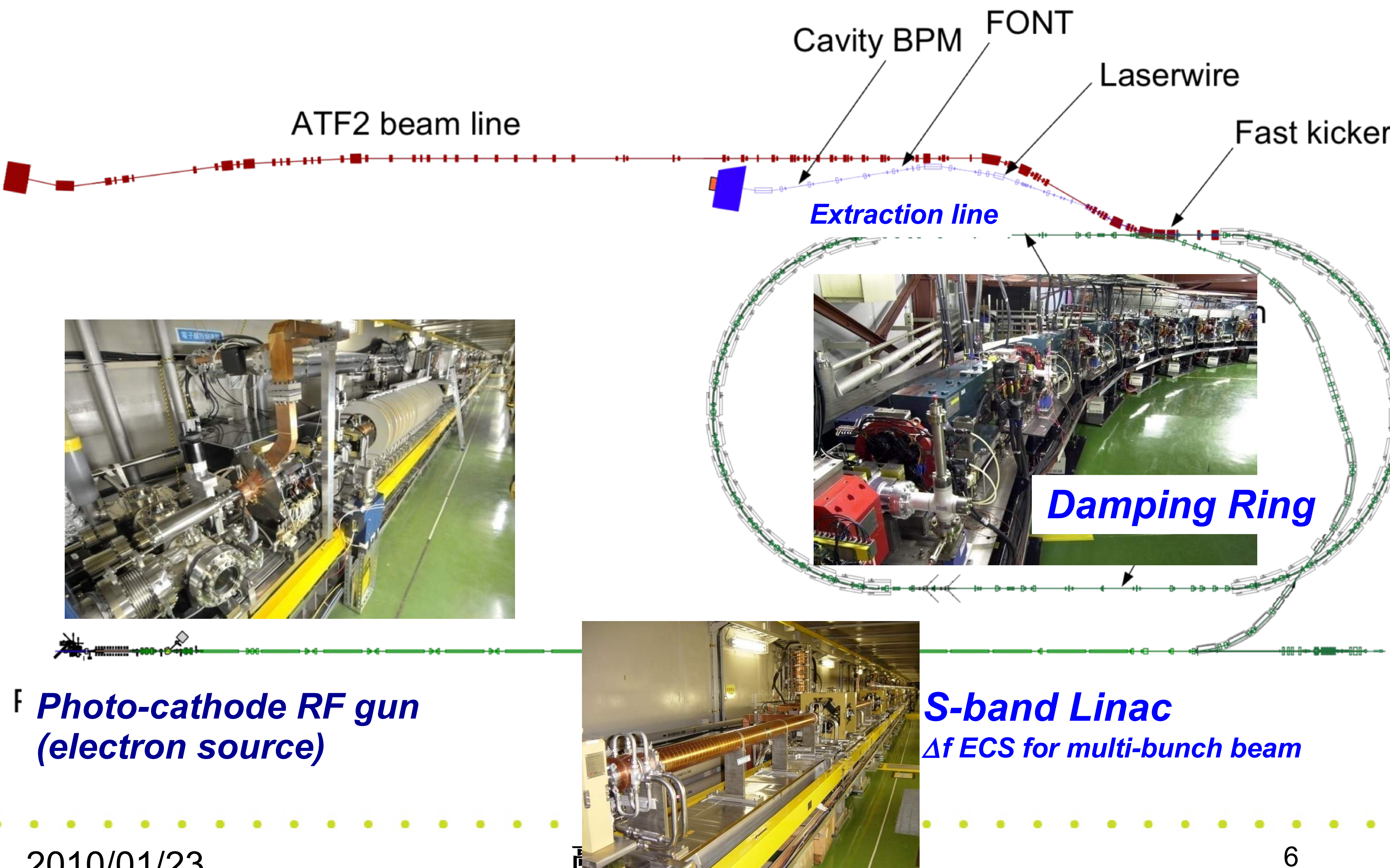
- To achieve the enough luminosity in LC
  - **Generate extremely low-emittance (polarized) beam**
  - **Accelerate it without any beam quality degradation.**
  - **Focus down to adequate beam size and precise control the collision**
- ATF/ATF2 is a test facility to demonstrate the key technologies for LC
  - **Extremely low-emittance beam (ATF)**
  - **Focus system (ATF2)**
  - **Precise beam control and diagnostic techniques (ATF/ATF2)**

Milestone

	Conventional	FFTB	ATF/ATF2 Design	ATF/ATF2 Achieved	ILC	unit
$\gamma\varepsilon_y$	>10	2.0	0.03	0.03	0.04	μm
BPM resolution	>1000	<1000	2	9	2	nm
Beam size	>1000	70	34	?	5	nm
Position jitter	>100	10>?	2	?	2	nm

- Normalized emittance ($\gamma\varepsilon_y$) is already achieved.
- BPM resolution is close to the target.
- Beam size and position jitter at IP should be demonstrated in ATF2.
- ATF2 can prove the reliable collision in ILC except the geometrical beam size, which is just scale as the beam energy.

ATF/ATF2 layout



ATF achievements

ATF

- Generate the extremely low emittance beam
  - Generate the electron bunches with a moderate emittance and required bunch intensity.
  - Inject the beam into DR and stored it.
  - During the storage, the beam emittance is damped by iterative process of synchrotron radiation and re-acceleration (radiation damping).
- Provide the damped beam to ATF2 stably and reliably.

	ATF	ILC	Unit
Bunch Intensity	1 – 4.8	3.2	nC
# of bunches	1-60	2625	
Bunch spacing	2.8	6.15 (369)	ns
Beam energy (DR)	1.3	5	GeV
γ Ex	4.3-5.1	10	mm.mrad
γ Ey	0.03	0.04	mm.mrad

ATF International Collaboration

CERN
DESY
IN2P3
- LAL
- LAPP
- LLR

John Adams Inst.
- Oxford Univ.
- Royal Holloway Univ.

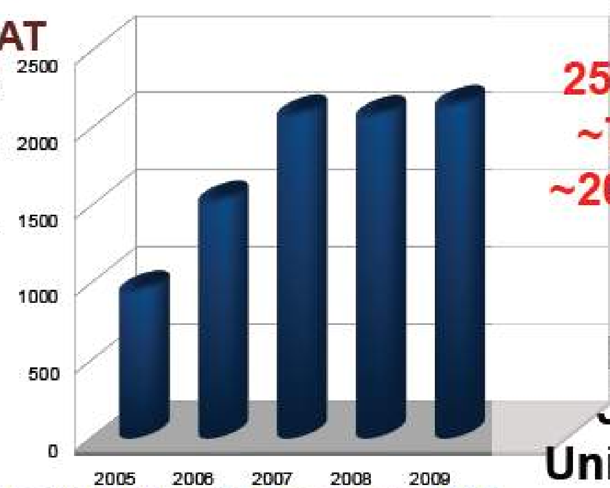
Cockcroft Inst.
- STFC, Daresbury
- Univ. of Manchester
- Univ. of Liverpool

University College London
INFN, Frascati
IFIC-CSIC/UV
Tomsk Polytechnic Univ.

KEK
Waseda U.
Nagoya U.
Tokyo U.
Kyoto U.
Tohoku Univ.
Hiroshima U.
IHEP
PAL
KNU
RRCAT

SLAC
LBNL
FNAL
Cornell Univ.
LLNL
BNL
Notre Dome Univ.

Oversea Collaborators visiting ATF (JFY)



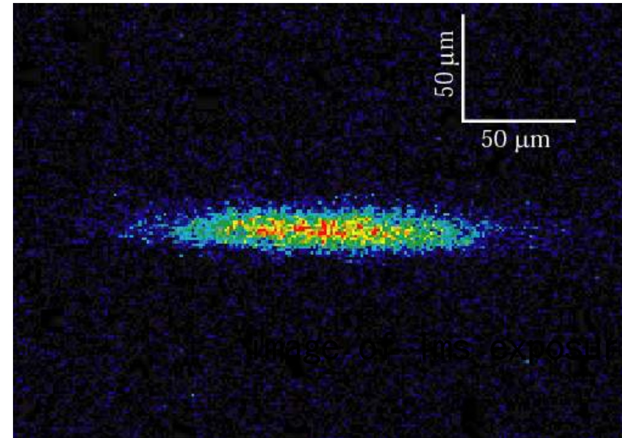
N. Terunuma, KEK LC Weekly Meting, 21 December, 2009

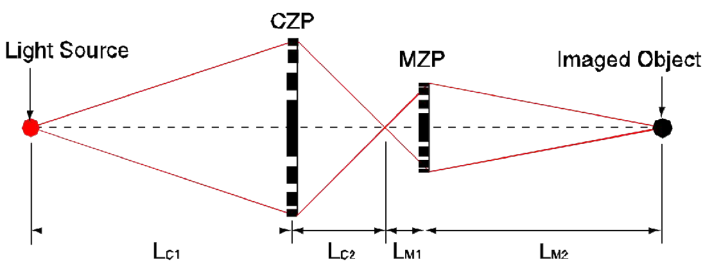
Oversea
25 Institutes, ~70 people, ~2000 people-days
+
KEK and Japanese Universities(6)

XSR beam-size monitor
（東大物性研, KEK）

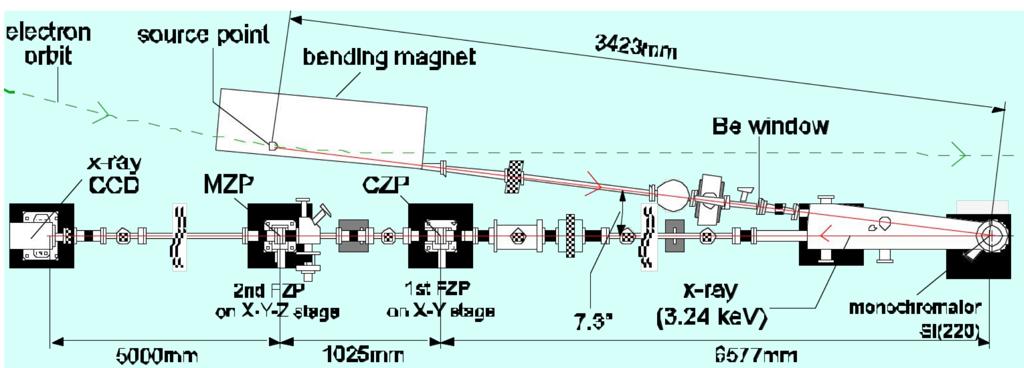
X-Ray Telescope using Zone Plate at 3.2KeV
magnification : 20

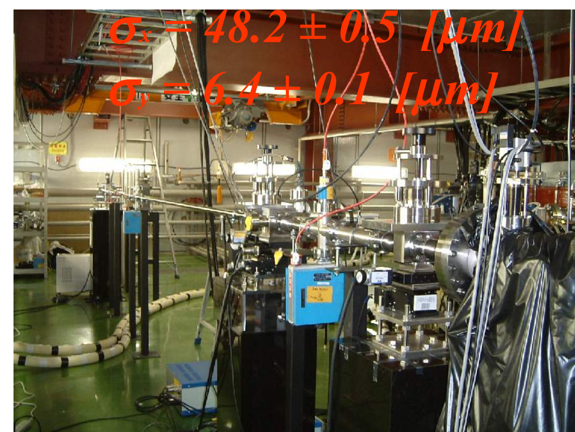
- *Non destructive measurement*
- *High resolution (< 1mm)*
- *2D direct imaging of the electron beam*
- *Real time monitoring (< 1ms)*





Zone plate

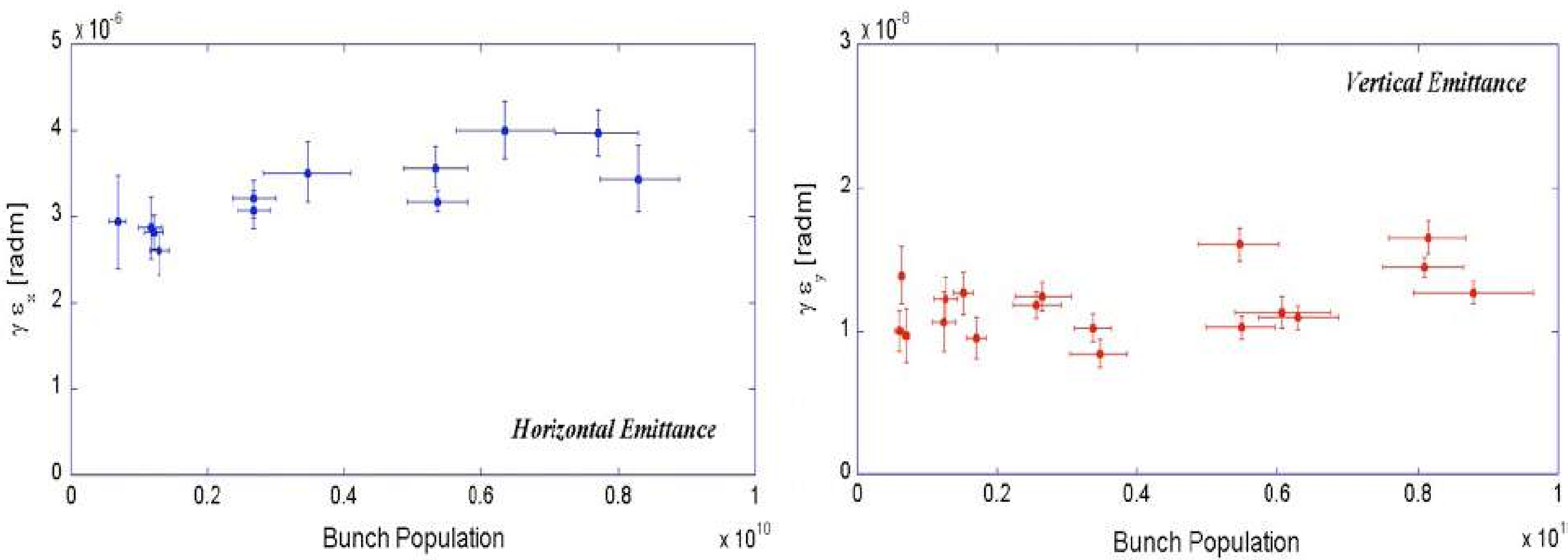




SR X-ray beam line

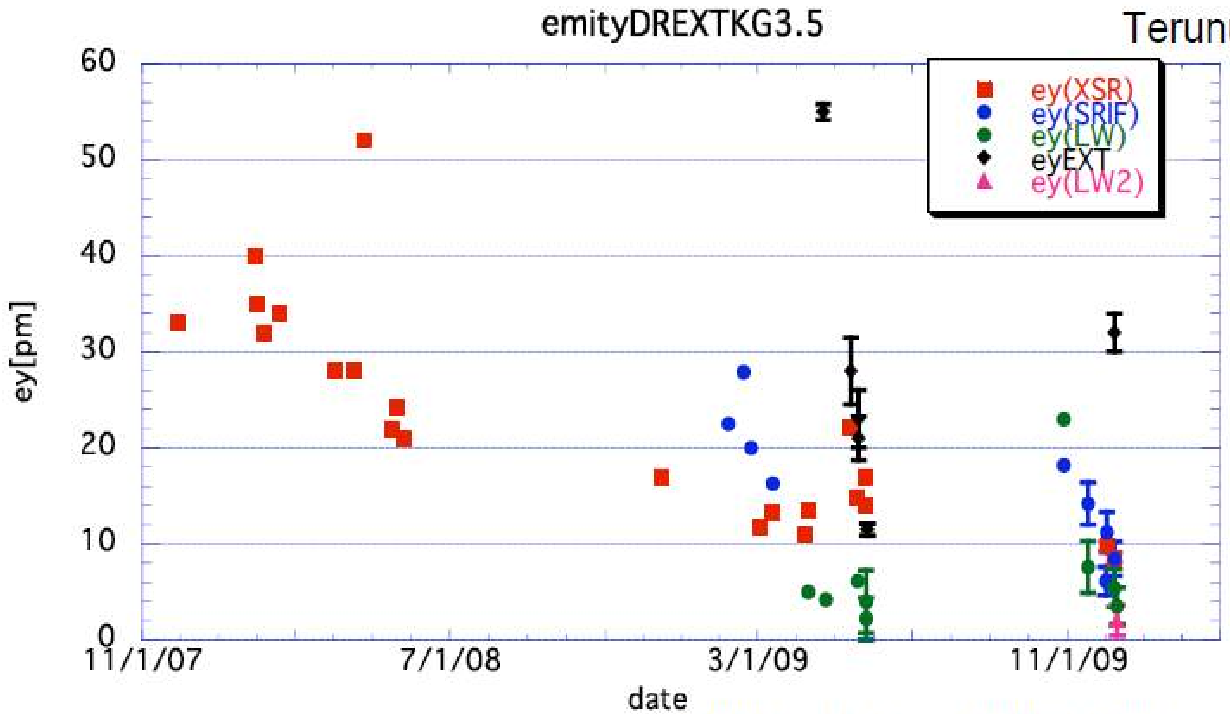
Emittance

- The target emittance is achieved in 2001.
- However, the emittance is not always reproduced even with careful tunings. The reproducibility has been an issue.



Emittance Reproducibility

Terunuma, Kuroda



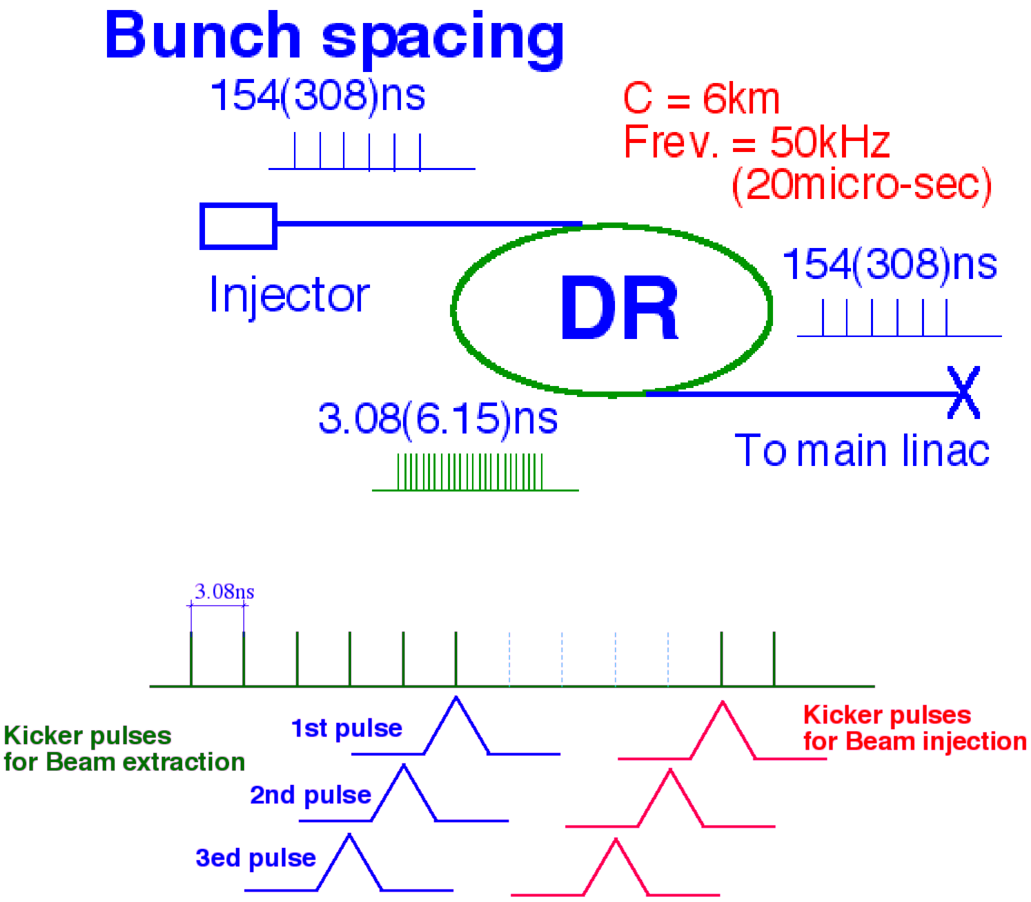
2009 spring
I=5-6x10[9]

2009 autum
I=4-5x10[9]

Emittance situation is similar to that in May 09.
Measured ε_y=8.56±0.46/ 8.43±1.79/ 3.50±1.78/ 2.00±1.61pm by XSR/ IF/ LW00/ LW01.
Study for the discrepancy is still on going.

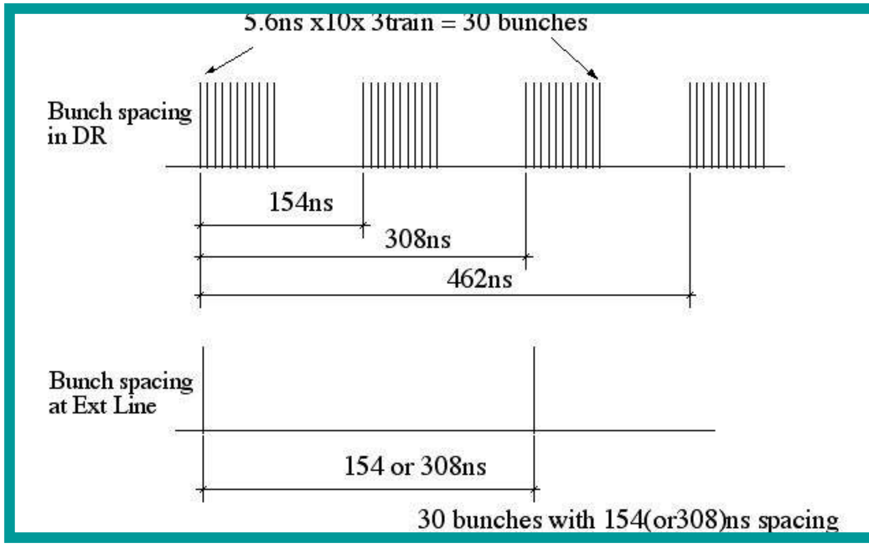
Fast Kicker R&D

- In ILC, 2625 bunches are stored in 6.4km DR with compressed spacing.
- Compress/de-compress injection/extraction are performed by fast-kicker.
- The kicker rise/fall time should be less than the bunch spacing in DR (3.1-6.2ns) for the bunch-by-bunch manipulation.
- In ATF, a fast kicker system is developed to provide the beam in ILC-like format to ATF2.

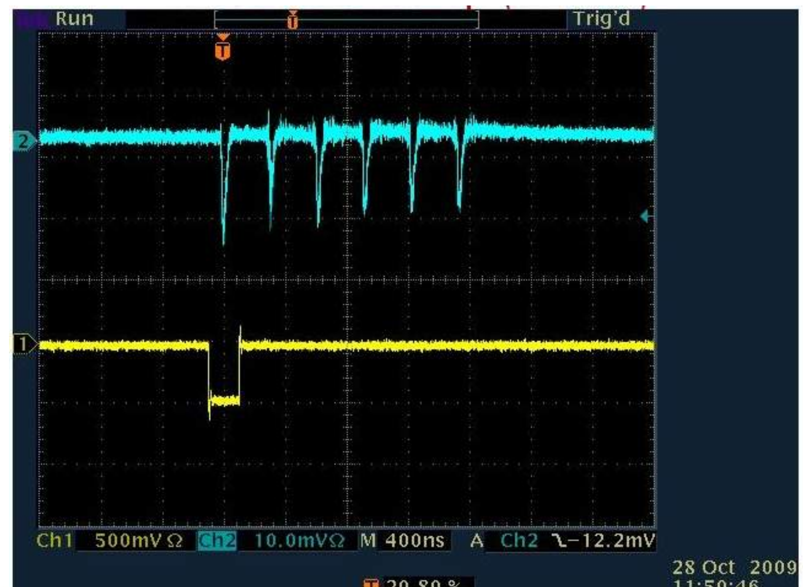


Multi-bunch beam extraction

- Stored beam in DR with 5.6ns bunch spacing is extracted by the fast kicker system to ATF2 beam line in 308ns spacing.
- Up to 17 bunches are extracted, but the intensity in-flatness and orbit fluctuation are observed.
- Improving the reliability and stability of the system, especially the fast power supply, is issue.



Stripline electrode



ATF2 latest status

ATF2

- ATF2 demonstrates feasibility of the local chromaticity correction scheme.
- This small beam size has to be maintained with adequate reproducibility and stability.
- Required technical aspects should be developed in the effort.
- ATF2 is in tight conditions more than that in ILC (smaller $\beta_{x,y}$ and equivalent position jitter). The performance can be extrapolated to ILC regime without critical risks.

	ATF2	ILC	Unit
Beam energy	1.3	250	GeV
$\gamma\varepsilon x$	4.3-5.1	10	mm.mrad
$\gamma\varepsilon y$	0.03	0.04	mm.mrad
σx	2.3	0.64	µm
σy	34	5.7	nm
βx	4	20	mm
βy	0.1	0.4	mm
Y position jitter	2.0	2.0	nm

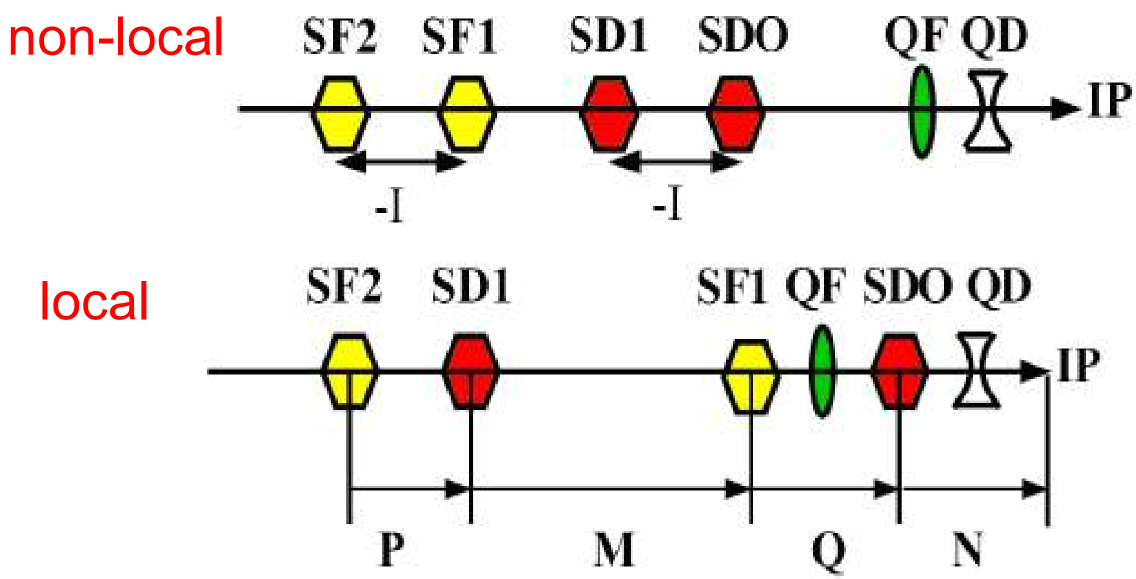
Local Chromaticity Correction

- Chromatic aberration and dispersion have to be compensated to obtain the small spot size at IP.
- ILC employ local chromaticity correction.
  - Total length could be compact.
  - Compensate the chromaticity induced by the final doublet effectively with the sextupoles (~10^4).
  - Suppress the dispersion induced by the sextupoles simultaneously.

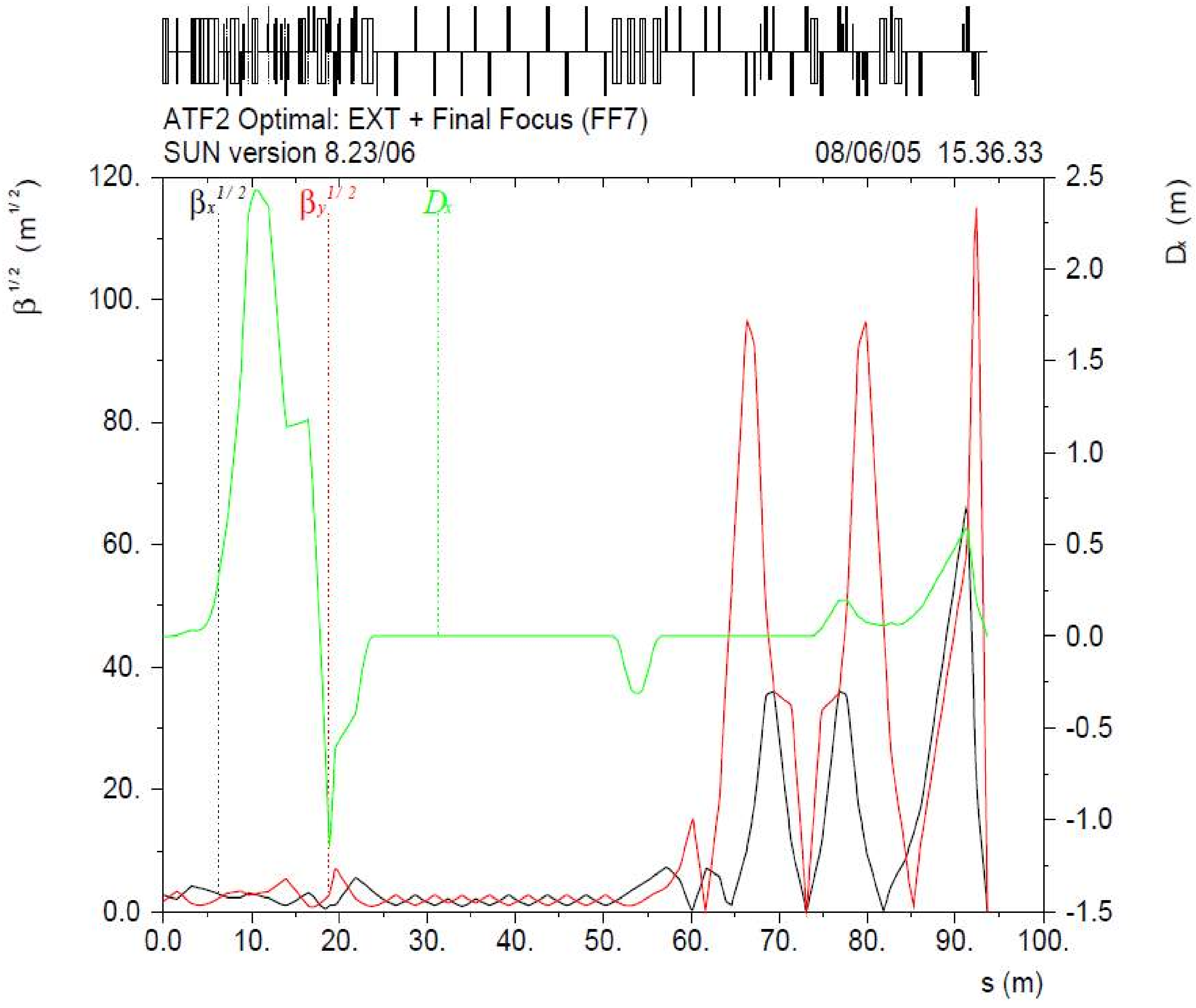
Dispersion $x = x_\beta + \eta\delta$

Chromaticity $\frac{\Delta\sigma_{x,y}}{\sigma_{x,y}} = W_{x,y}\delta$

$\delta = \frac{\Delta E}{E}$



ATF2 Optics

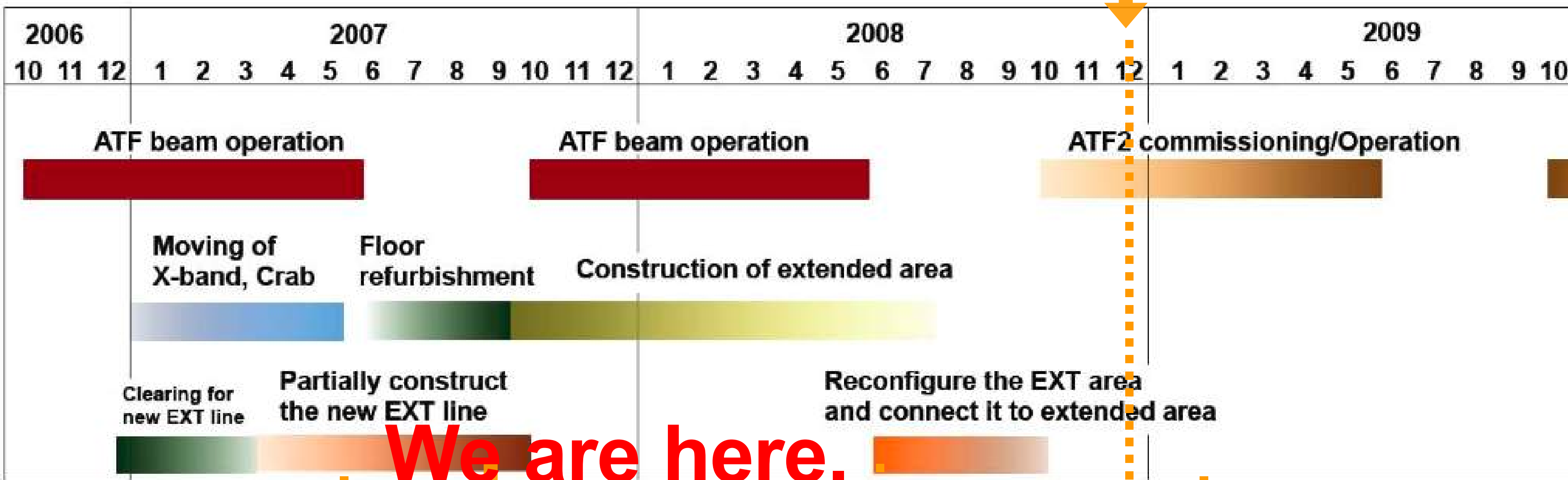

ATF2 Optimal: EXT + Final Focus (FF7)
SUN version 8.23/06
08/06/05 15.36.33
$\beta^{1/2}$ ($m^{1/2}$)
$\beta_x^{1/2}$
$\beta_y^{1/2}$
D_x
D_x (m)
s (m)
120.
100.
80.
60.
40.
20.
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.0
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.

ATF2 and FFTB

- Final focus system of NLC/GLC (conventional separated function) has been demonstrated in FFTB at SLAC (1994).
- Aim of ATF2 is
  - **Prove the new optics with a high-stability and reproducibility.**
  - **Establish the tuning method and required beam control and diagnostic system; ILC exercise.**

	ATF2	FFTB	Unit
Beam energy	1.3	47.0	GeV
Optics	Local non-linear	Non-local linear	
$\gamma\varepsilon_y$	0.03	2.0	mm.mrad
βy	0.1	0.1	mm
σy (design)	34.0	52.0	nm
σy (achieved)	?	70	nm
Stability	2	>10?	nm

ATF2 ON



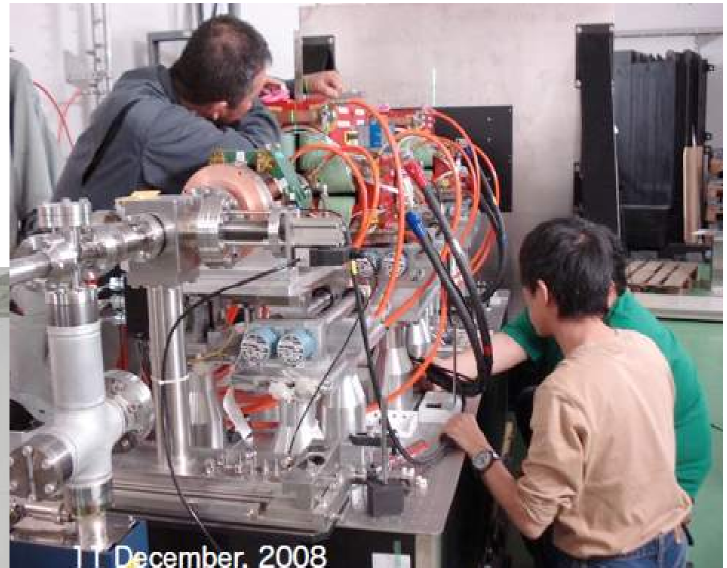
We are here.

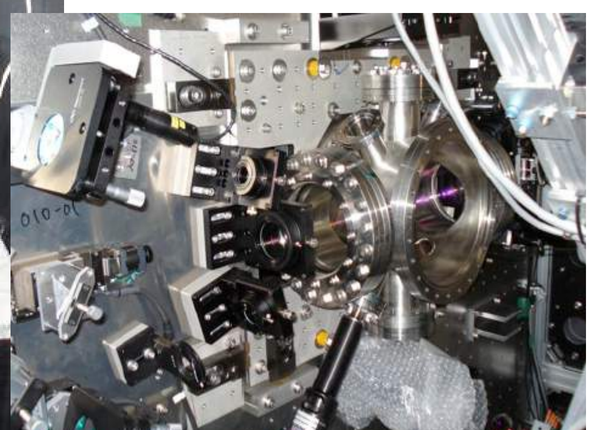
2009	2010	2011
6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3
Complete high beta optics.	Complete nominal optics.	
Preparation of laser-wire, Upgrade of Interference Monitor, Upgrade of DR BPM circuit and so on.	Develop many tuning tools and techniques to confirm beam quality in Damping ring and at ATF2 beam-line.	Stabilize beam orbit

Detect g from interference monitor, then confirm first milestone 70nm

Confirm design demagnification, resulting in a nominal 35 nm beam size at IP.

Installation in ATF2

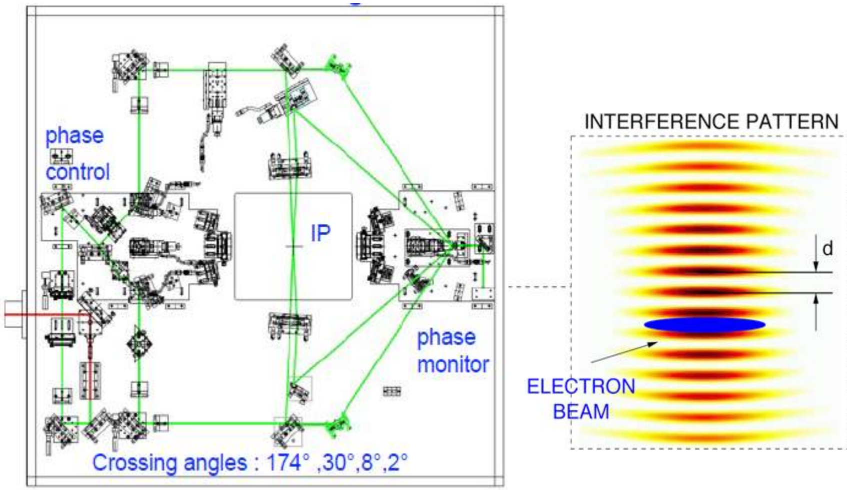




ATF2 strategy

- Mode I : establish 34nm beam size (~2010)
  - **Demonstrate feasibility of the new optics.**
  - **Maintain the small beam size with an enough long period.**
- Mode II: stabilize the beam orbit (~2012)
  - **Prove the several nm level orbit stability at the virtual IP.**
  - **Develop the precise beam control to realize the same stability in multi-bunch ILC format beam.**

IP-Beam Size Monitor



- Beam size at virtual IP is measured by scanning the laser-interference pattern with the e-beam.
- By changing crossing angle of two lasers, a wide range of resolution is covered.
- First interference pattern is observed by the beam in 2009/11.

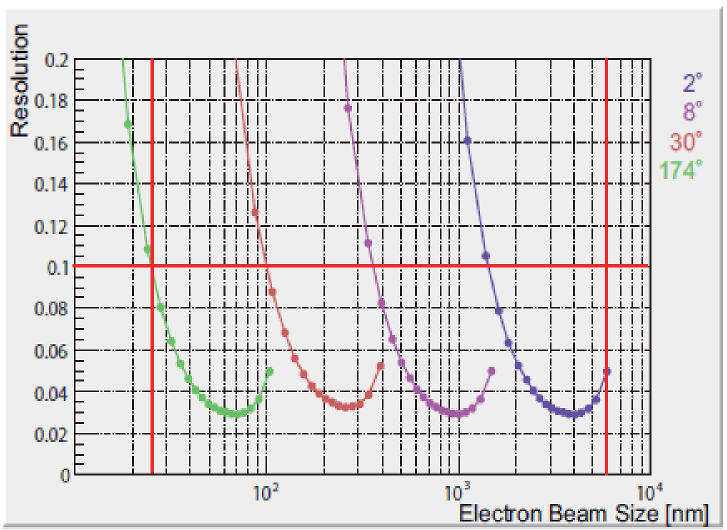
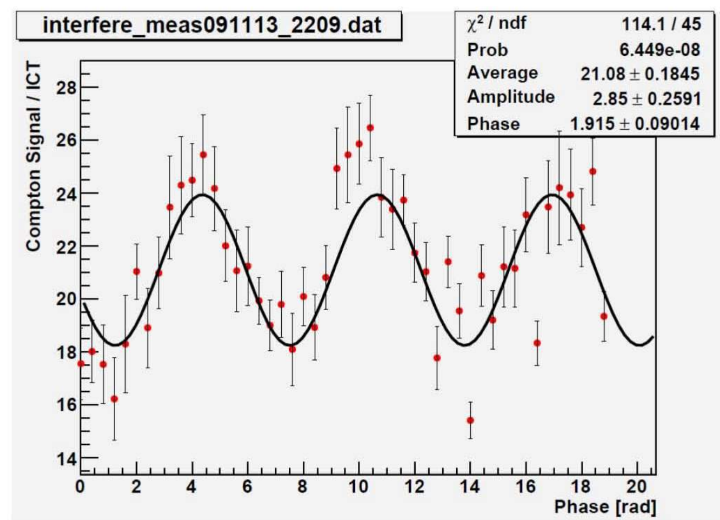
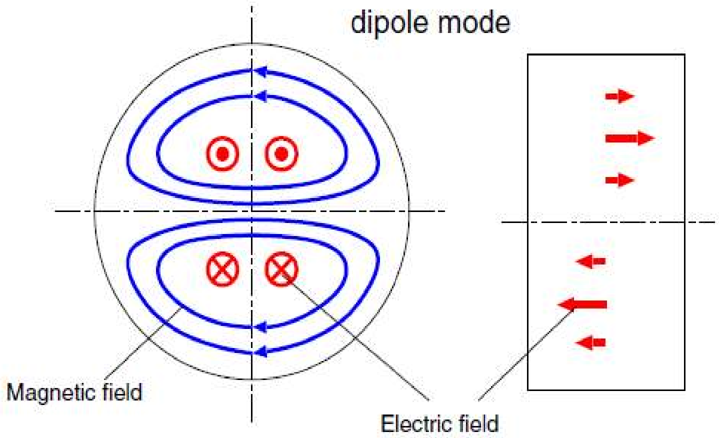


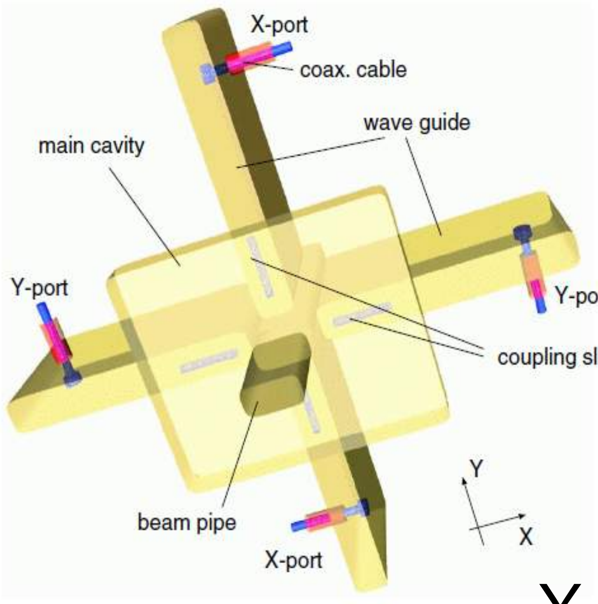
Fig. 33. The estimated beam size resolution. For the 25 - 6000 nm beam size, target resolution 10% can be achieved using 2°, 8°, 30° and 174° crossing angle modes.

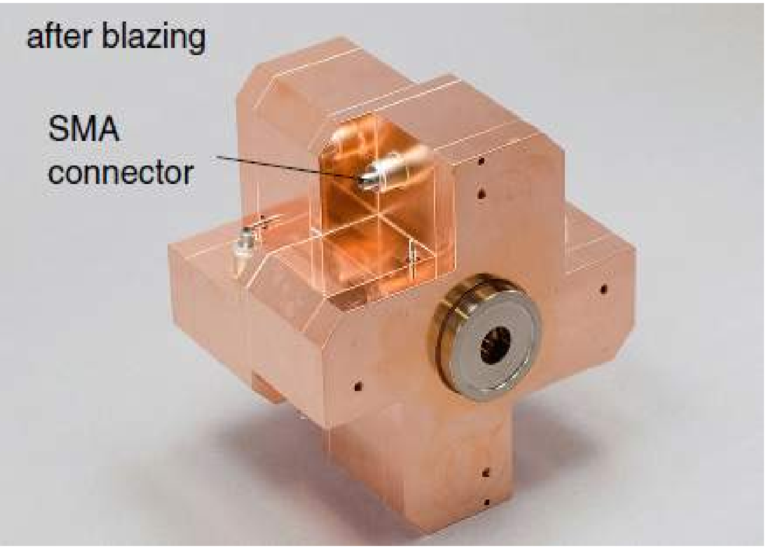


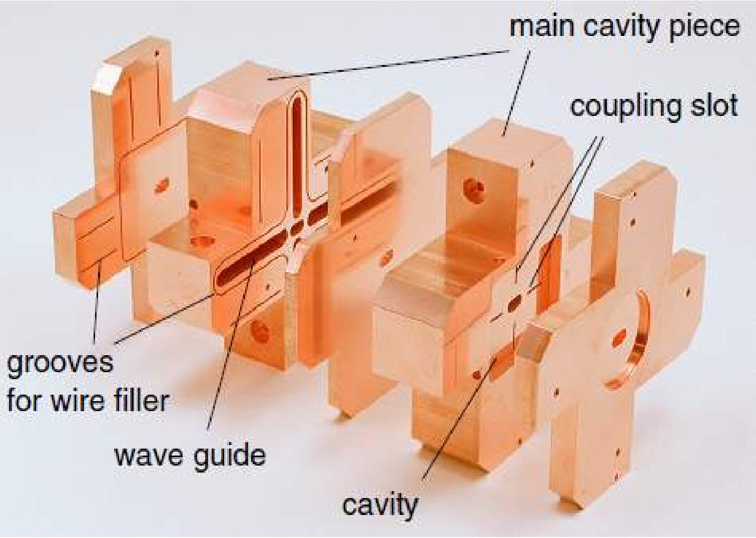
First observation of the fringe pattern signal

IP Cavity BPM





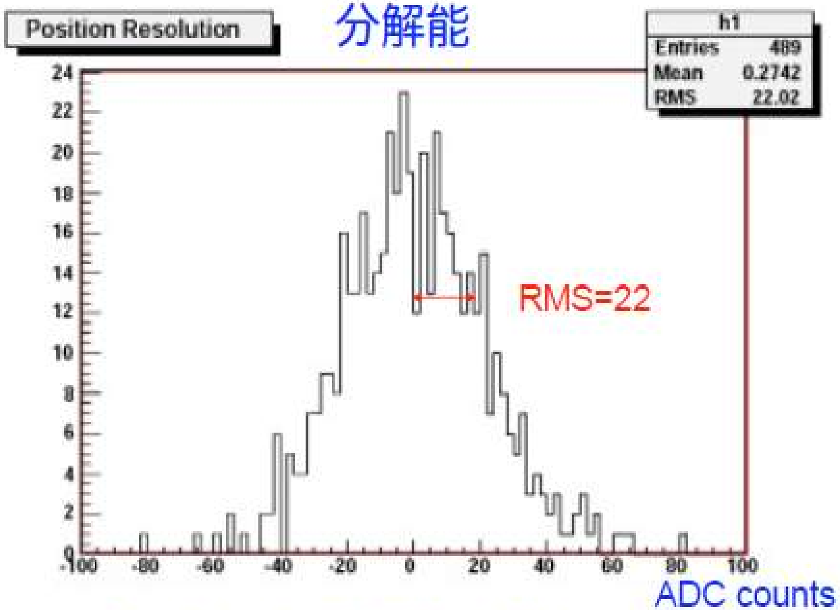




Y. Inoue

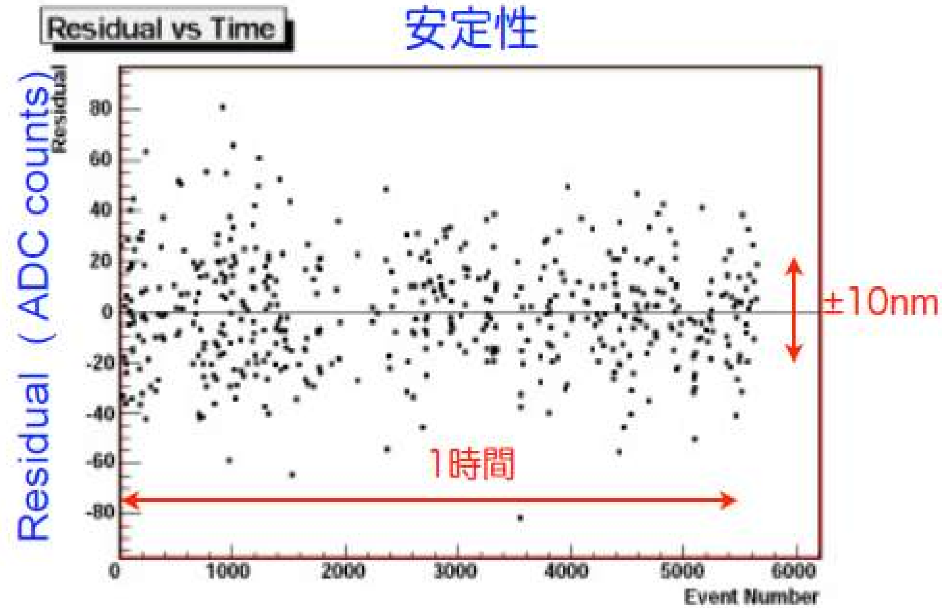
IP CBPM resolution

分解能



Residual of ($Y2I - Y2I_{predicted}$)

安定性



Time (event number, 1.5Hz)

測定条件：ビーム強度=0.7×10^{10}/bunch, dynamic range = 5μm

分解能(1時間測定) = 8.7±0.3(統計)±0.4(系統) nm

2nm目標：1×10^{10}/bunch, 温度安定化,シグナル増, active support ..

Issues not covered by ATF

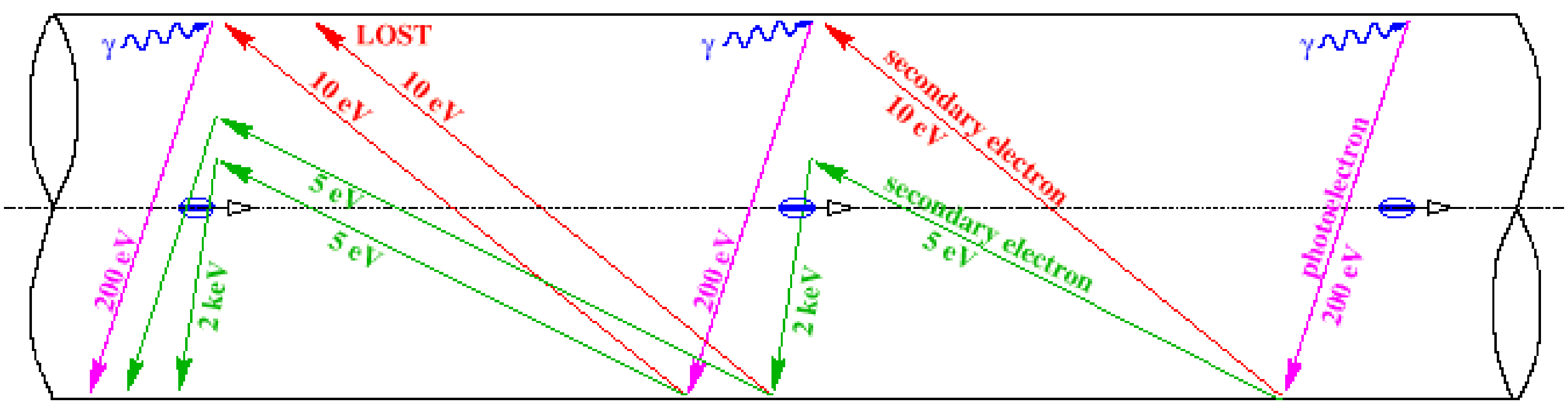
ILC and Super-B

- The latest design of Super-B factories based on nano-beam storage ring is close enough to ILC DR.
- Many issues are commonly able to be studied for ILC and Super-B.

	ILC-DR	KEK SB	Italian SB	Unit
Beam energy	5	4.0 / 7.0	4.1 / 6.8	GeV
C	6.40	3.00	1.30	km
$\gamma\varepsilon_y$	0.02	0.10	0.05	mm.mrad
βy	-	0.27 / 0.42	0.10	mm
I	0.4	3.6 / 2.6	3.5	A
Luminosity	-	~1E+36	~1E+36	$1/cm^2s$

Electron Cloud Effect

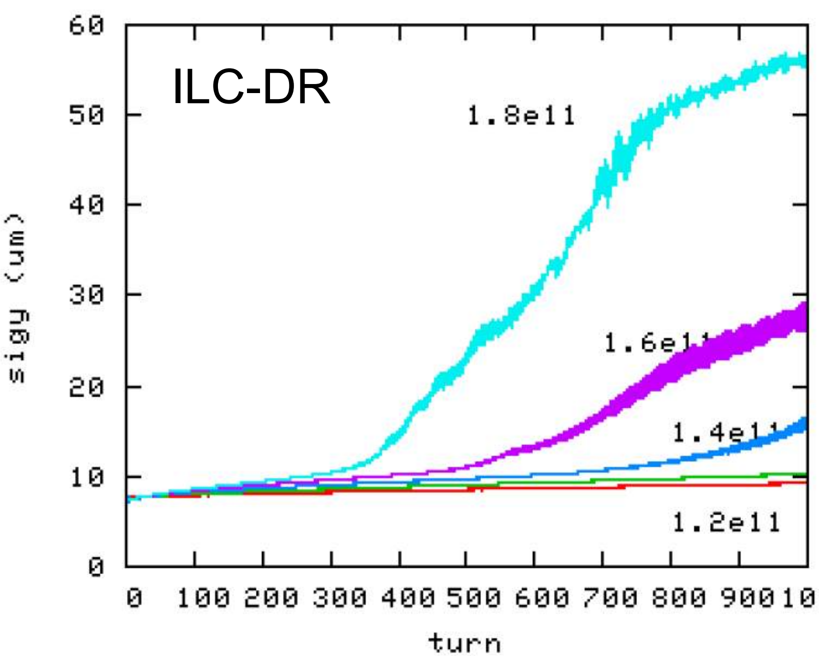
- This is one of the most critical issue not only for ILC-DR (e+ DR), but also Super-B factories.
  - **Primary photo-electrons by synchrotron photons.**
  - **The photoelectrons produce secondary electrons.**
  - **Rapid multiplication of the number of electrons can cause beam instabilities.**

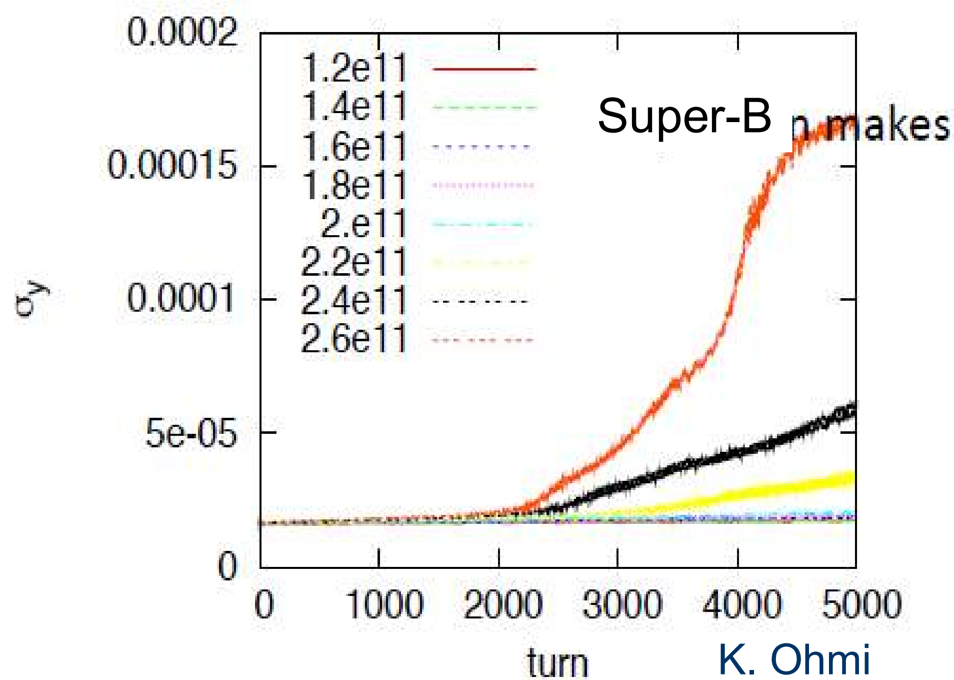


M. Palmer

E-cloud threshold

- Beam instability starts at cloud density of
  - **ILC:1.2E+11 1/m³**
  - **Super-B : 2E+11 1/m³**
- The cloud density in e+ ring has to be suppressed below the threshold.

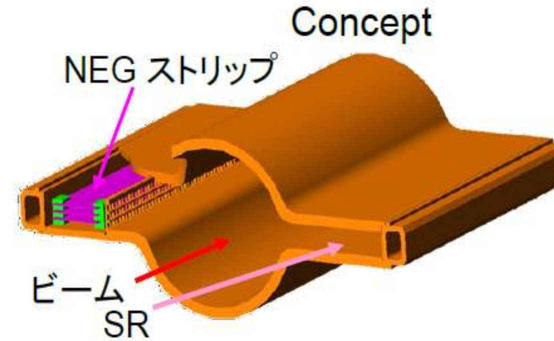




K. Ohmi

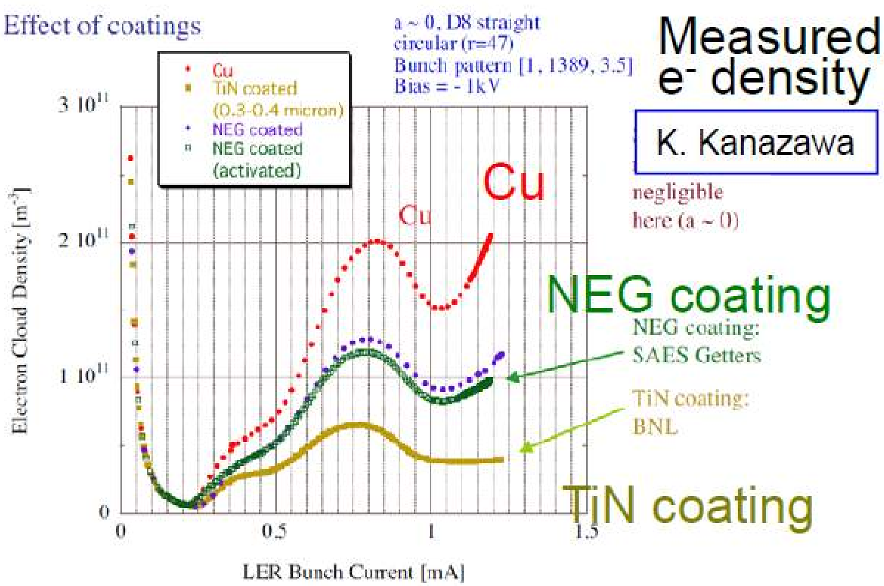
Mitigation techniques

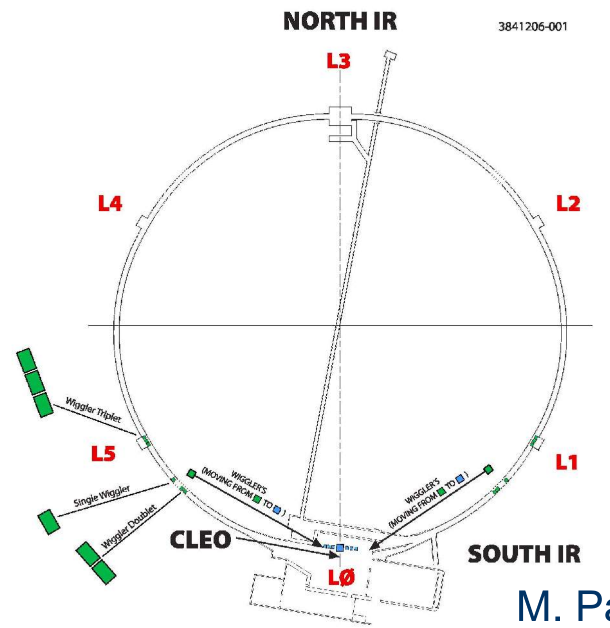
- Technologies to suppress the e-cloud
  - **TiN/NEG coating**
  - **Antechamber**
  - **Solenoid field**
  - **Collector electrode**
  - **Groove chamber**



Y. Suetsugu

- CESR-TA focuses on the study of e-cloud mitigation.

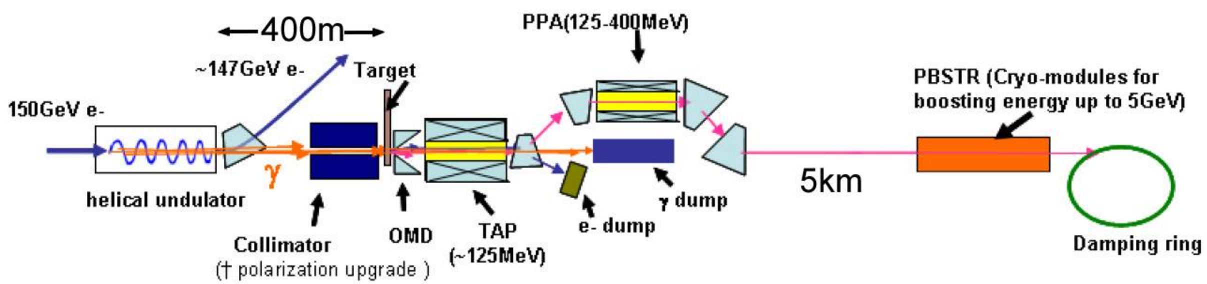


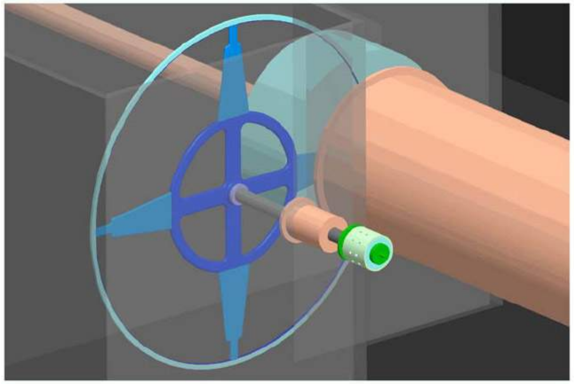


M. Palmer

Positron Source

- RDR: Undulator scheme
  - **High energy (>125GeV) e$^-$→undulator→photon (>10MeV)→e+**
  - **Undulator at 150GeV point (length ~150m)**
    - accelerate or decelerate electron in the remaining 100GeV section to reach 50~250GeV
  - **Rotating target (100M/s) for avoiding heat accumulation during 1ms beam**

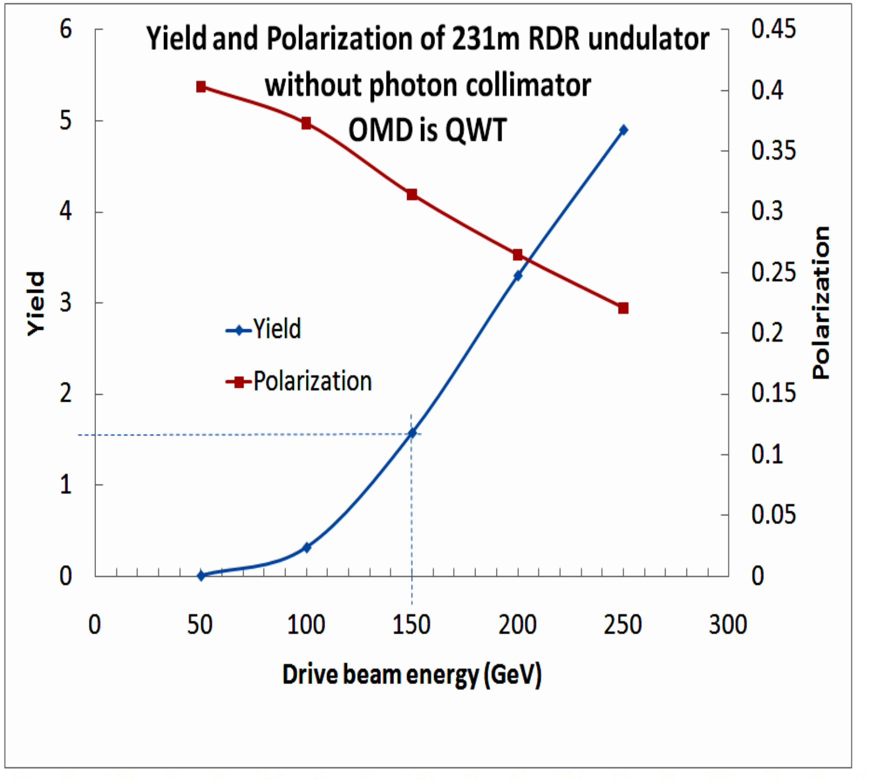




- Issues
  - Rotating target (vacuum, eddy current)
  - Capture device (feasibility of flux concentrator with 1ms pulse?)
  - Electron linac must be operated always at full gradient up to 150GeV to get sufficient yield of positron (commissioning problem)

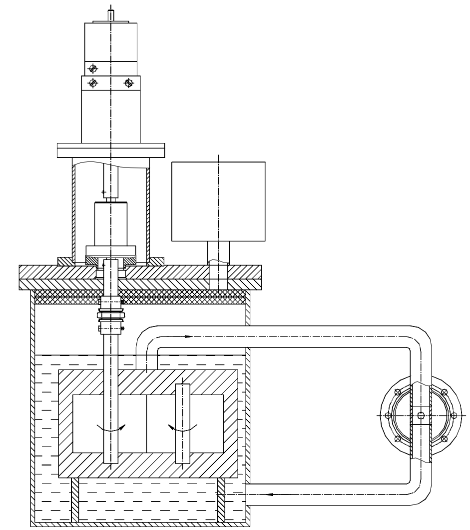
Positron in SB2009

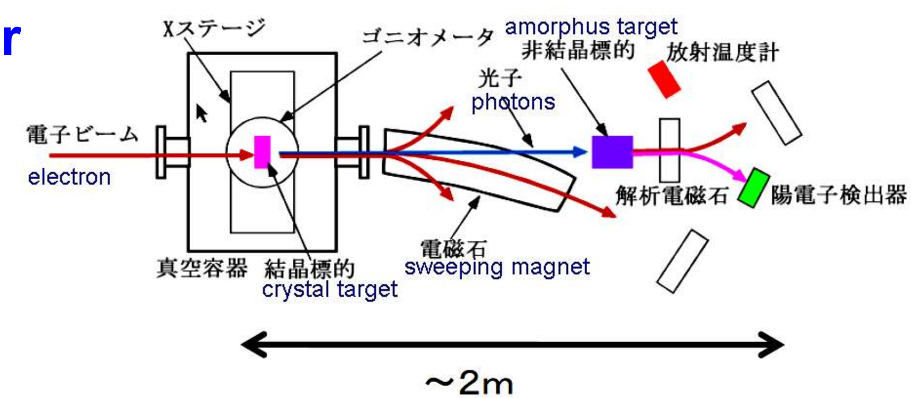
- Replace flux concentrator with Quarter Wave Transformer (less efficient but safer)
  → longer undulator (=230m), higher target load
- ▶ Place undulator at linac end (250GeV point)
  - No deceleration
  - Higher positron yield at high energy (>300GeV CM)
  - **But poor yield below 300GeV CM**
    (~half at 250GeV)
- Status
  - Many cures are being considered
  - R&D program proposed



KEK Positron R&D Plan

- KEK has not joined positron R&D (except Compton source).
- But in view of the slow progress of ILC positron R&D, decided to develop `conventional source' (a few GeV electron→target→e+)
- The present technology of `conventional source' is not sufficient for ILC.
- KEK facilitates
  - **Liquid Lead Target (covered with boron-nitride window)**
    - System test at ATF linac
    - Window test at KEKB abort line
  - **Hybrid target (Crystal radiator + Amorphous converter)**
    - Yield test at KEKB linac





Summary

- ATF is a unique and important facility to prove the extremely low-emittance beam for LC projects.
- By ATF2 project, the role is expanded to the FF system. ATF2 examines feasibility of the local chromaticity correction optics.
- Developing the precise beam control and fine beam diagnostic is also important tasks for ATF/ATF2.
- ATF2 commissioning is aggressively continued.
- Several critical issues not covered by ATF/ATF2 are studied in various contexts
  - **E-cloud**
  - **Positron**

Acknowledgment

- Materials are provided by T. Terunuma, T. Okugi, S. Kuroda, T. Tauchi, J. Urakawa, Y. Ohnishi, and K. Yokoya.
- I am grateful to all members of the ATF collaboration for the great progress and the excellent work.