Nanometre scale beam handling at the ATF

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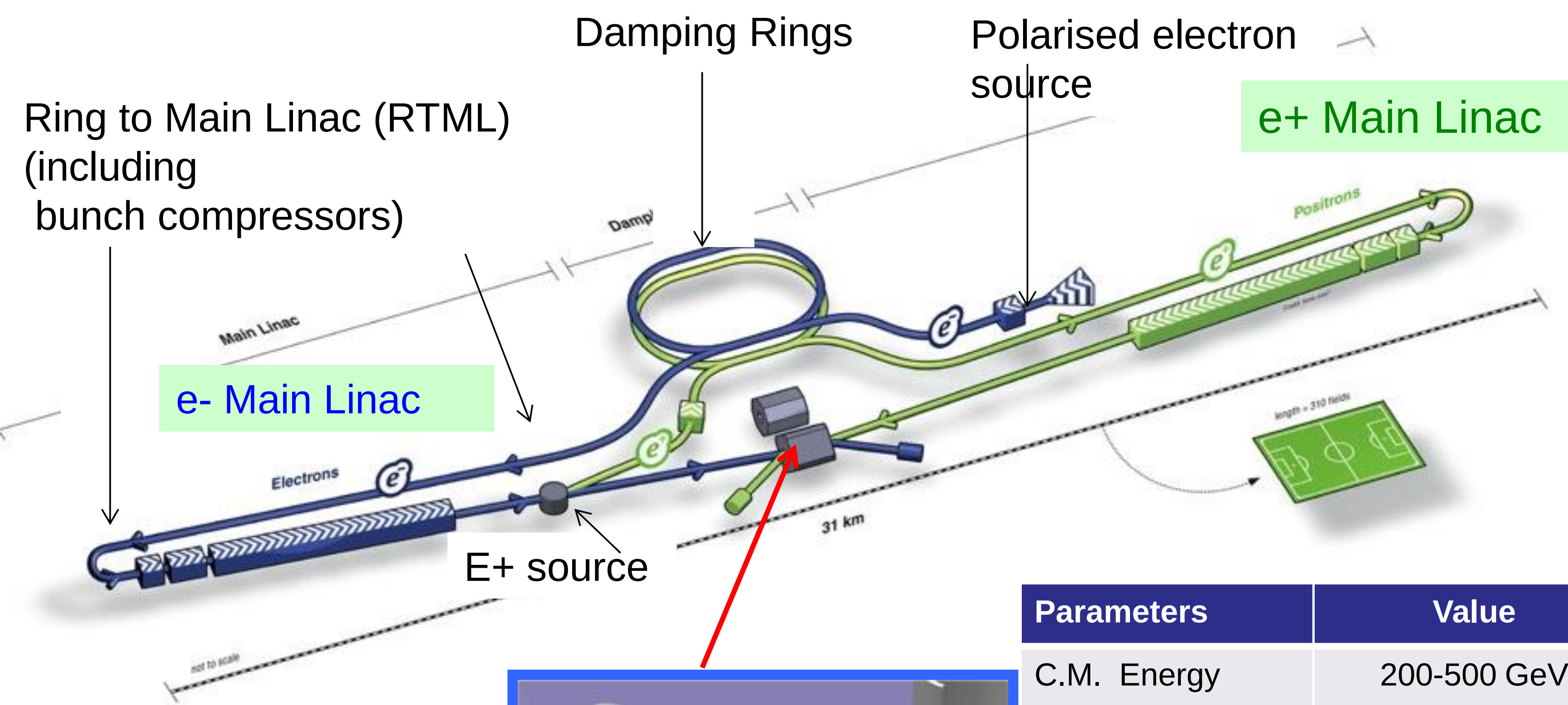
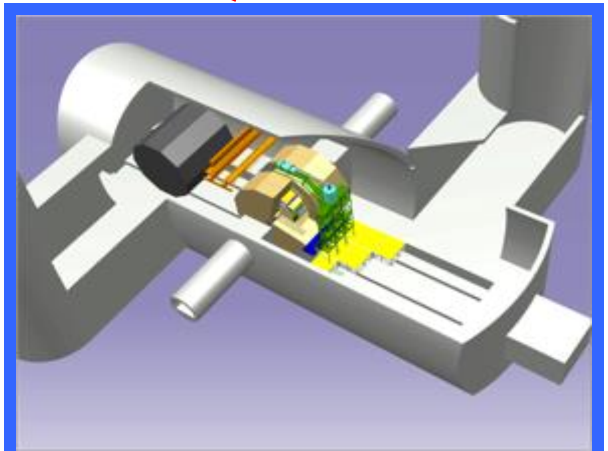
ILC TDR Layout

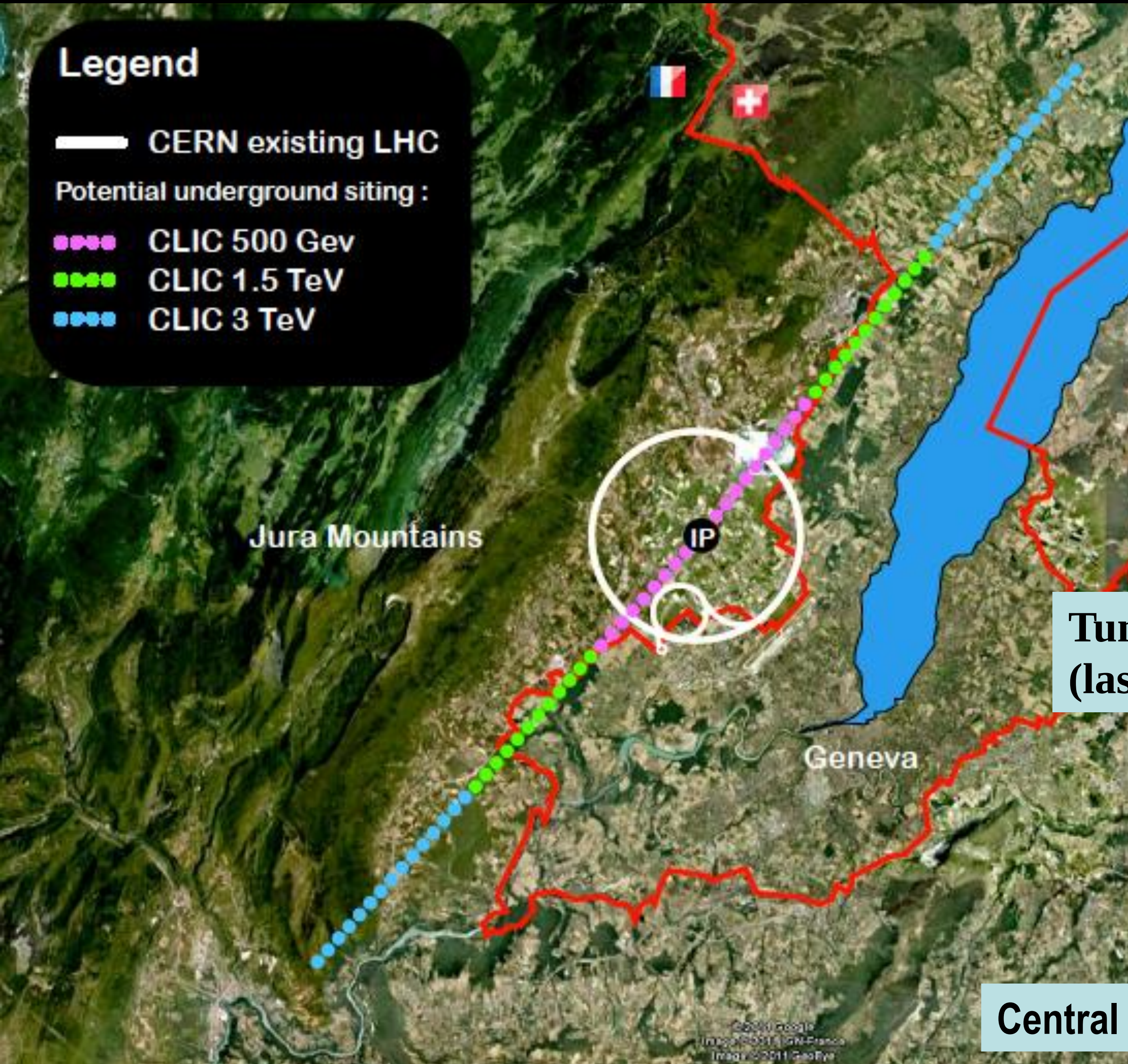


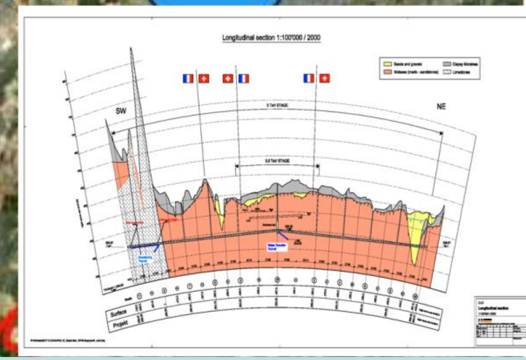
ILC Scheme | © www.form-one.de



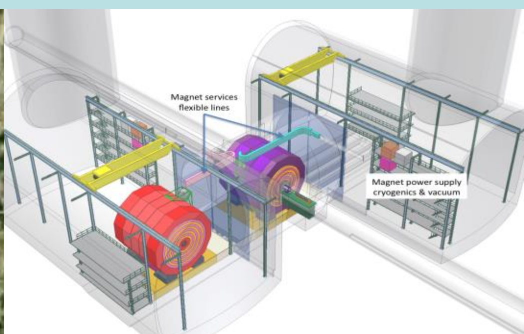
Parameters	Value
C.M. Energy	200-500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

CLIC



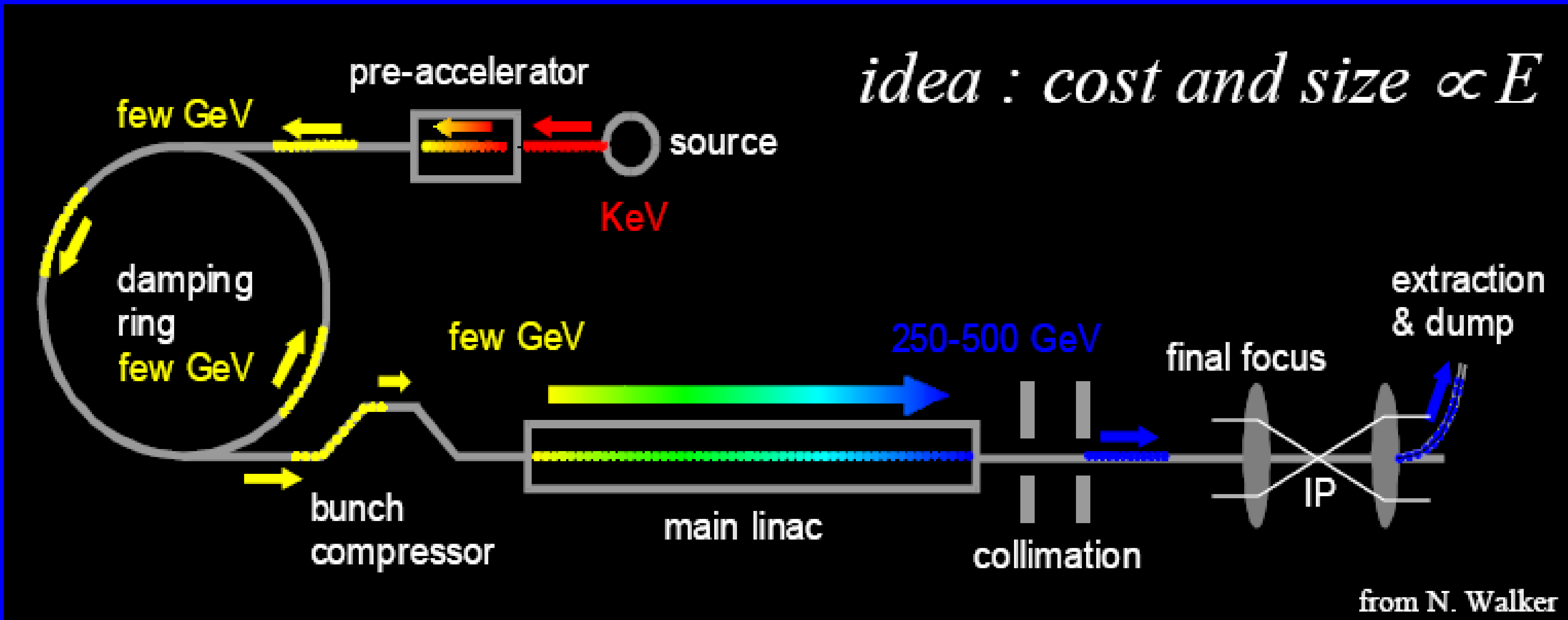


Tunnel implementations (laser straight)



Central MDI & Interaction Region

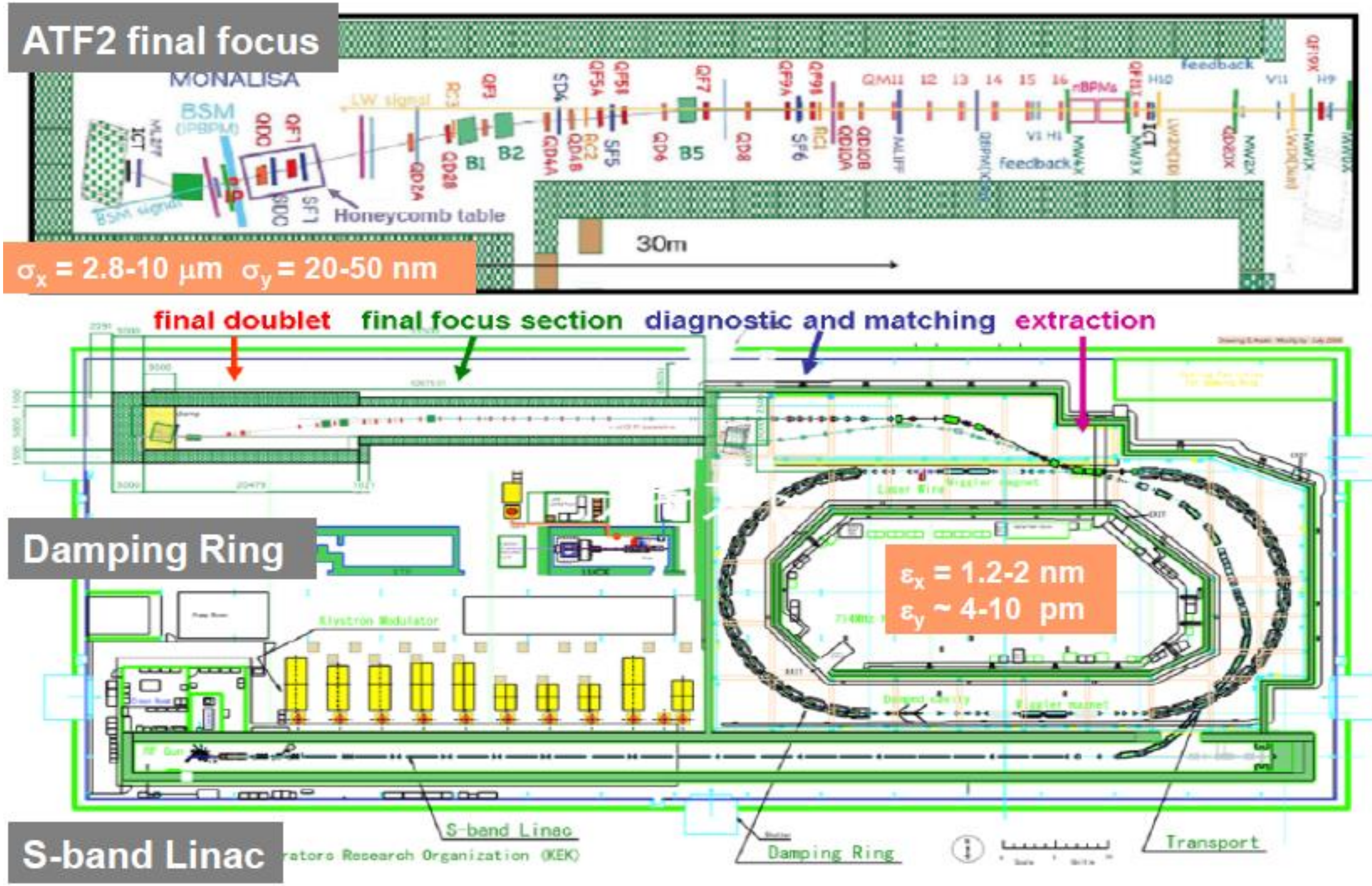
Linear collider concept



focus
- RF technology (gradient, efficient power transfer)
- beam phase-space control and stability

→ synchrotron radiation still drives design…

Nanometre scale beam handling R&D at the ATF (KEK, Japan)



ATFに参加している代表的研究機関
- ATF International Collaboration -

欧州原子核研究機構(CERN)

ドイツ(Germany)
- **電子シンクロトロン研究所(DESY)**

フランス(France)
- **IN2P3; LAL, LAPP**

イギリス(UK)
- **Univ. of Oxford**
- **Royal Holloway Univ. of London**
- **STFC, Daresbury**
- **Univ. of Manchester**
- **Univ. of Liverpool**
- **Univ. College London**

イタリア(Italy)
- **INFN, Frascati**

スペイン(Spain)
- **IFIC-CSIC/UV**

ロシア(Russia)
- **Tomsk Polytechnic Univ.**

Members of E-JADE WP2

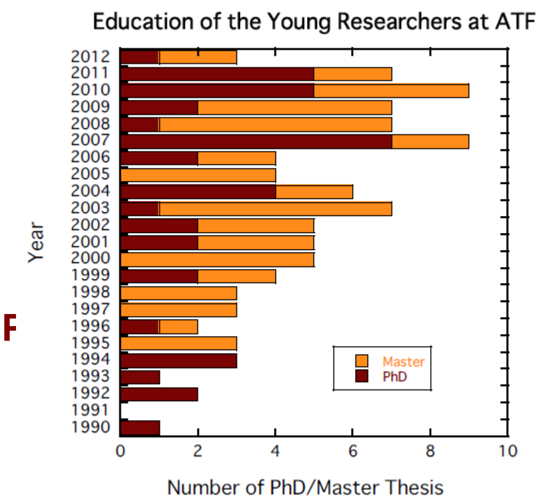
アメリカ(USA)
- **SLAC国立加速器研究所**
- **ローレンス・バークレー国立研究所(LBNL)**
- **フェルミ国立加速器研究所(FNAL)**
- **ローレンス・リバモア国立研究所(LLNL)**
- **ブルックヘブン国立研究所(BNL)**
- **コーネル大学(Cornell Univ.)**
- **ノートルダム大学(Notre Dome Univ.)**

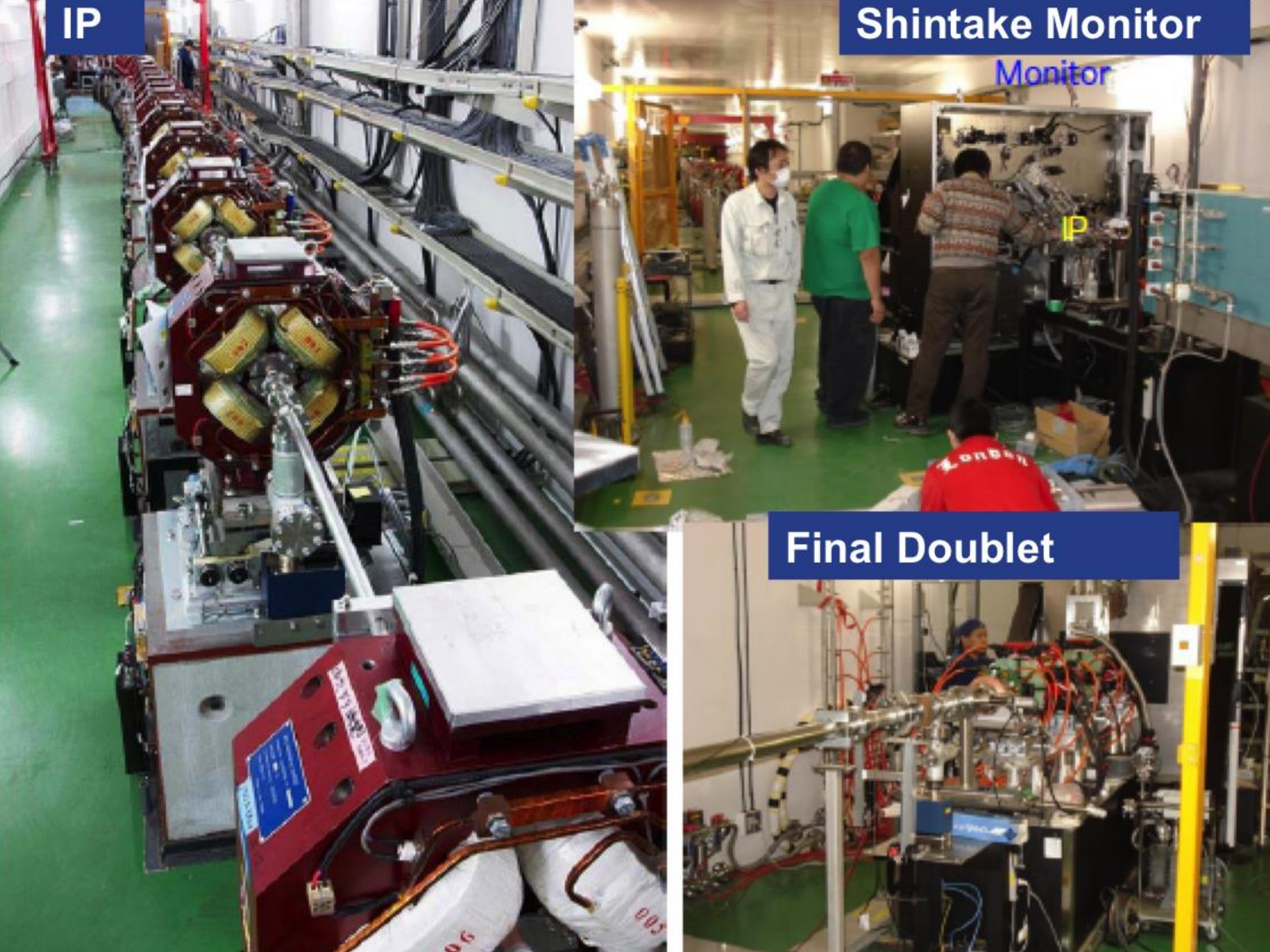
日本(Japan)
- **高エネルギー加速器研究機構(KEK)**
- **東北大学 (Tohoku Univ.)**
- **東京大学 (Univ. of Tokyo)**
- **早稲田大学(Waseda Univ.)**
- **名古屋大学(Nagoya Univ.)**
- **京都大学 (Kyoto Univ.)**
- **広島大学 (Hiroshima Univ.)**

中国(China)
- **中国科学院高能物理研究所(IHEF**

韓国(Korea)
- **ポハン加速器研究所(PAL)**
- **キョンプク大学(KNU)**

インド(India)
- **Raja Ramanna Centre for Advanced Technology**




IP
Shintake Monitor
Monitor
IP
Final Doublet

Parameters	ATF2	ILC	CLIC	SuperKEKB
Beam Energy [GeV]	1.3	250	1500	4-7
L* [m]	1	3.5 - 4.5	3.5	0.47-1.3
$\gamma\epsilon_{x/y}$ [m.rad]	**$5\ 10^{-6}$ / $3\ 10^{-8}$**	**10^{-5} / $4\ 10^{-8}$**	**$6.6\ 10^{-7}$ / $2\ 10^{-8}$**	**~ $3\ 10^{-5}$ / ~ $1\ 10^{-7}$**
IP $\beta_{x/y}$ [mm]	**4 / 0.1**	**21 / 0.4**	**6.9 / 0.07**	**25-32 / 0.27-0.41**
IP η' [rad]	0.14	0.0094	0.00144	
δ_E [%]	~ 0.1	~ 0.1	~ 0.3	0.065
Chromaticity ~ β / L*	**~ 10^4**	**~ 10^4**	**~ $5\ 10^4$**	**1.7-3.2 10^3**
Number of bunches	1-3	~ 3000	312	2500
Bunch population	1-2 10^{10}	2 10^{10}	3.7 10^9	
IP σ_y [nm]	**37**	**5.7**	**0.7**	**59**

$$L \sim \frac{n_b N_e^2 f}{4\pi\sigma_x\sigma_y} H_D$$

$$L \sim \eta \frac{P_{electrical}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

$$\beta_y < \sigma_z$$

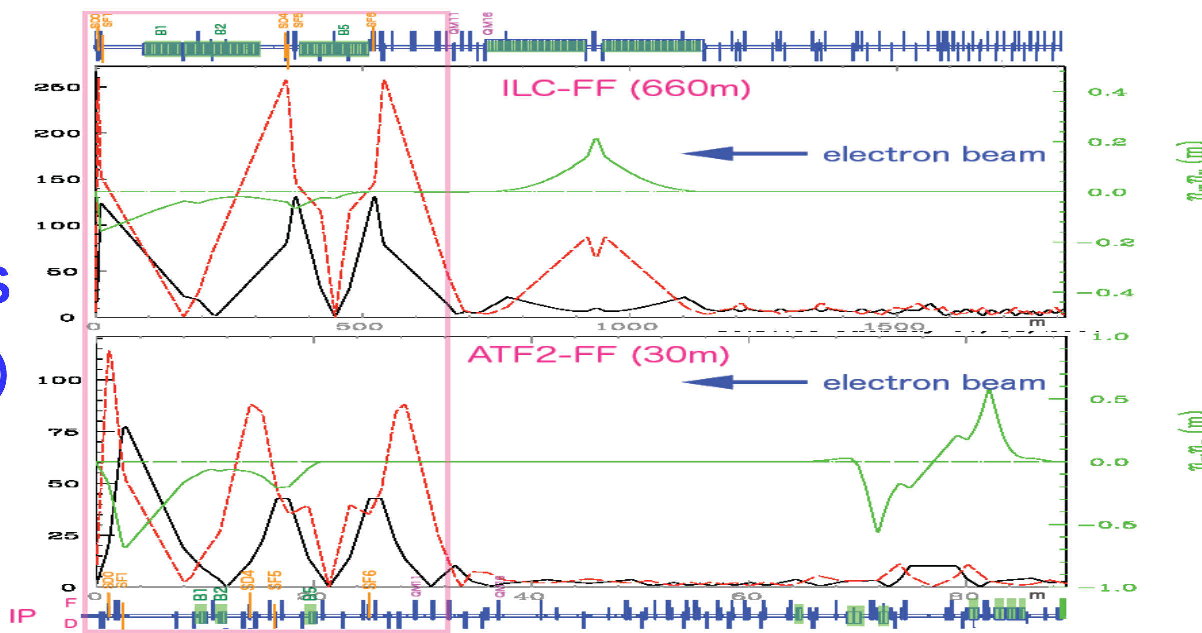
$$\sigma^2 = \varepsilon_N \beta / \gamma$$

ATF2 =

- ✓ **scaled ILC FFS**
- ✓ **start point of CLIC FFS**

(SuperKEKB + FCC-ee/CEPC)

concept of local compact chromaticity correction



Main LC beam delivery issues addressed by ATF / ATF2

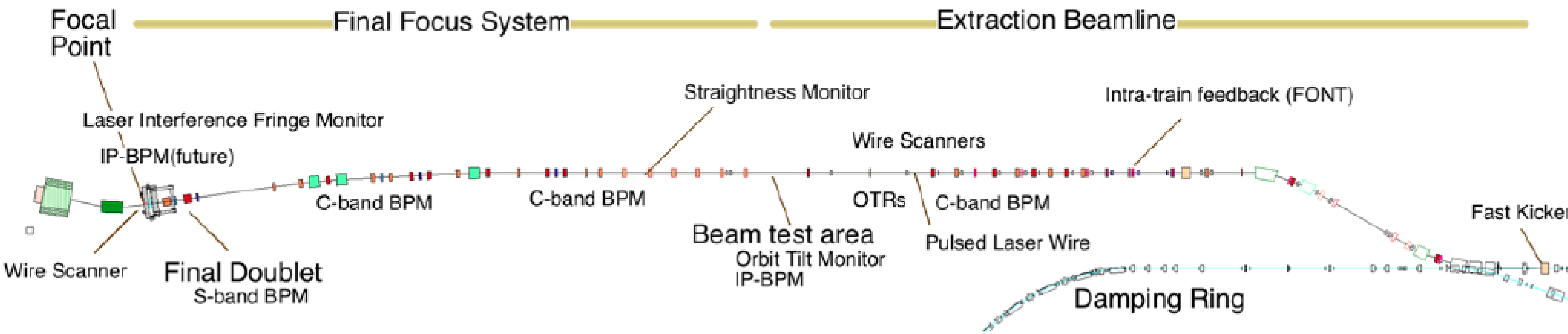
- Beam instrumentation
  - nm-level position
  - profile (x, y, tilt)
- Stabilization
  - passive / active mechanical stabilization
  - beam / vibration measurement based feed-back/forward
- 4+1 dim. beam tuning & control for small IP spot
  - emittance minimization via radiation damping
  - mitigation of 1st, 2nd and 3rd order optical aberration + wakefields
  - convergence time ↔ dynamical errors (sismic & thermal effect)
- Halo control
  - modeling, generation, propagation, monitoring…
  - collimation (physical, optics)

ATF / ATF2 project goals

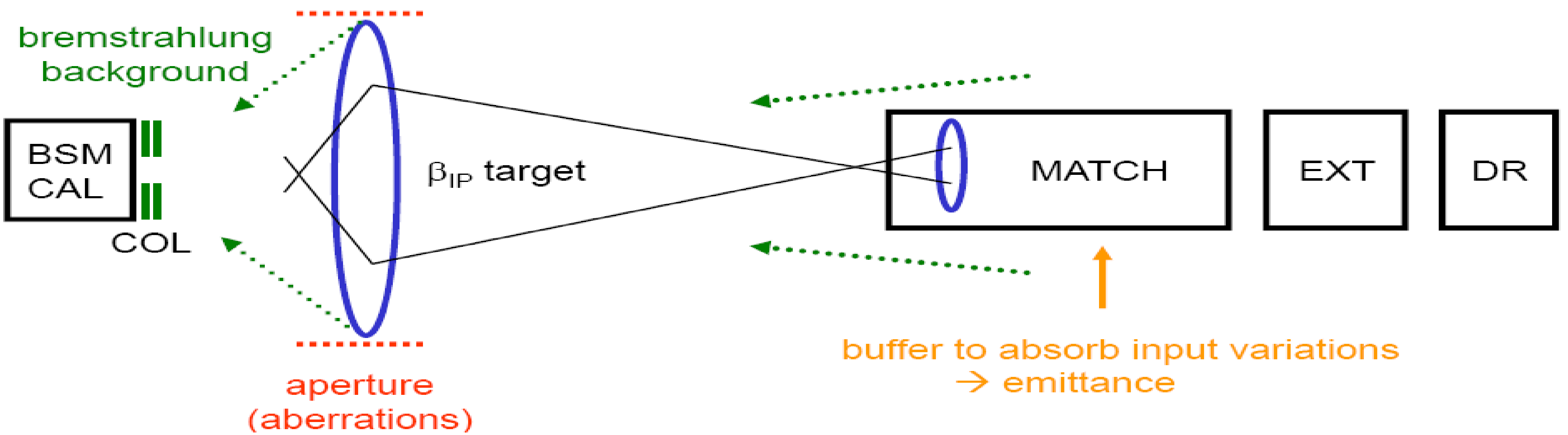
- ❑ **Very small damping ring vertical emittance**
  - from ~ 10 pm → 4 pm (achieved !) → 1-2 pm
- ❑ **Small vertical beam size** *"goal 1"*
  - achieve σ_y ~ 37 nm (cf. 5 / 1 nm in ILC / CLIC)
  - validate "compact local chromaticity correction"
- ❑ **Stabilization of beam center** *"goal 2"*
  - down to ~ 2nm
  - bunch-to-bunch feedback (~ 300 ns, for ILC)
- ❑ **R&D on nanometer resolution instrumentation**
- ❑ **Train young accelerator scientists on "real system"**
  - maintain and develop expertise by practicing operation

→ *open & unique facility*

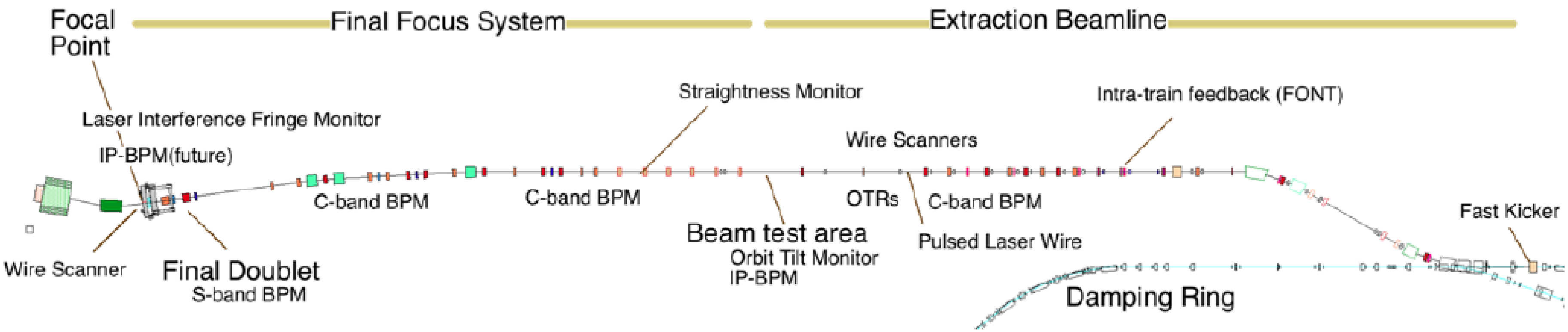
Experimentation with ATF2 nanometre beams

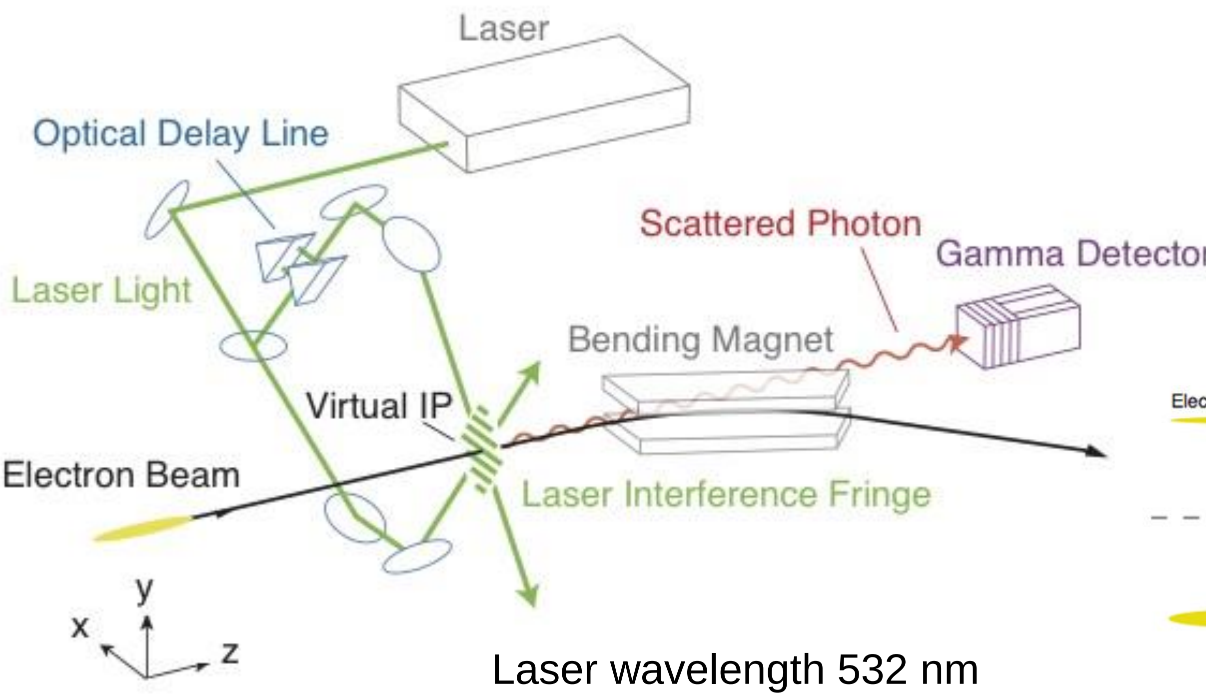


2nd order telescope *fine tuning of local errors*	Match optics into FF *buffer section for input errors*	DR extraction *setup, stability*

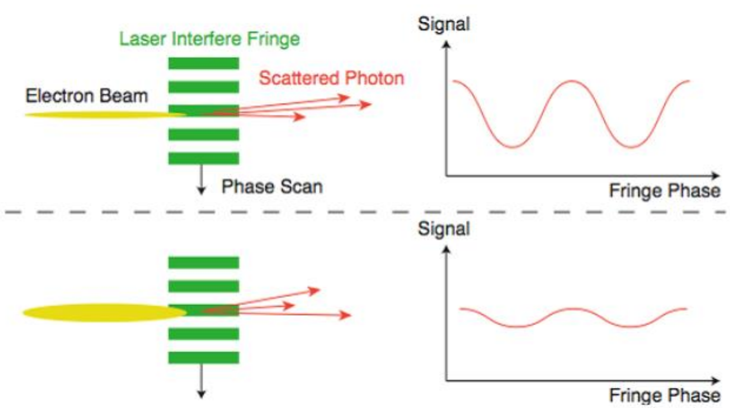


Measuring nanometre beam sizes at ATF2



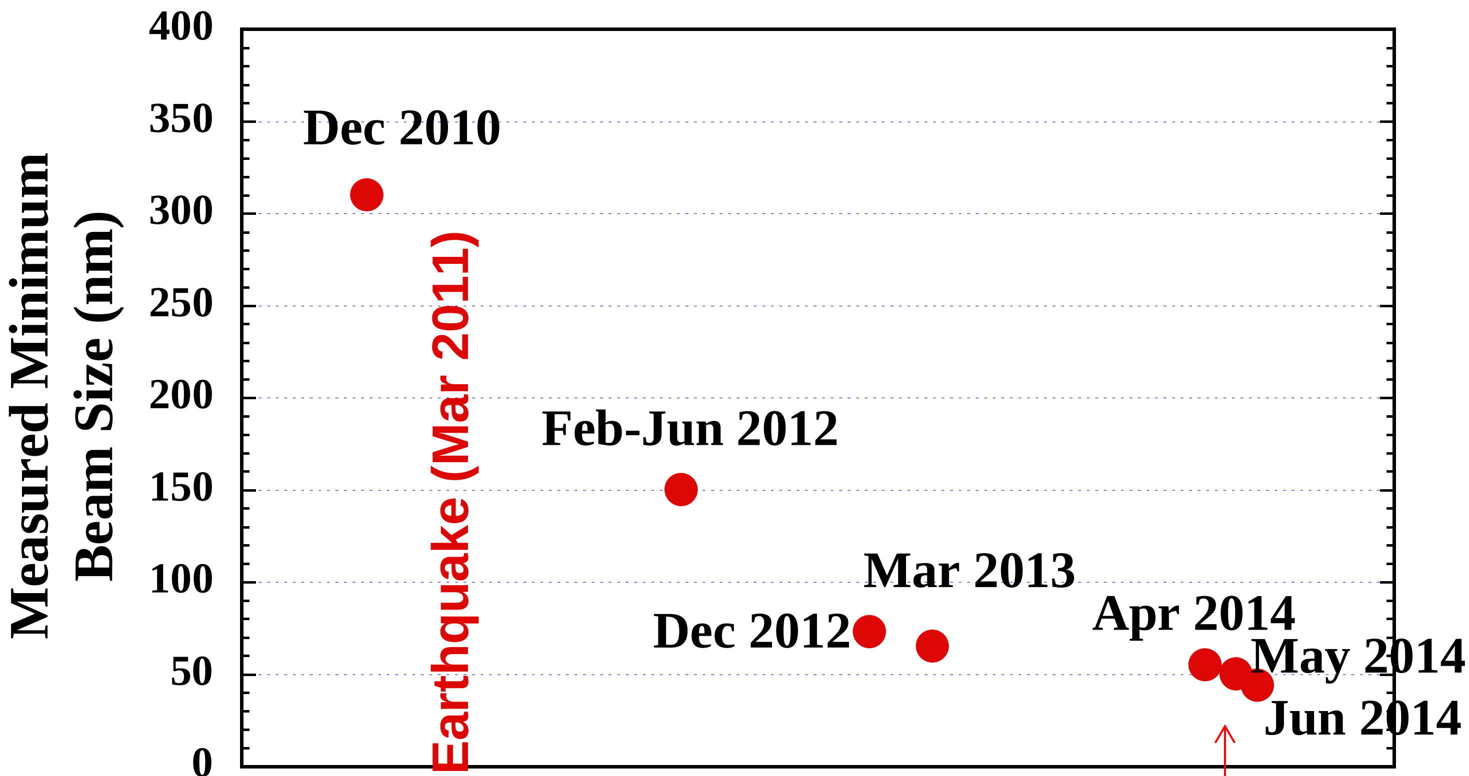


Modulation of Compton scattered photon rate from beam interaction with laser interference fringe pattern



Laser wavelength 532 nm

History of measured minimum beam size

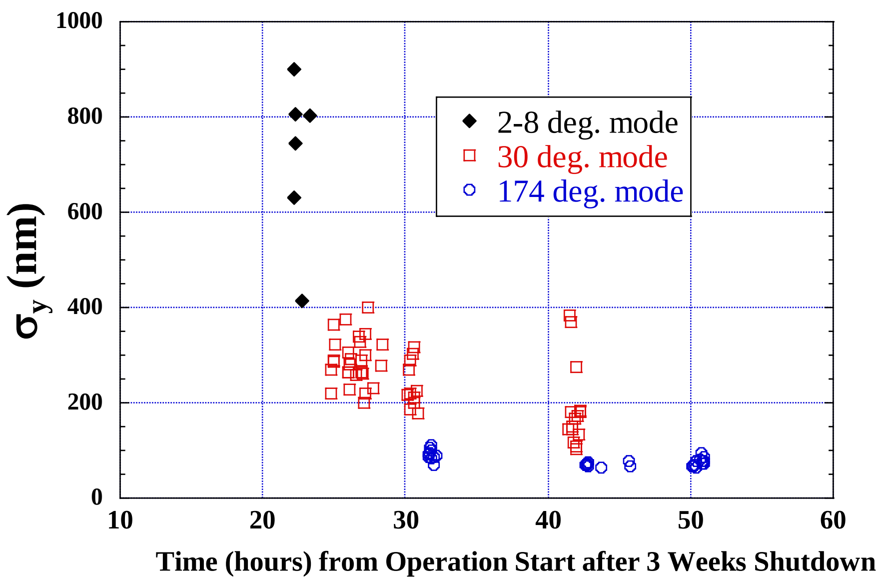


Bunch charge ~ 1-2 10^9 electrons → 1/5-1/10 × nominal
Horizontal β = 40 mm → 10 × nominal

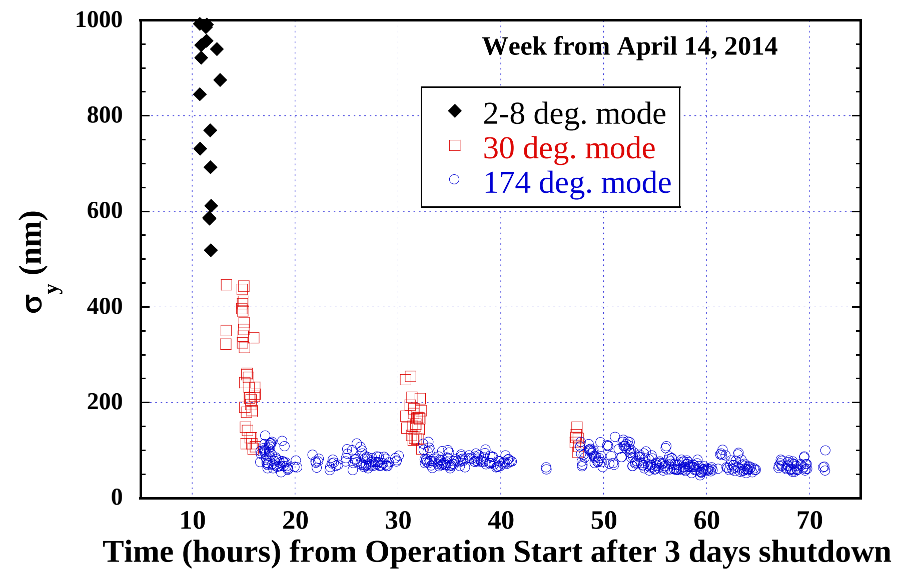
Still being improved.

Beam Size Tuning
after 3 weeks shutdown
Small beam (~60 nm) observed
~32 hours from operation start
~10 hours of IP beam size tuning

Beam Size Tuning
after 3 days shutdown
Small beam (~60 nm) observed
~16 hours from operation start
~8 hours of IP beam size tuning



Week 2014 April 7

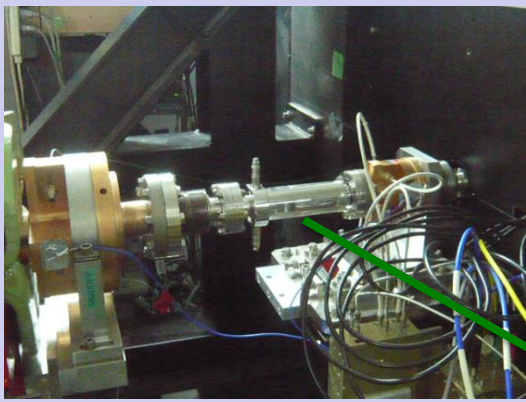


Week 2014 April 14

ATF2 goal 2 : nm-beam position stabilization

New kicker

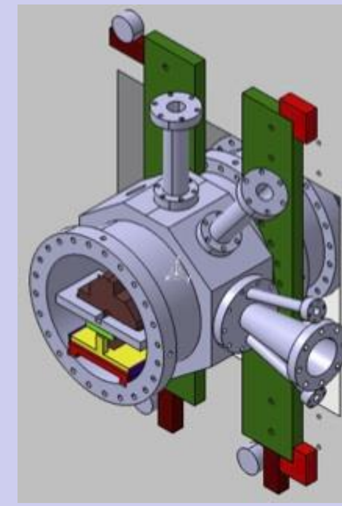
Installed near the ATF2-IP
Used since autumn 2012



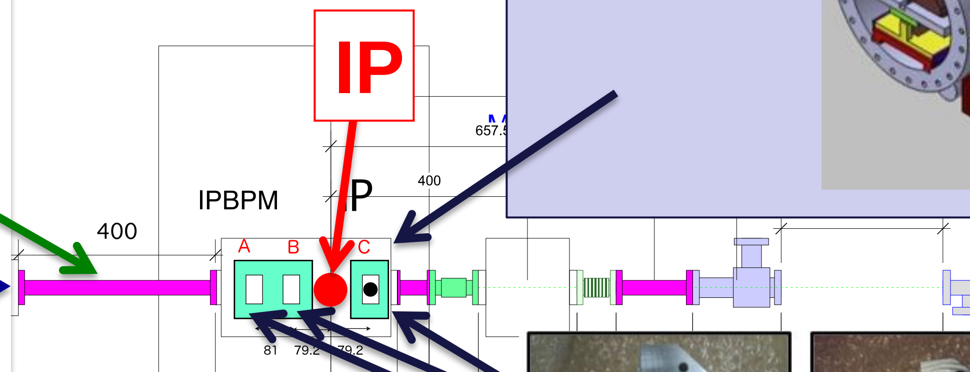
KEK
KNU
LAL
JAI/Oxford

New vacuum chamber

Precise positioning of IPBPM triplet



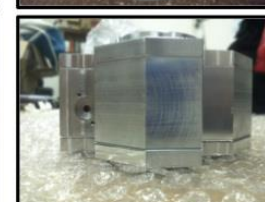
Beam



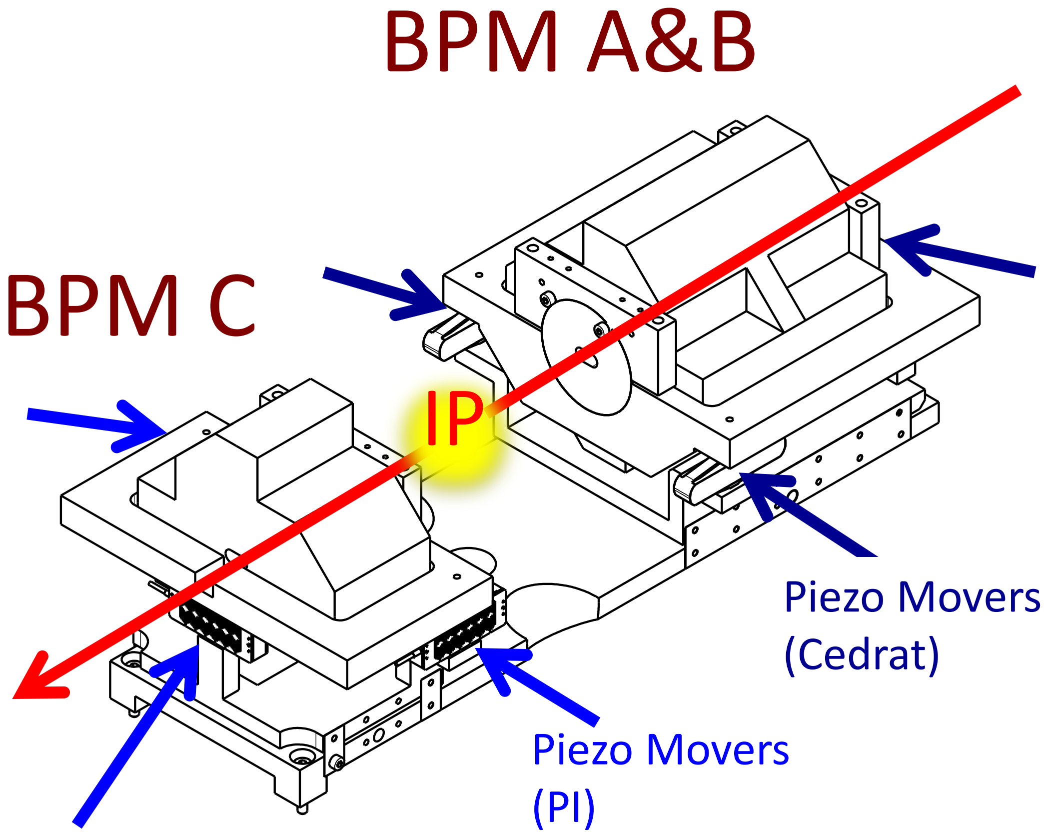
Triplet of New IPBPM

Low-Q short gap cavity light weight BPM
Sensitivity tested at ATF LINAC
Readout electronics tested at ATF2



In vacuum IP-BPMs and piezo movers



BPMs

- Bolted aluminum plates, no brazing because of In-vacuum.
- BPM A&B bolted together.
- BPM C is independent.

Piezo mover

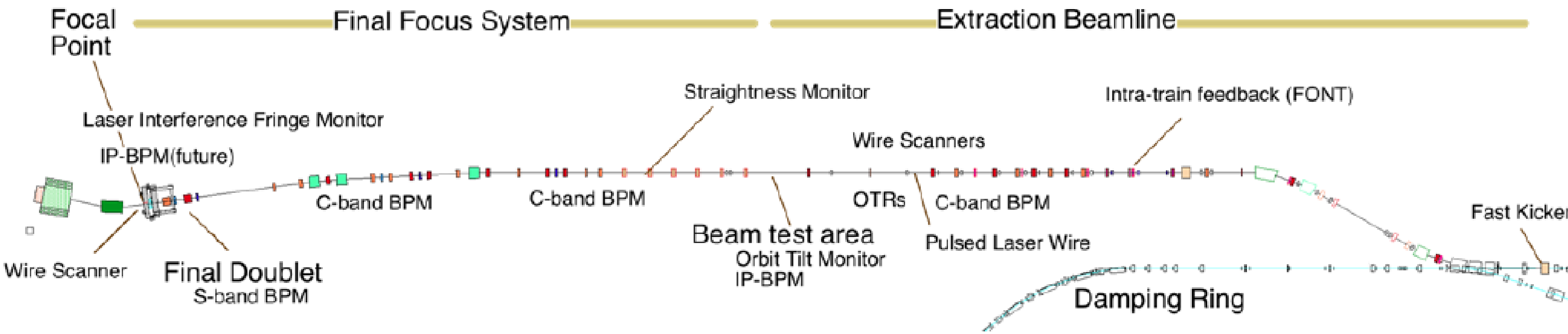
- BPM units are mounted on the base with three piezo movers.
- Dynamic range of each mover is +/-150 um.

  Initial alignment need to be better than this.

Installed summer 2013

Slide from Terunuma

Methodology for stabilization

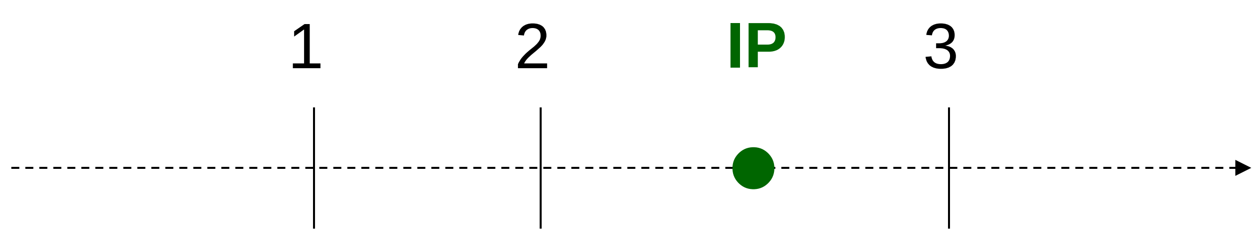


Goal 1 (beam size ~ 37 nm) **beam jitter < 10 nm**
Goal 2 (nm-scale stability with feedback) **beam jitter ~ 2 nm**

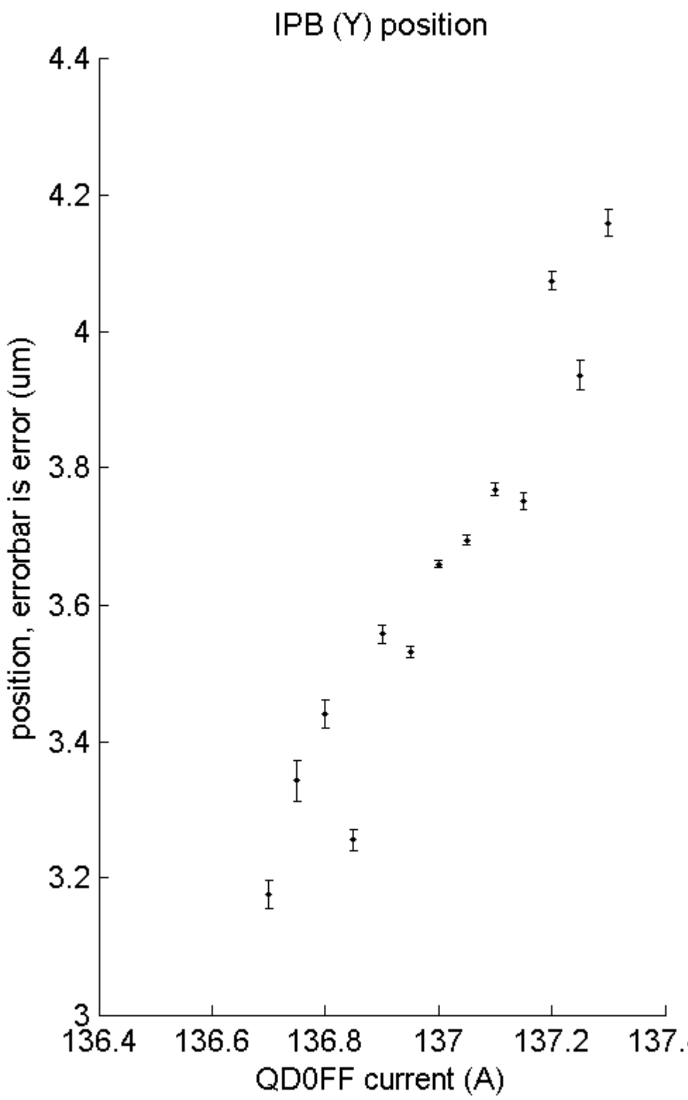
1. Measure stability at one of IP-BPMs after shifting the beam waists there
2. Infer position from measurements at the two other IP-BPMs
3. Use fast kicker just upstream of IP to correct second bunch within ATF2 train
4. Use fast feedback upstream to check for improved IP stability
5. Use fast kicker upstream for corrections based on IP-BPMs
6. Infer IP beam jitter based on IP-BPM measurement for use in beam size analysis

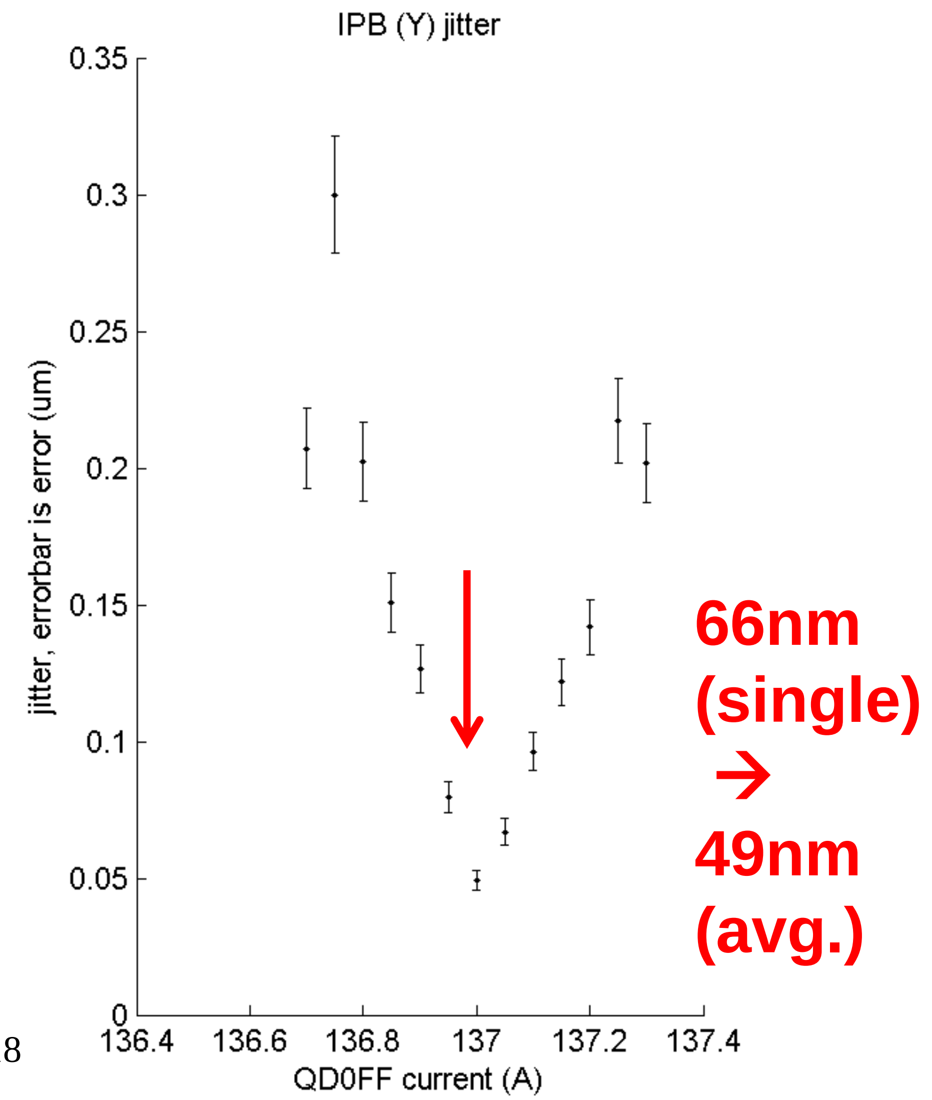
alignment - calibrate scale factors - study system resolution

beam kicker



Best standard jitter measurement





WP2 : Nanometre scale beam handling at the ATF

Objectives

1. Achievement and maintenance of nanometre scale beam size
2. Measurement and feedback to stabilise beam position at nanometre level
3. Development of advanced beam diagnostics instrumentation
4. Control of beam halo and background mitigation
5. Training of junior scientists and students in accelerator science

Participant Short Name	CERN	CNRS	CSIC	KEK	RHUL	UOXF	UoT
Person-months per Participant	31	50	12	13	21	49	2

➔ *Usual ATF beam operation: 21-21 weeks / year + maintenance (except 2014)*

Main focus of work

- ***Task 2.1*** ***Beam Size Minimisation*** ***(CERN, CNRS, KEK & UoT):*** Reduce effective β* parameter by improving corrections of optical aberrations. Install, commission and operate two new octupole correction magnets. Study alternative optics.
- ***Task 2.2*** ***Wake Field*** ***(CERN, CSIC, KEK & RHUL):*** Calculate and measure wakefields from beam position monitors and collimators. Test novel wake field free steering algorithm.
- ***Task 2.3*** ***Ground Motion*** ***(CERN, CNRS & KEK):*** Measure ground motion (GM) using 14 installed GM sensors synchronised with beam position measurements to assess novel GM based feed-forward algorithm. Test newly developed GM sensor.
- ***Task 2.4*** ***Halo Collimation and Backgrounds*** ***(CNRS, CSIC, KEK & RHUL):*** Calculate and measure beam halo propagation. Develop and test two new retractable collimators for halo reduction. Simulate beam induced backgrounds with GEANT4.
- ***Task 2.5*** ***Beam Instrumentation and control*** ***(CNRS, KEK, RHUL, UOXF & UoT):*** Operate, simulate and optimise performances of existing instrumentation, including laser wire and nanometre resolution beam position and size monitors. Install, commission and operate new radiation hard diamond sensor beam tail monitor. Develop and test new submicron optical transition/diffraction radiation beam emittance diagnostics.
- ***Task 2.6*** ***Beam Position Feedback*** ***(KEK & UOXF):*** Install, commission and operate fast digital feedback for nanometre level beam position stabilization at the collision point. Use beam tracking simulation to model and benchmark feedback performance.

Deliverables

- *Month 12* **HaloCollBgds-1**: Report on halo measurement and control using diamond sensor and collimators.
- *Month 12* **Instr-1**: Report on performance optimisation of installed high resolution beam position and size instrumentation.
- *Month 24* **Instr-2**: Design report of optical transition/diffraction radiation combined measurement station including initial beam tests.
- *Month 18* **GM-1**: Reports on synchronisation of GM and orbit measurements and on new GM sensor performance.
- *Month 24* **BeamSize-1**: Report on performance of installed octupole magnet pairs in correcting third order optical aberrations.
- *Month 24* **Wakefield-1**: Report on wakefield simulation and measurements including mitigation plans and implications for the Linear Collider.
- *Month 24* **Feedback-1**: Report on operation of collision point feedback system.
- *Month 24* **HaloCollBgds-2**: Report on integrated simulation and evaluation of beam transport including beam instrumentation and charged particle backgrounds.
- *Month 36* **Wakefield-2**: Report on wakefield free steering performance to mitigate wakefields.
- *Month 36* **GM-2**: Final report on correlation between GM and orbit measurements and implications for GM based feed-forward.
- *Month 48* **Feedback-2**: Final report on performance of interaction-point feedback system, and implications for its implementation in the Linear Collider.
- *Month 48* **BeamSize-2**: Final report on beam size minimisation in horizontal and vertical dimensions using optimised optics, and implications for the Linear Collider.

Conclusions and prospects

Stay tuned for very small & very stable beams in ATF2 in 2015-2018 !

ATF/ATF2 is a great opportunity for students and staff, in an international environment, especially for beam dynamics and instrumentation

→ Essential learning experience towards ILC/Japan & CLIC

And also useful for other projects…

H2020 / RISE / E-JADE will be of great importance to support the significant mobility to KEK needed for ATF2 research

Thank you for your attention !