ATF2 Commissioning Strategy & CERN participation in ATF2

Ralph Assmann, Hans Braun, Helmut Burkhardt, Angeles Faus-Golfe,
Maxim Korostelev, Andrea Latina, Peter Leunissen, Lionel Neukermans,
Stefano Redaelli, Daniel Schulte, Rogelio Tomas, Frank Zimmermann

a bit of history & references

R. Assmann et al, successful completion of ***CLIC stability study***: "***Tests in 2003 achieved stability to just 0.5 of a nanometre, making CERN one of the most stable places on Earth.***" (CERN press release), 2003

F. Zimmermann, ***ATF2 Commissioning Strategy***, ET&BDIR London Mtg, 22.06.2005

D. Schulte, ***CERN Contribution to ATF2***, ET&BDIR London Mtg, 22.06.2005

ATF MoU, established 1st August 2005, ***1st ICB Meeting***, Snowmass 2005

H. Braun et al, ATF2 Collaboration, ***ATF2 Proposal***, CLIC-Note-636, August 2005;

F. Zimmermann et al, ***CLIC R&D***, Nanobeam'05, Kyoto, October 2005

K. Okugi, ***Beam Instrumentation Devices for ATF2 Commissioning***,
Nanobeam'05, Kyoto, October 2005

1st TB & SGC joint meeting, KEK, December 13th, 2005

ATF2 mini-workshop, SLAC, 5 January 2005

1st ATF2 project meeting, SLAC, February 3-5, 2006

2nd TB & SGC mtg, KEK, 28-29.05.2006, ***2nd ATF2 project mtg,*** 20.05/01.06.2006
2nd ICB Meeting, Vancouver, 20 July 2006

F. Zimmermann et al, ***ATF2 Discussion***, CLIC Steering Committee, 24.08.2006

Strategy for ATF-2 Commissioning with Beam

Frank Zimmermann, CERN

discussions with
Yosuke Honda, KEK
Daniel Schulte, CERN
Andrei Seryi, SLAC

EUROTeV&BDIR Meeting, London, June 2005

general considerations:

- based on *operational experience gained at SLC & FFTB*
- employ similar procedures
- commissioning should comprise:
  - steering beam to dump
  - beam-based alignment of BPMs & magnets
  - verification & correction of linear & nonlinear optics
  - set up of precision diagnostics & feedback systems
  - tuning of focal-point (FP) spot size
- reliable provision of stable low–ε beam from ATF ring essential for rapid commissioning & achieving targeted spot size & stability
- tuning simulations with errors need to be performed prior to commissioning to understand level of accuracy required for each tuning step
- online model ('flight simulator') will be a great help
- 12 commissioning steps are proposed

(1) Pre-alignment without beam:
prior to beam operation all magnets are aligned with precision of **50-100 μm** with respect to smooth line

(2) Steering and ballistic alignment with dipole magnets only:
range of **rf BPMs** expanded by **attenuators**; conventional BPMs and screens useful; incoming beam orbit adjusted to “0” with “0” slope; possibly use relaxed incoming optics; **send ballistic beam between pairs of adjacent dipoles to determine BPM readings for beam defining straight line**; align BPMs with large offsets; adjust strengths of individual dipoles to keep beam centered in beam pipe; dipole roll errors are evident as vertical deflections; include BPM offsets in database and automatically subtract them for all later measurements;

remarks: ballistic alignment may be conducted in steps, switching or keeping off groups of quadrupoles, and possibly adjusting downstream optics for safe beam extraction; profile monitor in front of dump will indicate clean extraction; for understanding rf-BPM properties repeat ballistic alignment at various levels of attenuation

(3) Optics verification, alignment & correction with dipoles & quadrupoles:

study local optics with **dipoles & quadrupoles on**, but sextupoles still off (chromatic effects likely not a problem except for at the FP);

A) minimize steering effects of quadrupoles by changing transverse quadrupole position until beam follows ballistic trajectory of step (2); if required more complex BBA procedure could be applied for the quadrupoles (as in sector-1 of SLAC linac);

B) next, **characterize optics** by **exciting steering correctors** one by one,and measure **orbit response at all BPMs**; correct for incoming orbit changes with upstream BPMs; compare measured response matrix with model prediction; correct significant errors by adjusting quadrupole strengths and/or by verifying longitudinal magnet positions; modified LOCO code could be used for data analysis;

<u>remark:</u> instead of using steering correctors, the transverse quadrupole positions could also be varied for measuring the BPM response

(4) Dispersion matching and dispersion-free steering:

measure dispersion by injecting beam at different energies; **beam energy** is varied by changing ring rf frequency; **practical range +/-0.65%,** limited by finite aperture at high dispersion point (D=2.5 m) in extraction line; **incoming dispersion** inferred from slope of orbit readings vs. beam energy for BPMs at start of line;

(A) dispersion match into final focus accomplished by two normal and two skew quadrupoles in region with nonzero dispersion (QF3X, QF4X, QS1X, QS2X);

(B) after matching the incoming dispersion , **residual dispersion and orbit errors downstream** are corrected simultaneously using **dispersion-free steering;**

<u>remark:</u> varying the ring rf may also change the beam orbit at start of extraction line if dispersion at kicker & septum is not zero; simultaneous change of energy and orbit is not a problem, since combined effect is the "beam dispersion" which we correct; however, ring dispersion in extraction region needs to be stable

(5) Betatron matching and coupling correction:

measure incoming Twiss parameters, including coupling, in diagnostics section; use four or more quadrupoles at entrance of final focus to **adjust final-focus optics to measured β & α functions**; quadrupoles are varied together and need to be computed iteratively as so-called **nonlinear “Irwin knobs”;** incoming **coupling is removed with 4 skew quads** in skew correction section

(6) Squeezing or adjusting β*

Irwin knobs at entrance of final focus also offer **possibility to vary β*;** it might be wise to **start commissioning with relaxed optics** and squeeze β* later; control at **pre-image point** whether spot size & demagnification agree with expectation; if emittance is measured in diagnostics section, **β*** can also be inferred from **beam size at wire scanner close to final quadrupole**; in ATF-2 two such wires could be mounted, on incoming and outgoing side of the FP

(7) Chromatic correction, beam-based alignment of sextupoles, optics verification with sextupoles:

turn on sextupoles one by one; for each sextupole could measure the BPM corrector response (LOCO);

(A) **scan transverse sextupole position and find magnetic center** using either measured quadratic orbit deflection (FFTB style) or changes of waists, dispersions, and coupling (SLC style);

(B) **re-measure BPM corrector response** matrix after sextupole alignment;

(C) horizontal and vertical deflections induced by a sextupole when its position is varied allow **measurement of R_{12} and R_{34} matrix elements between sextupole and sextupole-BPMs** downstream; if matrix element larger than tolerable optics corrections (e.g., changes of quadrupole strengths) will be required;

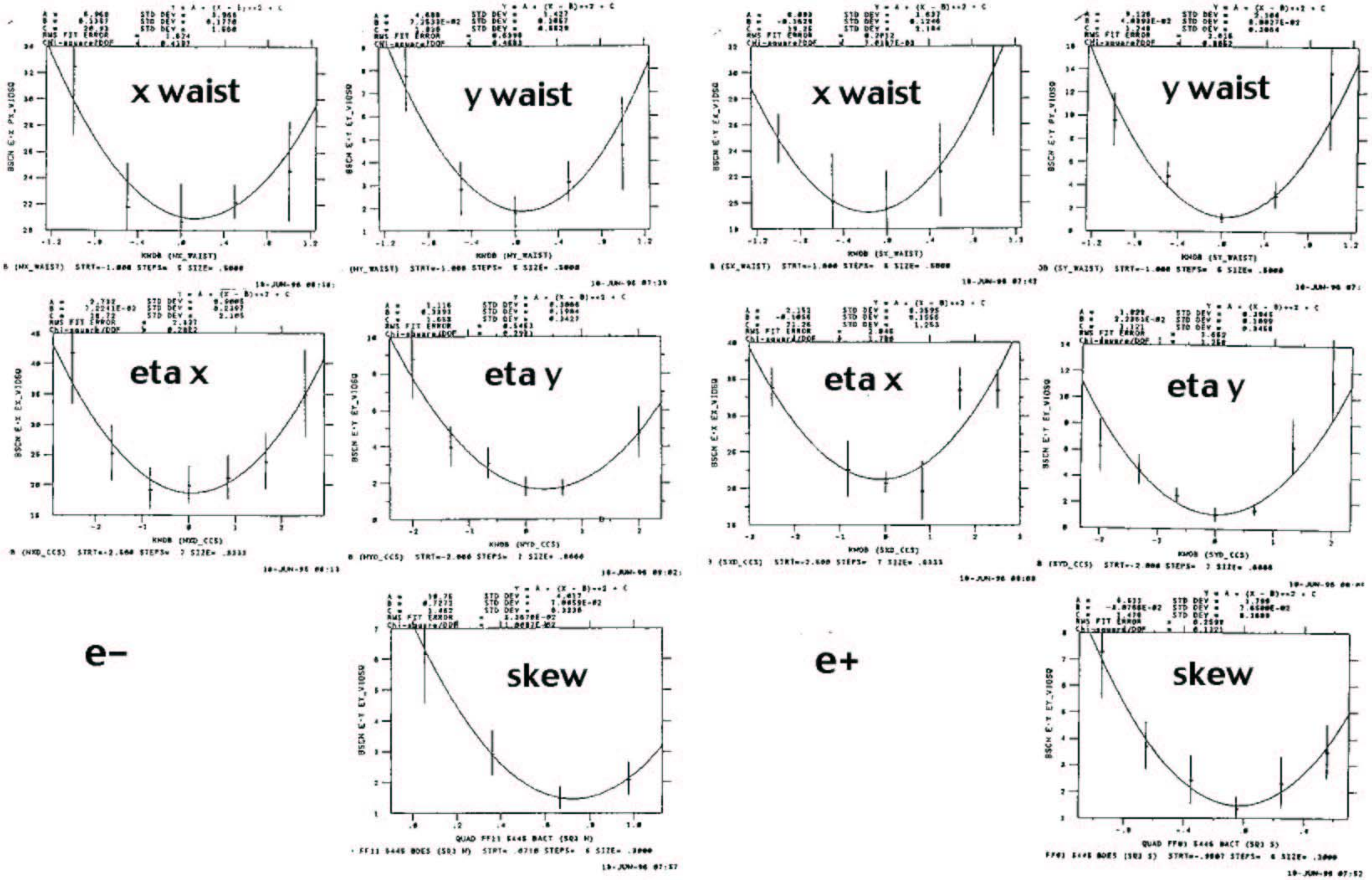
(D) after aligning all elements, increase rf-BPM resolution and **decrease rf-BPM range**

(8) Activating orbit feedback loops across critical regions:

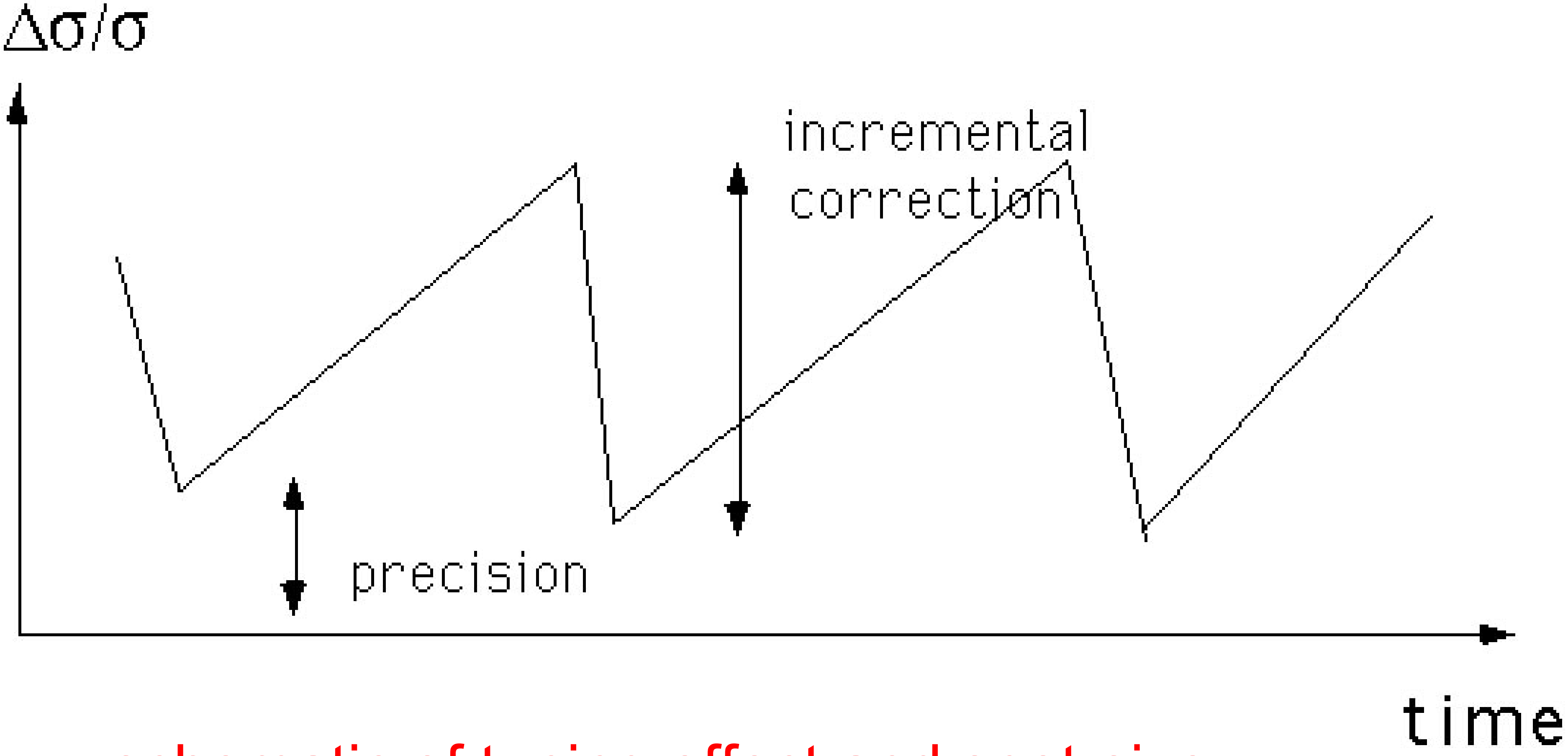
after beam-based alignment, orbit in critical regions must be maintained by **slow orbit feedback loops**; critical regions include the FP area, the region covering final-focus sextupoles, and diagnostics section; feedbacks need to be commissioned and their performance validated; possible cross talk & cascading; alternative could be one global orbit feedback with higher weights assigned to critical BPMs, like sextupole-BPMs; feedbacks stabilize orbits and optics throughout the system on time scale of minutes, which is precondition for successful spot-size tuning

(9) FP spot size tuning in regular intervals

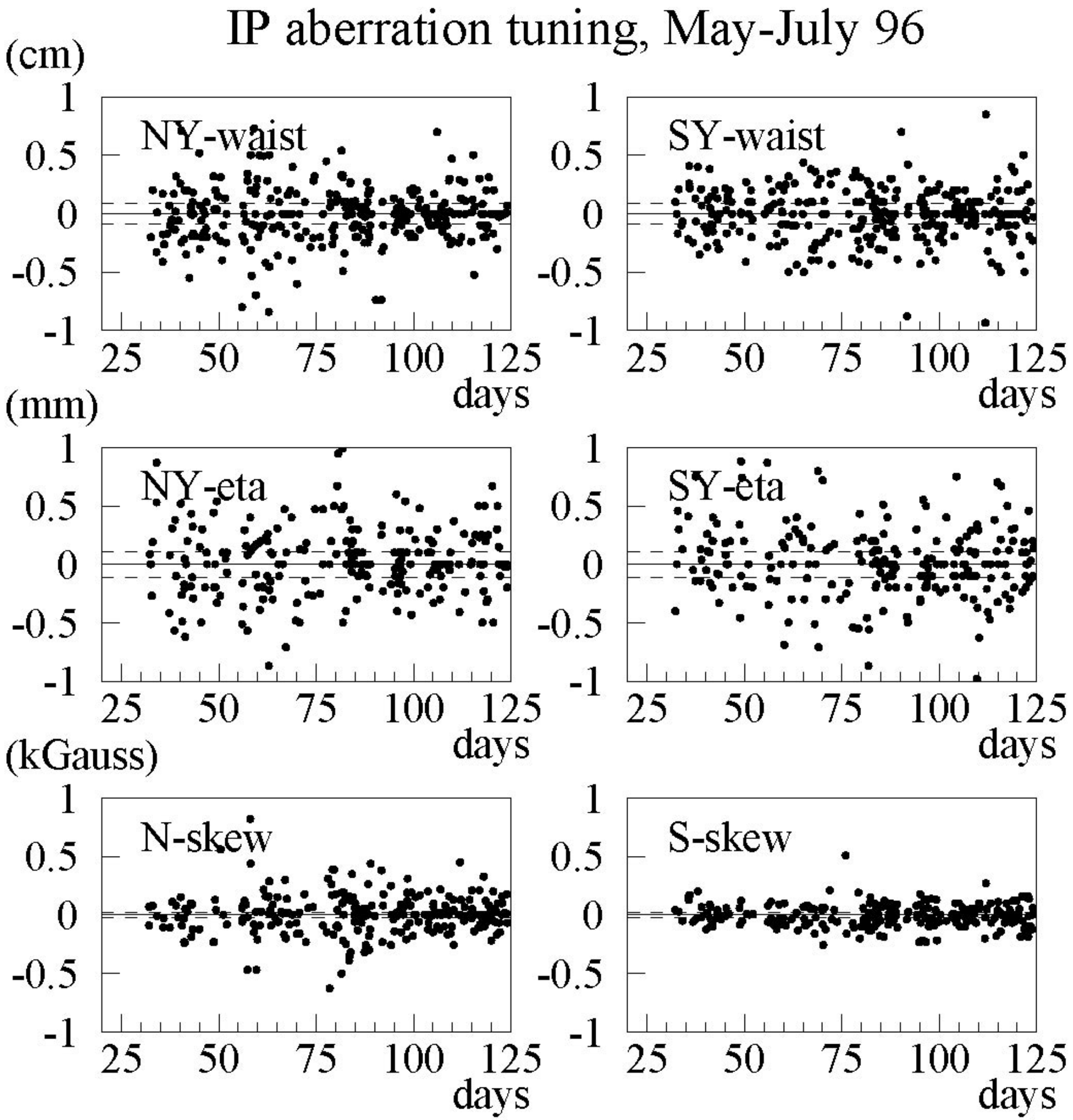
tune out residual aberrations at focal point using special orthogonal tuning knobs, which consist, e.g., of transversely moving two or three sextupoles with fixed step-size relation; maximum range of tuning knobs limited by additional higher-order aberrations which they introduce, due to interleaving of sextupoles; good upstream optics correction therefore is very important; tuning knobs control **waists, dispersion, coupling, sextupolar aberrations, ξ, higher-order terms,…** tuning needs to be repeated **in regular intervals** (hours); tuning by **dither feedback** optimizing spot size related signals vs. known step changes may be essential for achieving and maintaining the target spot size (SLC style)



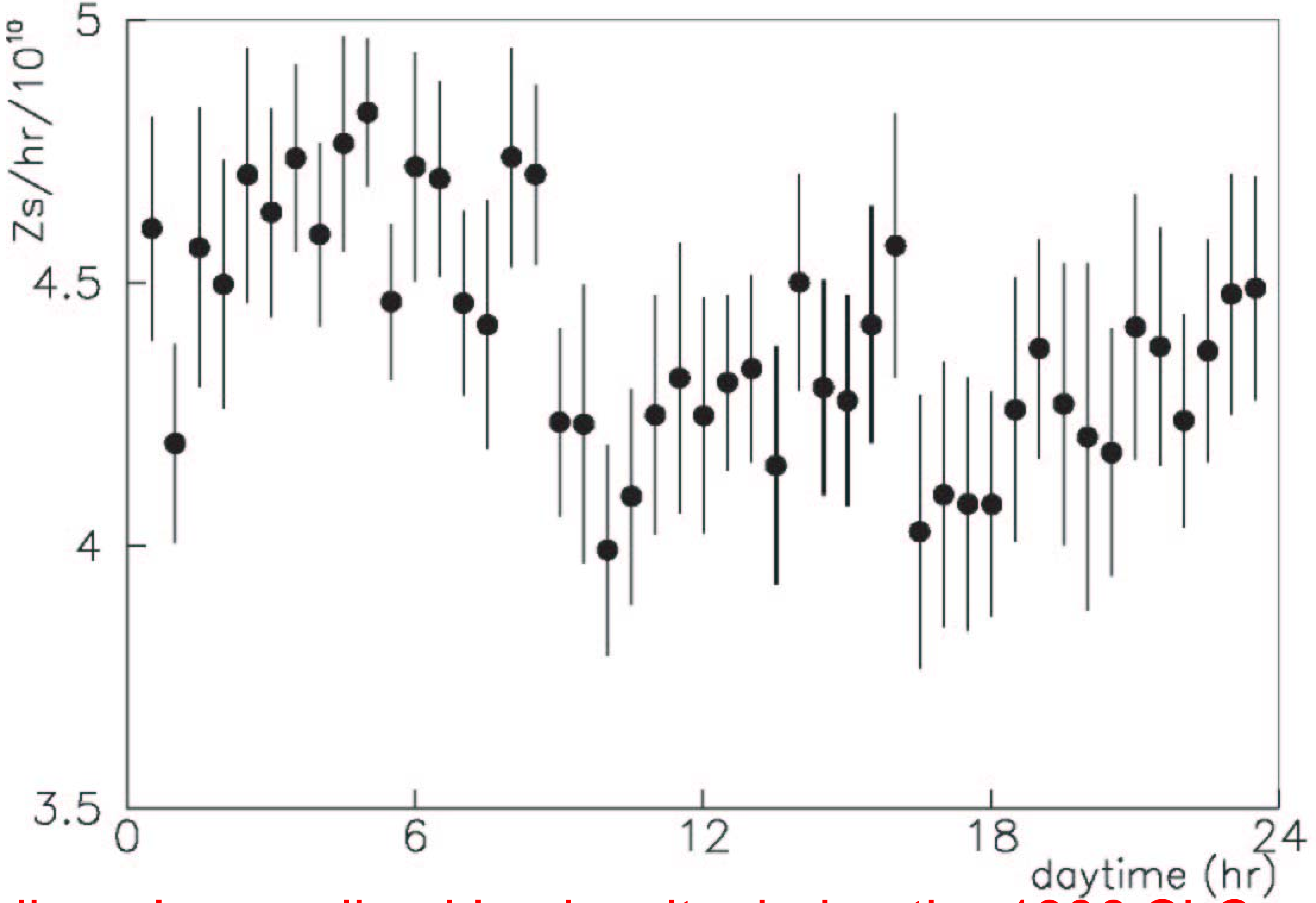
aberration scans at SLC collision point



schematic of tuning effect and spot-size increase between tunings



incremental IP corrections of waist, dispersion and coupling during the 1996 SLC run



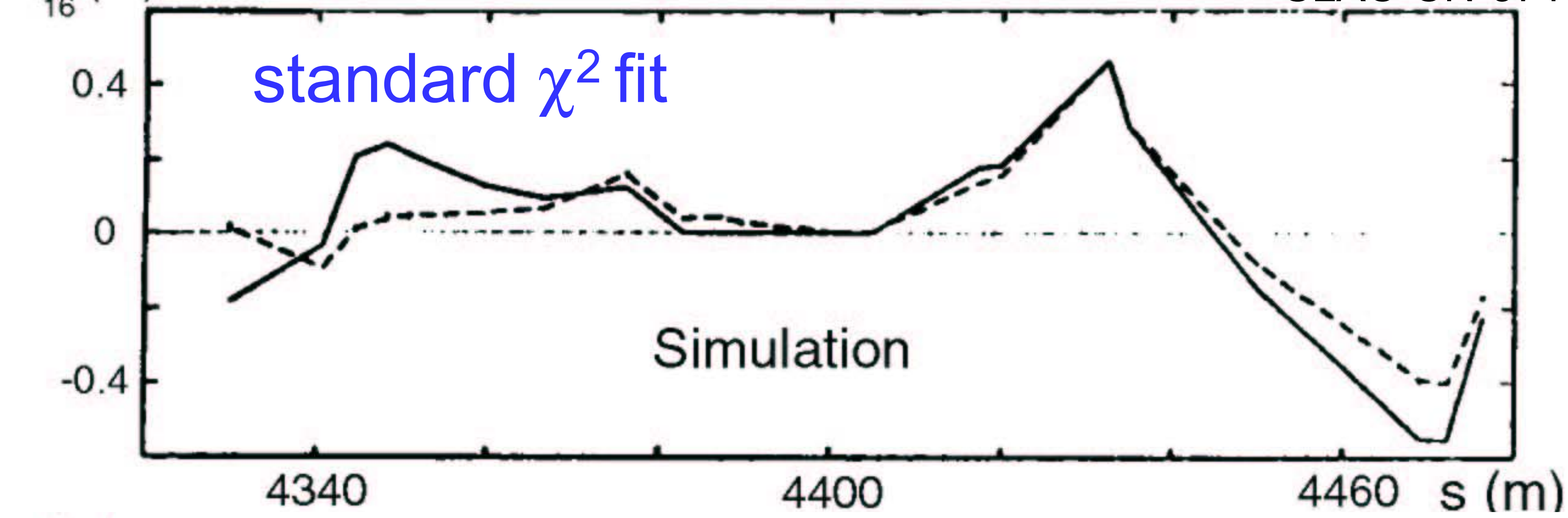
diurnal normalized luminosity during the 1996 SLC run; steady increases in day & swing shifts, drops at 8&16 h

(10) Continuous monitoring of the optics using jitter data or diagnostics pulse:

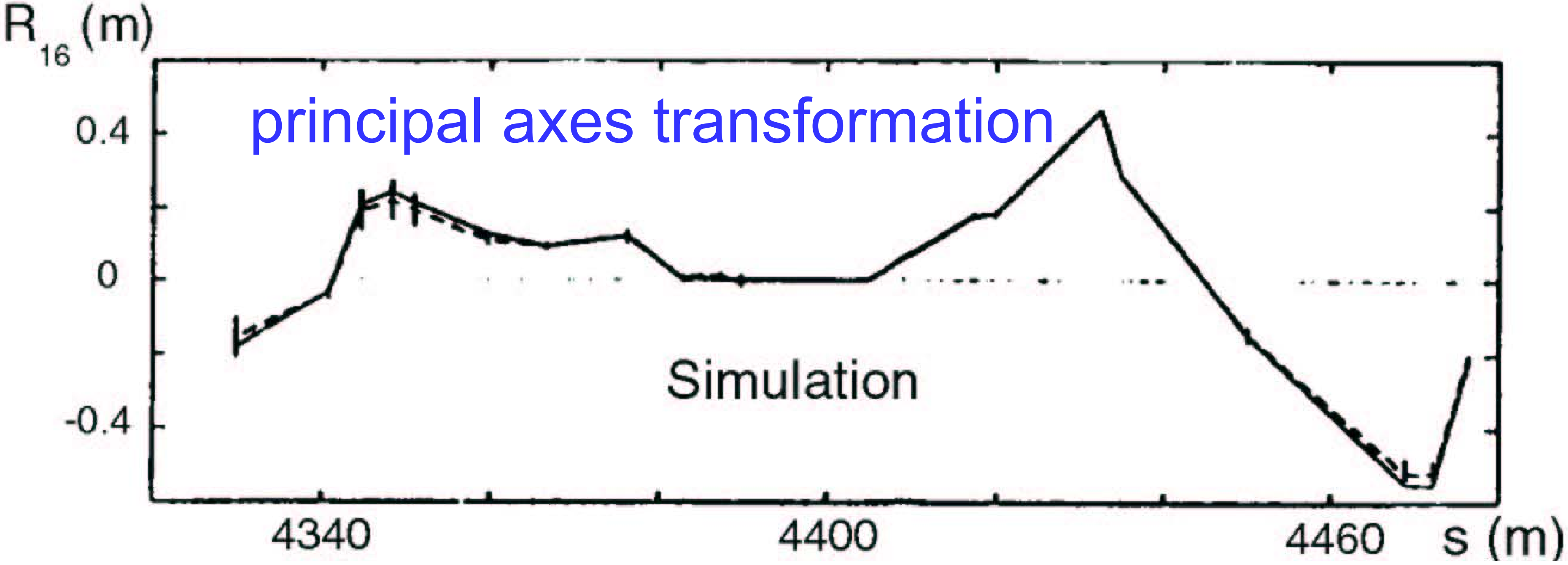
continuous optics quality control can be achieved in various ways; for the SLC a method was developed which **analyzed jitter data** (Lohse & Emma); also **sum readings of certain BPMs** allowed automatic detection of movements or dipole strength errors in the SLC chromatic correction section (where 80 μm diurnal variation was observed); another possibilty might be sending a diagnostics pulse as used in the SLAC linac

R matrix element R_{16} re-constructed from 100 jitter trajectories

T. Lohse, P. Emma,
SLAC-CN-371



standard χ^2 fit

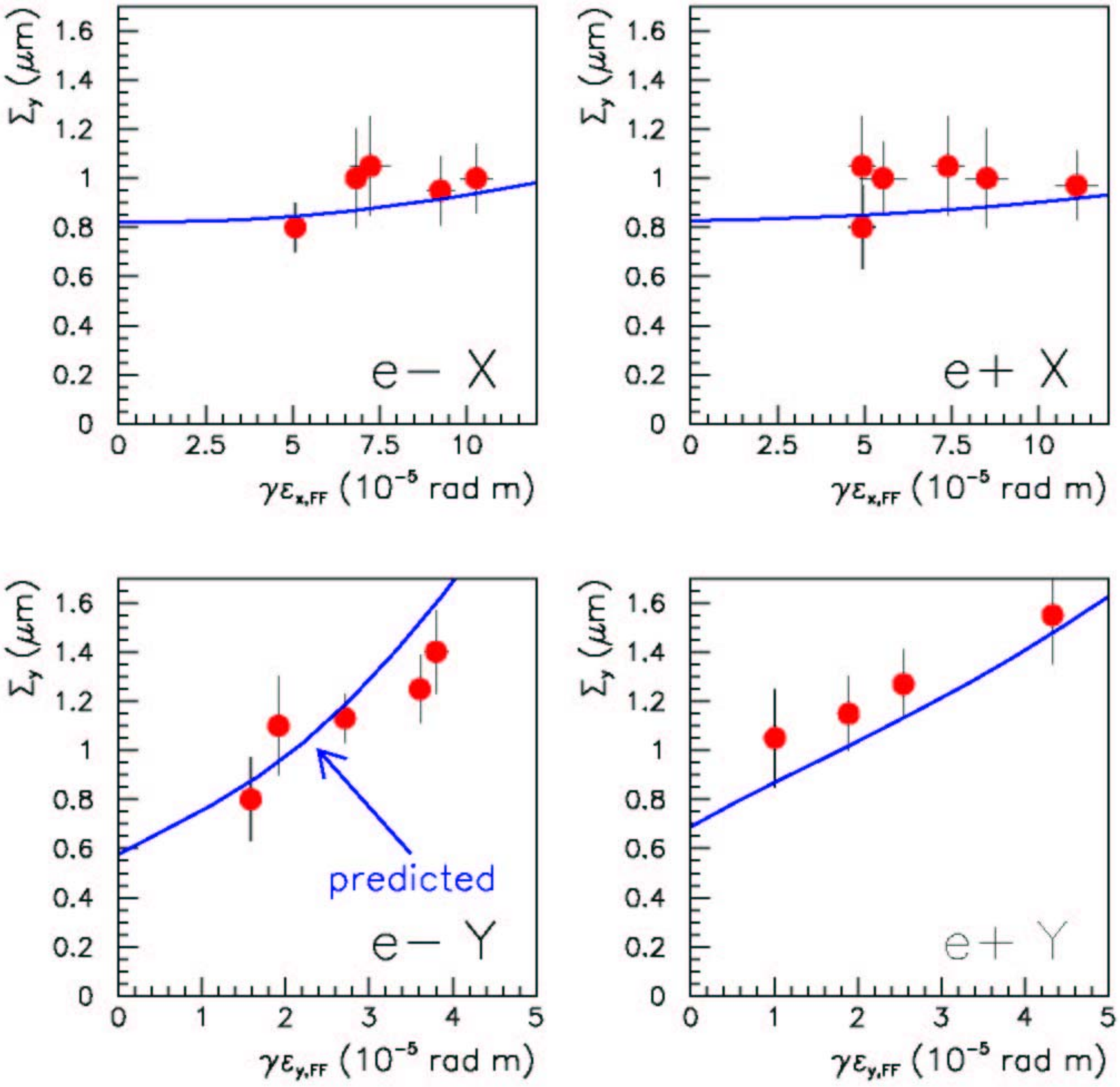


principal axes transformation

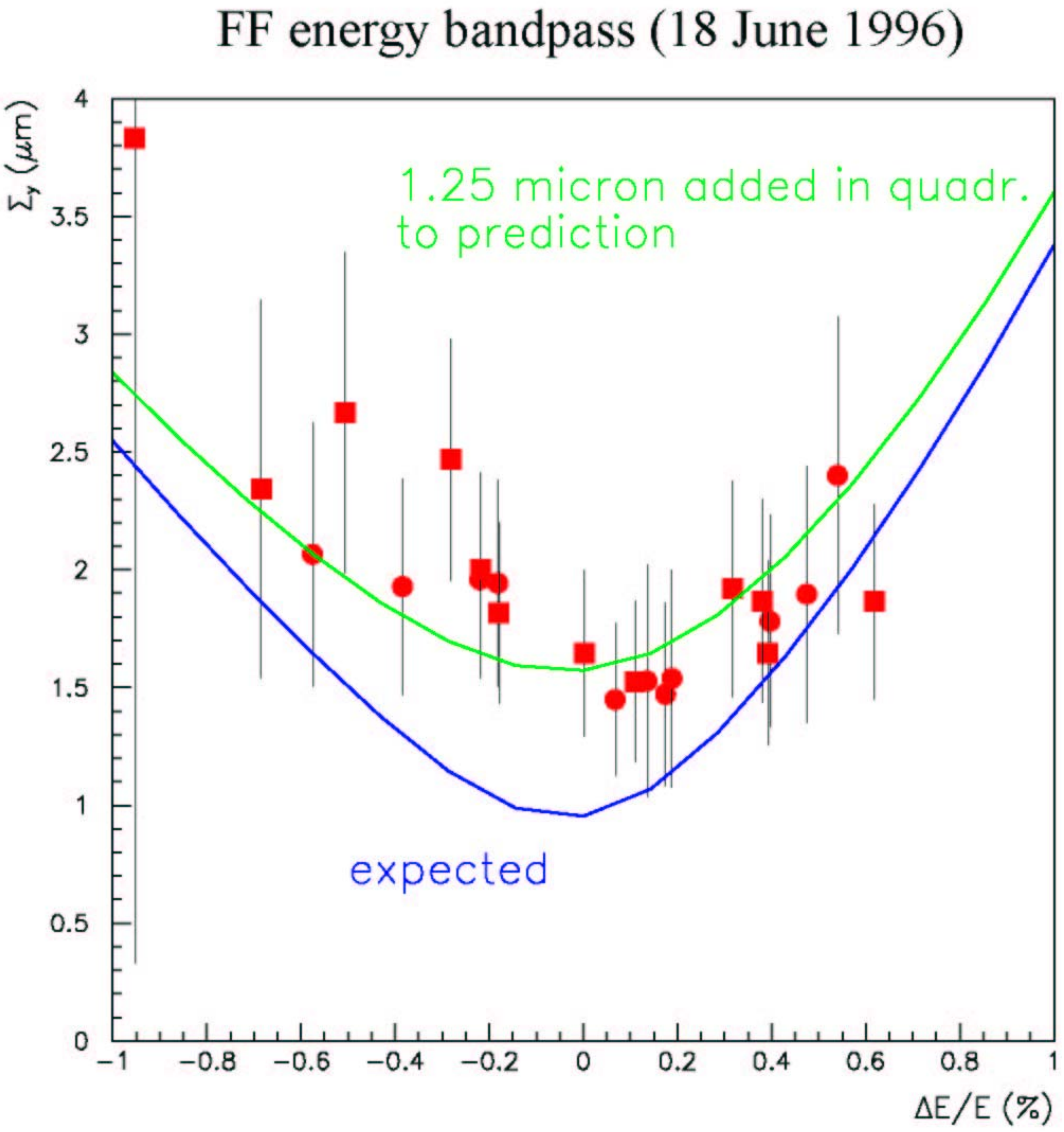
(11) Characterization of the system’s optical properties:

systematic measurements could **characterize optical properties**; useful for comparison with model & for identifying sources of dilution; examples: **spot size vs. beam emittance** (varied in the ring – horizontal emittance change by intentional mismatch, early extraction?!), **incoming beam energy, initial orbit** conditions; spot size can also be measured as function of **β* and intensity**

Y Spot Size vs. Final-Focus Emittances



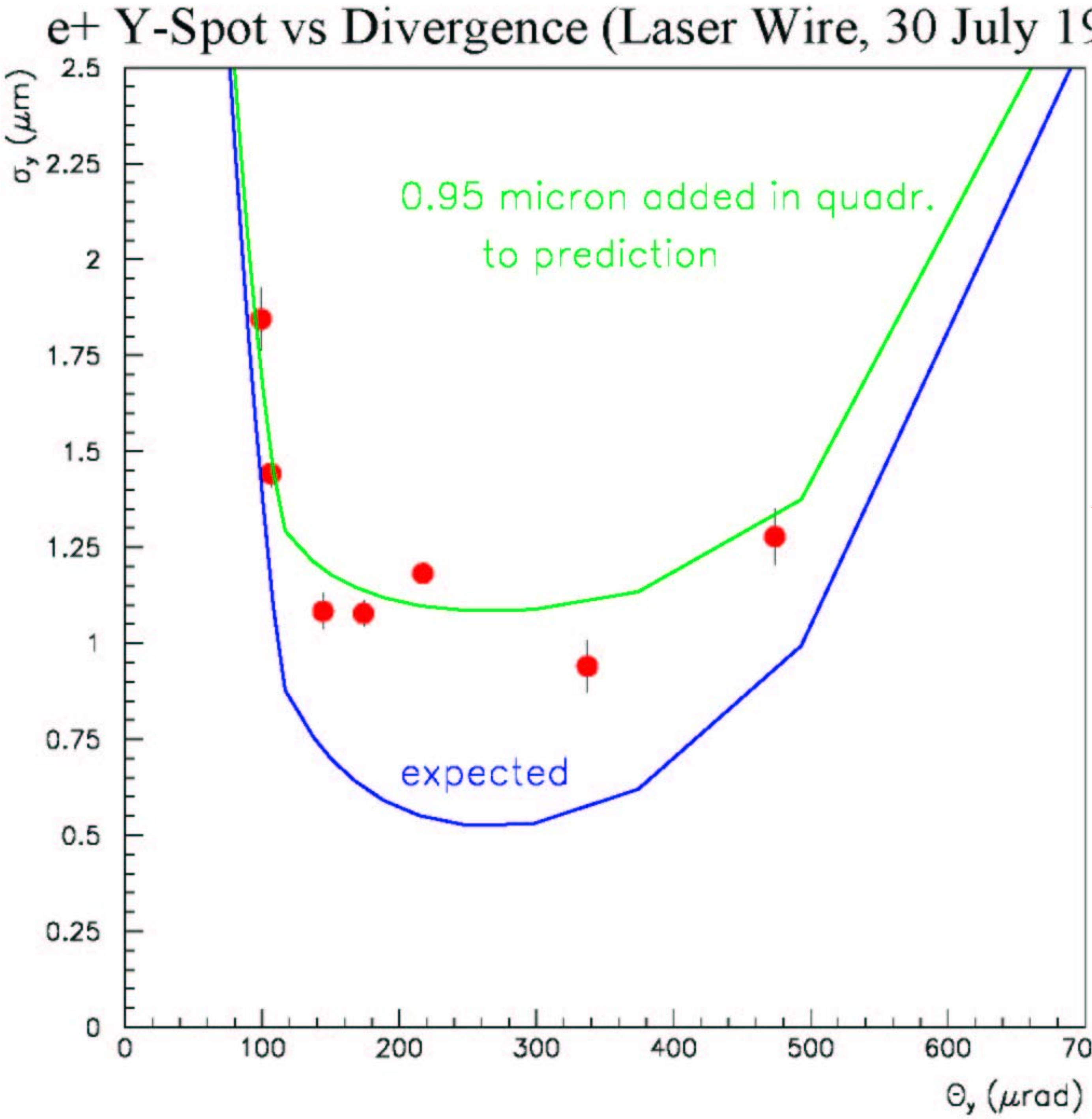
vertical convoluted IP spot size measured at low current as function of the 4 beam emittances; solid line is SLC final-focus flight-simulator prediction



vertical convoluted IP spot size measured at nominal SLC current as function of centroid energy; rms energy spread ~ 0.1%;

blue line is FFFS prediction

green line has 1.25 μm added



laser wire measurement of e+ IP beam size as function of vertical IP divergence, varied with Irwin knobs; blue line is FFFS prediction, green line has 0.95 μm single-beam dilution added in quadrature

further 93/94 SLC spot size measurements

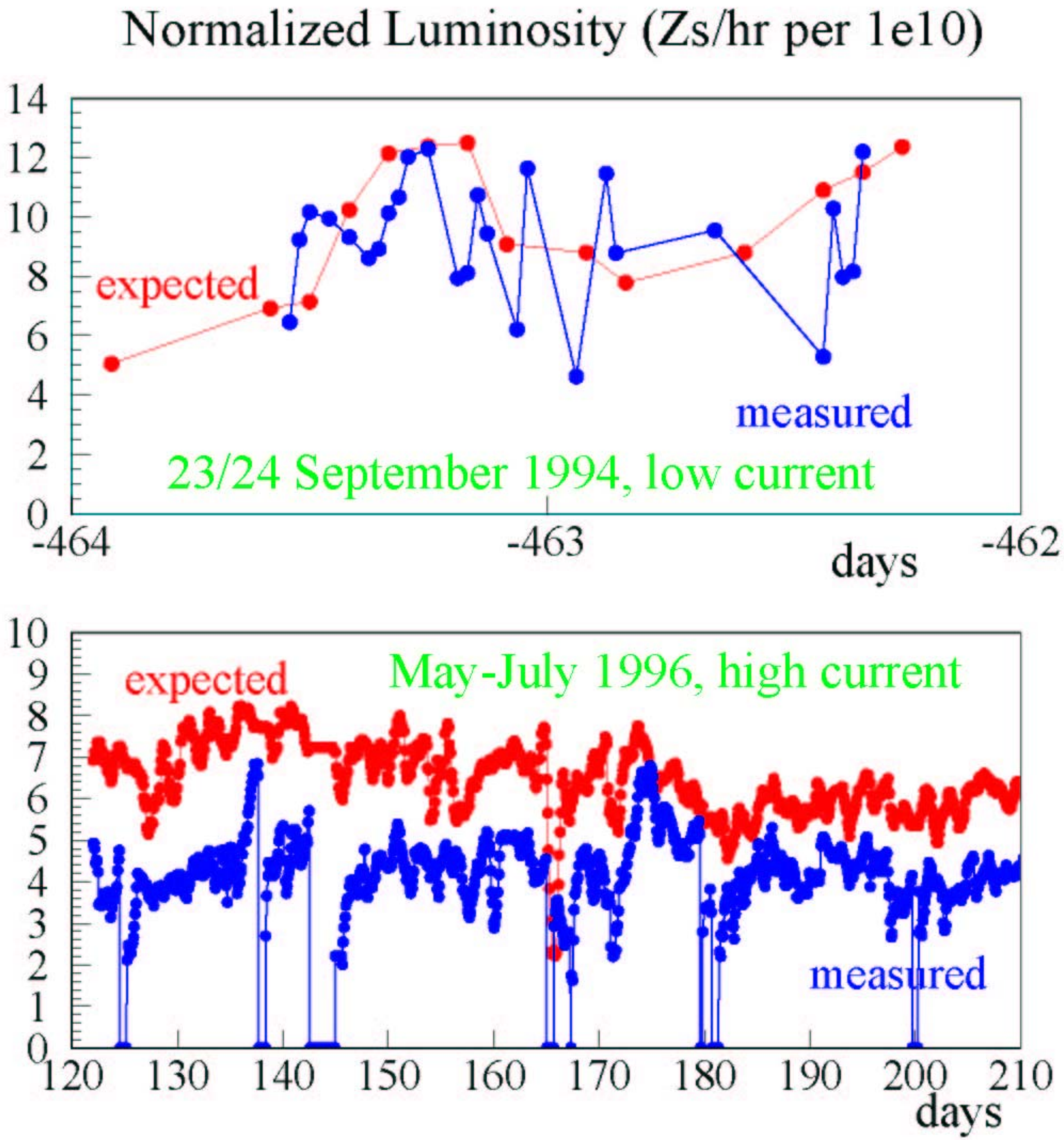
attempt to detect pulse-to-pulse variations in spot size, by colliding beams off center;
~30% variation

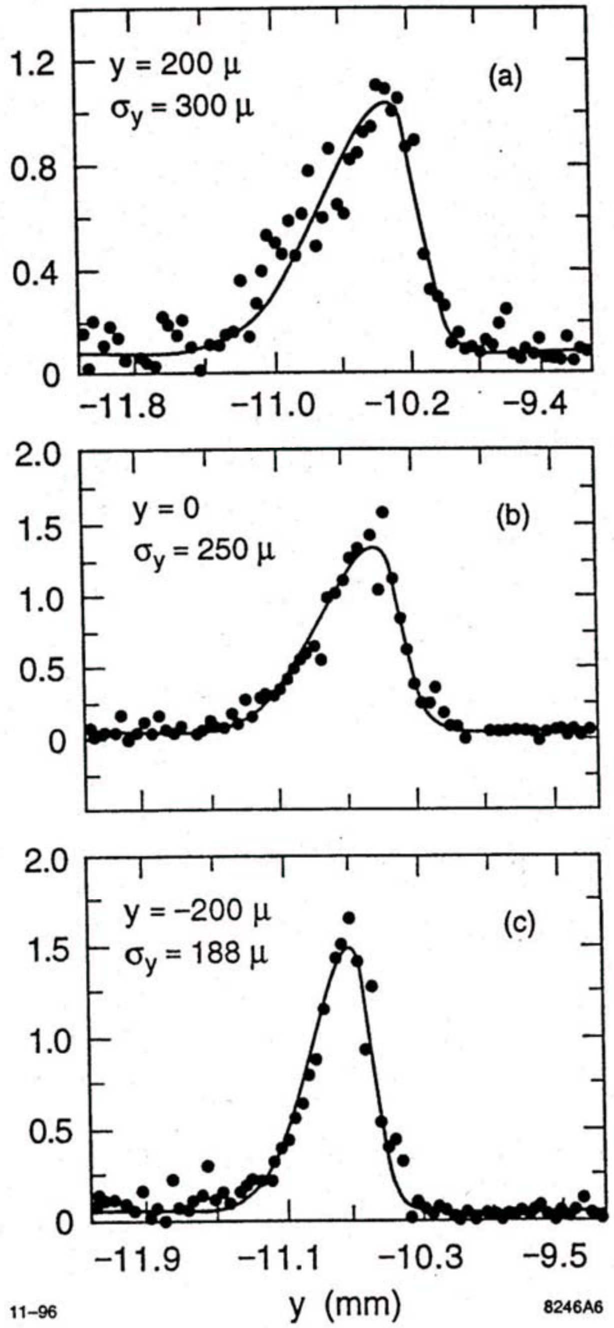
effect of incoming orbit: 2 mm orbit change at entrance of final focus increased IP spot size by factor 4.5, asymmetry indicated skew sextupole of 2×10^{-5} at 21 mm

IP beam position vs beam energy
→ 2nd order dispersion at IP, ~20 mm

(12) Multibunch operation & higher intensity

quantify **magnitude of wake fields** by studying **intensity dependence of spot size and beam orbit**; **multibunch operation** may require changes or upgrades to some of the diagnostics comparison of SLC luminosity expected from measured FF emittances and IP divergences with actual luminosity inferred from IP spot size measurements at low and high current





an orbit change of a few 100 microns in the SLC “Upper Transformer” could have a dramatic effect on spot sizes measured downstream, which has been attributed to wake fields

commissioning studies in collaboration with Okugi san, Nanobeam 2005

ATF2 has huge peak beta_y function ~10 km, so that *10 μm orbit offset at quadrupole generates 1 mm vertical orbit excursion at large β*

dynamic range of rf BPMs 250 μm, requires 20 dB attenuators

~30 minutes needed for readout electronics phase adjustment per rf BPM

beam must be passed to the dump during set up

→ we recommended several stripline monitors or profile monitors for safe and reliable operation

more commissioning studies in collaboration with Okugi san, Nanobeam 2005

Shintake monitor cannot measure beam sizes larger than 1 μm; one beam size measurement takes *~1 hr*

→ we recommended additional beam-size monitors, most likely carbon wires (range > 1 μm, 1 min per scan) and/or Mitsuhashi/Naito type

secondary monitors are installed at +/- 50 cm from main IP; the beam waist must be moved to secondary beam-size monitors by doublet change; minimum beam size at 2ndary IP ~ 200 nm

commissioning studies by Okugi san, Nanobeam 2005

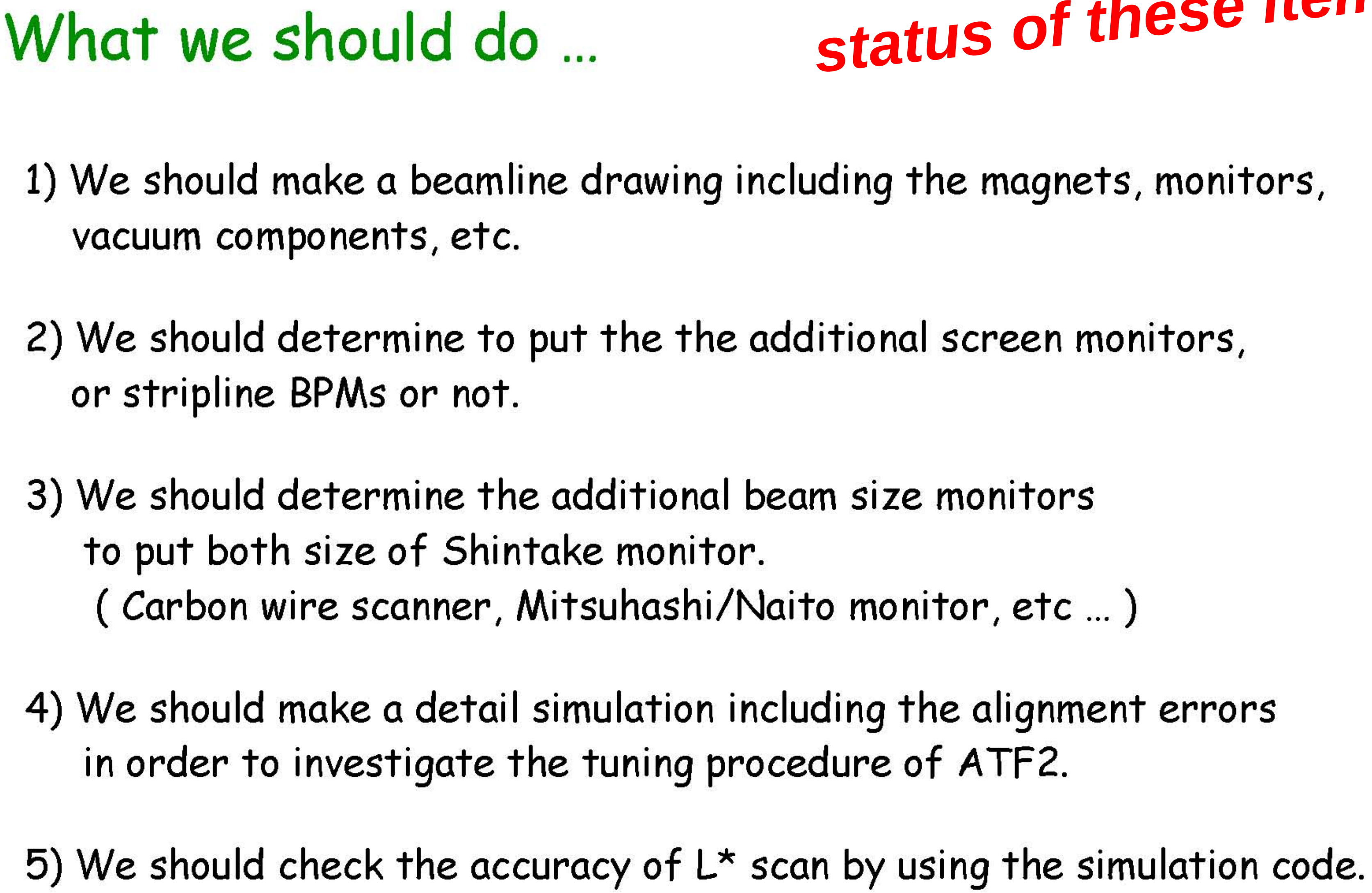
Shintake monitor requires *vertical position scan with step size ~30 nm*, achieved by varying quad position with fine guider

vertical beam offset at final-doublet sextupoles introduces coupling (why not changing the vertical position of the monitor instead?)

QF5A movement identified as best knob (4 μm scan range)

commissioning studies by Okugi san, Nanobeam 2005

status of these items?



What we should do …

1) We should make a beamline drawing including the magnets, monitors, vacuum components, etc.

2) We should determine to put the the additional screen monitors, or stripline BPMs or not.

3) We should determine the additional beam size monitors to put both size of Shintake monitor.
(Carbon wire scanner, Mitsuhashi/Naito monitor, etc …)

4) We should make a detail simulation including the alignment errors in order to investigate the tuning procedure of ATF2.

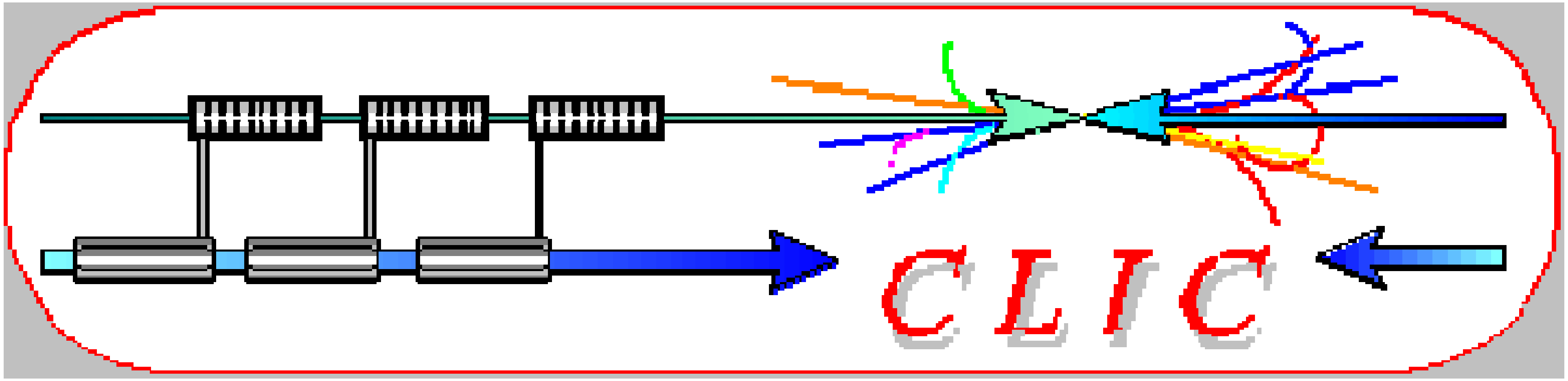
5) We should check the accuracy of L* scan by using the simulation code.

CERN contributions to ATF&ATF2

IFIC–Valencia

CSIC

Univ. Valencia

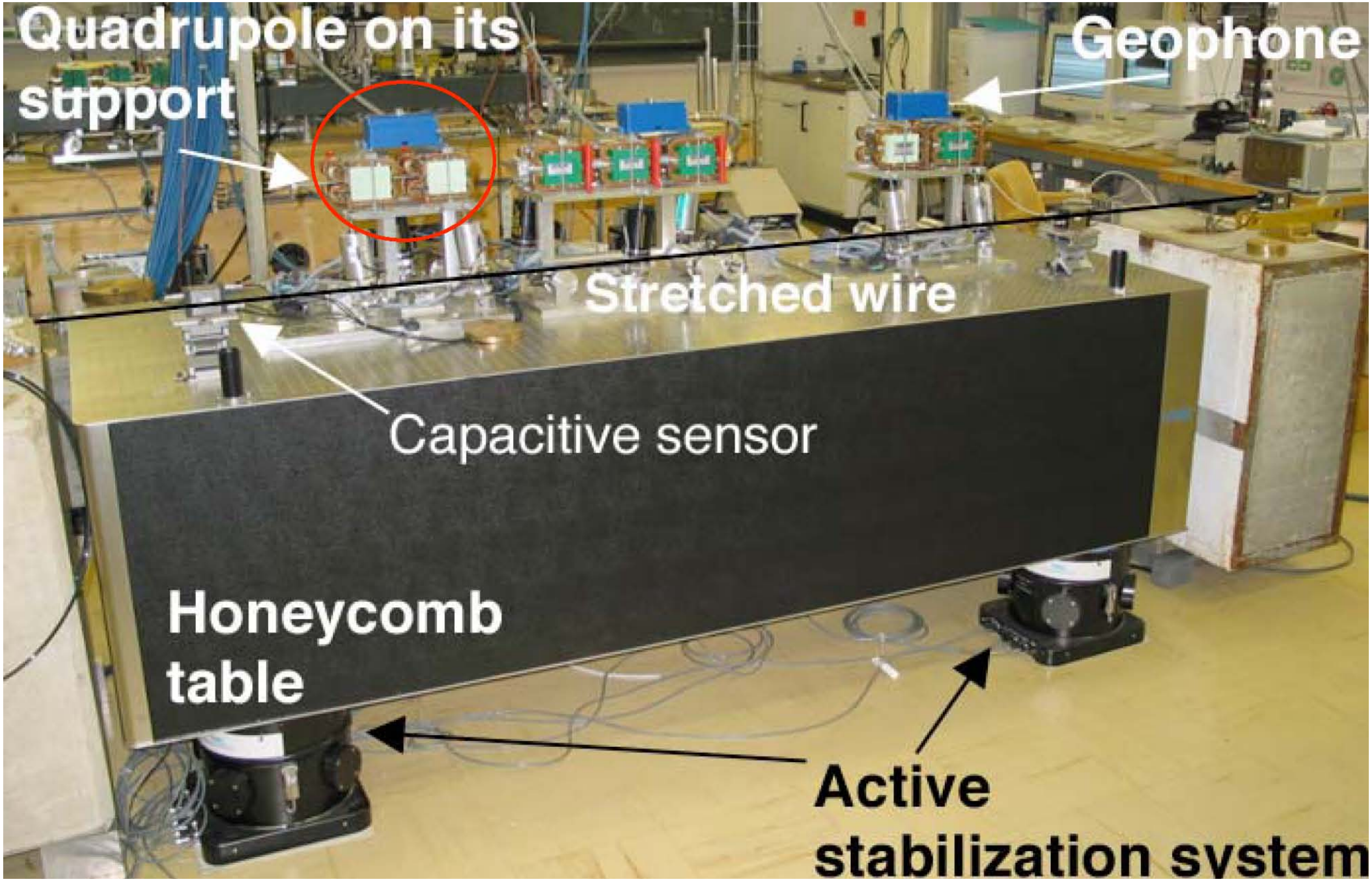


CERN Hardware Contributions to ATF-2

1) active stabilization table including stabilizing feet (STACIS2000 from TMC);
   honeycomb structure with length 2.4 m, width 0.8 m, height 0.8 m; absence of structural resonance below 230 Hz; stabilizing feet are equipped with geophones, rubber pads for passive damping, and piezo-electric movers for active damping of load vibrations induced from the ground; table was used for CLIC stabilization study; presently on loan at Annecy; available from mid-2006; best use at ATF-2 to be identified; e.g., stabilize final quadrupoles and IP monitors

value about 100,000 CHF (8.72 MYen)

CLIC test stand for vibration measurements & magnet stabilization studies



S. Redaelli, R. Assmann

Information from Toshiaki Tauchi 28.05.2006 and 14.08.2006

Three options exist for stabilized table [whose height is too large by 8 cm];
excavation in the floor [unelegant, less flexible]
modification of magnet movers
new honeycomb table?

There is some concern about lack of stability on the stabilized table; simulations including supports & movers are now being done by Annecy group.

At the 2nd ATF2 project meeting 30 May 2006 (agenda on http://ilcagenda.cern.ch/conferenceDisplay.py?confId=379), CLIC table was discussed. “CLIC table can be used with modification of the support base of FFTB mover which needs to be reduced by more than 8cm. A new honeycomb table is also desirable for more flexible option.”

“French group (P.Bambade, A.Jeremie et.al.) succeeded to get the ANR funding for next 4 years, while final funding will be decided in this September. Therefore, they can ship the table to KEK with the ANR funding. “

CERN Hardware Contributions to ATF-2

2) Three precision transformer BPMs. Projected spatial resolution 100 nm and time resolution 15 ns; aperture 4 mm; available at the end of 2007;
aperture might be increased within limits
development cost about 160,000 CHF (13.95 MYen) plus manpower; co-financed by EU via EUROTeV

Unfortunately, the precision transformer BPMs turned out to be not applicable at the ATF2
6mm diameter of the BPM is too small at the ATF2 with a beam pipe of 30mm outer-diameter [email T. Tauchi, 27.11.2005]

EUROTeV-PBPMs could nevertheless be tested at ATF or ATF2

CERN "studies" contributions – original proposal

EUROTeV&
BDIR London
Meeting 2005;
Nanobeam'05

1) development of commissioning strategy;
already wrote section of design report

1 person month

2) investigation of optimum beam-based alignment procedures with pertinent specification of BPM ranges

3 person months

3) simulation of IP tuning and maximum tuning knob ranges

4 person months

4) survey of relevant collective effects in ATF-2 and ATF extraction line; particularly wake fields

1 person month

5) participation in commissioning activities

3 person months

in total:
1 person year
approved by CSC
on 13.10.2005

more concrete plans

- ***tuning simulations & tools***; on 14.08.2006 I sent an email to Okugi san and Kuroda san asking about the needed beam-based tuning and performance simulations which are not done already and/or where CERN could contribute; no response yet
- closer collaboration with LAL and Annecy (& UK?) on ATF ***stabilization studies***? – would require resources at CERN??
- active participation in ATF/ATF2: ***Rogelio Tomas will visit ATF for 3 weeks in December*** to participate in beam operation, ATF2 studies, and ATF collaboration meeting, - contribute directly (ATF β beating & spurious dispersion correction, dynamic aperture, ATF2 final focus design, FF tuning, POSIPOL, explore where CERN could contribute)
- ***Maria Carmen Alabau / U. Valencia will spend 2 years at ATF*** (A. Faus-Golfe, P. Bambade, *R. Tomas & F. Zimmermann*)
- contribute to ***ATF DR*** (fast ion inst., e-cloud cures, emittance tuning, extraction line problems, optics problems, dynamic aperture, halo studies…) and ***POSIPOL studies***

Ideas for measurements and simulations in the context of ATF/ ATF2

by H. Burkhardt / CERN, based on few, brainstorming discussion with

Frank Zimmermann, Daniel Schulte and Lionel Neukermans

- **Beam Halo / Tail measurements**

- **Self consistent (non-Gaussian) beam-distribution ; simulation in the presence of strong intra-beam scattering**

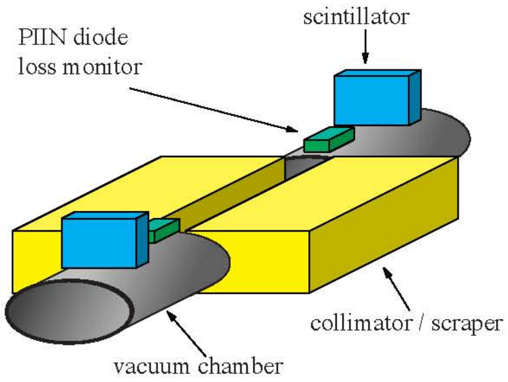
ideas on halo & IBS studies by Helmut Burkhardt

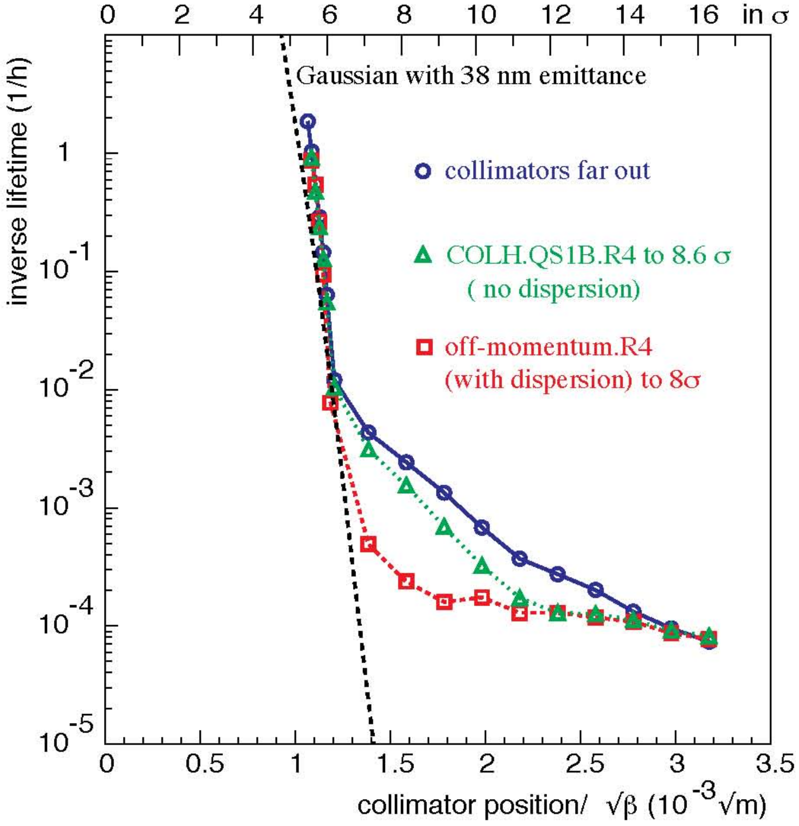
Beam Halo / Tail measurements

usually very hard to see tails with profile monitors, instead rather successful:

Quantitative tail measurements using scraper + loss monitors

as pioneered in LEP, Burkhardt et al. Phys.Rev.ST Accel.Beams 3:091001,2000, I. Reichel THESIS-98-017 (Aachen, CERN)





ideas on halo & IBS studies by Helmut Burkhardt

Self consistent (non-Gaussian) beam-distribution : Simulation in the presence of strong intra-beam scattering

- Intrabeam calculations and simulations typically rely on Gaussian beams
- strong intrabeam scattering significantly modifies the beam-distribution

Are there existing, fully consistent calculations / simulations ?

If not - this could be a very useful subject for a PhD work
with possible benchmarking using measurements @ ATF

ideas on halo & IBS studies by Helmut Burkhardt

summary

- draft scheme for commissioning based on SLC & FFTB experience
- diagnostics studies by Okugi san
- above 2 items need to be developed with concrete simulations for actual optics, diagnostics and errors
- CLIC team would like to contribute to the success of ATF and ATF2; we will send R. Tomas as explorer
- we have many ideas e.g., help with linear & nonlinear, ring optics & emittance dilution at extraction, ATF2 design optimization, ATF2 commissioning simulations, ATF/ATF2 halo modeling & halo measurements, POSIPO experiments
- we need some input & your collaboration to optimize our contribution

thank you for your attention!