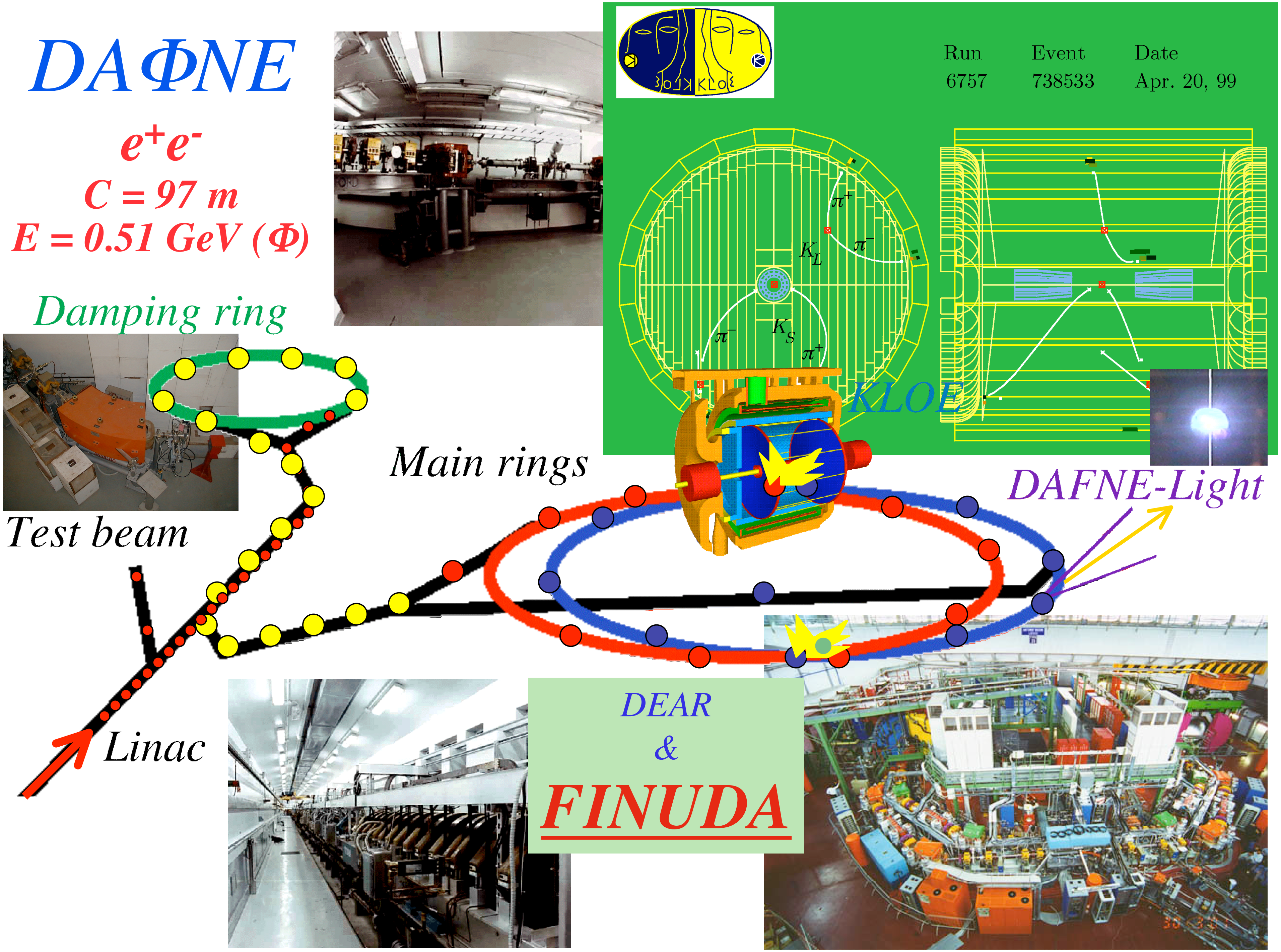
Low emittance tuning experience and plans in DAΦNE

Catia Milardi

ILCDR07 Damping Rings R&D Meetings
INFN-LNF Frascati March 5 ÷ 7 2007

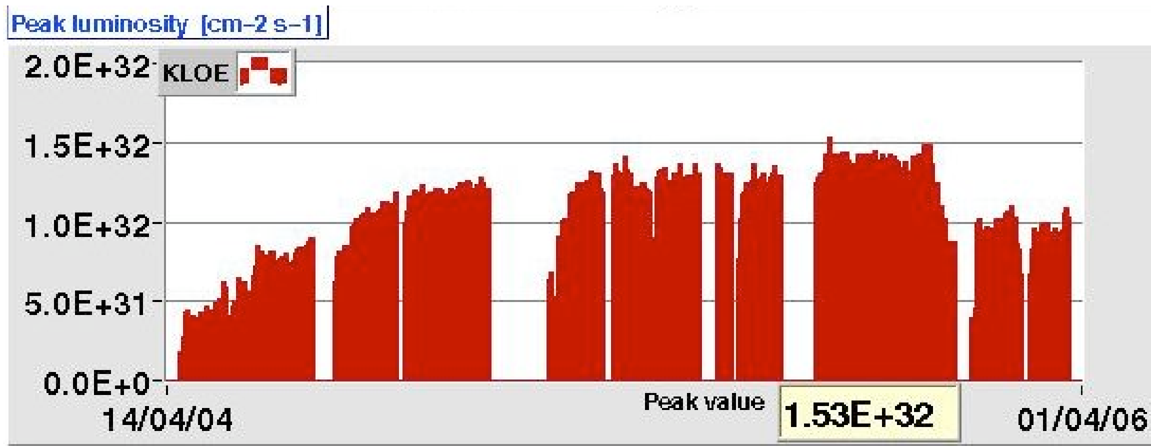
Outline

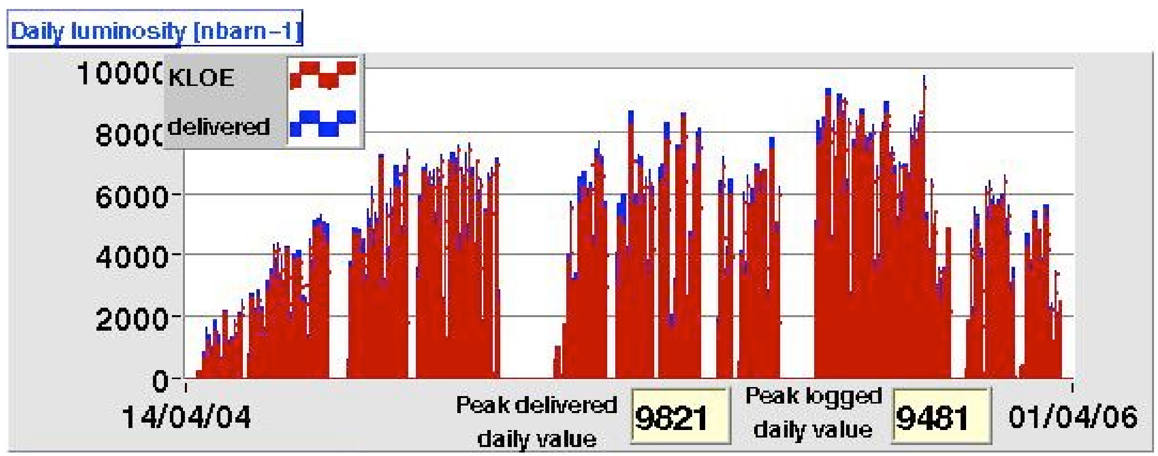
- Few words about DAΦNE
- ε_x tuning
- ε_y tuning
- ring impedance impact on ε_y


DAΦNE
e^+e^-
C = 97 m
E = 0.51 GeV (Φ)
Damping ring
Test beam
Linac
Main rings
Run 6757
Event 738533
Date Apr. 20, 99
π^+
π^-
K_L
K_S
KLOE
DAFNE-Light
DEAR
&
FINUDA

Best DAΦNE performances

Obtained during the run for the KLOE experiment (May 2004 ÷ Nov 2005)





$\mathcal{L}_{peak}$ ~ 1.5×10^{32} cm^{-2} s^{-1}

$\mathcal{L}_{\int day}$ ~ 10 pb^{-1} (maximum value)

$\mathcal{L}_{\int KLOE\ run}$ = 2 fb^{-1} (May 2004 ÷ Nov 2005)

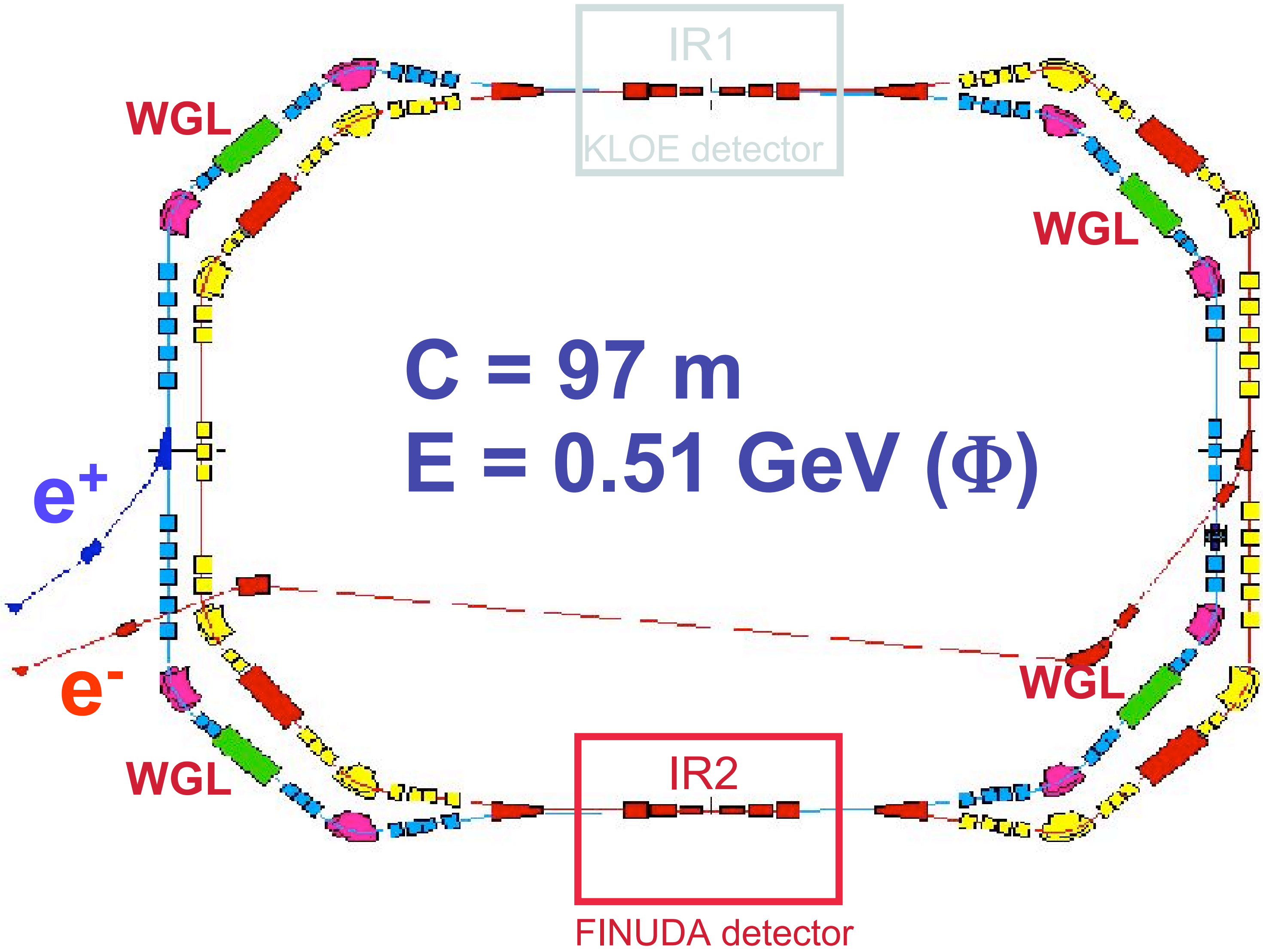
DAΦNE parameters

KLOE configuration

Energy [GeV]	.51
Circumference [m]	97.69
RF frequency [MHz]	368.26
Harmonic number	120
Damping time τ_E/τ_x [ms]	17.8 / 36.0
Bunch length full I e^-/e^+ [cm]	2.7 ÷ 2.
Emittance [m]	$.34x10^{-6}$
Betatron coupling at I~ 0 [%]	.2
$\beta_{x,y}$ at main IP [m]	1.7 / .017
Maximum $\xi_{x,y}$	.03 ÷ .04
Colliding bunches	108
Max. coll. currents I^-, I^+ [A]	2.4 / 1.4

Main Rings magnetic layout

4 arcs based on 4 different bending magnets each including a wiggler



ε_x tuning

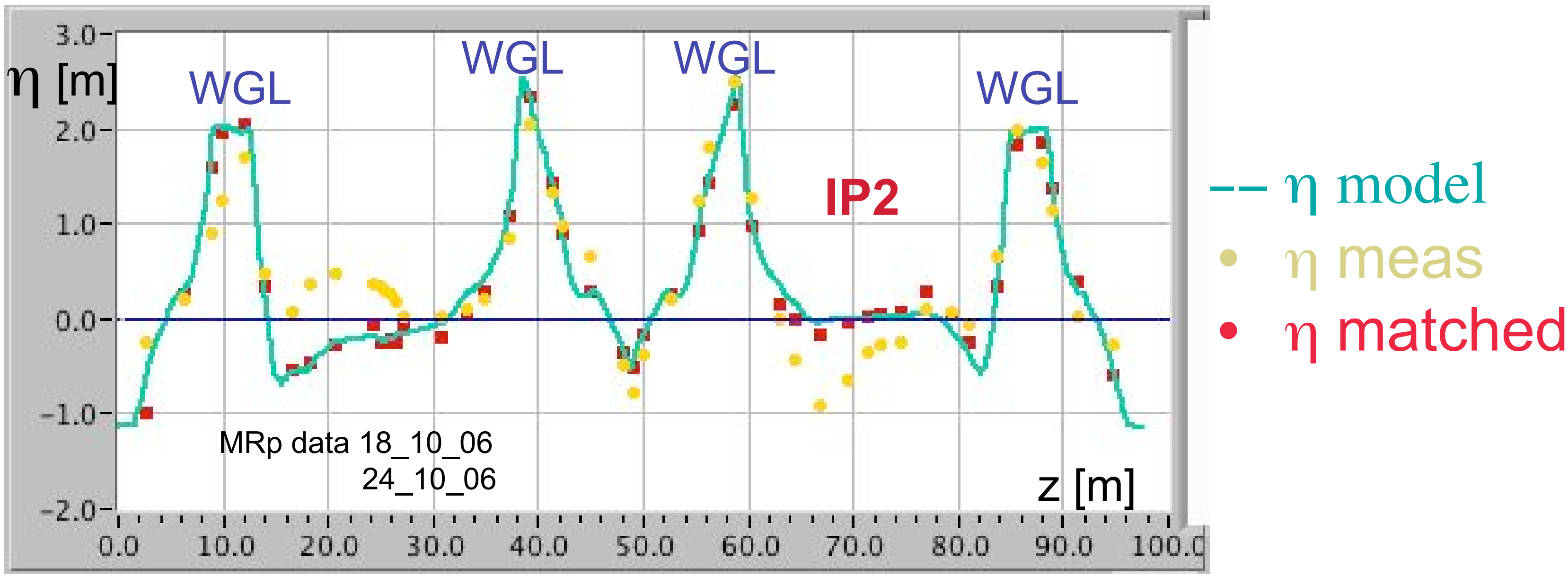
ε_x is tuned by a proper choice of the machine optics

Dominant source of $\Delta\varepsilon_x$ are:

- mismatch in the horizontal η and β functions due to:
    - large horizontal orbit
    - large steering magnet strengths
- large values of the W_x W_y η'' functions

η matching by:

- Measuring dispersive orbit at the BPMs
- Fitting the measurement by the first order multipole in the wigglers end-poles
- Matching the dispersion function to the required value by using the 3 QUADs installed around each wiggler

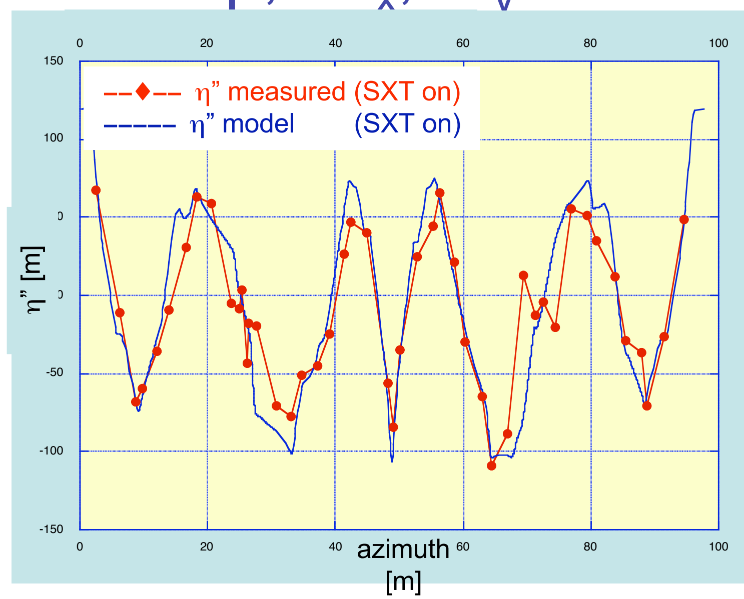


In this way the required ε_x and α_c are obtained

Non-linear optics matching

- Build a reliable machine model including non-linear terms
- design the optics in order to minimize the second order optical functions:

η'', W_x, W_y

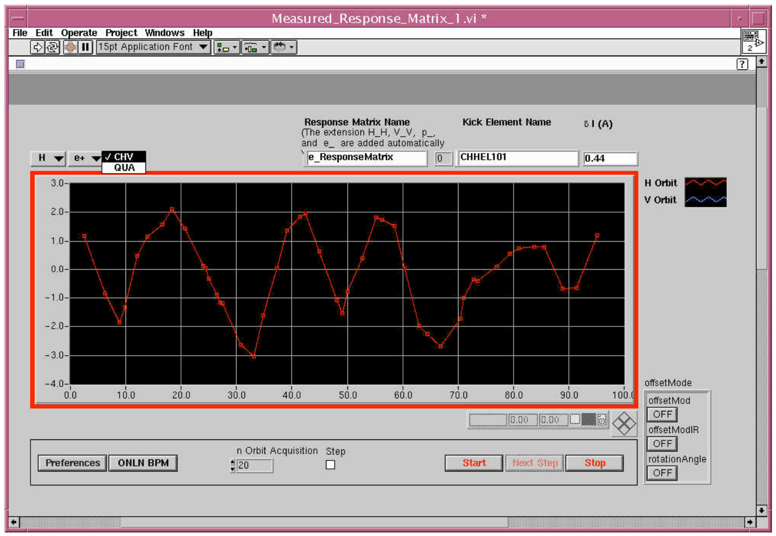


Finuda run 2003 - 2004

Beam Steering by Measured Response Matrix

Response Matrix measurement

$$A_{ij} = \frac{\partial z_j}{\partial I_i} \qquad z = x,y$$



$$A^H = \begin{vmatrix} A^{HH} & 0 \\ 0 & A^{HV} \end{vmatrix}$$

$$A^V = \begin{vmatrix} 0 & A^{VV} \\ A^{VH} & 0 \end{vmatrix}$$

$i=1..n_{kick}$ $\quad n_{kick} = 31$ *for CHH* $\quad n_{kick} = 31$ *for CVV*

$j=1..n_{mon}$ $\quad n_{mon} = 47$

MRS is also used to:

- understand & improve machine linear model
- dispersion function control
- coupling evaluation
- orbit correction
- closed bump calculation
- corrector strength reduction

- Orbit Correction $\bar{z} = A\Delta\bar{I}$
- Corrector strengths reduction $(\bar{z} + A\bar{I}_0) = A\bar{I}$
- Vertical Dispersion Correction $\bar{u} = D\Delta\bar{I}$

Equations are least square solved by Singular Value Decomposition

$$u = \left| \begin{array}{c} z_1 \\ . \\ z_{n_{mon}} \\ \eta_1 \\ . \\ \eta_{n_{mon}} \end{array} \right| \; 2{*}\mathrm{n_{mon}} \qquad D = \left| \begin{array}{ccccc} . & . & . & . & . \\ . & . & \dfrac{\partial z_i}{\partial I_j} & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & \dfrac{\partial \eta_i}{\partial I_j} & . & . \\ . & . & . & . & . \end{array} \right| \; 2{*}\mathrm{n_{mon}} \times \mathrm{n_{kick}}$$

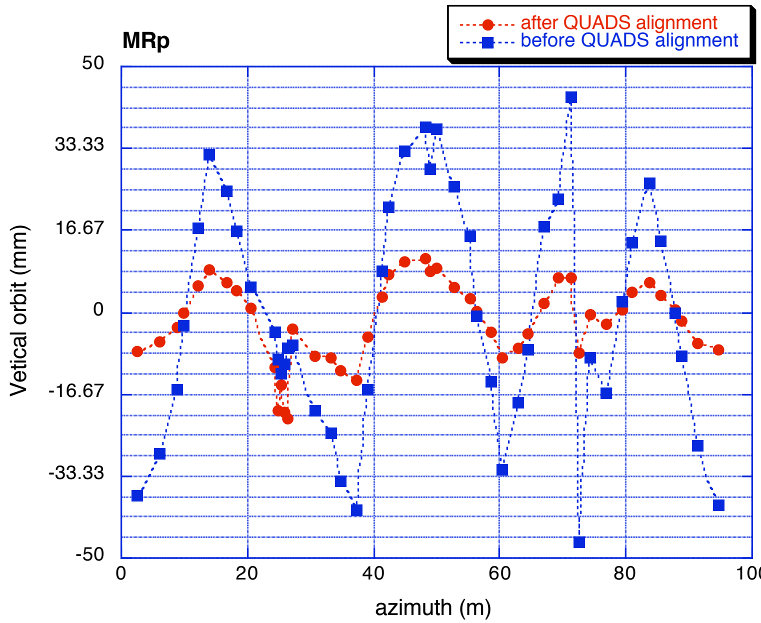
is not affected by:

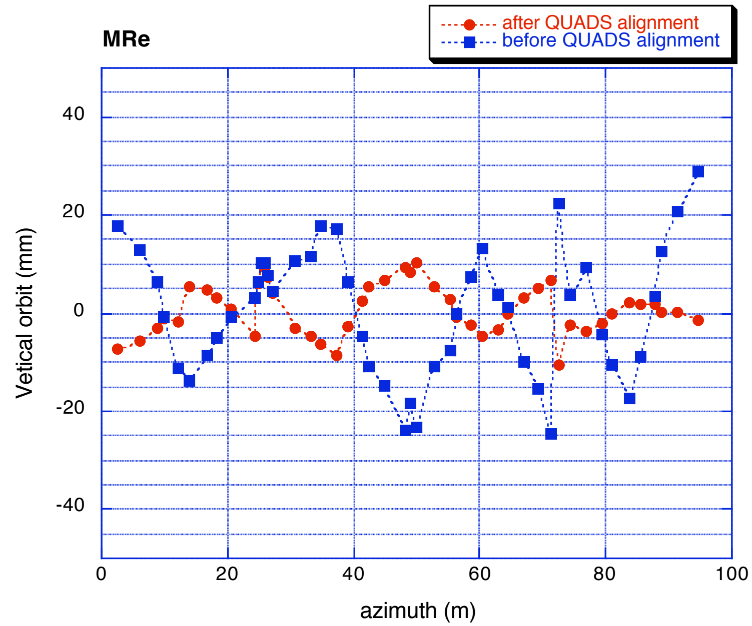
- model imperfections
- corrector calibration constants
- offsets in BPMs alignment

Bare orbit minimization by element alignment

$$z_{bare} = z_{beam} - z_{\sum Steers}$$

- Misalignment errors are identified by fitting the measured bare orbit with the machine model
- Bare orbit has been reduced in both rings by repositioning the outer electromagnetic QUADS in the FINUDA IR
- After alignment:
  - strengths of the steering magnets adjacent to the IR2 section are considerably reduced
  - bare orbit is significantly reduced and is comparable in the two rings





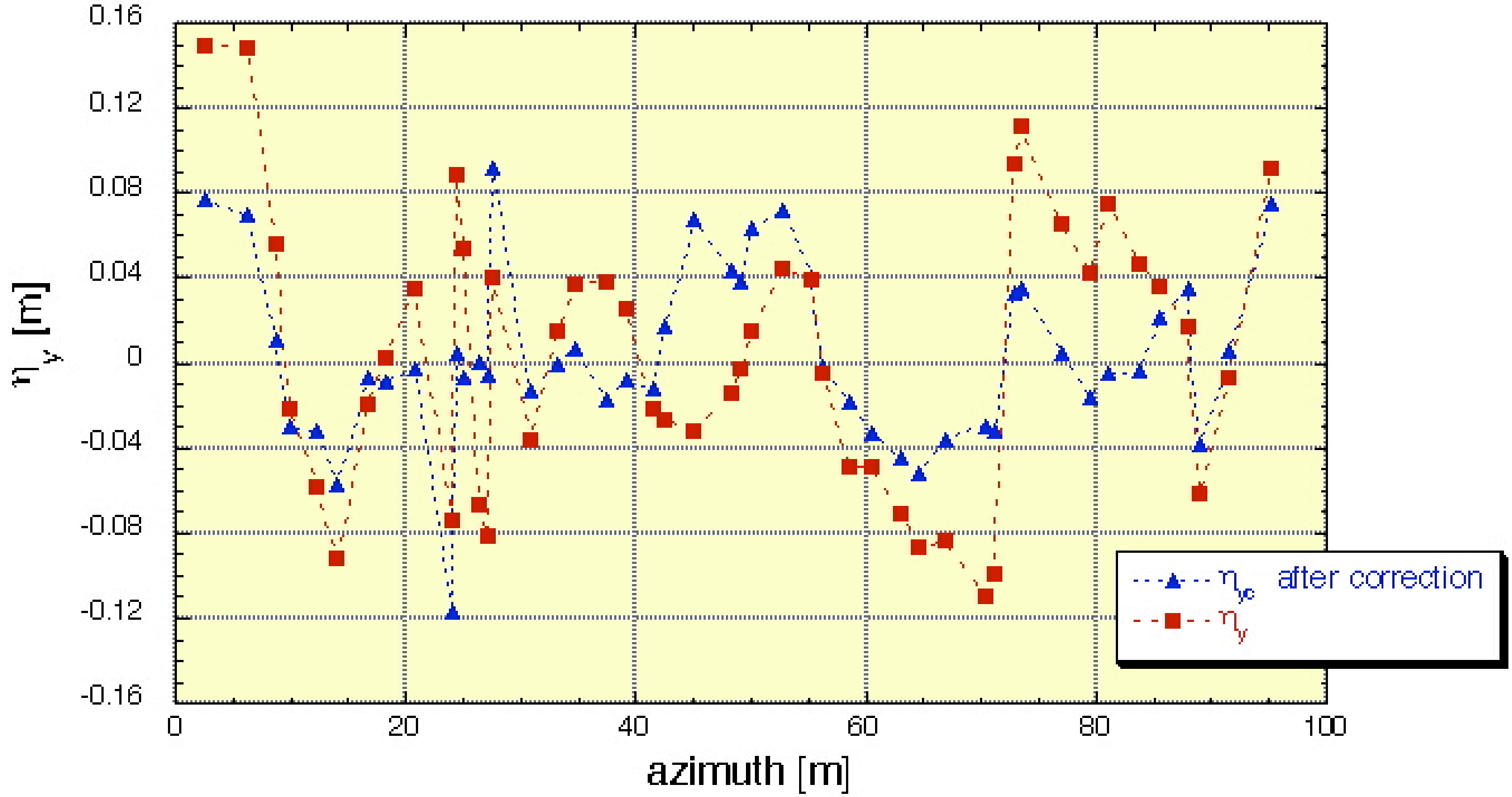
FINUDA run 2006 ÷ 2007

ε_y tuning

Dominant source of ε_y are:

- large vertical orbit
- vertical dispersion
- transverse betatron coupling due to:
  - experimental solenoid
  - roll errors in quadrupoles
  - vertical orbit distortion in sextupoles
- vacuum chamber impedance

e+ Ring Vertical Dispersion Correction



$\mathrm{rms}(\eta_{yc}) = .0411$ [m]

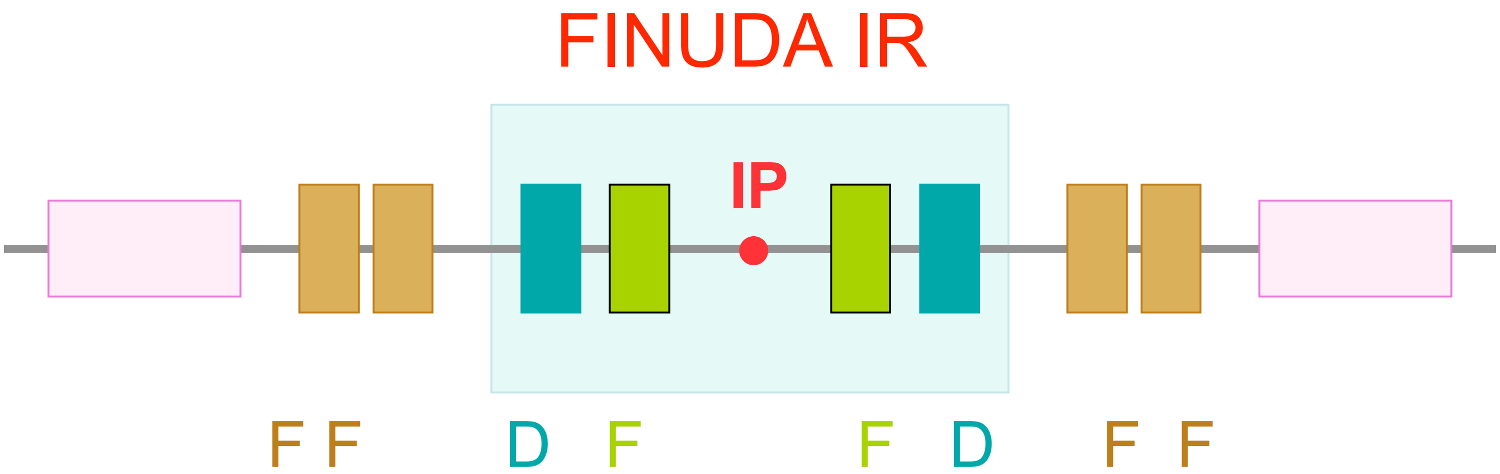
$\mathrm{rms}(\eta_y) = .0647$ [m]

$R^+ = .093$

$R^+_{\eta_c} = .081$

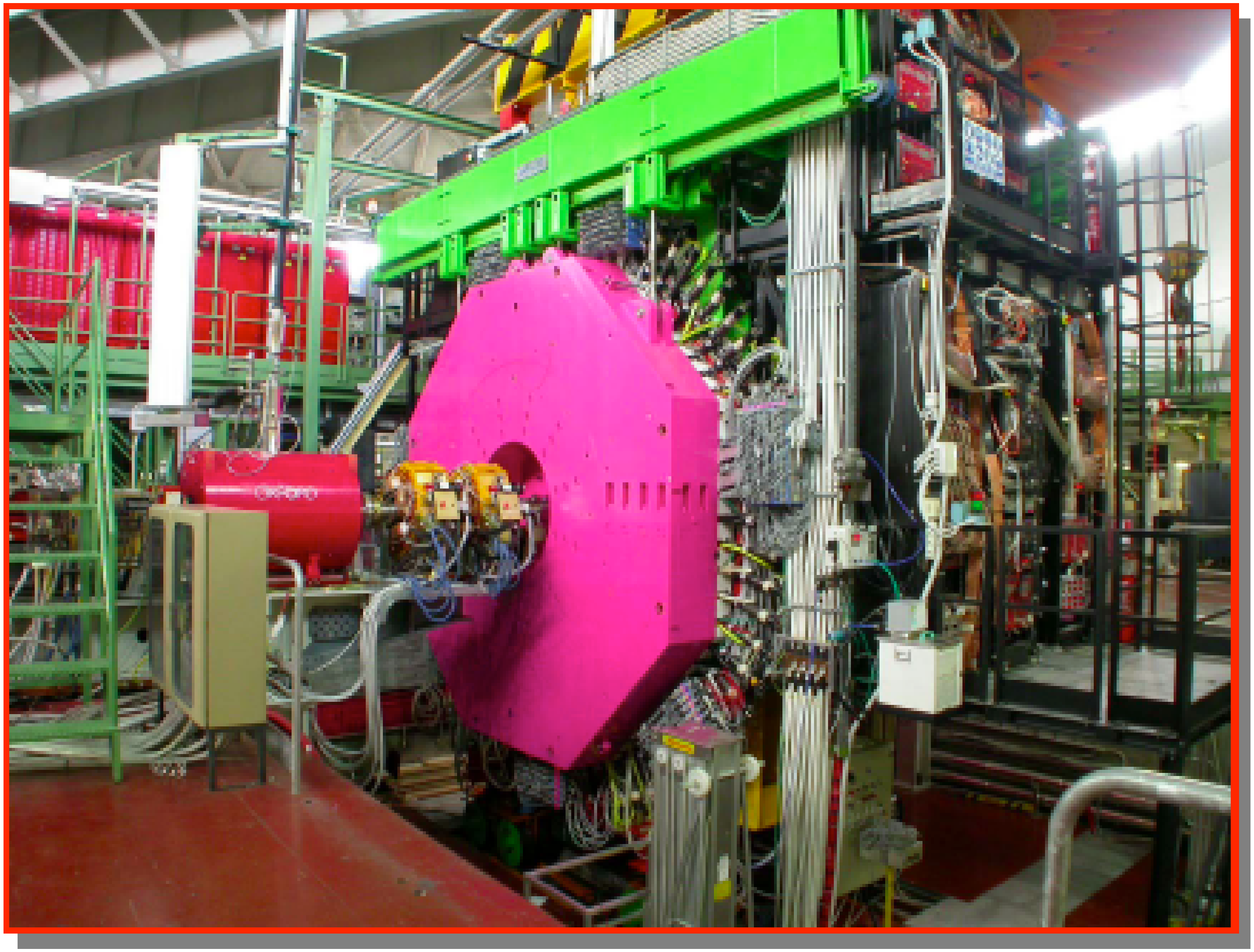
measured at SLM

Compensation scheme for the coupling due to the experimental detector



- $\int B\, \delta l$ = 2.4 Tm
- 2 superconductive compensator solenoids
- 4 permanent magnet QUADs
- 4 electromagnetic QUADs
- Independent QUADs rotation

FINUDA @ DAΦNE



Betatron coupling correction alghoritm

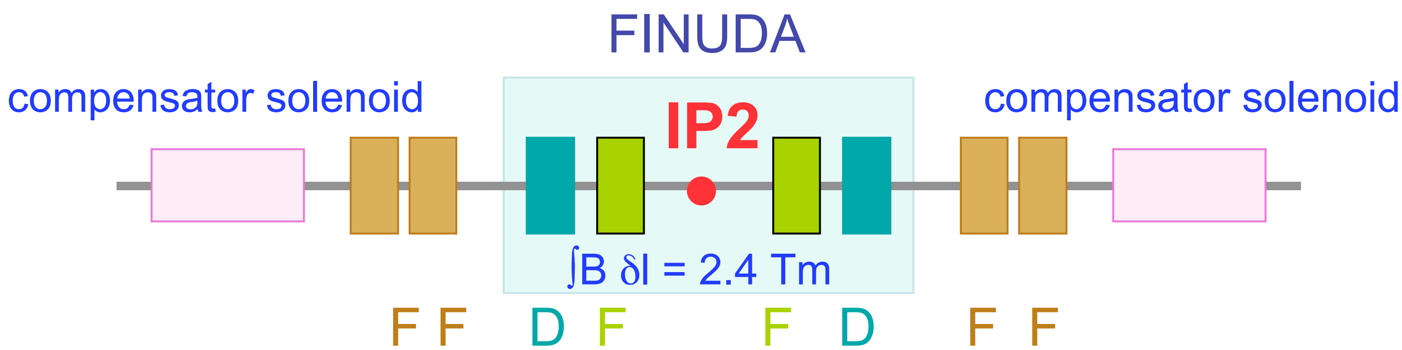
- local correction
  - by minimizing the coupling term of the measured Response Matrix by the IRs QUAD rotations $\Delta\phi_j$ j=1..r

$$M\Delta\phi = C^{meas}$$

$$M^{\mathrm{mod}} = \begin{pmatrix} \dfrac{\partial y_{m_1}}{\partial k_{h1}\partial\phi_1} & \cdots & \dfrac{\partial y_{m_1}}{\partial k_{h1}\partial\phi_r} \\ \vdots & \cdots & \vdots \\ \dfrac{\partial y_{m_{nBPM}}}{\partial k_{h\,n\,kick}\partial\phi_1} & \cdots & \dfrac{\partial y_{m_{nBPM}}}{\partial k_{h\,n\,kick}\partial\phi_r} \\ \dfrac{\partial x_{m_1}}{\partial k_{v1}\partial\phi_1} & & \dfrac{\partial x_{m_1}}{\partial k_{v1}\partial\phi_r} \\ \vdots & & \vdots \\ \dfrac{\partial x_{m_{nBPM}}}{\partial k_{v\,n\,kick}\partial\phi_1} & & \dfrac{\partial x_{m_{nBPM}}}{\partial k_{v\,n\,kick}\partial\phi_1} \end{pmatrix} \qquad C^{meas} = \begin{pmatrix} \dfrac{\partial y_{m_1}}{\partial k_{h_1}} \\ \vdots \\ \dfrac{\partial y_{m_{nBPM}}}{\partial k_{h\,n_{nkick}}} \\ \dfrac{\partial x_{m_1}}{\partial k_{v_1}} \\ \vdots \\ \dfrac{\partial x_{m_{nmon}}}{\partial k_{vn_{kick}}} \end{pmatrix}$$

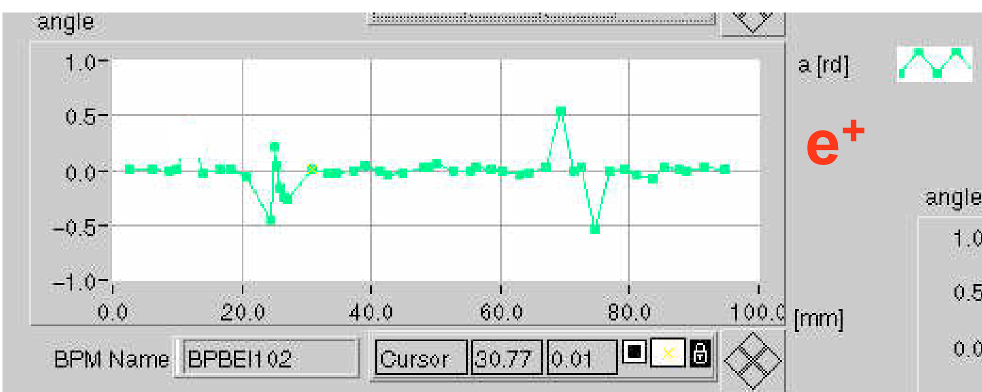
- linear system solved by SVD
- after few iterations 40% reduction in rms (C^{meas})

Betatron coupling correction

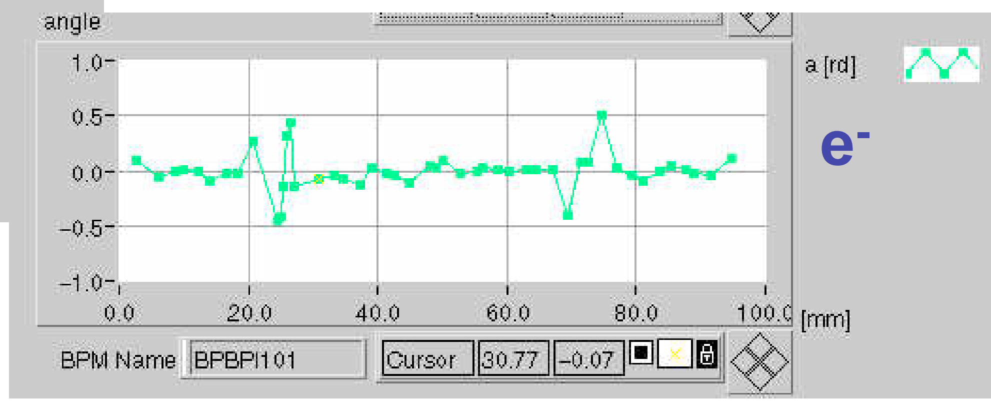


The main part of natural transverse coupling is corrected by rotating the QUADs in IR2

Fine tuning is performed using skew QUADs



K ~ .2%



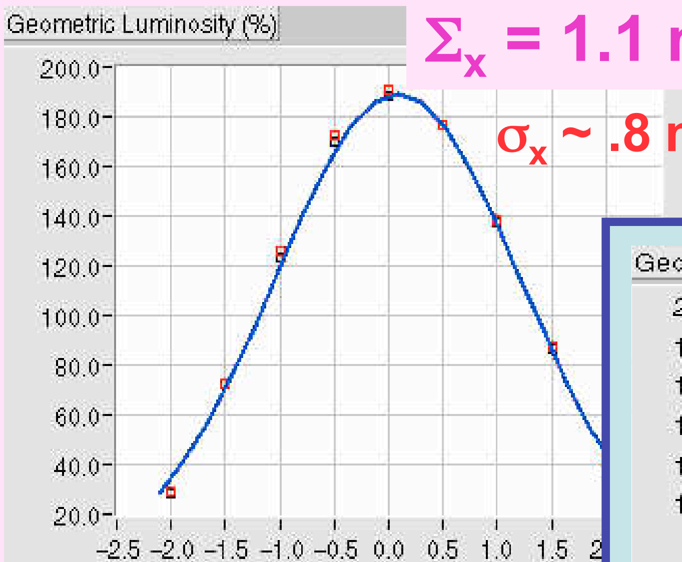
α is the amount of horizontal oscillation transferred to the vertical plane
α -> 0 means no betatron coupling

- global correction by SKEW QUADs

κ = .2%

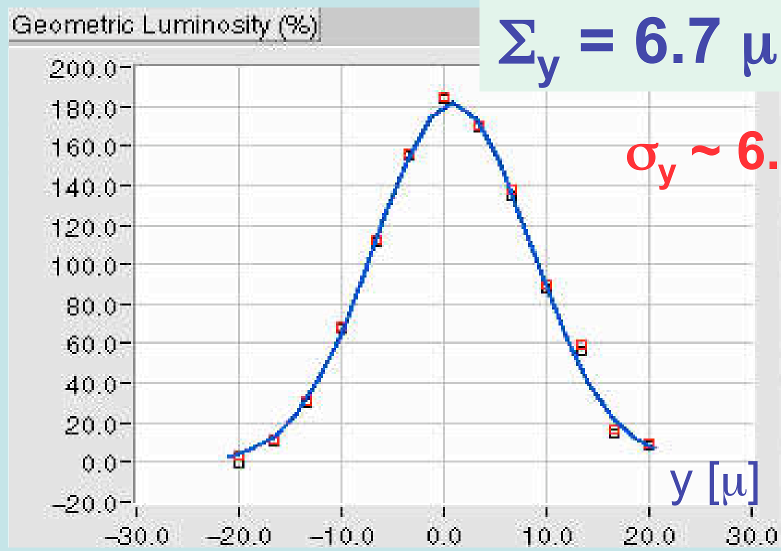
measured by

- beam - beam scan at low current
- beam aspect ratio @ SLM



Σ_x = 1.1 mm

σ_x ~ .8 mm @IP



Σ_y = 6.7 μ

σ_y ~ 6.9 μ @IP

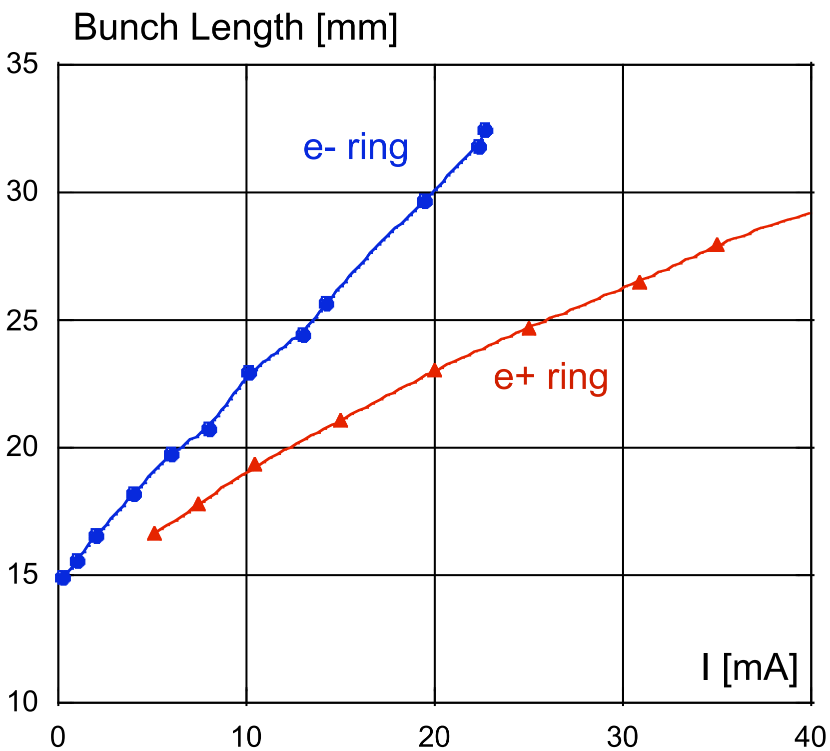
$$\Sigma_{x,y} = \sqrt{(\sigma^{+\,2}_{x,y} + \sigma^{-\,2}_{x,y})}$$

It's possible to reach a satisfactory κ correction even in presence of huge coupling sources and without sophisticated diagnostic tools.

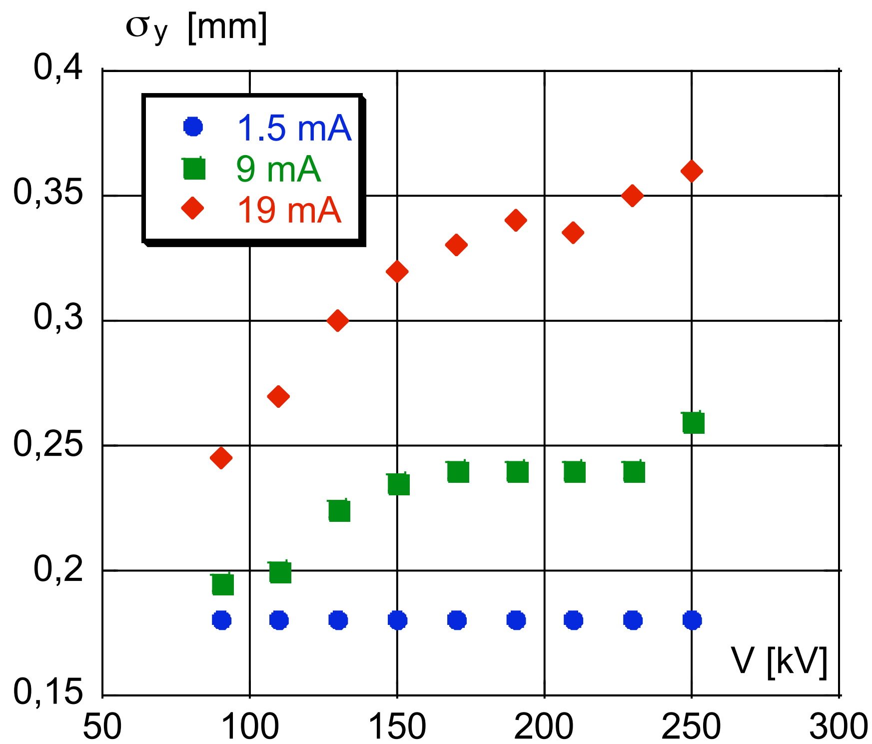
Impedance Effects in the e$^-$ Ring

$\alpha_c = 0.02$

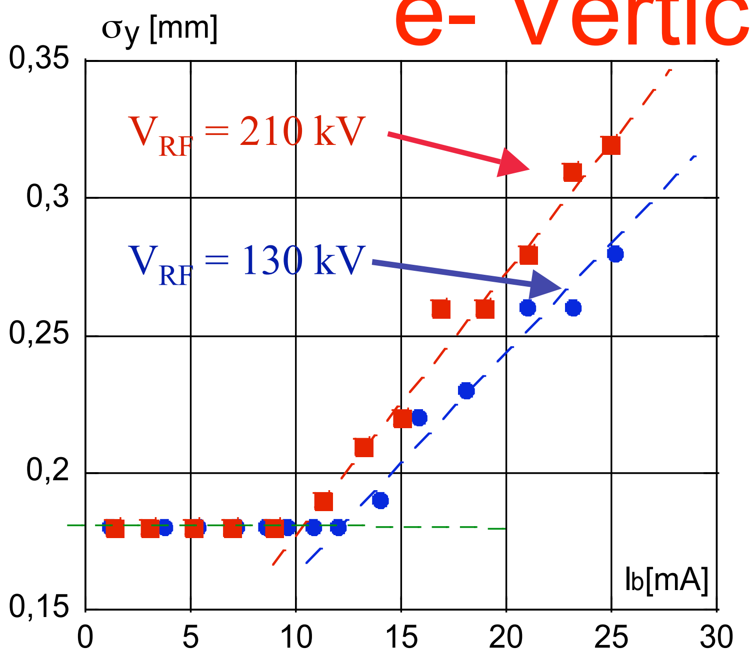
Stronger Bunch Lengthening

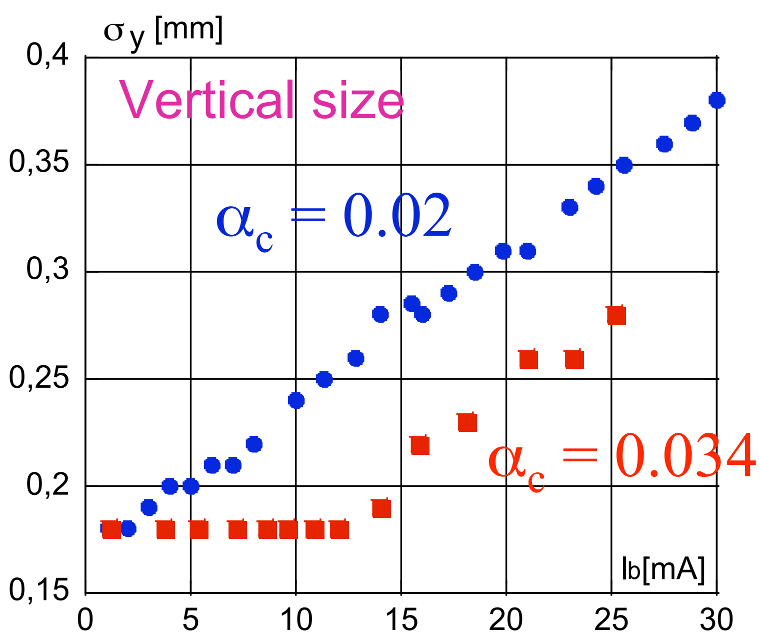


Vertical Size Blow f(V_{RF}, I_b)



e- Vertical Size Blow Up





- Single bunch (beam) effect
- It is correlated with the longitudinal microwave instability treshold:

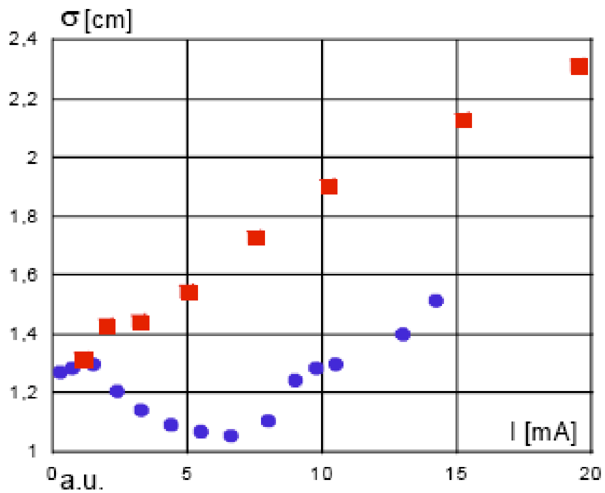
$$\mathit{Threshold} \quad \mathit{scales} \approx \sqrt{\frac{1}{V_{RF}}} \propto 1.27$$

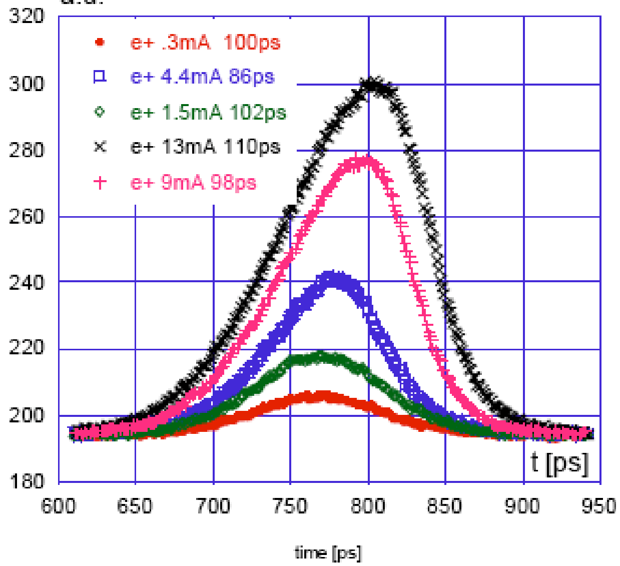
- the same threshold and the same dependence on RF voltage
- It is relevant for the e- ring having higher coupling impedance

- The threshold is higher for higher momentum compaction

Data from KLOE run Apr. 05

Experiment with $\alpha_c < 0$





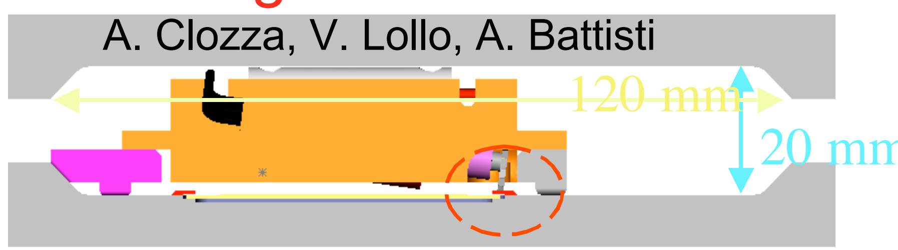
- Bunch shortens as predicted by numerical simulations
- Good agreement with DAΦNE optics model
- I_{bunch} > 40 mA is stored with negative chromaticity
- No problems with RF and feedbacks: about 1 A of stable current in both beams
- Coupling and geometric luminosity as in usual operation conditions
- First collisions at low currents (200 mAmps) with L_{peak} =2.5 x10^{31}
- Fast growth of electron vertical beam size with currents above the longitudinal microwave instability threshold => hardware changes are needed to overcome the effect

e- Vertical Size Blow Up has been neutralized halving the e^- ring impedance by

removing all broken Ion-Clearing-Electrodes (ICEs) and all ICEs in wigglers since they were, according simulations, responsible for the difference in coupling impedance between e^+ and e^- ring:

$$\left(\frac{Z}{n}\right)_0^{e^+} \approx 0.54\,\Omega \qquad \left(\frac{Z}{n}\right)_0^{e^-} \approx 1\,\Omega$$

Milling machine to cut ICE fingers



Presently no beam blow up is observed for the e^- beam with RF voltage

Conclusions

Efficient tools have been developed to:

- correct closed orbit, vertical dispersion and coupling
- tune horizontal dispersion

Betatron coupling can be made as low as .2% despite the huge coupling source introduced by the experimental detector

Dependence of transverse vertical dimension on coupling impedance, in the e^- ring, has been detected, studied and eventually removed