DAΦNE IRs commissioning and operation

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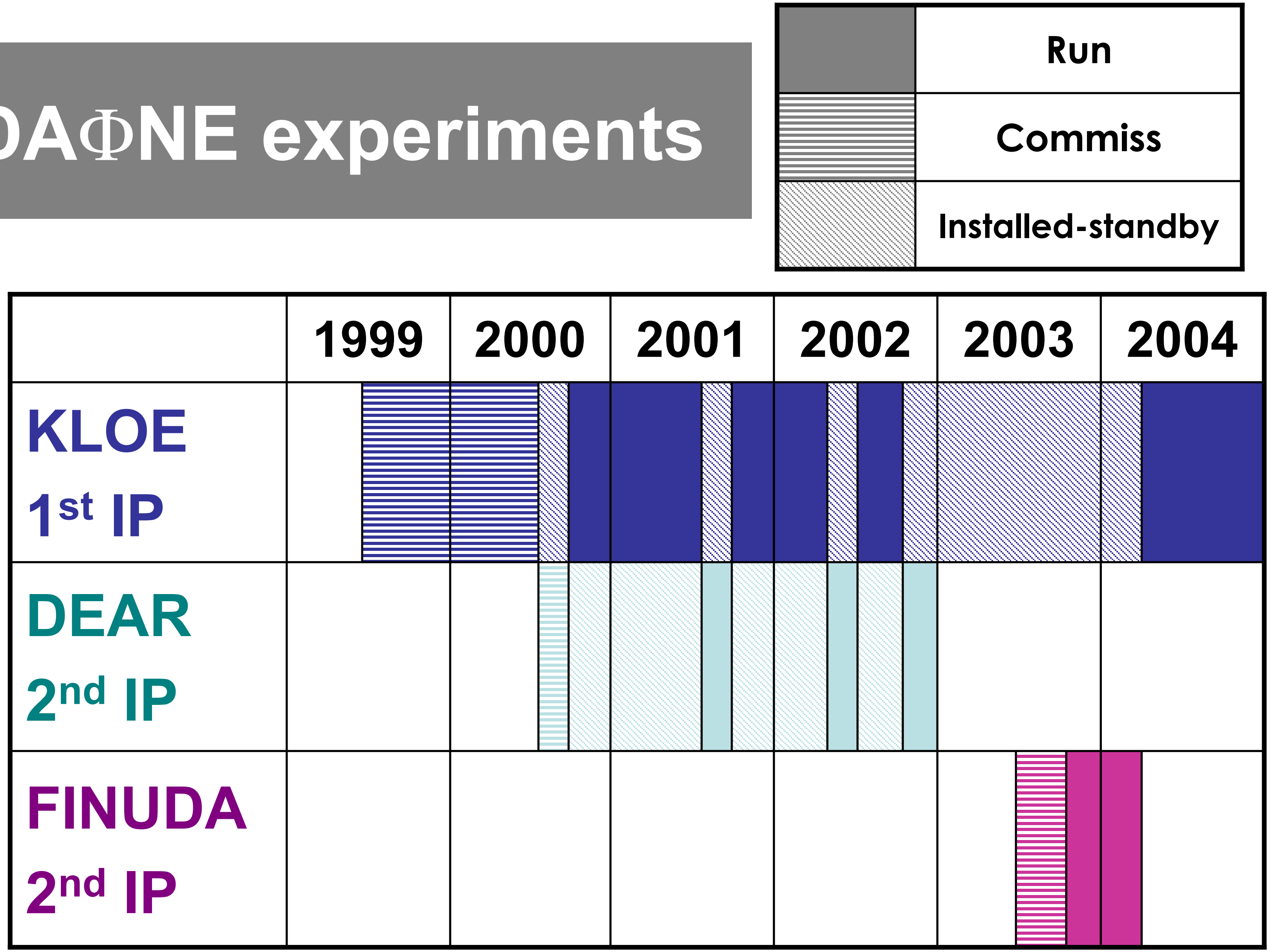
Beijing, 12-16 January 2004

DAΦNE experiments



3 experiments

- Time to install-disinstall
- Time to commission experiment and new configuration of the collider
- Loss in both peak and integrated luminosity

Single bunch luminosity steps

- Much lower coupling than design to counteract beam-beam blow-up (factor 3-4)
- Betas* lower than design (factor 2)
- Emittance lower than design (factor 1.5-2)
- Separation at 2nd IP, detuning when possible
- Working point choice (asymmetric)
- Continuos non linear dynamics optimisation

Total luminosity steps

- Successive Instability threshold increase
- Feedback systems continous tune-up
- Background minimization (scrapers, optics, dynamic aperture)
- Increase of crossing angle for increasing #bunches
- Continuos non linear dynamics optimisation

Beam-beam history (symplified)

$$\xi_x \propto \frac{N}{\varepsilon_x}$$

$$\xi_y \propto \xi_x \sqrt{\frac{\beta_y}{\kappa \beta_x}}$$

DESIGN

β_x = 4.5 m
β_y = 4.5 cm
ε_x = 1 mm rad
K = 1%
$\xi_x = \xi_y$ = 0.04
$N = 8.9\ 10^{10}$
$L_{sb} = 4\ 10^{30}$

DAY-ONE	DEAR initial	DEAR final	KLOE	KLOE final
β_x = 4.5 m	β_x = 4.5 m	β_x = 2 m	β_x = 4.5 m	β_x = 3 m
β_y = 4.5 cm	β_y = 4.5 cm	β_y = 2. cm	β_y = 4.5 cm	β_y = 3 cm
ε_x = 1 mm rad	ε_x = 0.8 mm rad	ε_x = 0.65 mm rad	ε_x = 0.8 mm rad	ε_x = 0.75 mm rad
κ = 0.5%-1%	κ = 0.5%-1.5%	κ = 0.3%-1.%	κ = 0.5%-1.0%	κ = 0.3%-1.%
$\xi_x = \xi_y$ = 0.02	ξ_x = 0.019 ξ_y = 0.016	ξ_x = 0.014 ξ_y = 0.014	ξ_x = 0.018 ξ_y = 0.018	ξ_x = 0.024 ξ_y = 0.024
$N = 4.5\ 10^{10}$	$N = 3.5\ 10^{10}$	$N = 2.\ 10^{10}$	$N = 3.5\ 10^{10}$	$N = 4.\ 10^{10}$
$L_{sb} = 1\ 10^{30}$	$L_{sb} = 0.6\ 10^{30}$	$L_{sb} = 0.7\ 10^{30}$	$L_{sb} = 0.8\ 10^{30}$	$L_{sb} = 1.6\ 10^{30}$
N bunches = 1	N bunches = 50	N bunches = 100	N bunches = 50	N bunches = 50
I_{tot} = 22 mA	I_{tot} = 850 mA	I_{tot} = 1000 mA	I_{tot} = 870 mA	I_{tot} = 980 mA
$L_{tot} = 1\ 10^{30}$	$L_{tot} = 3\ 10^{31}$	$L_{tot} = 7\ 10^{31}$	$L_{tot} = 4\ 10^{31}$	$L_{tot} = 8\ 10^{31}$
1998	**2002**	**2002**	**2001**	**2002**

Crossing angle and parasitic crossings

	design	Day-1	DEAR in	DEAR fin	KLOE I	KLOE II	FINUDA
σ_L (cm)	3	1.5	1.5	1.5	2.0	2.	1.5
σ_x (cm)	0.21	0.21	0.19	0.11	0.19	0.15	0.12
θ (mrad)	10-15	10-15	11-16	13-20	10-15	12-18	11-16
Θ	.14-.21	.07-.11	.09-.13	.18-.27	.11-.16	.16-.24	.14-.20
N	120	1	50	100	50	100	100
1^{st} pc (m)	0.42	-	0.84	0.42	0.84	0.42	0.42
$\#\sigma$ @1^{st} pc	4-6	-	10-15	10-15	10-15	9-14	10-15

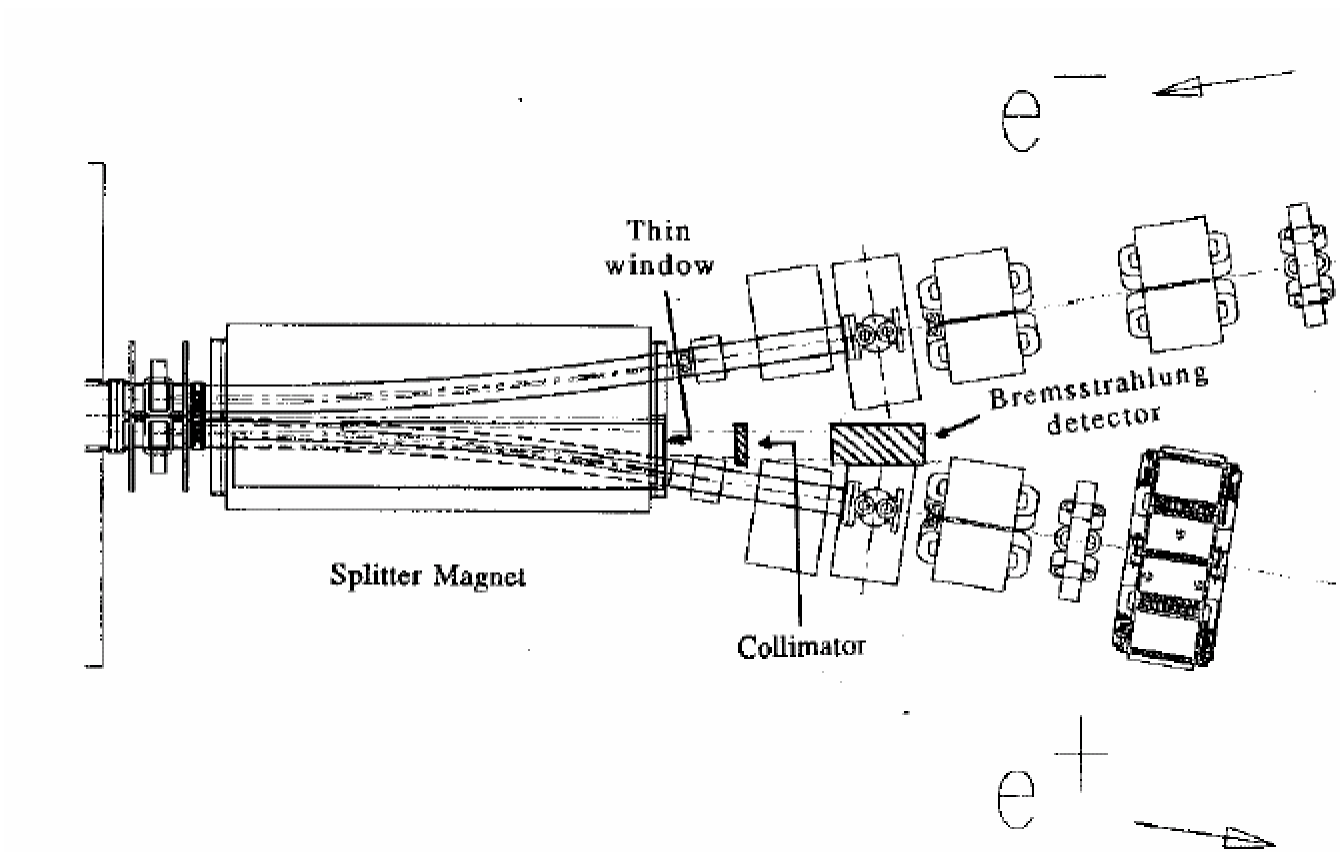
Piwinski angle: $\Theta = \theta\ \sigma_l/\sigma_x$ (θ = half crossing angle)

Luminometer

- Luminosity measurements are performed by detecting Single Bremsstrahlung at the two interaction points.
- i) capability of performing very fast measurements to allow machine parameters tuning in real time,
- ii) measurement stability with respect to variations of the beam position and angle at the IP
- iii) no interference with the experiments to ensure independent luminosity measurements during the data taking and during the initial phase of the machine commissioning with no experiment installed in the two IRs.

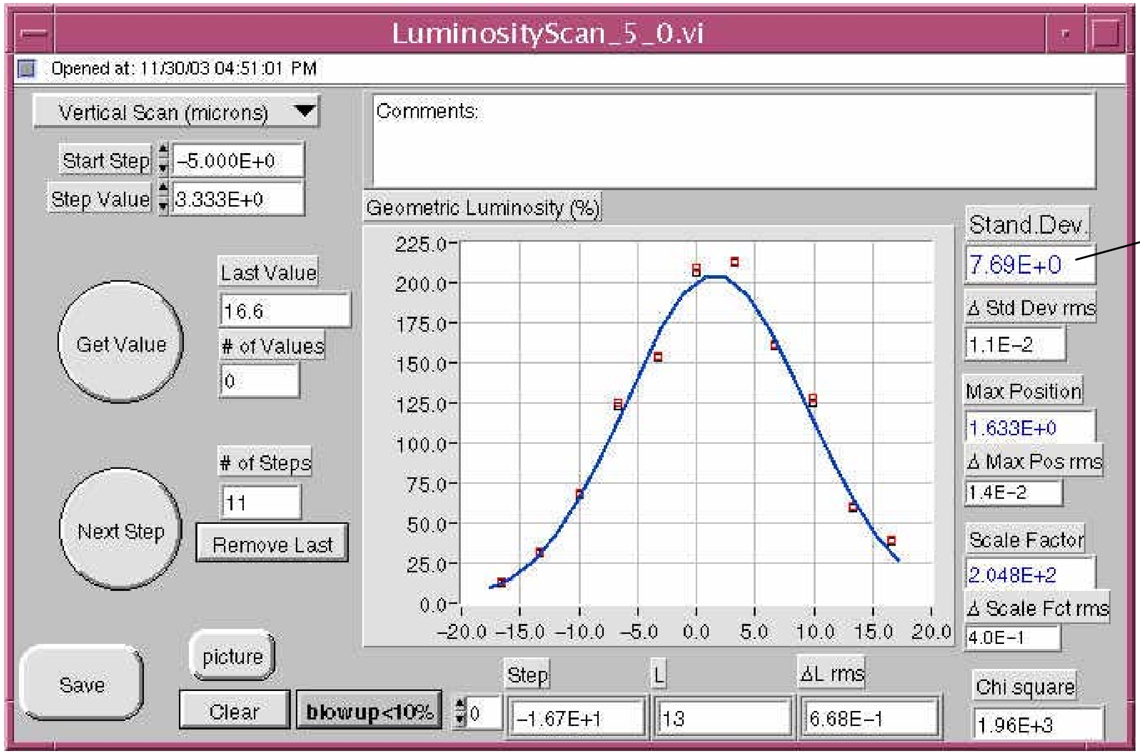
Luminometer position

IP



Beam-beam scans for Σ* measurements

Move one beam vertically or horizontally with IR closed bump
Multibunch, Very low current per bunch (no beam-beam effects)

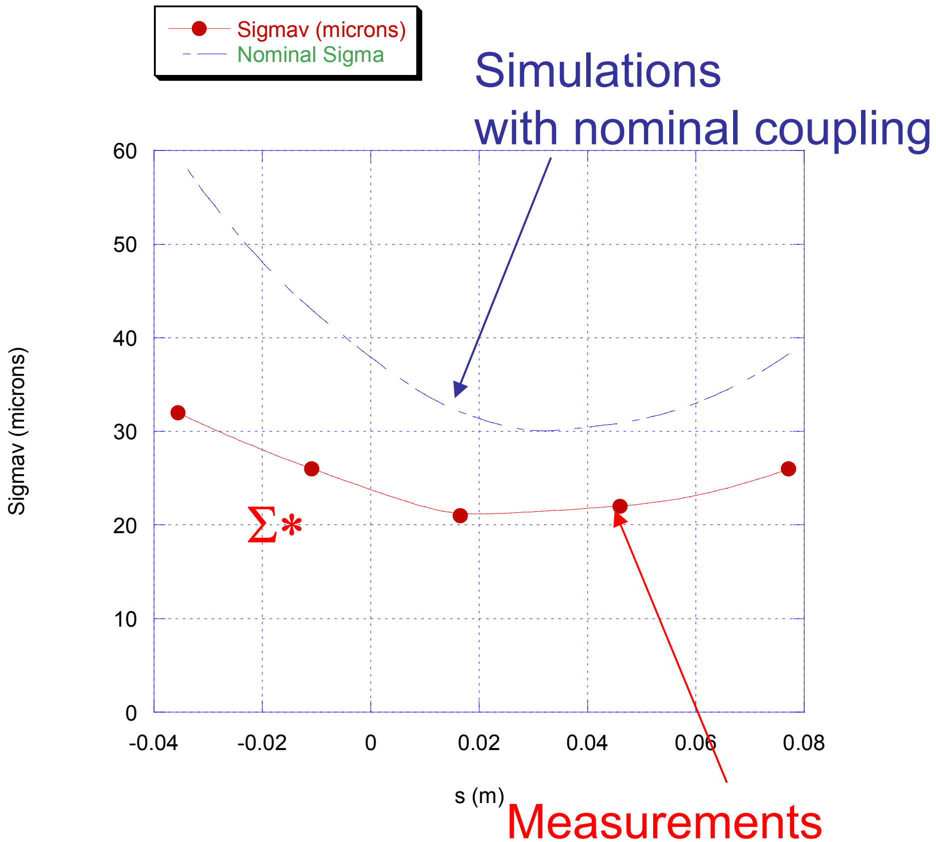


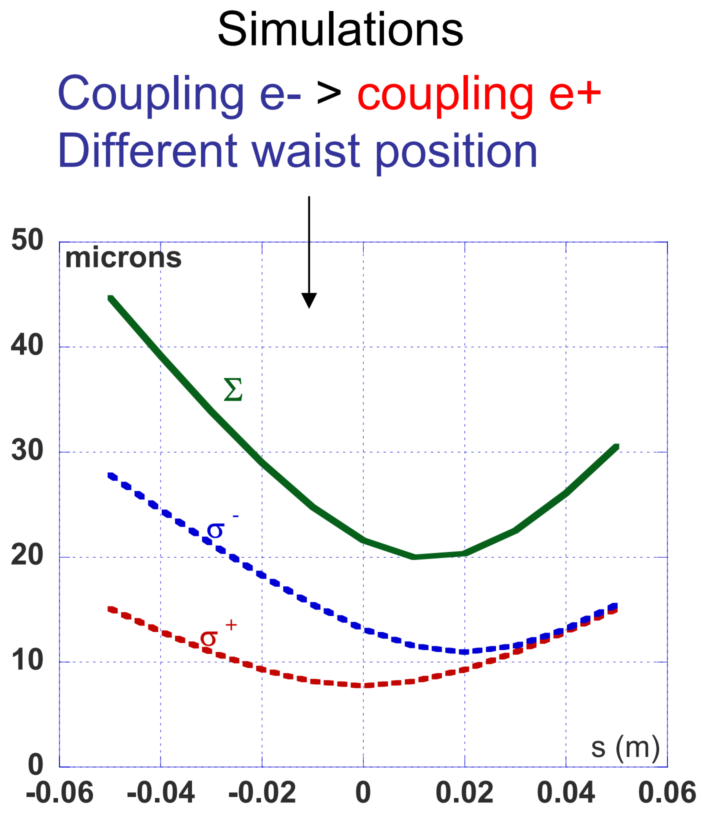
7.7 μ

Example of vertical Σ*

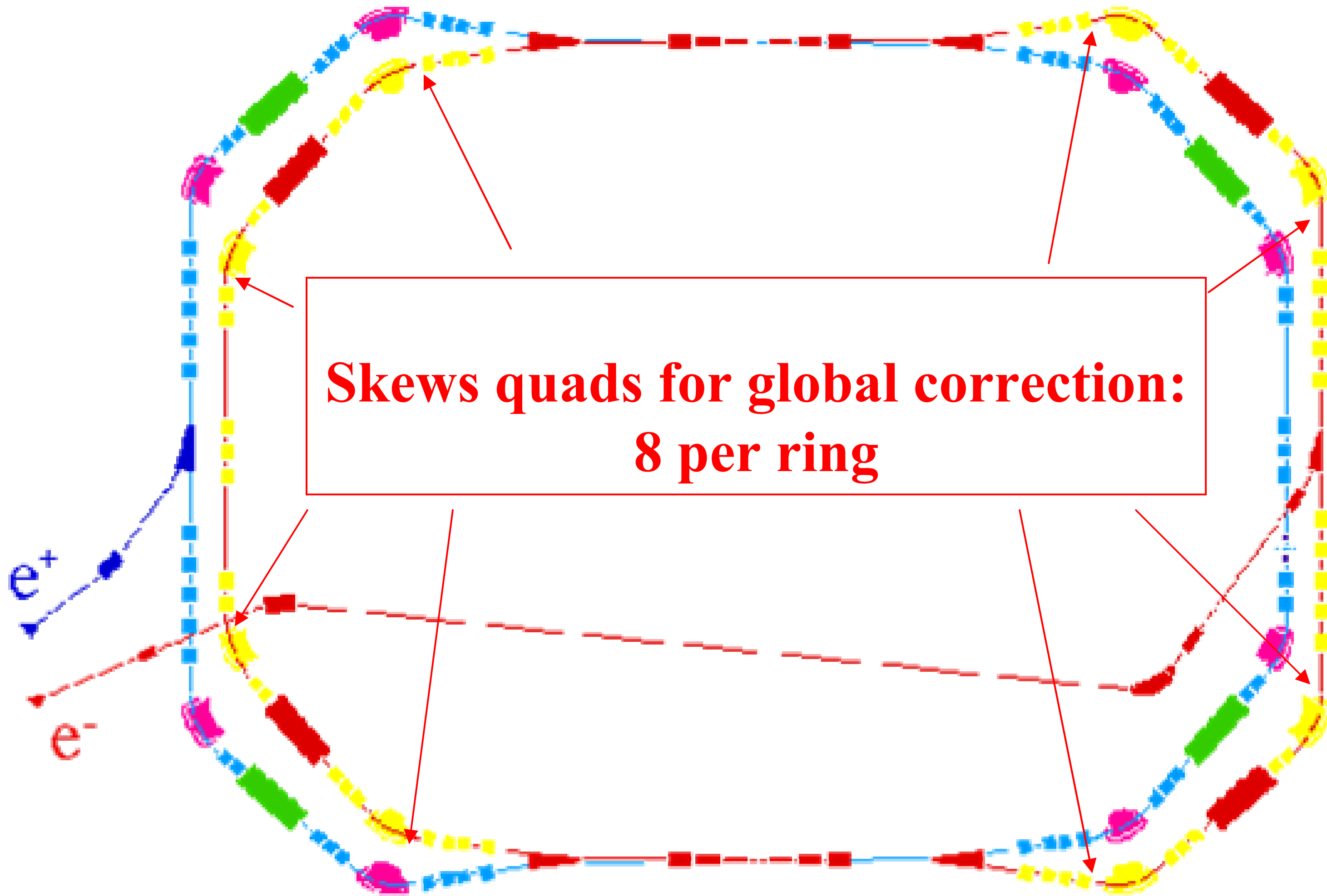
Beam-beam scans for waist position measurement and fixing

$$\Sigma^* = \sqrt{\sigma_+^2 + \sigma_-^2} = \varepsilon\sqrt{\kappa_+\beta_+ + \kappa_-\beta_-}$$





Coupling correction



Skews quads for global correction: 8 per ring

NORMAL MODES FORMALISM (sagan, rubin)

The linear motion in the transverse plane can always be described in two independent planes, the normal planes (a,b)

The 4x4 one-turn transport matrix **T** in the laboratory system is related to the normal planes via:

$$\mathbf{T} = \begin{pmatrix} \mathbf{M} & \mathbf{m} \\ \mathbf{n} & \mathbf{N} \end{pmatrix} = \mathbf{V}\mathbf{U}\mathbf{V}^{-1}$$

(m=n=0 for a fully uncoupled point in the ring)

U is the normal modes one-turn transport matrix:

$$\mathbf{U} = \begin{pmatrix} \mathbf{A} & \mathbf{0} \\ \mathbf{0} & \mathbf{B} \end{pmatrix} \qquad \mathbf{V} = \begin{pmatrix} \gamma\mathbf{I} & \mathbf{C} \\ -\mathbf{C}^{+} & \gamma\mathbf{I} \end{pmatrix}$$

(+ = symplectic conjugate)

γ is a function of *s* along the ring:

$$\gamma^2 + \|\mathbf{C}\| = 1$$

$$\gamma = \sqrt{\frac{1}{2} + \frac{1}{2}\sqrt{\frac{\left(Tr[\mathbf{M} - \mathbf{N}]\right)^2}{\left(Tr[M - N]\right)^2 + 4\|\mathbf{H}\|}}}$$

$$\mathbf{H} \equiv \mathbf{m} + \mathbf{n}^+$$

$$\mathbf{C} = \frac{-\mathbf{H}\,\mathrm{sgn}\left(Tr[\mathbf{M} - \mathbf{N}]\right)}{\gamma\sqrt{\left(Tr[\mathbf{M} - \mathbf{N}]\right)^2 + 4\|\mathbf{H}\|}}$$

Normal planes　　　　Laboratory frame

$$\mathbf{a} = (a, a', b, b') \quad \Leftrightarrow \quad \mathbf{x} = (x, x' y, y')$$

related by

$$\boxed{\mathbf{a} = \mathbf{V}^{-1}\mathbf{x}}$$

$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} \gamma & 0 & C_{11} & C_{12} \\ 0 & \gamma & C_{21} & C_{22} \\ -C_{22} & C_{12} & \gamma & 0 \\ C_{21} & -C_{11} & 0 & \gamma \end{pmatrix} \begin{pmatrix} a \\ a' \\ b \\ b' \end{pmatrix}$$

The ratio κ is a characteristic of the ring:

$$\kappa = \frac{\varepsilon_b}{\varepsilon_a}$$

The dimensions in the real space (x,y) are given by the quadratic contribution of the two modes:

$$\sigma^2 = \sigma_a^2 + \sigma_b^2$$

$$\sigma_{x,a} = \gamma\sqrt{\varepsilon_a \beta_a}$$

$$\sigma_{x,b} = \sqrt{\varepsilon_b}\sqrt{\beta_b C_{11}^2 - 2\alpha_b C_{12} C_{11} + \gamma_b C_{12}^2}$$

$$\sigma_{y,b} = \gamma\sqrt{\varepsilon_b \beta_b}$$

$$\sigma_{y,a} = \sqrt{\varepsilon_a}\sqrt{\beta_a C_{22}^2 + 2\alpha_a C_{12} C_{22} + \gamma_a C_{12}^2}$$

Angle between the laboratory frame and the normal modes axis

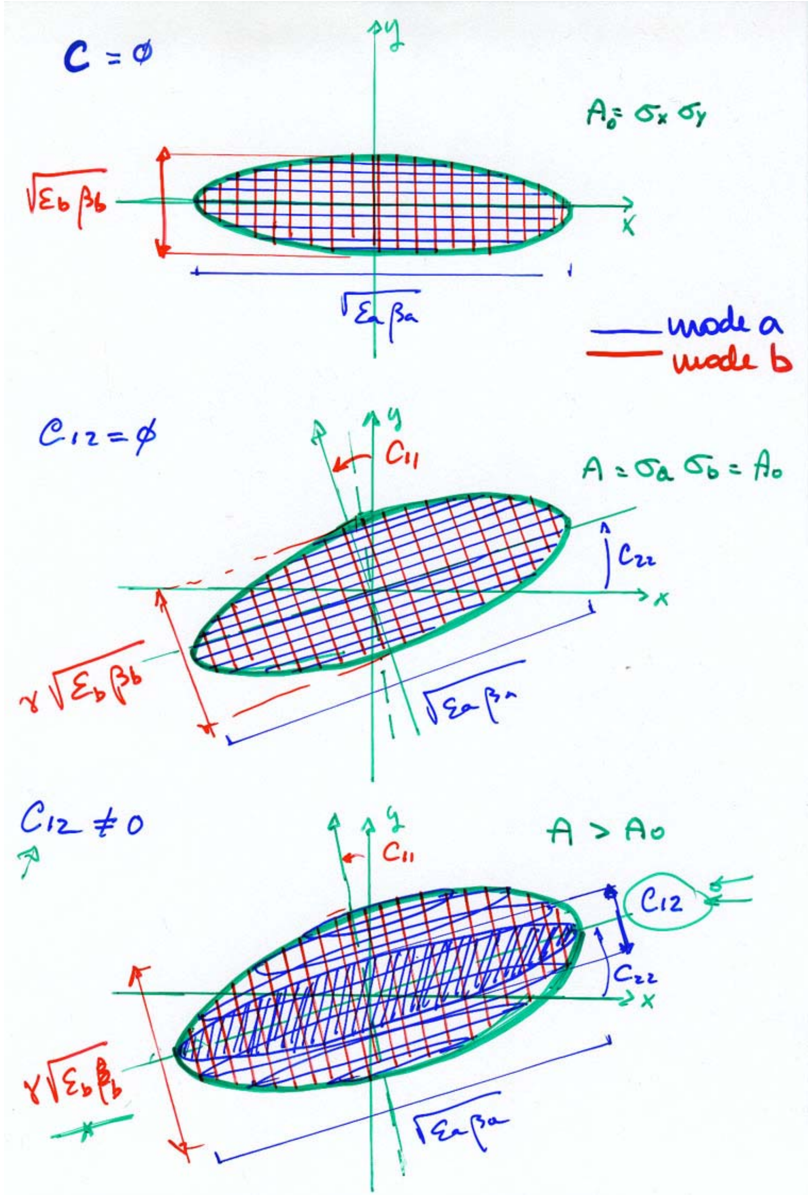
$$\theta_a = C_{22} + \frac{\alpha_a}{\beta_a} C_{12}$$

$$\theta_b = C_{11} - \frac{\alpha_b}{\beta_b} C_{12}$$

Uncoupled motion:
Mode a = h
Mode b = v

Coupled motion
C12 = 0
Mode a projection = line
Ellipse area = uncoupled case

Coupled motion
C12 ≠ 0
Mode a projection = ellipse
Ellipse area > uncoupled

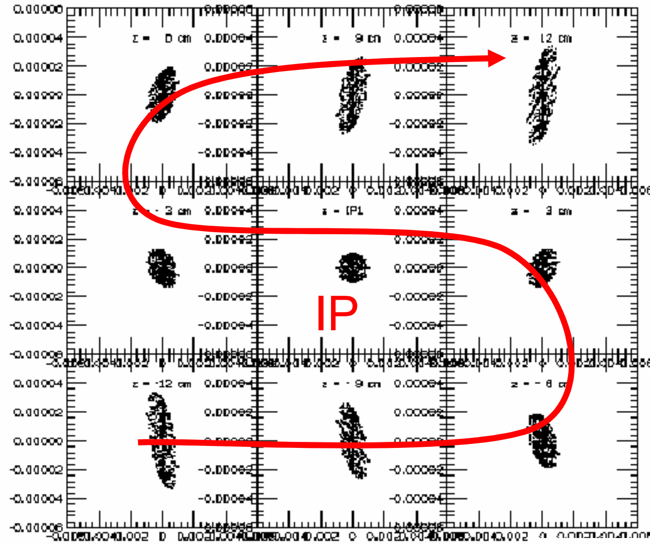


- any not locally compensated coupling source produces:
  - **LINEARLY along the ring**
  - **Tilt of 1st mode**
  - **C_{12} (s)**
  - **+**
  - **QUADRATICALLY**
  - **transfer of emittance in the 2nd mode**

TRANSVERSE PLANE (X,Y) AROUND THE IP: κ = 1%

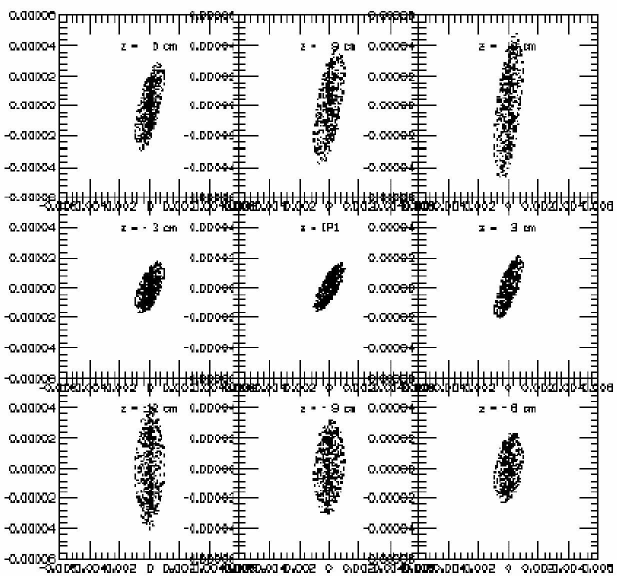
(simulations)

(Vscale =1/100 Hscale)

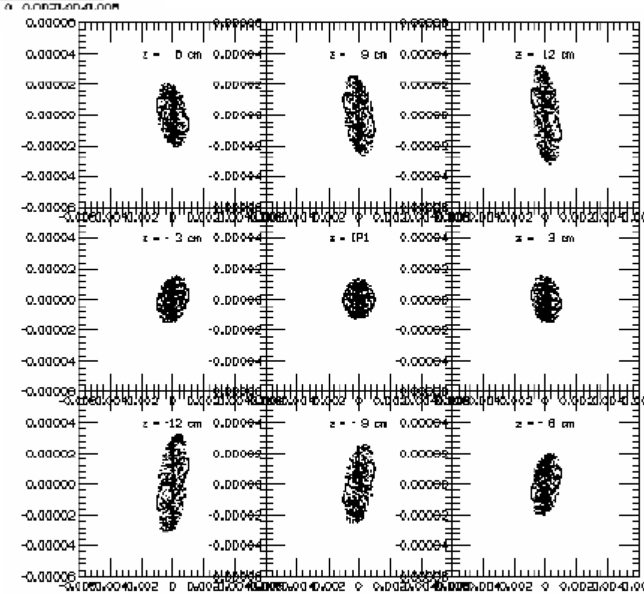


Nominal case
(no coupling source)
$C_{22} \neq 0$ (=0 @IP)

κ = 1%
Due to asymmetric compensators

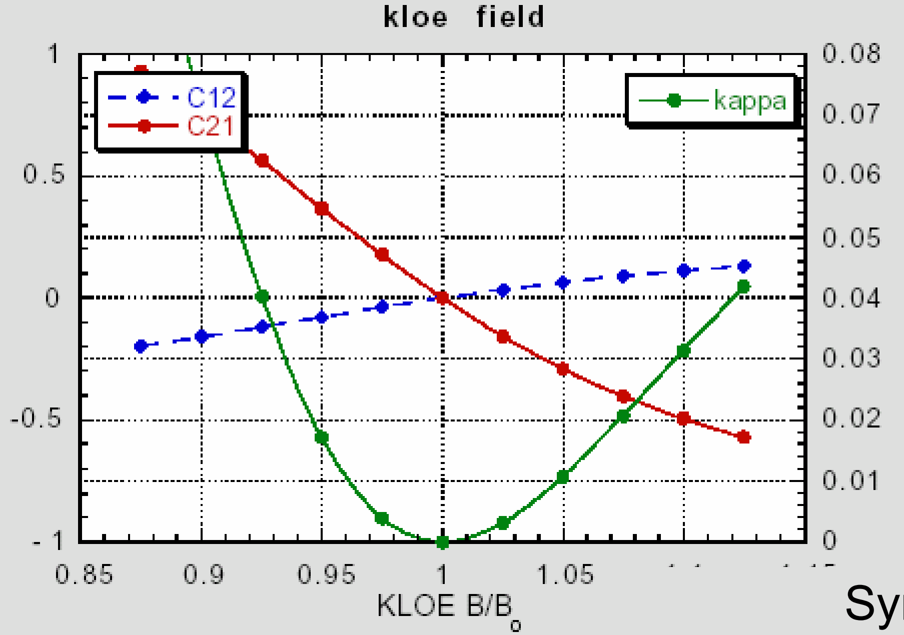


κ = 1%
Due to equally asymmetric skews

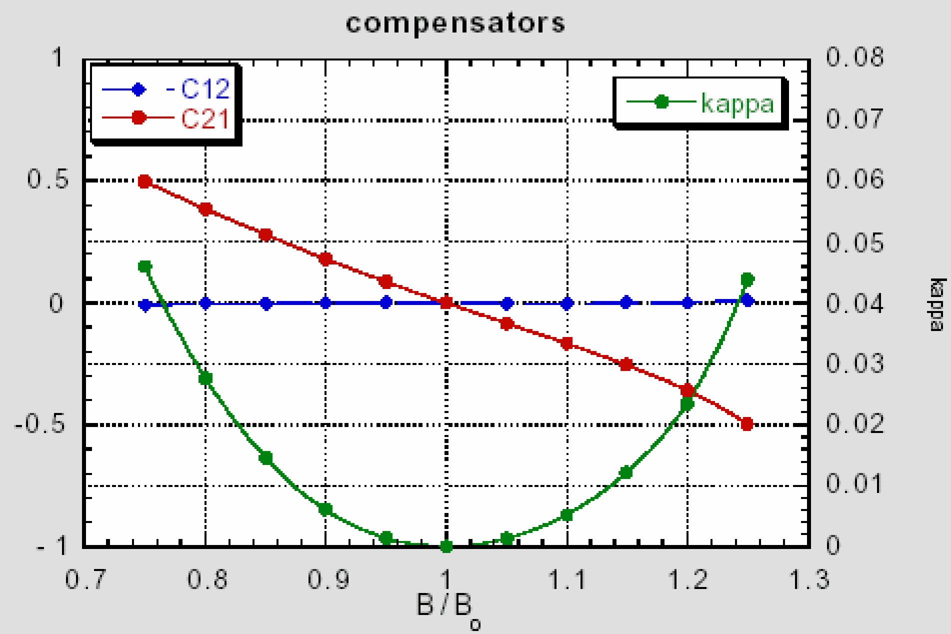


Effect of Solenoid change on coupling (simulations)

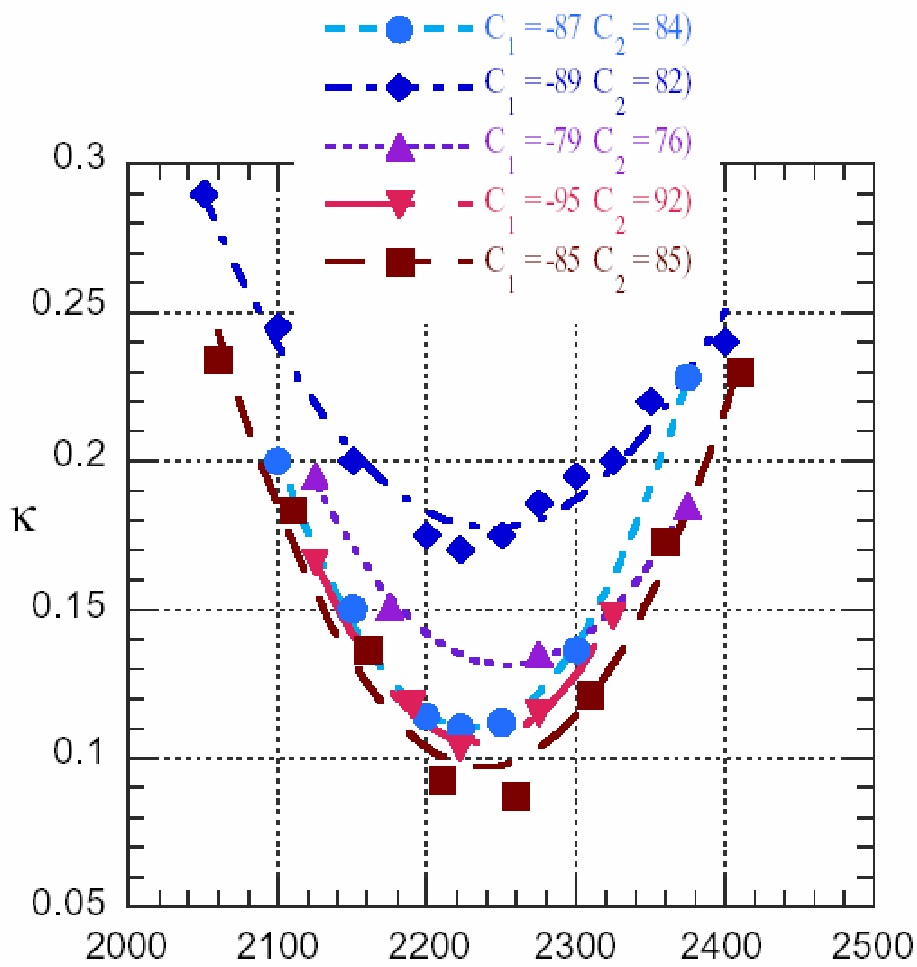
KLOE detector change



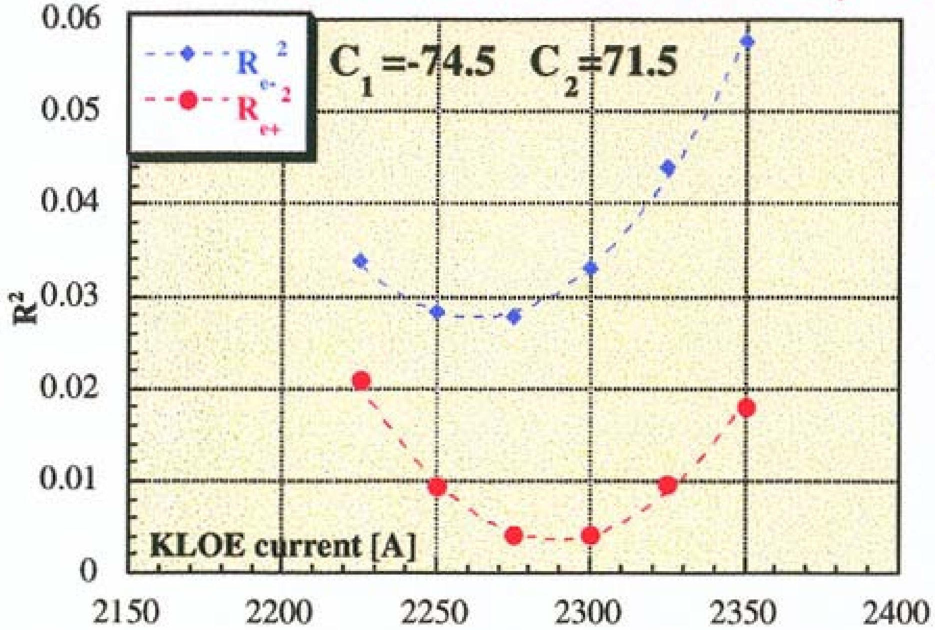
Symmetric change of compensators

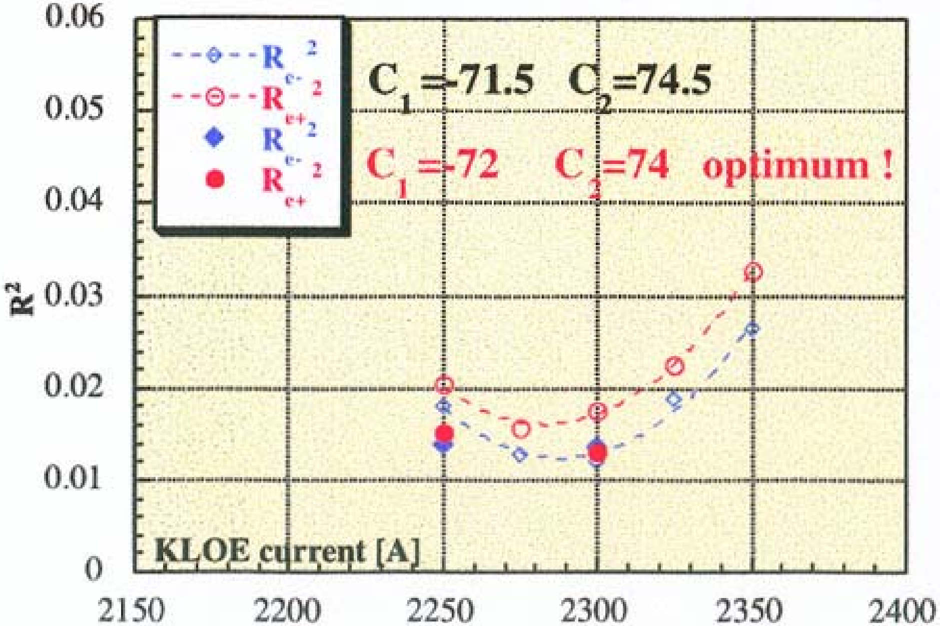


Coupling correction by tuning IR solenoidal field



Detuned Lattice, Coupling Correction

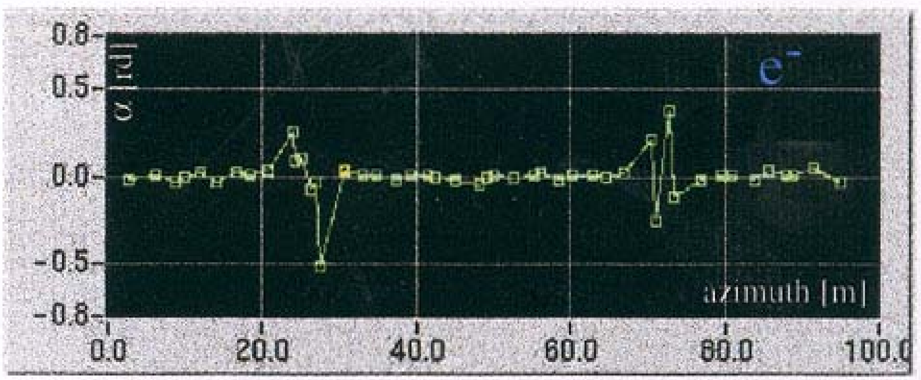


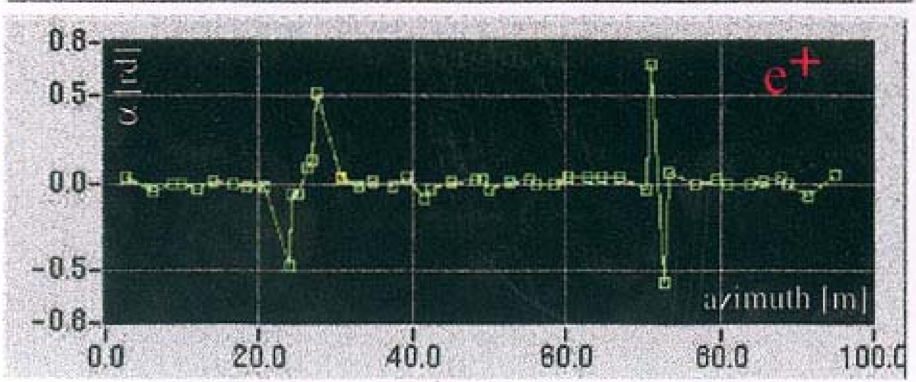


- **R** is the beam aspect ratio as measured at the SLM
- α is the measured amount of Horizontal oscillation transferred to the Vertical plane

$\alpha \longrightarrow 0$ **means no coupling !**

$\kappa < 0.2\%$





After 2003 shutdown

- Rotation of both IRs quads free
- Possibility of correcting coupling perfectly

but

- Possibility of creating unwanted coupling easily:
- Need of new correction system

Coupling Correction
with low-beta quads rotations by RM fitting*

- **Response Matrix**
- **Used for c.o. correction (SVD method)**

$$\begin{pmatrix} Xx & Xy \\ Yx & YY \end{pmatrix}$$

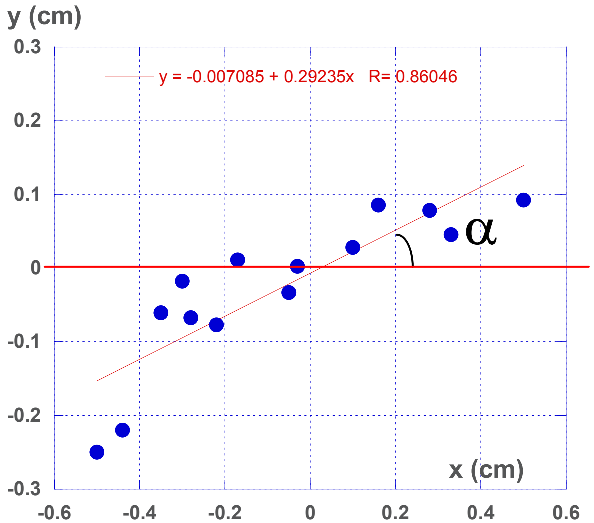
RM

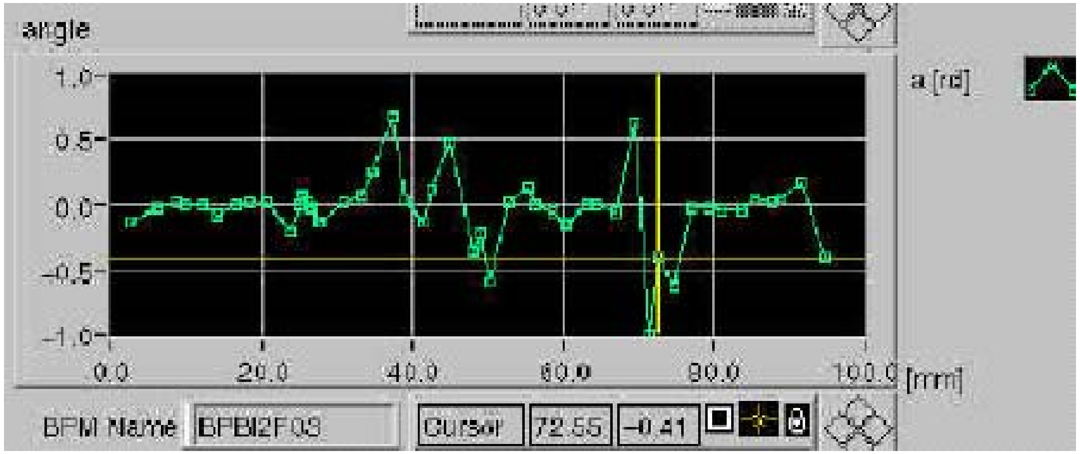
Indipendent c.o. correction in both planes

*** Catia Milardi et al. :"Coupling correction at DAΦNE by low-β quadrupoles rotation", to be published**

For c.o. correction is model independent

RM: measured and modelled (MAD):
good agreement after steering calibration





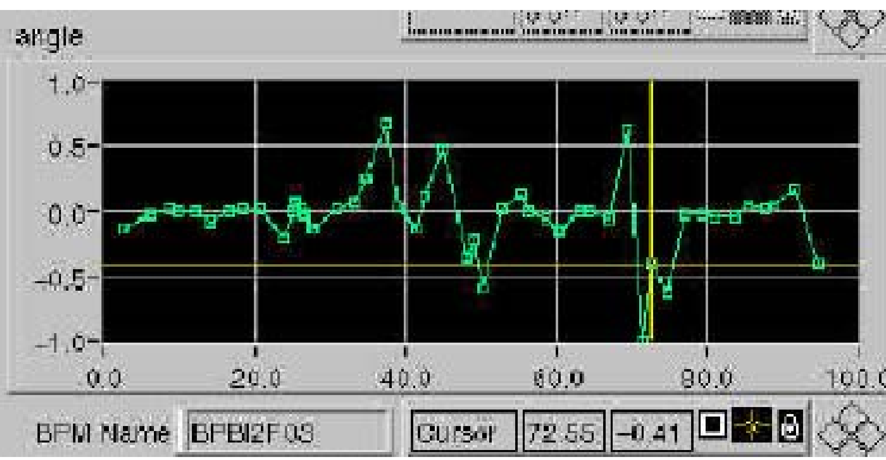
Response in one monitor
to horizontal excitation of all steerings

α in all the monitors along the ring
Related to C_{22} term of coupling matrix

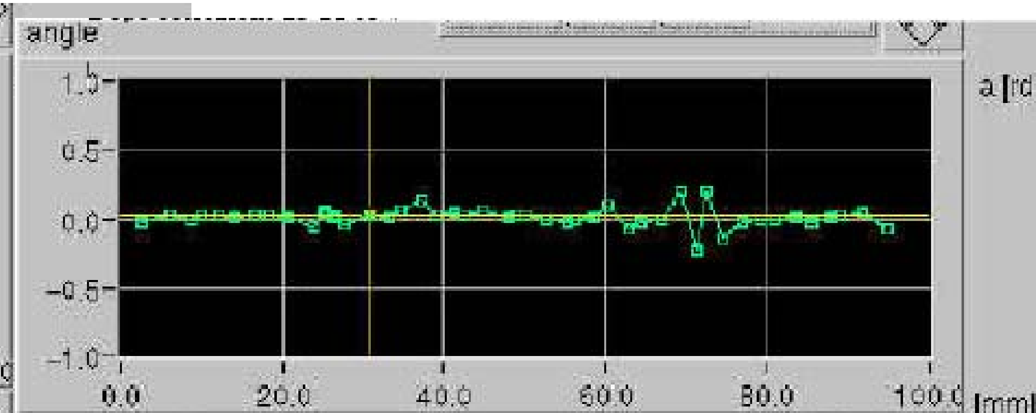
$$\begin{pmatrix} Xx & Xy \\ Yx & YY \end{pmatrix}$$

Depend on coupling sources
Measured with all possible coupling sources off (skews, sext, critical steerings)
Fitted through the model with 8 low-beta quad rotations: RM^+, RM^-, together
$\delta\theta$ (°) = -1, -1.2, 0.9, 1.4, -1.3, -0.1, -0.7, -0.4

Before correction κ >1%



after correction κ <0.5 %



From here on the variation in the quadrupole rotation are below the mechanical resolution of the system

Coupling hystory

Design			**1%**	**1%**
Day-one	**1998**	**No solenoids**	**Steering and skew quads**	**0.6 %**
KLOE+ lowbeta@2nd IP	**2001**	**One solenoid**	**+ Tuning solenoids**	**0.4 %**
KLOE + Detuned 2nd IP	**2002**	**One solenoid**	**+ Minimize kicks**	**0.2 %**
KLOE+FINUDA	**2003**	**F solenoid on K solenoid off**	**+ RM matrix fitting**	**0.4 %**

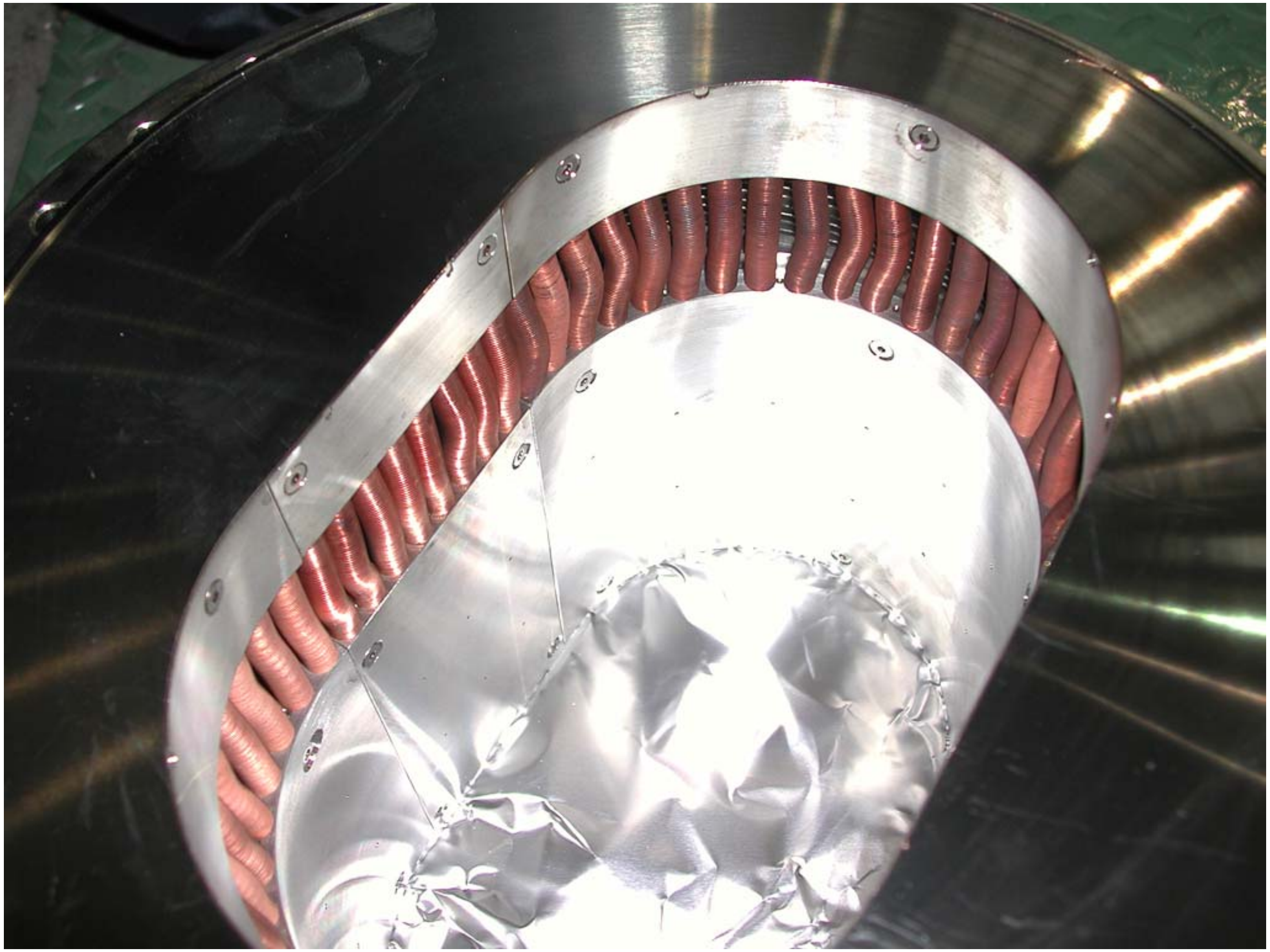
1% coupling produces beam-beam blowup at relatively low currents

Operation at high currents

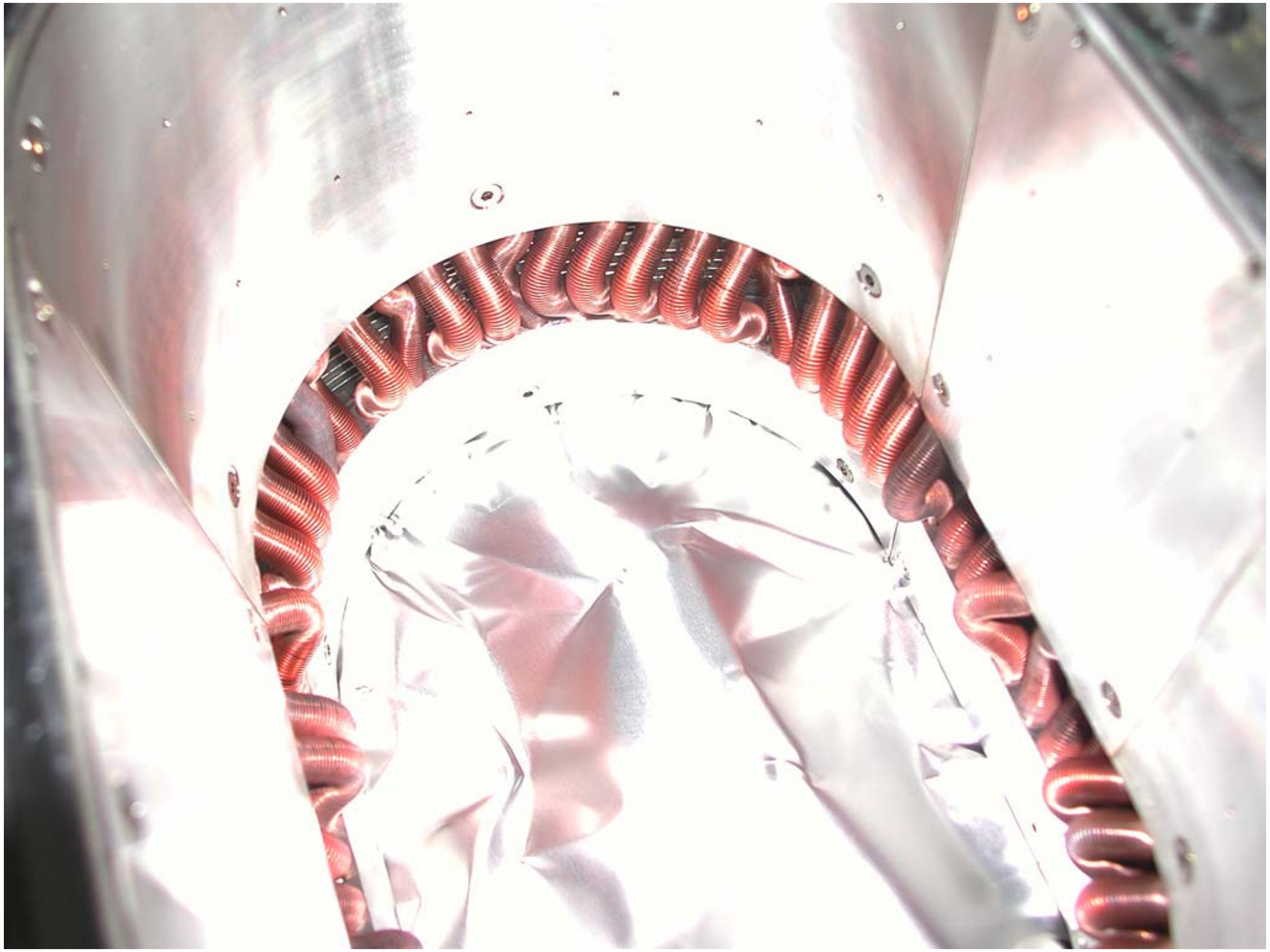
- Highest currents:
- KLOE : I+ 1.1 A, I- 0.8 A – 50 bunches
- DEAR : I+ 1.0 A, I-1.3 A – 100 bunches

- No problems found in technological IR aspects
- Good vacuum after some tens of Ah

Bellows with mini bellows
Between IR and arcs



After 4 years of operation   good



After 4 years of operation   bad

DAΦNE peak luminosity 2000-2003