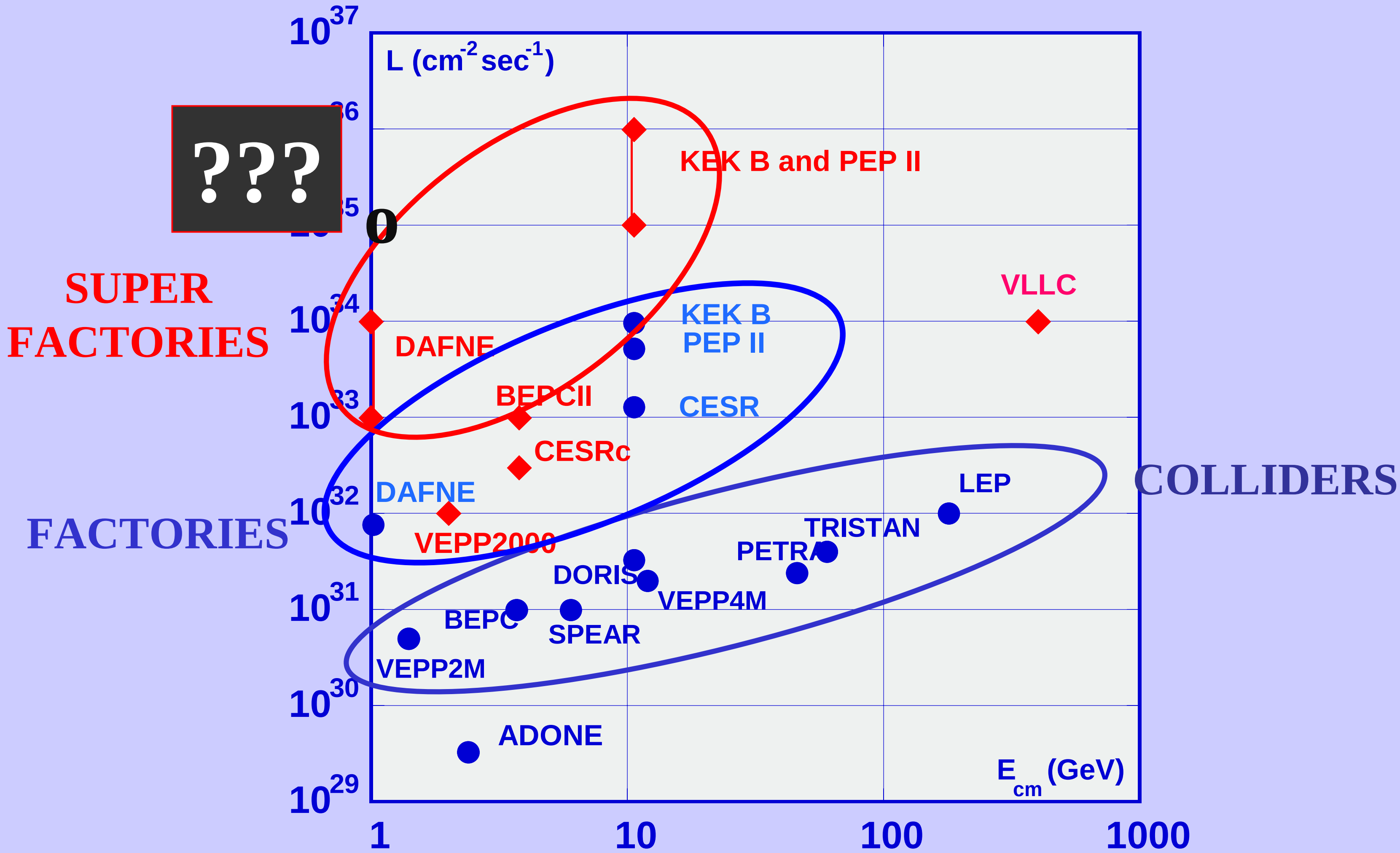
Accelerator working group

Three sessions on the option for High luminosity at Φ- energy …. Going towards SUPERDAFNE

The session on the option for 2 GeV will be held this Afternoon DAFNE2

PAST, PRESENT AND FUTURE



PEAK Luminosity

increase **total current**

and per **bunch current**

increase **n of bunches**

decrease **beam sizes**

AVERAGE Luminosity

continuos injection

$$L = \frac{f_{coll}}{4\pi} \frac{N^+ N^-}{\sigma_x^* \sigma_y^*}$$

high currents

Singlebunch instabilities
Multibunch instabilities
Feedbacks
impedance
ECI
CSR
Power : vacuum, rf, cooling

beam-beam

crossing angle
low β_y – short bunch length
resonances
dynamic aperture
blowup

Background

masks
collimators
cooling
touschek scattering
lattice phase advances
IR designs

lifetime - injection

beam-gas scattering
touschek effect
beam-beam loss rate

$\tau \sim$ *hours* -> $\tau \sim$ *few minutes*
$L \sim 10^{34}$ -> $L \sim 10^{36}$

continuos injection

CESR-c Energy dependence

Beam-beam effect

- In collision, beam-beam tune shift parameter ~ I_b/E
- Long range beam-beam interaction at 89 parasitic crossings ~ I_b/E (for fixed emittance)
  (and this is the current limit at 5.3GeV)

Single beam collective effects, instabilities

- Impedance is independent of energy
- Effect of impedance ~I/E

Few months ago
Informal meeting at Frascati

- Premessa: Kaon fluxes

Kaons produced at existing fixed–targed facilities:

K_L	3×10^{11}	KTeV	[on tape, decays inside fiducial volume]
K_S	3×10^{10}	NA48/1	[on tape]
K^+	6×10^{12}	BNL–E787	[on tape]
$K^\pm$	3×10^{11}	NA48/2	[expected in 2003]

Possible Φ–Factory fluxes:

$$1 \ \text{fb}^{-1} \ (= 10^{32}\ \text{cm}^{-2}\text{s}^{-1} \times 10^7\ \text{s}) \Rightarrow 10^9 \ [\, K_L K_S + 1.5\, K^\pm \,]$$
$$10 \ \text{fb}^{-1} \ (= 10^{33}\ \text{cm}^{-2}\text{s}^{-1} \times 10^7\ \text{s}) \Rightarrow 10^{10} \ [\, K_L K_S + 1.5\, K^\pm \,]$$
$$100 \ \text{fb}^{-1} \ (= 10^{34}\ \text{cm}^{-2}\text{s}^{-1} \times 10^7\ \text{s}) \Rightarrow 10^{11} \ [\, K_L K_S + 1.5\, K^\pm \,]$$

$\Rightarrow$ $\int \mathscr{L} \geq 100\ \text{fb}^{-1}$ mandatory to start a new competitive program

Main guidelines for the design
$L > 10^{34}$

- **Powerful damping**
- **Short bunch at IP**
- **Negative momentum compaction**

Which kind of collider is possible at Frascati using present infrastructures?

Beam Dynamics with $\alpha_c < 0$

The DAΦNE lattice is enough flexible to provide collider operation with a negative momentum compaction (P. Raimondi). There can be several advantages for beam dynamics and luminosity performance in this case:

- Bunch is shorter with a more regular shape
- Longitudinal beam-beam effects are less dangerous
- Microwave instability threshold is higher (?)
- Sextupoles are not necessary

- The minimum value of the vertical beta-function β_y at the IP in a collider is set by the hour-glass effect and it is almost equal to the bunch length σ_z. Reducing the bunch length in storage rings is therefore one of the most promising way to make a step forward in the achievable Luminosity

$$L \propto \frac{1}{\sigma_x \sigma_y} \propto \frac{1}{\sqrt{\beta_x \beta_y}}$$

- It may be seen that by only scaling the horizontal and vertical beta functions β_x and β_y at the IP as the bunch length σ_z, the linear tune shift parameters $\xi_{x,y}$ are unaffected, while the luminosity scales as:

$$L \propto \frac{1}{\sqrt{\beta_x \beta_y}} \propto \frac{1}{\sigma_z}$$

Strong RF Focusing for Luminosity Increase

A. Gallo, P. Raimondi, M.Zobov

Longitudinal Lattice Model

IP

$$M(s_0, s) = \begin{bmatrix} 1 & R_{56}(s) - R_{56}(s_0) \\ 0 & 1 \end{bmatrix}$$

Drift Space

s

Longitudinal conjugate variables => $\begin{bmatrix} z \\ \varepsilon_E \end{bmatrix}$

$z = c \cdot \tau$ (τ = particle delay respect to synch. phase)

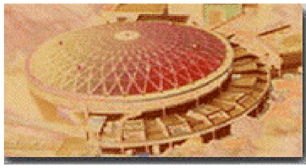
$\varepsilon_E = \Delta E / E$ = relative energy error

$$R_{56}(s) = \int_0^s \frac{\eta(\tilde{s})}{\rho(\tilde{s})} \, d\tilde{s}$$

RF

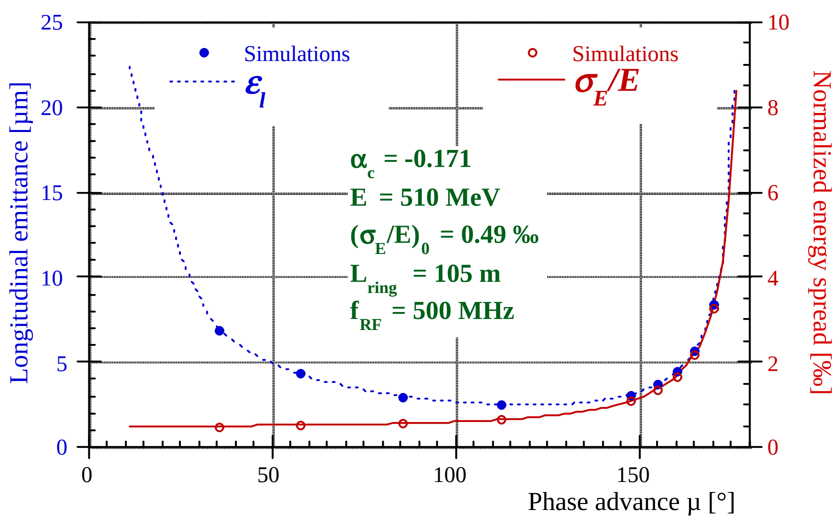
$$M(s_c^-, s_c^+) = \begin{bmatrix} 1 & 0 \\ -\frac{V_{RF}}{E/e} \frac{2\pi}{\lambda_{RF}} & 1 \end{bmatrix}$$

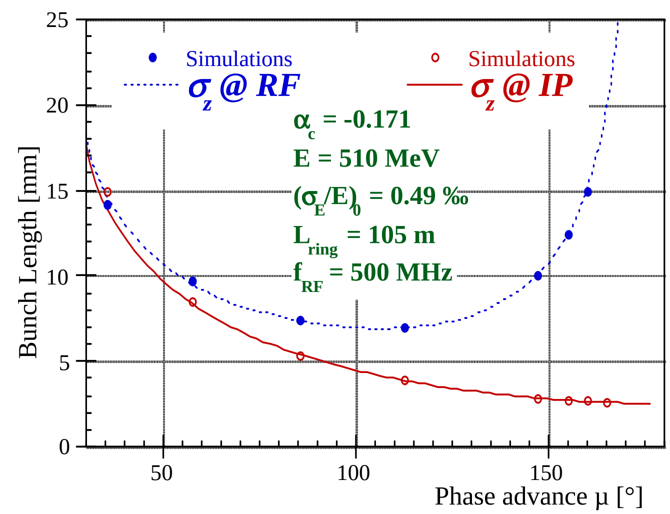
RF Cavity = long. thin lens



Comparison with Numerical Results:

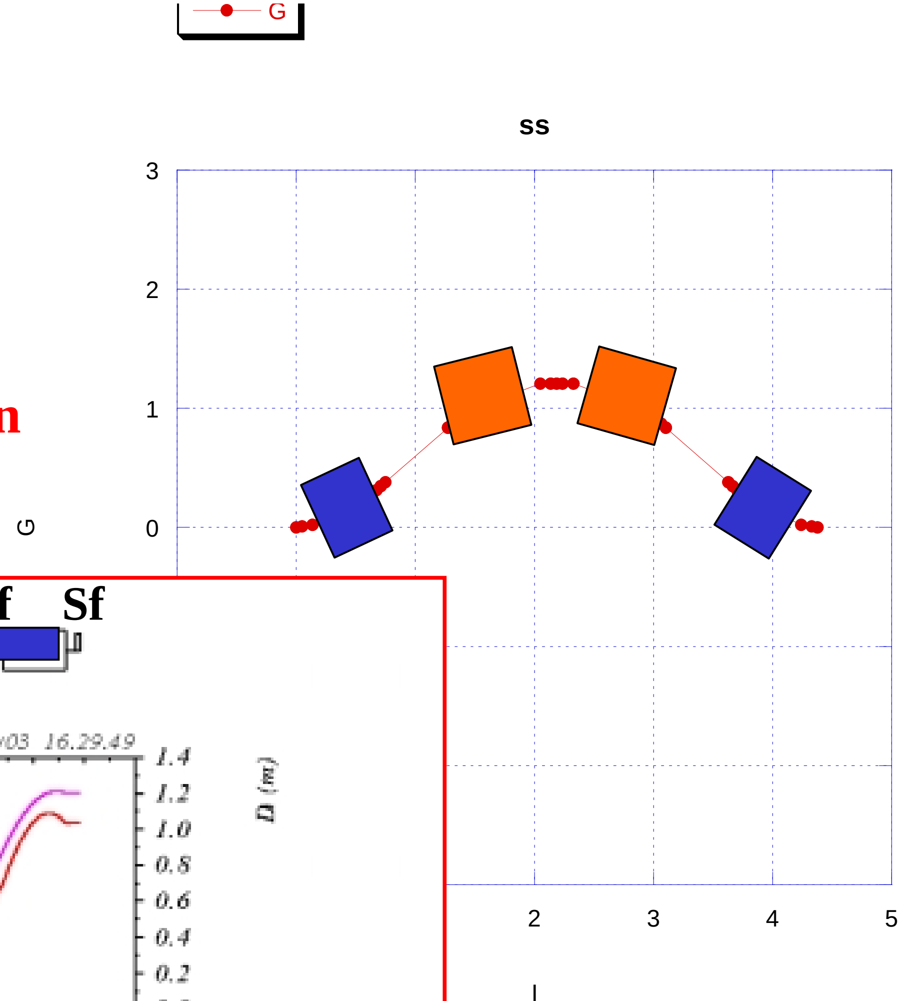
These analytical results have been compared with multi-particle tracking simulations of the bunch longitudinal dynamics in a strong RF focusing configuration. Uniform R_{56} growth and emission rate in the arcs have been assumed in the tracking. The agreement is evident.

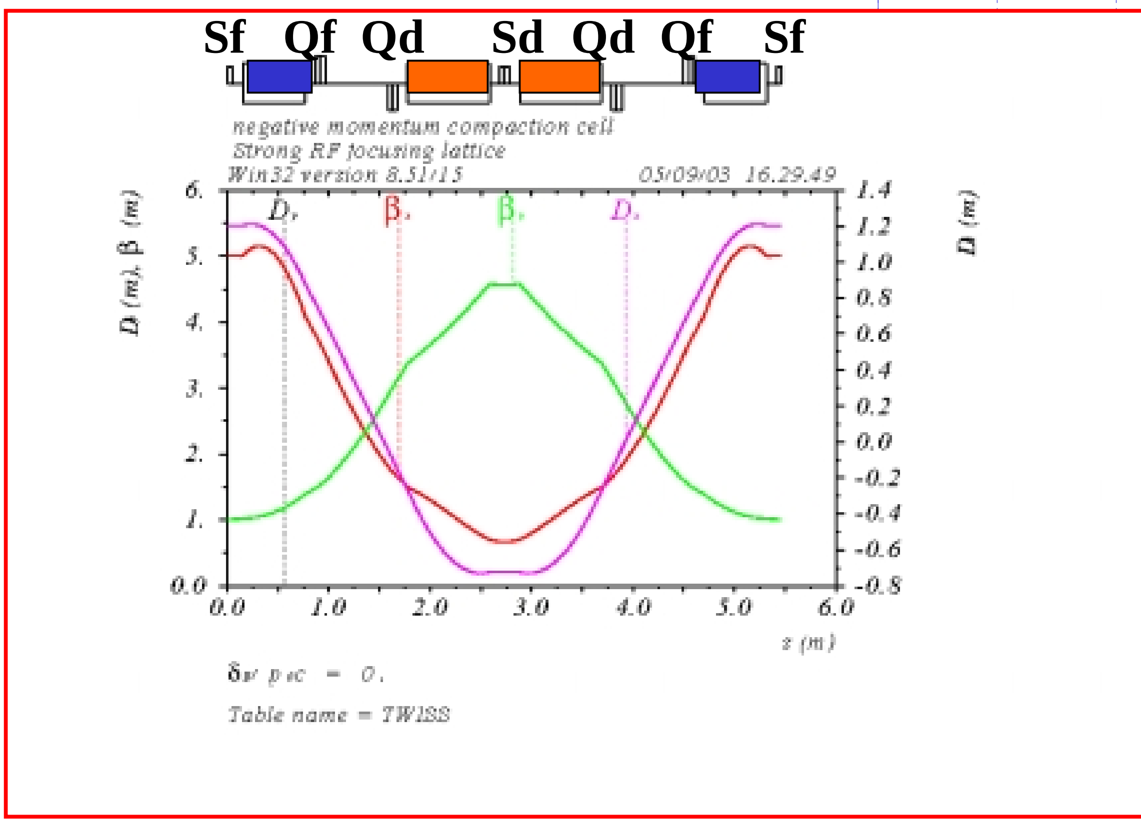




HIGH and NEGATIVE MOMENTUM COMPACTION

strong RADIATION emission





Alternating positive and negative bending dipoles

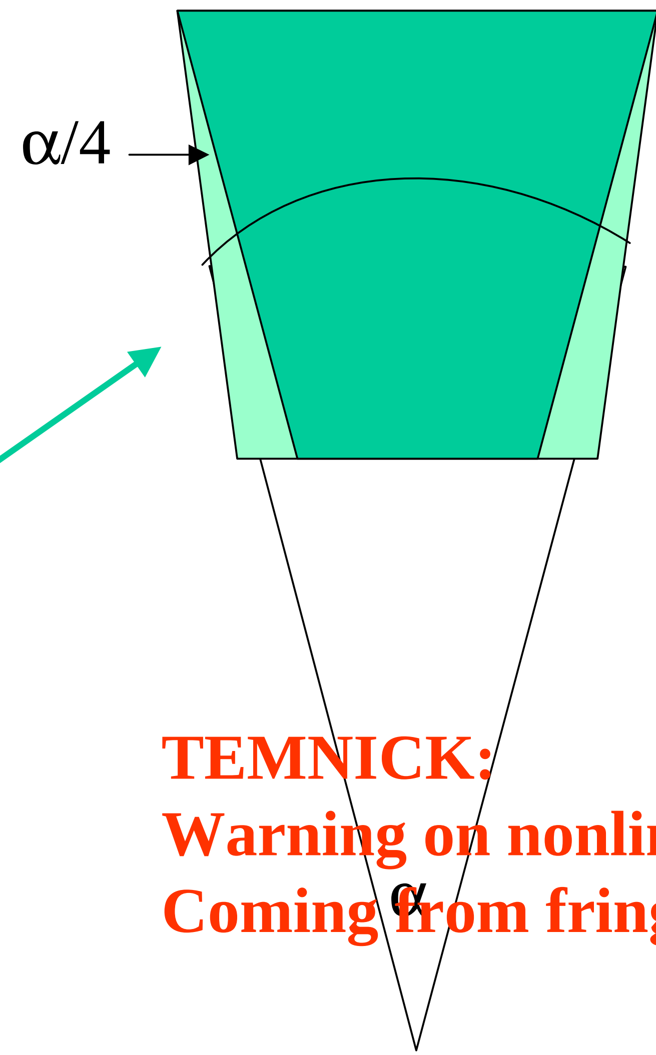
(proposed by Raimondi)

Dipoles

Sector magnet:
horizontal focusing

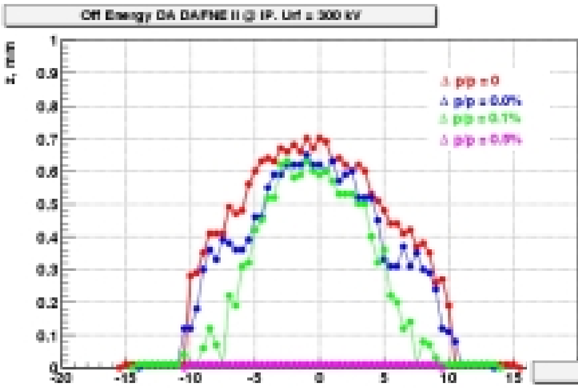
Rectangular magnet:
Vertical focusing

In between:
(H + V)/2 focusing

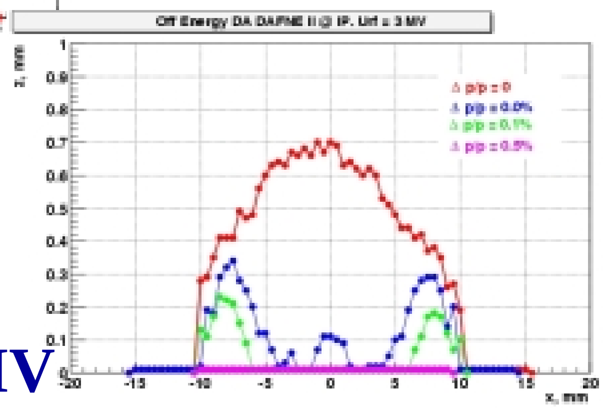


TEMNICK:
Warning on nonlinearities
Coming from fringing fields

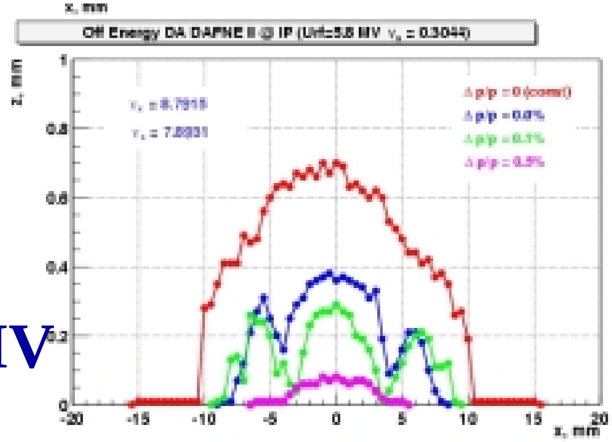
----- no synchr oscill
----- Dp/p = 0
----- Dp/p = 0.1%
----- Dp/p = 0.5%



V = 300 kV
Q_s = 0.059



V = 3 MV
Q_s = 0.2



V = 5 MV
Q_s = 0.3

Strong dependence on V
but specially on Q_s
=> Resonances in 3D

DAΦNE with strong RF focusing

As an example we will consider the effect of proposed RF configuration on longitudinal feedback

The proposed design has a much higher gap voltage which results in significantly shorter bunches at the IP and higher synchrotron frequency.

Parameter	Current	Proposed
RF frequency (f_{rf})	368.25 MHz	500 MHz
Momentum compaction (α_c)	0.029	-0.171
Circumference (L)	97.69 m	105 m
Revolution frequency (f_{rev})	3.069 MHz	2.857 MHz
Harmonic number	120	175
RF voltage (V_{rf})	120 kV	10.677 MV
Synchrotron frequency (f_s)	30 kHz	1.31 MHz
Revolutions per synchrotron period	~102	2.18
Bunch length (σ_z)	19 - 38 mm	2.6 - 20.4 mm

System issues

Signal processing

- High synchrotron frequency means that we need to process every bunch on every turn. This is addressed by the Gboard architecture described earlier by John Fox.
- Processing for odd harmonic numbers is more difficult to implement than that for even numbers.

Synchronous gap transients

- ~5 deg@RF at 1 A, not an issue since their amplitude scales as $1 / V_{rf}$
- Front-end gain can be increased relative to the current setting.

Loop gain

- Gap voltage increases 89 times, thus effective feedback gain drops by 9.4 for constant growth rates.
- Partially compensated by the higher front-end gain
- Kicker gain for the quadrupole instabilities goes down with the bunch length, need to place the kicker near the RF cavity or design a separate higher frequency quadrupole kicker.

Mode 0 tune shifts

- Not a significant problem since very high synchrotron tune samples the RF cavity impedance far from resonance.

Longitudinal coupled-bunch instabilities

Consider the modal eigenvalues Λ_l:

$$\Lambda_l = -d_r + i\omega_s + \frac{\alpha e f_{rf}}{2E_0 \nu_s} I_0 Z^{eff}(l\omega_{rev} + \omega_s)$$

If the effective impedance and beam current stay the same, the eigenvalues change as $\frac{6 \cdot 1.36}{47} = 0.17$ where factor of 6 is from change in α, 1.36 - from f_{rf}, and 47 - from ν_s.

These are good news - the growth rates are reduced.

Another advantage is that at higher synchrotron frequency faster growth rates can be controlled.

Problems

- Shorter bunches sample higher frequency impedances, impedance is aliased with linear (dipole) or quadratic (quadrupole) frequency weighting.
- Achieving the same feedback loop gain is harder

Conclusions

There are many interactions between the RF system and the coupled-bunch instability feedback

Experience from operating LBL/LNF/SLAC designed feedback systems at 5 different machines allowed us to carefully characterize these interactions.

Information on the RF parameters together with the impedance data can be used to predict with high degree of confidence the feasibility of the proposed configuration.

Analysis of the proposed strong RF focusing for DAΦNE shows feasibility of the design with respect to longitudinal coupled-bunch feedback with several possible problems:

- Excitation of the beam by the RF noise
- Reduced effective loop gain
- Lower kicker gain for quadrupole control
- High-frequency impedances sampled by a shorter bunch

More analysis needs to be done at the later stages of the design process.

Most importantly, from our experience with the LFB at multiple installations two things stand out

- In operating the machine you almost always find instability surprises not predicted in the design.
- Flexibility of the feedback architecture is critical to effectively control these “surprises”.

Variable σ_l

μ_l	165	150
Emittance (mm mrad)	.19	.19
κ	.01	.01
I (mA)	16	16
α_c	-.17	-.17
VRF (MV)	10.68	10.15
σ_l^{IP} (mm)	2.5	2.8
σ_l^{RF} (mm)	20.0	10.9
σ_p	2.2e-3	1.2e-3
ε_{RF} at IP	1.1e-2	1.1e-2
ε_{RF} at RF	4.5e-3	4.5e-3
Luminosity/csi	1e34/.083	1e34/.083
τ_{TOU} (s)	1050 (17.5')	550 (9.2')
$\tau_{quantum}$ (s)	86 (1.4') !!	6.1e14

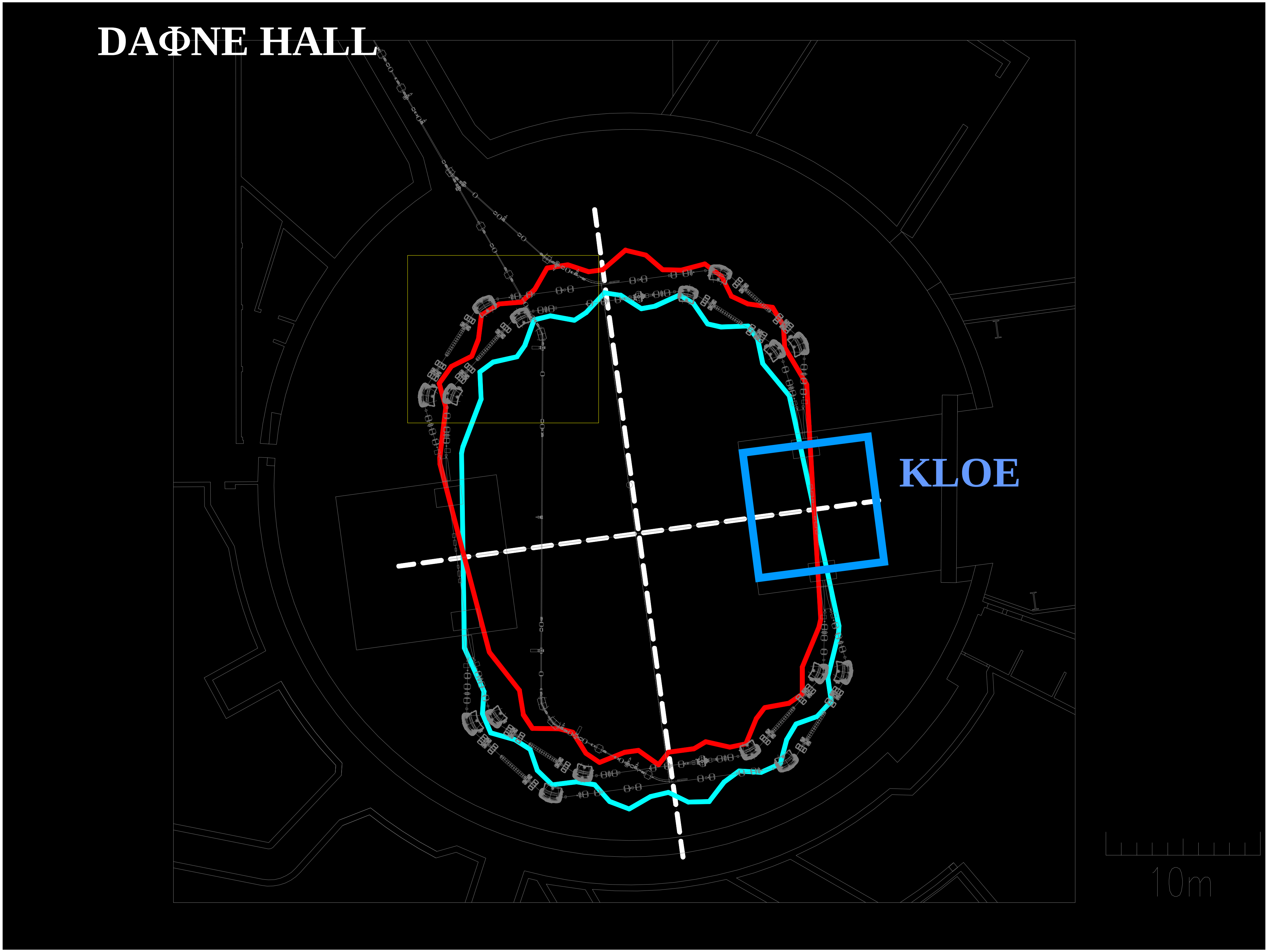
Conclusions

Strong RF focusing (bunch length variation along the ring) seems promising to get very short bunch length at the IP.

Touschek lifetime has been calculated with a preliminary set of longitudinal parameters. A further optimization is possible.

Anyway at $L = 10^{34}$ lifetimes are of the order of 10 minutes:

- continous injection is needed
- a setup for Luminosity optimization with rapidily decreasing currents has to be provided.


DAΦNE HALL
KLOE
10m

Luminosity 10^{34}

set of consistent parameters

$N^{+,-} = 5\ 10^{10}$

$\beta_x = 0.5\,m$

$\beta_y = 4\,mm$

$\varepsilon_x = 0.26\,\mu rad$

$\kappa = 0.6\%$

$n_b = 150$

$I_b = 24\,mA$

$I_{tot} = 3.7\,A$

challenges

MAIN PARAMETERS	
C (m)	100
E (MeV)	510
f_{rf} (MHz)	503
V (MV)	8.2
ε_x (μ rad)	0.26
ε_y (μ rad)	0.002
α_c	- 0.23
β_x^* (m)	0.5
β_y^* (mm)	4.0
N / bunch	5 e10
h	168
L /bunch (cm^{-2} sec^{-1})	$6\ 10^{31}$
L tot (cm^{-2} sec^{-1})	10^{34}

high currents

Singlebunch instabilities
Multibunch instabilities
Feedbacks
impedance
ECI
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Power : vacuum, rf, cooling

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crossing angle
low β_y – short bunch length
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Background

masks
collimators
cooling
touschek scattering
lattice phase advances
IR designs

lifetime - injection

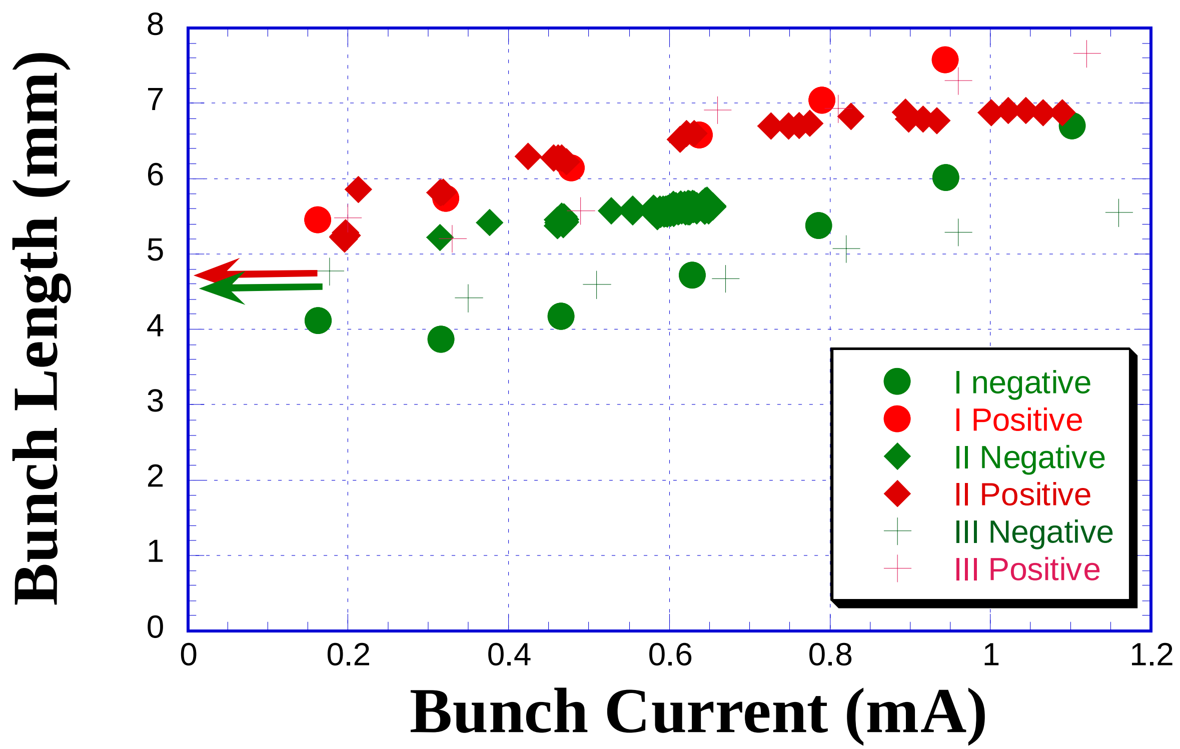
beam-gas scattering
touschek effect
beam-beam loss rate

τ~ hours -> τ ~ few minutes
$L \sim 10^{34}$ -> $L \sim 10^{36}$

continuos injection

Tests needed in collaboration with other machines

Negative alfa tests at KEKB



Ikeda, KEKb

For the discussion

M.Serio, A. Ghigo, J.Fox

Possibility of testing the strong RF focusing in an existing machine ?

PEP2, KEK-B , CESR

ALS - Placidi

10^{33}

Optimistic extrapolation of present knowledge and technologies

10^{34}

Very challenging design based on new ideas

Proofs of principle and validation needed

R&D

10^{35}

**...

L	**32**	**33**	**34**
C	**100**	**100**	**100**
Frf	**368**	**368**	**500**
Alfa	**0.01-0.02**	**-0.02**	**-0.2**
Nb	**100**	**100**	**150**
I/bunch	**20 mA**	**20 mA**	**25 mA**
I tot	**1.5**	**2**	**3.7**
Betay	**2 cm**	**1.5cm**	**2-4mm**
L bunch	10^{30}	10^{31}	$6\ 10^{31}$
σ_L	**2.5**	**1.3**	**variable**
ξ	**.02**	**.04**	**.08**