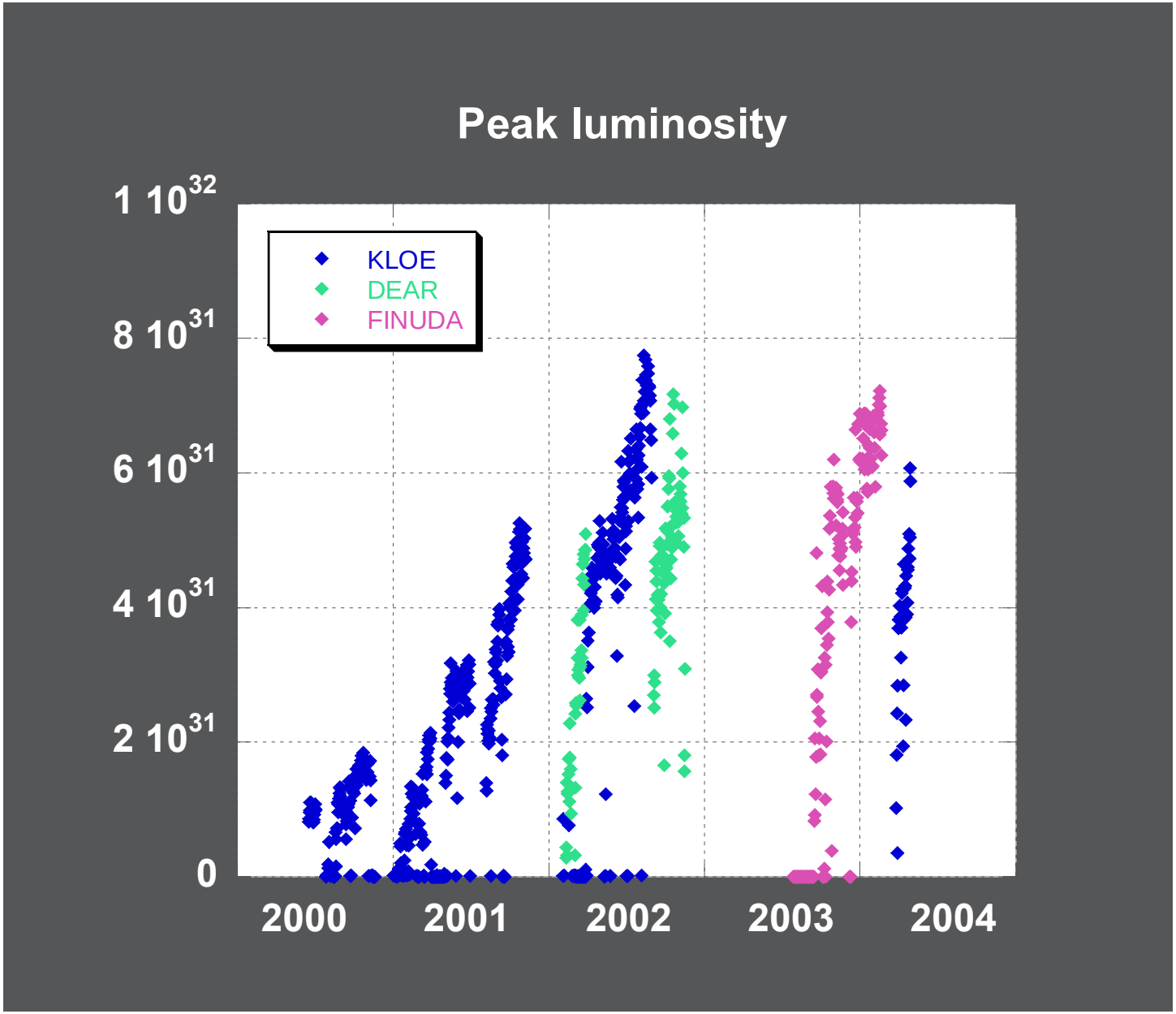
Design considerations for Energy/Luminosity upgrade

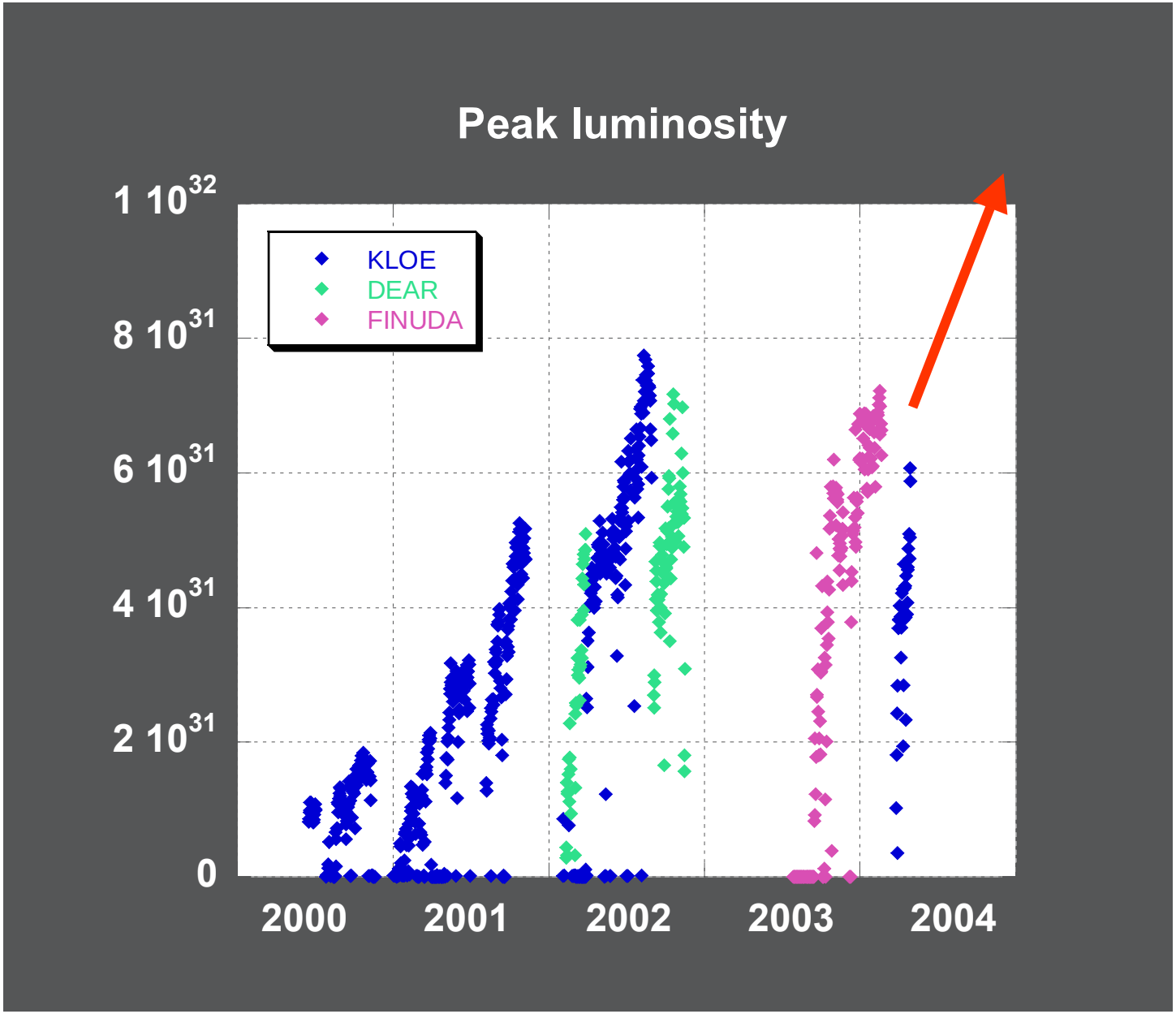
A. Gallo for the DAΦNE team

DAFNE2004, June 11th 2004,
Frascati

so far ...


Peak luminosity
1 10^32
8 10^31
6 10^31
4 10^31
2 10^31
0
KLOE
DEAR
FINUDA
2000
2001
2002
2003
2004

short term


Peak luminosity
1 10^32
8 10^31
6 10^31
4 10^31
2 10^31
0
KLOE
DEAR
FINUDA
2000
2001
2002
2003
2004

What's next ?

1. No major upgrades – Do the best with the existing hardware
2. Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ
3. New machine for both E upgrade and $L > 10^{33}$ @ Φ
4. New machine for $L > 10^{34}$ @ Φ

What's next ?

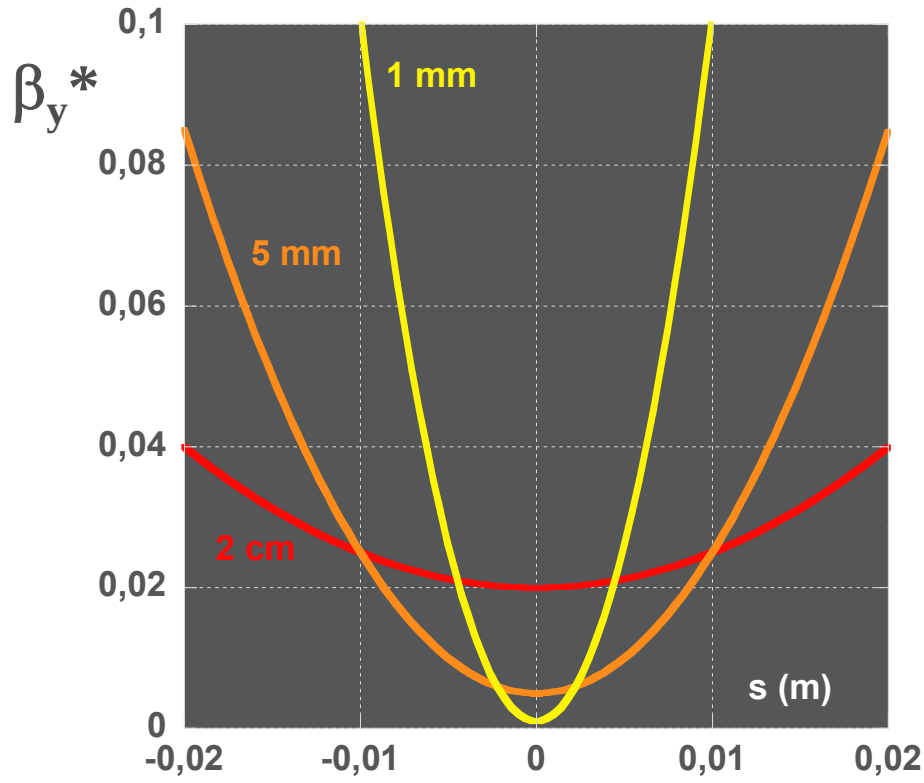
1. **No major upgrades – Do the best with the existing hardware**
2. **Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ**
3. **New machine for both E upgrade and $L > 10^{33}$ @ Φ**
4. **New machine for $L > 10^{34}$ @ Φ**

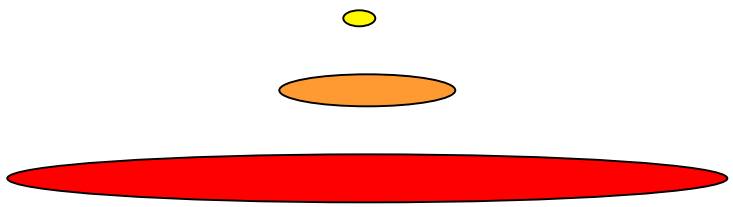
The Road to L > 10^{32}

- **Negative momentum compaction: shorter bunch**
- **Lower β_y**
- **Lower Tunes**
- **Reaching 2 A per beam**

“Hourglass” effect

Gain in luminosity by squeezing the bunch vertical dimensions through the β-function is only possible if the bunch length is also decreased





Bunch length

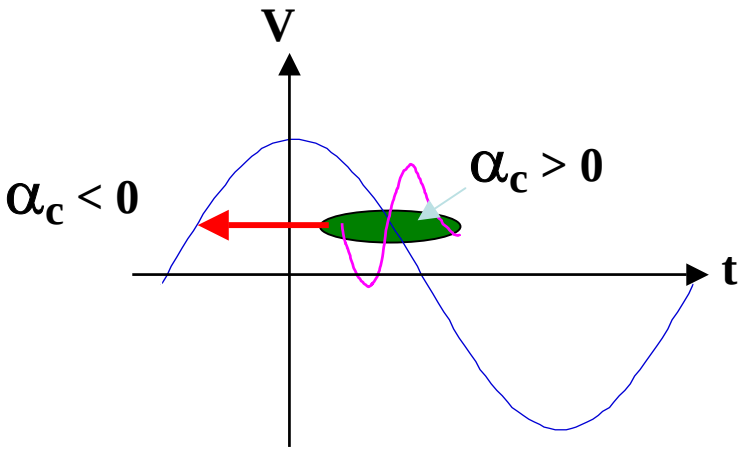
Negative momentum compaction α_c

$$\frac{\Delta L}{L} = \alpha_C \frac{\Delta p}{p}$$

relates normalized one-turn path elongation and energy deviation

α_c>0 (usual): particles with higher energy run a longer closed orbit

α_c<0 (possible): particles with higher energy run a shorter closed orbit



The bunch wake has always a positive slope on the bunch core.

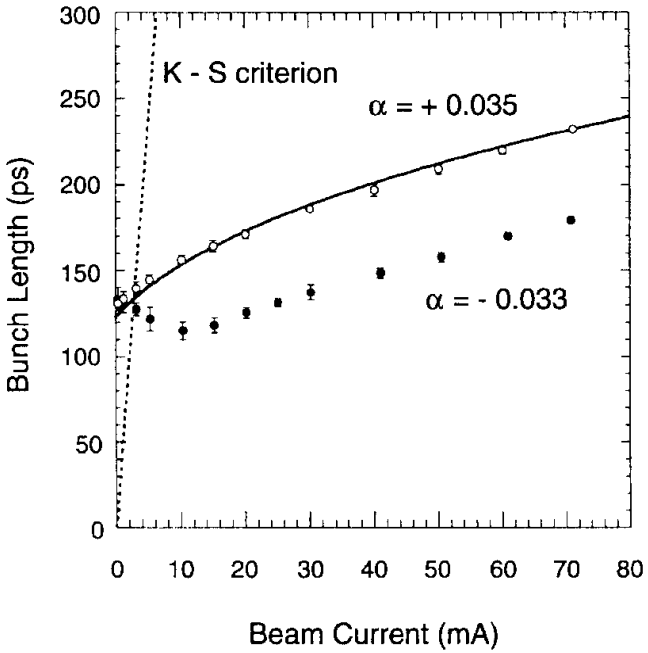
For positive (negative) momentum compaction the stable phase is on the RF negative (positive) slope.

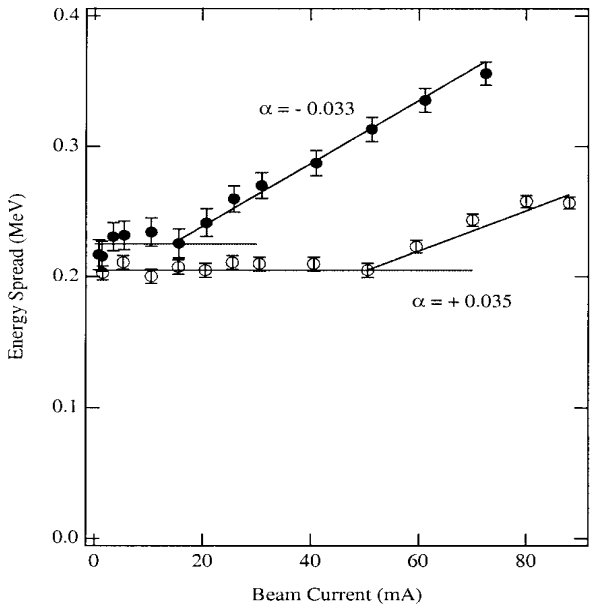
The wake is defocusing for α_c>0 (bunch lengthens), while it is focusing for α_c<0.

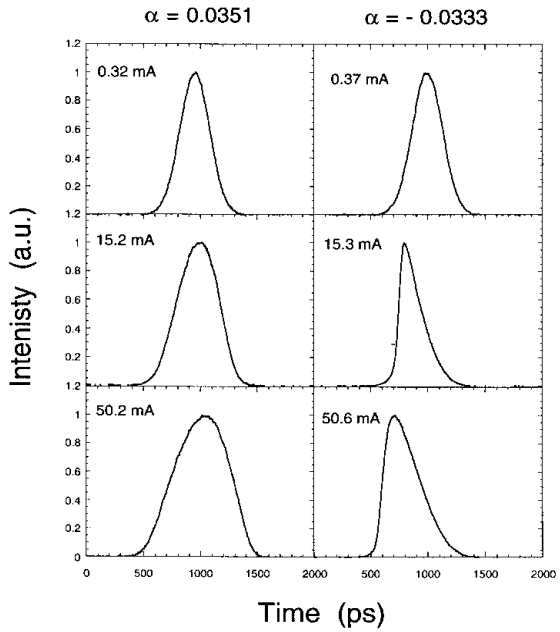
- **Bunch is shorter with a more regular shape**
- **Longitudinal beam-beam effects are less dangerous**
- **Microwave instability threshold is higher**
- **Sextupoles can be relaxed since head-tail disappears**

Experimental Data from UVSOR

References: 1. M. Hosaka et al., Nucl.Instr.Meth. A407 (1998) 234-240
2. M. Hosaka et al., APAC98, 426-428



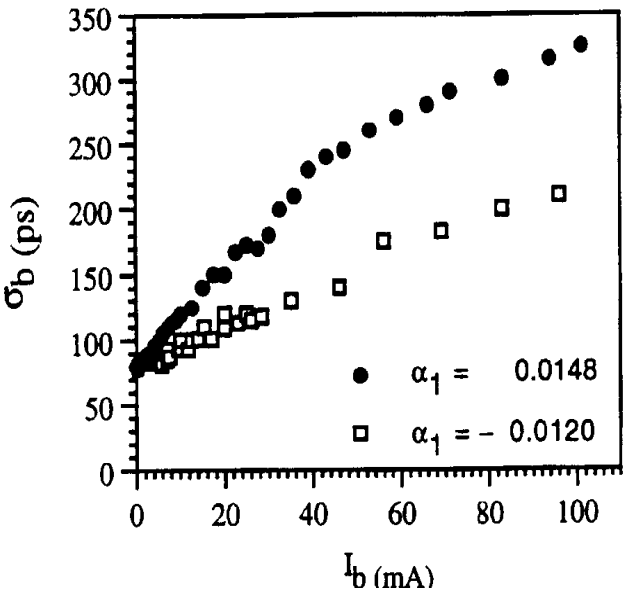


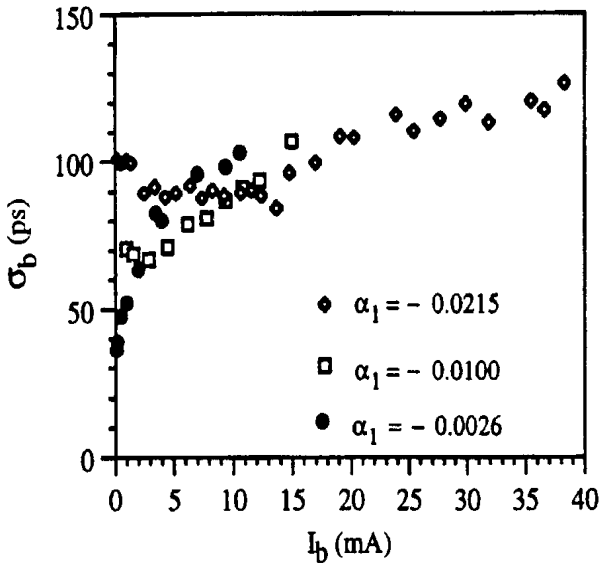


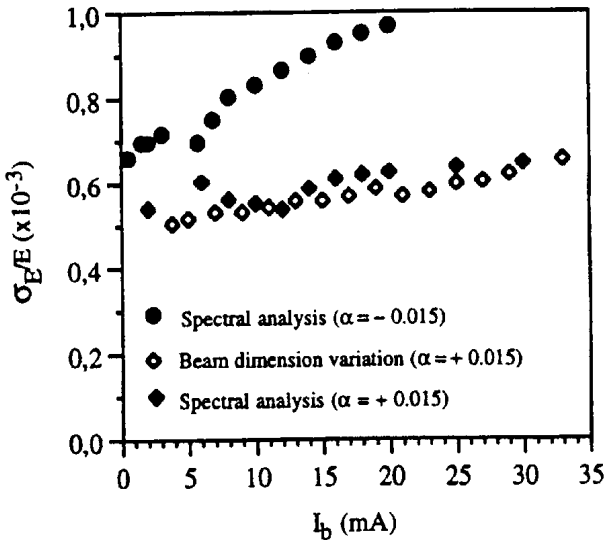
Experimental Data from SUPER-ACO

References: 1. A. Nadji et al., EPAC96, 234-240

More than 100 mA have been stored in a single bunch without sextupoles!!





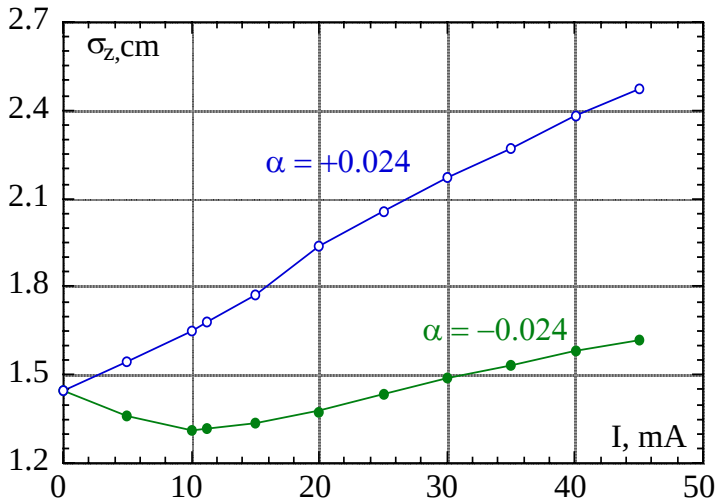


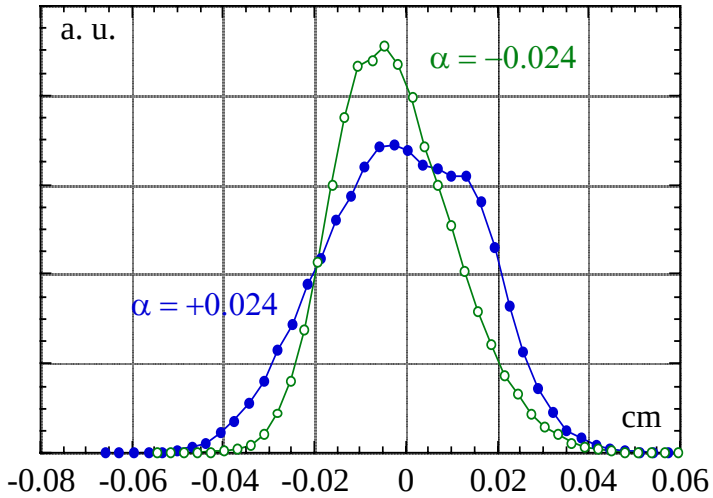
Bunch length is notably smaller for $\alpha_c < 0$

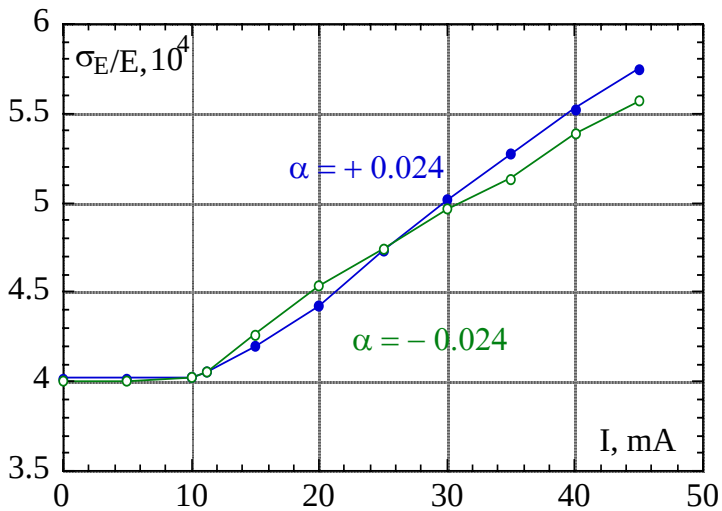
Bunch length does not depend on α_c at high currents

Energy spread is higher for $\alpha_c < 0$

The DAFNE Case:
Bunch Length and Energy Spread Simulations





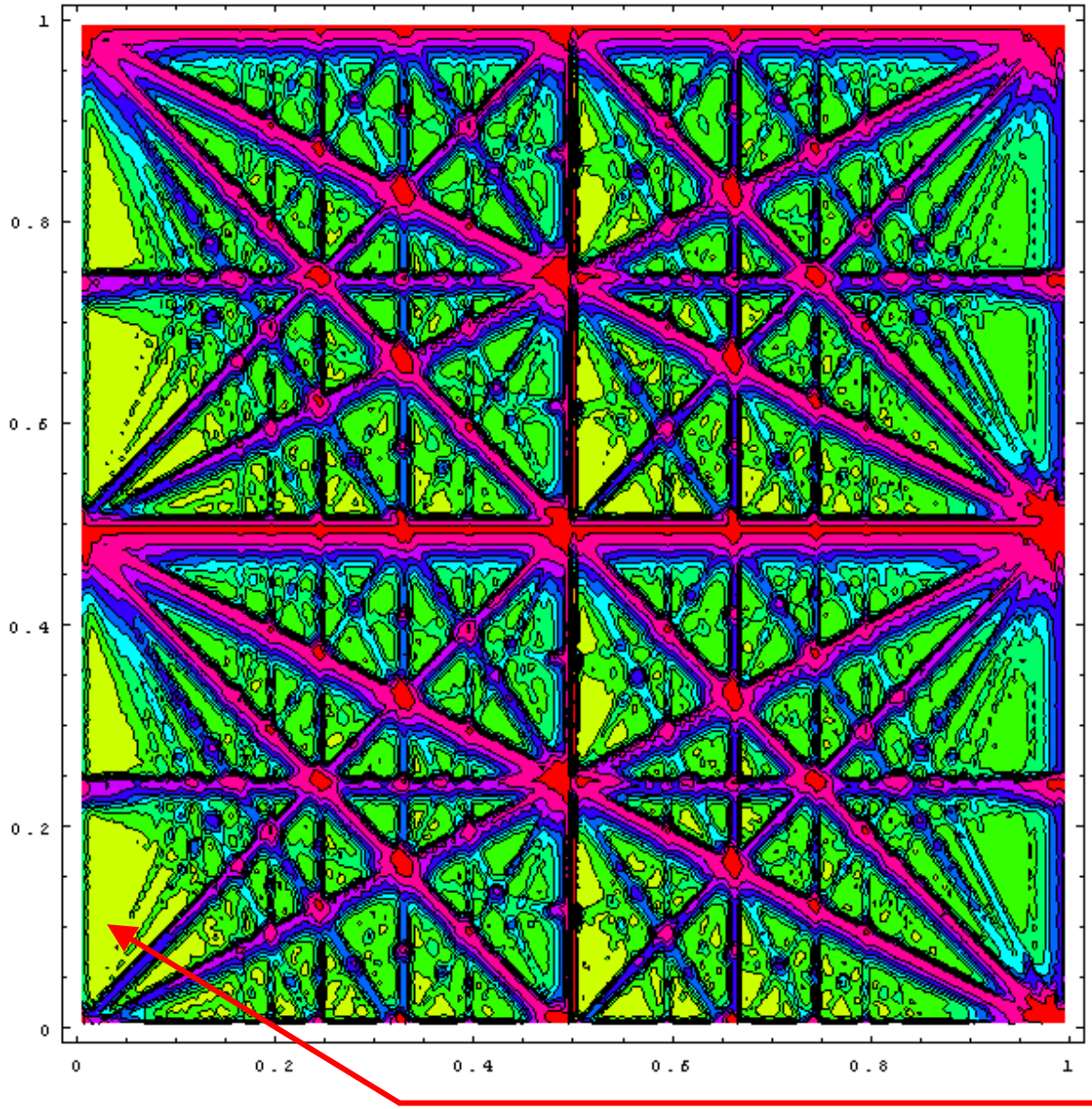


α_c = - 0.024 seems to be an optimum considering given DAΦNE wake:

- microwave threshold is equal for the positive and the negative momentum compaction (~10-12 mA)

-bunch length does not exceed 1.5 cm up to the bunch current of 30 mA

Change of the Working Point: toward lower tunes



- Enlarging the Dynamic Aperture
- Possibility to shift the working point closer to integers

Evolution with no major upgrades

	K Physics	Hyper-nuclei	Exotic atoms		
2004 2006	$2\ 10^{32}$ $>2\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$		
2007 2010	$>2\ 10^{32}$ $10\ fb^{-1}$	$>2\ 10^{32}$ $>1\ fb^{-1}$			
2011	???	???	???		
	KLOE	FINUDA	SIDDHARTA		

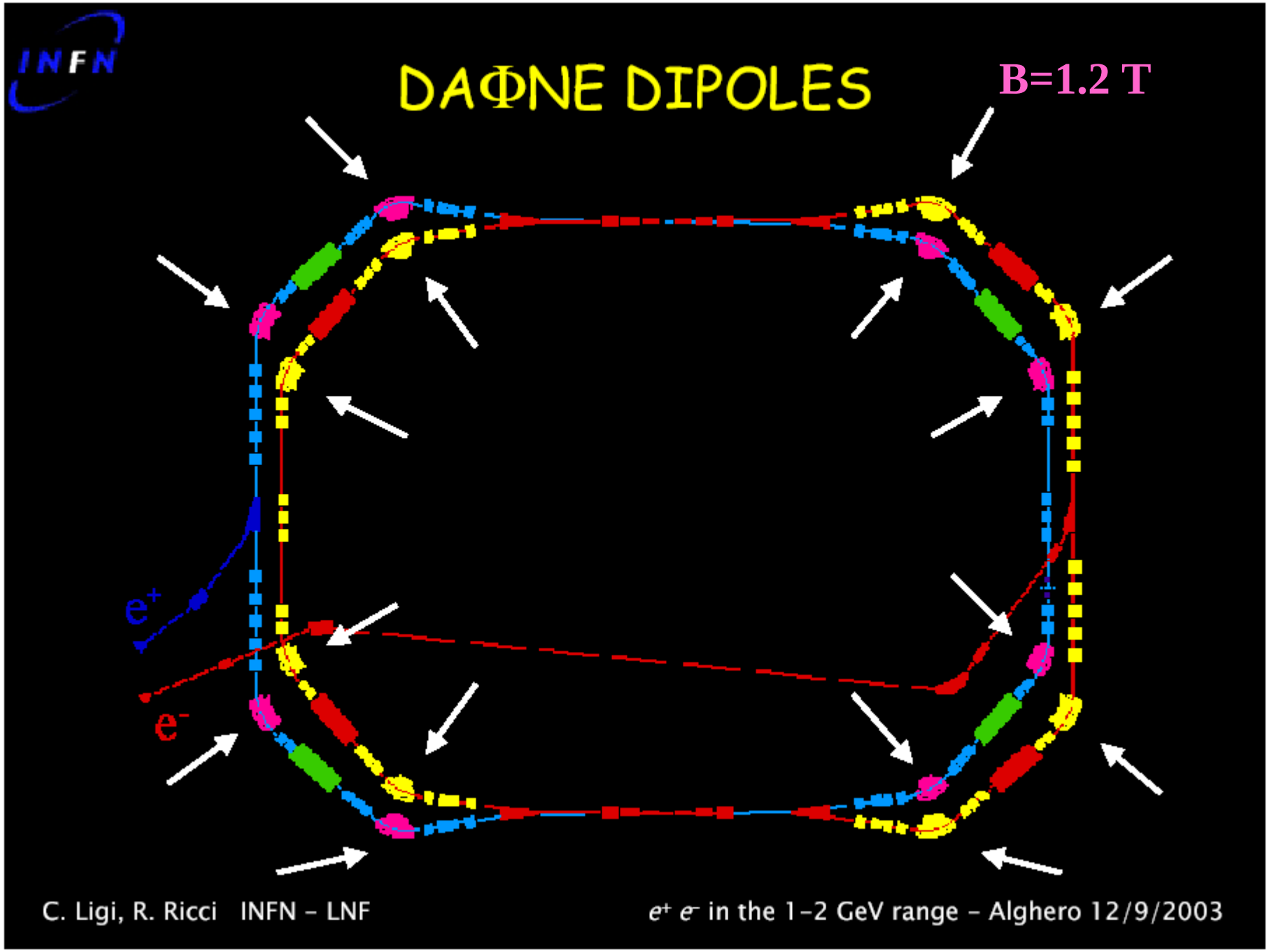
What's next ?

1. No major upgrades – Do the best with the existing hardware

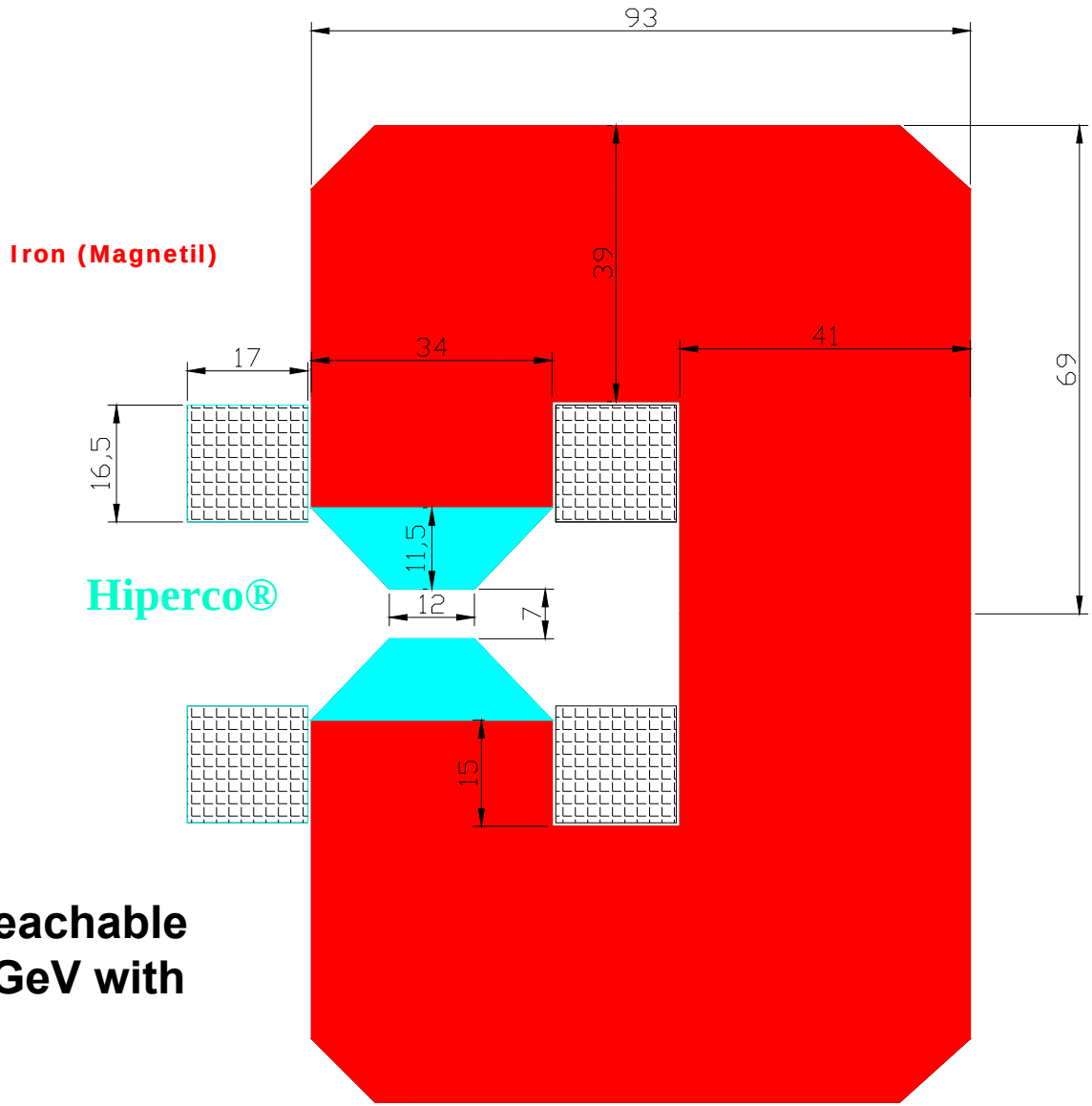
2. **Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ**

3. New machine for both E upgrade and $L > 10^{33}$ @ Φ

4. New machine for $L > 10^{34}$ @ Φ

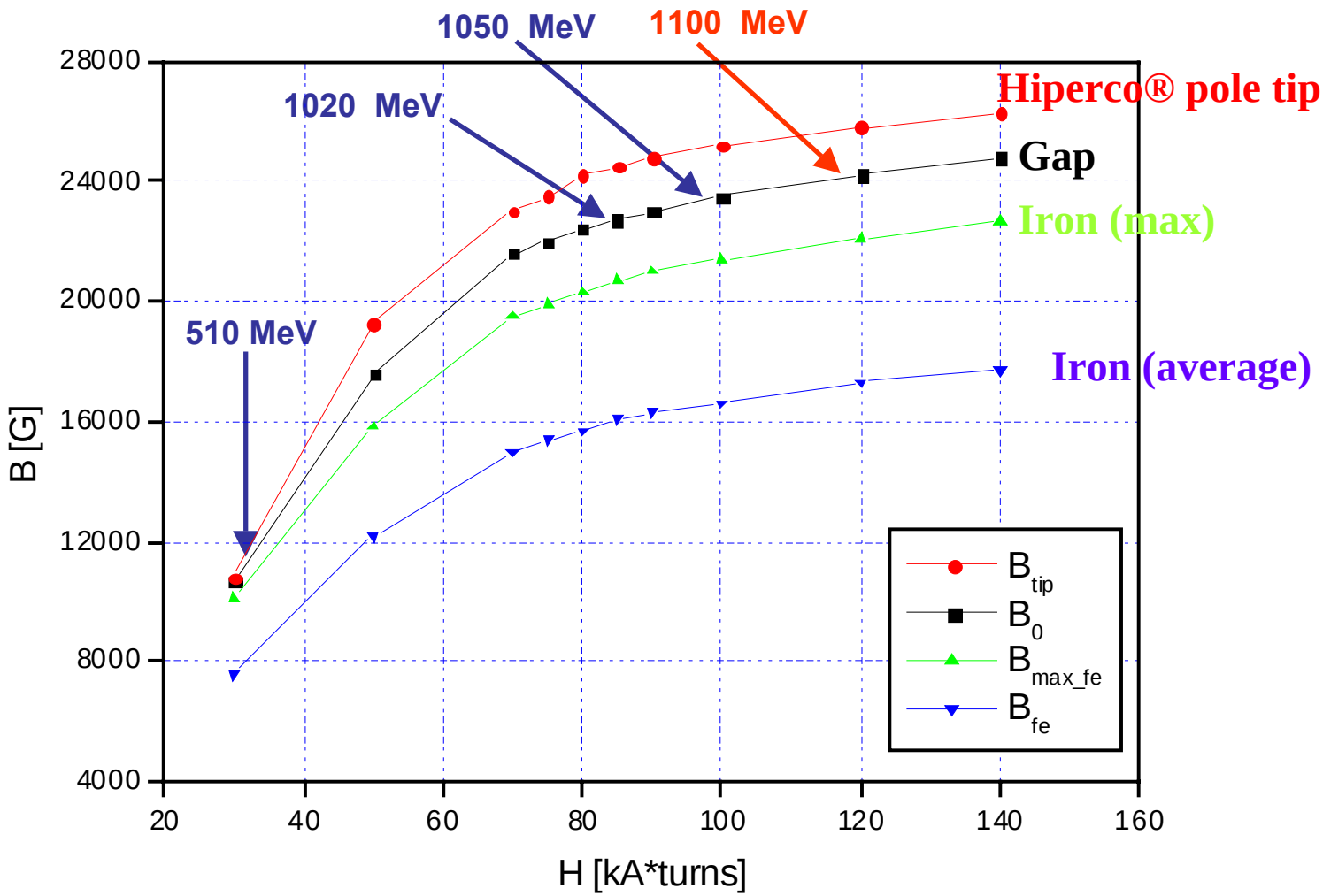

INFN
DAΦNE DIPOLES
B=1.2 T
e+
e-
C. Ligi, R. Ricci INFN – LNF
e+ e- in the 1–2 GeV range – Alghero 12/9/2003

Dipole Section – preliminary design



Maximum energy reachable (this design): 1.06 GeV with high saturation

Magnetization curve



Collaboration with BINP

(may 2004)

Pavel Vobly is looking at the possibility of designing a higher magnetic field dipole fitting our vacuum chamber and space constraints

VEPP2000 dipole – 2.4 T normal conducting

Φ and n-nbar sharing DAFNE

Energy (GeV)	**0.51**	**1.1**
Current (A)	**1 - 2**	**0.5**
Luminosity (10^{32})	**2**	**1**
N bunches	**100**	**30**
I/bunch (mA)	**10-20**	**17**
τ damping (msec)	**70/40**	**11/9**
Uo (keV)	**4.3 / 9.3**	**64 / 84**
τ (h)	**<1**	**> 4**

Minimum modifications for E upgrade & Φ

	K Physics	Hyper-nuclei	Exotic atoms	1 to 2.2 GeV physics	
2004 2006	$2\ 10^{32}$ $>2\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$		
2007	**SHUTDOWN**				
2008 2010	$2\ 10^{32}$ $3\ fb^{-1}$	$2\ 10^{32}$ $1\ fb^{-1}$		10^{32} $1\ fb^{-1}$	
2011	???	???	???	???	
	KLOE	FINUDA	SIDDHARTA	n-nbar…	
Cost (M€)				10 Accel 10 Linac	

What's next ?

1. No major upgrades – Do the best with the existing hardware

2. Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ

3. **New machine for both E upgrade and $L > 10^{33}$ @ Φ**

4. New machine for $L > 10^{34}$ @ Φ

Damping time vs. energy

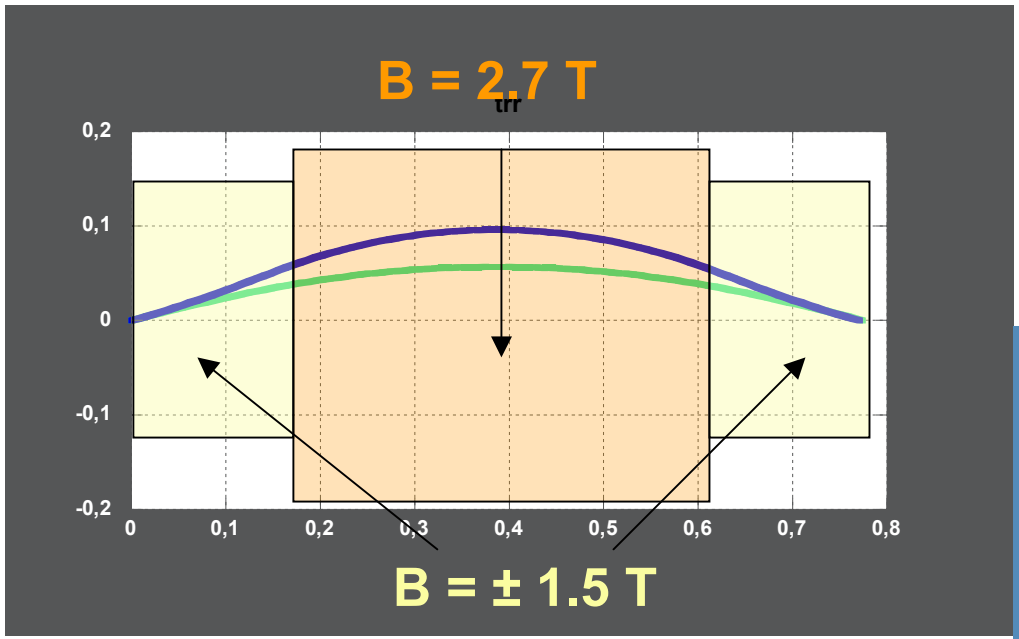
$$\alpha_x \approx \frac{C_\alpha}{C} E^3 I_2$$

$$U_o = C_\gamma \frac{E^4}{2\pi} I_2$$

$$I_2 = \int_{dipoles} \frac{ds}{\rho^2}$$

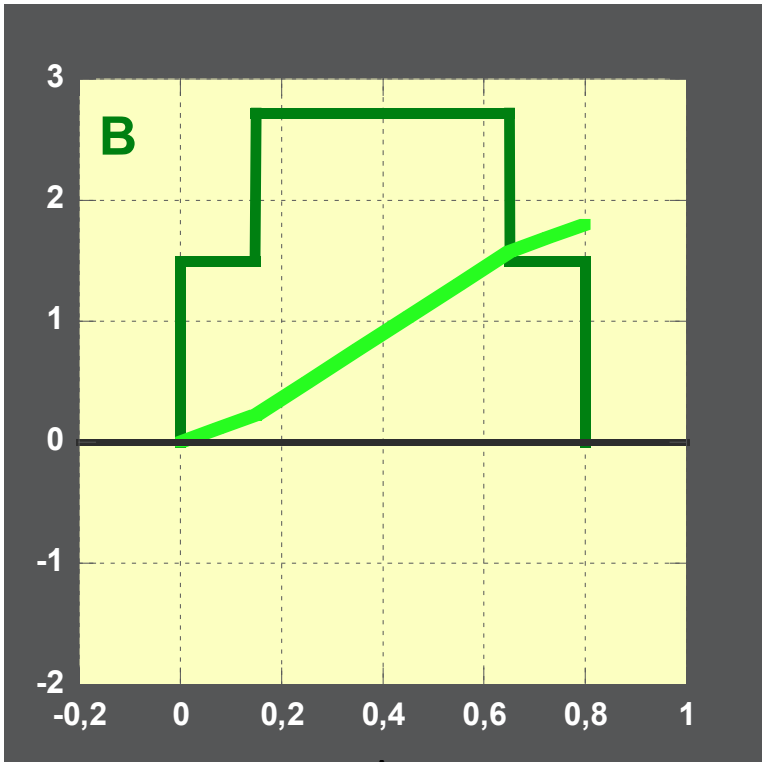
Optimization of luminosity at low energy by **increasing I_2**

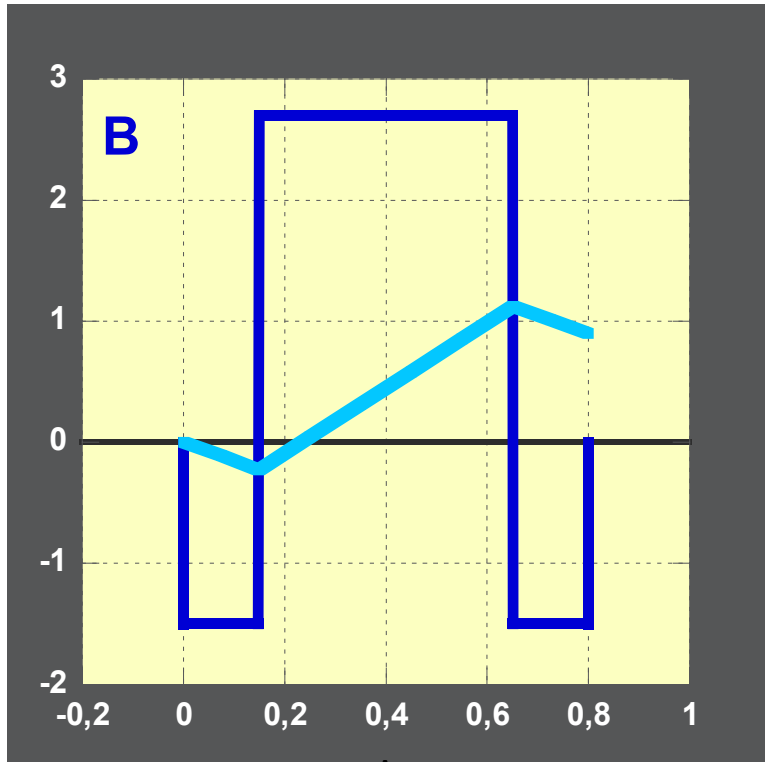
3-Pieces SC Dipole (Wiggler like)



$$\theta = \frac{1}{B\rho}\oint B\,dl = 2\pi$$

$$I_2 = \int_{dipoles} \frac{ds}{\rho^2} = \int \frac{|B|^2}{(B\rho)^2} ds$$





E = 1.1 GeV

$\int$Bds = 1.8 Tm

Bending angle = 30°

$I_2 = 0.38\ m^{-1}$

$U_0 = 94$ keV

E = 0.5 GeV

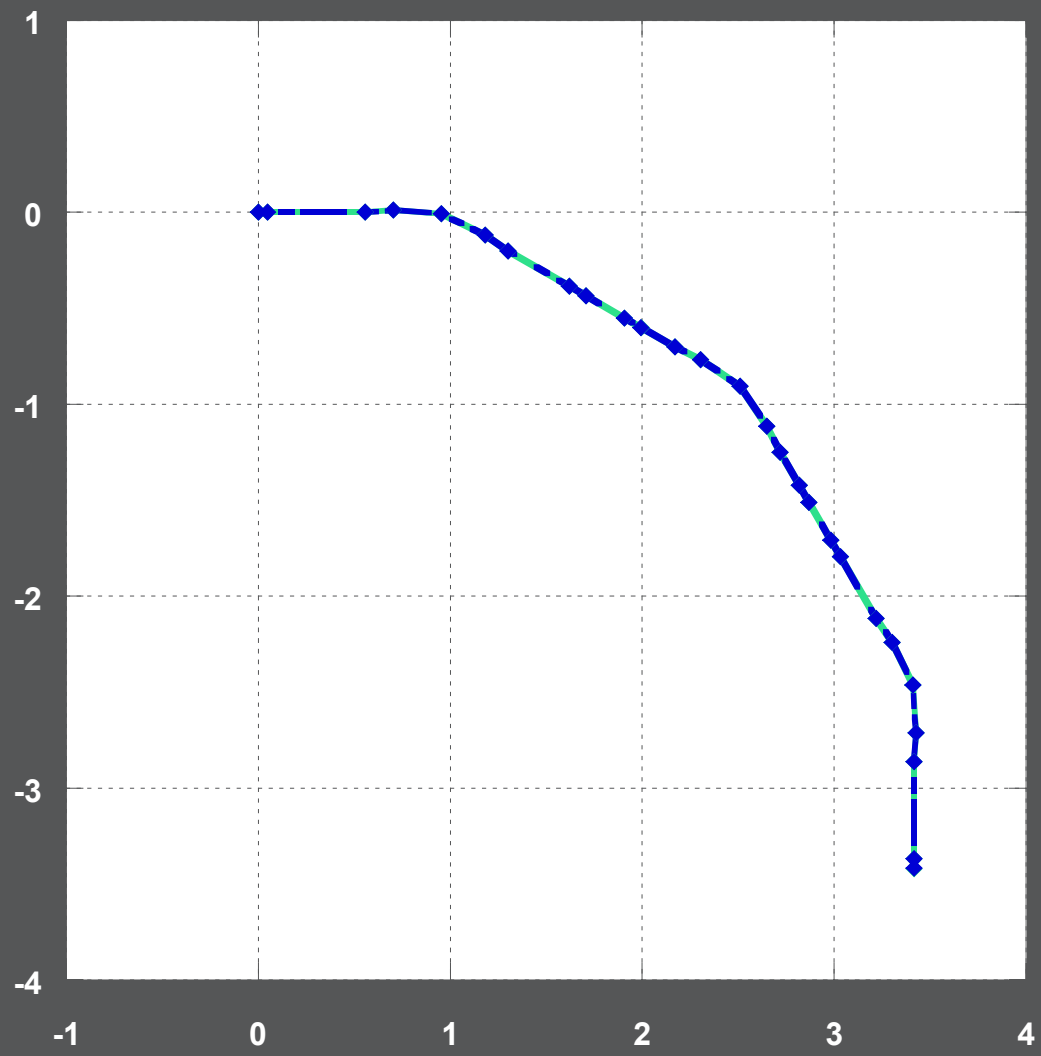
$\int$Bds = 0.9 Tm

Bending angle = 30°

$I_2 = 1.46\ m^{-1}$

$U_0 = 17$ keV

Total length of arcs – 20 m



Total ring < 90 m

Φ and n-nbar sharing new DAFNE

very preliminary considerations

Energy (GeV)	0.51	1.1
Current (A)	3	1
Luminosity (10^{32})	10	5
N bunches	100	50
I/bunch (mA)	>20	20
τ damping (msec)	6	3

SC DAFNE for upgrading both E & Φ Luminosity

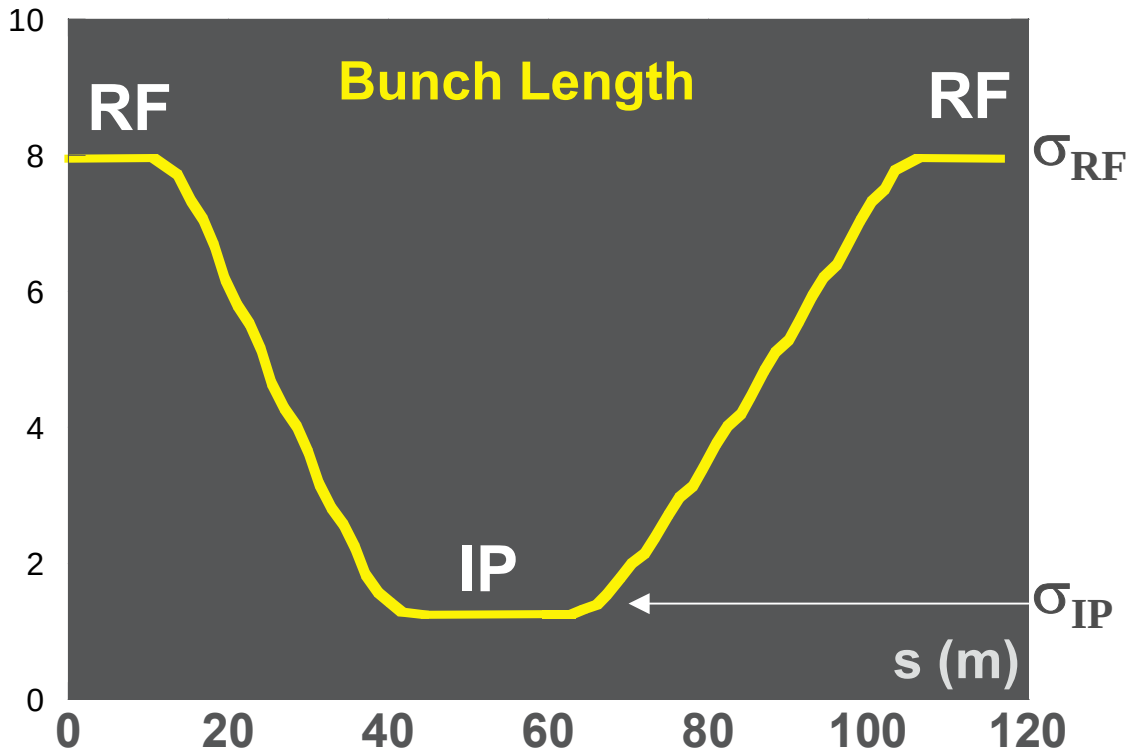
	K Physics	Hyper-nuclei	Exotic atoms	1÷2.2 GeV physics	>3 GeV
2004 2006	$2\ 10^{32}$ $>2\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$		
2007	**SHUTDOWN**				
2008 2012	10^{33} $10\ fb^{-1}$	10^{33} $1\ fb^{-1}$		$>10^{32}$ $>1\ fb^{-1}$	$>10^{32}$ $>1\ fb^{-1}$
2013	???	???	???	???	???
	KLOE	FINUDA	SIDDHARTA	n-nbar…	J/Ψ, τ…
Cost (M€)				50 Accel. , 10 Linac	

What's next ?

1. No major upgrades – Do the best with the existing hardware
2. Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ
3. New machine for both E upgrade and $L > 10^{33}$ @ Φ
4. **New machine for $L > 10^{34}$ @ Φ**

Strong RF Focusing (SRFF)

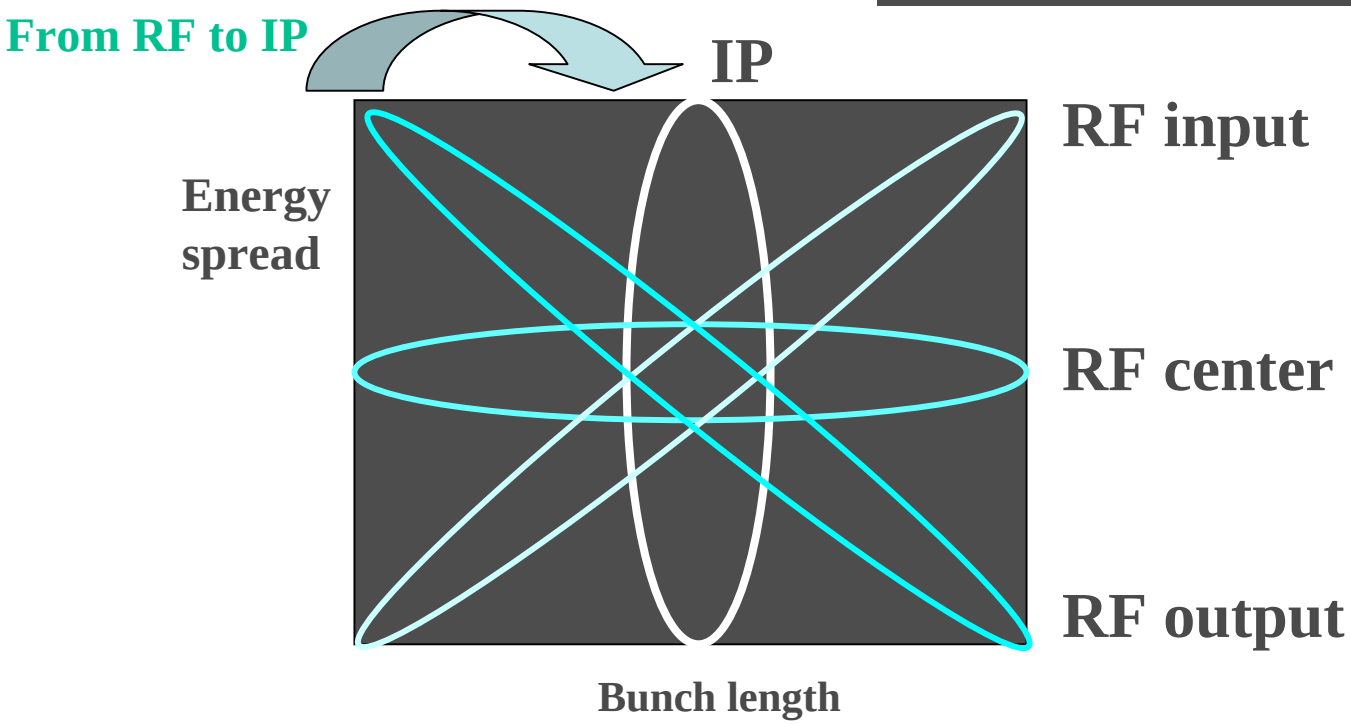
Modulation of bunch length along the ring with a minimum at the IP



Allows very small vertical β^* (few mm)

High RF voltage + **Magnetic lattice which correlates longitudinal position with energy deviation (high α_c)**

Longitudinal phase space



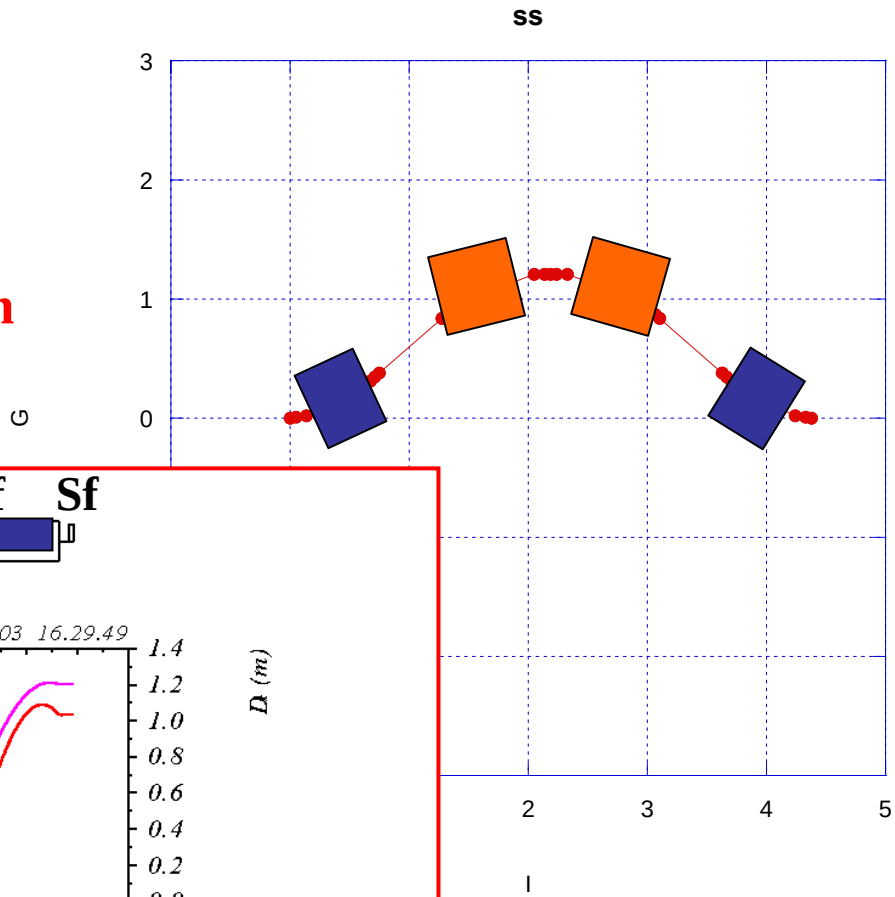
$$\frac{\sigma_{z_{\min}}}{\sigma_{z_{\max}}} = \sqrt{\frac{1+\cos\mu}{2}}$$

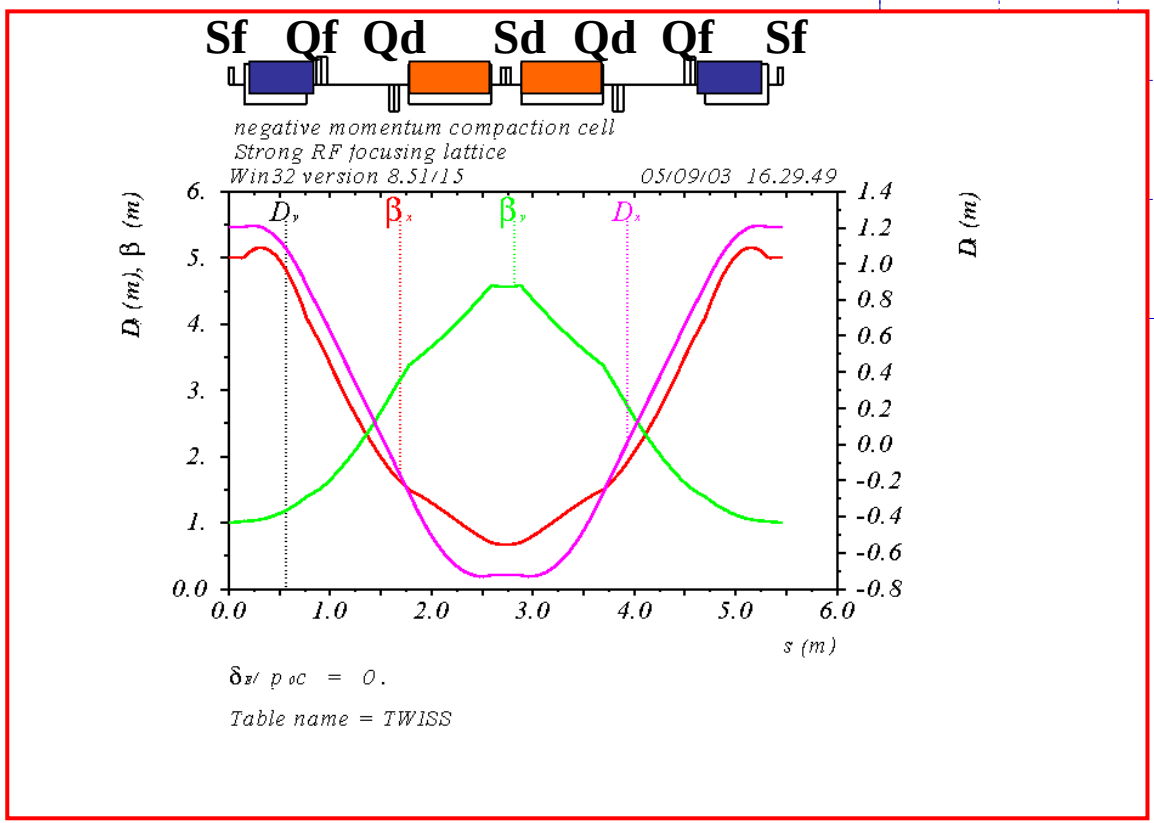
$$\cos\mu = 1 - \pi \frac{\alpha_c L}{\lambda_{rf}} \frac{V_{rf}}{E/e}$$

μ = one-turn longitudinal phase advance

HIGH and NEGATIVE MOMENTUM COMPACTION

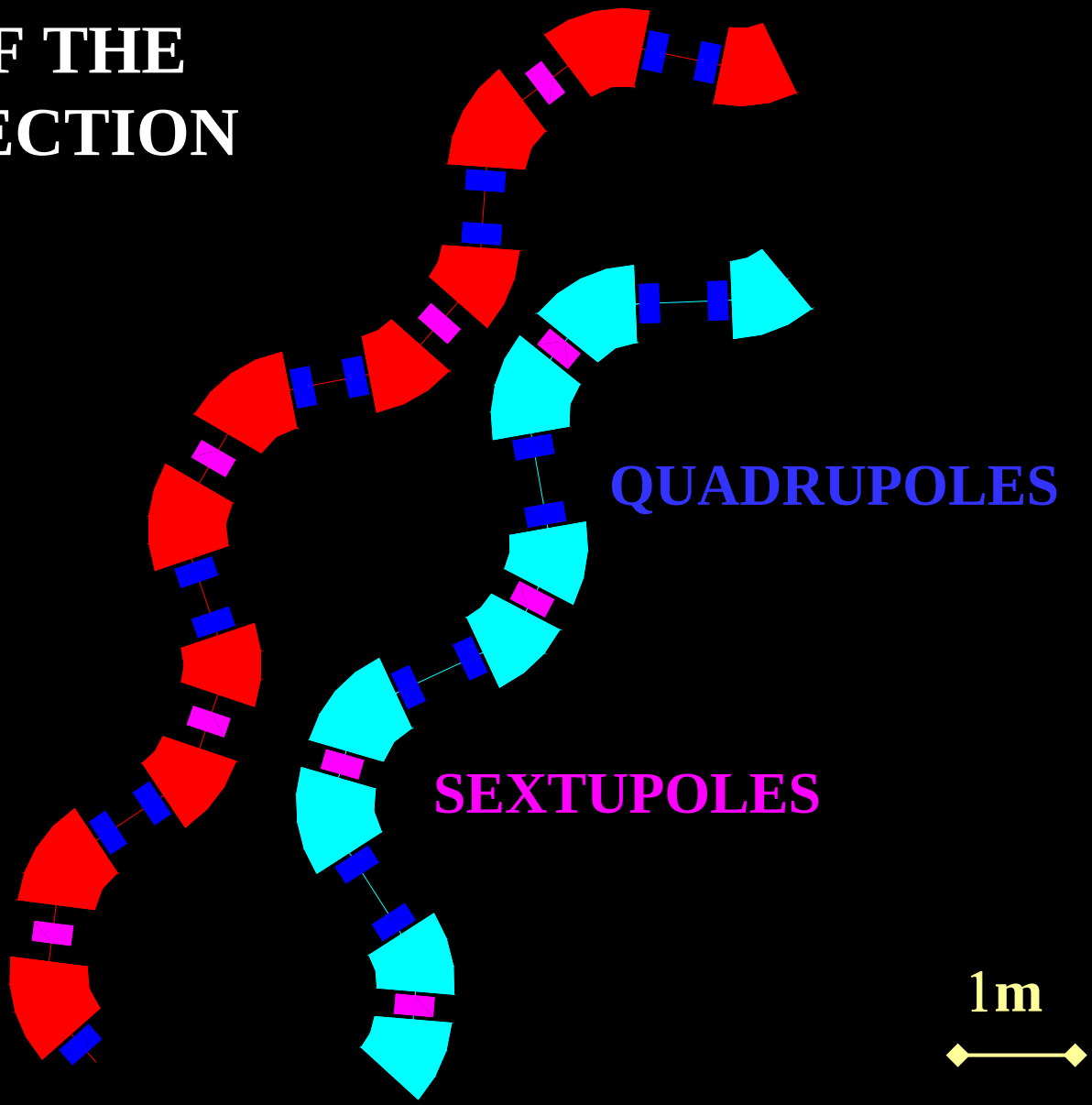
strong RADIATION emission





Alternating positive and negative bending dipoles

ZOOM OF THE RINGS SECTION



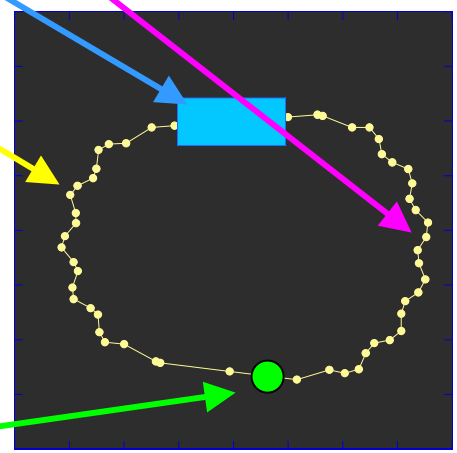
Layout similar to present DAΦNE rings:

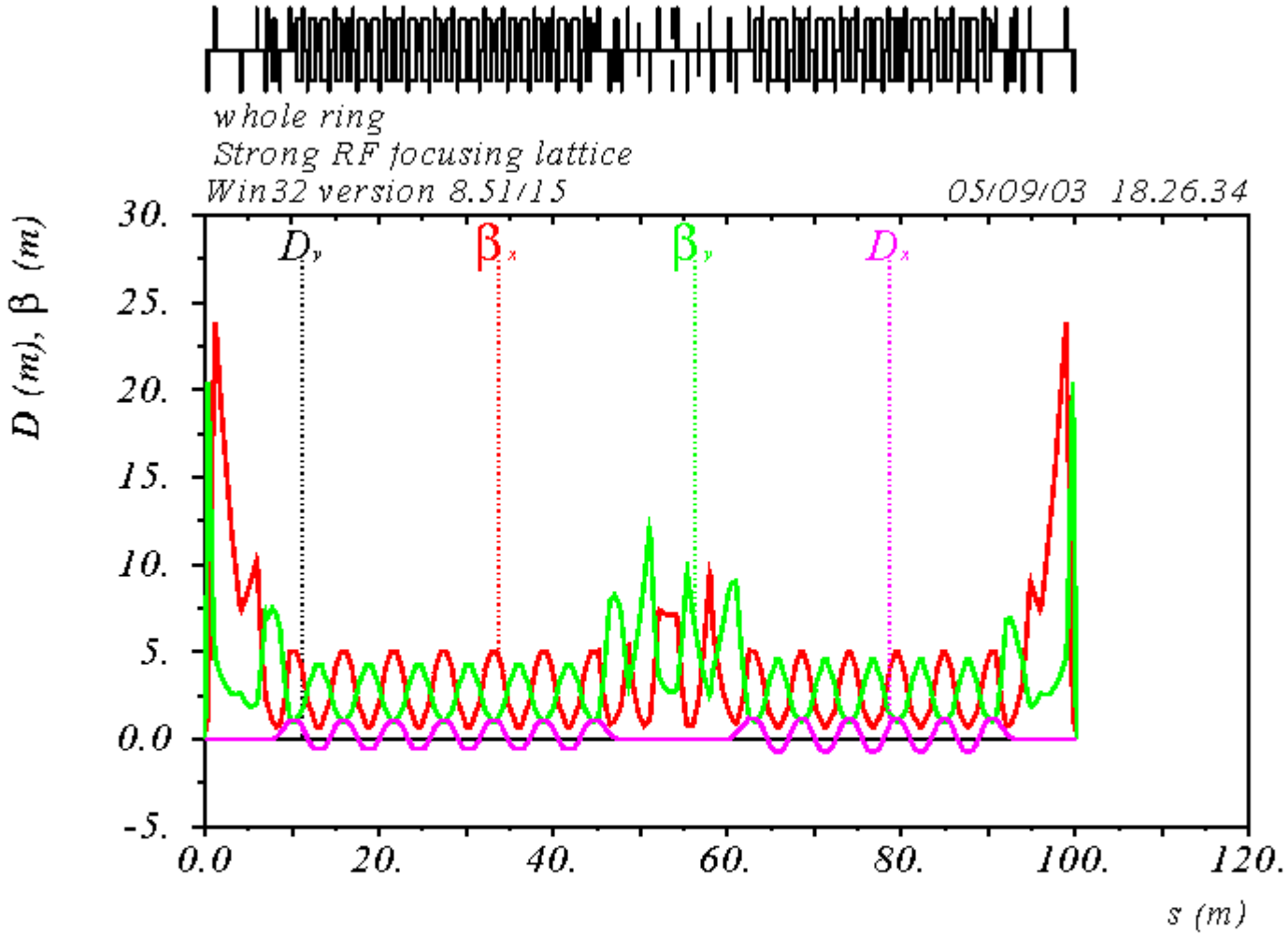
One IR

Second crossing for injection, RF, diagnostics

Short inner arc and long outer arc with the condition of equal longitudinal phase advance between cavity and IP in both directions

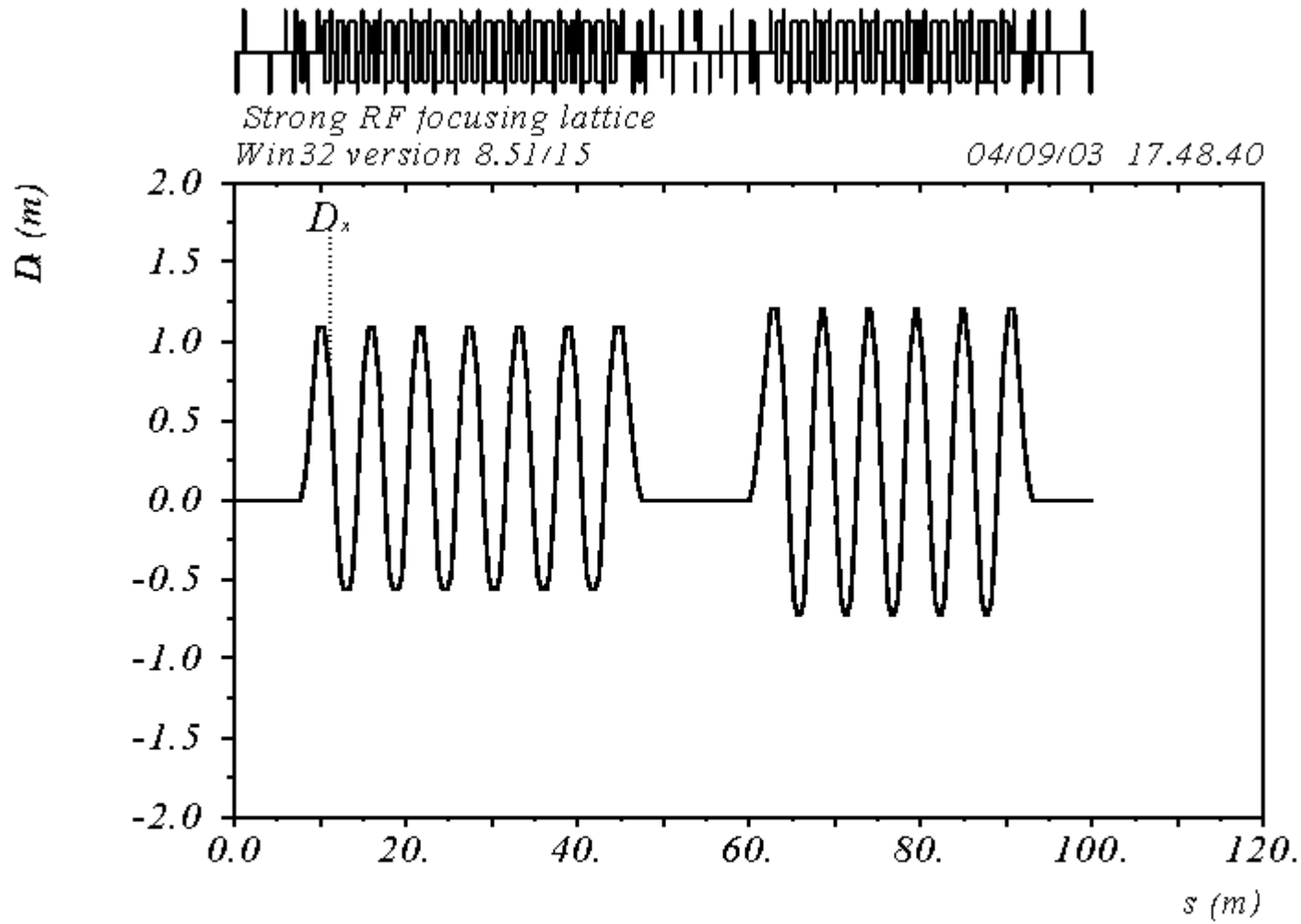
$$R_{56}(rf \rightarrow IP) = R_{56}(IP \rightarrow rf)$$





$\delta_{E/pc} = 0.$

Table name = TWISS

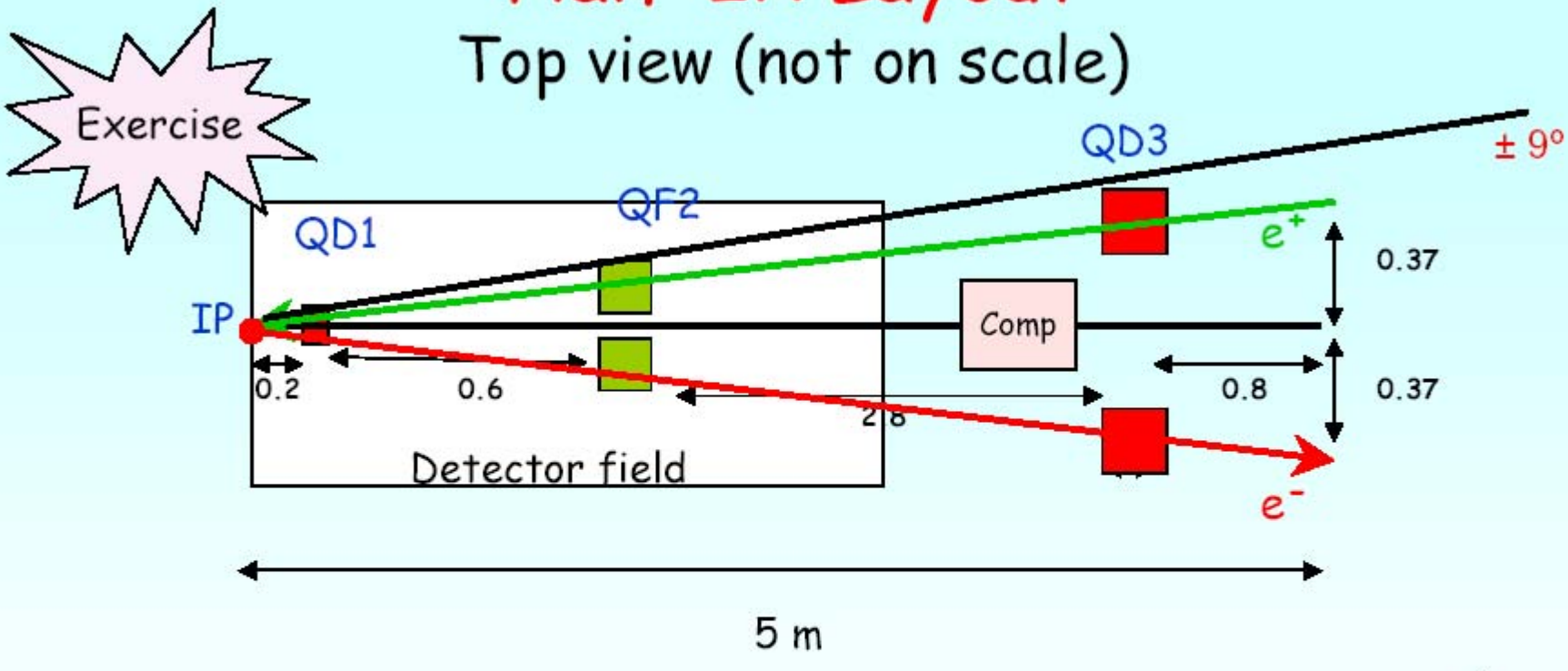


$\delta_{E/pc} = 0.$

Table name = TWISS

Half-IR Layout

Top view (not on scale)



With ± 10σ_x clearance, ± 9° cone, ±30 mrad angle:

small

QD1: L= 20 cm, pole radius = 1.5 cm, R_{ext} = 3 cm, pm thickness= 1.5 cm

QF2: L= 20 cm, pole radius = 11 cm, R_{ext} = 16 cm, pm thickness= 1.5 cm,
4 cm space between 2 quads

QD3: L= 20 cm, pole radius = 15 cm , R_{ext} = 63 cm, 25 cm space between 2 quads

First evaluation by *E.Levichev, P.Piminov)**

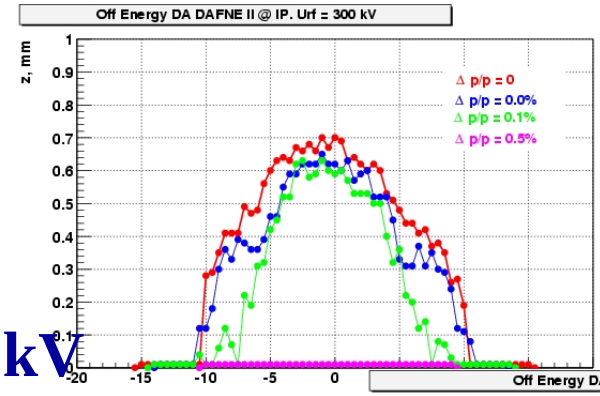
BINP, Lavrentiev 13, Novosibirsk 630090, Russia

----- no synchr oscill

----- Dp/p = 0

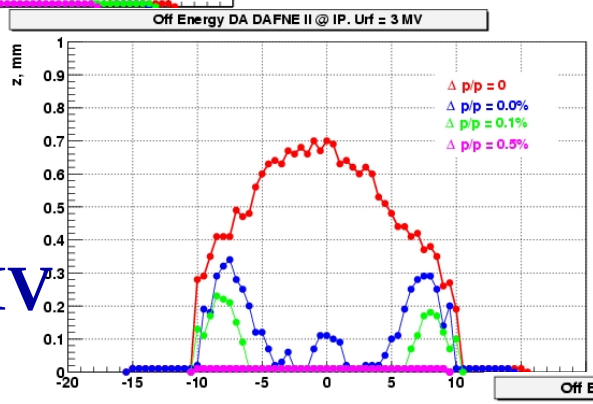
----- Dp/p = 0.1%

----- Dp/p = 0.5%



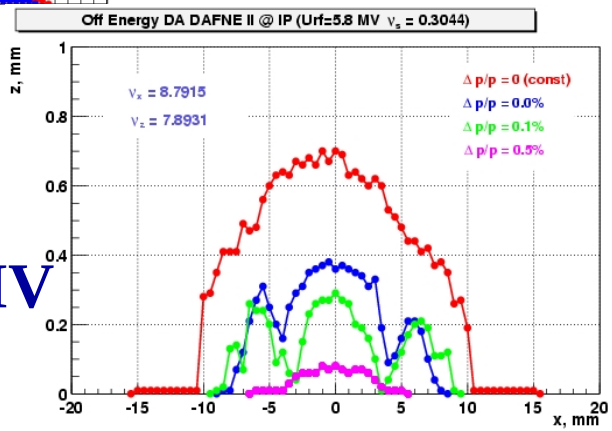
V = 300 kV

Q_s = 0.059



V = 3 MV

Q_s = 0.2



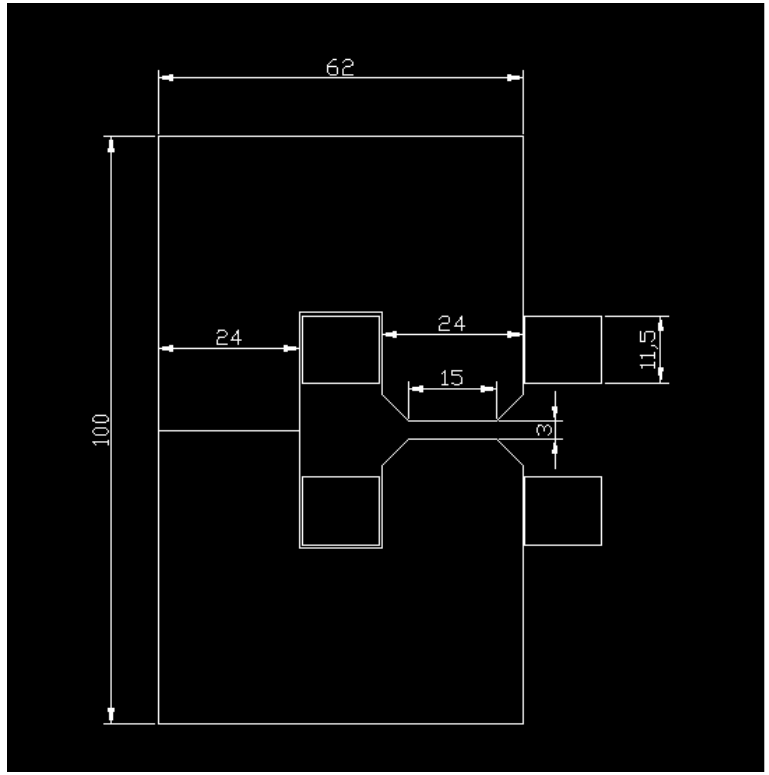
V = 5 MV

Q_s = 0.3

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

Dipole parameters

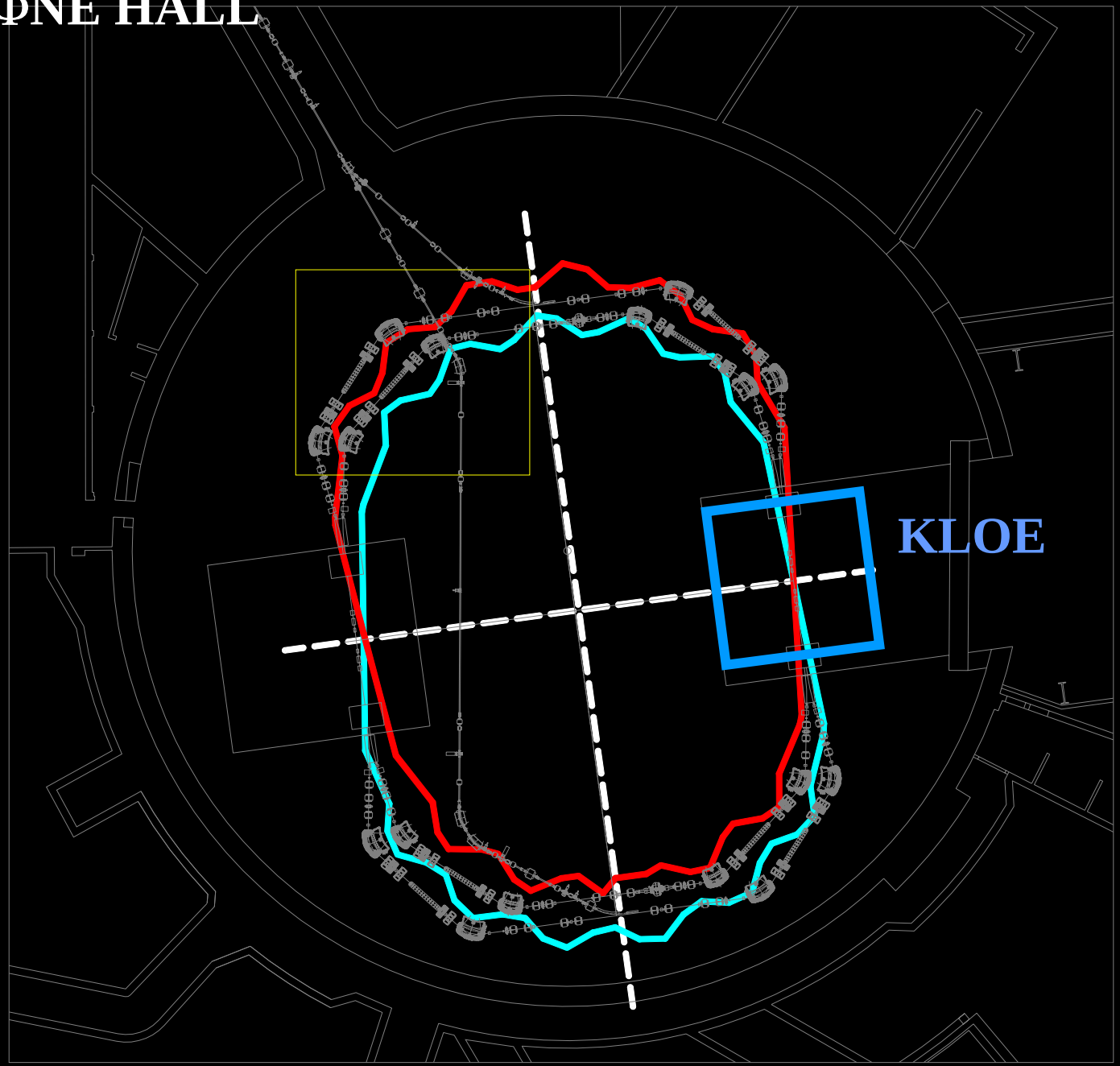
Type	A	B	C
N	22	22	4
Alfa [rad]	0.6545	0.8528	0.5236
Chord [m]	0.607	0.781	0.489
Sagitta [m]	0.050	0.085	0.032
Mag lenght	0.618	0.805	0.494
Vol Fe [mc]	0.282	0.362	0.227
Vol Cu [mc]	0.041	0.047	0.037
Weight Fe [kg]	2222	2859	1789
Weight Cu [kg]	359	410	324
Total Weight [kg]	2581	3269	2113
Power [W]	7234	8260	6537



NI[A]	26350
J[A/mmq]	3.2
Total power [kW]	370

Cost evaluated: 1600 k€

DAΦNE HALL

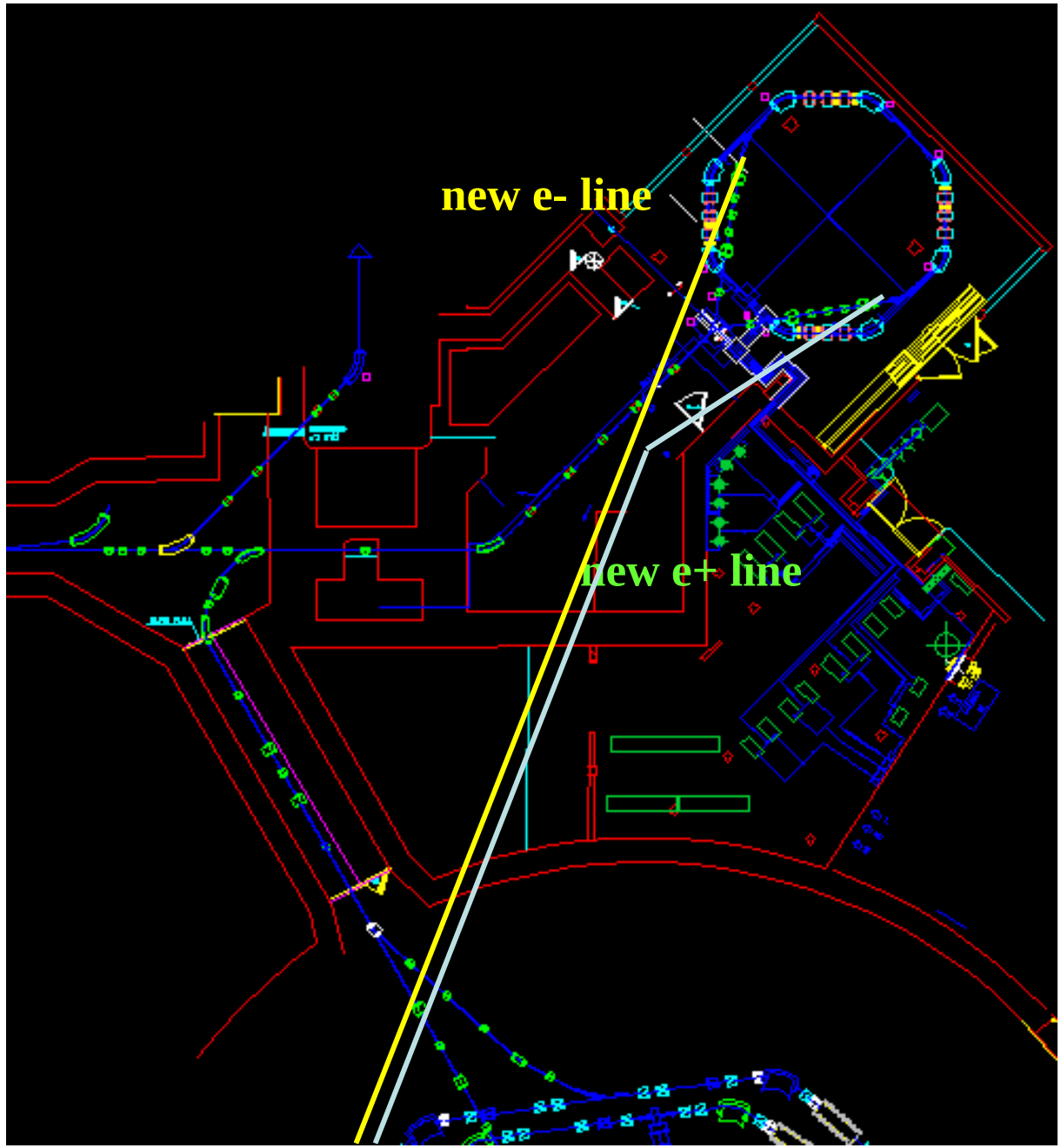


F. Sgamma

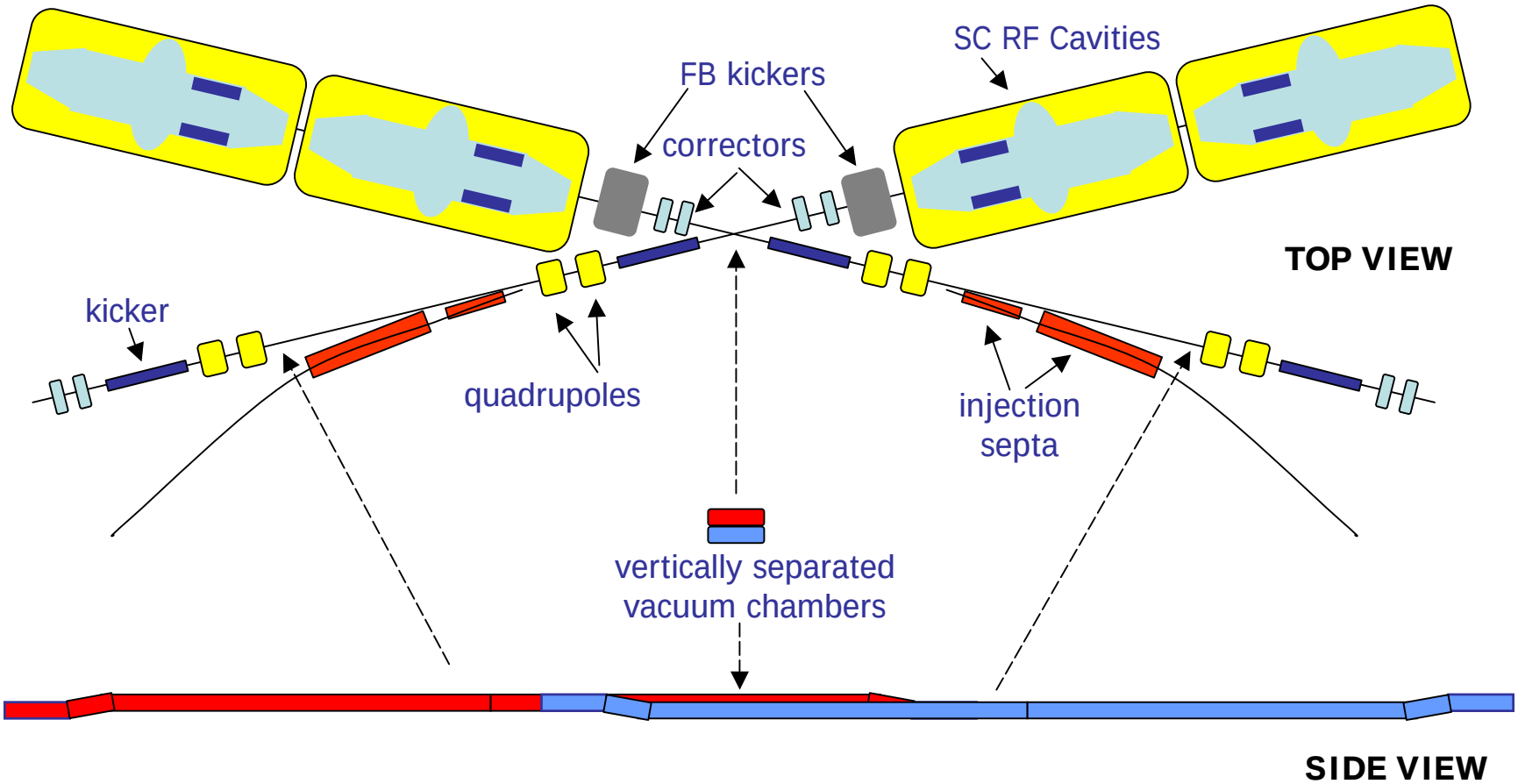
Injection system upgrade

- The proposed transfer lines pass in existing controlled area

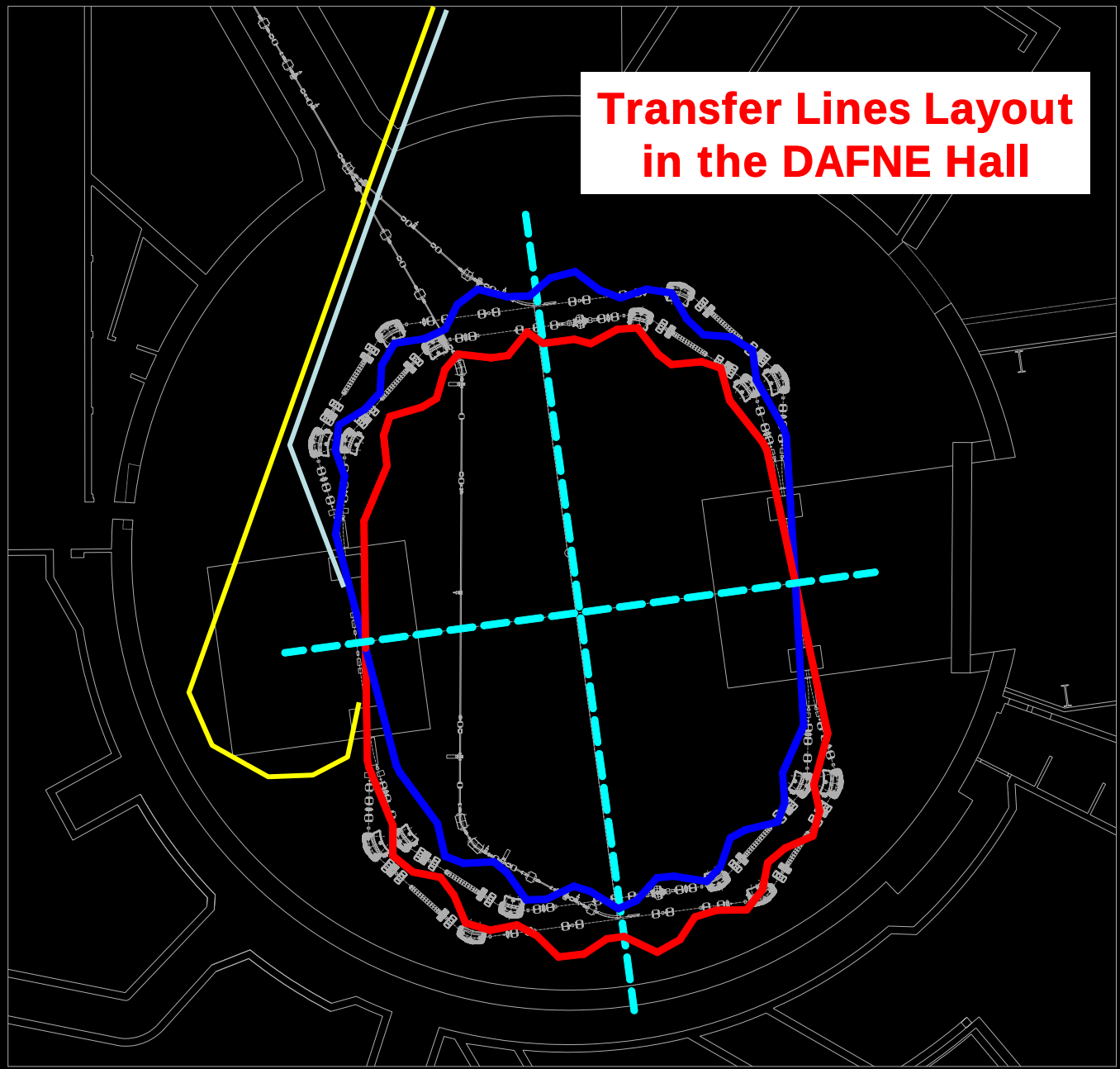
- Additional shielding needed in the area between the accumulator and DAFNE buildings



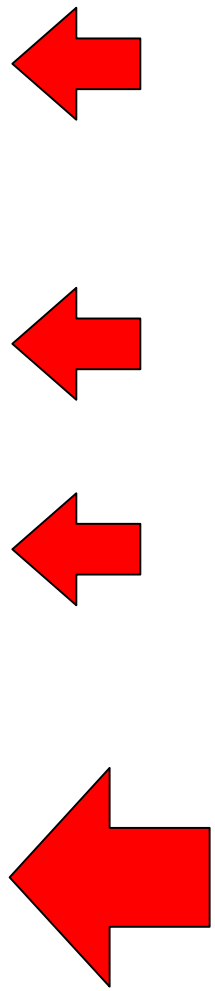
Crossing point section schematic layout



Transfer Lines Layout in the DAFNE Hall



MAIN PARAMETERS	
C (m)	105
E (MeV)	510
f_{rf} (MHz)	497
V (MV)	10
ε_x (μ rad)	0.26
ε_y (μ rad)	0.002
α_c	- 0.165
β_x^* (m)	0.5
β_y^* (mm)	2.0
N / bunch	5 e10
h	180
L /bunch (cm^{-2} sec^{-1})	$9\ 10^{31}$
L tot (cm^{-2} sec^{-1})	$\sim 10^{34}$



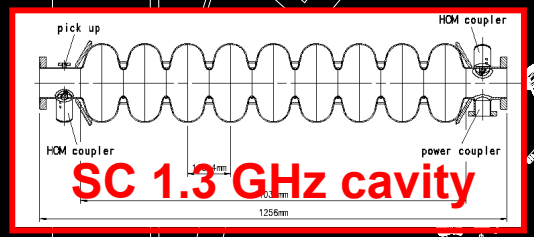
SRFF at DAΦNE

First experimental demonstration of the Strong RF Focusing concept:

- ✓ Measuring the bunch length variation along the ring
- ✓ Study the single bunch dynamics (effects of the distributed wake on the bunch length)
- ✓ Study the multibunch dynamics and LFB behaviour at very large synchrotron tunes
- ✓ Study of the 3D coupled dynamics
- ✓ Collisions of short bunches (with β_y ~1 cm)
- ✓ Study of CSR

What is needed

- **New SC RF cavity with cryostat (to be placed in the FINUDA IR)**
- **High momentum compaction lattice (feasible with present hardware)**
- **Criogenic system modification for providing 1.8 K liquid Helium to the RF cavity**
- **Few days ($\approx 10 \div 15$) of MD in 2004, 2005**
- **$2 \div 3$ months in 2006 for installation of the SC cavity and experimental activity**



SC 1.3 GHz cavity

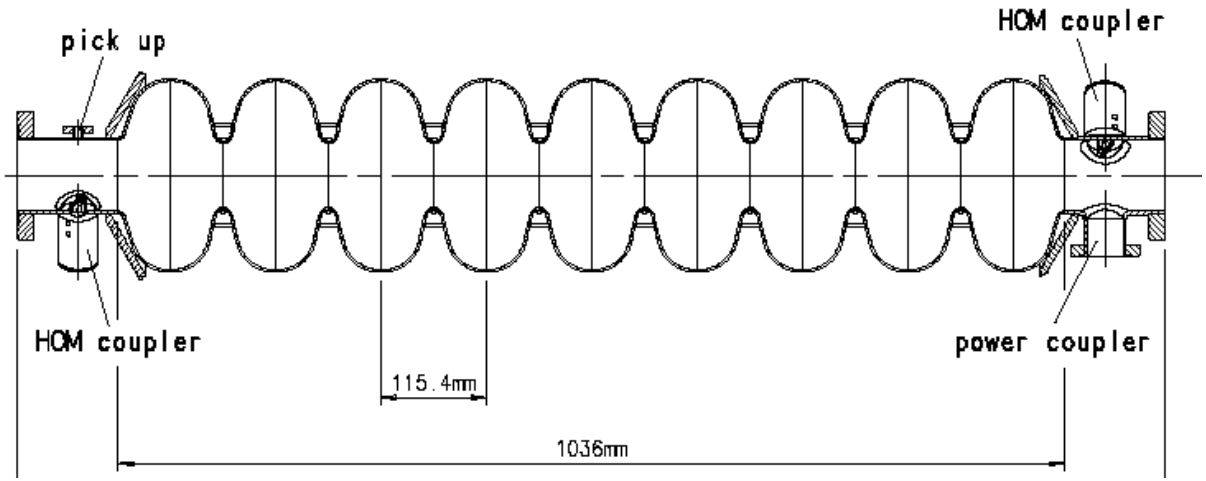
KLOE

10m

Parameter List for a Strong RF Focusing Experiment at DAFNE

Momentum Compaction	α_c	0.07 - 0.1
RF Frequency	f_{RF}	1288.973 MHz
RF Voltage	V_{RF}	8 - 5.8 MV
Harmonic Number	h	420 (= 3.5 × 120)
Longitudinal Phase Advance	μ_l	120°
Natural Energy Spread	$\left.\frac{\sigma_E}{E}\right\|_0$	$4 \cdot 10^{-4}$
Energy Spread @ μ_l = 120°	$\frac{\sigma_E}{E}$	$6 \cdot 10^{-4}$
Bunch Length	σ_z	1.3 - 2.5 mm 3 - 5.0 mm
RF Acceptance (waist/cavity)	$\left.\frac{\Delta E}{E}\right\|_{max}$	$7 \cdot 10^{-3}$ / $5 \cdot 10^{-3}$

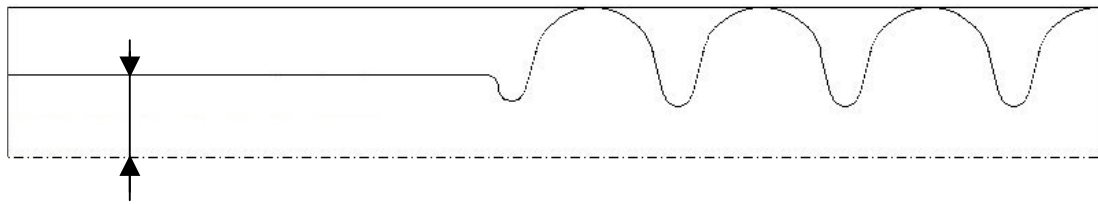
RF Cavity Parameter List



Cavity type		SC TESLA like, 9 cells
RF frequency	f_{RFSC}	1288.973 MHz (-0.85 %)
RF voltage	V_{RF}	7 MV
R/Q geometric factor	R/Q	500 Ω
Quality factor (@ 1.8 K)	Q_0	$1 \cdot 10^{10}$
Cavity wall power	P_{cav}	5 W
Loaded quality factor	Q_L	$2 \cdot 10^{7}$
Cavity detuning for Beam Loading	Δf_{RFSC}	- 100 kHz (@ 7MV, Ib=1A)
RF generator power	P_{cav}	620 W
Cavity length	L_{cav}	1 m

Mode	*f[GHz]*	*R/Q[Ω]*
TM010-π/7	1.277025	0.0096
TM010-2π/7	1.280344	1.4445e-5
TM010-3π/7	1.285180	0.1185
TM010-4π/7	1.290604	4.3645e-4
TM010-5π/7	1.295544	1.3952
TM010-6π/7	1.299009	0.0016
TM010-π	**1.300079**	**388**
PE-1	2.239184	*Propagates*
PE-2	2.391076	*Propagates*
PE-3	2.415551	*Propagates*
PE-4	2.437571	*Propagates*
PE-5	2.480150	*Propagates*
PE-6	2.672732	*Propagates*
PE-7	2.690710	*Propagates*
PE-8	2.725986	*Propagates*
PE-9	2.759523	*Propagates*
PM-1	2.239184	*Propagates*
PM-2	2.382214	*Propagates*
PM-3	2.403431	*Propagates*
PM-4	2.425914	*Propagates*
PM-5	2.450676	*Propagates*
PM-6	2.480413	*Propagates*
PM-7	2.679110	*Propagates*
PM-8	2.707135	*Propagates*
PM-9	2.744299	*Propagates*
PM-10	2.769627	*Propagates*

MAFIA model of a 7-cells TESLA Cavity with enlarged beam tubes

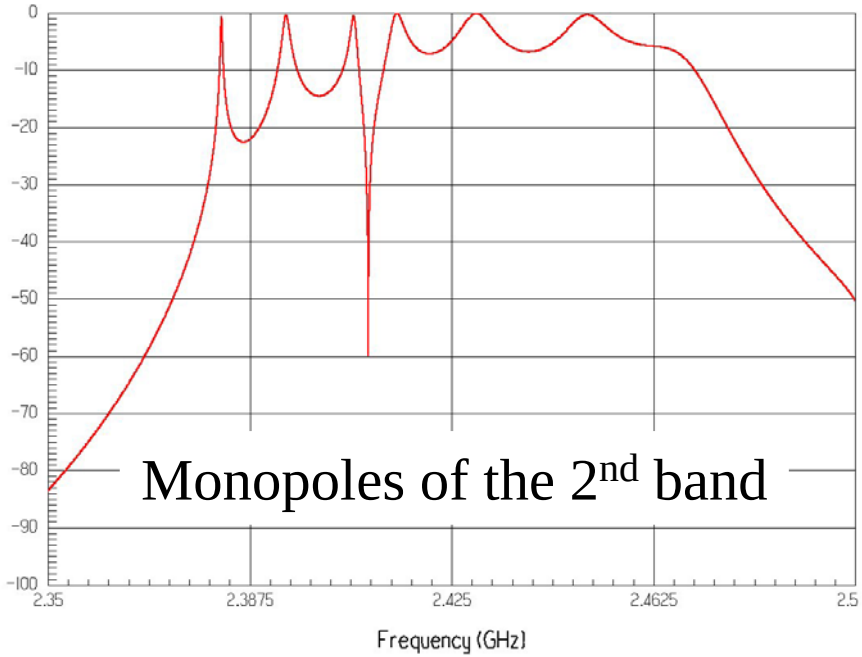


57 mm

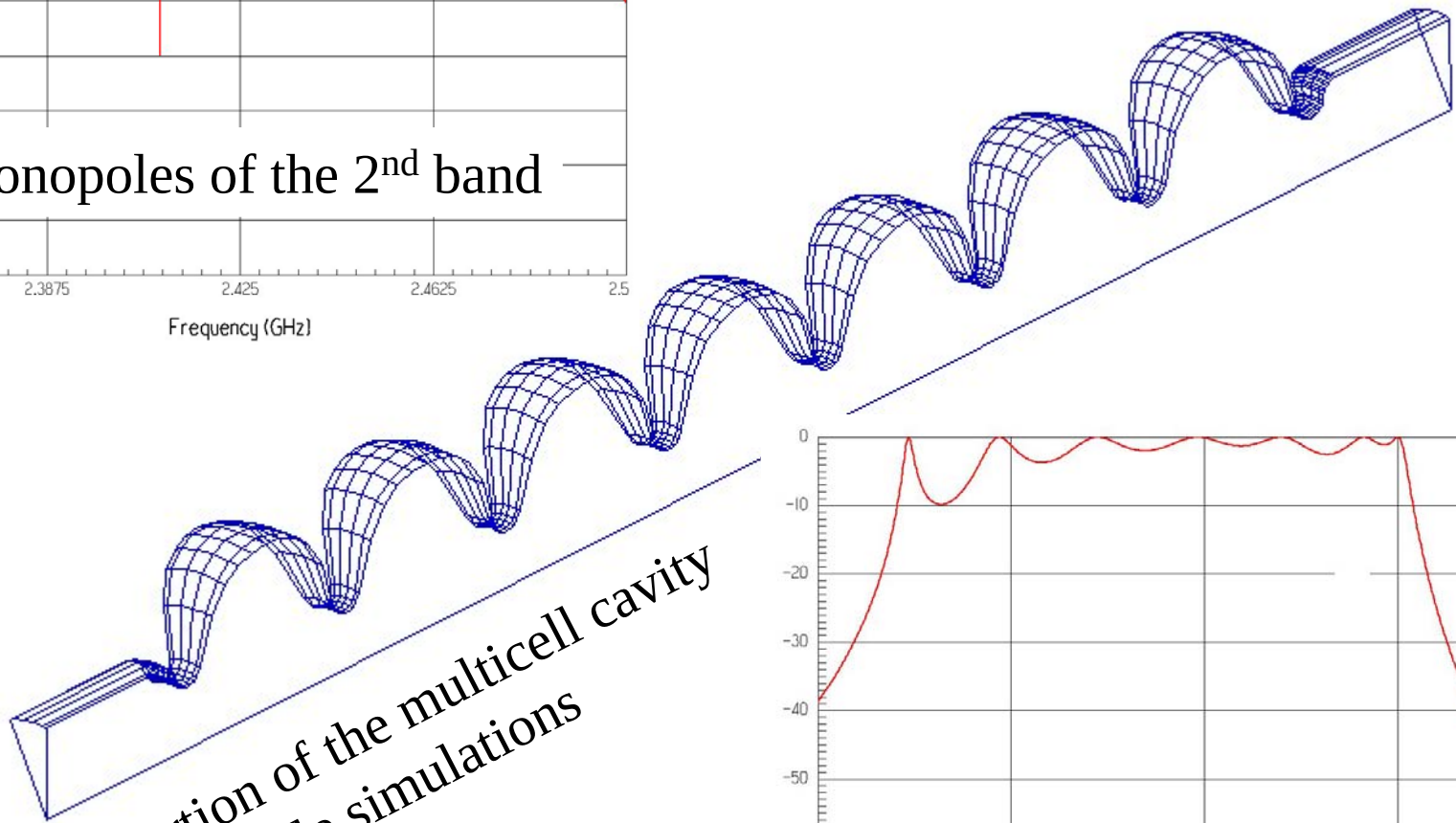
$$Long. \quad \Rightarrow \quad f_{c_{TM\,01}} \approx 2.0\ GHz$$

$$Transv. \quad \Rightarrow \quad f_{c_{TE\,11}} \approx 1.5\ GHz$$

HFSS model of a 7-cells TESLA Cavity with enlarged beam tubes

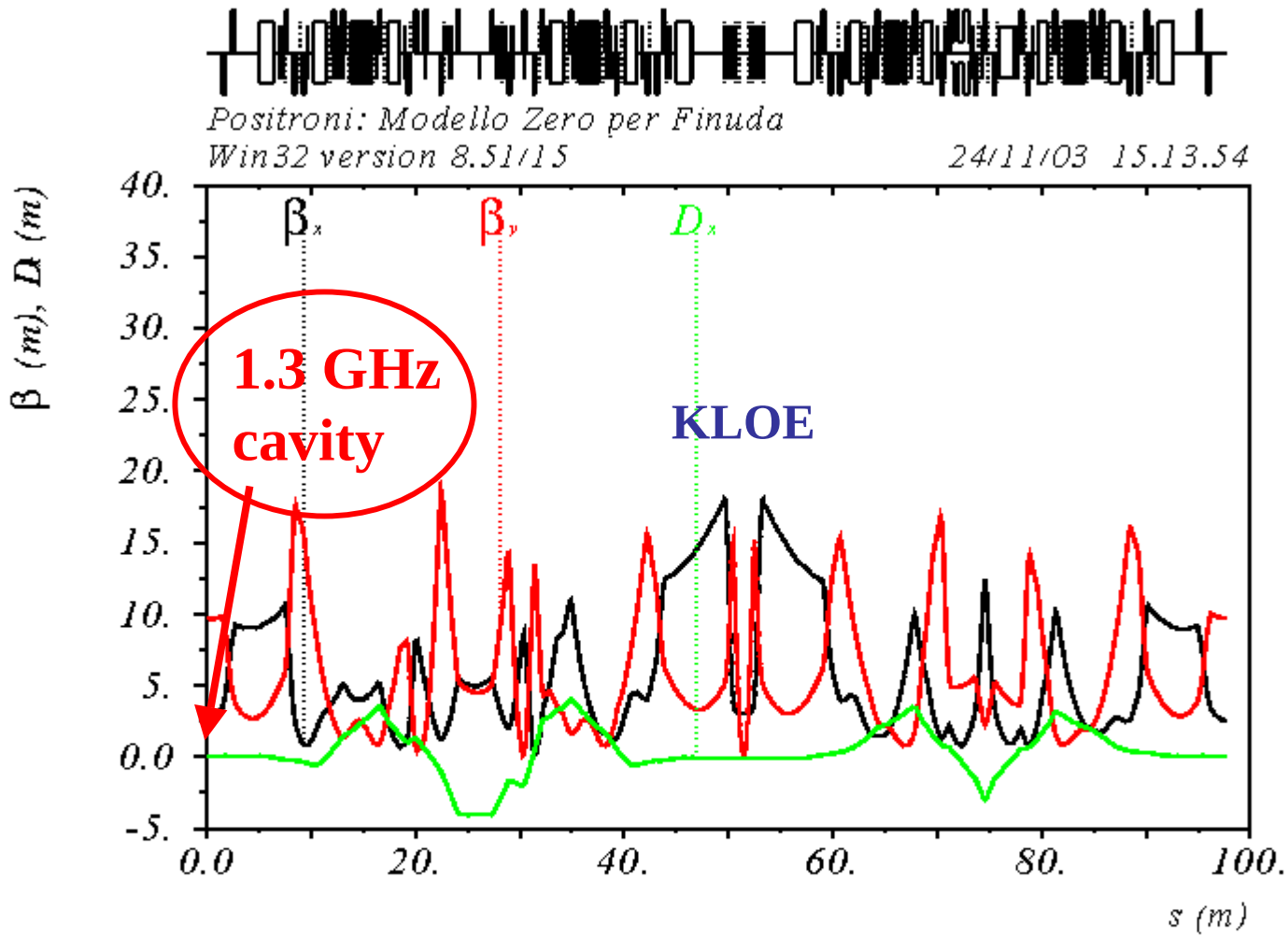


Monopoles of the 2nd band

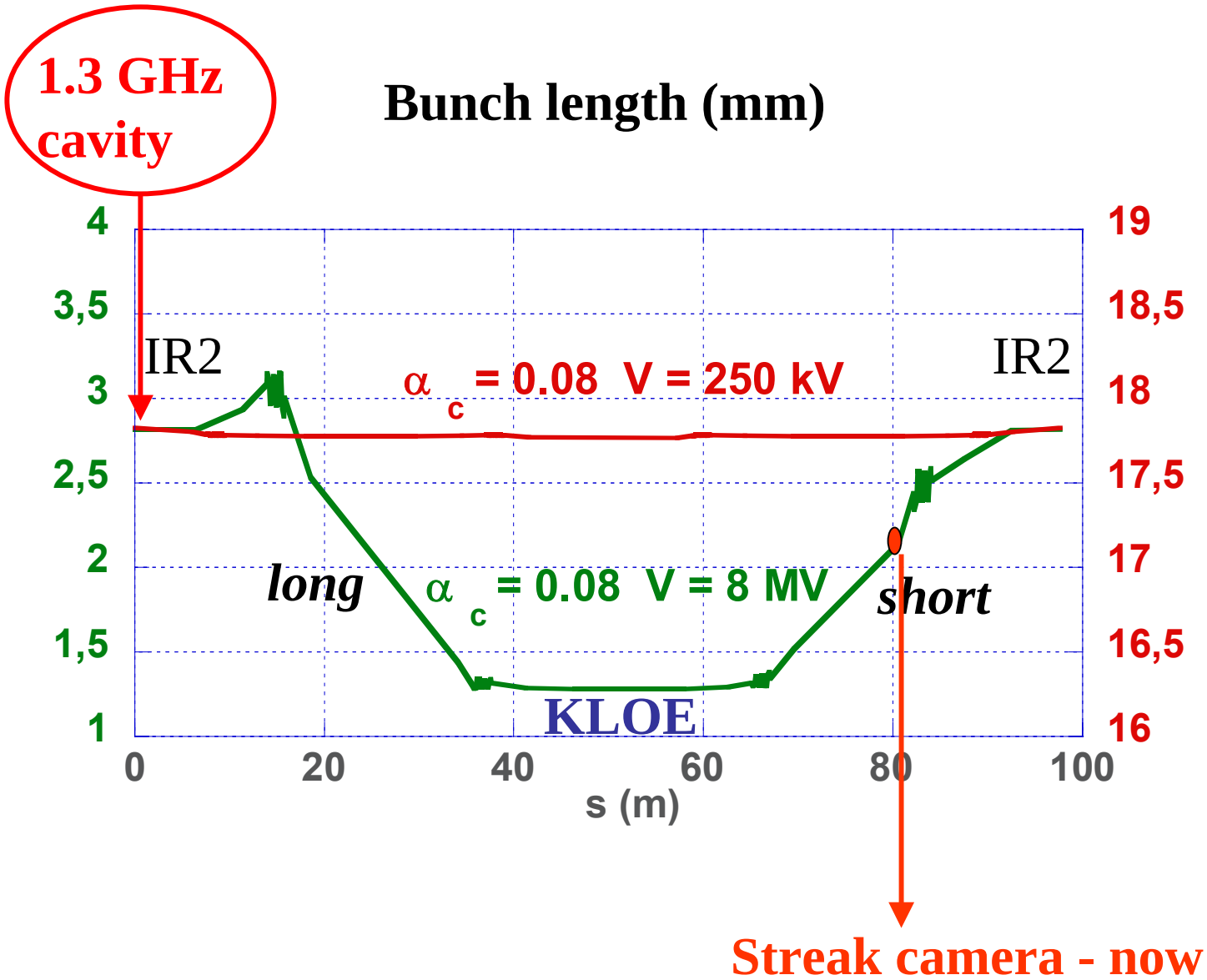


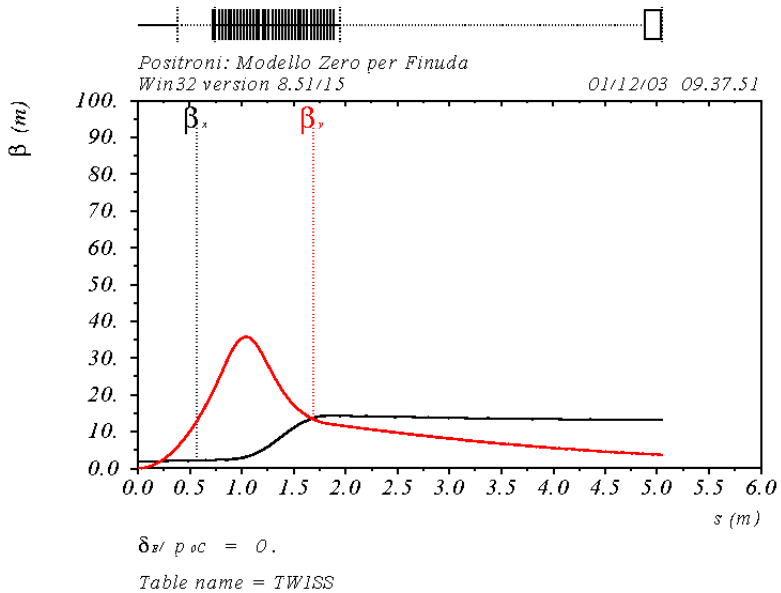
30° portion of the multicell cavity for monopole simulations

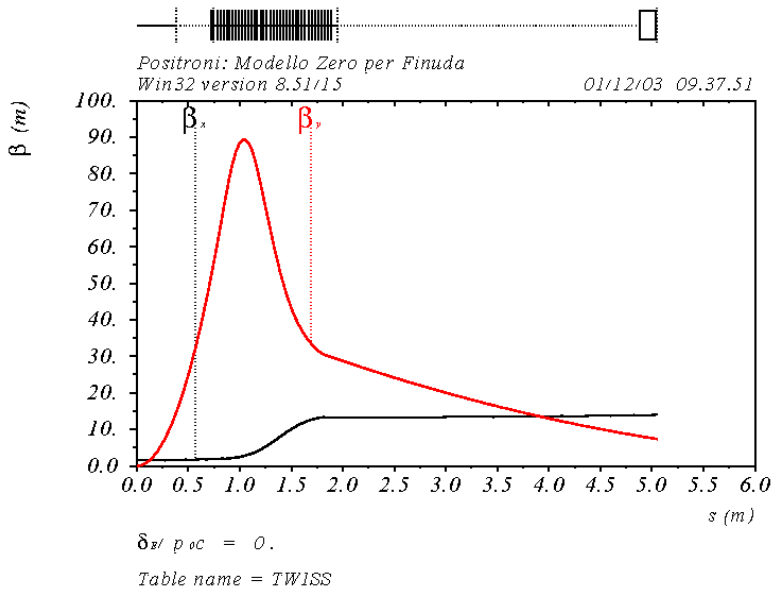
Monopoles of the 3rd band


Positroni: Modello Zero per Finuda
Win32 version 8.51/15
24/11/03 15.13.54
β (m), D (m)
40.
35.
30.
25.
20.
15.
10.
5.
0.0
-5.
0.0
20.
40.
60.
80.
100.
s (m)
βx
βy
Dx
1.3 GHz cavity
KLOE
δ = 0.
Table name = TWISS

$\alpha_C = 0.076$


1.3 GHz cavity
Bunch length (mm)
IR2
IR2
α_c = 0.08 V = 250 kV
long
α_c = 0.08 V = 8 MV
short
KLOE
4
3,5
3
2,5
2
1,5
1
19
18,5
18
17,5
17
16,5
16
0
20
40
60
80
100
s (m)
Streak camera - now





KLOE now

$\beta_x^* = 2$ m

$\beta_y^* = 2.5$ cm

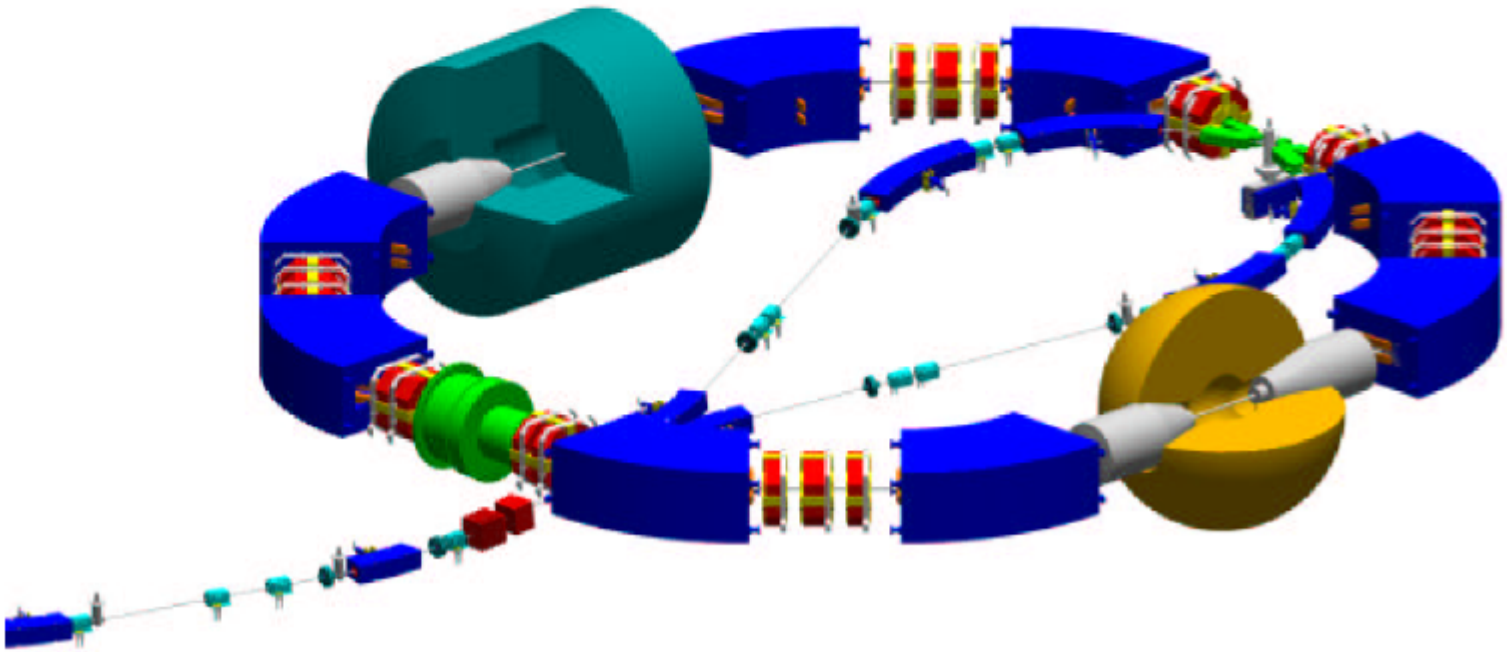
$N_{bunches}$	60
β_y^*	1 cm
β_x^*	1.5 m
ε_x	1 μ rad
ε_y	0.005 μ rad
I/beam	< 0.5 A
L	< 10^{32}

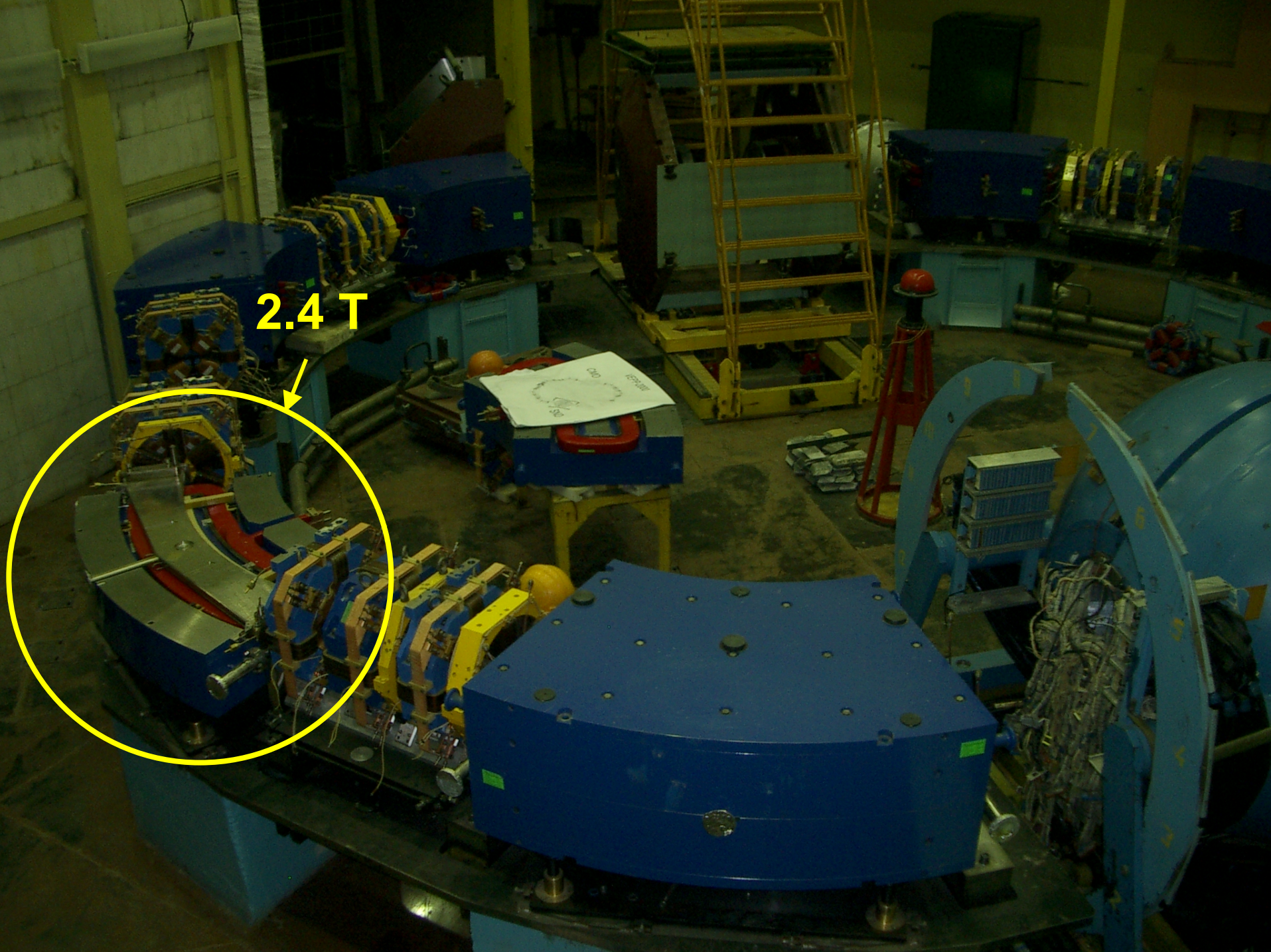
ALTERNATIVE PROPOSALS FOR ACHIEVING ULTRA-HIGH LUMINOSITY AT LOW ENERGIES:

Round Beams to increase the linear beam-beam tune shift parameter ξ

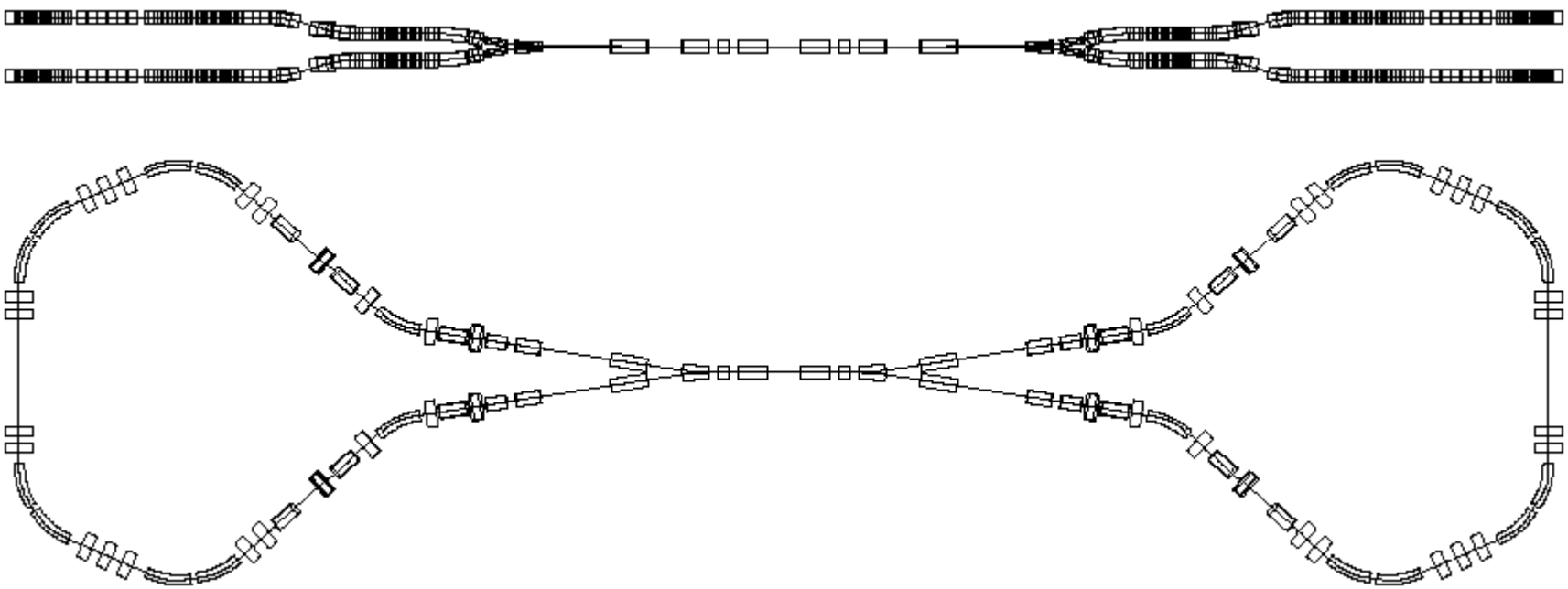
View of the VEPP-2000 collider

Experimental testing of RCB should verify predictions on extremely high attainable space charge parameters for the round beams.




2.4 T

Round beam Novosibirsk Φ – Factory: Four wings



Shatunov: if RCB @Vepp2000 : tune shifts >0.1 -> L @phi >10^{34}

Answer in 2005

Luminosity Upgrade @ Φ

	K Physics	Hyper-nuclei	Exotic atoms		
2004 2006	$2\ 10^{32}$ $>2\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$	10^{32} $0.5\ fb^{-1}$		
2007	**SHUTDOWN**				
2008 2014	10^{33} to 10^{34} $100\ fb^{-1}$	10^{33} $>1\ fb^{-1}$			
2015	???	???	???		
	KLOE	FINUDA	SIDDHARTA		
Cost (M€)	60 Accelerator				

What's next ?

1. No major upgrades – Do the best with the existing hardware
2. Minimum change for E upgrade (to 1.1 GeV/beam) – Preserve operation @ Φ
3. New machine for both E upgrade and $L > 10^{33}$ @ Φ
4. New machine for $L > 10^{34}$ @ Φ

Increasing
Challenge, cost, time, FTE
scientific interest

The DAFNE Team is willing of starting a new scientific enterprise in collaboration with the High-Energy Physics community