Status and perspectives of Phi-factories

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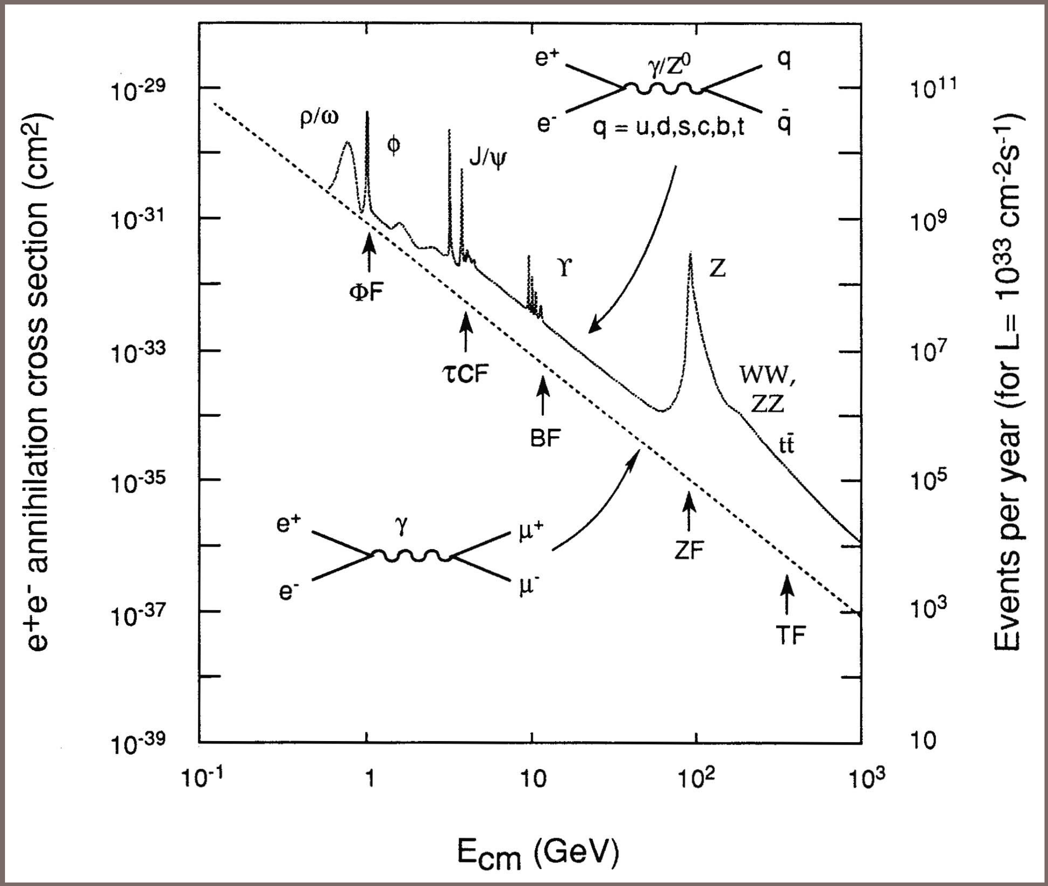
LNF, INFN

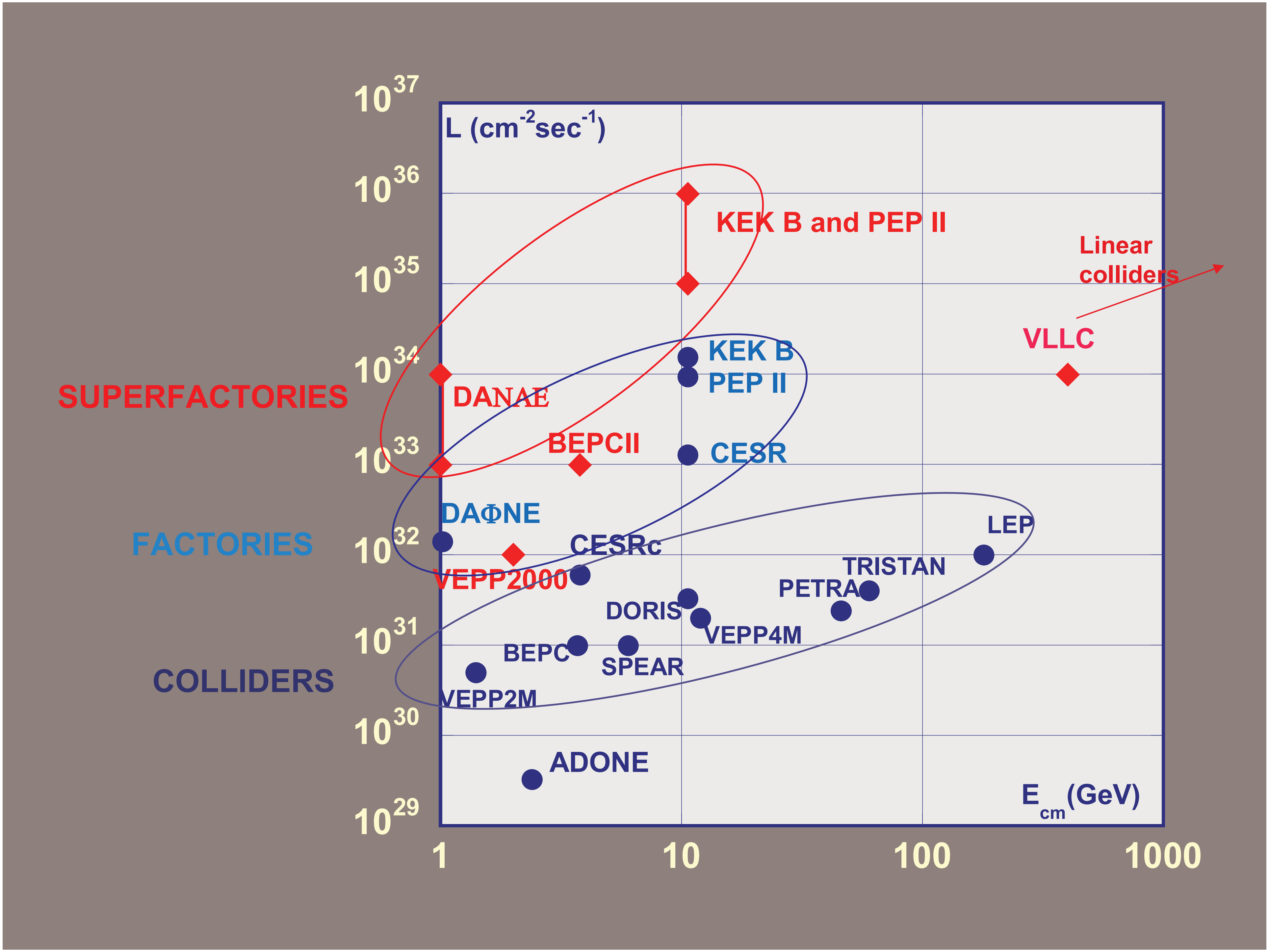
Workshop on **DISCOVERIES IN FLAVOUR PHYSICS AT e+e- COLLIDERS**, Frascati, 28 February 2006

e^+e^- annihilation cross-section up to 1 TeV



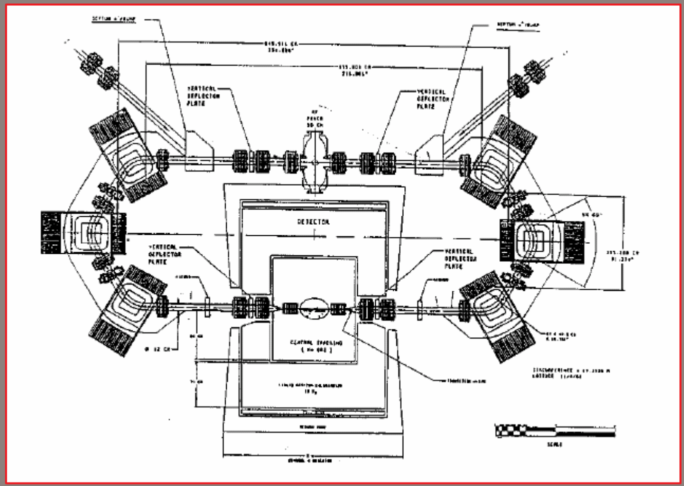
The annihilation production cross section in e^+e^- collisions and the necessary integrated luminosity scale with Energy:

$$L \propto \frac{1}{\sigma} \propto E^2$$

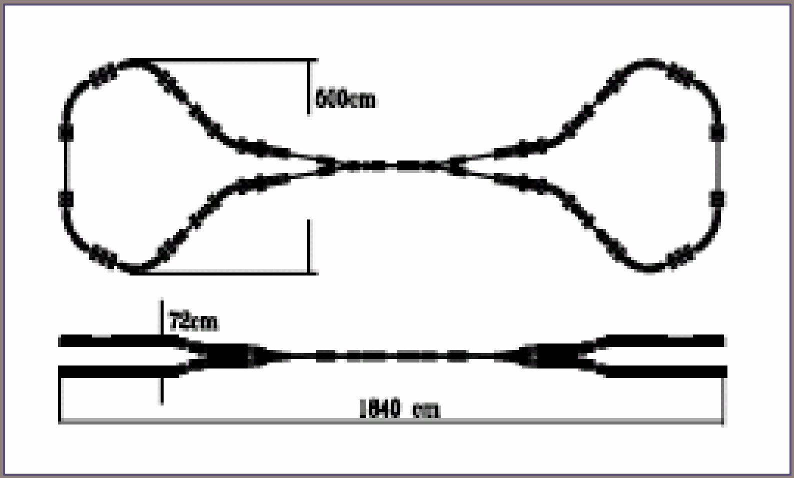


L (cm-2sec-1)
10^37
10^36
10^35
10^34
10^33
10^32
10^31
10^30
10^29
SUPERFACTORIES
FACTORIES
COLLIDERS
KEK B and PEP II
Linear colliders
VLLC
KEK B
PEP II
DANAE
BEPCII
CESR
DAΦNE
CESRc
VEPP2000
LEP
TRISTAN
PETRA
DORIS
VEPP4M
BEPC
SPEAR
VEPP2M
ADONE
Ecm (GeV)
1
10
100
1000

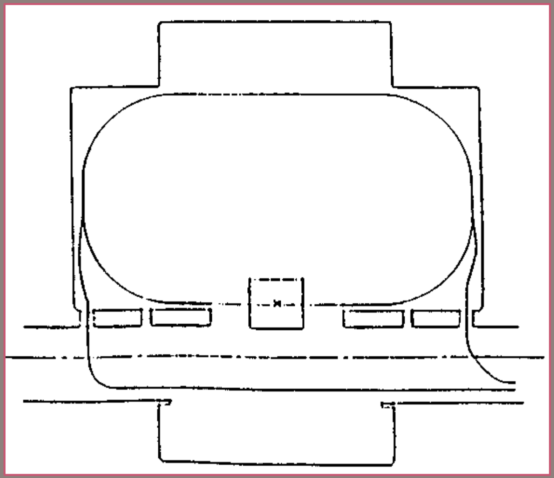
Different PHI factory designs



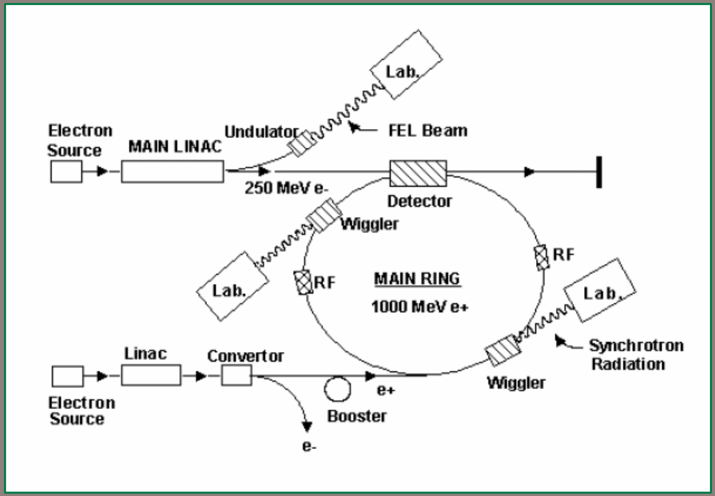
UCLA – QIR (1991)
(quasi isochronous compact ring)



Novosibirsk butterfly (since 80ies)
ROUND COLLIDING BEAMS

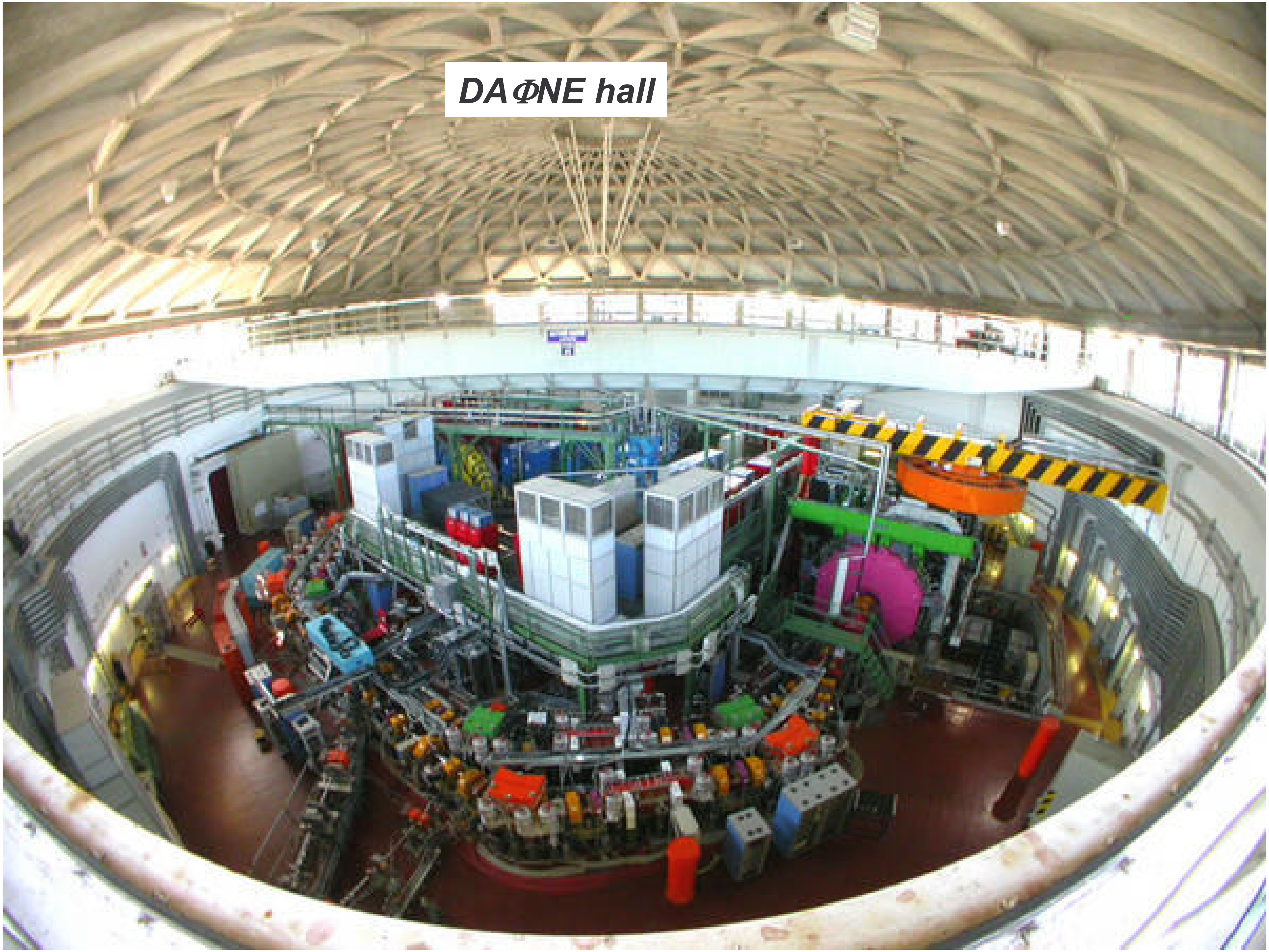


KEK design – 1991
Two superposed rings



Turkish design (1999)
LINAC to RING


Only Φ factory
DAΦNE: since 1998


DAΦNE hall

Design criteria of DAΦNE

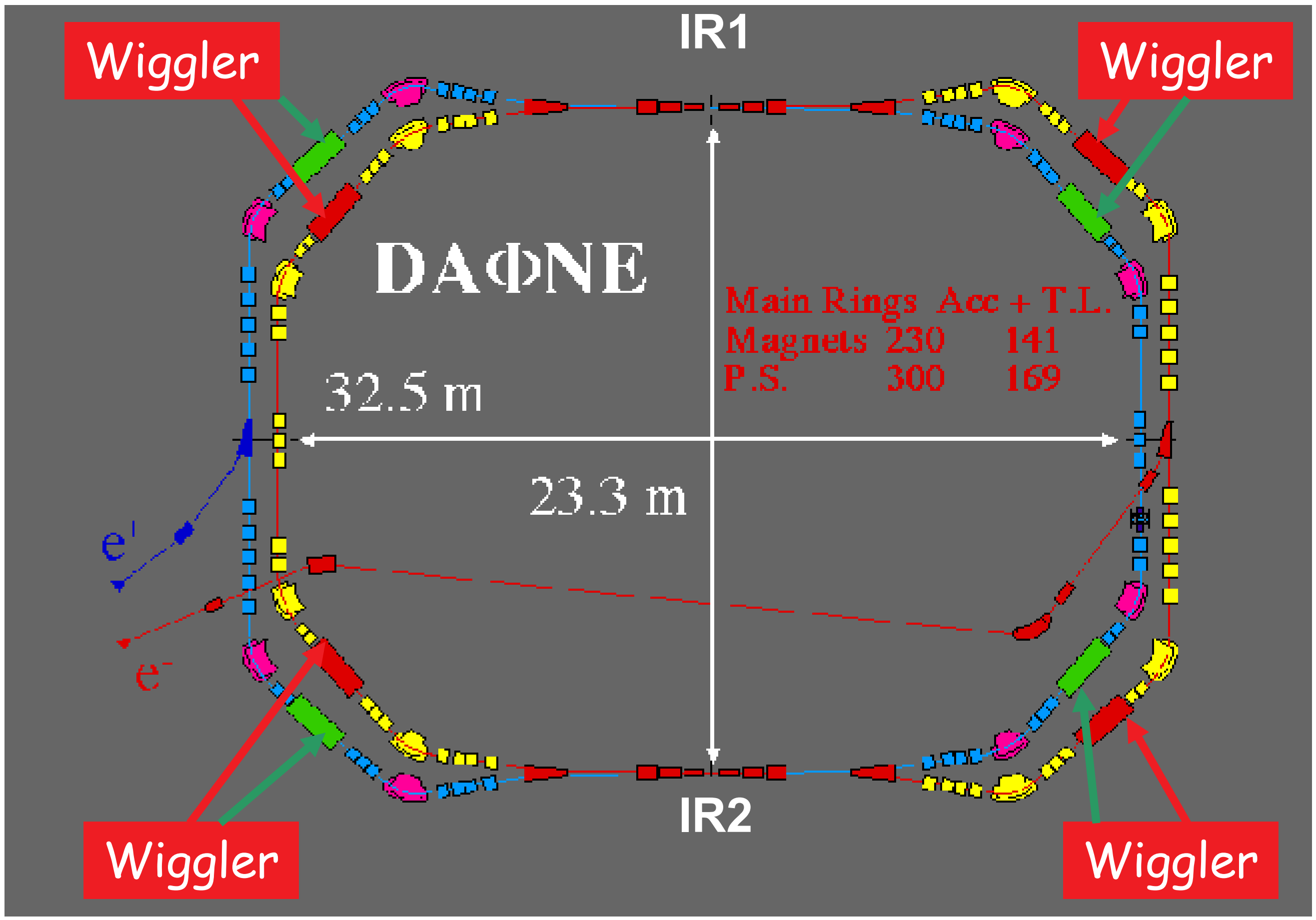
$$L = \frac{f_{coll}}{4\pi} \frac{N^+ N^-}{\sigma_x^* \sigma_y^*}$$

Luminosity	$L \sim 10^{32}\ cm^{-2}\ sec^{-1}$
Collision frequency	$f_{coll} \sim 300$ MHz
Particles per bunch	$N \sim 3\ 10^{10}$
Beam dimensions	$\sigma^*_{x/y} \sim 1$mm / 10μ

High current per bunch
short distance between bunches
small beam size at collision – flat beam

Double ring and multibunch operation
Crossing angle at IP
Rf frequency determines the distance between bunches

DAΦNE MAIN RINGS layout



DAΦNE challenges

(all enhanced by the low energy)

High currents

High densities

Long damping time

Strong Beam-beam effect

DAΦNE challenges

(all enhanced by the low energy)

High currents

Electron ring : I_{max} = 2.4 A

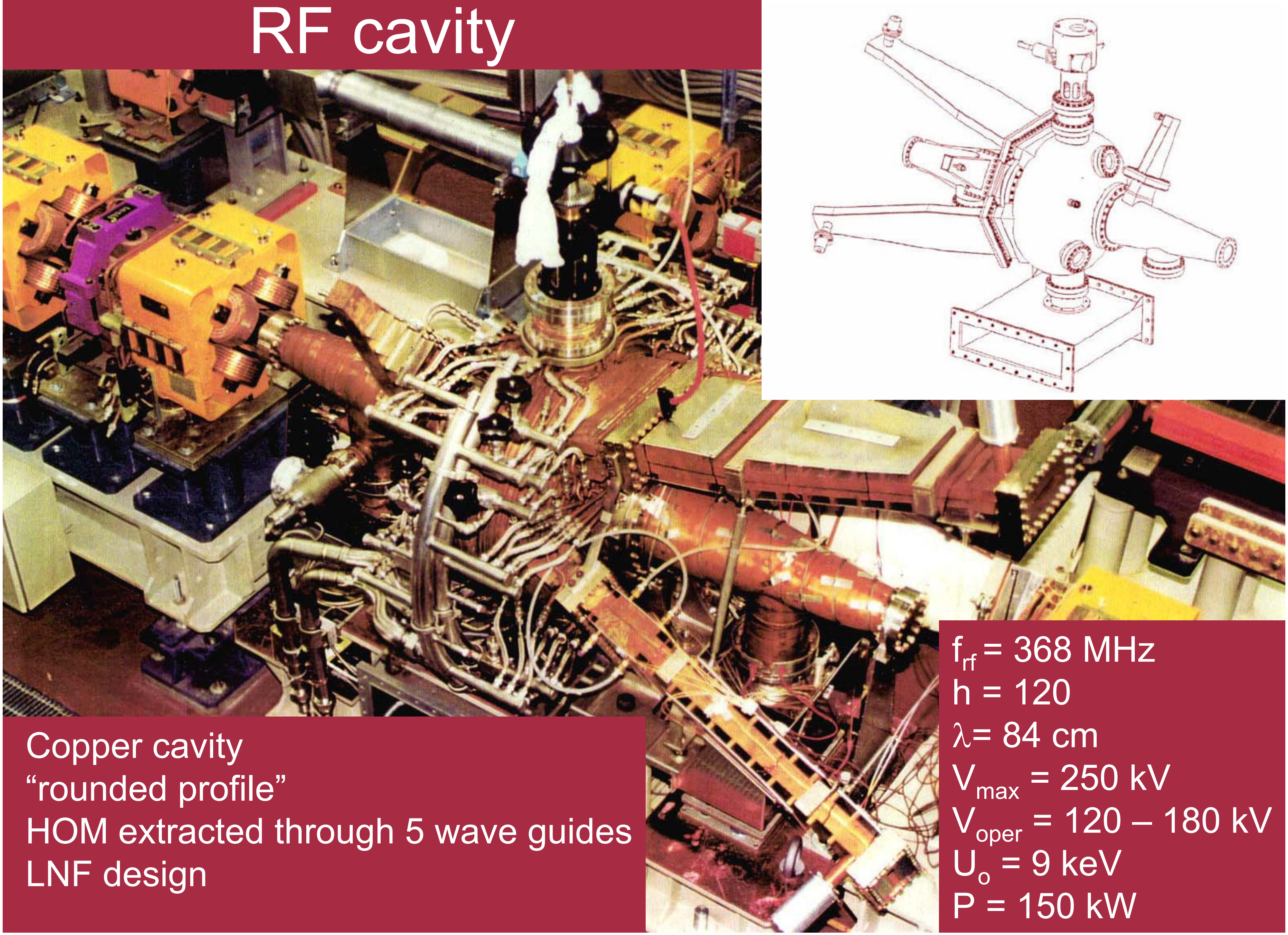
Positron ring : I_{max} = 1.5 A

Feedback systems

Impedance minimisation

Rf cavity design HOM free

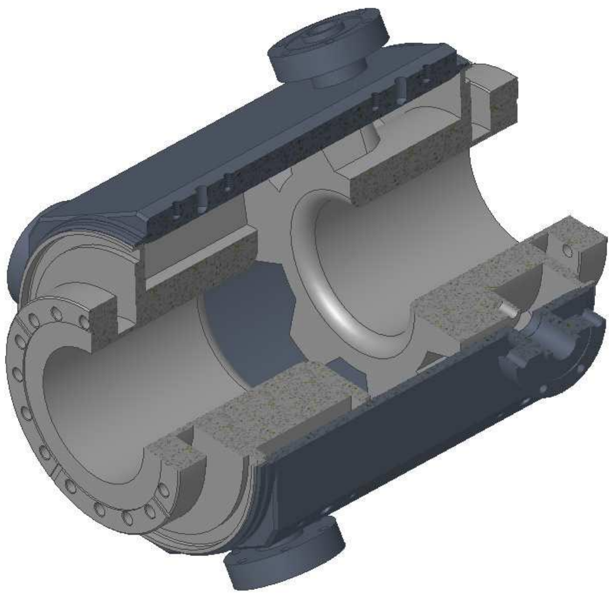
RF cavity



Copper cavity
“rounded profile”
HOM extracted through 5 wave guides
LNF design

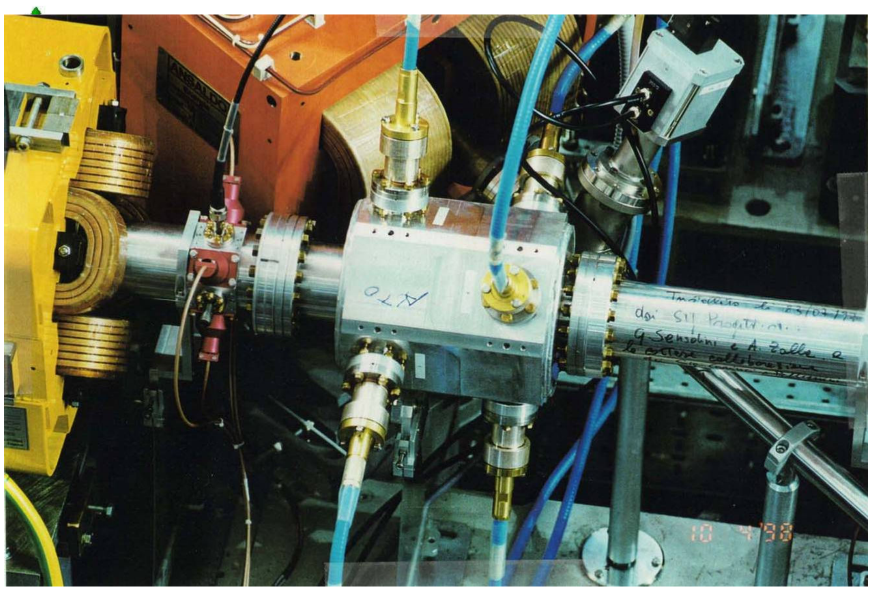
f_{rf} = 368 MHz
h = 120
λ= 84 cm
V_{max} = 250 kV
V_{oper} = 120 – 180 kV
U_o = 9 keV
P = 150 kW

Longitudinal feedback for multibunch instabilities



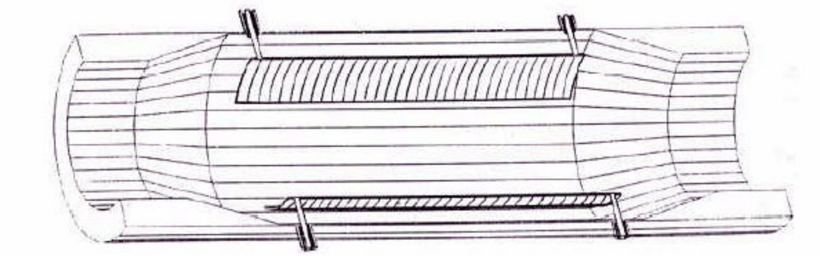
Bunch by bunch feedback
Time domain
based on DSPs (digital signal processors)

Feedback cavity kicker (f_o = 3.25 f_{rf})
Waveguide overloaded cavity
Broadband
Large bandwidth (180 MHz)
Power dissipated in external loads



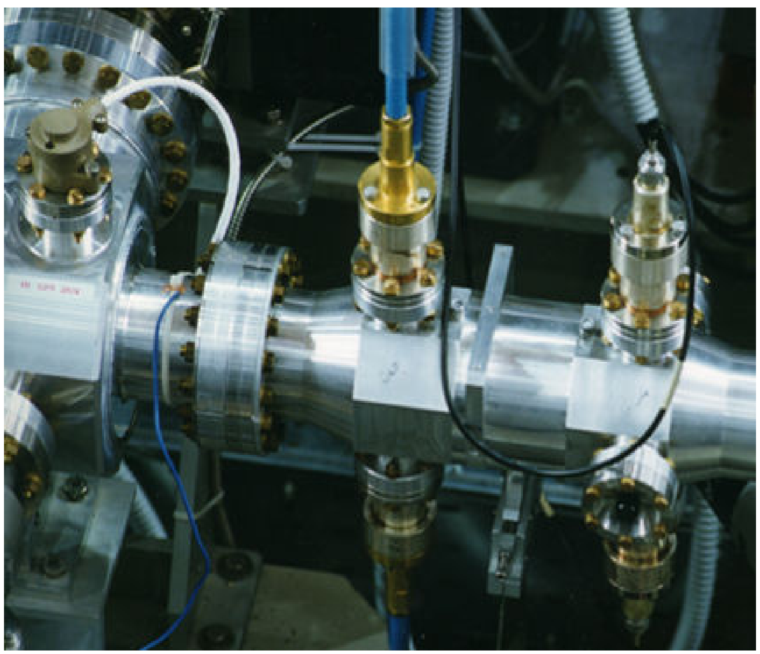
Adopted also by KEK-B, PLS, BESSY II, CESR, PEP II, BEPCII, …

Transverse feedbacks for resistive wall instability



Striplines matched @ 50 Ohm
Characteristic impedance

Different BPMs can be used as pick-ups



Operational from beginning 2000
Every step in current needs feedback tune-up

DAΦNE challenges

(all enhanced by the low energy)

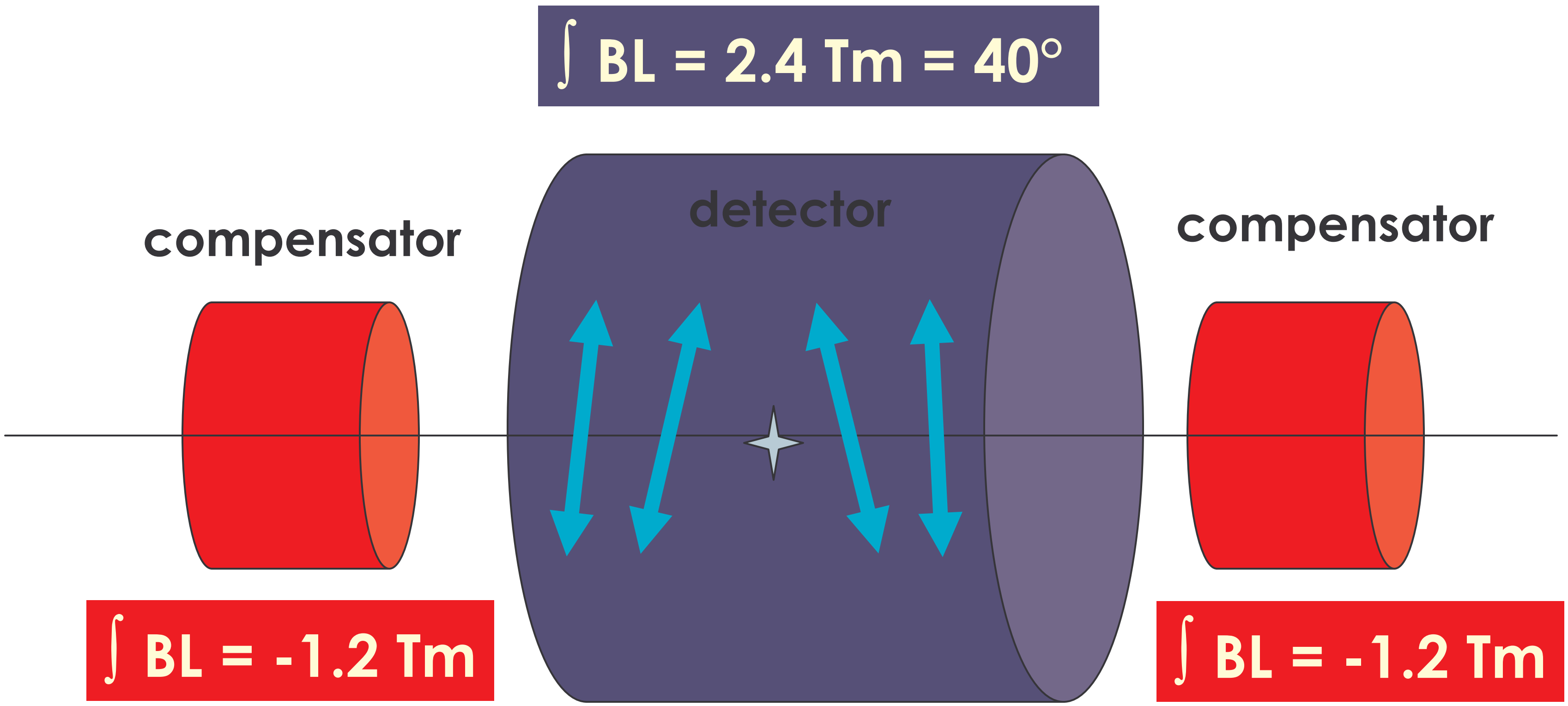
Coupling correction (0.2 %)

High densities

Low beta @IP
(high chromaticity)

Low impedance
to limit bunch lengthening
And transverse blowup over
Microwave instability threshold

coupling compensation in IR

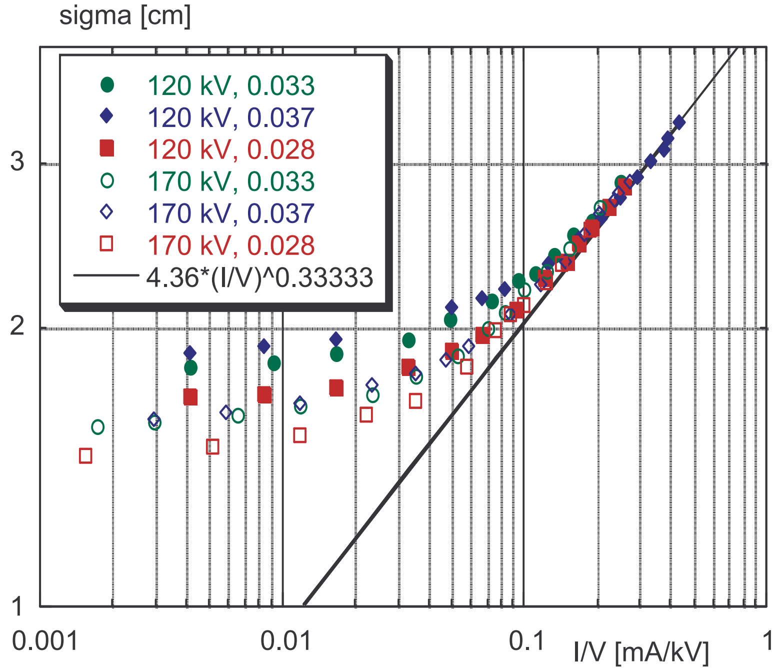


Quads tilted by $$\frac{1}{2B\rho}\int_{IP}^{s_q} B\,ds + \delta\theta_q$$

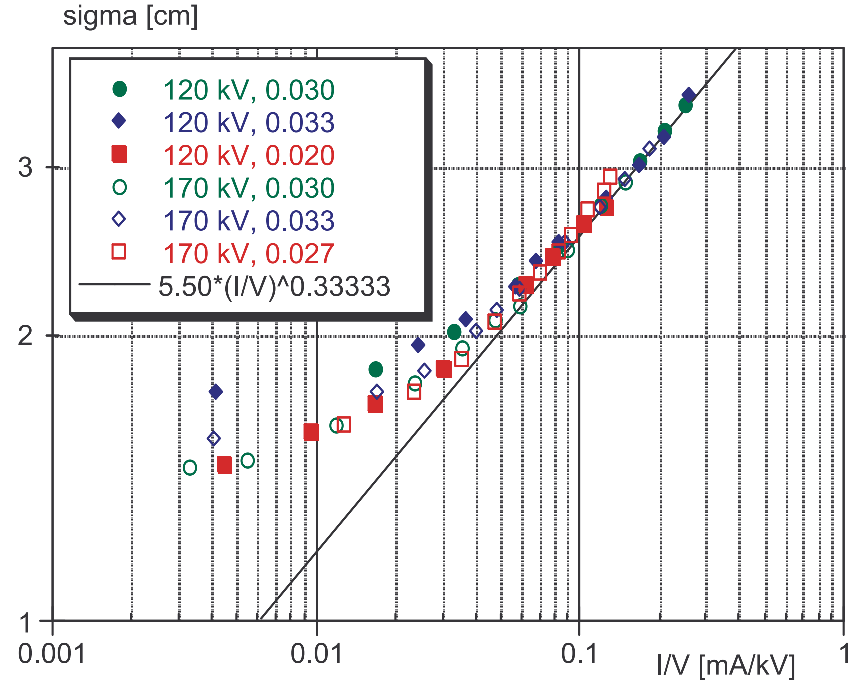
Bunch length and impedance

$$\sigma_z[cm] = 4.36 \times \left(\frac{I[mA]}{V[kV]}\right)^{1/3} \quad ; for \quad positron \quad ring$$

$$\sigma_z[cm] = 5.50 \times \left(\frac{I[mA]}{V[kV]}\right)^{1/3} \quad ; for \quad electron \quad ring$$



Positron ring: Z/n = 0.6 Ohm

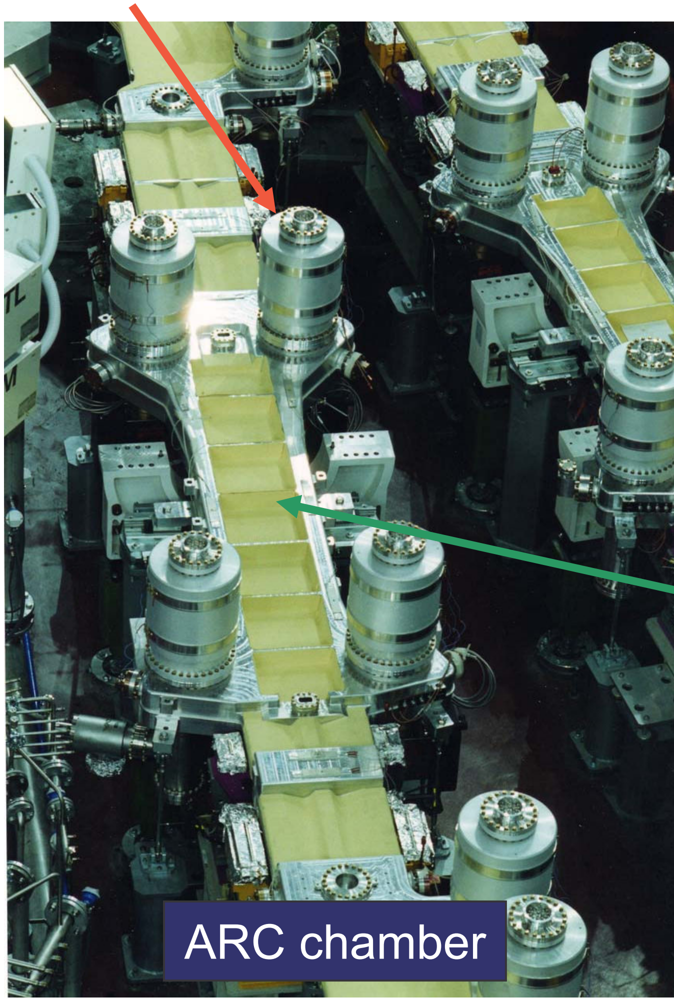


Electron ring: Z/n = 1 Ohm

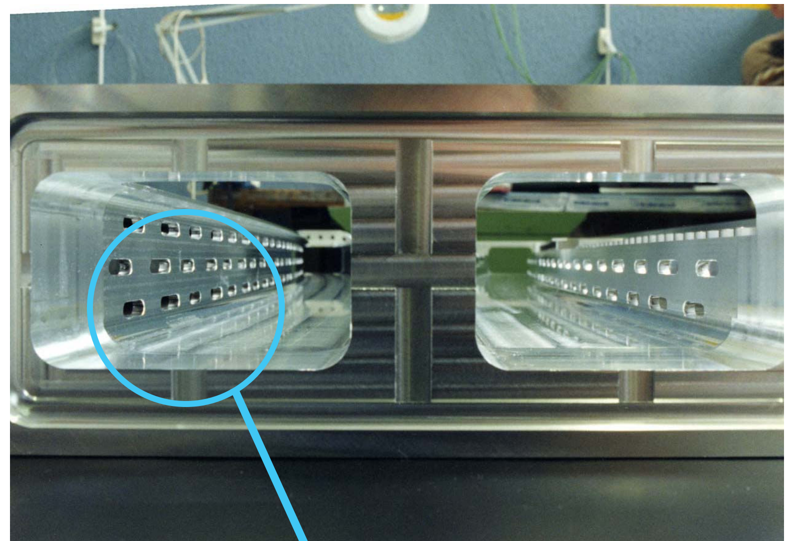
(ICE presence)

Examples of vacuum chamber parts

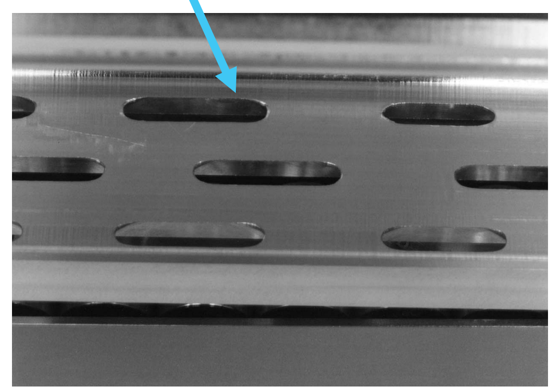
Titanium sublimation pumps



Wiggler positions



Splitter vacuum chamber



Asymmetric slots for vacuum pumping
Avoid overlap with beam spectrum

DAΦNE challenges

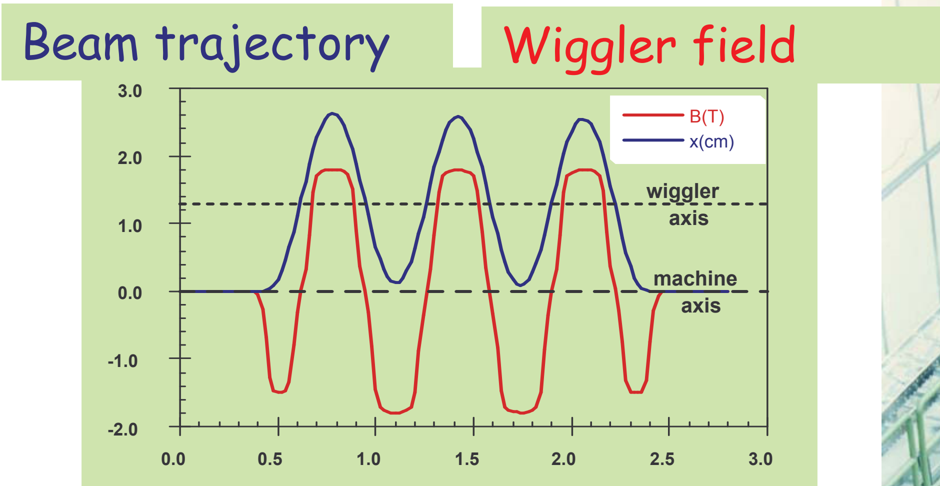
(all enhanced by the low energy)

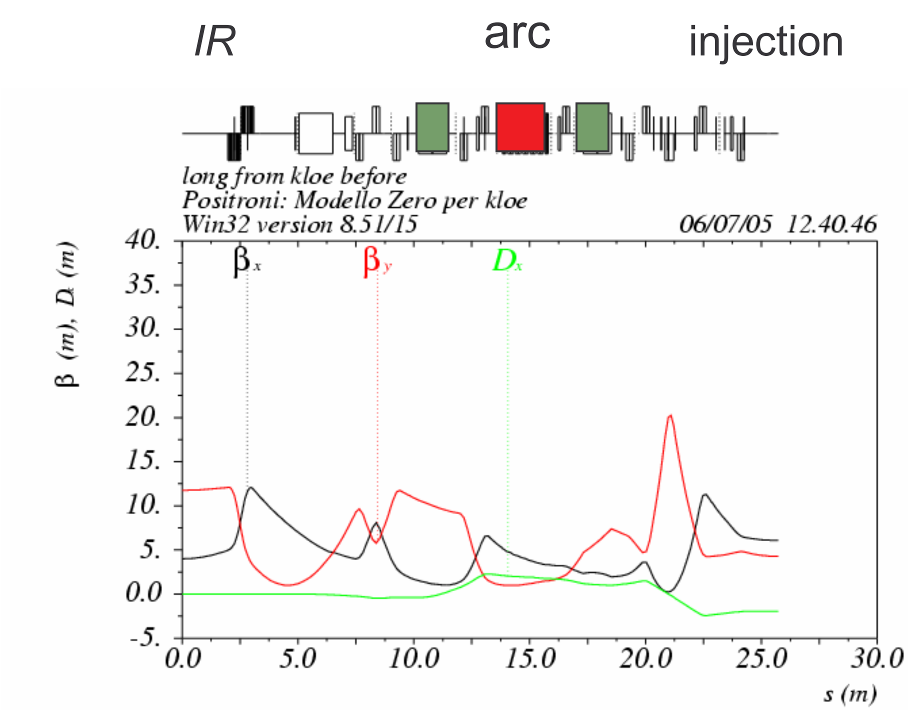
Long damping time

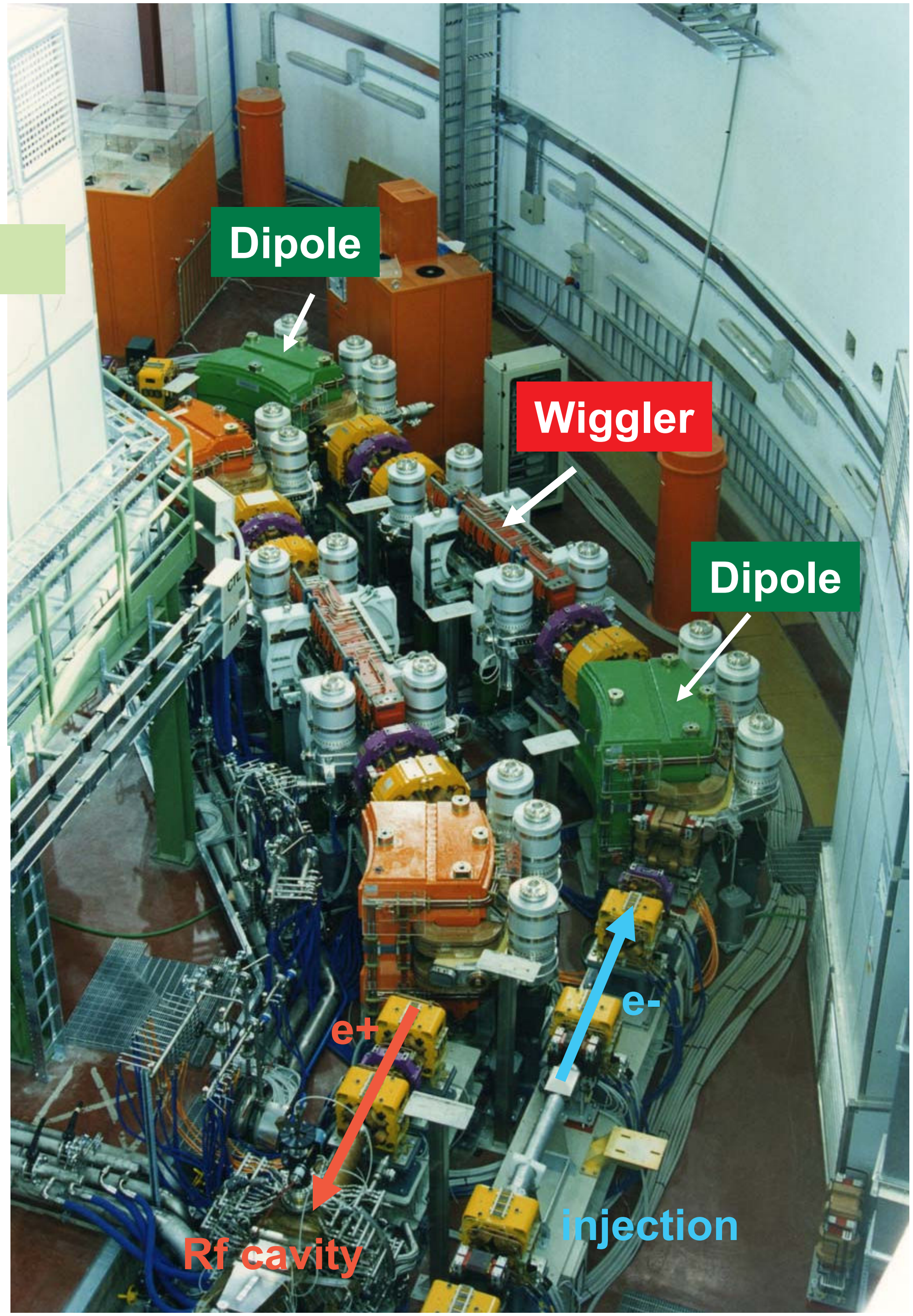
Wigglers to increase radiation
4 (1.8 T) wigglers (8m) per ring

DAFNE is the 1° ring with optics based on wiggler presence

ARC with wigglers







Damping time

$$\alpha_x = \frac{C_\alpha E^3}{C}(I_2 - I_4)$$

$$\alpha_y = \frac{C_\alpha E^3}{C} I_2$$

$$\alpha_s = \frac{C_\alpha E^3}{C}(2I_2 + I_4)$$

$B\rho$ = 1.7 Tm

ρ_D = 1.4 m B_D = 1.4 T

ρ_W = 0.9 m B_W = 1.8 T

	Dipoles	Dipoles + wigglers
I_2 [m^{-1}]	4.5	10.2
τ_x [msec]	80	35
N_{turns}	240 000	105 000

DAΦNE challenges

(all enhanced by the low energy)

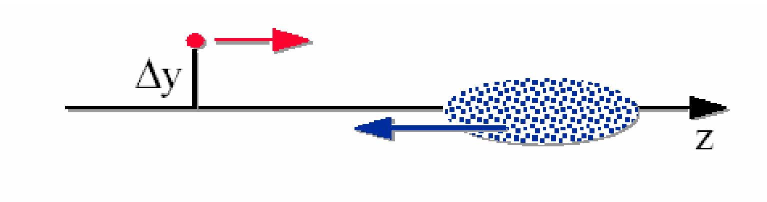
Large emittance (wigglers)

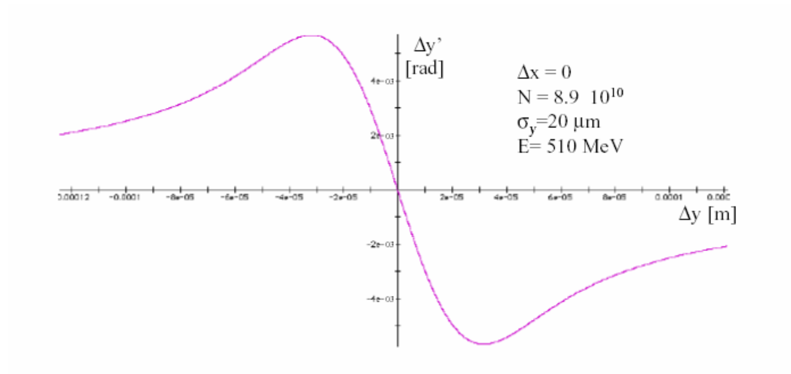
Working point choice

Non linear dynamics driven by
Non linearities + sextupoles

Strong Beam-beam effect

Beam – beam effect





Beam – beam force

$$Q_{x,y} = Q_{x,y} + \xi_{x,y}$$

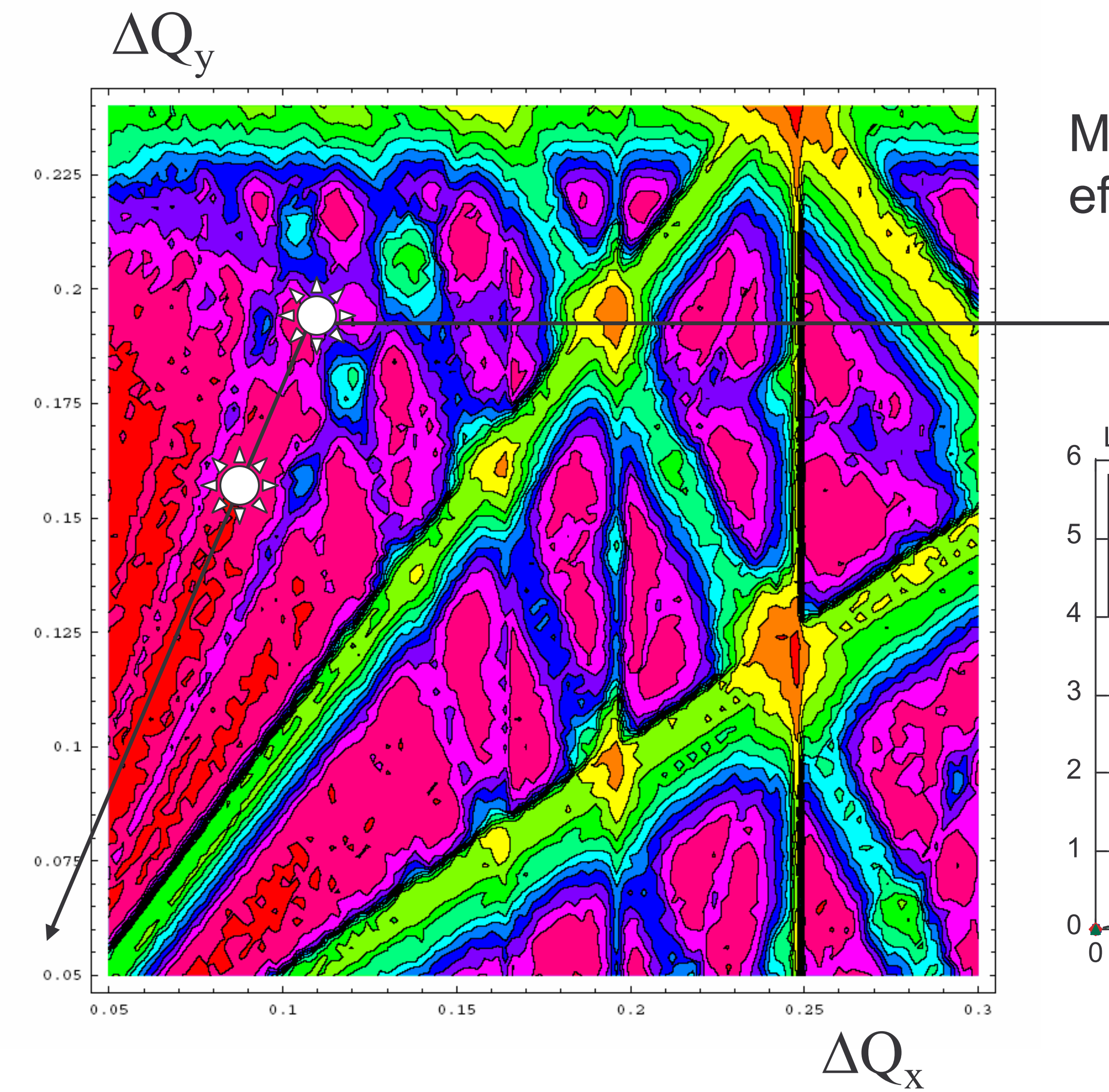
Linear tune shift < 0.04

$$\xi_x = \frac{r_e}{2\pi\gamma}\frac{N\beta_x}{\sigma_x\left(\sigma_x+\sigma_y\right)} \approx \frac{r_e}{2\pi\gamma}\frac{N}{\varepsilon_x}$$

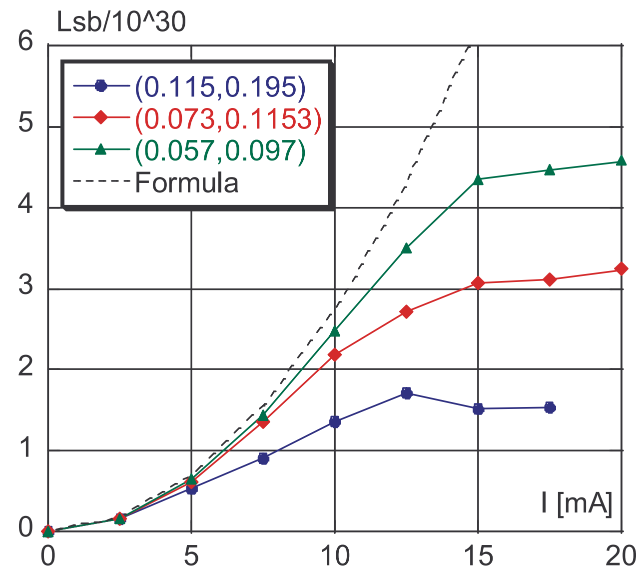
$$\xi_y = \frac{r_e}{2\pi\gamma}\frac{N\beta_y}{\sigma_y\left(\sigma_x+\sigma_y\right)} \approx \xi_x\sqrt{\frac{\beta_y}{\kappa\beta_x}}$$

- Large emittance
- Demand on damping time
- Demand on dynamic aperture

Working Point Choice



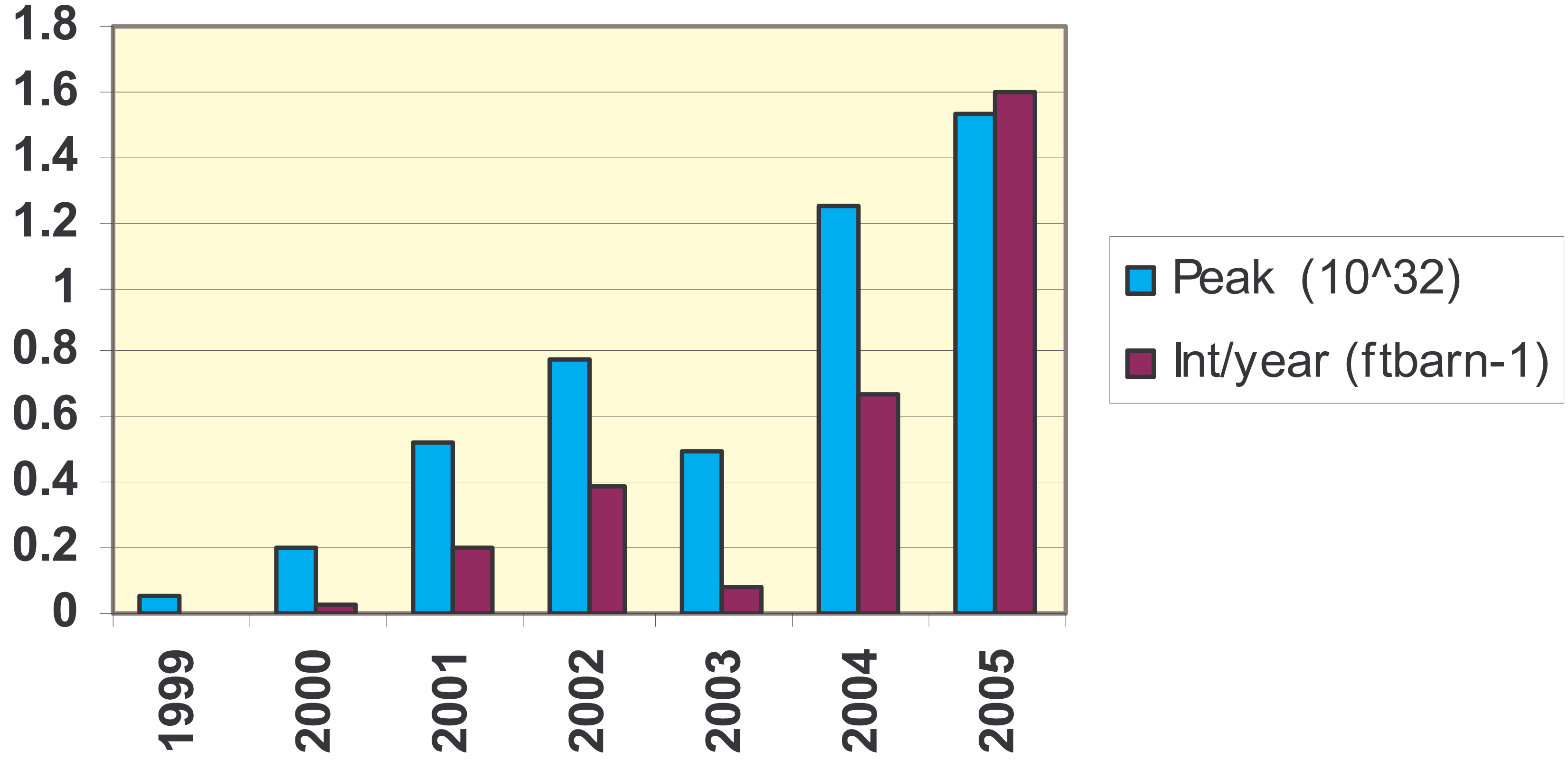
Mainly driven by beam-beam effects



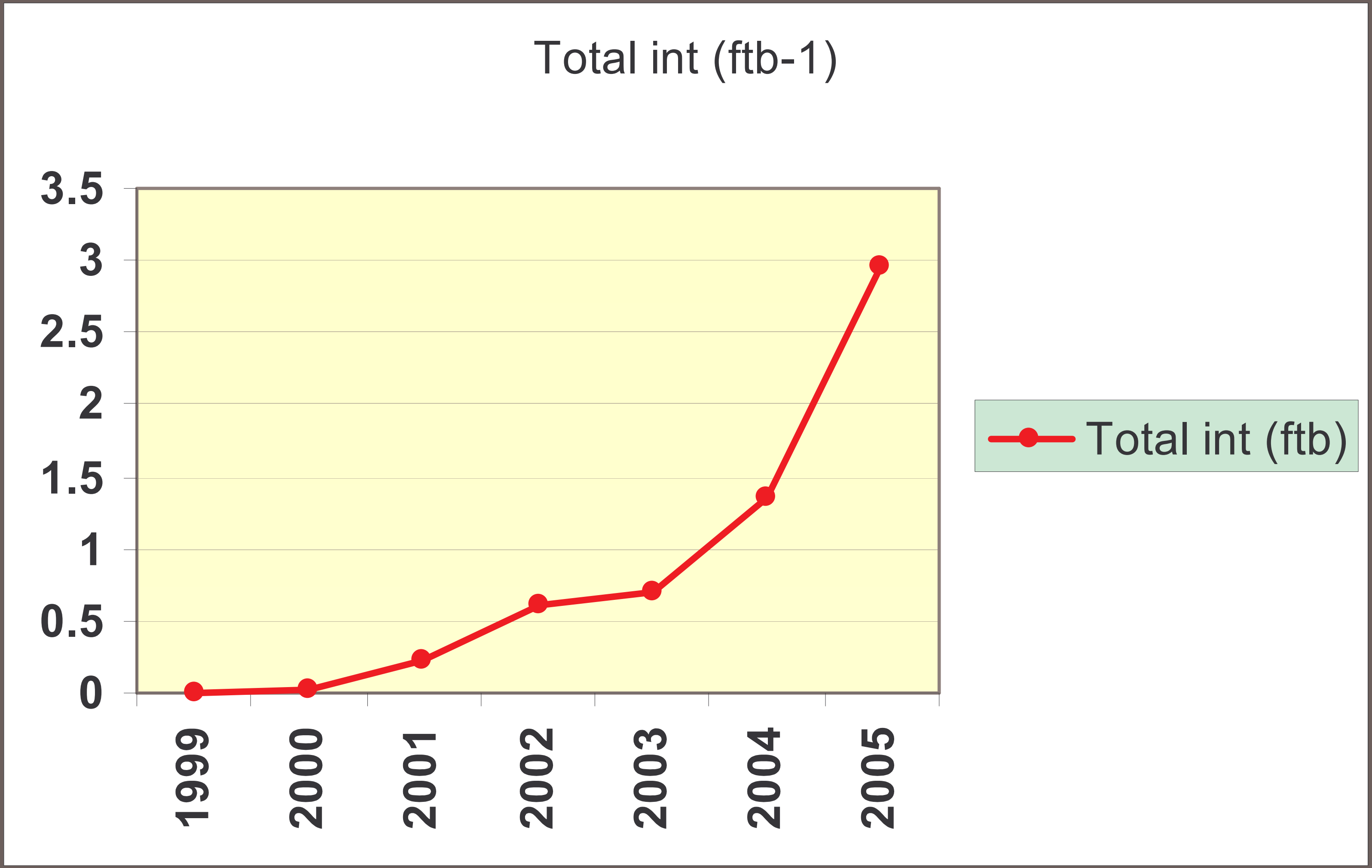
DAΦNE main parameters

Energy per beam	E	510 *MeV*
Luminosity	L	$1.5 \cdot 10^{32}$ $cm^{-2}\ s^{-1}$
Circumference	C	97.69 *m*
Emittance	ε	$0.4 \cdot 10^{-6}$ *rad m*
Coupling	κ	0.3 % - 1% (out-in collision)
Beta functions at IP	β_x^* / β_y^*	1.8 / 0.019 *m*
Crossing angle at IP	θ_x^*	±12.5 *mrad*
Beam size at IP	σ_x^* / σ_y^*	0.85 / 0.005 *mm*
Bunch length	σ_z	1.5 – 2.5 *cm*
Betatron tunes e-	ν_x / ν_y	5.11 / 5.17
Betatron tunes e+	ν_x / ν_y	5.14 / 5.19
Momentum compaction	α_c	0.024
Number of bunches		110 (over 120)
RF frequency	f_{RF}	368.26 *MHz*
Beam currents @L_{max}	I^+_{max} / I^-_{max}	1.3/1.4 *A*

Daϕne Integrated and peak luminosity per year

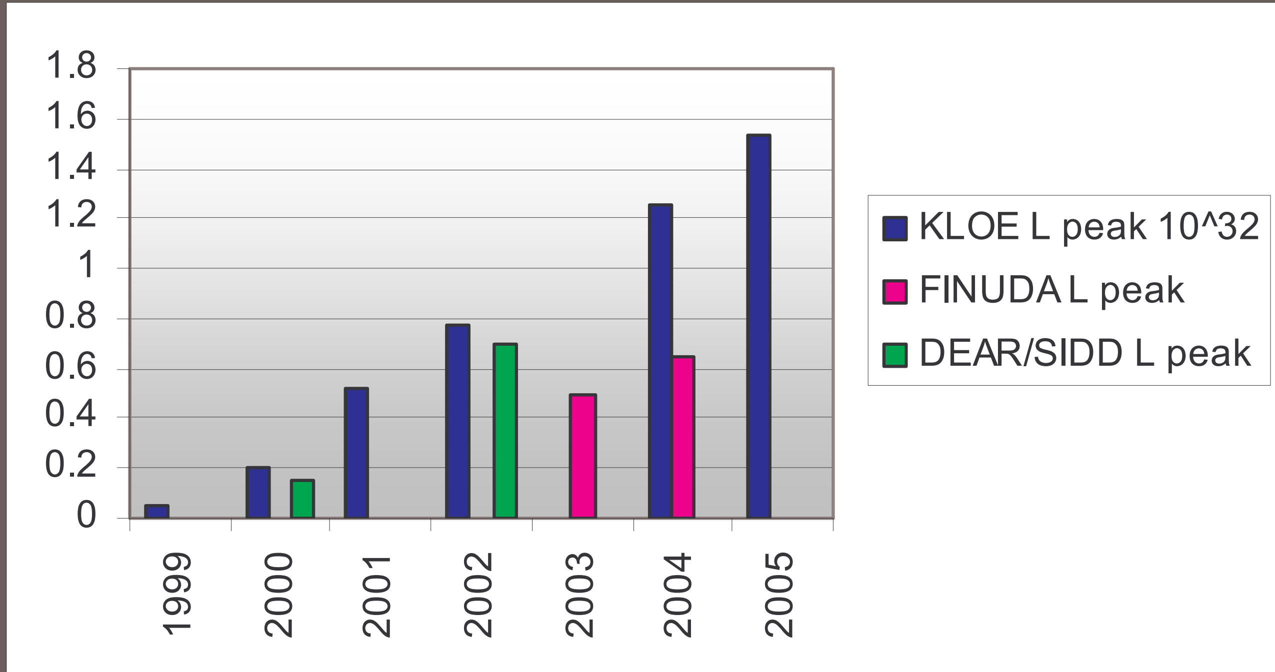


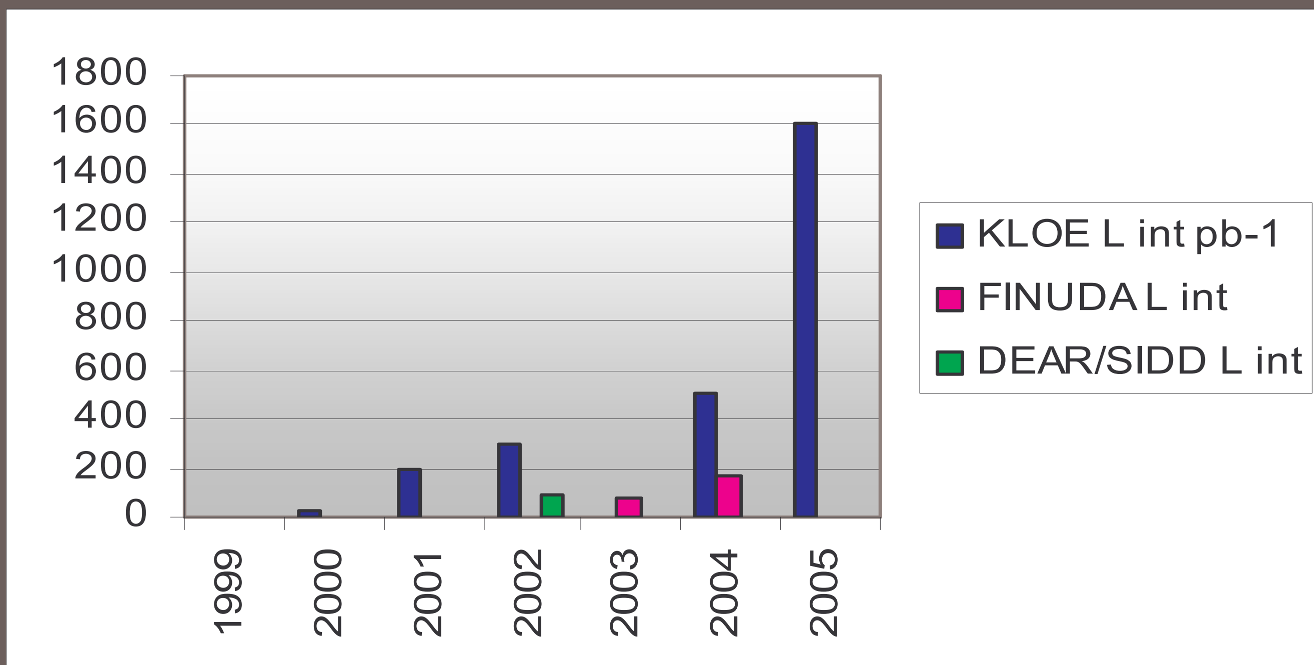
DAΦNE total integrated luminosity



DAΦNE shared luminosity by three Experiments:

KLOE
FINUDA
DEAR





Near term future

2006 – Final KLOE run
- Shutdown for FINUDA installation
- FINUDA run

2007 – FINUDA run (up to 1 fbarn-1)
- Shutdown for SIDDHARTA installation
- SIDDHARTA run

2008 – SIDDHARTA run (up to 1 fbarn-1)
- Shutdown for FINUDA installation
- FINUDA run (up to 2 fbarn-1)

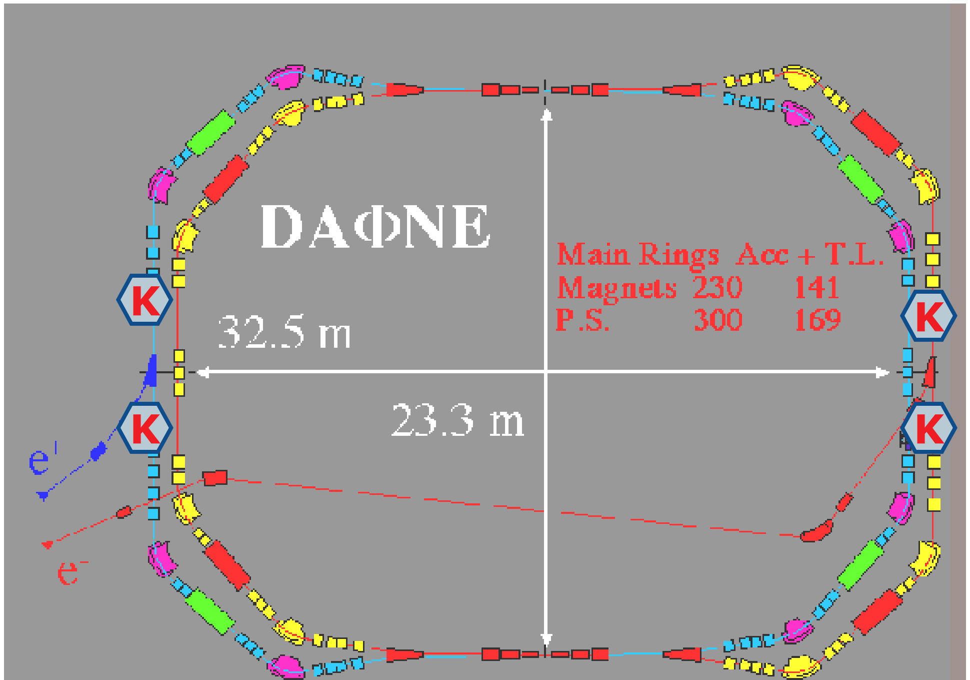
Present Luminosity limits due to:

- Bunch lengthening + vertical size blow up, specially e-ring
- E+ current threshold (e- cloud)
- Beam-beam limit
- Beam lifetime dropping at higher current
- Parasitic crossing beam-beam

Foreseen upgrades to increase luminosity during next runs

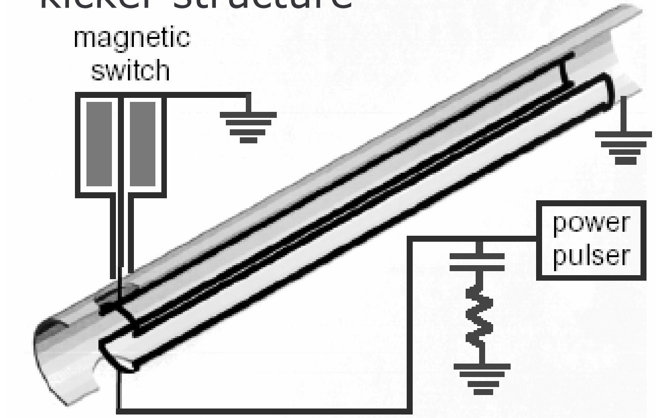
- ICE shieldings => decrease of e- vacuum chamber impedance =>shorter bunches
- Short pulse injector kickers => increase of injection efficiency and positron current
- Remodelling of wiggler poles => increase of beam lifetime
- Ti coating of e+ vacuum chamber => increase of positron current
- Optimisation of feedbacks systems, IR set ups (new experiments), ...

STUDIES FOR NEW DAFNE INJECTION KICKERS

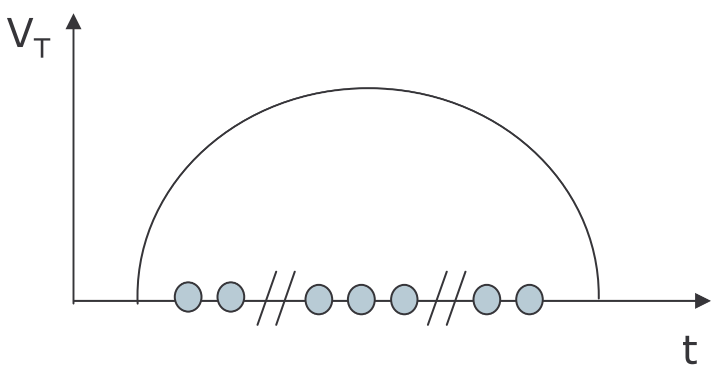


E=510 Mev
# of bunches=120(max)
Stored current=1.5-2.0A

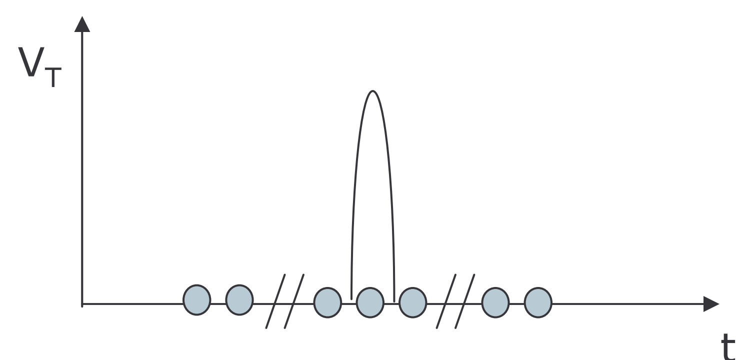
Schematic of the present injection kicker system and kicker structure



2 kickers for each ring
φ ~ 10mrad
Beam pipe radius = 44 mm
Kicker length = 1m



present pulse length ~150ns



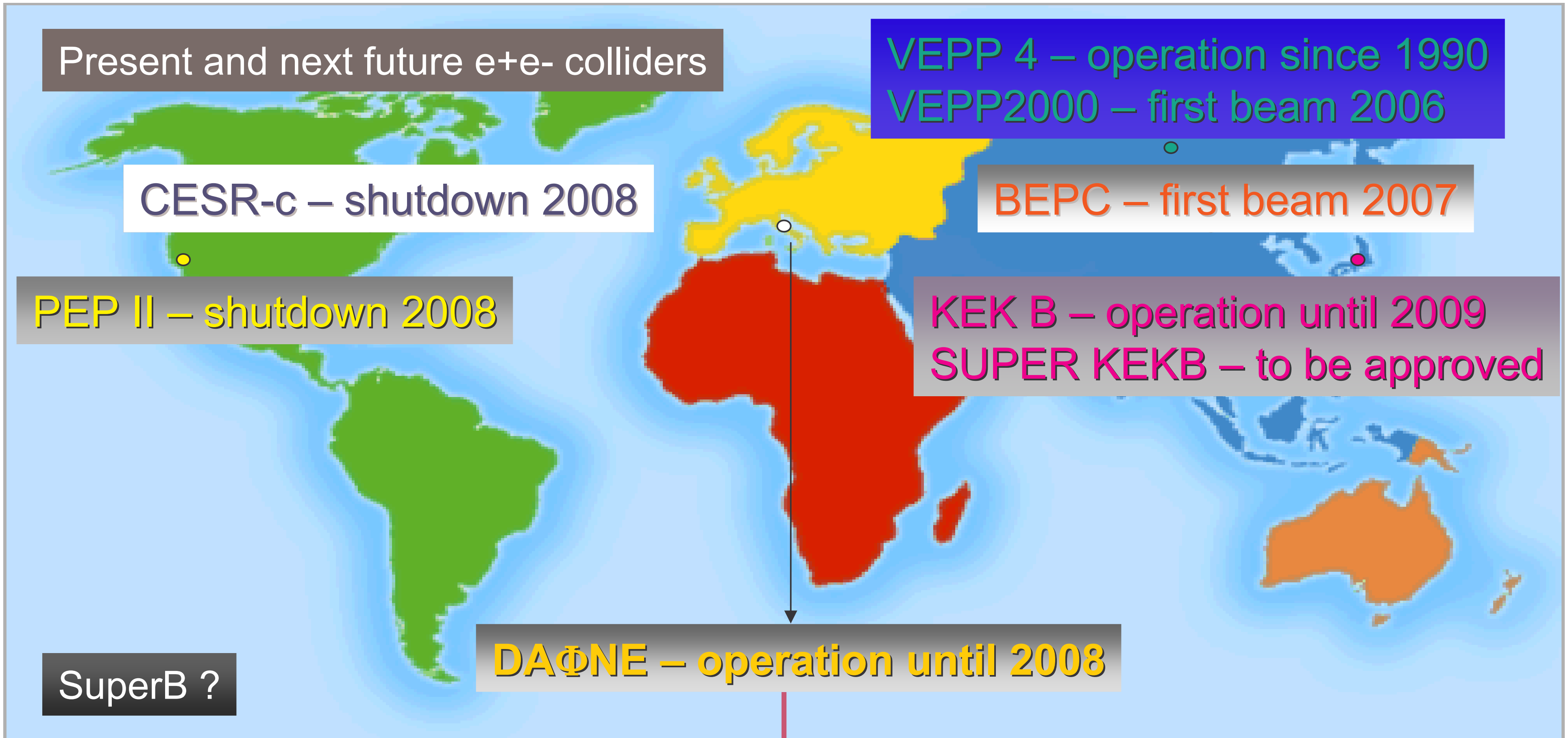
aimed FWHM pulse length ~5.4 ns

Extra possibilities

- Crab cavity
- Longitudinal modulated vertical β^* by Rf quadrupole

Physics prospects at LNF after DAΦNE

- K physics (www.lnf.infn.it/kloe/kloe2)
- Neutron – antineutron form factor
  (www.lnf.infn.it/conference/nucleon05/)
  Workshop on Nucleon Form Factors - *LNF, 12-14 October, 2005*
- Physics of γ - γ (www.roma1.infn.it/people/bini/roadmap)
- Nuclear physics
  (http://www.lnf.infn.it/committee/talks/31talks/31Feliciello.pdf)
- Kaonic physics
  (http://www.lnf.infn.it/esperimenti/dear/LOI_FINAL_15sept.pdf,
  http://www.lnf.infn.it/committee/talks/31talks/31CurcZmes.ppt)
- Synchrotron light source
  (http://www.lnf.infn.it/esperimenti/sr_dafne_light)



DANAE

(DAfne New – Adjustable Energy)

PHI-factory + Wide energy range

High luminosity at PHI energy

Bernini – Galleria Borghese

Correggio – Galleria Borghese

Danaë, the daughter of Acrisius, King of Argos, and of Eurydice, had been shut up by her father in a tower with bronze doors, as it had been prophesied that she would gave birth to a son who would be the cause of Acrisius' own death. But Zeus visited her in the form of a shower of gold falling from a cloud, and from their union Perseus was born

DANAE
Energy and Luminosity Range

Energy @center of mass (GeV)	1.02	2.4
Integrated Luminosity per year ($ftbarn^{-1}$) >	10	1
Total integrated luminosity >	50	3
Peak luminosity > ($cm^{-2}sec^{-1}$)	10^{33}	10^{32}

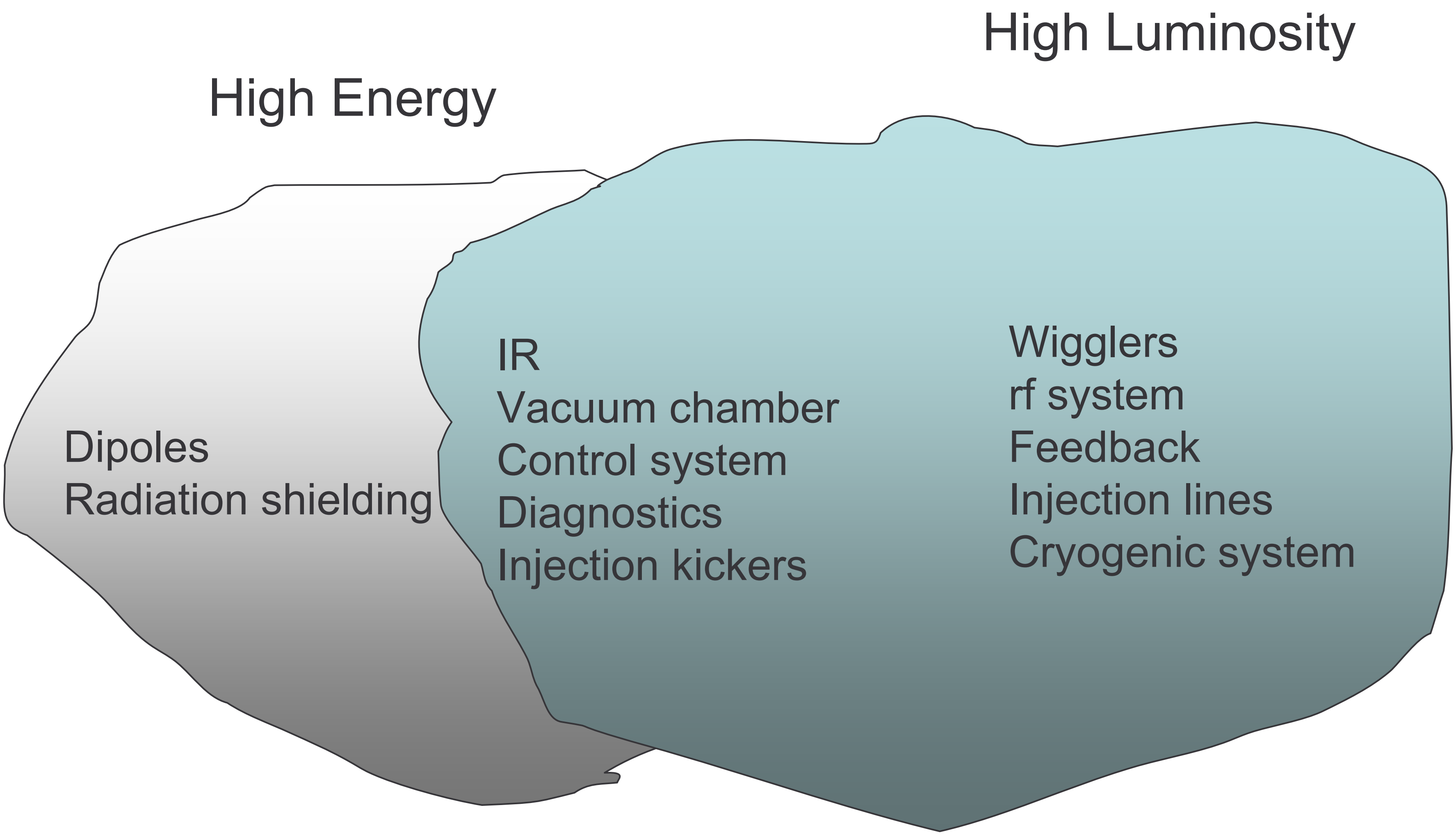
Use of DAΦNE buildings
Use of DAΦNE infrastructures
Use of DAΦNE injection system + upgrade of transfer lines
Use of large part of magnets, diagnostics

New

- Dipoles
- Wigglers
- Rf system
- Vacuum chamber
- Interaction region

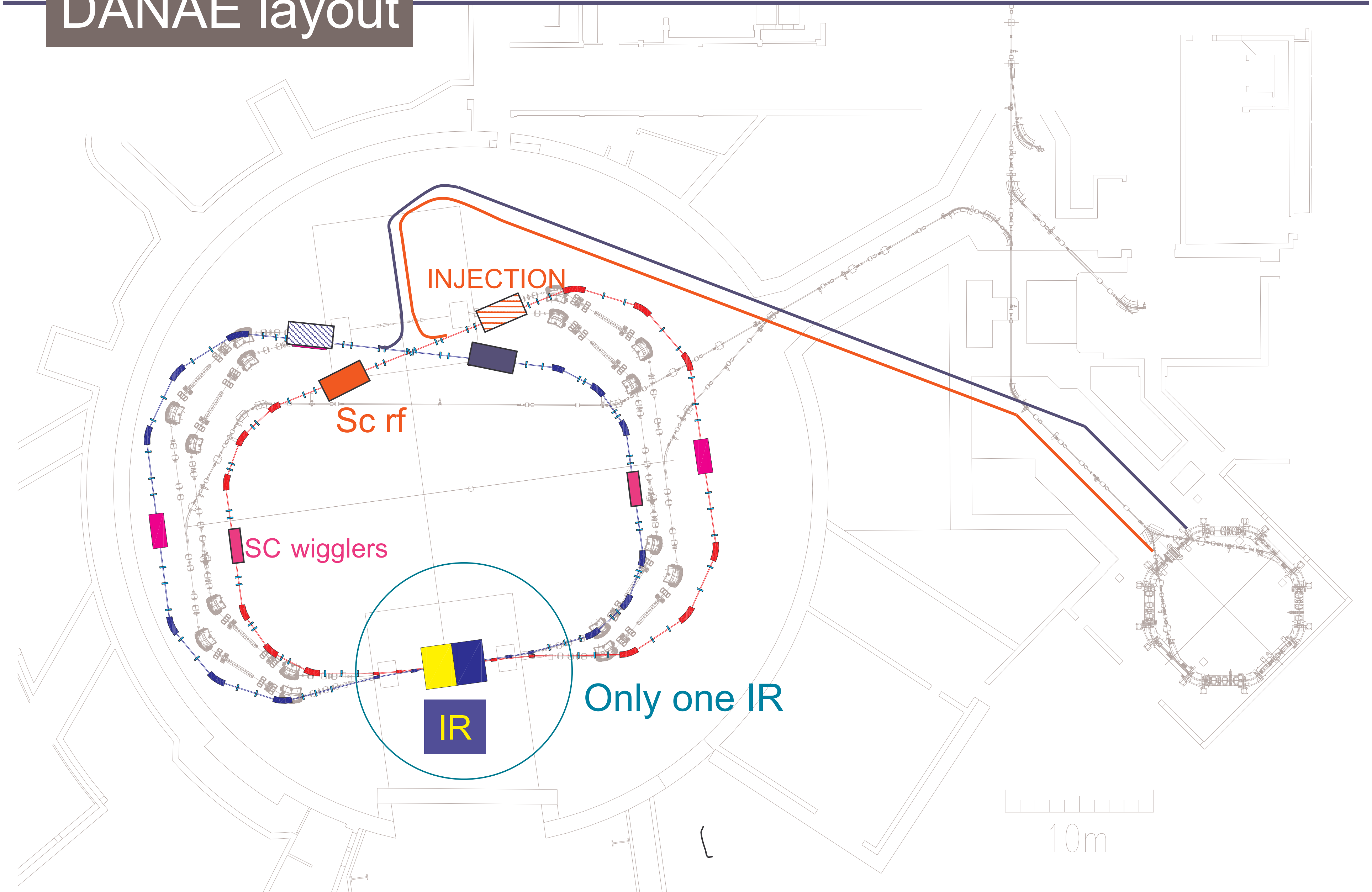
Application of new technologies
Use of all expertise and experience of DAΦNE
Use of DAΦNE runs for R&D while increasing L for next experiments

From DAΦNE to DANAE



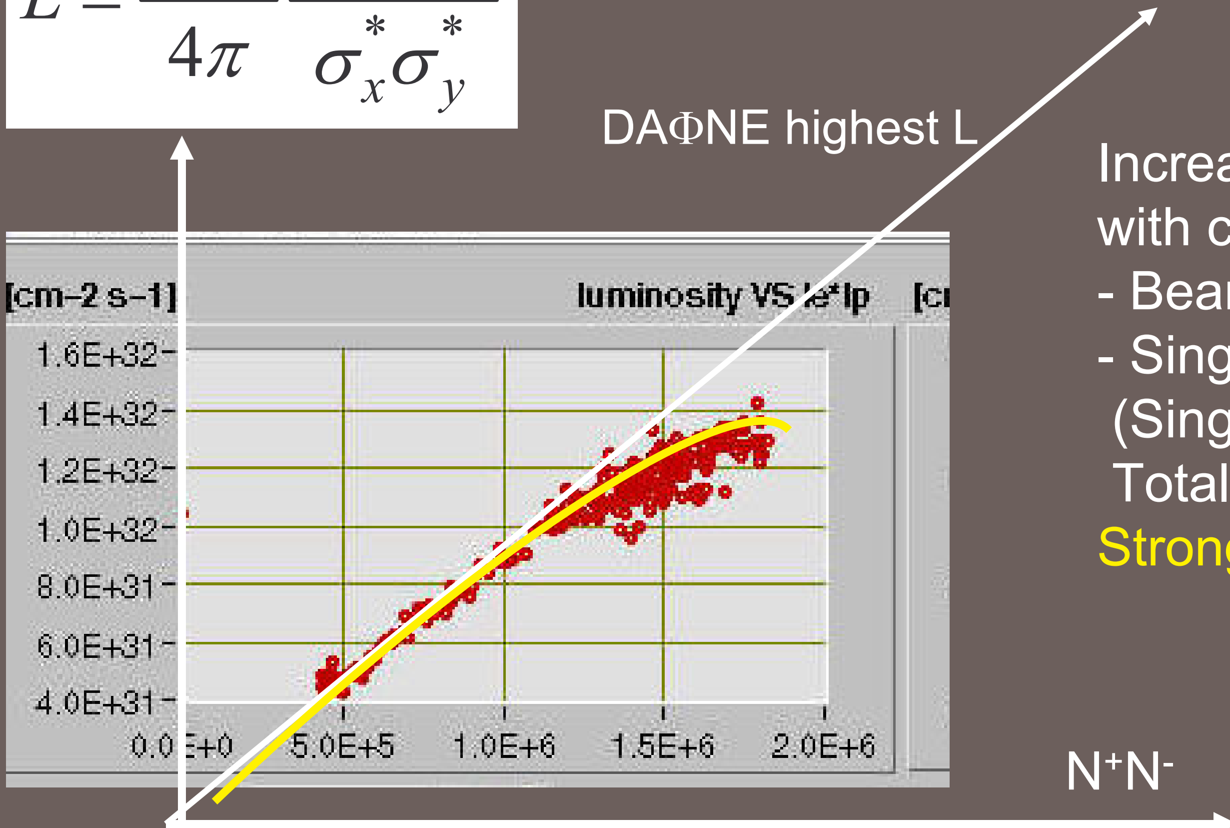
(Simplified scheme)

DANAE layout



Higher luminosities

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



Increasing of cross section with current due

- Beam-beam
- Single beam effects
  (Single bunch effects + Total current effects)

Stronger for lower energy

Increasing the luminosity by:

Increasing the slope (smaller cross section)

Increasing the current

Fighting the blowup effects

Higher energies ⟺ Higher Magnetic fields

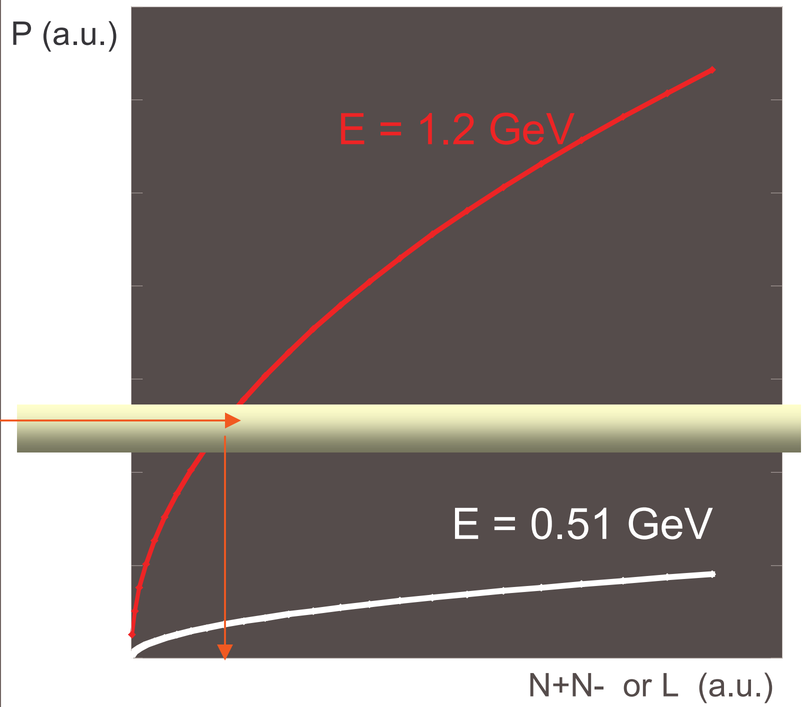
EASIER

Increasing the luminosity by:
Increasing the slope (smaller cross section)
Fighting the blowup effects

BUT
Power = Current x Energy loss

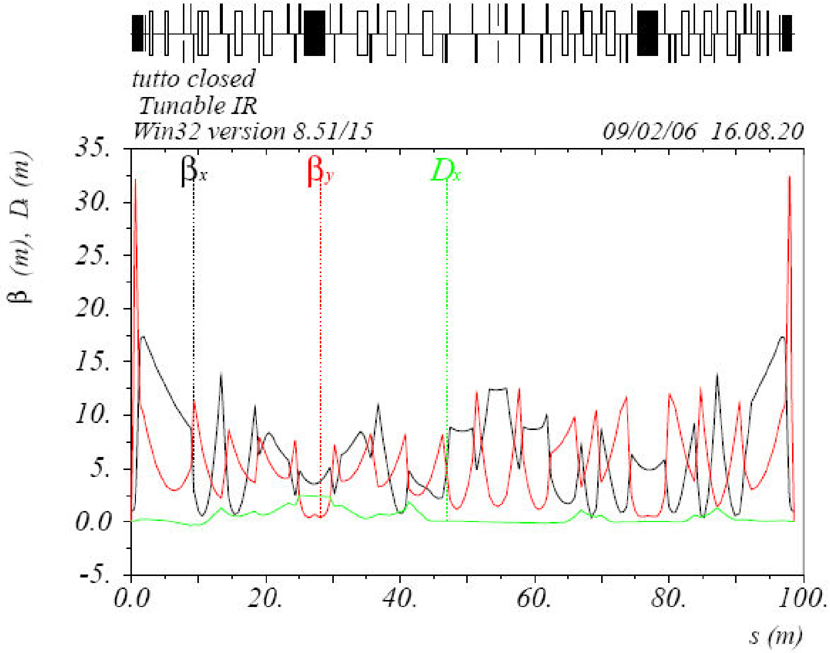
$$U_o \propto \left(I_{2dip} E^4 ,\ I_{2wig} E^2 \right)$$

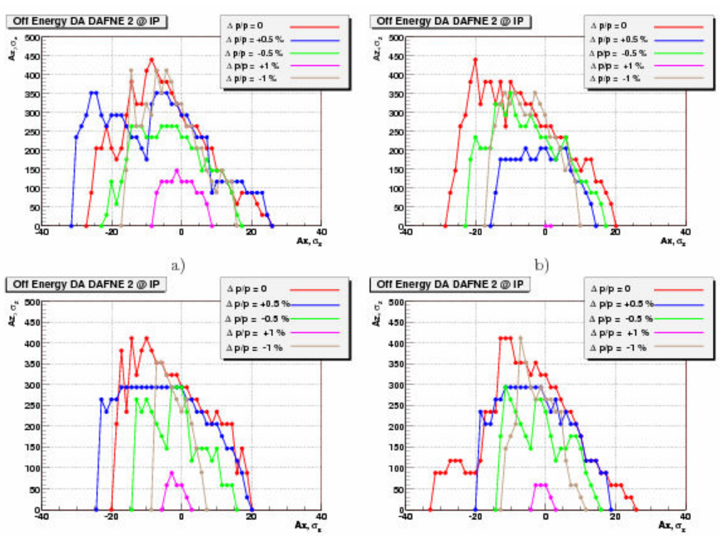
Limit in power =
Limit in current



DANAE PARAMETERS			Φ	N-N
Energy per beam	E	GeV	0.51	1.2
Circumference	C	m	100	100
Luminosity	L	$cm^{-2}\ sec^{-1}$	10^{33}	10^{32}
Current per beam	I	A	2.5	0.5
N of bunches	N_b		150	30
Particles per bunch	N	10^{10}	3.1	3.4
Emittance	ε	mm mrad	0.4	0.6
Horizontal beta*	β_x	m	1	1
Vertical beta*	β_y	cm	0.8	1.5
Bunch length	σ_L	cm	1	1.5
Coupling	κ	%	0.5	1
Energy lost per turn	U_o	(keV)	25	189
H damping time	τ_x	(msec)	13	5
Beam Power	P_w	(kW)	62 (55w + 7d)	94.6 (42w + 53d)
Power per meter	P_w/m	(kW/m)	8.6w + 0.5d	8.4w + 3.8d

DANAE lattice and dynamic aperture





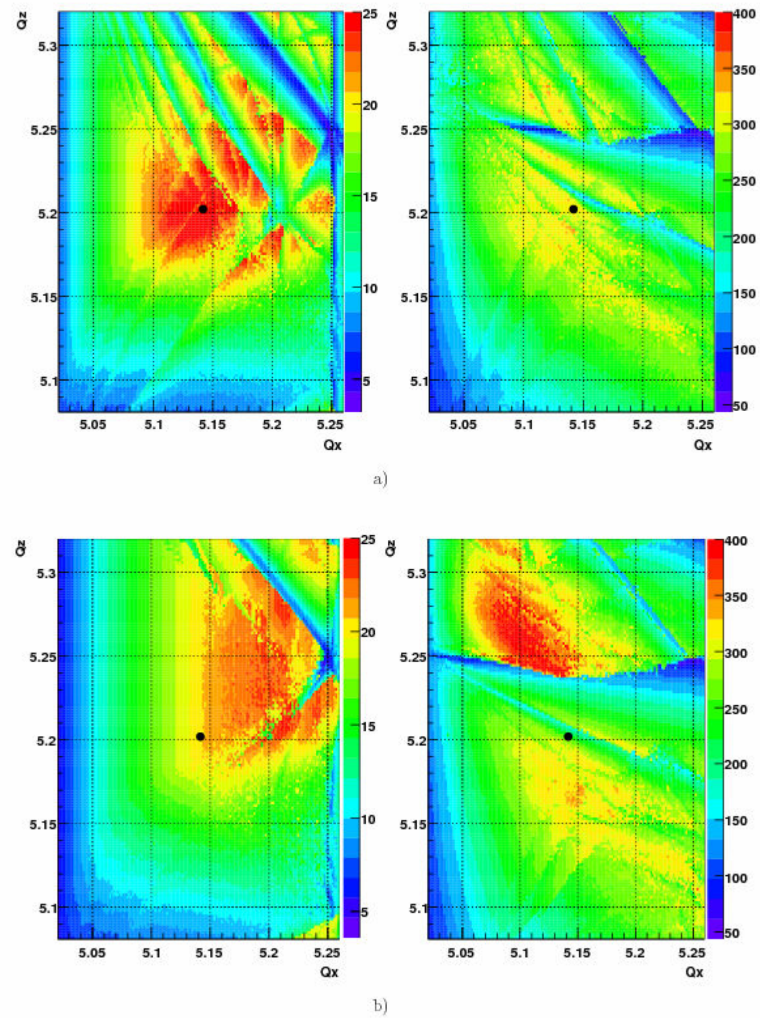
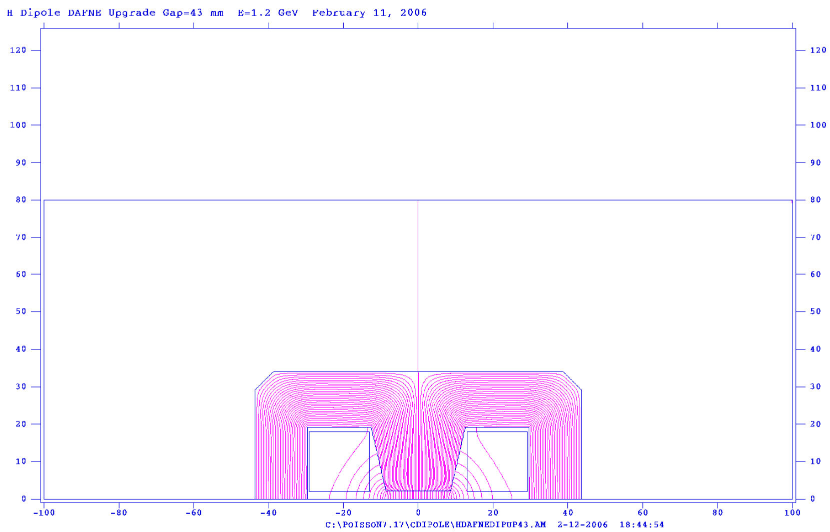


Figure 4: 4D dynamic aperture betatron tune scan.

DIPOLES



1.72 T Dipole Magnet, POISSON simulation

normal conducting dipoles

Maximum field:

1.72 T @1.2 GeV

$I_2 = 2.7\ m^{-1}$

Dipoles per ring	**12**
B (T)	**0.73 – 1.72**
ρ (m)	**2.33**
Gap (cm)	**4.3**
Current (A)	**198 / 517**

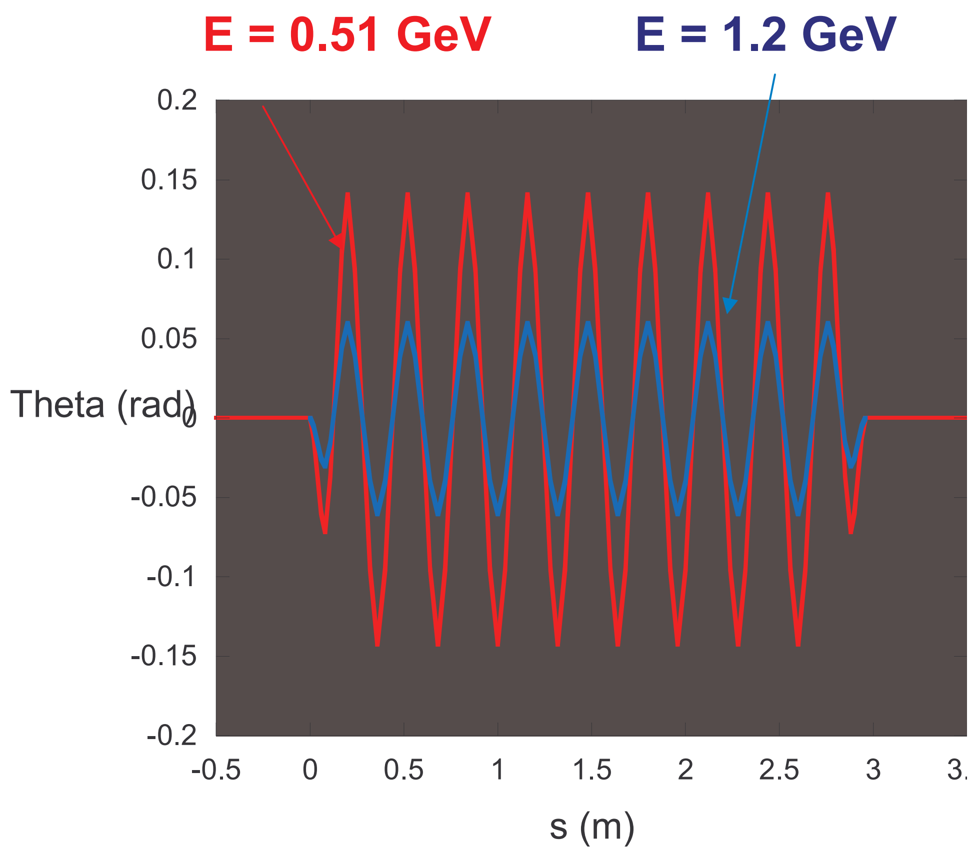
SC Wigglers to further increase radiation

L_w = 6 m @ B = 4 T

τ_x (@510 MeV) = 13 msec $I_2 = 22\ m^{-1}$

τ_x (@1.2 GeV) = 5 msec $I_2 = 6\ m^{-1}$

$$i_2 = \frac{1}{2}\left(\frac{B}{B\rho}\right)^2 L_w$$

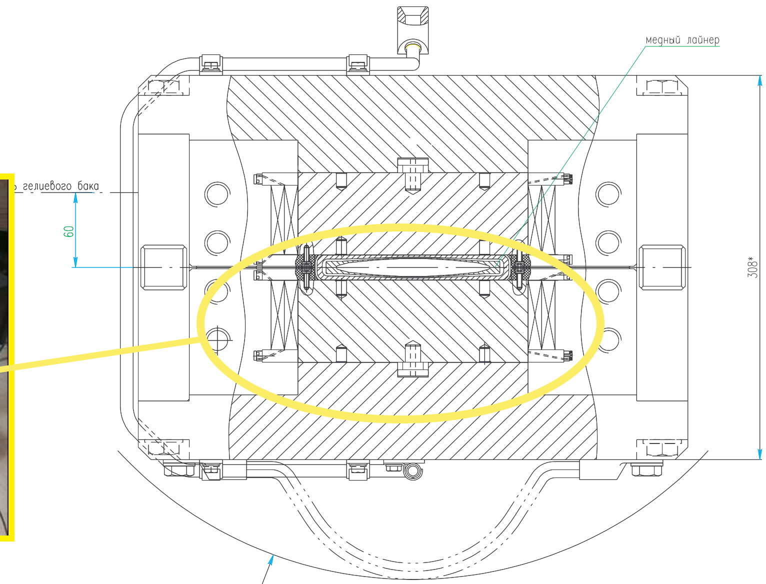


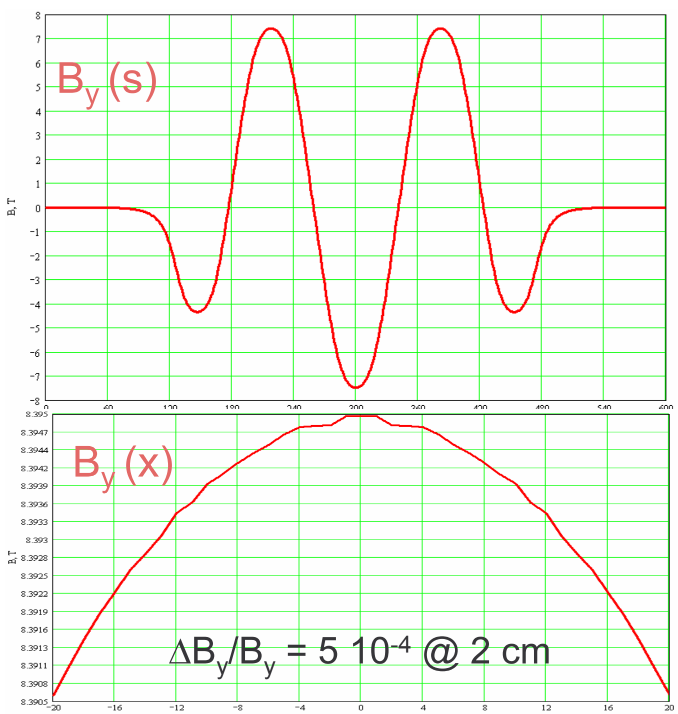
DANAE wiggler parameters

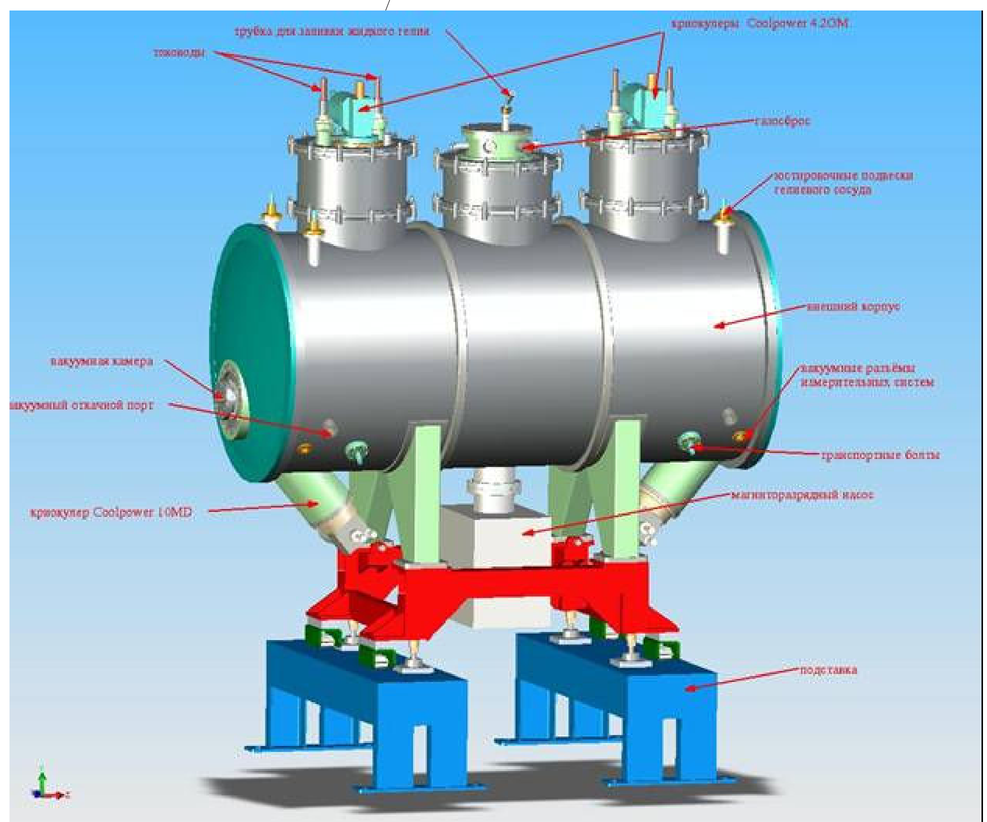
Energy		0.51	1.2
Maximum magnetic field B_{max}	T	4	4
Total number of poles		19	19
Total length	m	2.96	2.96
Central pole length	cm	16	16
End poles length	cm	8	8
2^{nd} and penultimate poles length	cm	12	12
End poles field ratio with B_{max}		0.5	0.5
2^{nd} and penultimate field ratio with B_{max}		1	1
Max trajectory oscillation	mm	6	2.5
Path – wiggler length difference	mm	11.8	2.1
Total vertical beam stay clear	cm	2	2
Total horizontal beam stay clear	cm	8.5	8.5

Collaboration with BINP group:

SC Wiggler
built at BINP
B_{max} = 7 T
for SIBERIAII







RF system @ 500 MHz

Harmonic number : 160
Maximum # bunches: 150

Our candidate cavity is the SC cavity operating at KEKB

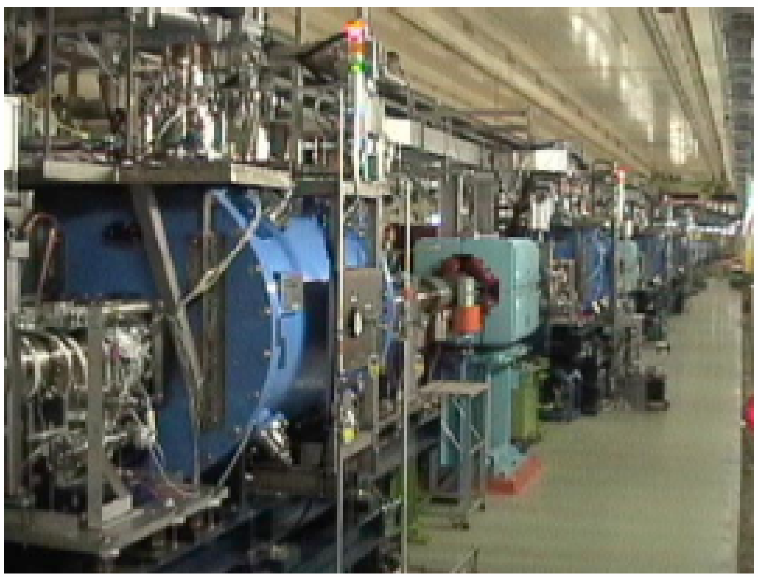
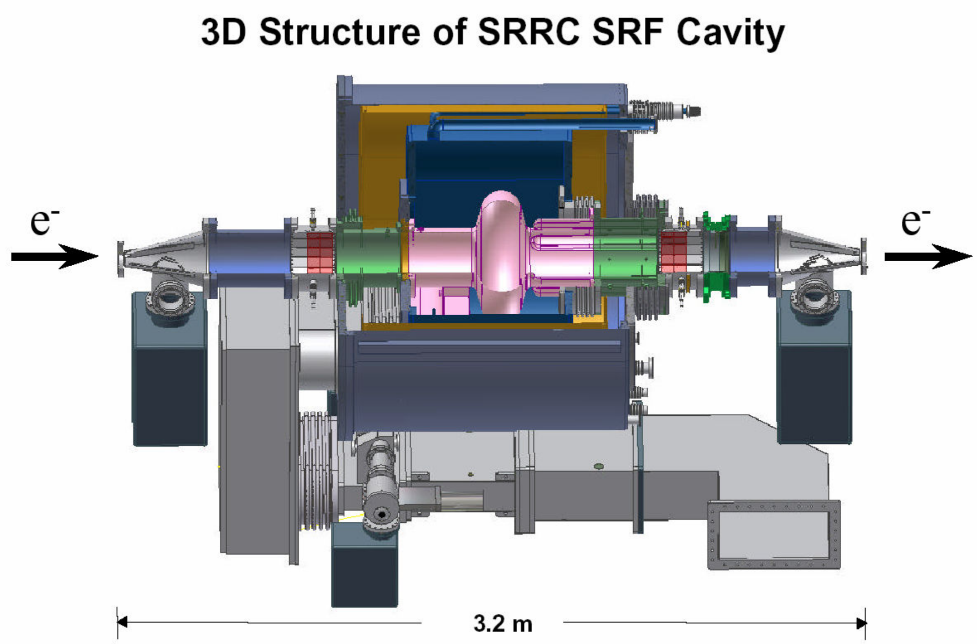
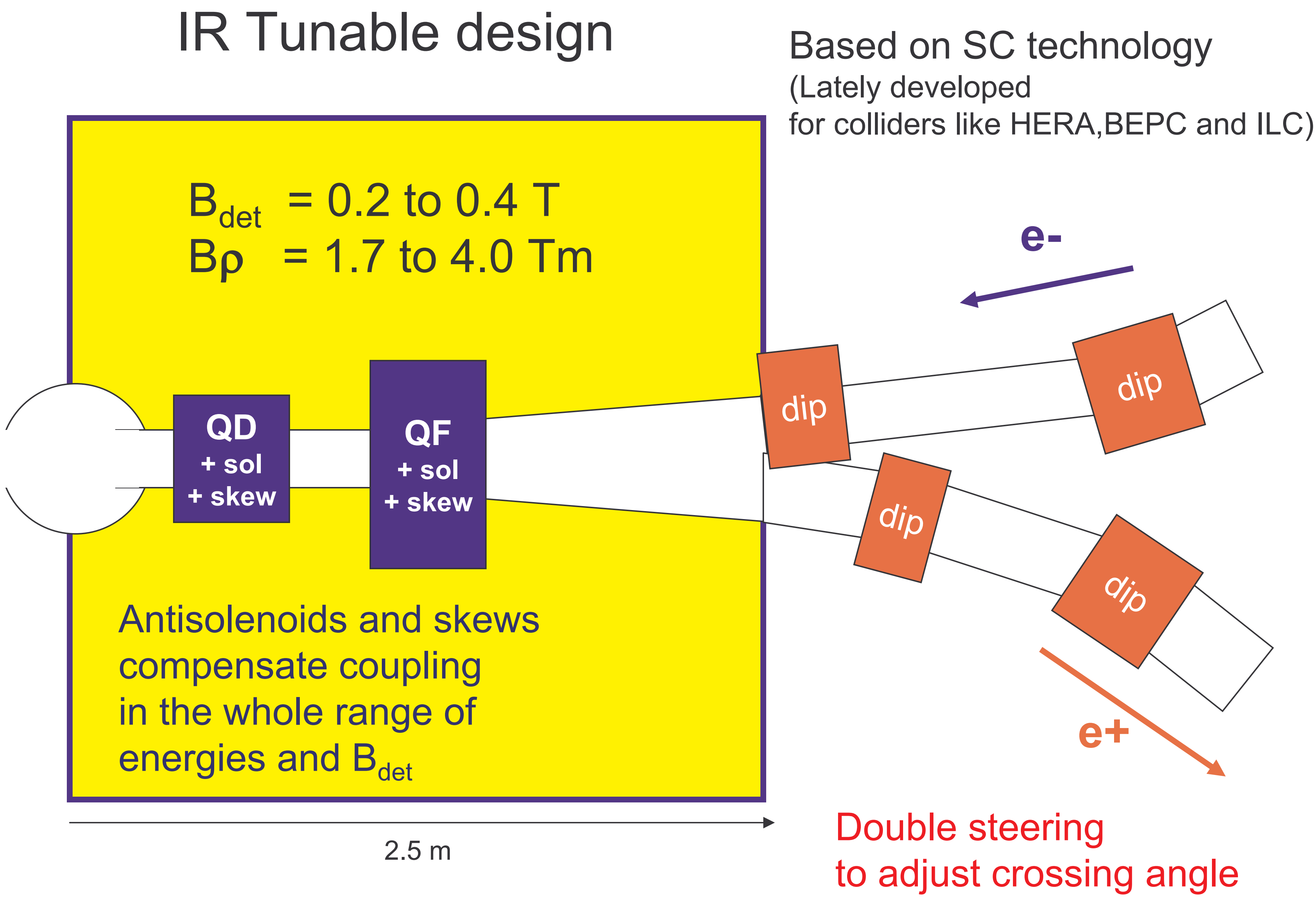


Figure 2: A picture of four SCC modules in Nikko-D11 tunnel

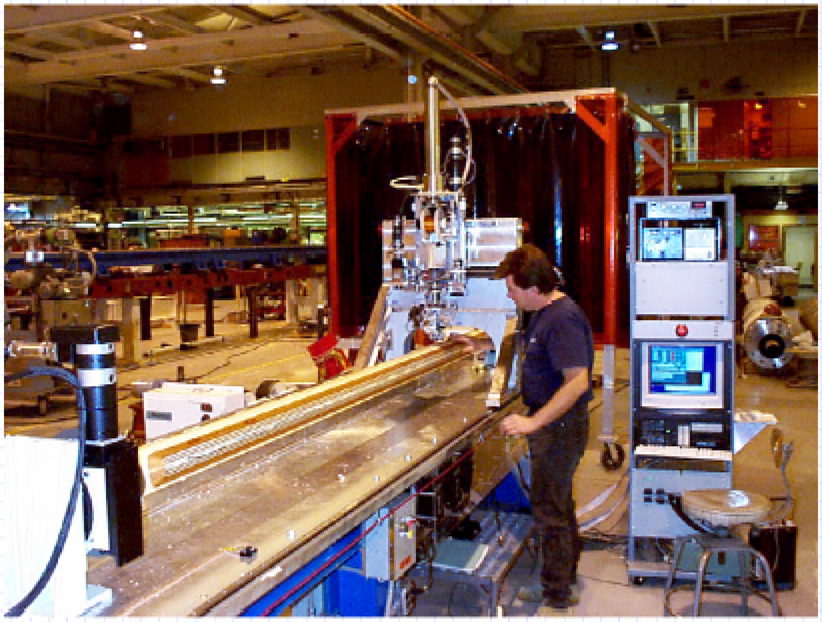



IR Tunable design
Based on SC technology
(Lately developed
for colliders like HERA,BEPC and ILC)
B_{det} = 0.2 to 0.4 T
$B\rho$ = 1.7 to 4.0 Tm
e-
QD
+ sol
+ skew
QF
+ sol
+ skew
dip
dip
dip
dip
Antisolenoids and skews
compensate coupling
in the whole range of
energies and B_{det}
e+
2.5 m
Double steering
to adjust crossing angle

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

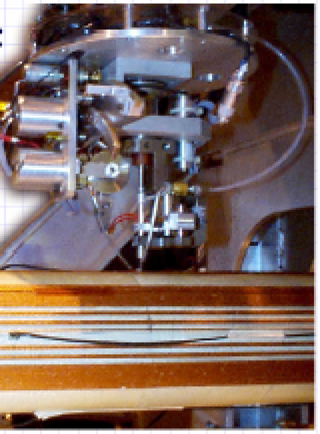
Take advantage of BNL experience making superconducting magnets for HERA-II.

...BNL Direct Wind Superconducting Magnets



Production of IR magnets for the HERA-II luminosity upgrade using a computer controlled winding machine.

Close up of winding in progress



Ultrasonic heating bonds epoxy coated conductor to substrate on a support tube (tack in place).

Energy spread – bunch length – rf system

Natural bunch length and energy spread at low current are defined by the magnetic lattice, the momentum compaction and the rf system

$$\left(\frac{\sigma_E}{E}\right)^2 = C_q \gamma^2 \frac{I_3}{2I_2 + I_4} \approx \frac{C_q \gamma^2}{\rho}$$

More radiation – larger energy spread – longer bunch

$$\sigma_L = \frac{c\left|\alpha_c\right|}{\omega_s} \frac{\sigma_E}{E} = \frac{\sqrt{2\pi c}}{\omega_o} \sqrt{\frac{\alpha_c E}{heV}} \frac{\sigma_E}{E}$$

Bunch length can be shortened by increasing h, V

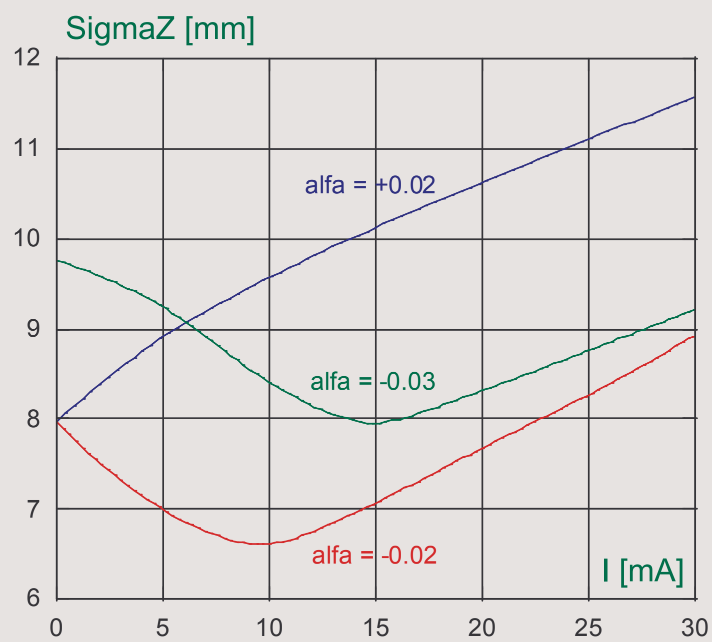
Short bunch length at high current:

- Low impedance
- High voltage

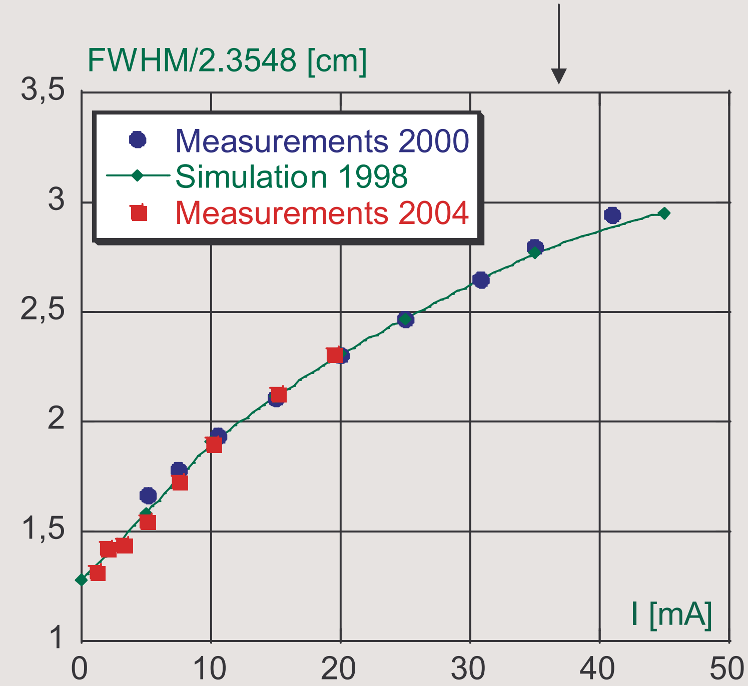
$$I_{th} = \sqrt{2\pi}\,\frac{\alpha_c E/e\left(\sigma_E/E\right)^2\,\sigma_l}{\left|Z_{\parallel}/n\right| R}$$

Above the microwave instability current threshold
σ_L increases with the current, not depending on α_c

SIMULATIONS for DANAE

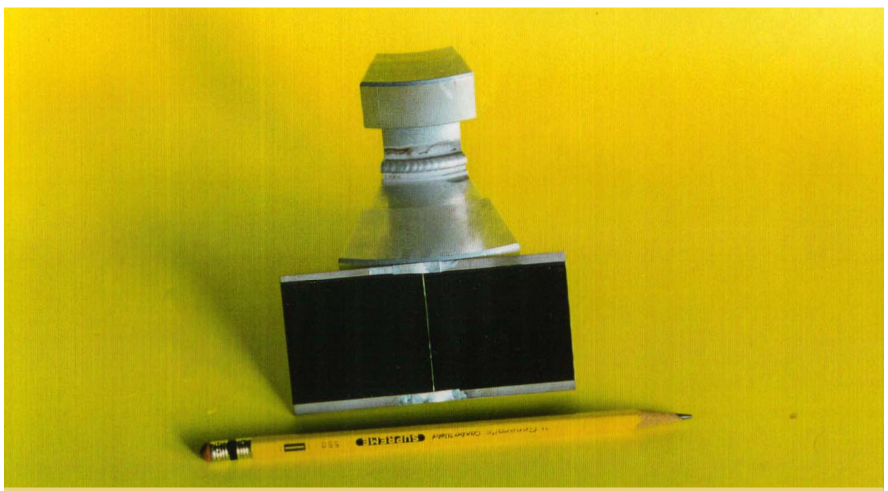


SIMULATIONS and MEASUREMENTS ON DAΦNE

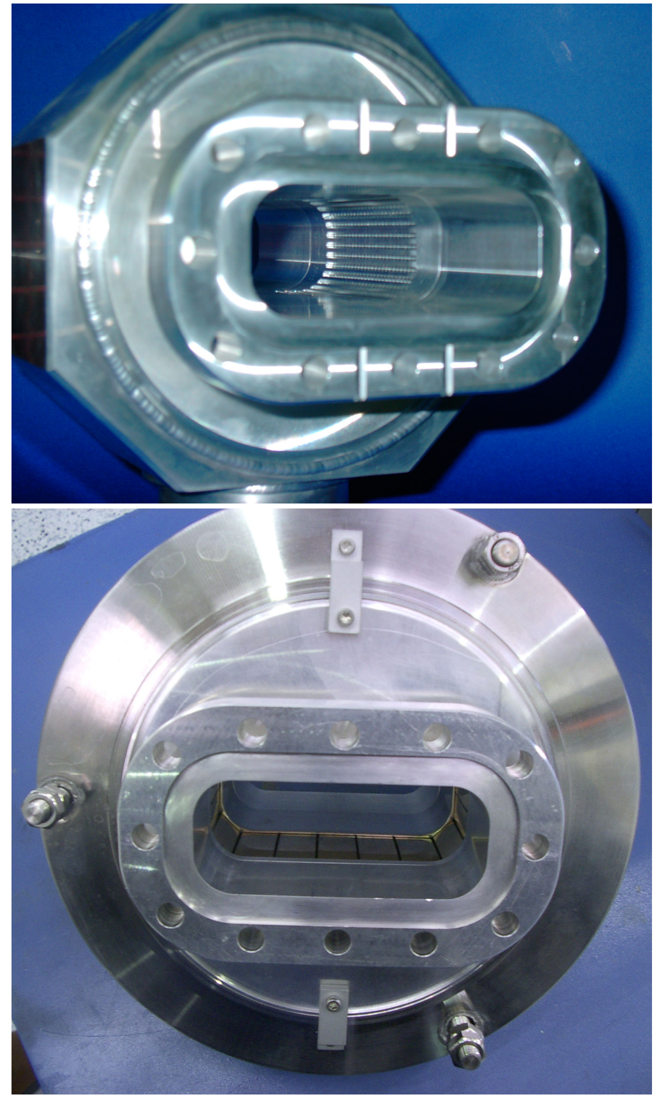


VACUUM CHAMBERS

Keep more regular vacuum chamber shape (experience from DAΦNE and CTF3)
Use of small ICE wih negligible impedance
Ti coating for e+ surfaces
Optimisation of slots and bellows for 1 cm bunch lengths



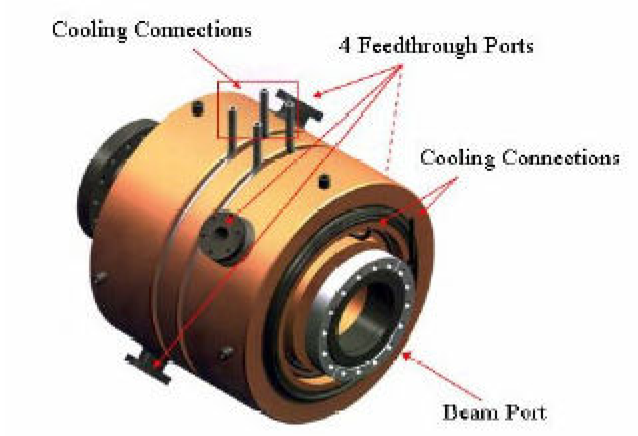
Negligible contribution to impedance of short ICEs

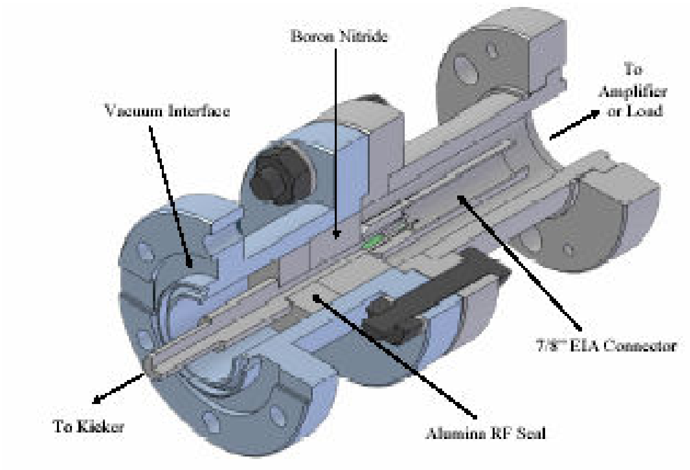


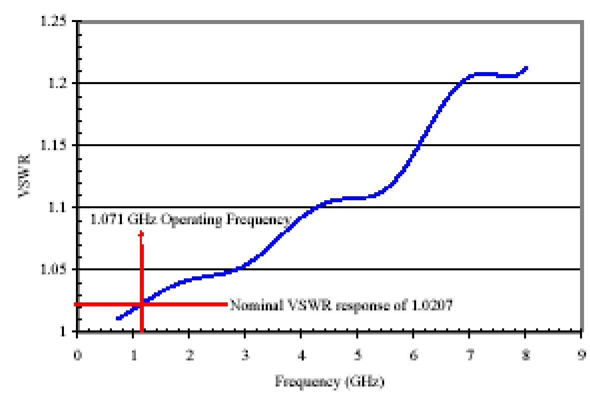
CTF3 vacuum chambers

Longitudinal Feedback kicker

Parameters of PEPII kicker,
designed by LNF,
almost equal to DANAE ones.







Injection system

- Linac + Accumulatore   OK
- Doubling transfer lines for optimizing <L>
- New kickers (R&D on DAΦNE in progress)
- Ramping for high energy option

The High Luminosity option needs continuous injection

Tentative schedule

- To ➡ CDR and Project approval (2006)
- To + 1 year ➡ call for tender
- To + 2 years ➡ construction and delivery
- To + 3 years ➡ DAΦNE decommissioning and DANAE installation
- To + 4 years ➡ 1st beam for commissioning and for 1st experiment (2010)

Many HE labs are questioning their future
Programs are defined for the next few years

Frascati history:

ADA	1960 - 1962
ADONE	1969 - 1993
DAΦNE	1998 - 2009

with
DANAE
based on DAΦNE,
and amplifying its goals in terms of energy and luminosity
we are proposing to the international community to gather around the project.

LNF can be the HE physics lab in Europe where to continue the lepton physics at low energy in LHC era and before ILC comes to reality