PHD Theses at DAΦNE

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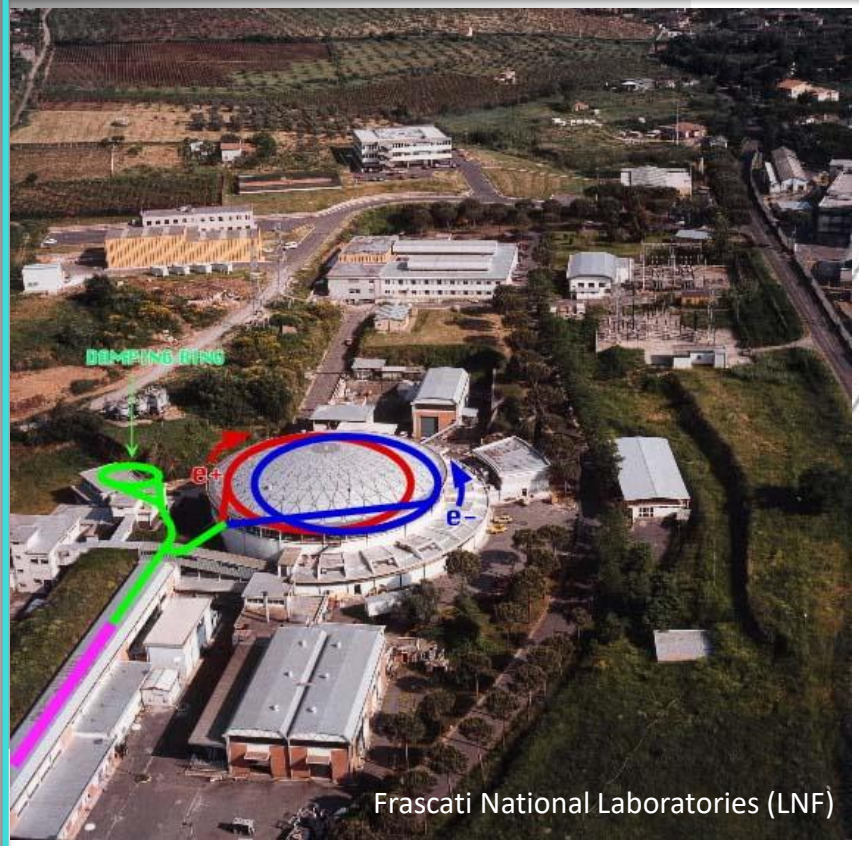
on behalf of the DAΦNE Team

PHD Theses, Oct 2019, La Sapienza, Roma

Outline

- *DAΦNE overview*
- *DAΦNE contribution to the development in the field of Particle Accelerator Physics*
- *Crab-Waist Collision Scheme*
- *Present situation and future programs*
- *PHD Theses*

The DAΦNE Accelerator Complex



Frascati National Laboratories (LNF)

$e^+ e^-$

$C \approx 97\ m$

$E_{CM} = 1.02\ GeV\ (\Phi)$

LINAC

550 MeV e+
800 MeV e-

FINUDA

BTF

DAΦNE

UV 2 - 10 eV

X-ray 900 - 3000 eV

X- ray

IR 1.24 meV - 1.24 eV

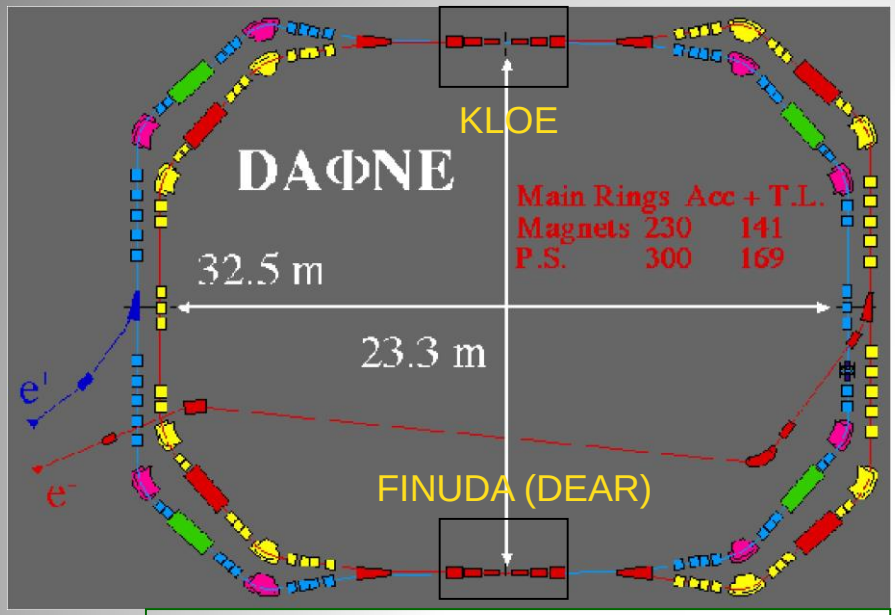
IR

KLOE

ACCUMULATOR
510 MeV

LNF are also part of the European synchrotron light Infrastructures

DAΦNE parameters

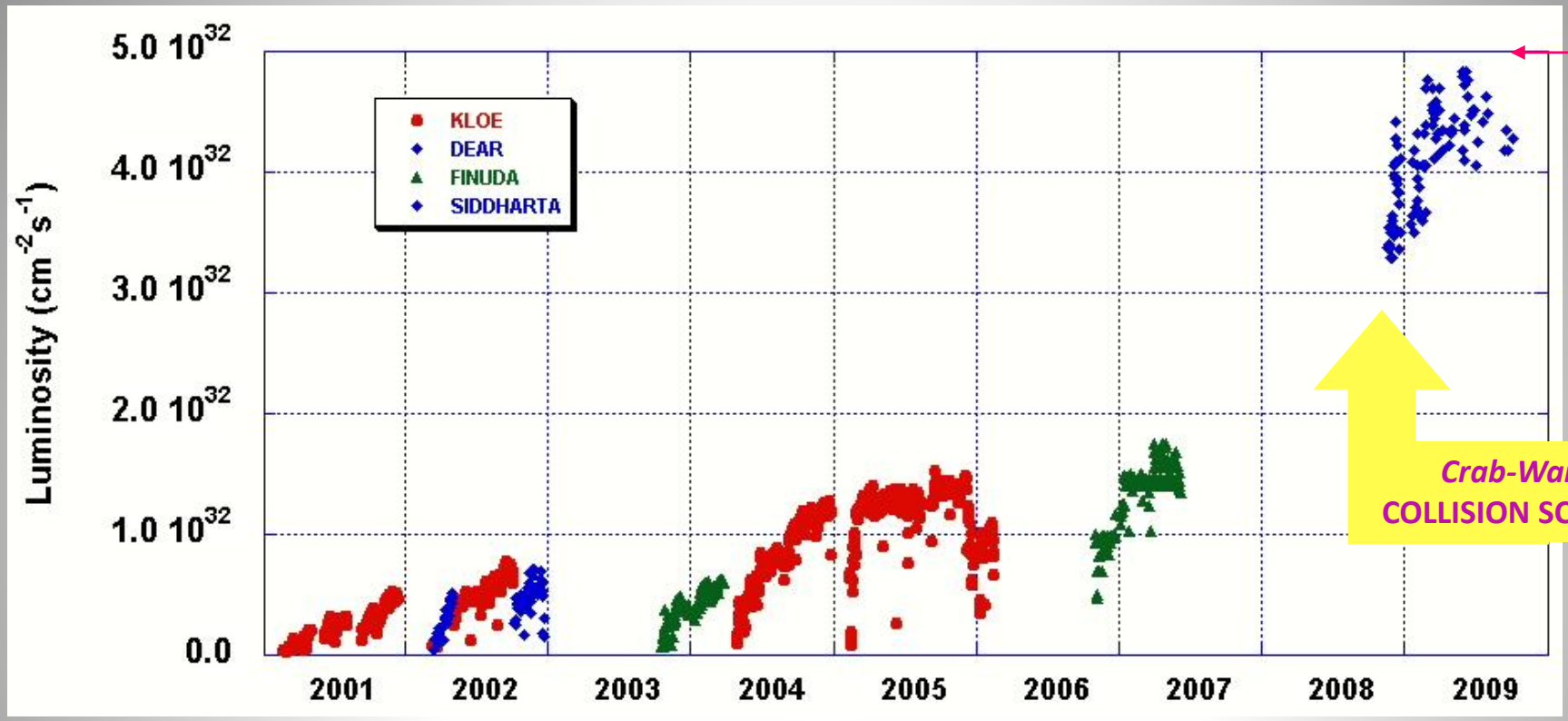


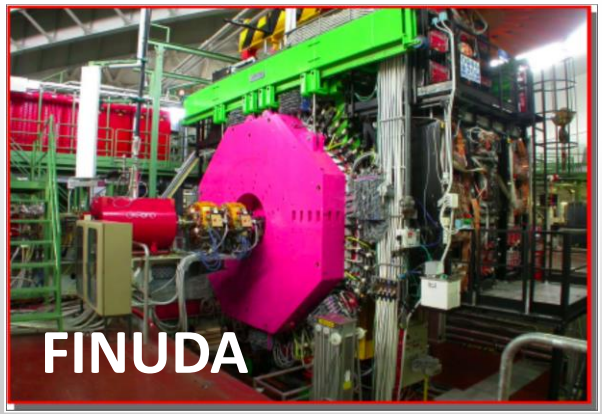
"Proposal for a Φ-factory", LNF-90/031 (IR),1990.

	DAΦNE native	DAΦNE Crab-Waist
Energy (MeV)	510	510
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mmxmrad)	0.34	0.26
β_x^* (cm)	160	26
σ_x^* (mm)	0.70	0.26
$\Phi_{Piwinski}$	0.6	1.9
β_y^* (cm)	1.80	0.85
σ_y^* (μm) low current	5.4	3.1
Coupling, %	0.5	0.5
Bunch spacing (ns)	2.7	2.7
I_{bunch} (mA)	13	13
σ_z (mm)	25	20
N_{bunch}	110	110
L ($cm^{-2}s^{-1}$) x10^{32}	1.6	5

Colliding beams have:
- *low E*
- *high currents*
- *short bunch spacing*
- *long damping time*

Luminosity at DAΦNE 2001 ÷ 2009





Contributions to particle accelerator physics

Ideas and studies aimed at improving beam dynamics and beam-beam performances:

- Low impedance vacuum chamber components
- innovative bunch by bunch feedback systems
- short pulse PS for injection kickers
- non-linearities mitigation in magnet fields especially in wigglers
- collisions with negative momentum compaction
- parasitic crossing compensation by current carrying wires
- collisions with very high crossing angle
- strong RF focusing
- **crab Waist collisions**
- electrodes for e-cloud compensation

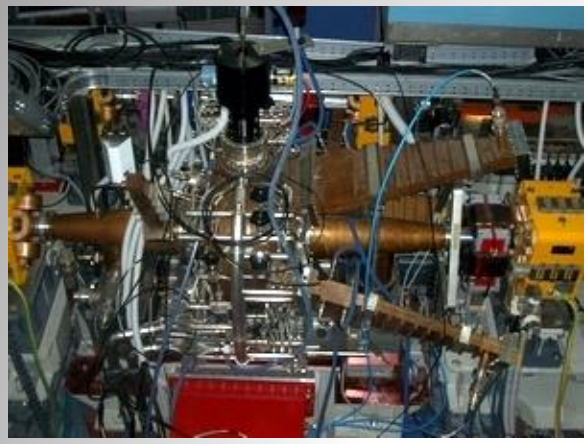
Proposals:

- DANAE (1.02 GeV ÷ 2.4 GeV)
- Bunch lenght modulation experiment
- DAFNE-VE (0.6 GeV ÷ 3 GeV with CW)

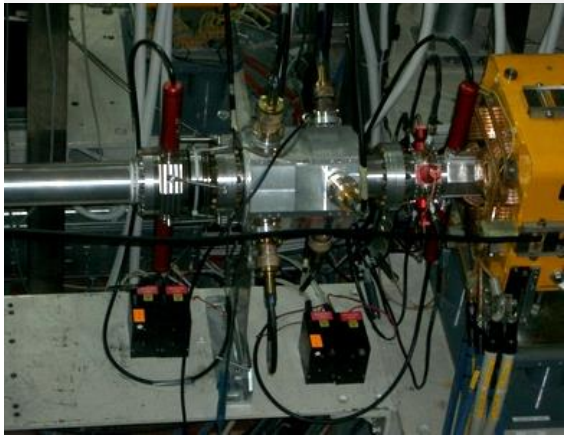
DAΦNE achievements

- luminosity achieved at DAΦNE is by two orders of magnitude higher than the one obtained at other colliders operating in the same energy range
- Impedance budget is a factor 80 lower than in similar storage ring (EPA)
- Collisions with negative momentum compaction gave a 25% gain in terms of specific luminosity at low current without sextupoles
- Longitudinal feedback kicker designed for DAFNE has been adopted at: KEKB, BESSYII, PLS, SLS, HLS, ELETTRA, KEK Photon Factory, PEP II …
- Maximum current stored in the DAFNE electron ring, 2.45 A, is the higher ever achieved in the world
- DAΦNE is the only collider operating routinely with, and thanks to the electrodes for e-Cloud mitigation
- *Crab-Waist collision scheme has become a basic design concept for future new projects*

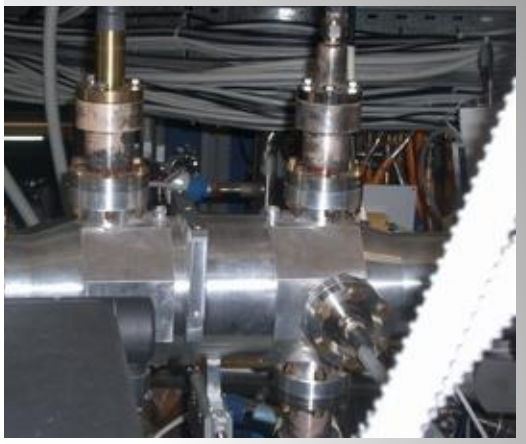
HOM Damped Vacuum Chamber Elements



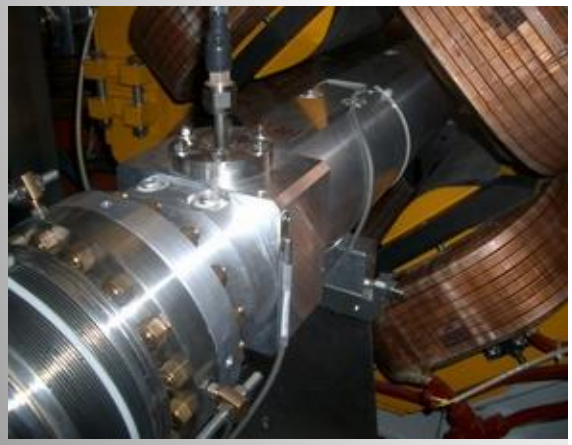
RF CAVITY



LONGITUDINAL KICKER

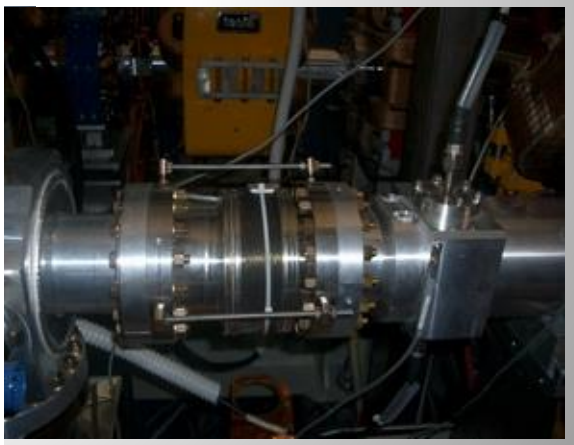


TRANSVERSE KICKER



INJECTION KICKER

WALL CURRENT & DCCT MONITOR



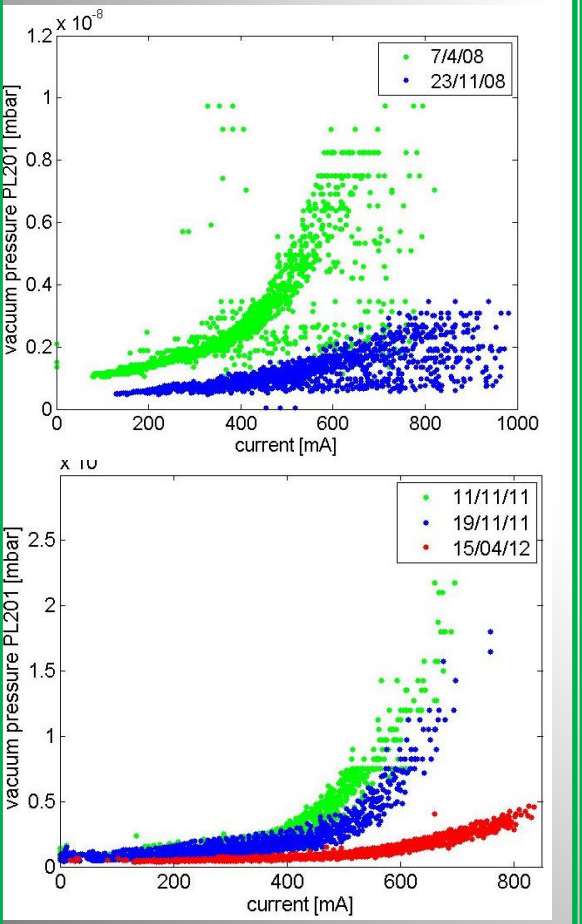
SHIELDED BELLOWS

e-Cloud at DAΦNE

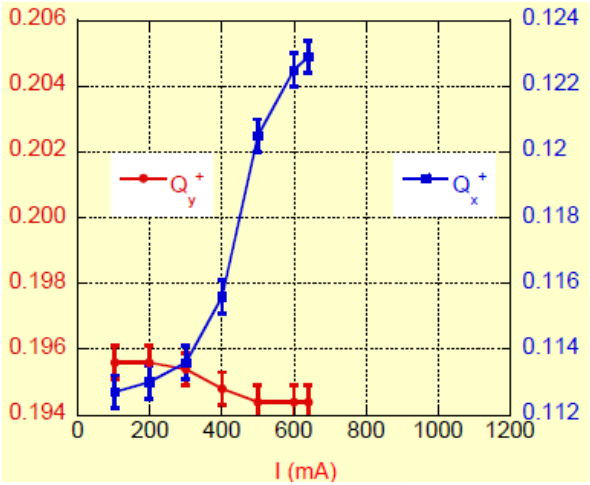
The worst case:

1. *Aluminium vacuum chamber*
2. *Shortest bunch separation of 2.7 ns*

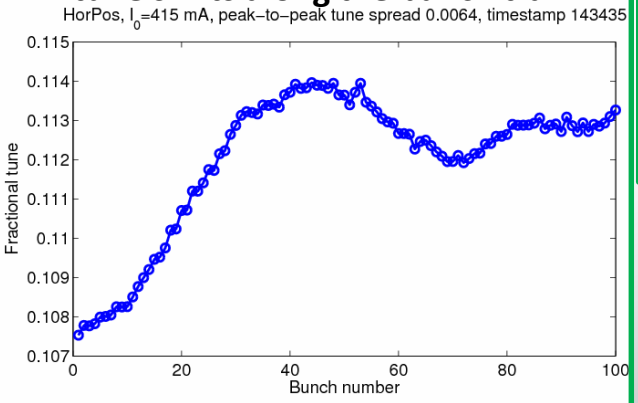
anomalous vacuum pressure rise



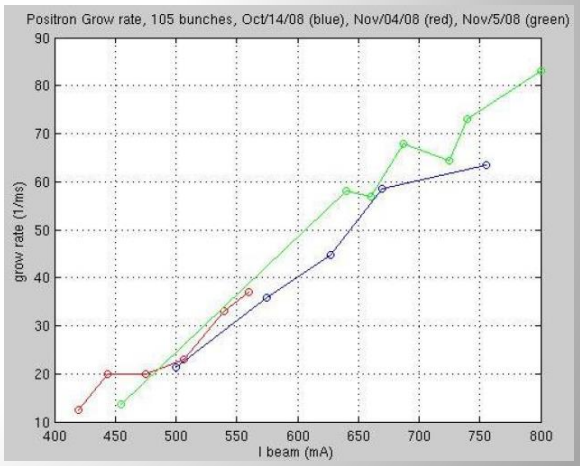
larger positive tune shift



tune shifts along the bunch train



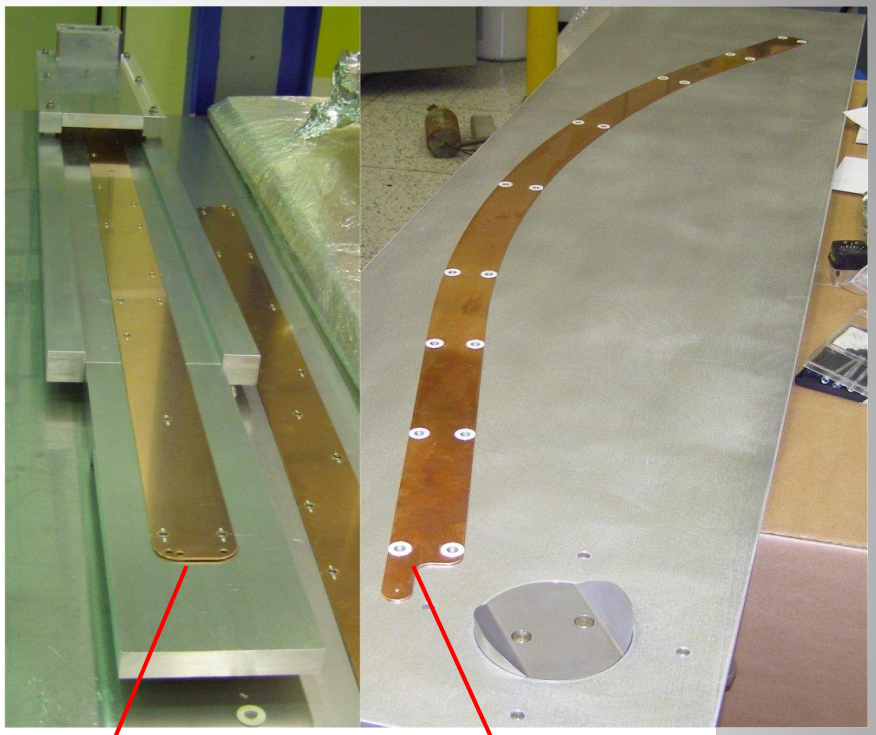
Very **fast horizontal instability** not explainable by parasitic HOMs

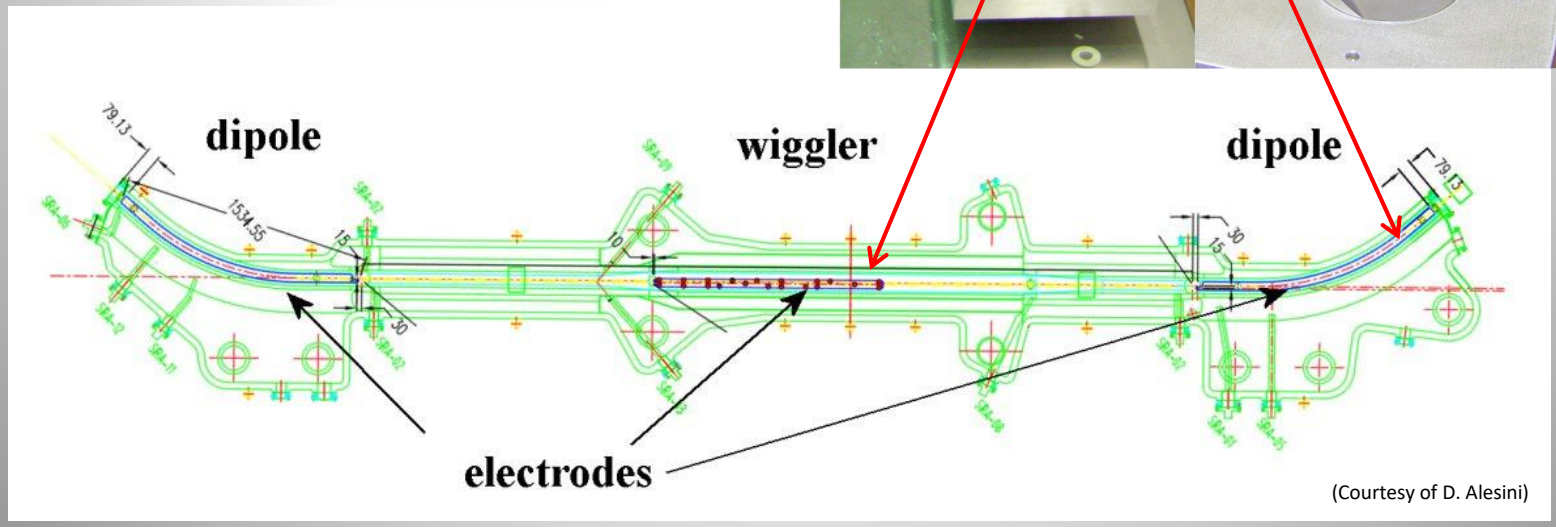


Electron Clearing Electrodes

To mitigate the e-cloud instability *copper electrodes have been inserted in all dipole and wiggler chambers* of the machine and have been connected to external dc voltage generators.

The dipole electrodes have a length of 1.4 or 1.6 m depending on the considered arc, while the wiggler ones are 1.4 m long.



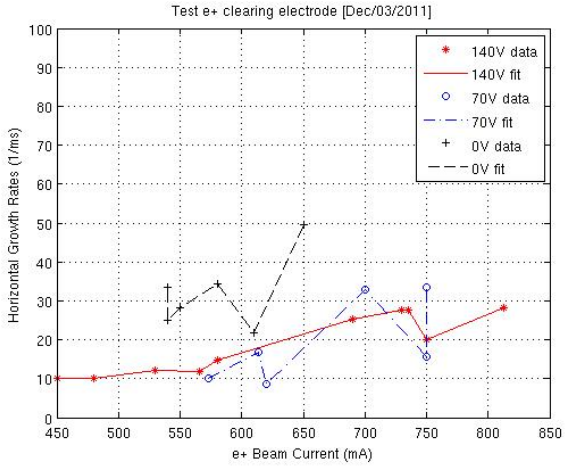


(Courtesy of D. Alesini)

Clearing electrodes for *e-cloud* suppression

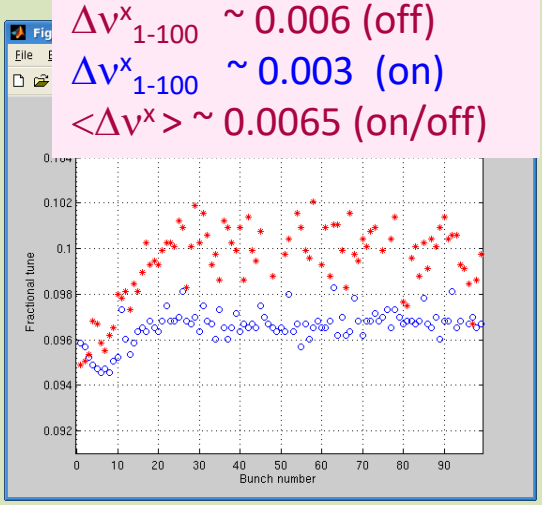
DAΦNE is the first collider operating routinely with long electrodes, for e-cloud mitigation. Electrodes let more stable operation with the positron beam, and allowed unique measurements such as: e-cloud instabilities' growth rate, transverse beam size variation, and tune shifts along the bunch train, demonstrating their effectiveness in restraining e-cloud induced effects.
(D. Alesini et al, Phys. Rev. Lett. 110, 124801 (2013)

Horizontal Instability Growth Rate measured by using bunch-by-bunch feedback as a function of the electrode voltage

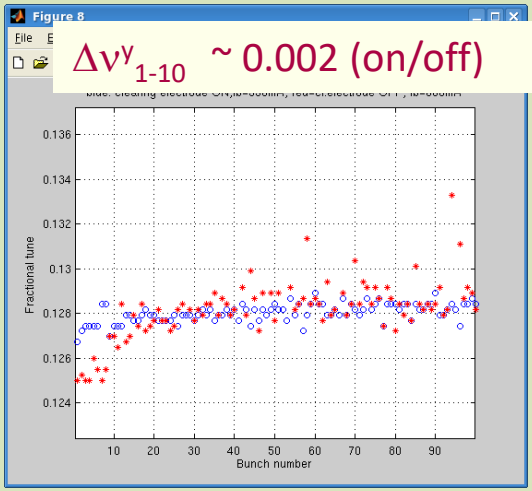


Tune Spread measurements

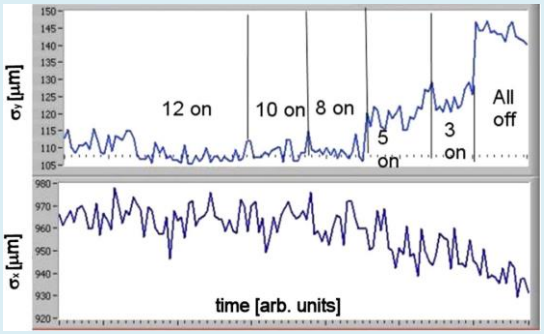
$\Delta\nu^x_{1\text{-}100}$ ~ 0.006 (off)
$\Delta\nu^x_{1\text{-}100}$ ~ 0.003 (on)
$\langle\Delta\nu^x\rangle$ ~ 0.0065 (on/off)



$\Delta\nu^y_{1\text{-}10}$ ~ 0.002 (on/off)



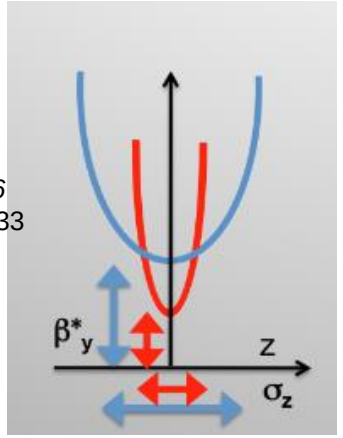
Beam Dimension



Crab-Waist Collision Scheme

A new collision scheme has been designed and implemented on the DAΦNE collider, the *Crab-Waist* collision scheme to overcome limitation in ***L*** due to:

- hourglass effect $\beta^*_y \sim \sigma_z$
- ***LRBB*** interactions
- beam transverse sizes enlargement due to ***BB*** **interaction**



P. Raimondi , *2° SuperB Workshop, March 2006*
P.Raimondi, D.Shatilov, M.Zobov, physics/0702033
C. Milardi et al., Int.J.Mod.Phys.A24, 2009
M. Zobov et al., Phys. Rev. Lett. 104, 2010

Crab-Waist is based on:

Large Piwinski angle Φ

$$\Phi \approx \frac{\sigma_z}{\sigma^*_x} tg\left(\frac{\theta}{2}\right) >> 1$$

large θ
small σ^*_x

→ ***L*** gain with N
low ξ_x
ξ_y decrease with Y oscillation amplitude

β^*_y comparable with overlap area

$$\beta^*_y \approx 2\sigma^*_x / \theta$$

→ ***L*** geometrical gain
lower ξ_y
Y Synchro-betatron resonances suppression

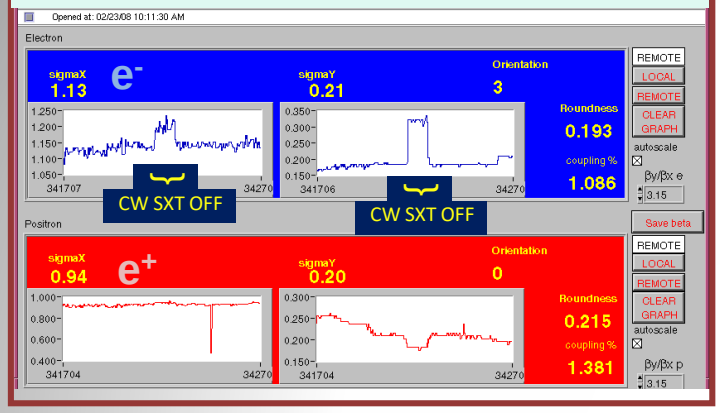
Crab-Waist transformation by two Sextupoles

$$y = \frac{xy'}{\theta}$$

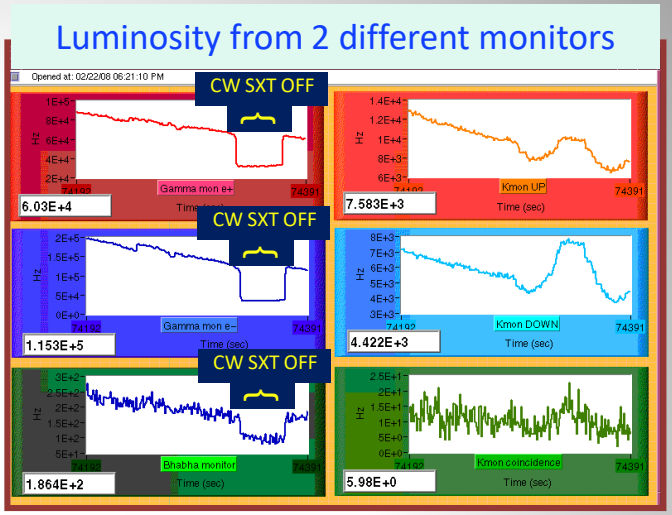
→ ***L*** geometrical gain
lower ξ_y
X-Y Synchro-betatron resonances suppression

Crab-Waist Compensation First Experimental Evidence

Beam transverse size measured at the SLM

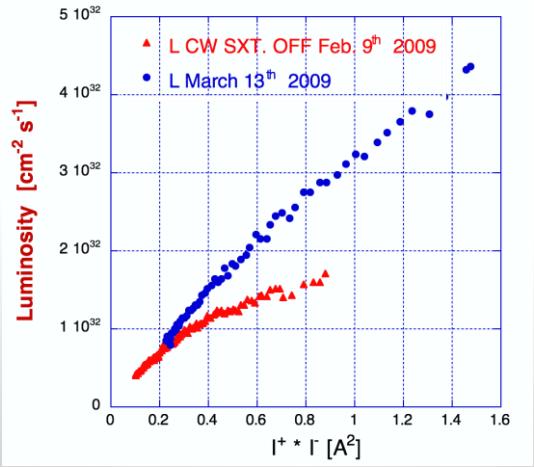


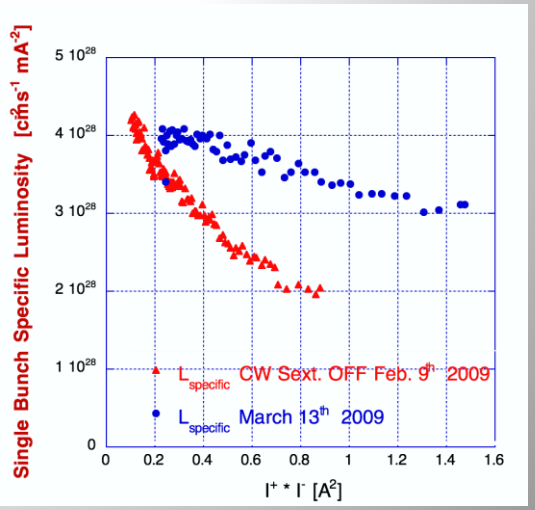
Luminosity from 2 different monitors



Transverse sizes (left) and **luminosity** (right) dependence on the ***CW-Sextupole*** **excitation** in the e⁻ ring

Luminosity as a function of colliding currents *CW-Sextupole* excitation





Crab-Waist collision scheme and SIDDHARTA

- Large crossing angle and Crab-Waist scheme proved to be effective in increasing luminosity, a factor 3 higher than in the past

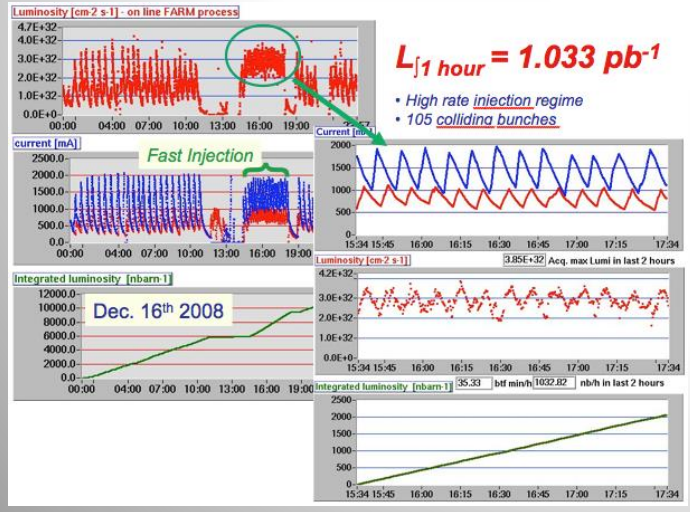
- The DAΦNE collider, based on a new collision scheme including Large Piwinski angle and Crab-Waist, has been successfully commissioned and has delivered:

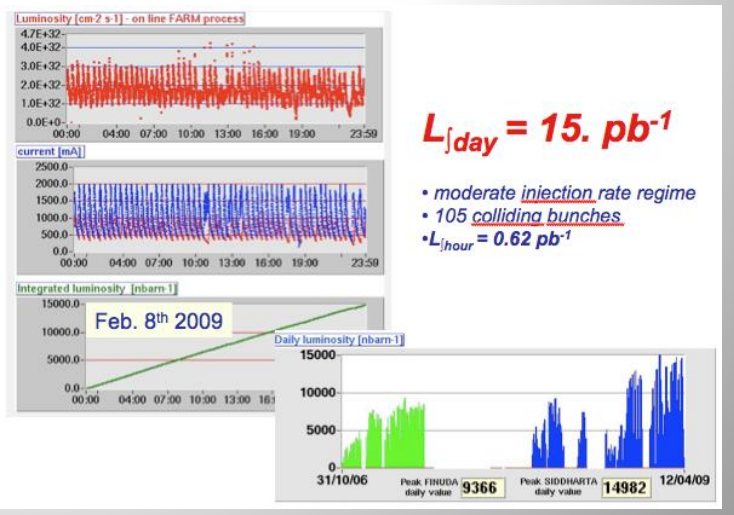
$L_{peak} = 4.5 * 10^{32}\ cm^{-2}\ s^{-1}$

$L_{\int 1\ day} = 15.0\ pb^{-1}$

$L_{\int 1\ hour} = 1.033\ pb^{-1}$

$L_{\int run} \sim 2.8\ fb^{-1}$ (SIDDHARTA detector)





KLOE-2 run

Integrating the high luminosity collision scheme with a large experimental detector introduces new challenges in terms of:

- IR layout
- optics
- beam acceptance
- coupling correction

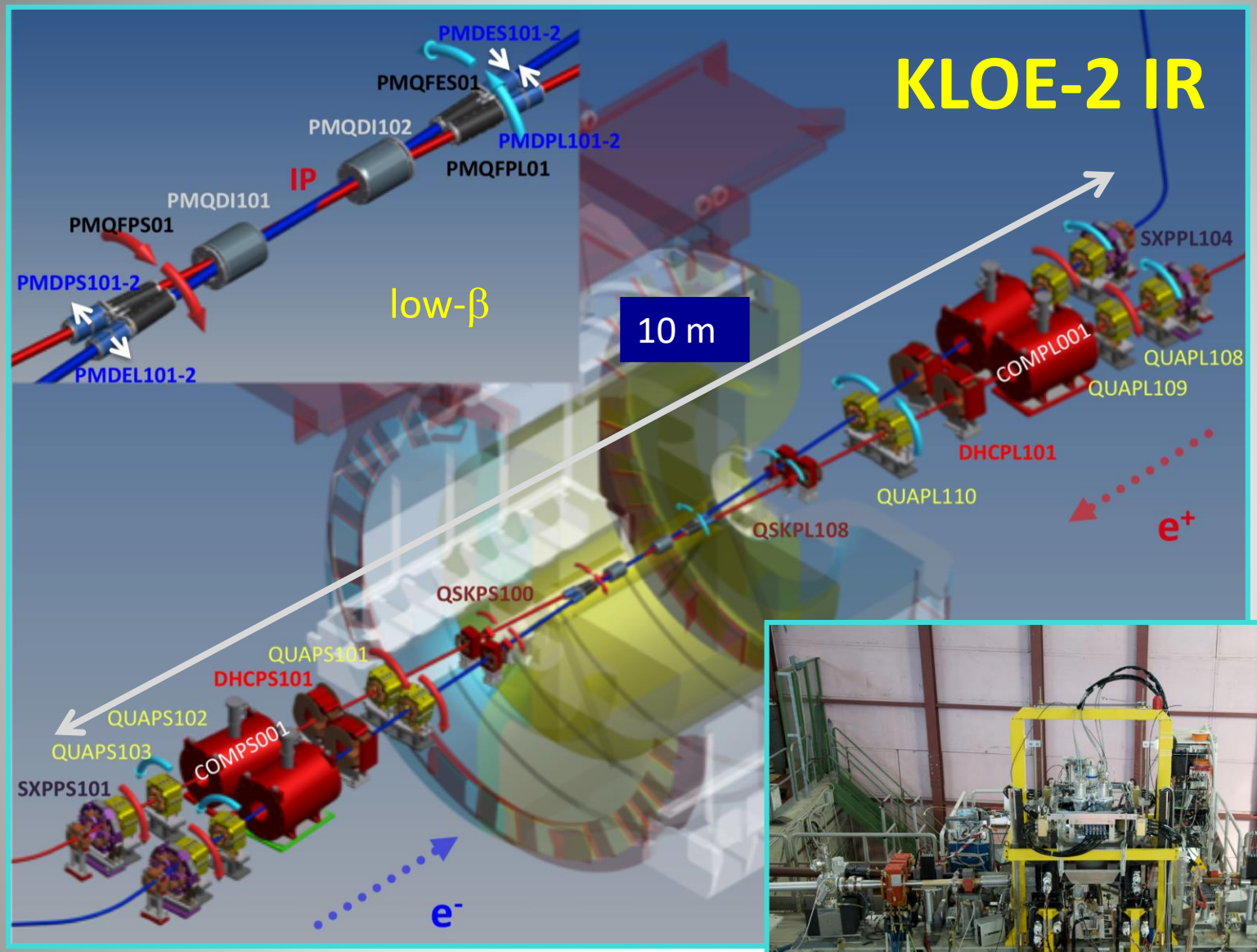
Crucial Points:

IR optics complying with:

- Low-β
- ***Crab-Waist*** collision scheme
- Coupling compensation
- Beam trajectory control

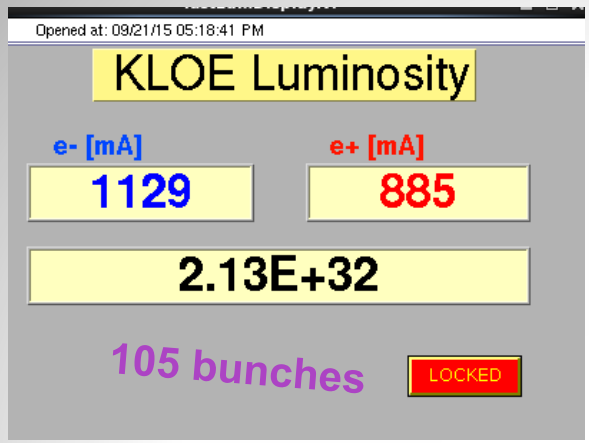
IR mechanical design allowing:

- Large crossing angle
- Early vacuum pipe separation after IP inside the detector



C. Milardi *et al 2012 JINST 7 T03002.*

Peak Luminosity during the KLOE-2 run

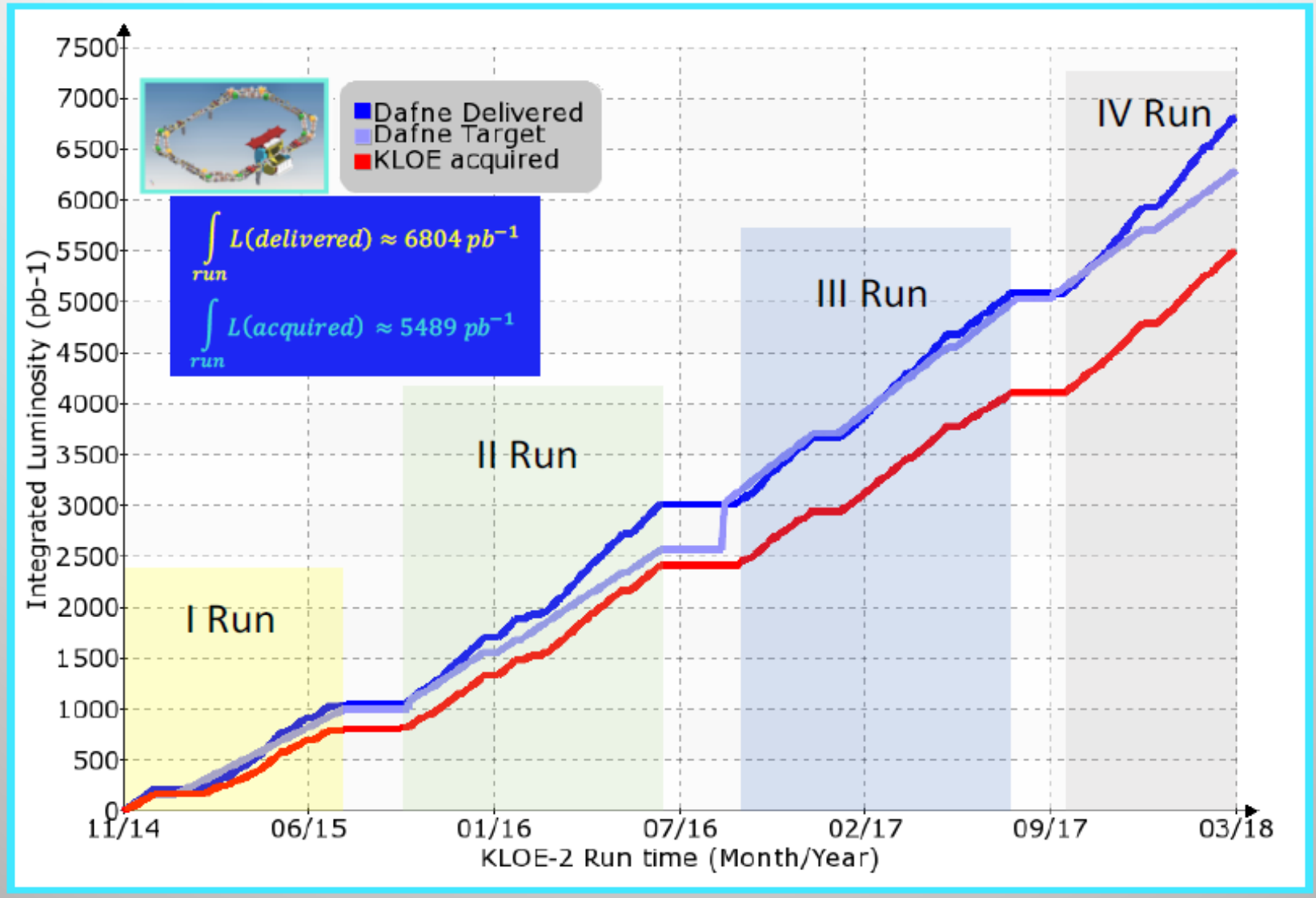


Still the full potential of the new *CW* collision scheme has not been completely exploited

	DAΦNE CW upgrade SIDDHARTA (2009)	DAΦNE CW KLOE-2 (2016)
L_{peak} $[10^{32}\ cm^{-2}s^{-1}]$	4.53 **(5.0)**	**2.13**
$L_{\int day}$ $[pb^{-1}]$	14.98	**14.03**
$L_{\int 1\ hour}$ $[pb^{-1}]$	1.033	**0.62**
I^-_{MAX} in collision [A]	1.52	**1.129**
I^+_{MAX} in collision [A]	1.0	**0.885**
$N_{bunches}$	105	**105**

The new collision scheme including Large Piwinski angle and Crab-Waist compensation of the beam-beam interactions has proved to be a viable approach to increase the luminosity of the DAΦNE collider even in presence of a large detector equipped with a high intensity solenoidal field.

KLOE-2 Run Overview



Colliders based on Crab Waist concept

Colliders	Location	Status
DAΦNE	Φ-Factory Frascati, Italy	In operation (SIDDHARTA, KLOE-2)
SuperKEKB	B-Factory Tsukuba, Japan	Phase III commissioning in 2019
SuperC-Tau	C-Tau-Factory Novosibirsk, Russia	Russian mega-science project
FCC-ee	Z,W,H,tt-Factory CERN,Switzerland	100 km, CDR at the end of 2018
CEPC	Higgs-Factory China	100 km, CDR released in September 2018
HIEPA	2-7 GeV China	Considered option

Bunch-by-bunch Feedback systems

Used to damp coupled bunch instabilities both in the longitudinal and transverse plane

DAFNE FBKs are based on **iGp** (Integrated Gigasample Processor) an innovative digital bunch-by-bunch hardware developed by a **KEK / SLAC / INFN-LNF joint collaboration**.

Processing unit can sample at **500 MHz** and compute the bunch-by-bunch output signal for up to ~5000 bunches.

The FBK gateware code is implemented inside just one FPGA chip, a Virtex by Xilinx.
The FPGA implements two banks of 16-tap FIR (Finite Impulse Response) filters. Each filter is realtime programmable through the operator interface. At DAΦNE, the Frascati Φ-Factory, seven iGp units are used to maintain control of the beams.

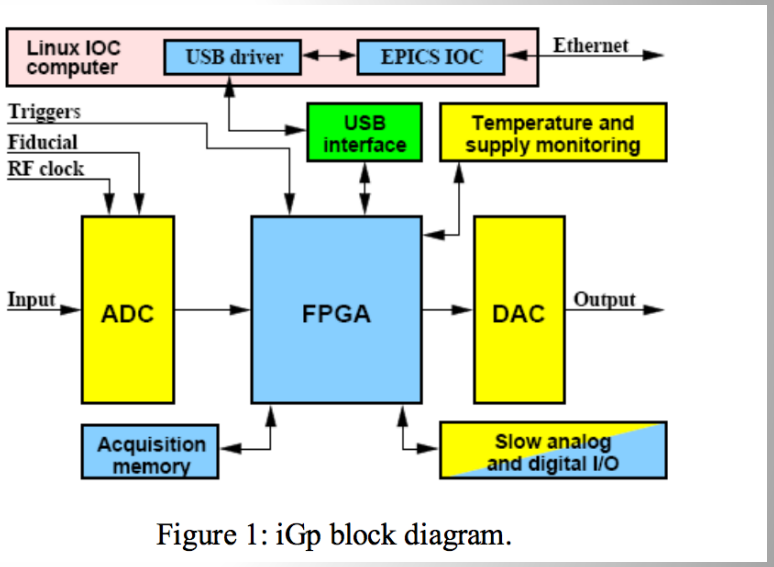


Figure 1: iGp block diagram.

(A.Drago,
"Trends in Fast Feedback R&D",
arXiv:0806.1864 , Jun 12, 2008)

Bunch-by-bunch Feedback systems

Maintaining high current stable and efficient operations requires a continuous effort aimed at upgrading and developing FBKs systems. Noise effects must be carefully kept under control.

Transverse FBKs have been equipped with **new horizontal kickers** having doubled strip-line length and providing larger shunt impedance at the low frequencies typical of the unstable modes. This allows doubling the FBK damping rate for the same setup (gain, power amplifier, etc.).

New software and gateware revisions have been implemented in four iGp-12 units and tested with the beams.

The **EPICS client package**, for Linux environment, has been installed in a powerful dual core personal computer used as dedicated interface for the operators in control room.
This revision allowed to develop powerful measurement tools.

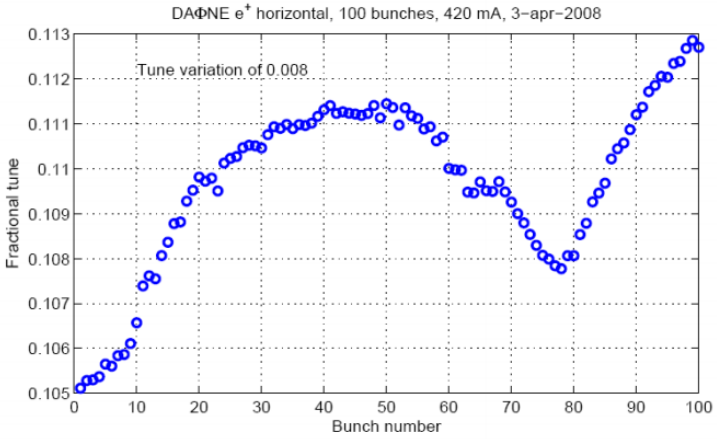
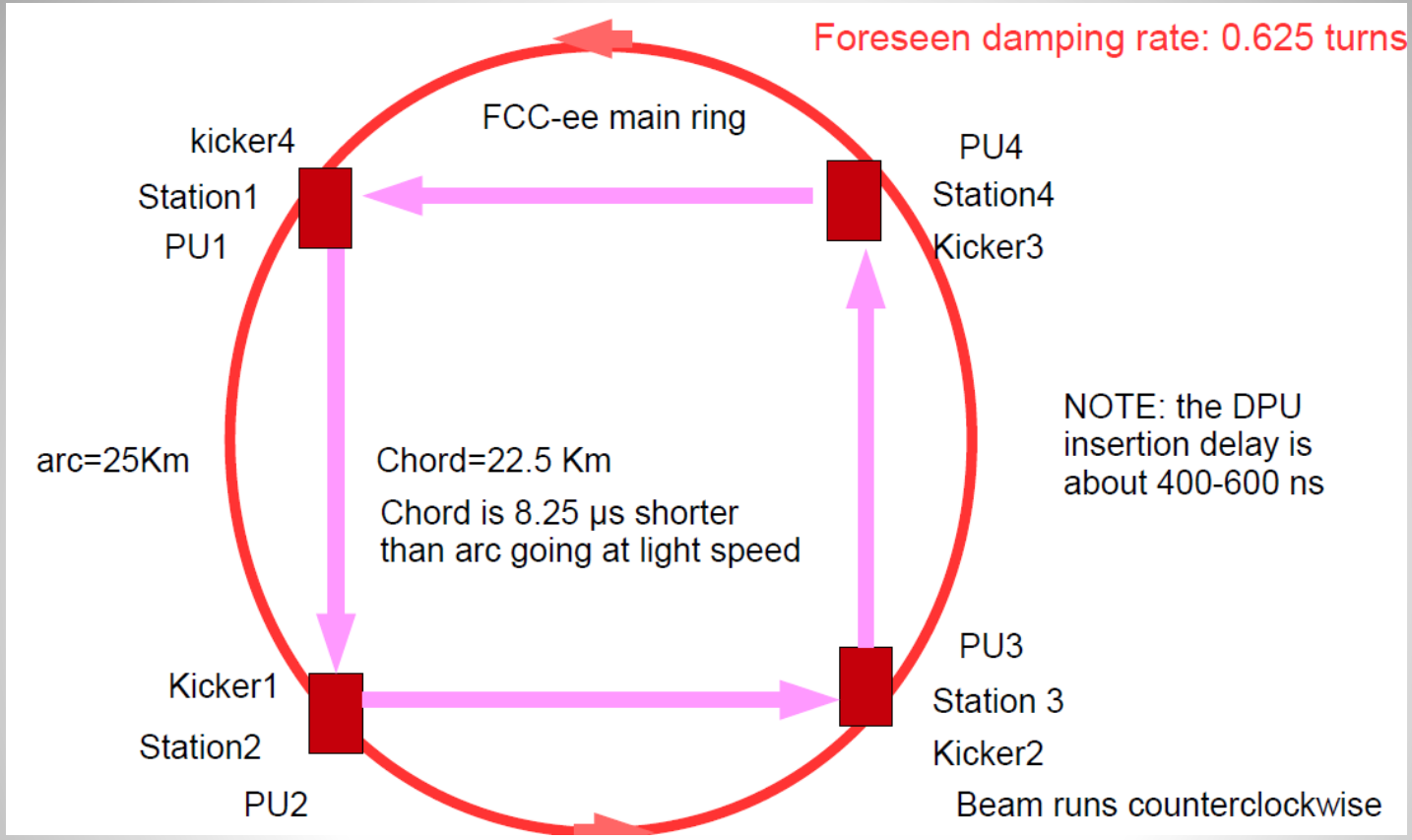


Figure 6: Bunch-by-bunch e+ horizontal tune.

Distributed feedback system proposed for FCC-ee



- However the FCC ring lenght gives a very interesting chance to build "*feeding forward*" systems, producing damping rate even faster than 1 revolution turn. This can be possible applying the correction signal quickly than one revolution period.

From A.Drago talk at ICFA mini-Workshop on Impedances and Beam instabilities, Benevento, 19-22 September 2017

Open points & possible solutions

1. betatron coupling fine tuning
2. e-cloud effects
3. Microwave single bunch instability
4. TMCI single bunch instability
5. ....

1. Trimming rotation of IR quadrupoles
2. More bunches
3. Higher chromaticity
4. Higher lattice momentum compaction factor
5. Stronger CW sextupoles
6. Nonlinear dynamics optimization
7. Vacuum conditioning and beam scrabbing
8. Feedback noise improvement
9. ....

Complete this plan requires a huge program involving: machine studies, beam measurements and simulation.

Thesis about Beam Dynamics at DAΦNE, and not only …
(C. Milardi LNF - INFN)

"Beam dynamics in present and future circular lepton colliders "

- The proposed PHD thesis aims at studying beam dynamics and its interplay with the beam-beam interaction for the DAΦNE configuration based on the Crab Waist collision scheme.
- The purpose of this work is twofold: to push DAFNE luminosity to its ultimate limit, and achieve a detailed comprehension of the collider limiting factors.
- The experimental studies undertaken at the Frascati Φ-factory will be of primary interest for all the other communities working at the design of future colliders based on the Crab Waist approach.
- The research program includes experimental and simulation activities to be done at the Frascati laboratories (LNF) of INFN.

Theses about Feedback Systems at DAΦNE
(A. Drago LNF - INFN)

- ***"Development of a simulation code for design and optimization of bunch-by-bunch feedback systems dedicated to circular lepton accelerators"***
- **FBK thesis n. 1** is suitable for candidates having theorical skill in accelerator physics and interested in developing software models for stored beams instabilities and cures.

- ***"Development of a real time bunch by bunch feedback system based on FPGA technology aimed at stabilizing beam motion in circular lepton accelerators"***
- **FBK thesis n. 2** is intended for candidates interested in hardware development, firmware, and software design, better if already aware of FPGA components and code.

FBK Thesis n. 1

- The proposed work aims at developping a model to study the behavior of lepton beams under the effect of bunch-by-bunch feedback.
- The beam model will be based on parameters from future or existing circular accelerators.
- It will implement circular accelerator concepts for describing beam evolution and instability.
- The feedback model will be used to design a system able to damp the instabilities based on F.I.R filter theory.
- Both models should be most likely implemented in Matlab and/or Simulink language.
- Interfaces to other models written in FORTRAN or C/C++ are possible.
- Some knowledges of dynamic system theory is desirable
- Feedback stability criteria as well as zero-pole-gain model should be known
- Matlab Control System Toolbox can be used as basic development tool. Linux and C/C++ working knowledge is also welcome.

FBK Thesis n. 2

- The goal of the thesis work is to develop a real time feedback system based on FPGA technology.
- Signals from each bunch are acquired, digitally converted and stored in dedicated memory space to produce individual feedback correction kick at each bunch passage.
- FIR (Finite Impulse Response) filters have to be implemented in FPGA based boards to stabilize the beam motion.
- Digital electronics, FPGA programming, VHDL and/or Verilog, C/C++, Matlab languages will be used.
- Linux working experience is welcome.

Thank you for your attention