The DAΦNE Φ-Factory

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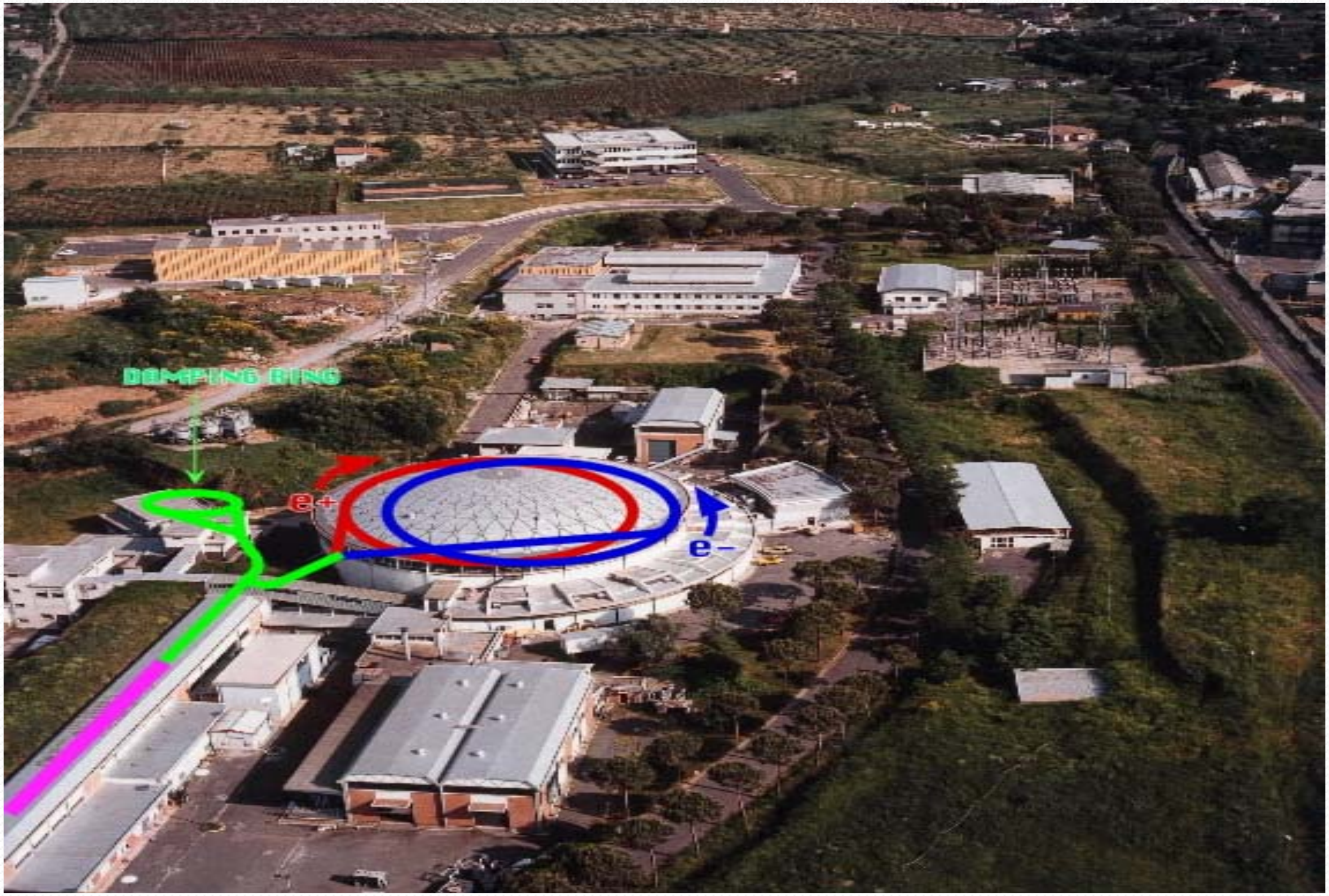
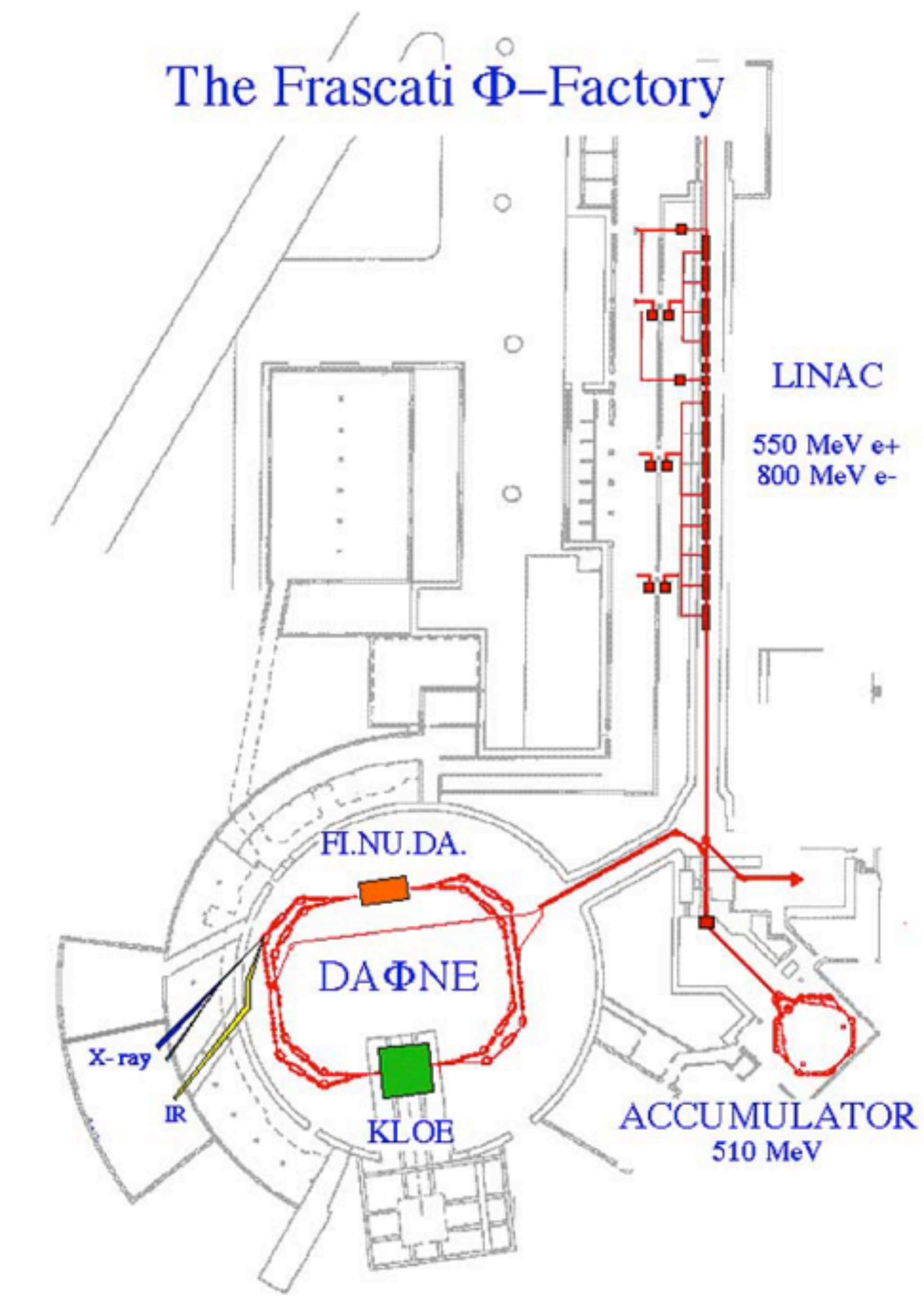
Corso di “Teoria degli acceleratori”
per dottorato Universita’ di Roma 3
LNF, 13 Giugno 2016

DAΦNE Φ-Factory (E_{cm} = 1.02 GeV)

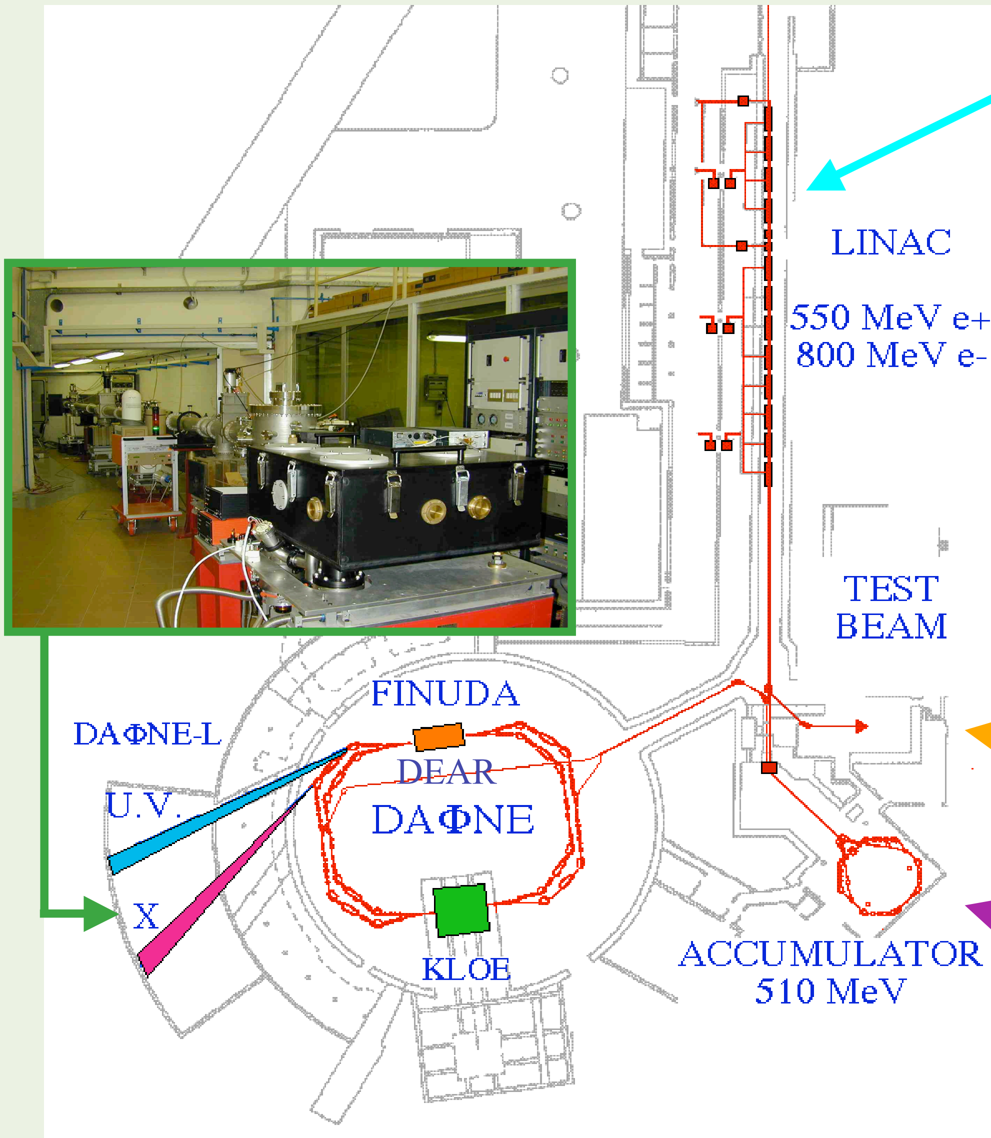


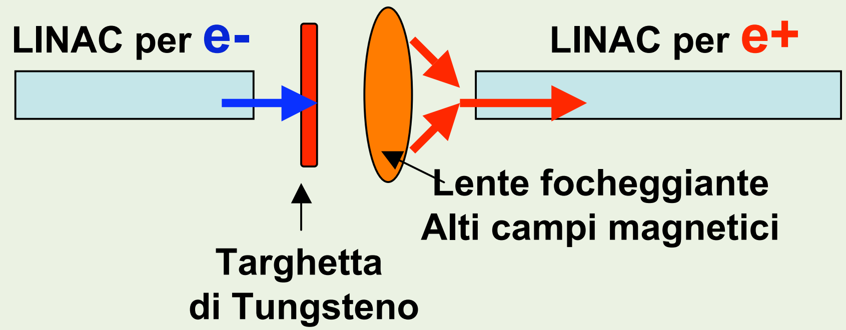


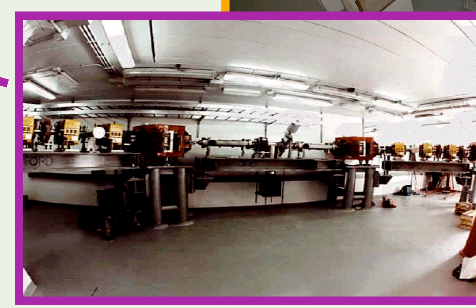
DAΦNE complex is:
(1) LINAC
(2) Accumulator
(3) Two main Rings
(4) Four beam lines for synchrotron light users
(5) Beam Test facility for new detectors

It was completed in 1997 and first collisions happened in March 1998

Il complesso di acceleratori DAΦNE





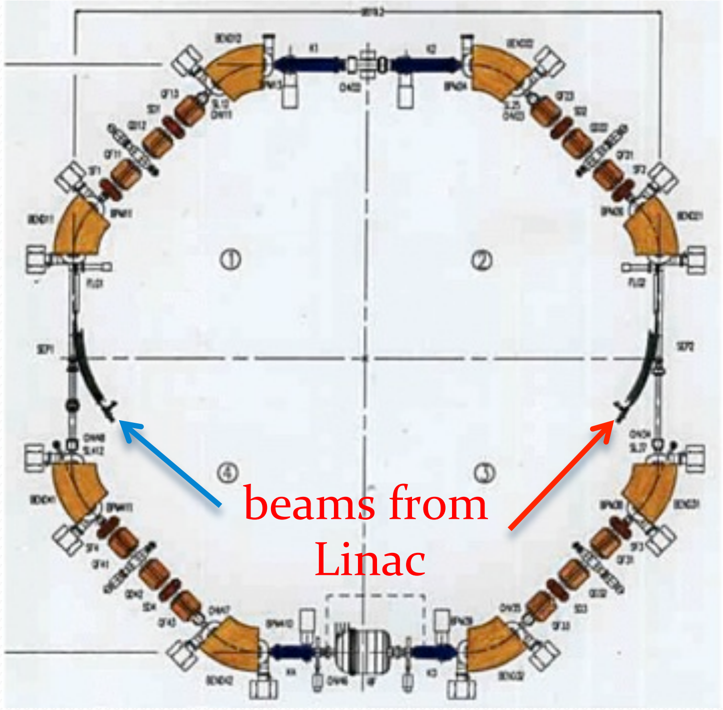


DAΦNE Linac

- Can produce and accelerate electrons (up to 800 MeV) and positrons (up to 510 MeV)

Accumulator

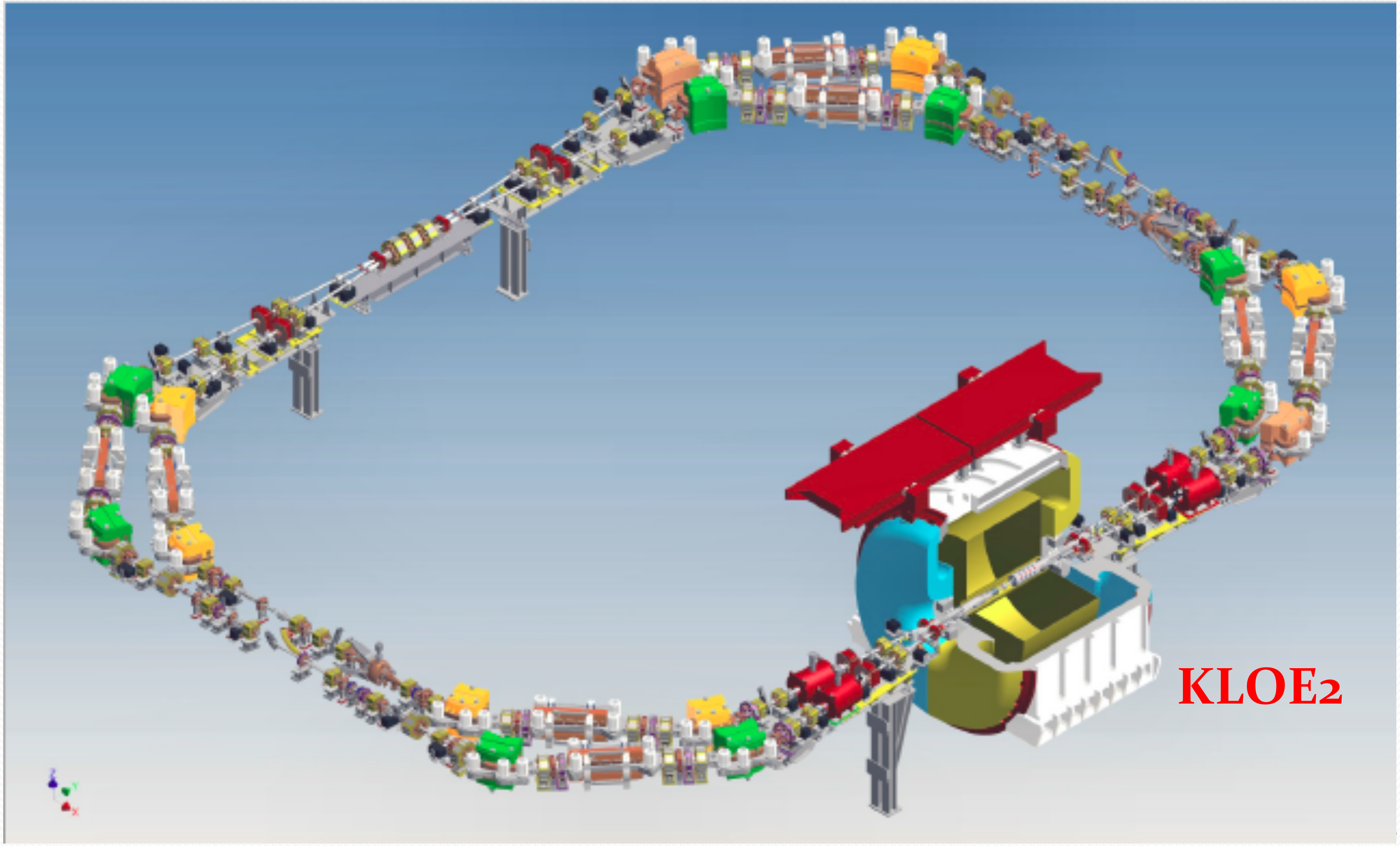
- Used to damp the Linac emittance for both beams thus avoiding the necessity of designing Main Rings lattice with a larger physical and dynamic acceptance, and relaxing the requirements on Main Rings magnets with substantial savings on the overall cost of the facility
- Serves both beams → injections and extraction lines
- Magnets in Transfer Lines to the Main Rings change polarity according to beam charge
- Circumference is 1/3 of the Main Rings
- Electron beam coming from the Linac is injected into the ring by means of a system of two septum magnets, the first bending the beam by 34 deg and the second performing the final deflection of 2 deg
- The stored beam is extracted by a mirror symmetric system placed in the opposite straight section
- The positron beam follows the opposite path



DAΦNE Main Rings

- Beams circulate in 2 separate Rings (abour 100 m circumference) in opposite directions
- Beams travel in the same beam pipe only in the Interaction Region (about 10 m)
- Collide in only 1 Interaction Point, where the KLOE2 detector is installed, with a horizontal crossing angle
- Each ring, made of a Long and a Short half, besides quadrupoles, sextupoles and correctors has:
  - 8 dipoles
  - 1 RF cavity (368 MHz)
  - 4 wiggler magnets

DAΦNE Main Rings



DAΦNE Features

- Electron/positron collider for production of the Φ resonance at high intensity for precision measurements on Kaons decays, Hypernuclei and exotic atoms
- Beam Energy: 0.51 GeV
- Center of mass Energy: 1.02 GeV
- High beam current (> 2 A electrons, 1 A positrons)
- Wigglers to increase beam radiation and damping
- 3 Beam lines for synchrotron light users from dipole and wiggler

DAΦNE parameters

Parameter	Units	e+	e-
L Measured	$cm^{-2}\ s^{-1}$	2.18e32	
Energy	GeV	0.51	0.51
Circumference	m	97.59	
X-Angle (full)	mrad	51.4	
β_x @ IP	cm	27	27
β_y @ IP	cm	0.9	0.9
Coupling (full current)	%	3.5	1.9
Emittance x (from model)	nm	280	280
Emittance y	pm	10850	6289
Bunch length (full current)	mm	12	13
Beam current	mA	1029	1026
Buckets distance	#	1	
RF frequency	Hz	3.69E+08	
Revolution frequency	Hz	3.07E+06	
Harmonic number	#	120	
Number of bunches	#	103	
N. Particle/bunch	#	2.03E+10	2.03E+10
Piwinski angle	rad	1.07	1.12
Tune shift x		0.0216	0.0252
Tune shift y		0.0320	0.0262
Longitudinal damping time	msec	17	17.0
Energy Loss/turn	MeV	0.009	0.009
Momentum compaction		1.90E-02	1.90E-02
Energy spread (full current)	ΔE/E	6.00E-04	6.00E-04
SR power loss	MW	0.01	0.01
RF Wall Plug Power (SR only)	MW	0.04	

Luminosity strategy with 2 rings

- Small IP beta function β_y^*
- High number of particles per bunch N_{part}
- More colliding bunches N_b
- Large beam emittance (area) ε_x
- High bb tune shift parameters $\xi_{x,y}$
- Crossing angle θ ← **To avoid parasitic crossing**
- Small Piwinski angle $\Phi = \sigma_l \, tg(\theta/2)/\sigma_x < 1$

⇒ *small crossing angle* $\theta < \sigma_x/\sigma_l$

To reduce synchro-betatron resonances

Changing the approach…

- Less than 10 years ago the “brute force” (increasing currents) was the only approach to higher luminosity
- P. Raimondi (LNF) studied a new collision scheme with larger crossing angle and lower IP beam sizes (*Large Piwinski Angle*) **PLUS** a couple of “*crab sextupoles*” to twist the IP waist and cure x-y and synchro-betatron resonances raising from the angle. Tested at DAΦNE
- Adopted by all Factory projects after 2008
- More in S. Guiducci talk tomorrow afternoon

Comparison of performances

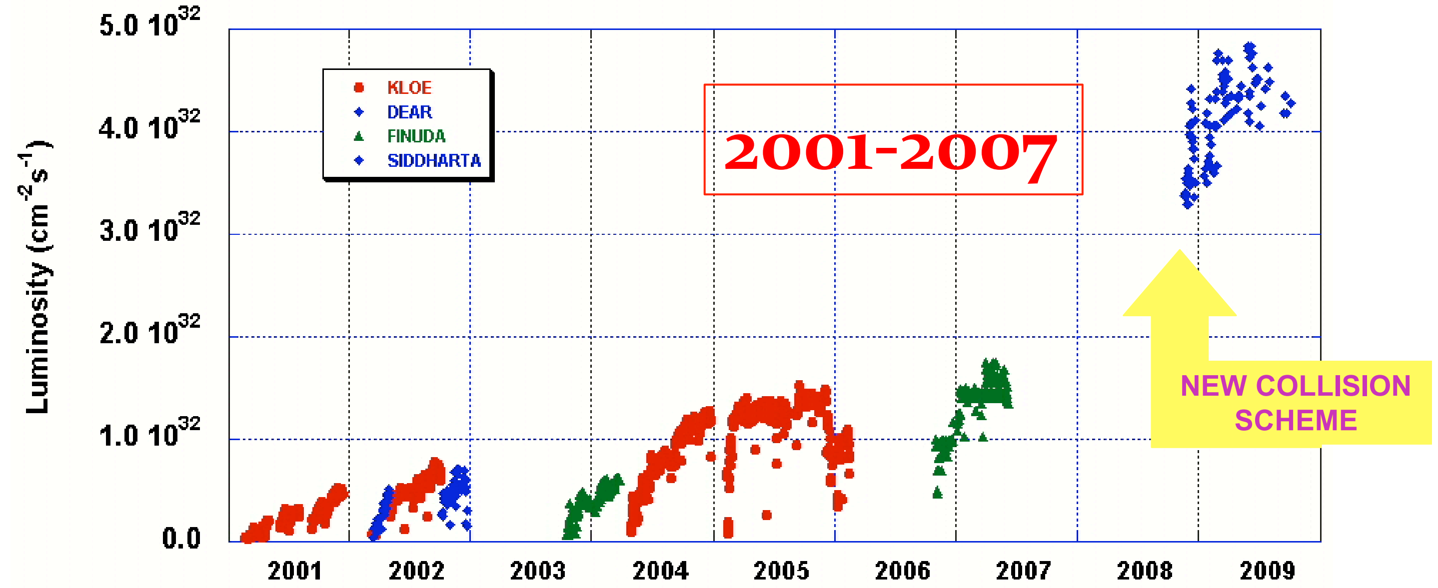
- Best performances with an without Crab Waist scheme, with and without detector solenoid

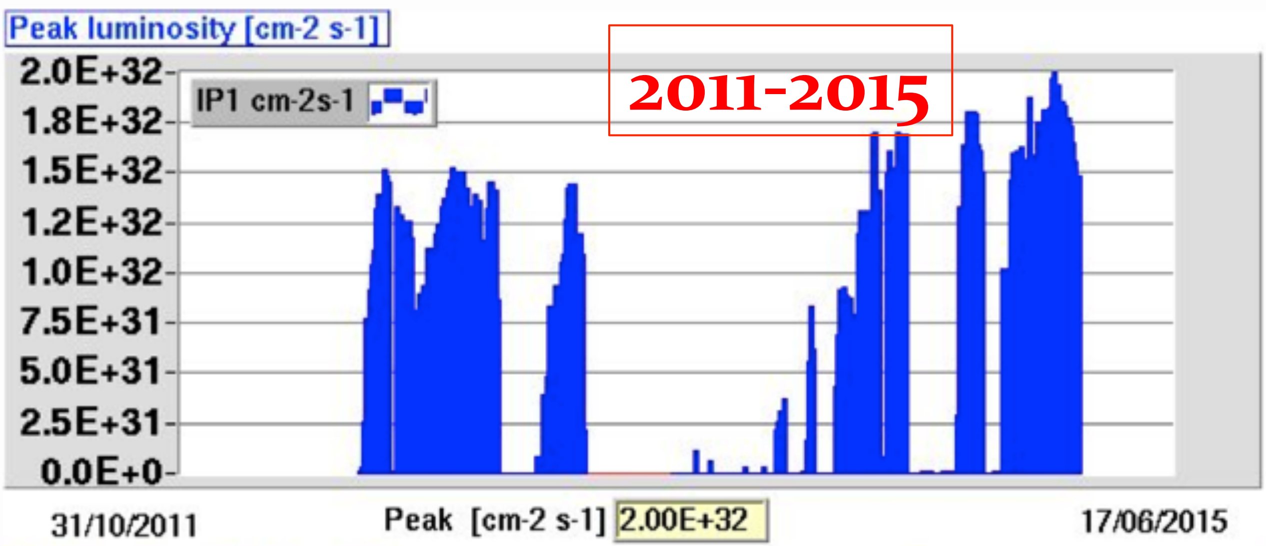
	DAΦNE CW upgrade SIDDHARTA (2009)	DAΦNE KLOE (2005)	DAΦNE (CW) KLOE (2012)	DAΦNE (CW) KLOE-2 (2014)
L_{peak} [$cm^{-2}s^{-1}$]	$4.53 \cdot 10^{32}$	$1.50 \cdot 10^{32}$	$1.52 \cdot 10^{32}$	~~$2.0 \cdot 10^{32}$~~ 2.18×10^{32}
I^- [A]	1.52	1.4	0.93	1.03
I^+ [A]	1.0	1.2	0.72	1.03
$N_{bunches}$	105	111	100	103
	CW, NO solenoid	NO CW, solenoid	CW, solenoid	CW, solenoid

New record

Courtesy C. Milardi

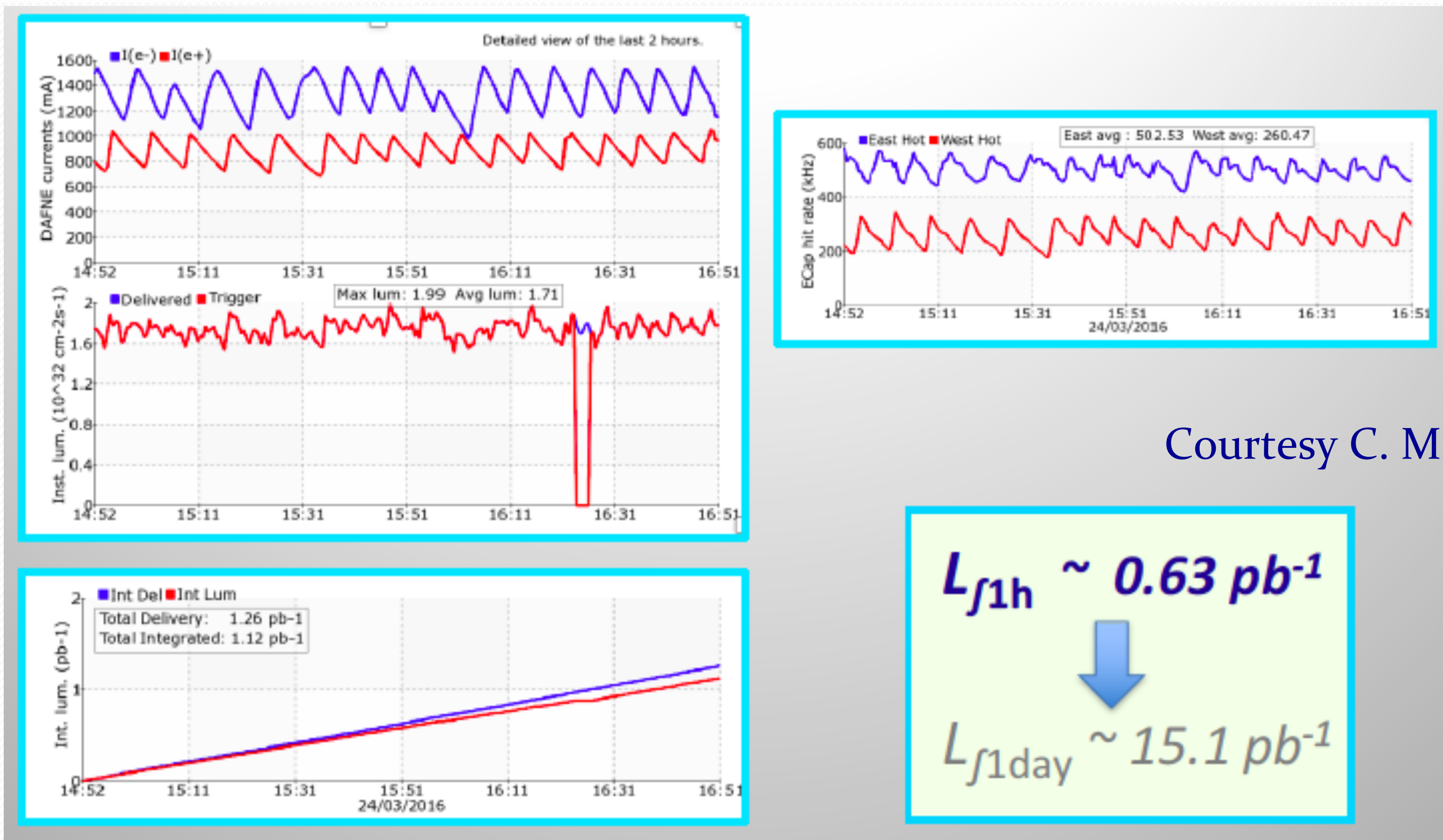
DAΦNE peak luminosity





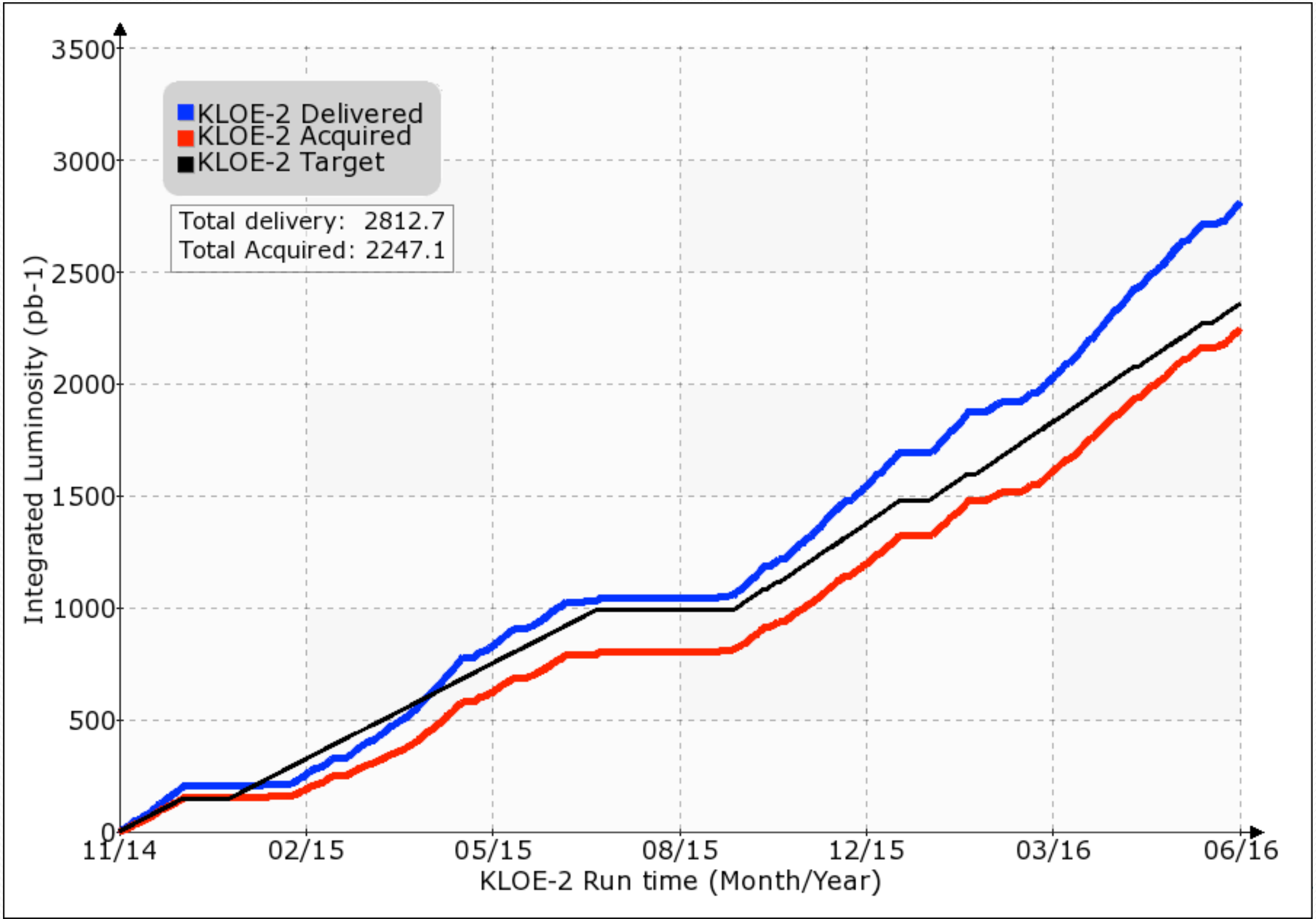
Integrated luminosity

- Collider performances are not only measured by peak Luminosity, but also by the **integrated Luminosity** that gives the number of events collected by the experiment, and must be the largest possible



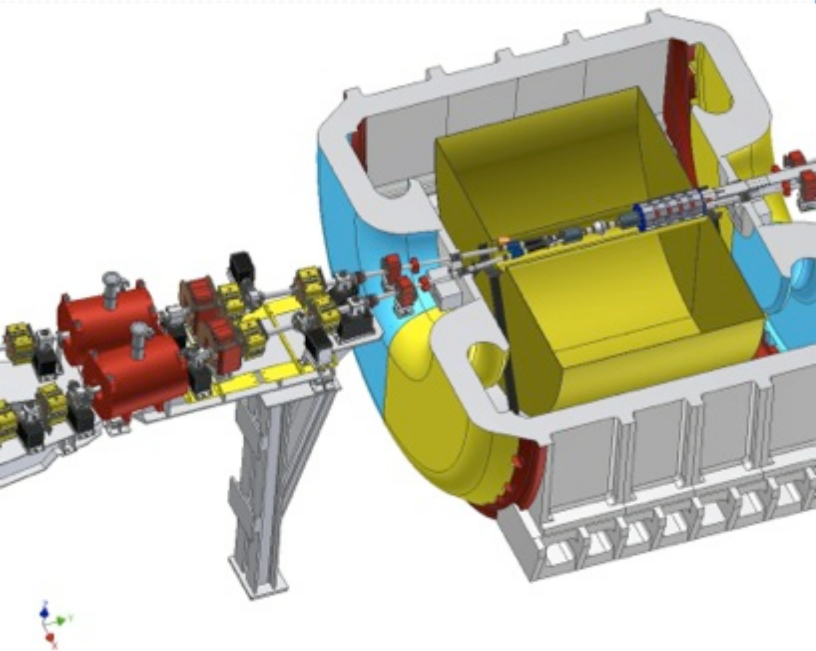
Courtesy C. Milardi

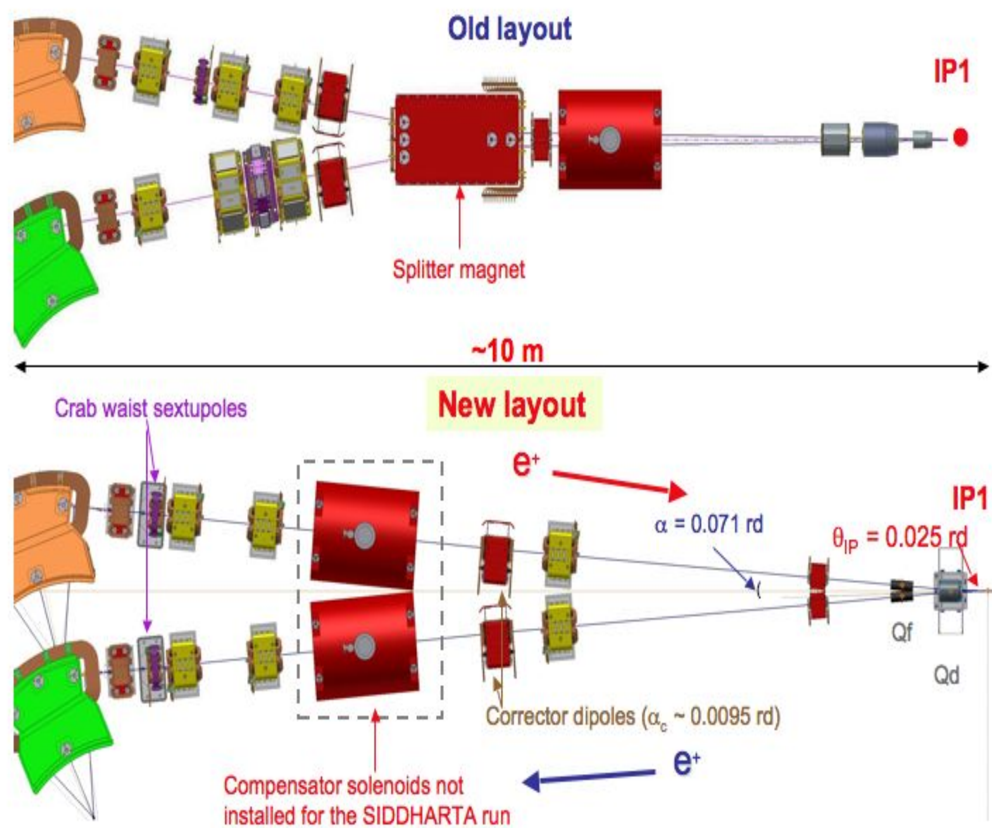
KLOE2 run integrated Luminosity



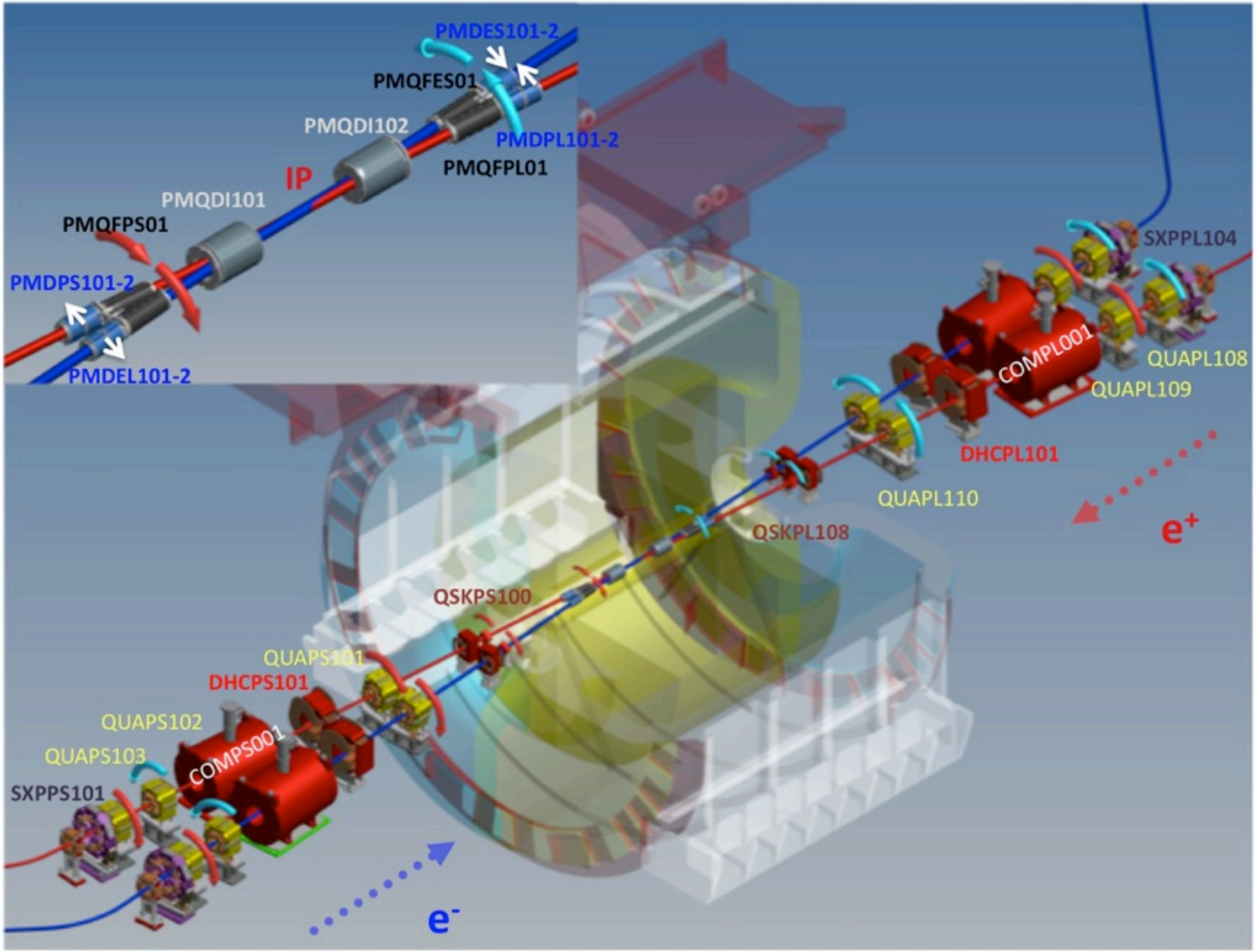
New DAΦNE Interaction Region for LPA&CW scheme

KLOE IR





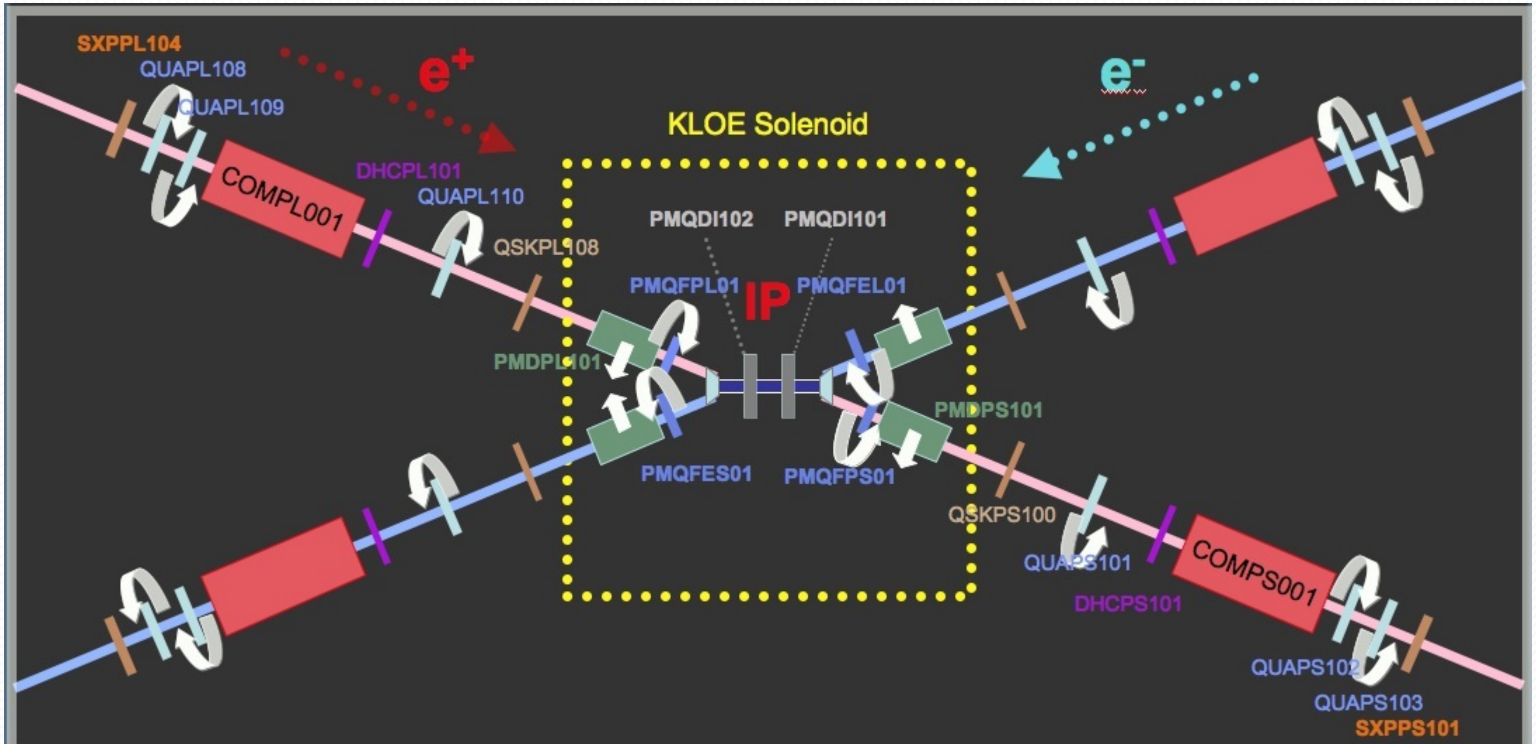
P. Raimondi, Aprile 2010



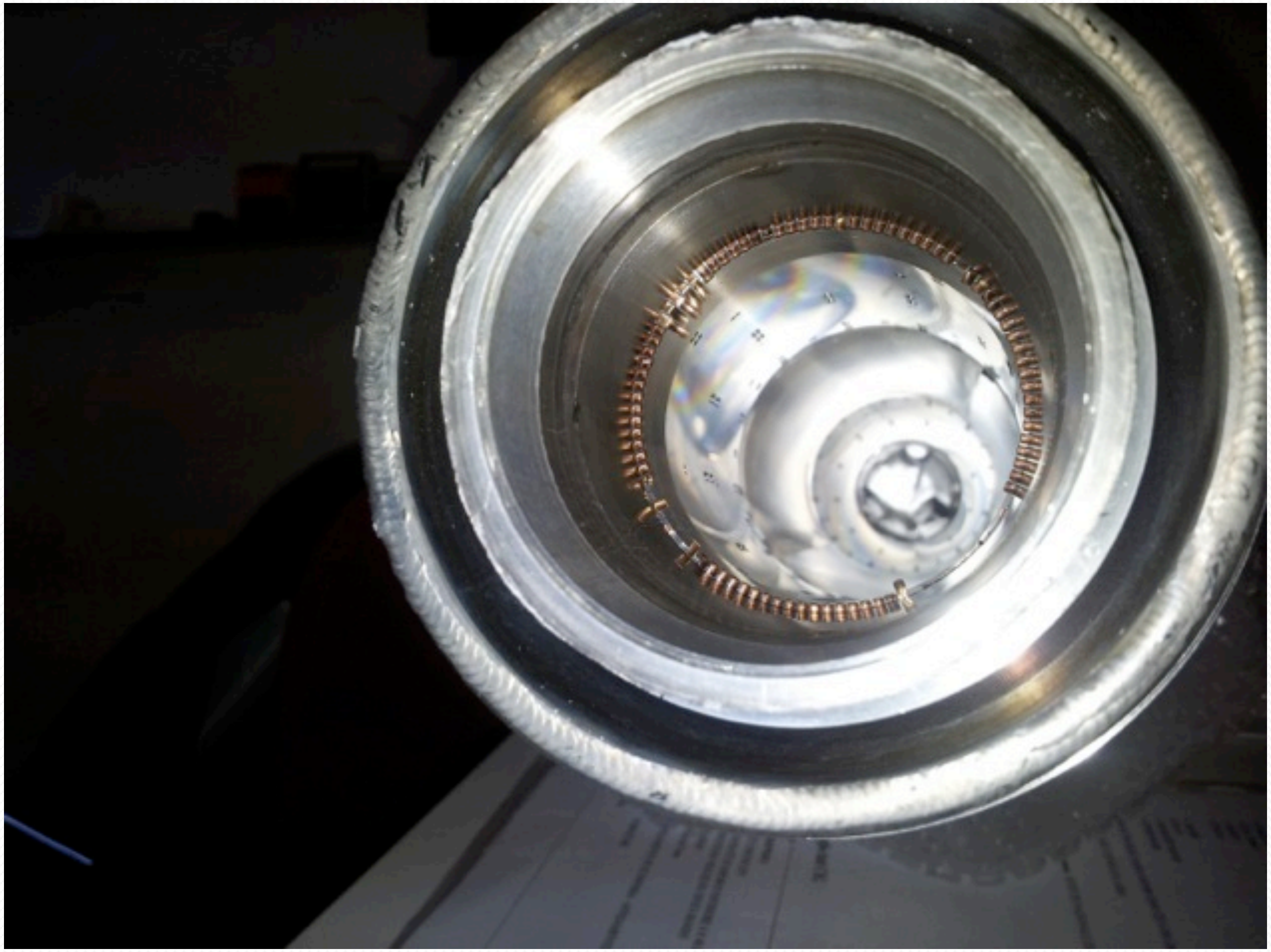
Courtesy S. Tomassini

Interaction Region detail

- The solenoidal field of KLOE2 must be corrected because it induces a strong beam coupling (beam rotated by 22.5° at IP if not corrected)
- Two compensating solenoids are installed in each ring outside the IR
- Quadrupoles need also to be tilted to follow the beam rotation inside the IR
- Residual coupling can be corrected by other skew quadrupoles in the ring
- Correctors provide the orbit adjustment in the IR

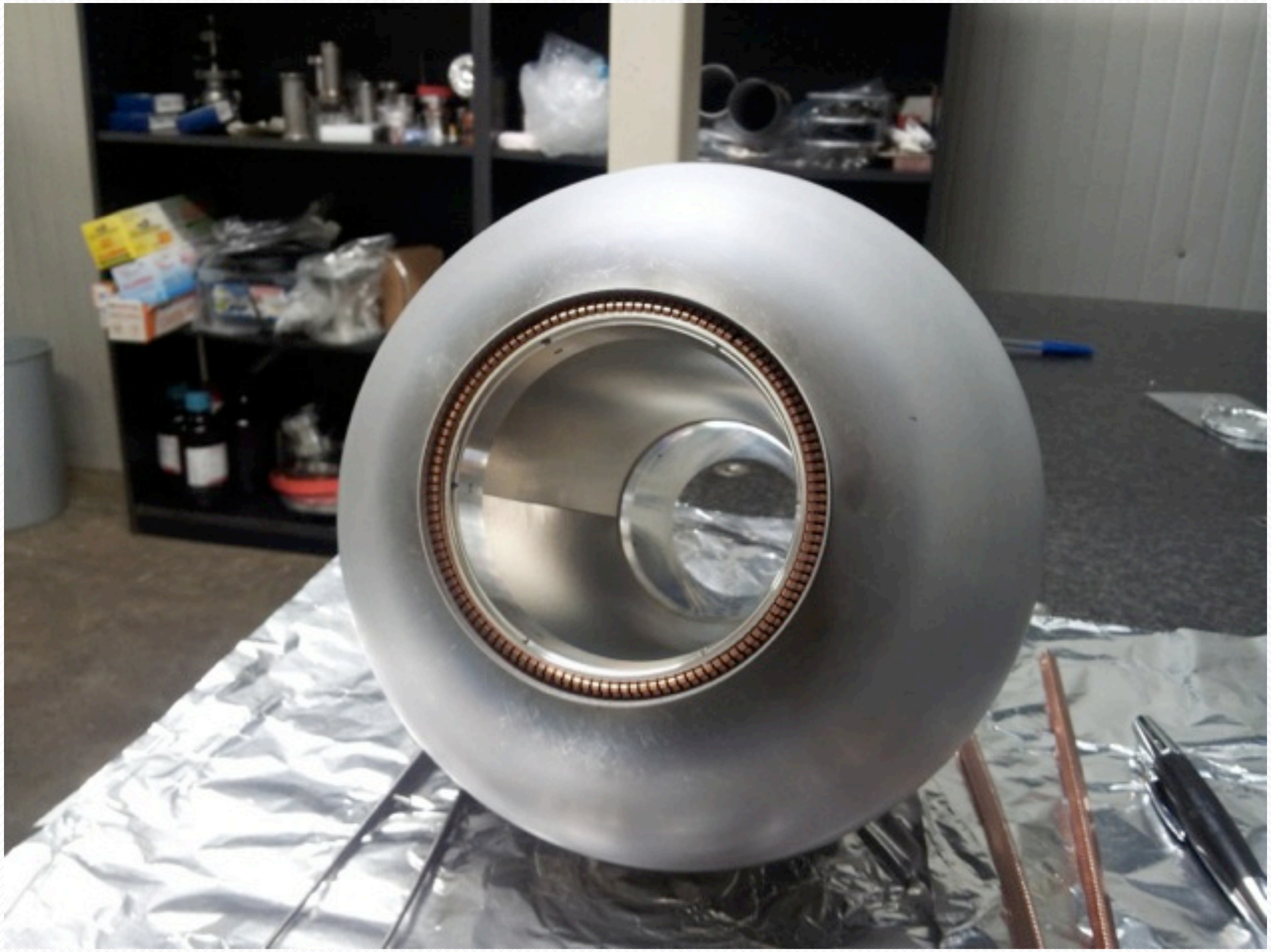


Old Spherical vacuum chamber with damaged RF contacts

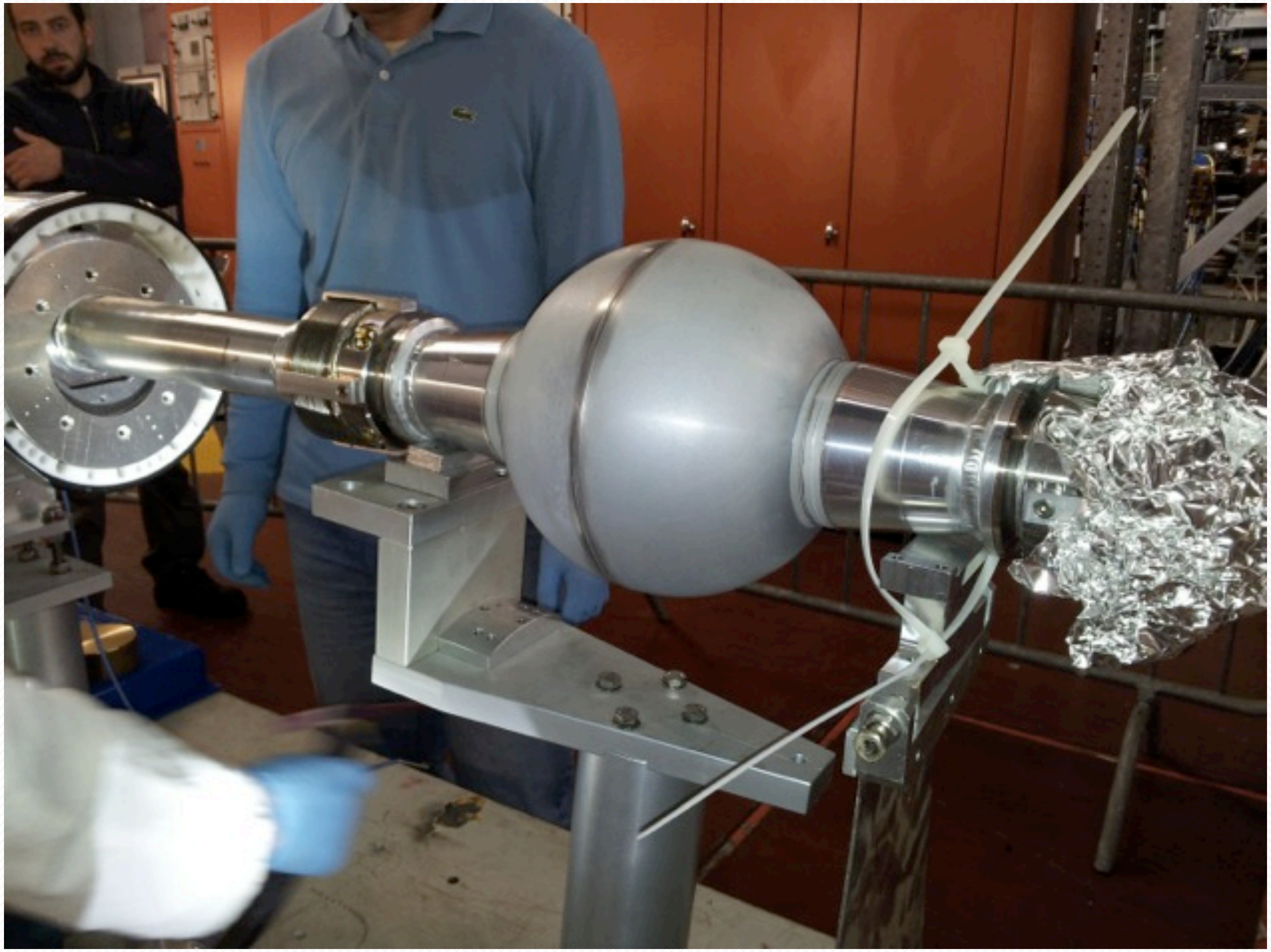


High beam currents can damage devices in the beam pipe !

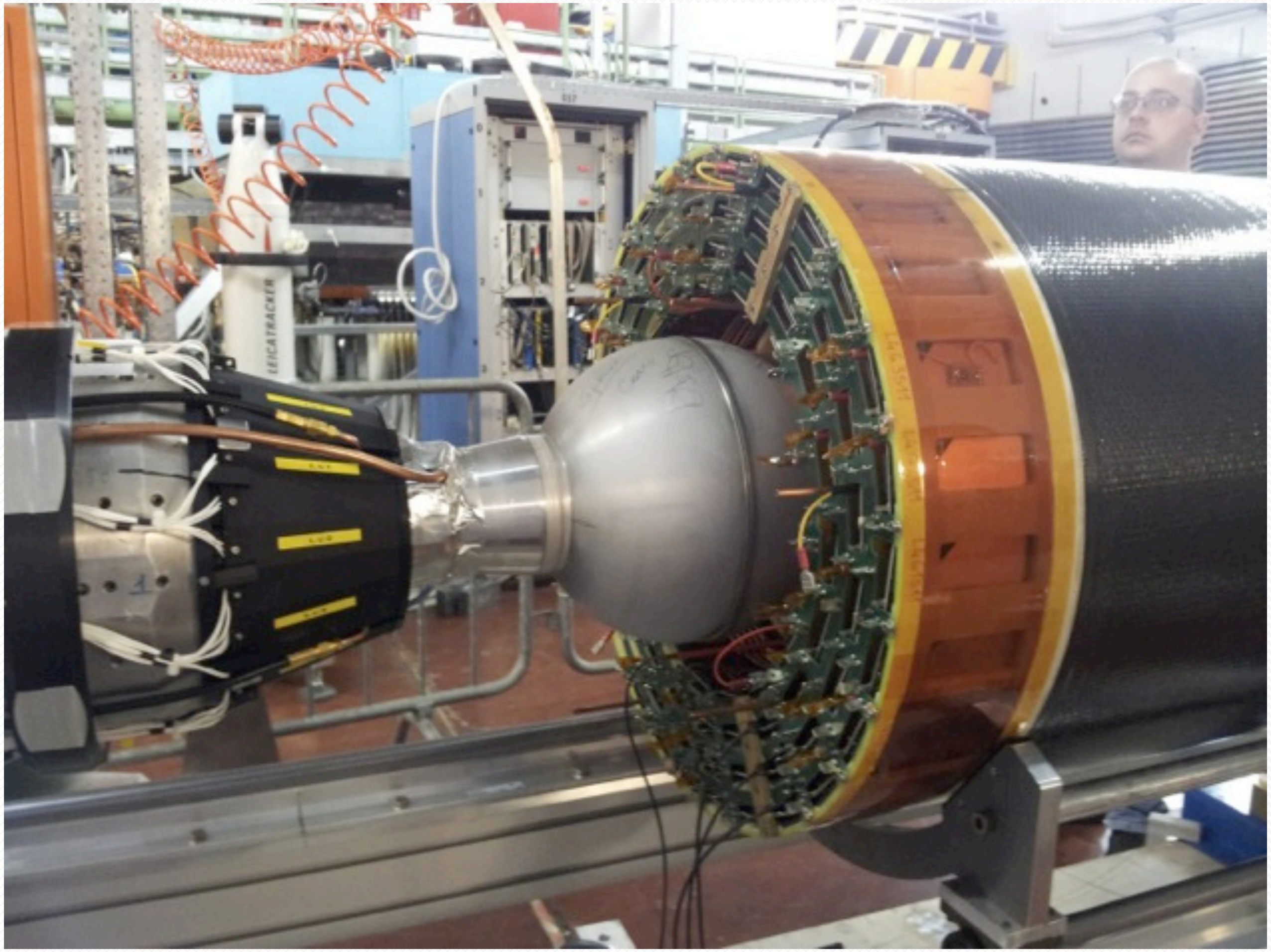
New spherical Vacuum chamber before EB welding (RF contacts between sphere and Be shield)



Sphere assembly in final position before TIG welding

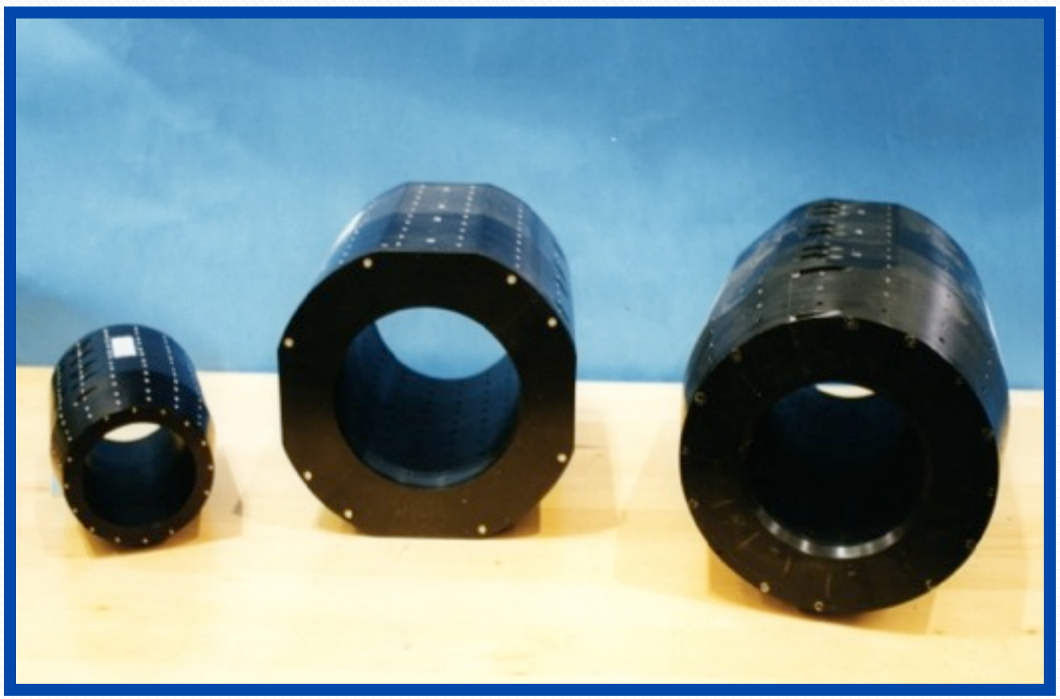


Insertion of the Inner Tracker before 2°welding



Permanent Magnets

- For some applications materials which are permanently magnetized are used
- B field is fixed and cannot vary with the beam energy, but they are extremely compact and don't use any power



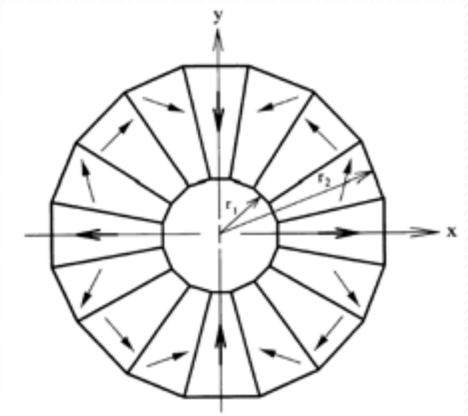
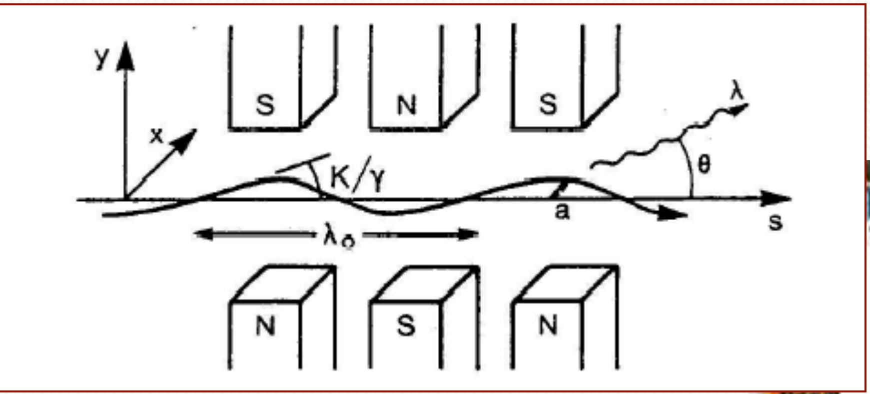


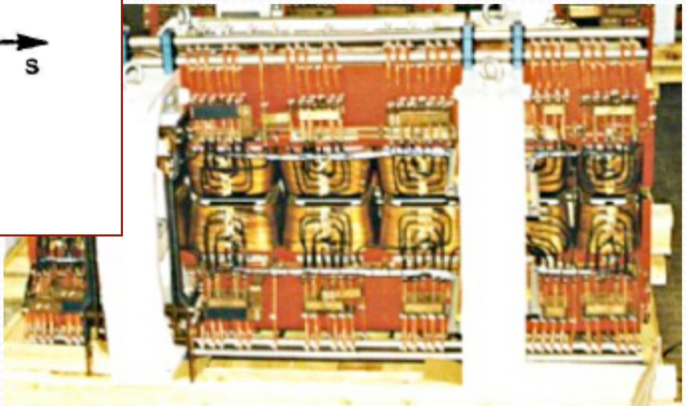
Fig. 4 Segmented quadrupole magnet

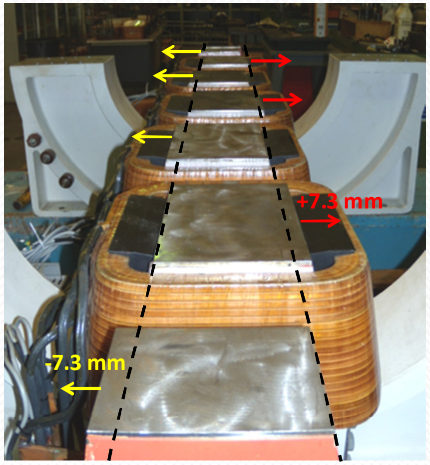
Quadrupoles used in DAΦNE Interaction Region

Wigglers

- Wigglers, multipolar magnets with alternating positive and negative B field, are use to increase the natural damping and manipulate the emittance
- The beam orbit "wiggles" with a small amplitude around the ideal orbit, emitting photons that are used from synchrotron light users
- At DAΦNE 4 wigglers are installed in each ring
- Recently a modification of the arrangement of the poles has allowed to correct intrinsic non-linearities improving the dynamic aperture

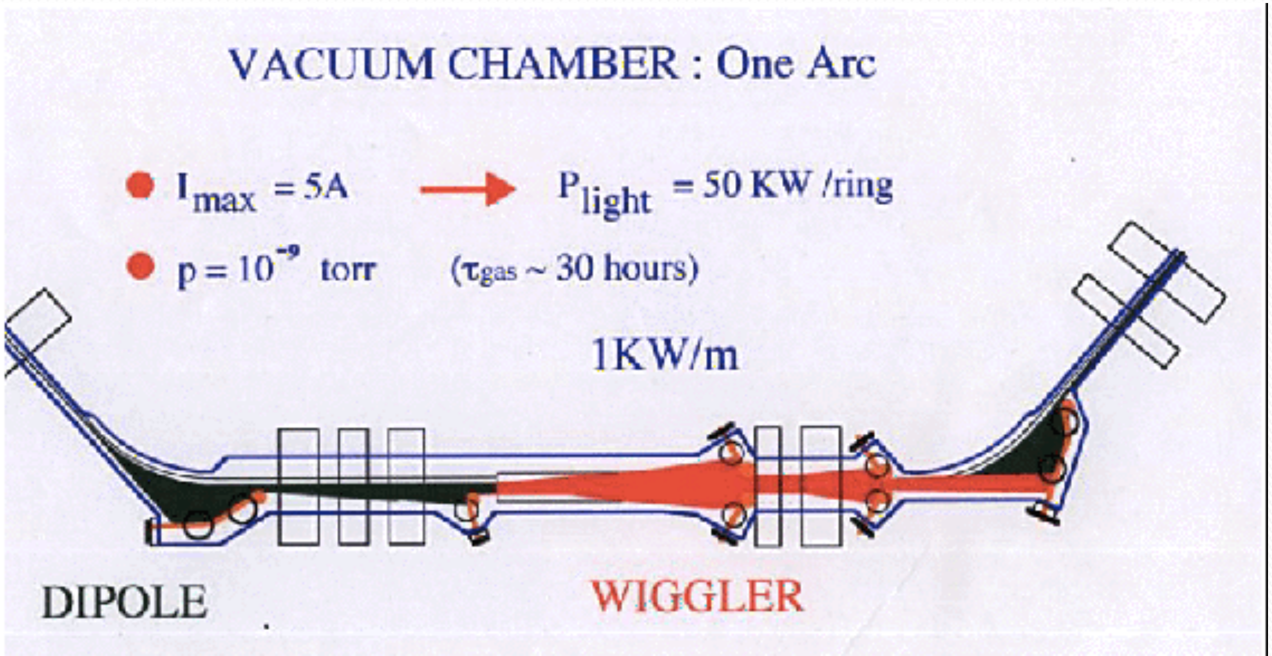




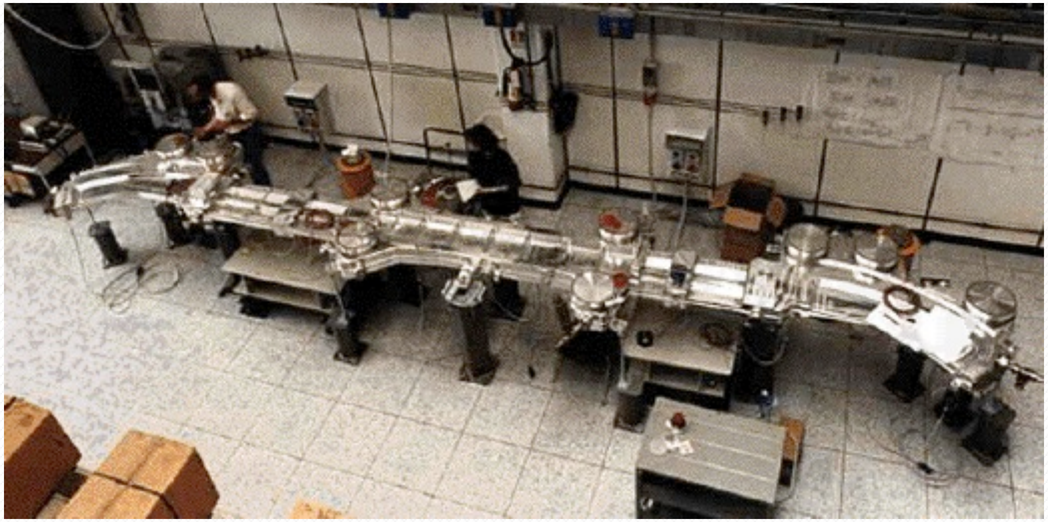


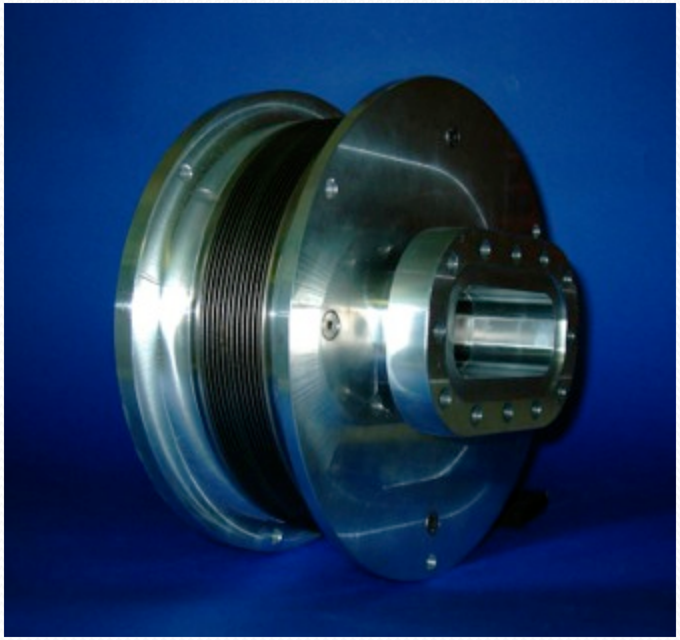
Arc Vacuum chamber

- Specially designed Aluminum chamber
- Radiation from dipoles and wiggler travels through the slots to the antechamber, where it hits special water-cooled copper absorbers.
- Near each synchrotron radiation absorber there is a titanium sublimation pump (~2000 liters per second)



Arc vacuum chamber (one piece, Aluminum)





Bellow, used to join different beam pipe pieces

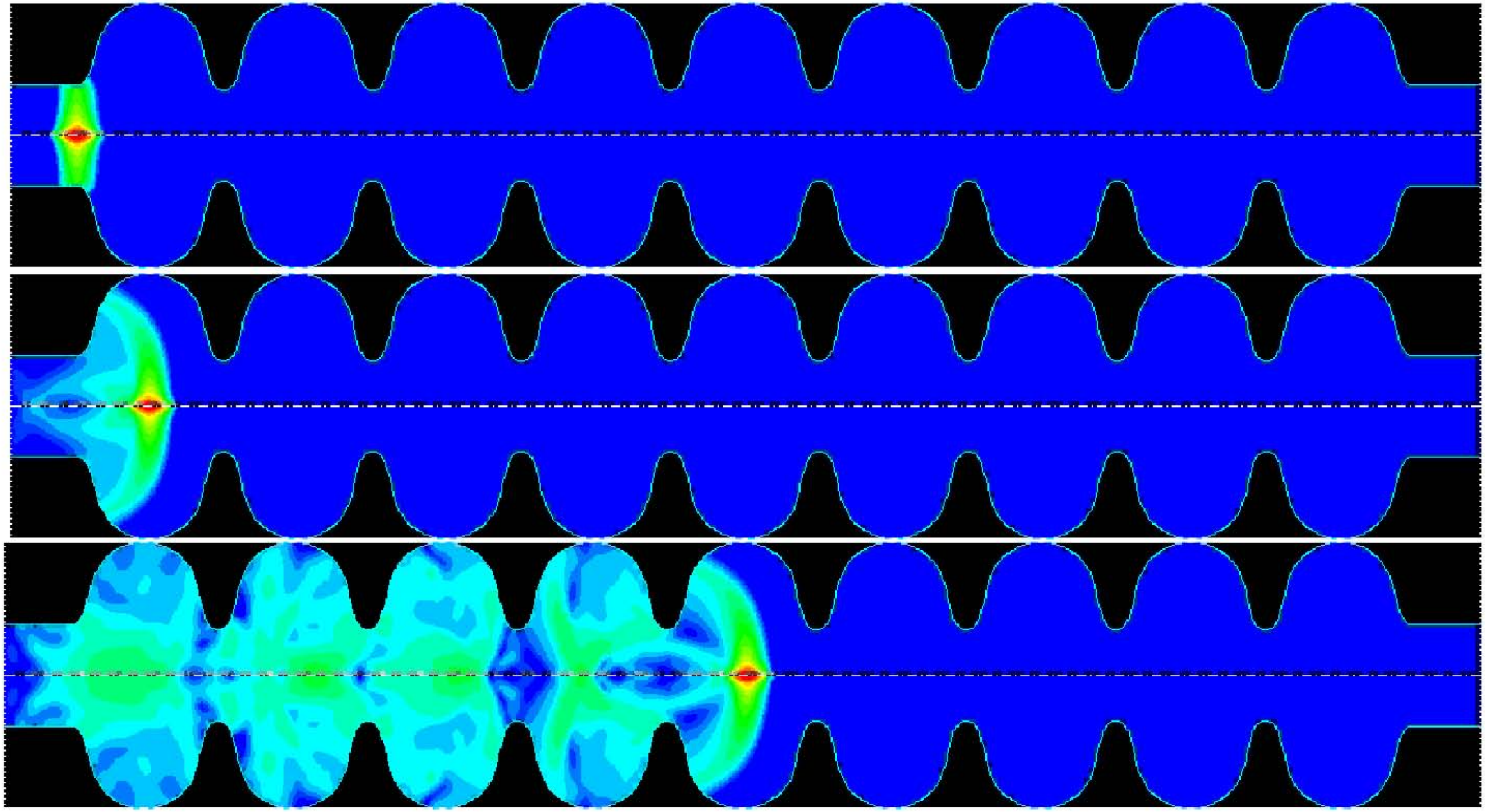
Collective effects

- The particle motion in reality is non independent (i.e. "incoherent"), besides the charge in high intensity beam can be very high (order of Amperes)
- What happens if all particles move in phase ("coherent" motion) when excited ?
- Particles interact in 2 ways :
  - Direct Coulomb Interaction (space charge effects, Intra Beam Scattering,…)
  - Through the beam pipe (transverse and longitudinal instabilities)

Collective effects 2

- A particle is a “source” of e.m. fields: self fields
- These fields interact with the environment (beam pipe, RF cavity, diagnostics), are modified and interact back with the beam
- Small perturbations to the bunch motion change these induced fields: if this change amplifies the perturbation (for ex. with variations of the beam betatron and synchrotron frequencies) instabilities can occur, with consequent modification in the beam distribution, bunch lengthening, possible beam loss
- These phenomena, dependent on the number of particles in the bunch, are called “collective effects”

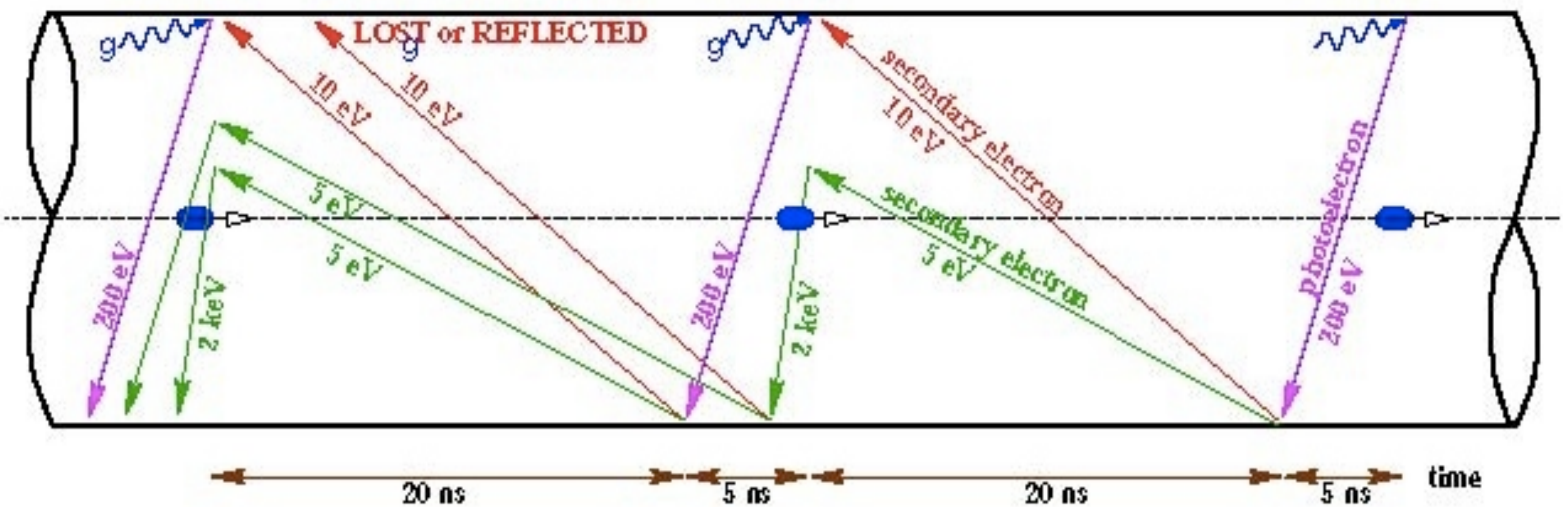
Example of "wake fields"



The e.m. fields induced by the beam can act on the particles arriving later (tail of the bunch) or even in the following turns ⇒ Instability

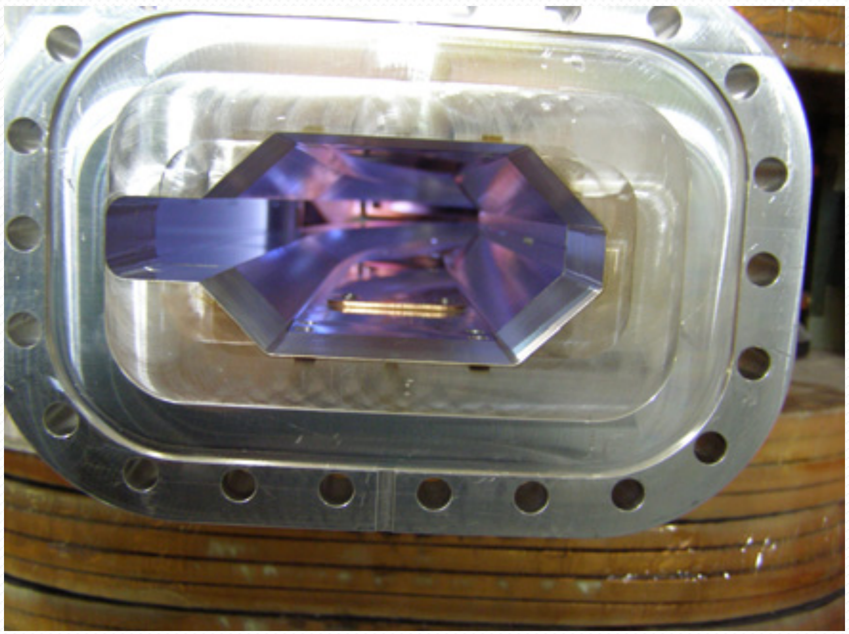
Example of collective effect in e^+ ring: the electron cloud instability

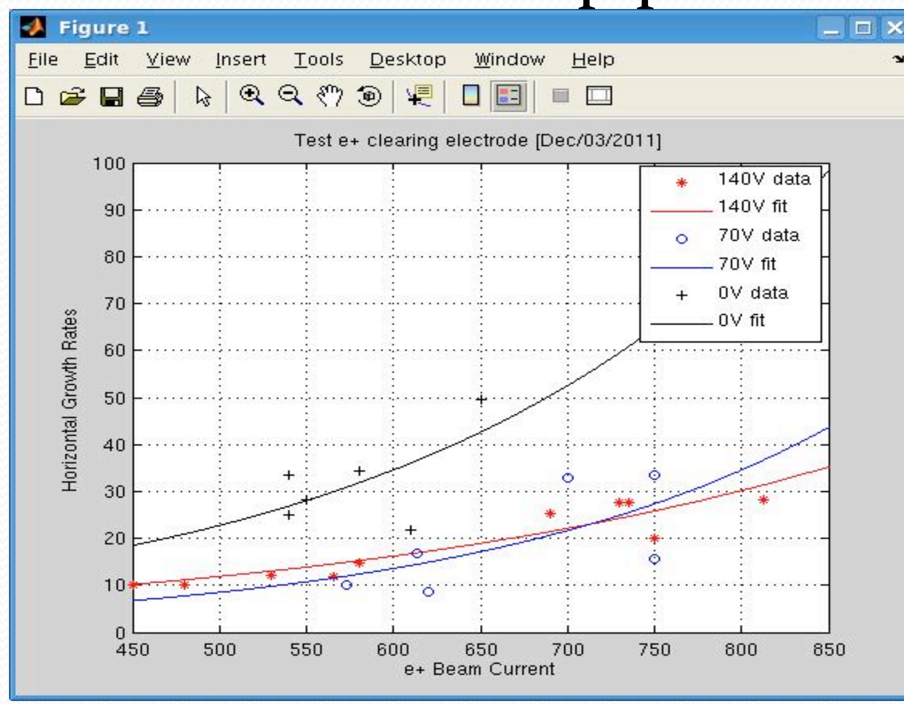
- "*Electron cloud*" instability comes from the interaction between the beam and the vacuum chamber for positively charged beams (positrons, protons, heavy ions)
- The beam emits synchrotron radiation → photons hitting the pipe walls emit photo-electrons that bounce on the walls, with a "cascade" effect
- This effect is amplified by the successive passages of many bunches
- Photo-electrons produce secondary electrons: the number depends from the secondary emission coefficient SEY of the pipe material (which has to be reduced as much as possible)



e-cloud clearing electrodes

- In DAΦNE this instability has been reduced by installing in the dipoles and wigglers special electrodes whose voltage can attract photo-electrons back to the pipe walls

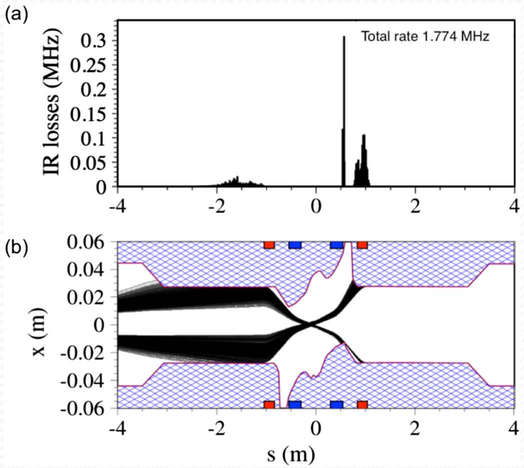




Instability growth rates (ms^{-1}) vs. beam current (mA) at different voltages applied to the clearing electrodes

Touschek effect

- Touschek effect is a Coulomb scattering between 2 particles in the same bunch at large angle, associated with a transfer of momentum from the transverse plane to the longitudinal plane.
- As a consequence particles with a large energy deviation can be lost outside of the accelerator acceptance
- Total effect is the decrease of the beam "lifetime" (up to few minutes!)
- Usually important for energy below 2 GeV. In DAΦNE is a dominant effect
- It depends from energy acceptance of the RF cavity and the dynamic aperture
- An intense work is routinely done to mitigate this effect with collimators and improving the dynamic aperture
- Monte Carlo tracking codes allow to predict lost particles rates and position



(a) IR loss particles distribution for the KLOE crab-waist optics, with scrapers at their experimental set.
(b) Trajectories with hit positions on the physical aperture that the particles actually see.

Conclusions

- Among all e^+e^- colliders DAΦNE is unique also as a test bench of new ideas in the Accelerators field
- The present performances are close to the top for an accelerator of this low energy
- Continuous work is spent in optimizing the beam properties and luminosity, and in maintaining all hardware components performances at their best
- Optimizing the collider performances is generally a difficult task, but in DAΦNE one has also to cope with the reliability of hardware systems designed and built almost 20 years ago