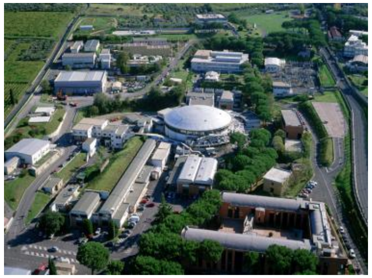


The Quest for Nano Beams

P. Raimondi

Erice, 12 May 2010

OUTLINE

- Why Nano Beams
- How to make Nanobeams:
- DAΦNE Collider
- SuperB Accelerator Project Overview
- Linear Colliders

Nano beams

- A lot of High Energy Physics is made by using Colliders:

  By smashing particles accelerated at high velocity (<=>energy), one against each other and look at what comes out, Physicsts have made great progress in understanding the laws that rule our Universe.

- First Accelerator that discovered a particle built by Millikan in the 19th Century, energy few Volts => Electrons Discover
- Last Accelerator that discovered a particle built in Fermilab at the end of 20th Century, energy 2000Billions Volts => Top Quarks Discover
- New Accelerators (existing (LHC) or planned (ILC)) are pushing the frontier forward and forward

- How we figure how cars are made with no tools?

Basic Idea:

1) Accelerate a car and smash it into a wall

2) see what comes out

How much do we need to accelerate the car?

At low velocity we can see only the gross picture:

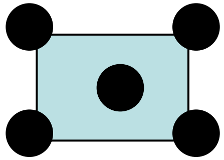
For instance:

- at about 100Km/hour we can see a few tires (never more than "4") coming)out => A car is a box with 4 tires attached

- at about 200Km/hour sometimes we see "5" tires

=> A car is a box with 4 tires attached and 1 inside

Car Model (200Km/hour collision speed):



- At higher speeds we see more and smaller parts coming out,

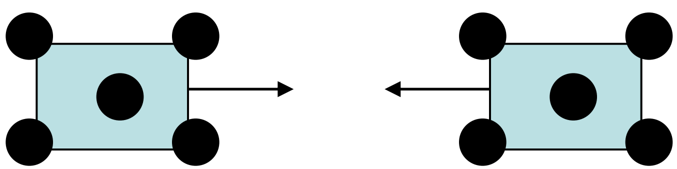
  Head Lights, Pistons and at very high energy even bolts.

  The more we accelerate more and more details we see.

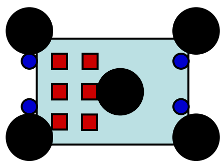
- How to increase the collision speed (Energy from the time being) above 200-300km/hour?

  Collide cars one against each other:

  As everybody unfortunately knows, it is much more destructive an Head-On collision w.r.t. a collision with a standing object.



Car Model (higher collision speed):



- Unfortunately the particles that we are dealing with are very small (Billionth of a billionth of a meter) => Difficult to have them to collide (Unlike Cars!!!!) against each other

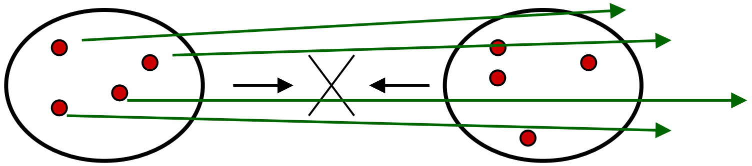
  (Whereas it is very easy to throw them against a wall!!!)

- **How to Do?**

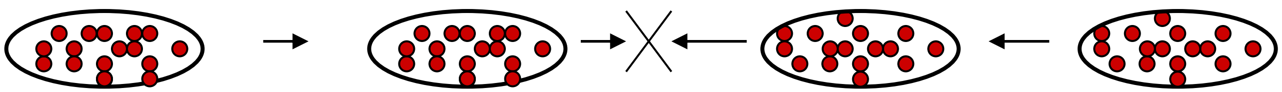
  We pack them in “bunches” with as many particles as possible (billions of them)

  We make the bunches as small as possible (NANO BEAMS)

  We throw as many bunches one against each other as fast (frequently) as possible.



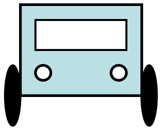
2 big bunches with 4 particles: Few collision!!!



Many small bunches with many particles: Many collisions!!!

Physicist talk about "Cross Section" and Luminosity:

A car as a cross section of about 1m*1m:



A sequence of 1 bunch of cars each second of size 1m*1m with one car in each bunch will make 1 "Collision/Sec" :

A collider with luminosity: "1"

- Colliders with luminosities of 10^34 have been realized.
- There are projects to get up to 10^36 (1billion of billions of billions of billions).
- Even with such Luminosities we do expect a few collisions per second.

These particles are really SMALL.

If we were dealing with cars we would get 1billion of billions of billions of billions of collision each second !!

To make the luminosity as high as possible, infinite tricks have been perfected.

One trick is to make the bunches very flat and long:

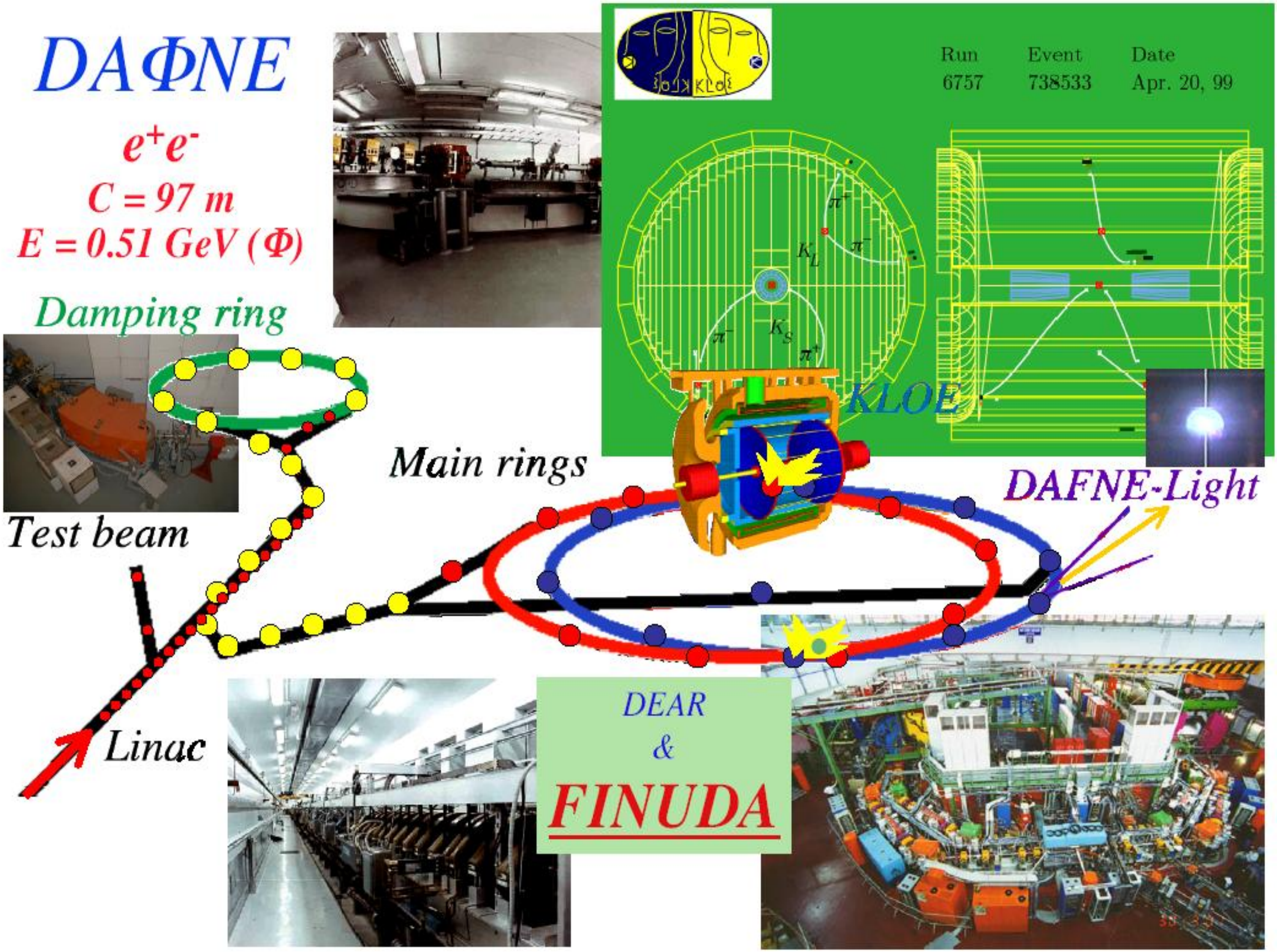
e.g. Length= 10mm

Width = 0.1mm

High = 0.001mm

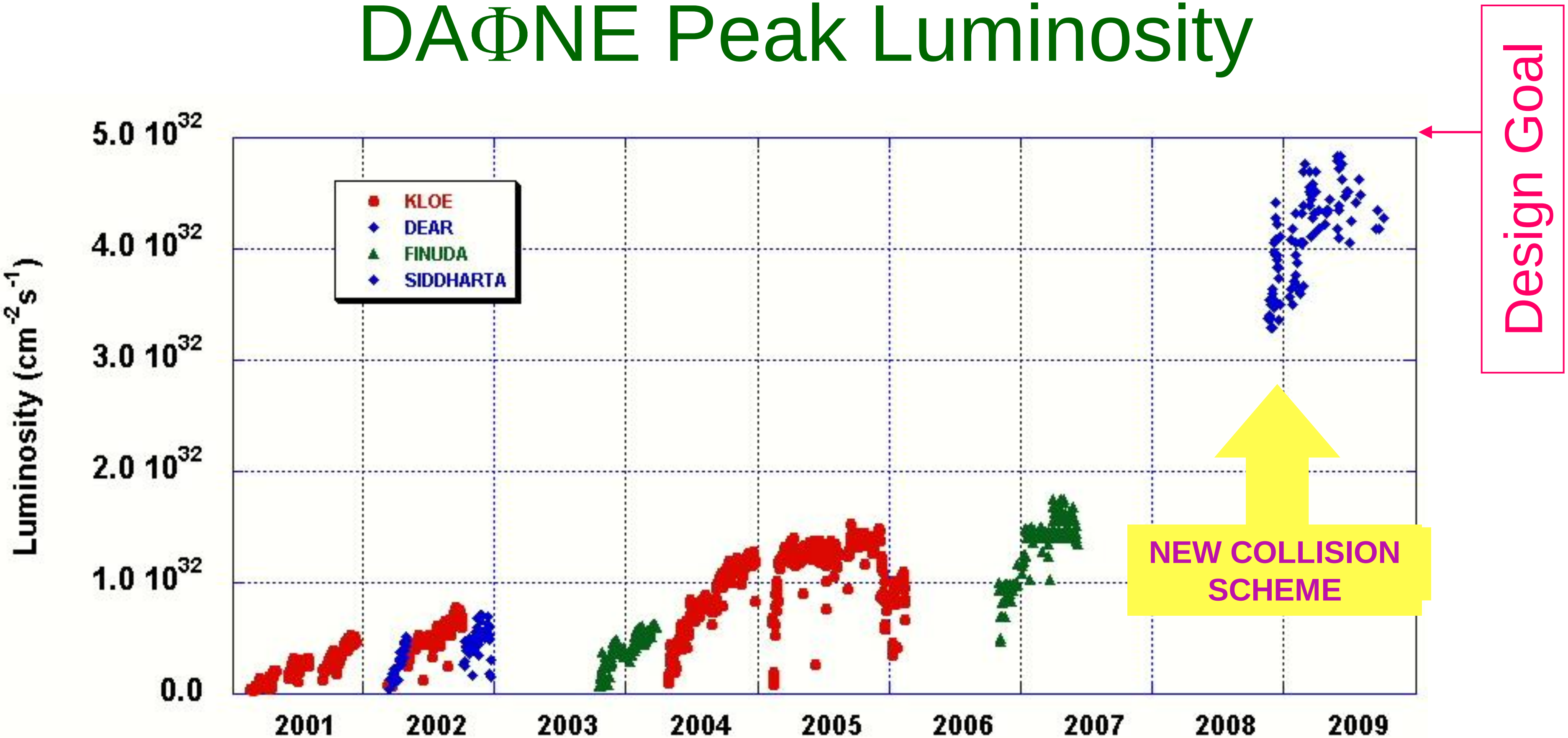
This scheme is usually employed in most “Circular Colliders”

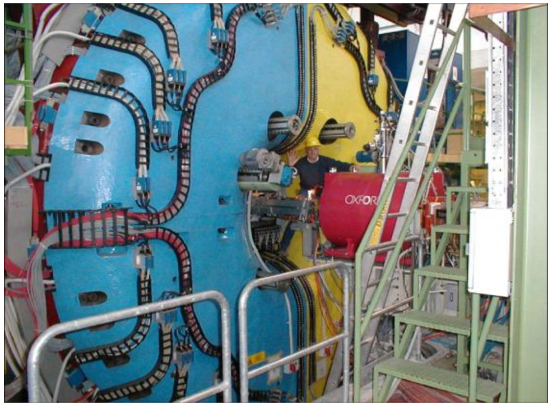
These colliders have the advantage of recirculating the bunches, so the bunch collision frequency is very high: millions of times per second

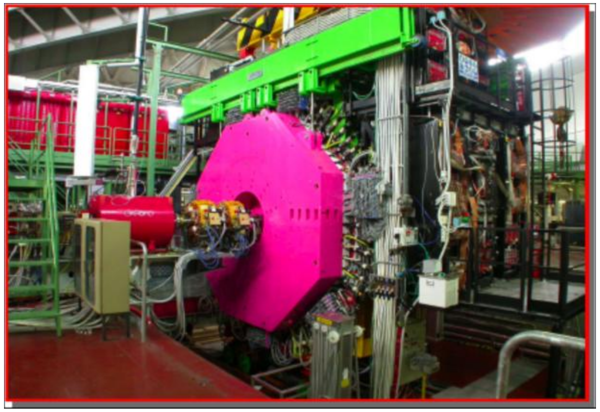


DAΦNE
e+e-
C = 97 m
E = 0.51 GeV (Φ)
Damping ring
Test beam
Linac
Main rings
Run 6757
Event 738533
Date Apr. 20, 99
π+
π−
K_L
K_S
π−
π+
KLOE
DAFNE-Light
DEAR
&
FINUDA

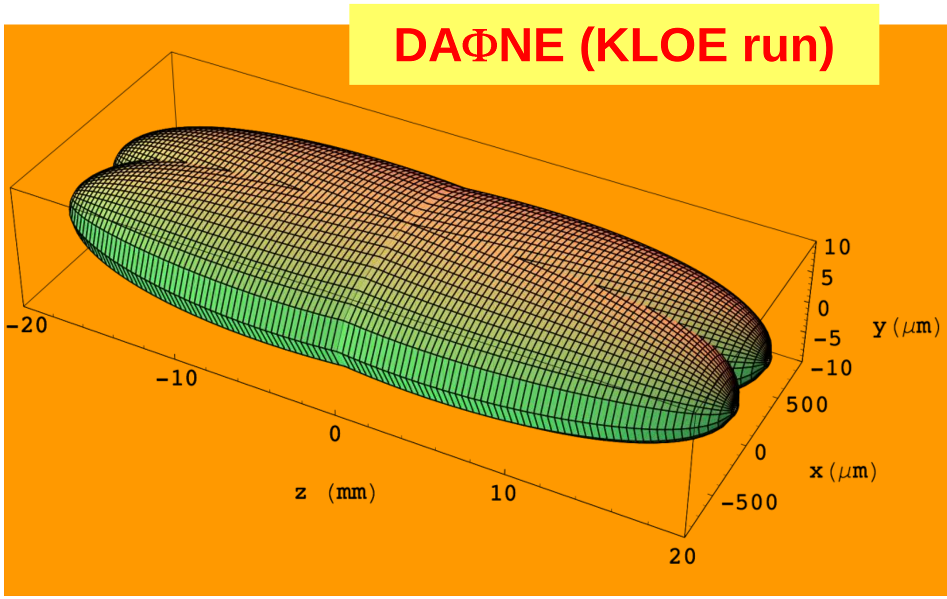
DAΦNE Peak Luminosity

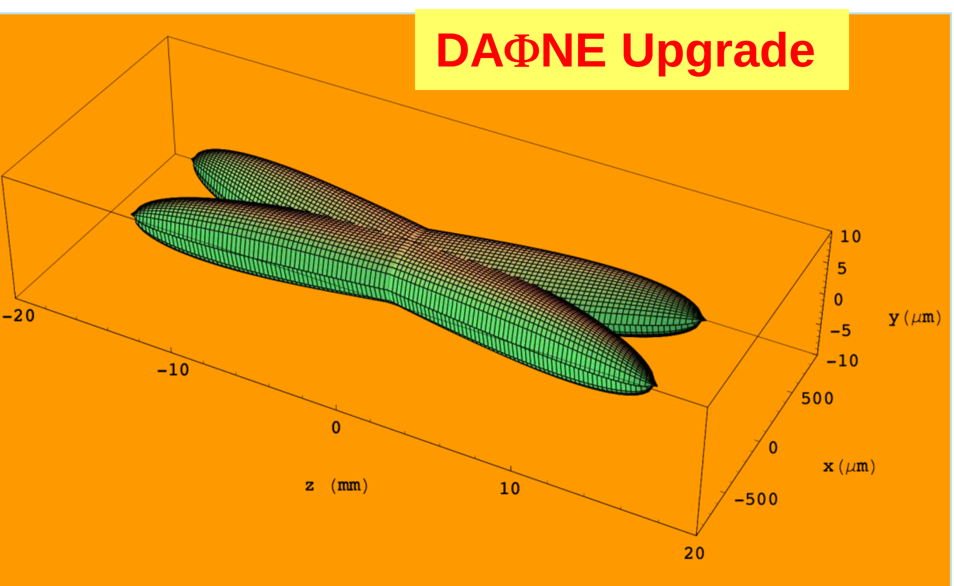






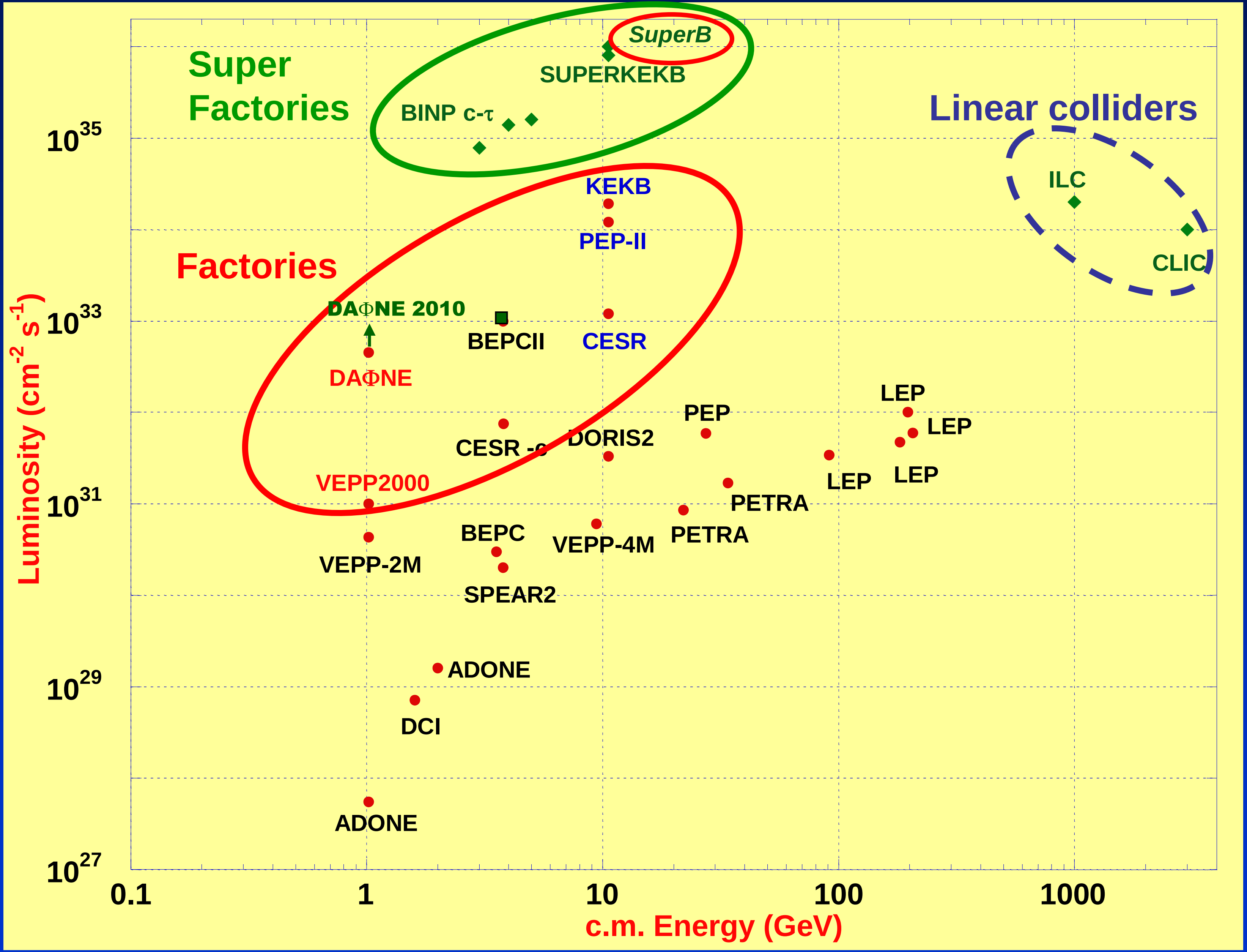
BEAM PROFILES @IP before and after the upgrade





	DAΦNE (KLOE run)	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.8	0.85
β_x^* (cm)	160	26
σ_y^* (μm)	5.4 low curr	3.1
σ_x^* (μm)	700	260
σ_z (mm)	25	20
Horizontal tune shift	0.04	0.008
Vertical tune shift	0.04	0.055
θ_{cross} (mrad) (half)	12.5	25
$\Phi_{Piwinski}$	0.45	2.0
L ($cm^{-2}s^{-1}$)	1.5×10^{32}	$>5 \times 10^{32}$

World e⁺e⁻ colliders luminosity



The SuperB project

M. Biagini on behalf of SuperB Accelerator Team
J. Adams Institute, Oxford, UK, July 9th, 2009

SuperB Accelerator Team

CDR (2007)

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I.Koop, S. Nikitin, E. Levichev, P. Piminov, D. Shatilov (BINP, Russia)
A. Wolski (Cockcroft, UK)
M. Venturini (LBNL, US)
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D. Alesini, M. E. Biagini, A. Bocci, R. Boni, M. Boscolo, A. Clozza, T. Demma, A. Drago, M. Esposito, A. Gallo, S. Guiducci, V. Lollo, G. Mazzitelli, C. Milardi, L. Pellegrino, M. Preger, P. Raimondi, R. Ricci, C. Sanelli, G. Sensolini, M. Serio, F. Sgamma, A. Stecchi, A. Stella, S. Tomassini, C. Vaccarezza, M. Zobov (INFN/LNF, Italy)
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A. Chance, O. Napoly (CEA Saclay, France)
F. Bosi, E. Paoloni (Pisa University, Italy)

SuperB: a 10^{36} cm^{-2} s^{-1} accelerator

- *SuperB* is an international enterprise aiming at the construction of a very high luminosity (10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- Flavor Factory, with location at the campus of the University of Rome Tor Vergata, near the INFN Frascati National Laboratory
- A heavy flavor factory such as *SuperB* will be a complementary window to LHC and ILC
- The physics studies possible at such a machine will provide a uniquely important source of deeper understanding of the NP found at LHC, and if not found, will bring a sensitivity to seeing signs of NP at even higher energies than LHC to help set the scale of NP
- A Conceptual Design Report, signed by 85 Institutions was published in March 2007 (arXiv:0709.0451 [hep-ex])

Accelerator basic concepts (1)

- B-Factories (PEP-II and KEKB) have reached high luminosity (>10^{34} cm^{-2} s^{-1}) but, to increase L of ~ 2 orders of magnitude, bordeline parameters are needed such as:
  - Very high currents ⇒ HOM in beam pipe
    - *overheating, instabilities, power costs*
    - *detector backgrounds increase*
  - Very short bunches ⇒ RF voltage increases
    - *costs, instabilities*
  - Smaller damping times ⇒ Wiggler magnets
    - *costs, instabilities*
  - Crab cavities for head-on collision
    - KEKB experience

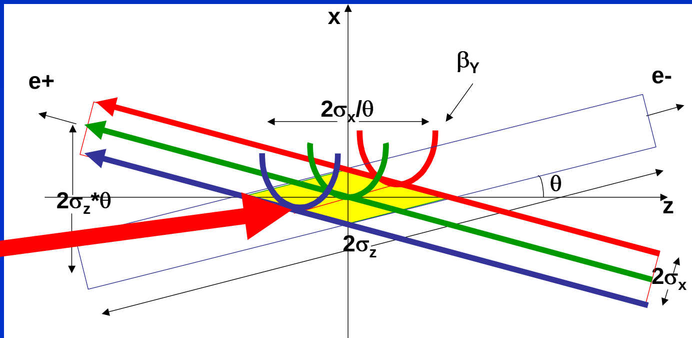
Difficult and costly operation

Accelerator basic concepts (2)

- *SuperB* exploits an alternative approach, with a new IP scheme:
  - Small beams (ILC-DR like)
    - very low emittances, ILC-DR R&D
  - Large Piwinsky angle and "*crab waist*" with a pair of sextupoles/ring $(\Phi = tg(\theta)\sigma_z/\sigma_x)$
    - interaction region geometry
  - Currents comparable to present Factories
    - lower backgrounds, less HOM and instabilities

Requires a lot of fine machine tuning

Small collision area: σ_x/θ

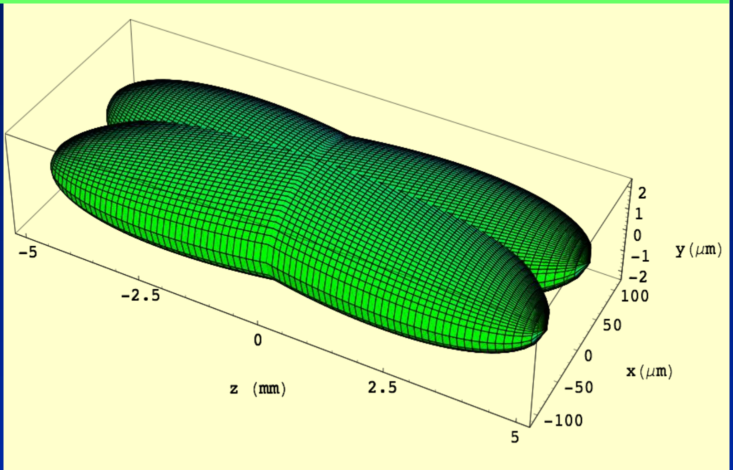


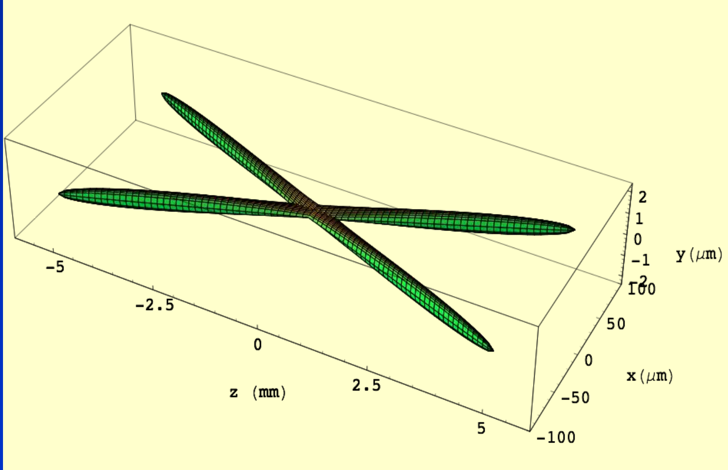
Comparison of SuperB to Super-KEKB

Parameter	Units	*SuperB*	Super-KEKB
Energy	GeV	4x7	3.5x8
Luminosity	10^{36}/ cm^2/s	1.0 to 2.0	0.5 to 0.8
Beam currents	A	1.9x1.9	9.4x4.1
β_y*	mm	0.22	3.
β_x*	cm	3.5x2.0	20.
Crossing angle (full)	mrad	48.	30. to 0.
RF power (AC line)	MW	20 to 25	80 to 90
Tune shifts	(x/y)	0.0004/0.2	0.27/0.3

100 times more luminosity obtained just with 100 times smaller vertical beam

IP beam distributions for KEKB



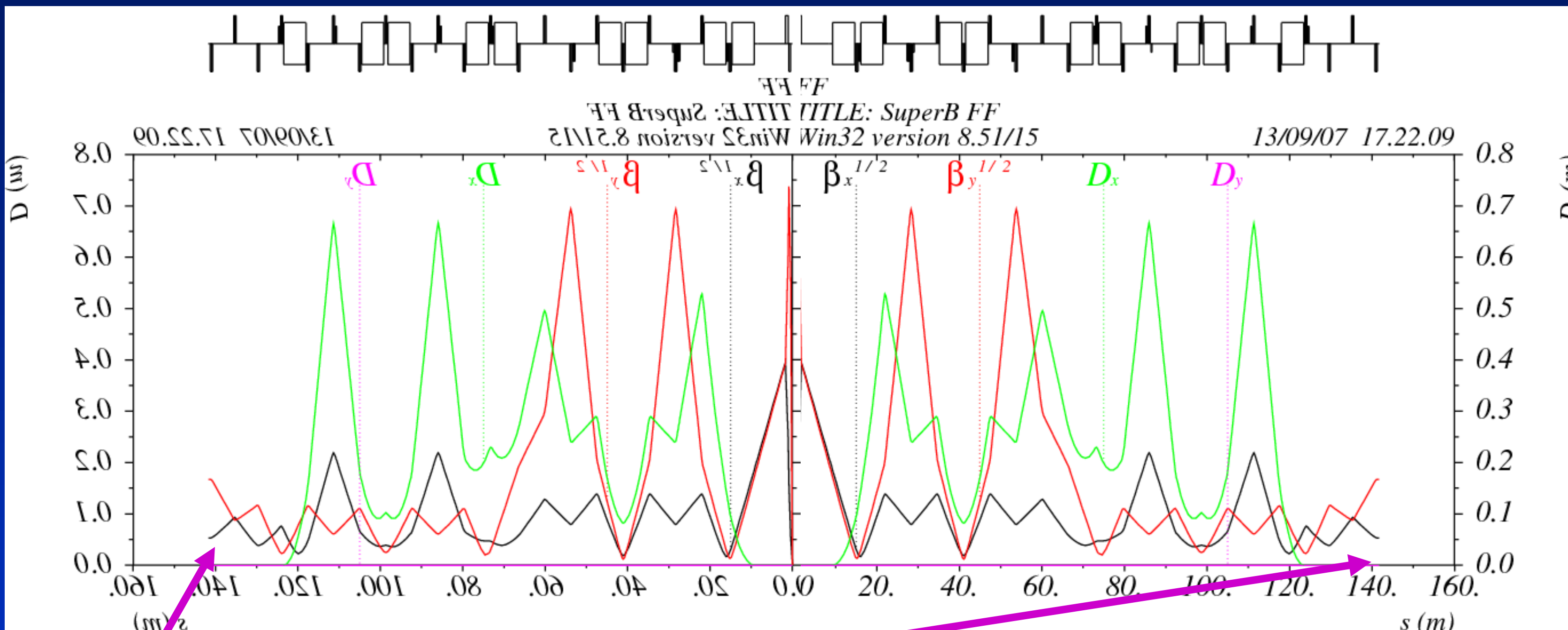


IP beam distributions for *SuperB*

Final Focus

To squeeze the beams to the microns and nanometers level is not that simple.
Nowdays, digital cameras with a set of 10-15 lens in a few cm can easily squeeze-enlarge the “beam” factors 10-20
For an accelerator we need 20-40 lens spread out over hundreds of meters

Final Focus optical functions ($\sqrt{\beta}$)



Crab sextupoles

LER: β_x^* = 35 mm, β_y^* = 220 μ

HER: β_x^* = 20 mm, β_y^* = 390 μ

M. Biagini

Super-B builds on the Successes of Past Accelerators

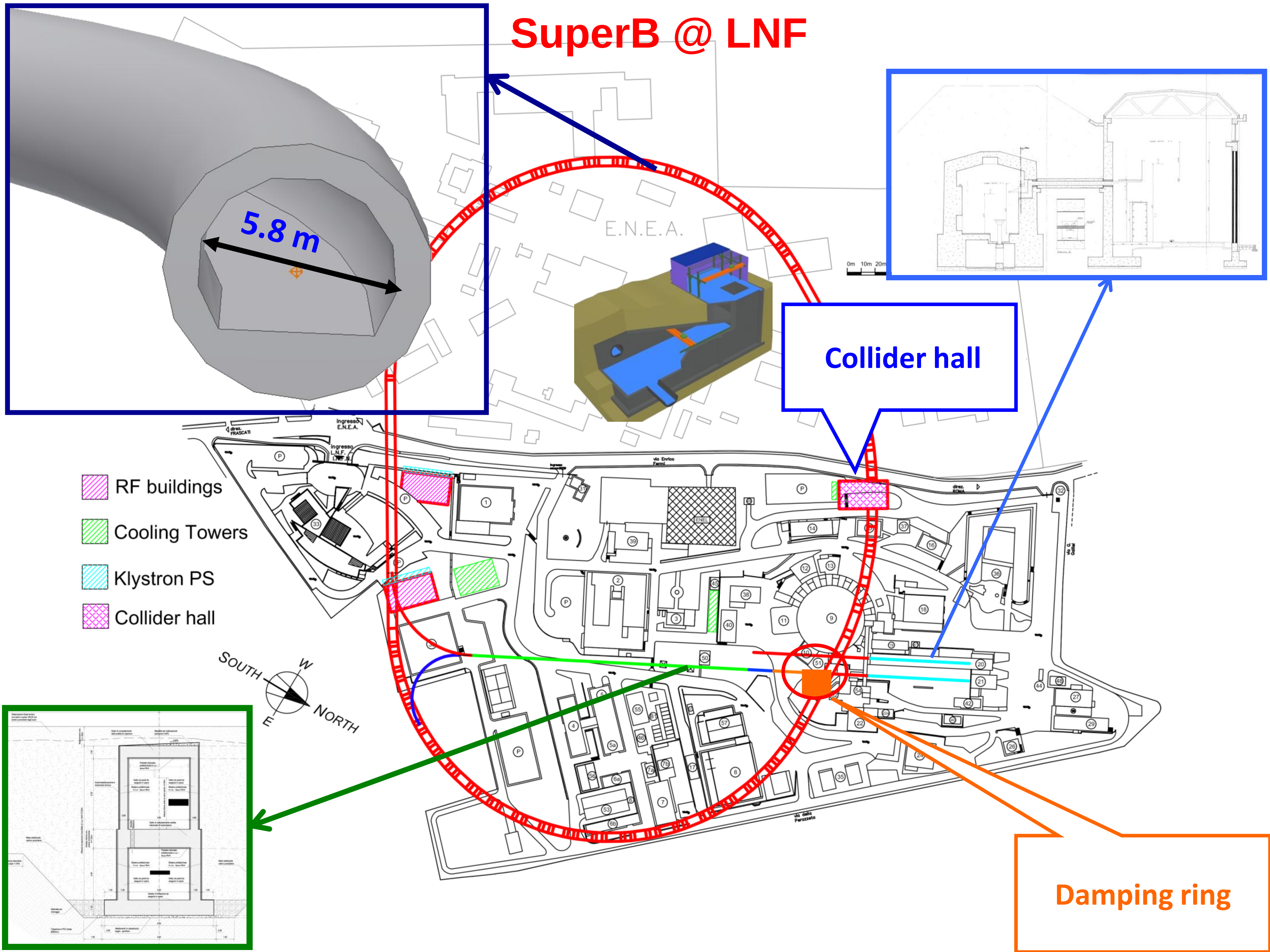
- PEP-II LER stored beam current: 3.2 A in 1722 bunches (4 nsec) @ 3.1 GeV and 23 nm, with little ECI effect on luminosity
- Low emittance lattices designed for ILC damping rings, PETRA-3, NSLC-II, and PEP-X (few nm horizontal x few pm vertical)
- Very low emittance achieved in an ILC test ring: ATF
- Successful crab waist luminosity improvement at DAΦNE
- Successful crab cavity tests at KEKB at low currents
- Spin manipulation tests in Novosibirsk
- Efficient spin generation with a high current gun and spin transport to the final focus at the SLC
- Successful two beams, asymmetric, interaction regions built by KEKB and PEP-II
- Continuous injection works with the detector taking data (KEKB and PEP-II)

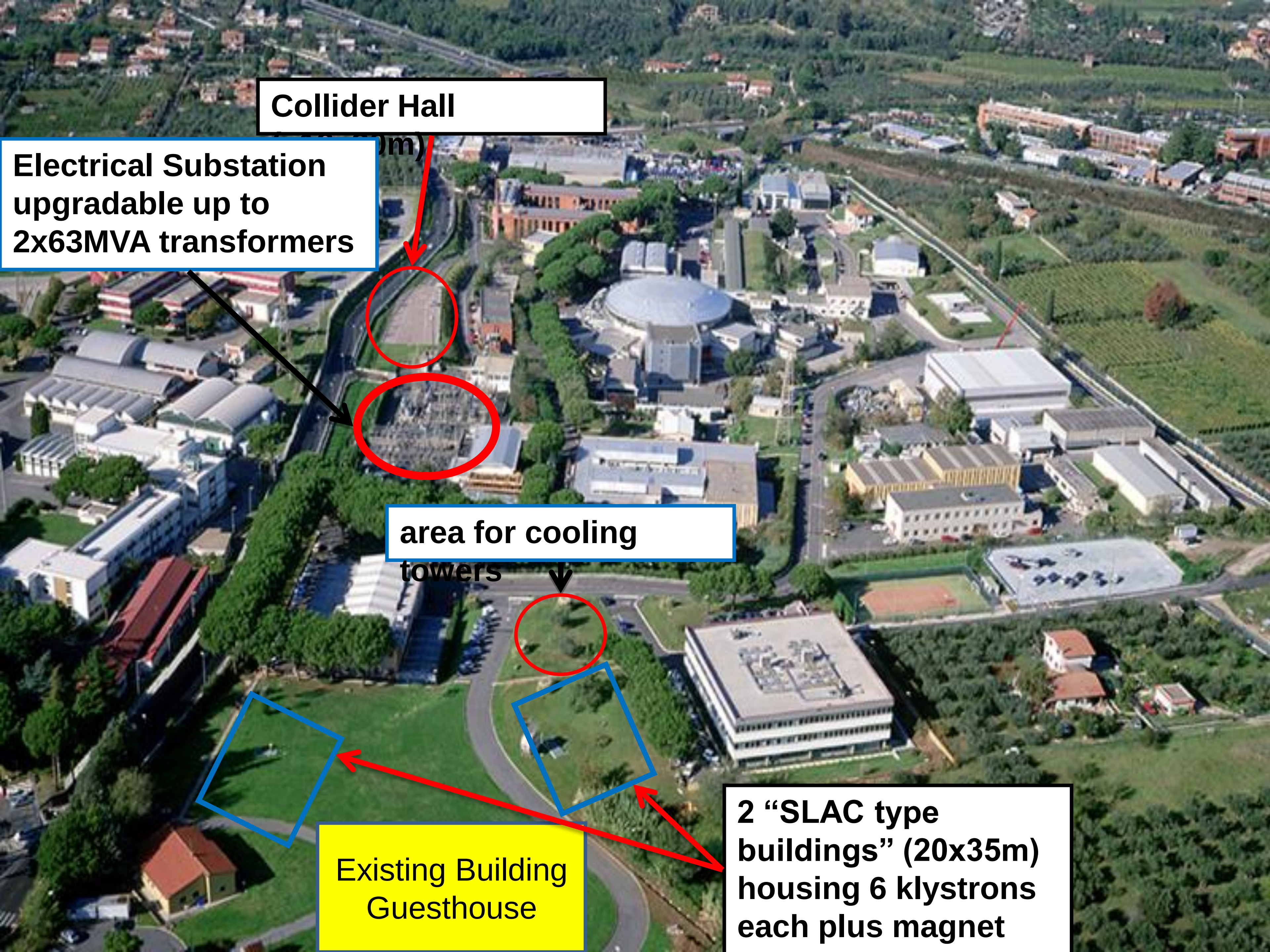
SuperB design challenges

- Beam beam
  - high tune shift
  - strong-strong simulations for large crossing angle
  - effect of tolerances and component errors
- Low emittance
  - tolerances
  - achieving vertical emittance
  - tuning and preserving
  - vibrations
- IR design
  - 50 nm IP vertical beam size
  - QD0 design
  - luminosity backgrounds
- Polarization
  - impact on lattice
  - depolarization time
  - impact on beam-beam
  - continous injection
- Lattice
  - dynamic aperture with crab sextupoles and spin rotator
  - choice of good working point

All are being addressed in view of the TDR

SuperB @ LNF


5.8 m
E.N.E.A.
Collider hall
RF buildings
Cooling Towers
Klystron PS
Collider hall
SOUTH
NORTH
W
E
Damping ring


Collider Hall
Electrical Substation upgradable up to 2x63MVA transformers
area for cooling towers
Existing Building Guesthouse
2 “SLAC type buildings” (20x35m) housing 6 klystrons each plus magnet

Linear Colliders

- Highest CM energy for a lepton collider reached at Lep: about 206 GeV with a luminosity of about 10e32*4 IPs
- Higher energy scaling for a ring makes the complex very big and expensive, doubling the CM energy make the ring at least 4 times longer (>120Km)
- Luminosity does not scale much faster than Ecm (unless you go with schemes similar to the

  B-Factories=> 2 rings)
- RF system much more demanding than the LEP one
- Power consumption very large

- Linear Collider complex scaling closer to be linear w.r.t. Ecm
- First Linear Collider, SLC has been operating until 1998 (10 years ago) at SLAC (SF California)
- Ecm=91.2GeV, L=3*10e30
- Linac about 3Km long + about 0.2Km for the Beam Delivery System (BDS)
- Overall Complex length about 6.4Km for a LC that does not share the Linac for electrons and positrons
- RF: 2857MHz, Gradient 20MeV/m, RF pulse compression with SLED Cavity

- Collision frequency for LC very low 100-1000Hz
- To reach high luminosity need to squeeze the beams much more
- SLC first collider were the beam was just 500nanometers “tall”
- SuperB aims to reach 50nanometers
- Next Linear Colliders target:

1-5nanometers!!!!!!

(Focusing System 2Km Long)

- On the wake of the SLC experience several studies have started since mid 90’s to push the LC Ecm. All the designs mainly concentrate on the biggest problem: have an efficient, reliable and cheap Linac
- All the other ingredients are very similar:

  - Electron and Positron sources

  - Damping Rings

  - Collimation Section and Final Focus

  - Beam Dump lines

- NLC (SLAC) targeted at 1TeVcm

  - Based on increasing the Linac gradient by increasing the RF frequency to 4*SLC: 11.4GHz

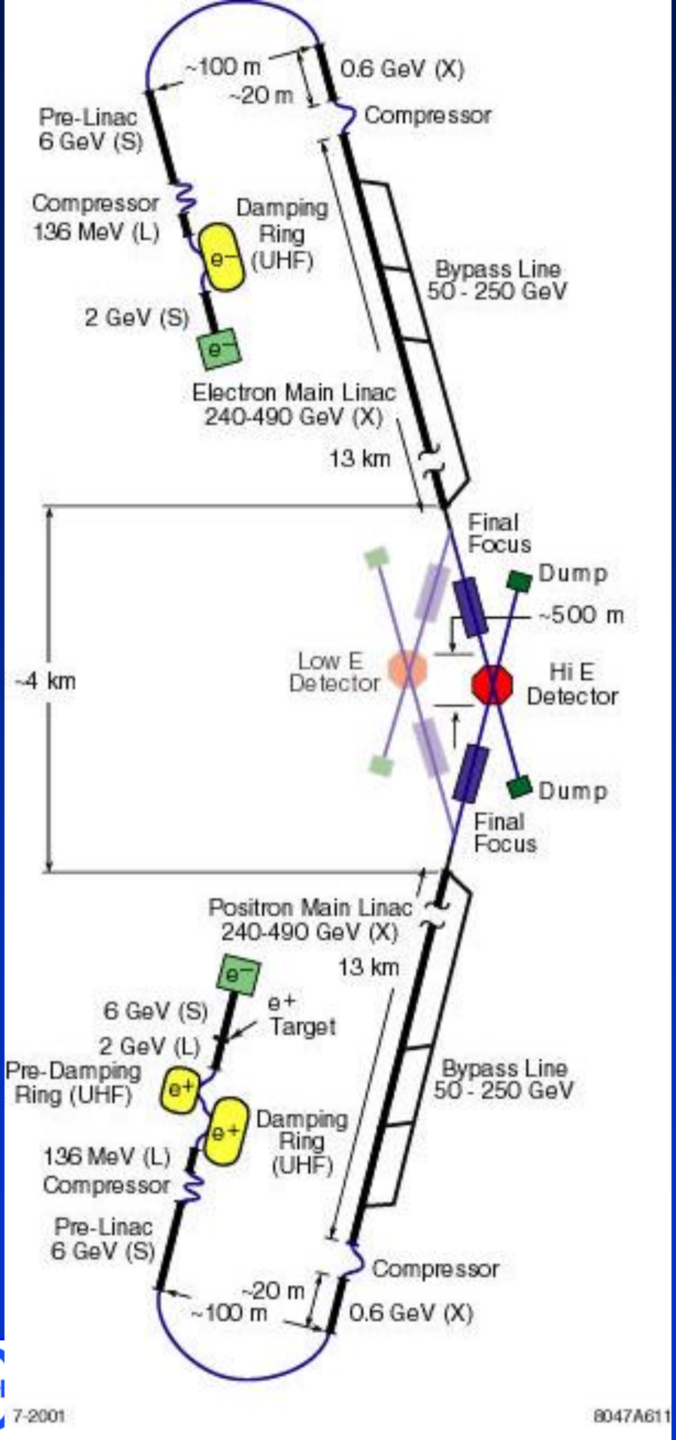
  - RF pulse compression by RF-Delay Lines (about 200Km of Overmoded WaveGuides)

  - Initial goal was about 100MeV/m

  - Lowered to about 70MeV/m

  - Reliably reached about 50MeV/m

  - Site about 25Km long



NLC Layout

SuperB

- ILC targeted at 0.5-1.0TeVcm
  - Based on Superconducting RF
  - RF frequency about 1.3GHz
  - Initial goal was about 20MeV/m
  - Reached up to 40MeV/m
  - Reliably reached about 20MeV/m
  - Site about 25Km long

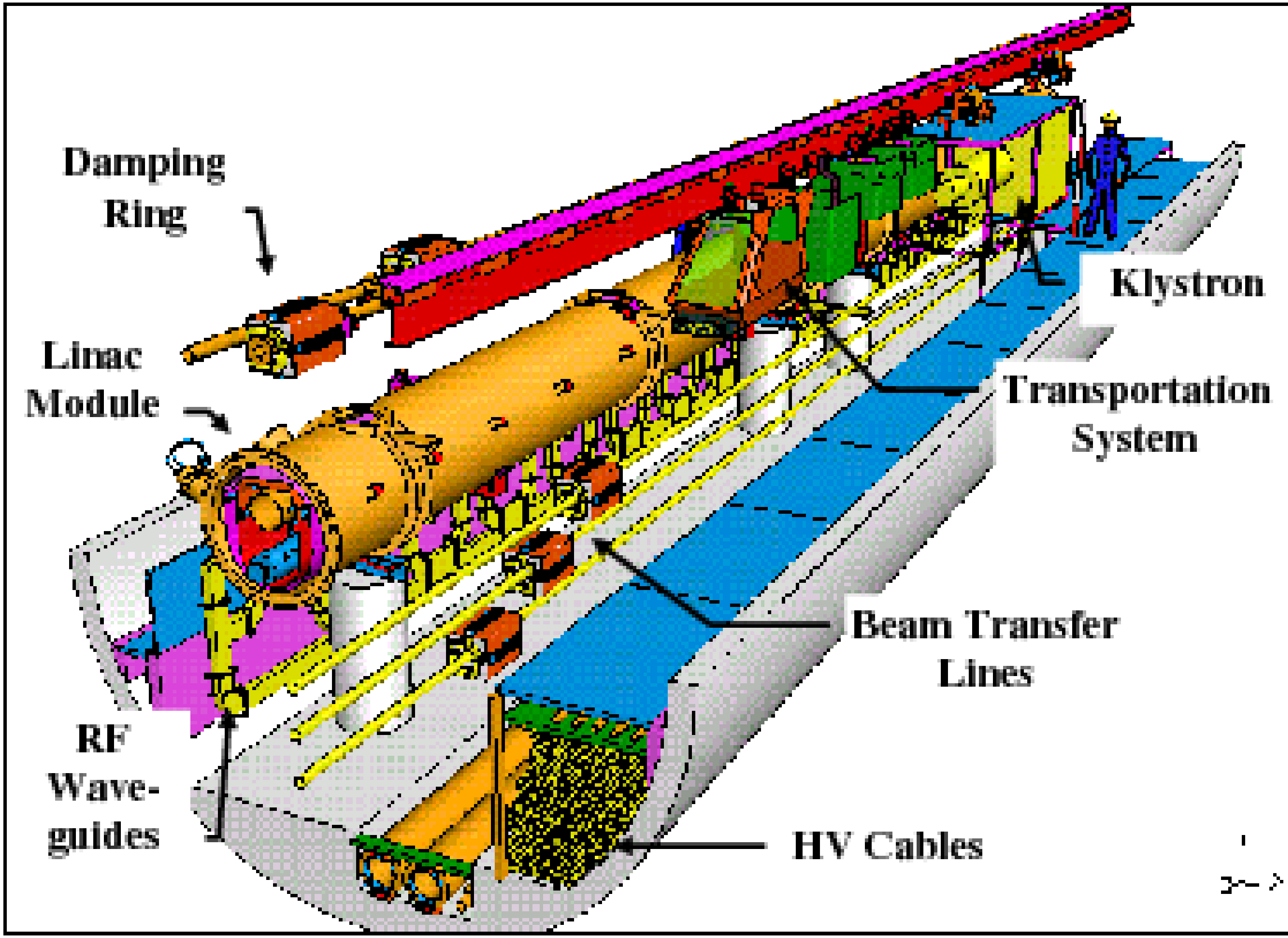
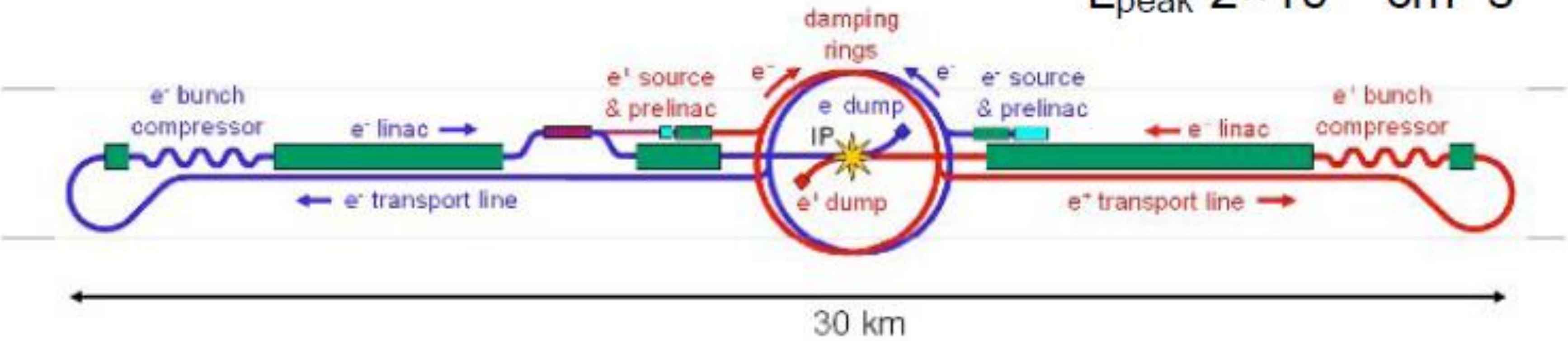


Figure 3.1.5: *Sketch of the 5 m diameter TESLA linac tunnel.*

ILC Layout

E_{CM} 500 GeV
L_{peak} 2×10^{34} $cm^{-2}s^{-1}$



- Polarized e^- source based on a photocathode DC gun
- Undulator-based e^+ source, driven by 150 GeV electrons
- 5 GeV e^- and e^+ damping rings (DR)
- Two 11 km long main linacs, with 1.3 GHz SCRF cavities
- A single interaction region shared by two detectors, 14 mrad crossing angle

- CLIC (CERN) targeted at 3TeVcm

Based on increasing the Linac gradient by increasing the RF frequency to 10.5*SLC: 30GHz

- RF pulse compression by Drive Beam Compression

- Initial goal was about 250MeV/m

- Lowered to about 200MeV/m

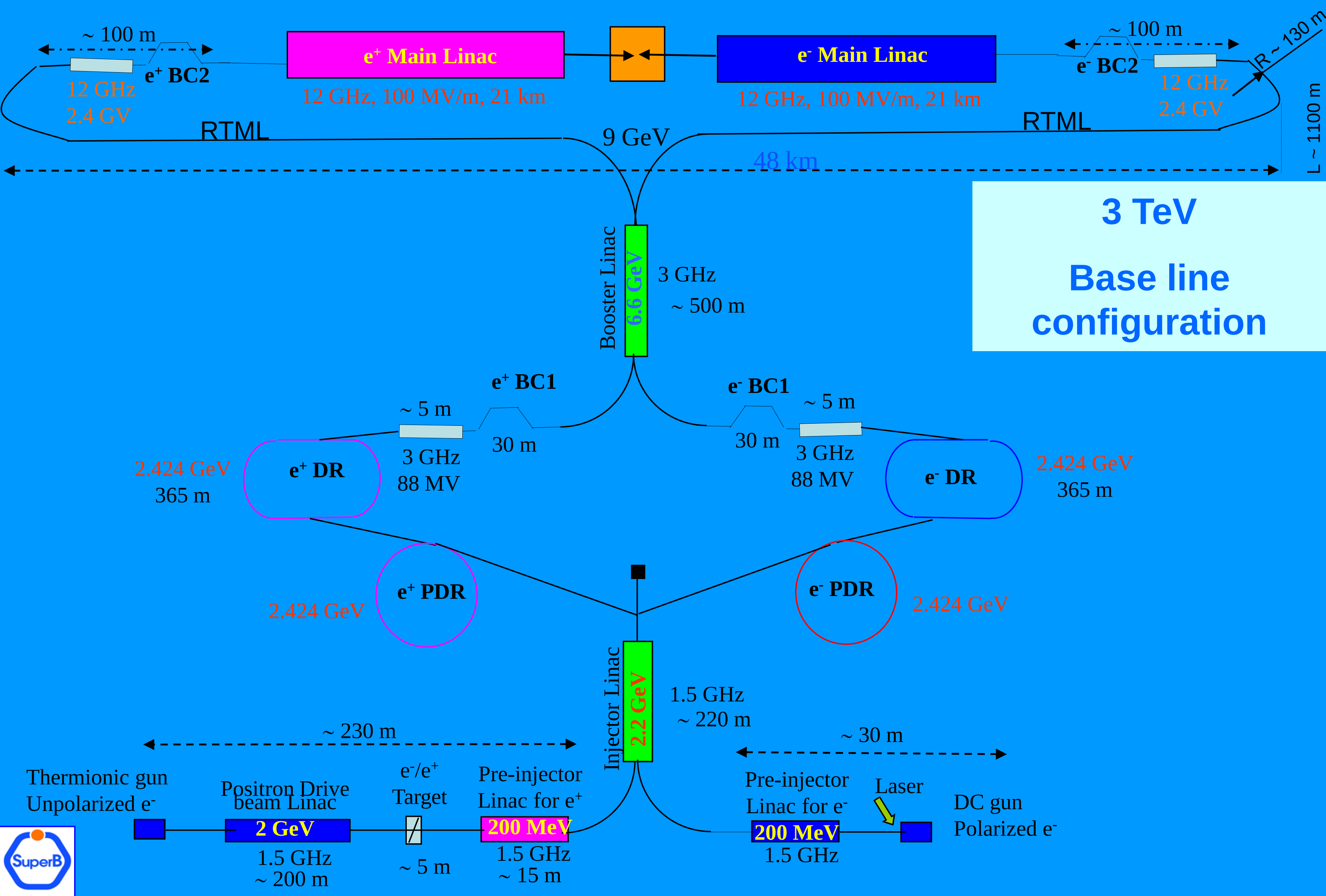
- Reached about 100MeV/m

- Lowered RF frequency to 12GHz

- Reached about 100MeV/m

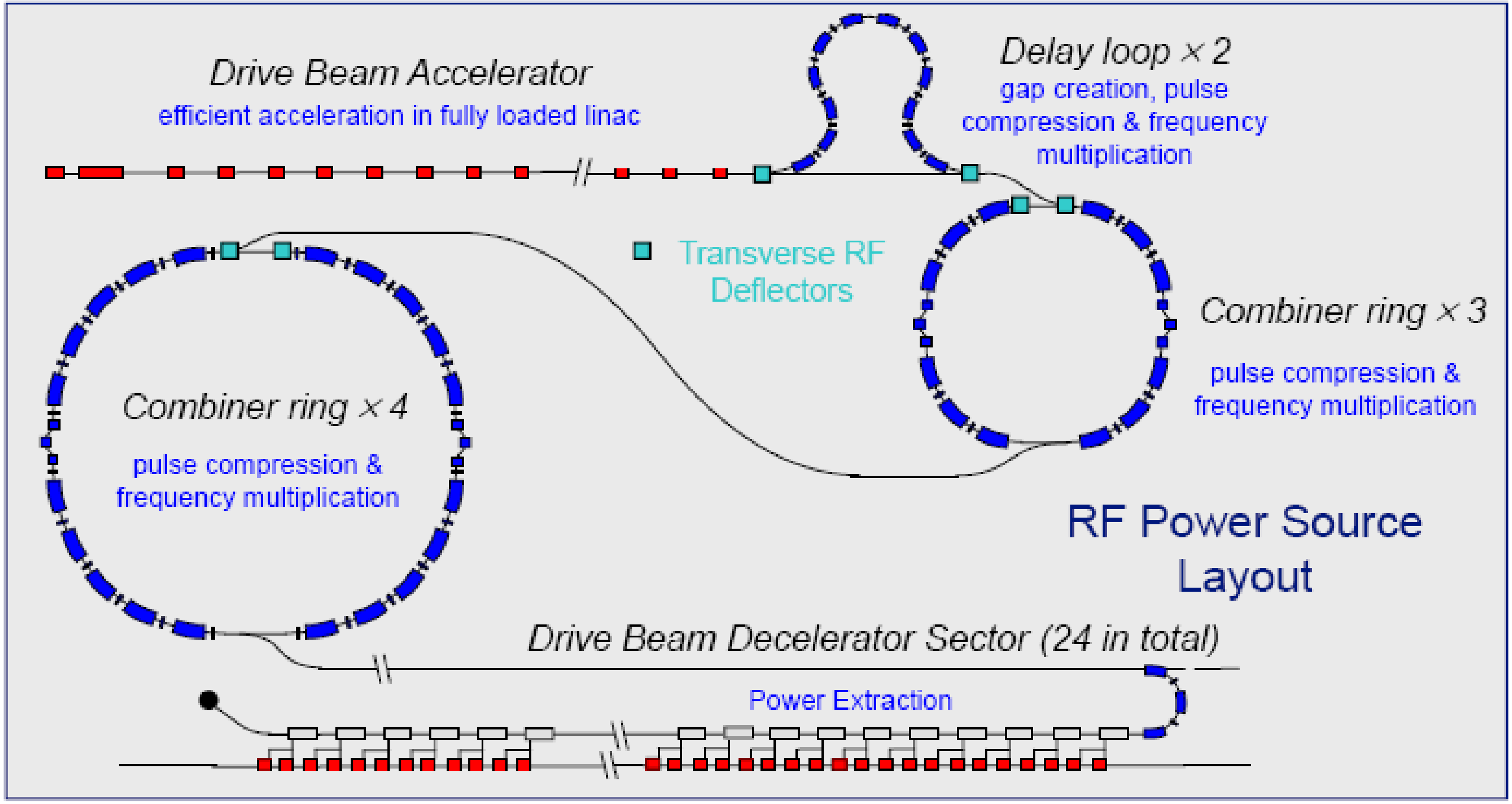
- Site about 50Km long

CLIC main Beam Layout

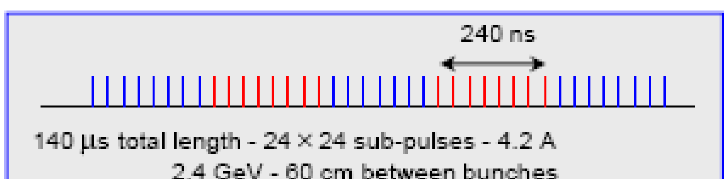


Drive Beam Generation Complex

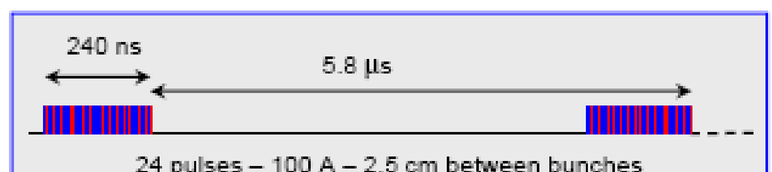
R. Corsini, J.B. Jeanneret, F. Stulle



Drive beam time structure - initial



Drive beam time structure - final



- CLIC has been steadly progressing on its own track, mainly thanks to the fact that is based at CERN and has a solid (although much smaller than ILC) group.
- The design has been evolved through the years
- The requirements on the Drive Beam have been easied.
- The RF frequency has been lowered down to the original NLC one, where a lot of know was available
- The beam dynamics in all the subsystems (DR Linac BDS) is very similar to the one extensively studied for NLC, and deemed mostly feasible by the accelerator community

- The Third CLIC Test Facility (CTF3) has been running since a few years and is producing more confidence on the feasibility of the Two-Beam-Accelerator
- Much more tests and R&D is scheduled
- There is a very aggressive plan to produce:

  - A CDR by 2010

  - A complete prove of principle of the Acceleration Complex (Drive Beam and Linac)
- The time frame for ILC is getting closer and closer to the CLIC one

Conclusions

- Worldwide effort through the years on Accelerators Development has spread on different approaches and solutions, to meet the more and more demanding requirements from the Particle Physics Community (PPC)
- So far “by chance?” the progress on Accelerators technology has had a close correspondence with the PPC needs.
- Do we seen hints that this marriage is about to end?