Status of LEP2

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Outline

- Optics and RF for 1998
- Beam current limitations
- Injection and ramp
- Performance at high energy
- Conclusions

A low emittance optics

After 5 years of operation with the 90°/60° optics (1993-1997) we have switched to a low emittance 102°/90° optics following a successful test at the end of the 1997 run.

Main visible differences & advantages :

+ : Smaller horizontal emittance/beam sizes.

+ : Achievable beam energy is 0.3 GeV higher.

(–) : Poorer performance at 45 GeV.

– : Shorter bunches.

Note : I will always quote BEAM energies.

More RF

The 1998 RF system consists of :

- 272 (16 Pure Nb) SC cavities
- 48 Cu cavities

→ nominal total voltage of 2870 MV
(SC RF gradient of 6 MV/m)

The physics energy is 94.5 GeV :

- Energy loss per turn = 2.33 GeV
- The minimum RF voltage is ≈ 2600 MV for a horizontal damping partition number $J_x = 1.6$. Loss of ≈ 0.6 GeV compared to $J_x = 1$.
- RF margin :
  1 Power Conv. trip (160 MV) ⊕ 4% reserve

Cryogenic cooling power limitations

The required dynamic cooling power depends on :

- the accelerating field gradient E_a :

$$P_{cryo}^{rf} \sim E_a^2/Q(E_a)$$

$Q(E_a)$ = cavity Q-value

- the beam ("discovered" in 1996 !) :

$$P_{cryo}^{beam} \sim Z(\sigma_s)\ 2\ n\ I_b^2$$

I_b = bunch current, n = # of bunches/beam,
σ_s = bunch length

With the presently available cooling power, I_b is limited to :

Maximum $I_b \simeq 850\ \mu A$ ($I_{tot} \simeq 6.8$ mA)

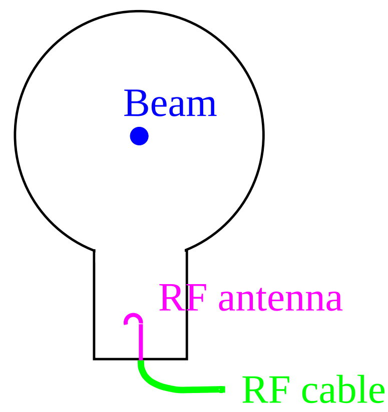
with 2 beams of 4 long bunches ($\sigma_s > 10$ mm).

The LEP cryoplants will be upgraded for 1999 to allow higher currents and gradients.

RF cable limitations

Each 4-cell cavity has 2 pick-up antennas to sample the field. The signals are used for cavity tuning ...

Unfortunately the port used to insert the RF antenna acts as a resonator for Higher Order Modes (HOM) induced by the beam (2-3 GHz).



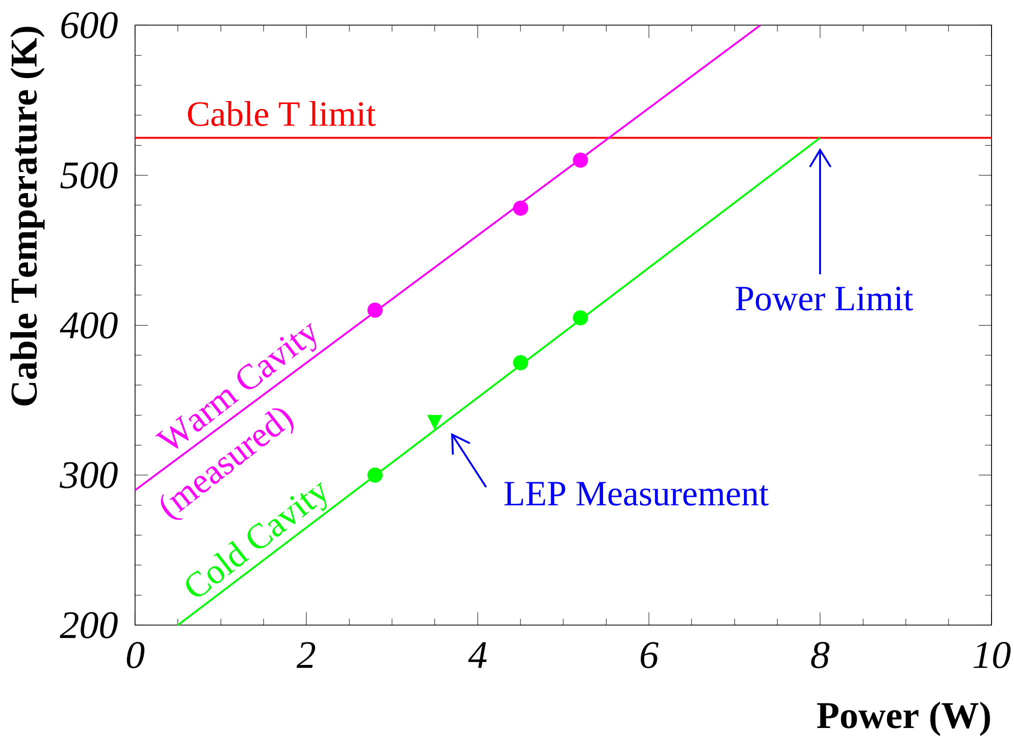
Consequences :

- Energy dissipation → contribution to P_{cryo}^{beam} (Bellows between cavities may also contribute)
- The well insulated antenna cable heats up and can be damaged by (too) high temperatures.

Short bunches excite more high frequency HOMs
→ keep bunches long !

Antenna cable power

Laboratory tests have been used to define a limit for the power transmitted by the antenna cables :



→ Maximum transmitted power = 8 W

The power is monitored in the LEP Control Room for 2 RF cables. Critical parameters :

- Bunch currents
- Bunch length

Antenna cable damage and repair

Antenna cable status :

- For RF modules installed in 1997 most cables were found "damaged" (modified electrical properties).
- 6 cables have been destroyed in 1998.
- 1 cavity has both cables destroyed, but it was recovered by tuning it on the forward and reflected RF power → Fall-back solution !

The next technical stop will be extended up to a maximum of 6 days for the RF group to test the replacement of the cables. This operation is delicate because the cables are inside the insulation vacuum.

It is planned to replace all RF cables in the coming winter shutdown.

1998 Startup

The LEP startup was smooth :

- 6th May : Circulating beam with the $60^\circ/60^\circ$ optics (problem with a SC quadrupole in IP2)
- 9th May : First beam with the $102^\circ/90^\circ$ optics
- 14th May : Z calibration run $\rightarrow$ 24th May
- 19th May : Single beam at 94.5 and 96.5 GeV
- 25th May : First physics at 94.5 GeV

Z calibration run

The Z calibration run :

- Each beam had 4 trains of 2 bunches.
- The maximum bunch current was 250 μA.
- $\mathcal{L} = 6 - 7 \cdot 10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 2.5 pb^{-1} were delivered in 11 days .
  A large fraction of this period was used to prepare the RF system and optics for the high energy run.

This modest performance was expected :

- The low emittance $102^\circ/90^\circ$ optics is not suited for physics at 45 GeV.
- Commissioning a dedicated optics for the calibration run would not have gained any time.

Injection and ramp

Injection at 22 GeV :

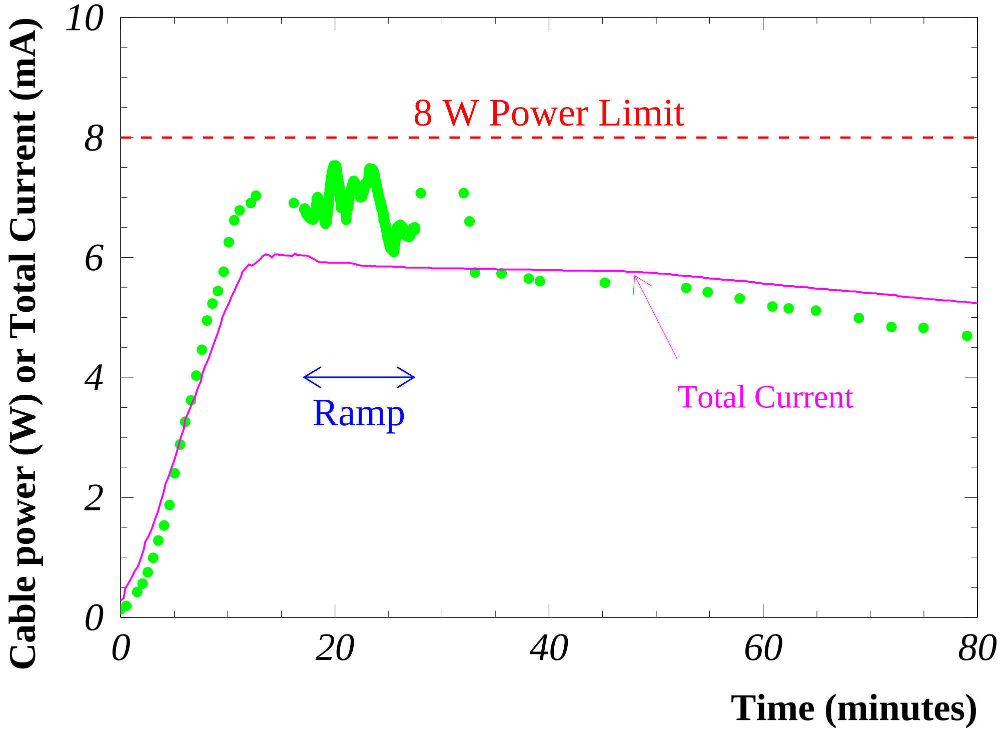
- No major problems.
- All RF ON (530 MV, $Q_s = 0.133$)
  $\rightarrow$ oscillating RF units (sometimes)
- Routinely accumulate $I_b \approx 760\ \mu A$ ($I_{tot} = 6.2$ mA)
- $I_b = 870\ \mu A$ obtained with a single beam.

Ramp :

- It took time to develop a ramp with good transmission and long bunches!
- The ramp is now stable for the present currents.
- The bunches are lengthened by :
  - Keeping the wigglers on at higher energies.
  - Shifting the RF frequency by +100 Hz.
  - Tuning the RF voltage while maintaining space between machine resonances to avoid beam losses.

The (powerful) ramp

Power transmitted by one antenna cable :



- The power is (anti) correlated to bunch length.
- The power fluctuates from ramp to ramp for the same current (↔ orbit).
- 8.5 W → BEAM DUMP (fired once !)
- To push the current further we need to control the bunch length even better...

RF system at high energy

The RF system performance was good :

- Many RF units can run at 6.3 MV/m .
- More margin → good for efficiency.
  6.5% of the fills were lost due to RF.
- All luminosity was delivered 94.5 GeV.
  In 1997 : ∼ 5% of the luminosity was delivered below 91.5 GeV (the target energy was 92 GeV).

HOM couplers : a recent worry ...

- Some SC HOM couplers show an increase of the outlet He gas temperature ↔ dissipation ?
  → triggers RF trips (interlock)
- One HOM coupler quenches.
- Related to the beam (current).
- This "phenomenon" is monitored by the RF group !

Luminosity optimisation

For head-on collisions :

$$\mathcal{L} = \frac{nI_b^2}{4\pi e^2 f \sigma_x \sigma_y}$$

$\mathcal{L}$ optimisation involves a lot of work on the beam sizes σ_u $(u = x, y)$:

$$\sigma_u^2 = \beta_u^* \varepsilon_u + (D_u \sigma_\delta)^2$$

where :

- β_u^* : optical (betatron) function at the IP.
- ε_u : beam emittance.
- D_u : local dispersion, ideally $D_u = 0$, not measurable at the IP (with good accuracy).
- σ_δ : relative energy spread ($\simeq 0.17\%$).
- Assumes no coupling between the planes.

Horizontal beam size optimisation

- Optics :

$$\varepsilon_x(102^\circ/90^\circ) = 0.78 \cdot \varepsilon_x(90^\circ/60^\circ)$$

- RF frequency +100 Hz (+120 Hz at end of fills) : Redistribution of the damping (Hor. damping partition number J_x shifted from 1 to 1.6)

$$\varepsilon_x \rightarrow \varepsilon_x/1.6$$

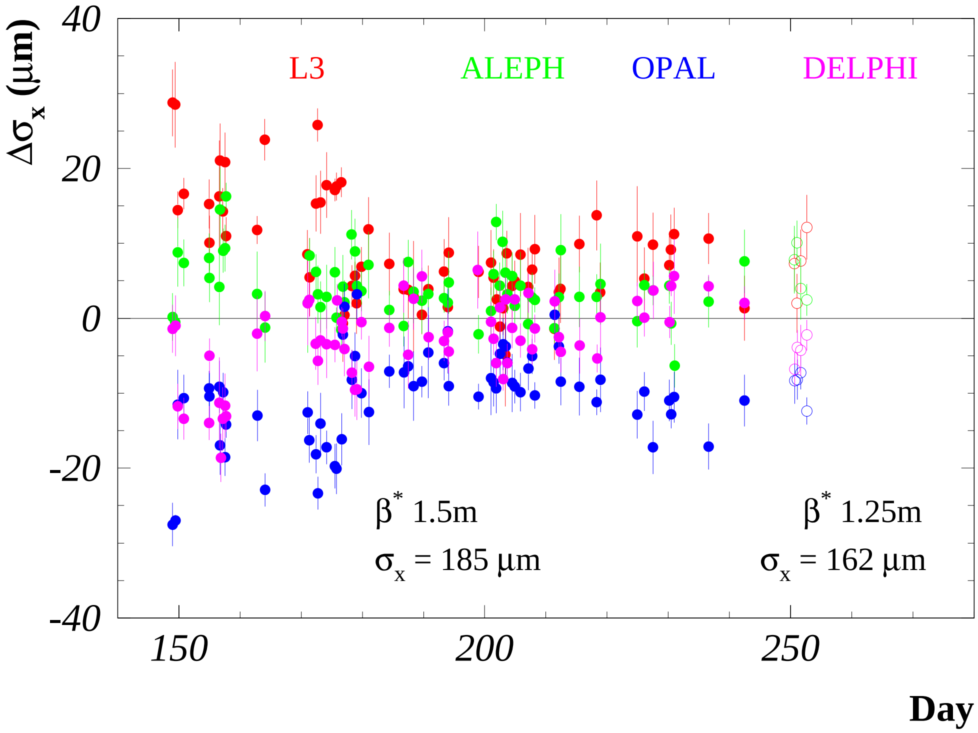
  Note associated energy shift of -0.17 GeV !
  94.5 GeV → 94.33 GeV

- Squeeze β_x^* :
  2 m → 1.5 m (May 29th)
  1.5 m → 1.25 m (Sept 8th)
  Limited by momentum aperture and background.

- D_x : negligible.

Horizontal β^*

- In August the OPAL $\mathcal{L}$ increased to 10-20% above the average following a drift of β_x^* from 1.5 to 1.2 m.



$\Delta\sigma_x$: difference of σ_x wrt the average.

- Following this "accidental success" β_x^* was reduced to 1.25 m in all IPs.
- The main gain in performance seems to come (for the moment) in the second half of fills.

Vertical beam size optimisation

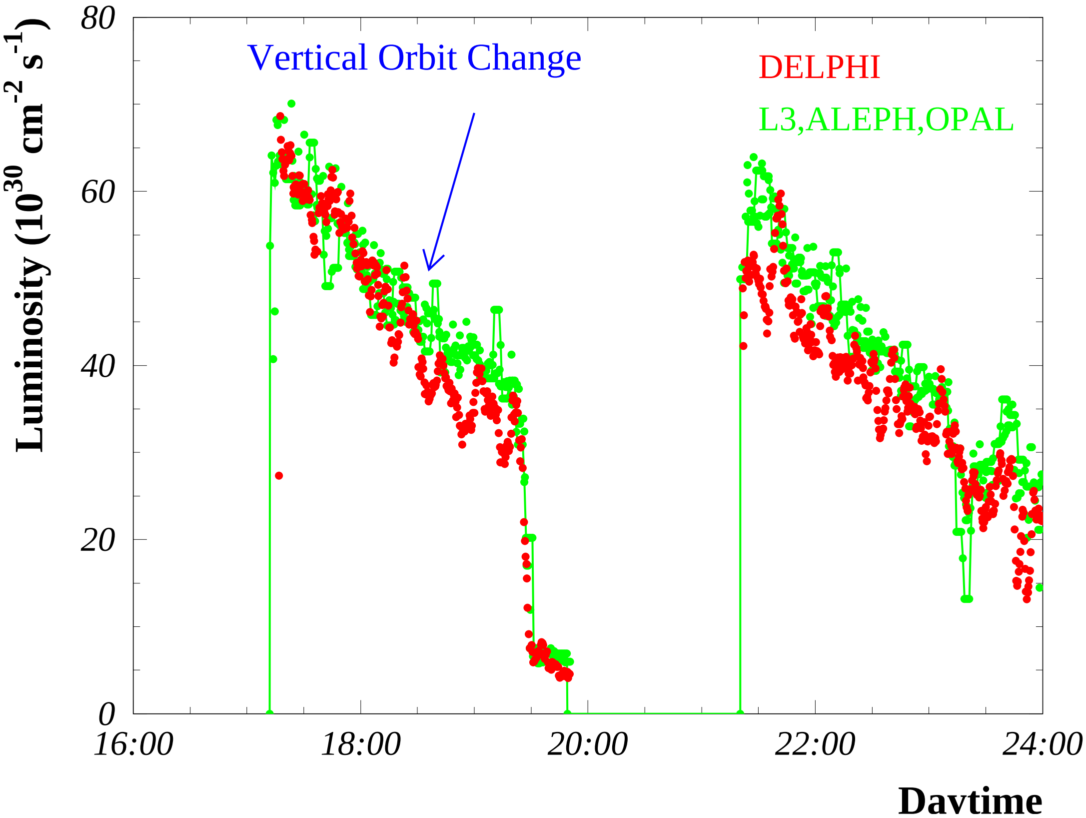
Key parameter for the vertical plane :
Orbit

- ε_y and D_y depend strongly on the orbit.
- $\mathcal{L}$ is optimised empirically by finding a "Golden Orbit" using well chosen orbit correction algorithms. Golden Orbits need constant retuning.
- Optimum $\sigma_y \simeq 3.5 - 4.5\mu\text{m}$.
- The coupling with the horizontal plane must be well corrected (solenoids).
- A strong beam-beam interaction at the IP can also blow up to beams. We actually have some evidence (specific luminosity, vertical beam size) of blowup.

Golden Orbits and dispersion

- For weeks the DELPHI luminosity was 10% low.
- σ_y was 10% larger in DELPHI and it was not related to β^* ...
- The problem was cured on July 20th by a small orbit and D_y change .

Effect on the DELPHI $\mathcal{L}$ of the orbit and D_y change :



Performance at 94.5 GeV

Operation at 94.5 GeV is very smooth.

The 102°/90° optics is performing very well !

- Peak performance :

Year	$\mathcal{L}$ ($cm^{-2}s^{-1}$)	I_b (μA)	Max. ξ_y
1996	$3.4\ 10^{31}$	520	0.040
1997	$5.0\ 10^{31}$	650	0.055
1998	$7.4\ 10^{31}$	740	0.062

Note : beam-beam tune shift $\xi_y \sim \mathcal{L}/I_b$.

- Efficiency (physics/total time) : 47%

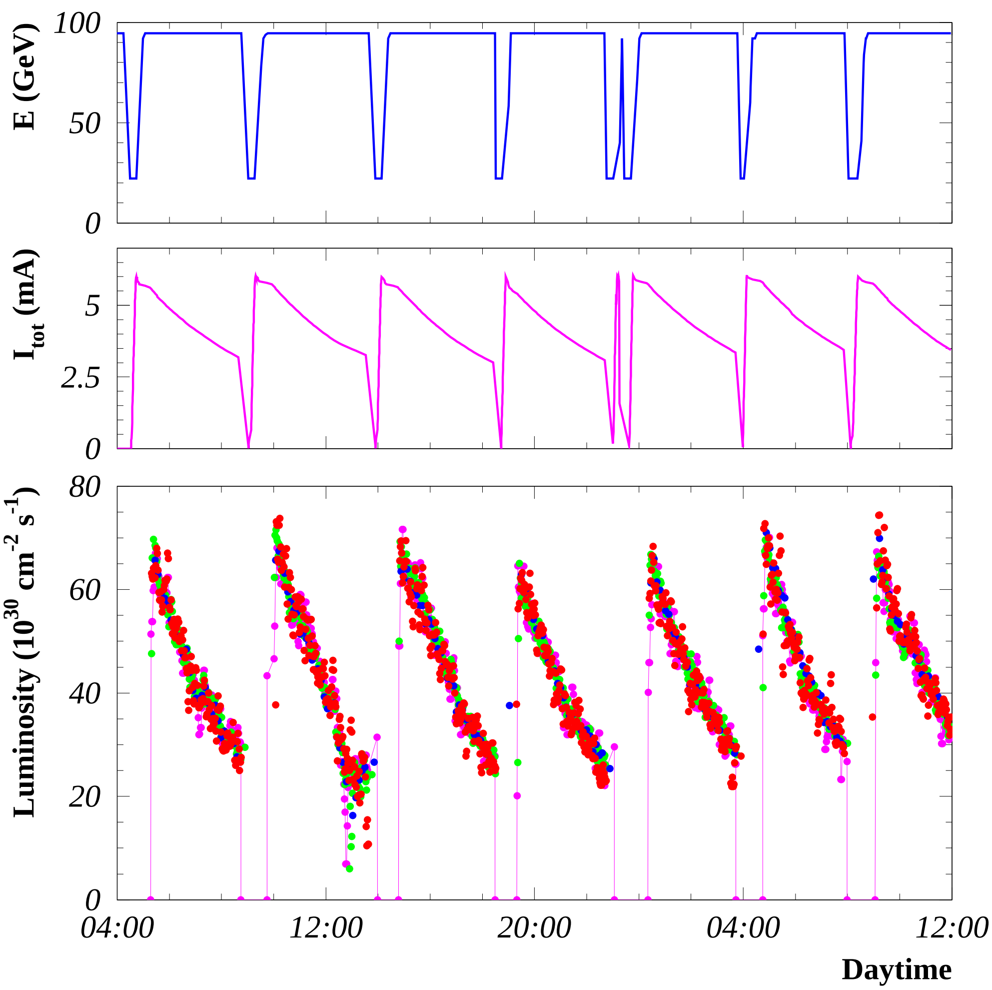
  Contributions to the down-time :
  - SPS & CPS : 50%.
  - RF : 13%.
  - ...
- Typical turn-around time : 70 minutes

  record time : 48 minutes

Approaching 3 pb^{-1}/day !

Best integrated luminosities :

- $2.9\ \text{pb}^{-1}$ over 24 hours
- $2.5\ \text{pb}^{-1}$ in a single day (00:00 to 24:00)



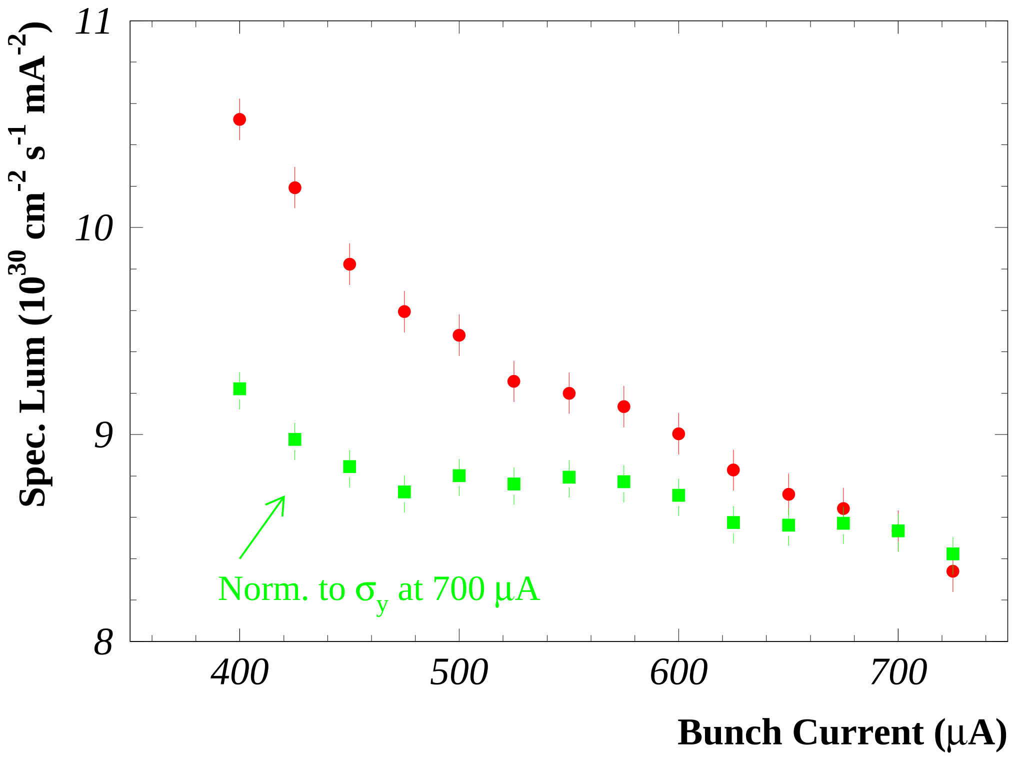
→ maximum efficiency of ∼ 80% !

The Beam-beam Limit

Beam-beam interaction regimes, characterised by the maximum beam-beam tune shift ξ_y^{max} :

- Below limit : $\mathcal{L} \sim I_b^2 \ (\xi_y \sim I_b)$
- Above limit : $\mathcal{L} \sim I_b \ (\sigma_y \sim I_b, \ \xi_y = \xi_y^{max})$

At 94.5 GeV the beam size increases slightly with I_b (data from August).

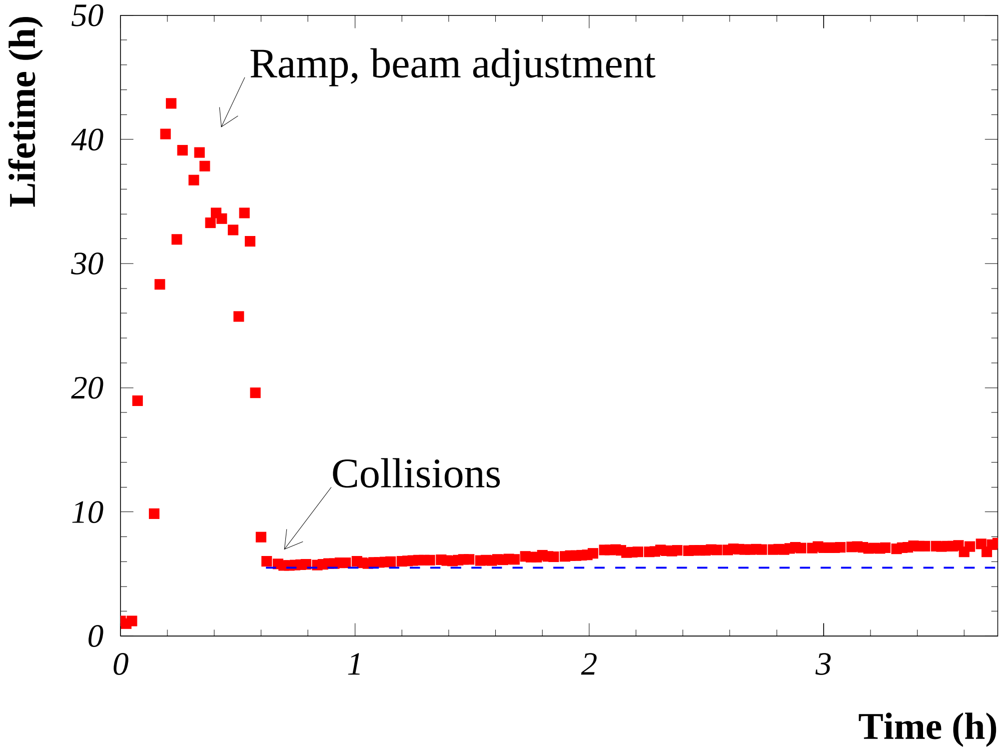


Beam Lifetime

The beam lifetime τ in collisions is dominated by beam-beam Bremsstrahlung :

$$1/\tau \sim \mathcal{L}/I_b \sim \xi_y \qquad (1)$$

The better the performance, the faster it decays !



Luminosity lifetime is $\approx \tau/2 \simeq 3$ hours.

The typical fill length is 3.5 hours.

Backgrounds

- Baseline background situation is good.
- Periodic "background storms" : related to particles hitting resonances. Tune changes are the usual cure.
- With $\beta_x^* = 1.25$ m situation is more delicate.

OPAL :

- Off-momentum background due to poor vacuum in Cu cavities at the start of the run.

DELPHI (ALEPH) : Most sensitive IP !

- Most sensitive to background storms.
- Related to the mask-protecting QS3/4 quadrupole collimators which cannot be closed as tightly as in IPs 2 and 6.

Conclusions

- 1998 "Hot" topic : antenna cables !
  Good ramps with high currents and long bunches were difficult to set up !

- The 102°/90° optics and LEP perform well.
- The integrated $\mathcal{L}$ should exceed 150 pb^{-1}.

- The future is in the hands of the LEP RF group...