Contents:

- Luminous Region for Collision of Long Flat Bunches
- Collisions with Displaced Beams at Point 8
- Feasibility of 50 ns Bunch Spacing

Frank Zimmermann & Walter Scandale

3 upgrade options

- 12.5 ns spacing, ultimate intensity
- 25 ns spacing, 2x ultimate intensity, 2x transverse emittance **New!**
- 75 ns spacing `4x intensity, long bunches

parameter	symbol	nominal	ultimate	baseline	alternative	backup
transverse emittance	ε [μm]	3.75	3.75	3.75	7.5	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	3.4	6
bunch spacing	Δt [ns]	25	25	12.5	25	75
beam current	I [A]	0.58	0.86	1.72	1.72	1
longitudinal profile		Gauss	Gauss	Gauss	Gauss	flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	3.78	14.4
beta* at IP1&5	$\beta*$ [m]	0.55	0.5	0.25	0.25	0.25
full crossing angle	θ_c [murad]	285	315	445	630	430
Piwinski parameter	$\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0.75	0.75	2.8
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	9.2	9.2	8.9
events per crossing		19	44	88	176	510
Initial lumi lifetime	τ_L [h]	22	14	7.2	7.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.7	2.7	2.1
	$T_{run,opt}$ [h]	21.2	17.0	12.0	12.0	9.4
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6	3.6	2.9
	$T_{run,opt}$ [h]	15.0	12.0	8.5	8.5	6.6
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	13.34 (7.85)	2.56 (2.05)	0.26
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.5	0.5	0.29
image current heat	P_{IC} [W/m]	0.15	0.33	1.87	3.74	0.96
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	0.113 (1.13)	0.11 (1.13)	0.07 (0.7)

?!

due to the crossing angle, colliding long bunches does not mean the events are spread out over a large area

rms length of luminous region $$\frac{1}{\sigma_l^2} \approx \left(\frac{2}{\sigma_z^2} + \frac{\theta_c^2}{2\sigma^{*2}_{x,y}} \right)$$

	nominal	ultimate	baseline	alternative	backup
σ_l [cm] w/o	**4.5**	**4.3**	**2.1**	**2.1**	**3.5**
& *w.crab cr.*	*5.3*	*5.3*	*2.6*	*2.6*	*(10.2)**

luminous region is largest for nominal LHC

*long bunch scenario assumes no crab crossing

optimum run time, integrated luminosity, etc.

$$\frac{1}{N_b}\frac{\Delta N_b}{\Delta t} = n_{IP} L \sigma \frac{1}{n_b}\frac{1}{N_b} + c\left(\frac{N}{V}\right)_{vac}\sigma_{vac}$$ collisions, gas scattering

$$N_b \approx \frac{N_b^0}{1 + n_{IP} L \sigma N_b^0 t / n_b} \equiv \frac{N_b^0}{1 + t/\tau}$$ intensity evolution for collisions only

$$\frac{1}{\varepsilon_x}\frac{\Delta \varepsilon_x}{\Delta t} = \frac{1}{\tau_{IBS}(N_b, \varepsilon_x, \varepsilon_y, \sigma_z, \sigma_\delta, \ldots)} \propto N_b^2$$ intrabeam scattering (IBS) growth

burn-off collision lifetime with σ~100 mbarn, n_{IP}~2:

$L_{peak}=10^{34}$ cm^{-2}s^{-1} in 2808 bunches, N_b~1.15x10^{11}:

τ~45 h (luminosity lifetime 22 h)

$L_{peak}=10^{35}$ cm^{-2}s^{-1} in 5616 bunches, N_b~1.7x10^{11}:

τ~14 h (luminosity lifetime 7 h)

τ_{gas} > 100 h (luminosity lifetime 50 h)

τ_{IBS}~105 h (horizontal emittance growth time; luminosity lifetime 210 h)

burn-off dominates over gas scattering and IBS

$$L(t) = \frac{\hat{L}}{\left(1 + t/\tau_{eff}\right)^2}$$ luminosity time evolution

$$L_{ave} = \frac{\hat{L}\,\tau_{eff}\,T_{run}}{\left(\tau_{eff} + T_{run}\right)\left(T_{run} + T_{turnaround}\right)}$$ average luminosity

$$\rightarrow \quad T_{run,optimum} = \sqrt{\tau_{eff}\,T_{turnaround}}$$ optimum run time

L_{peak} [$cm^{-2}\ s^{-1}$]	beam lifetime τ_{eff} [h]	$T_{turnaround}$ [h]	T_{run} [h]	Int *L* over 200 days [fb^{-1}]
10^{34}	45	10	21	79
10^{34}	45	5	15	6x 97
10^{35}	14	10	12	473
10^{35}	14	5	8	8x 629

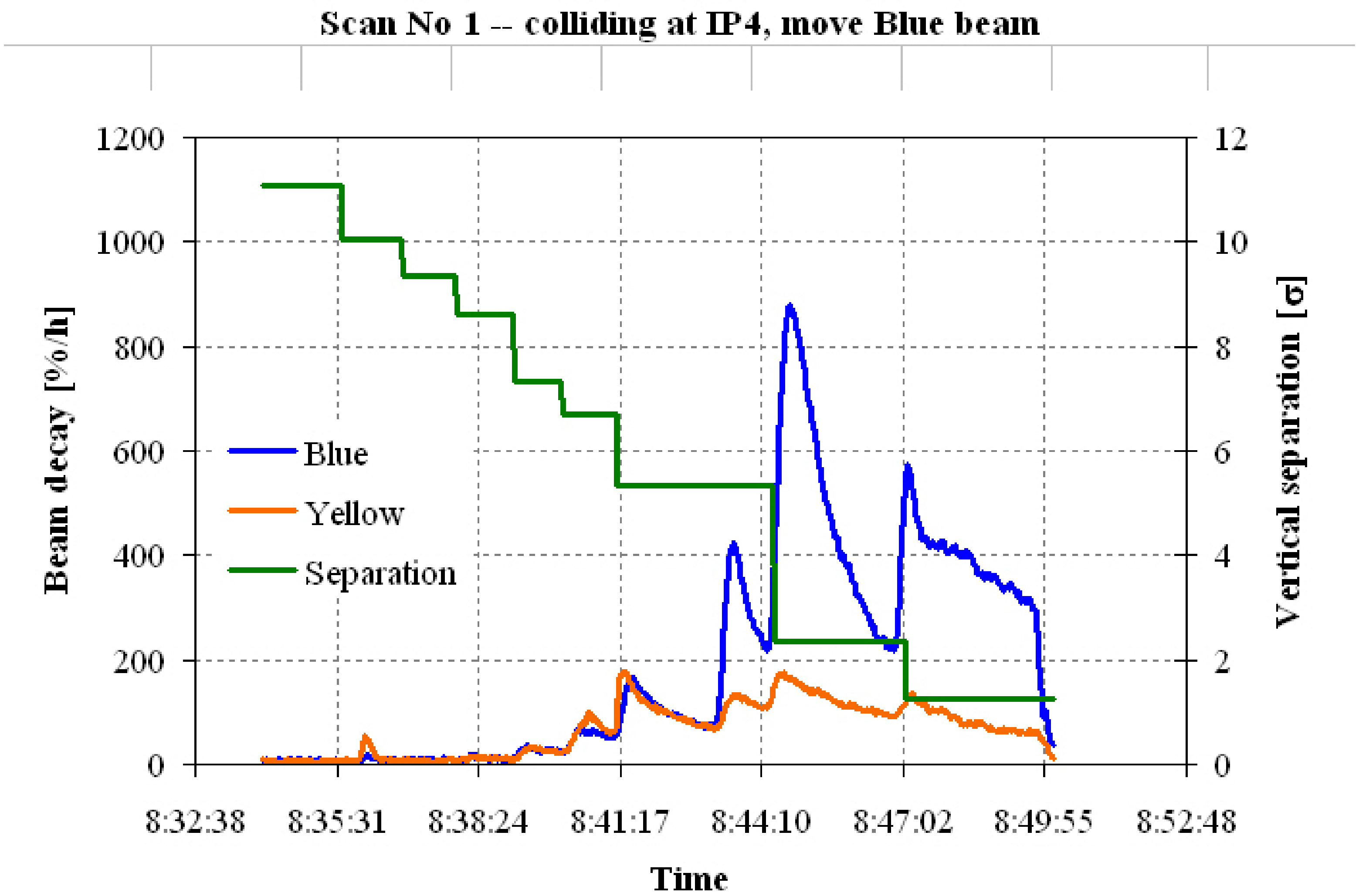
Collisions with Displaced Beams at Point 8

$L \sim L_0 \exp\left(-\Delta^2/(4\sigma^2)\right)$

if for nominal luminosity L_0 an offset $\Delta=5\sigma$ is needed, maintaining the same IP8 luminosity at 10x larger L_0 requires $\sim 6\sigma$ offset

RHIC experiment suggests that one collision with 5-6σ offset might already affect the beam lifetime; observations from the SPS indicate lifetime degradation due to single off-center collision, similar for HERA

RHIC experiment May 2005, at 24 GeV



single off-center collision

W. Fischer et al.

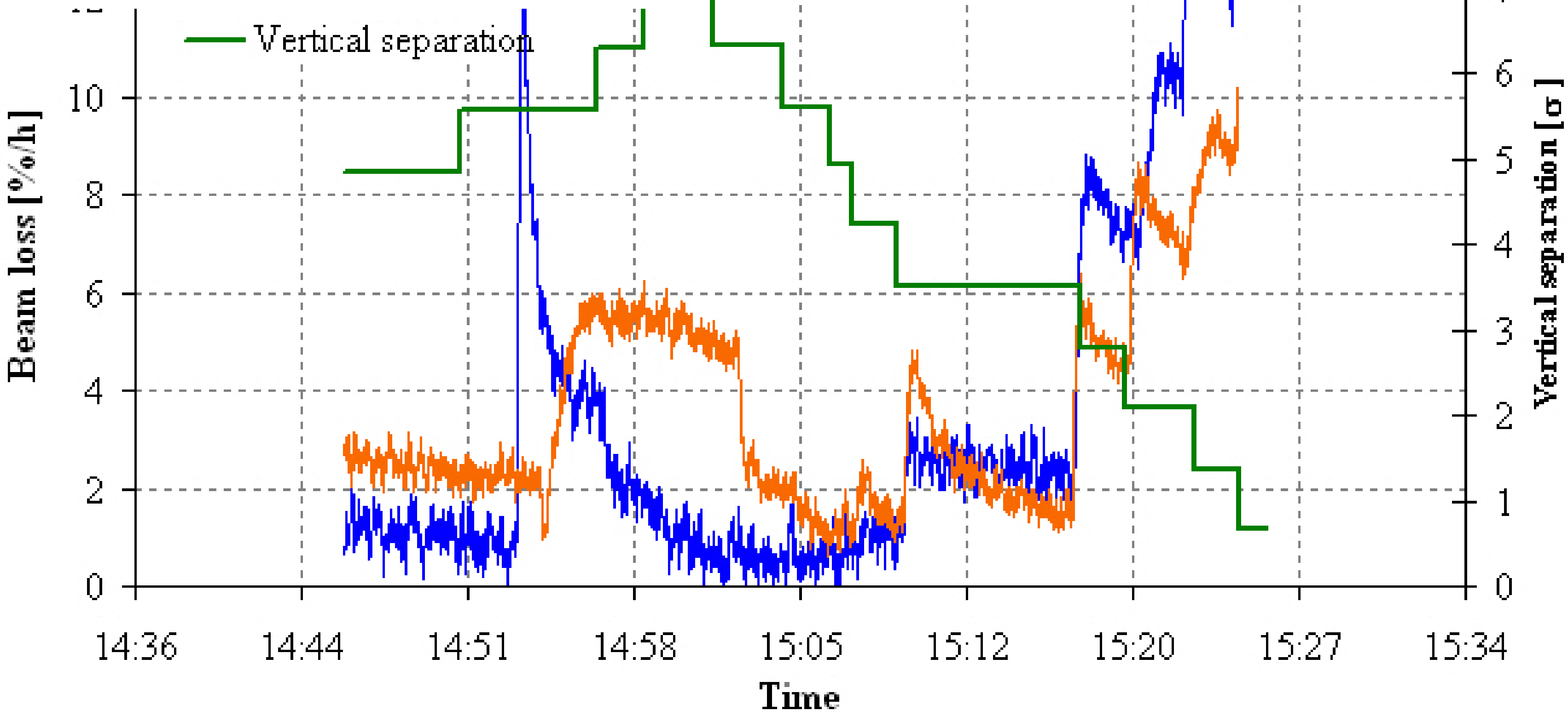
Long-range beam-beam effect in RHIC at 100 GeV

Table 1: Main parameters for the RHIC test at 100GeV.

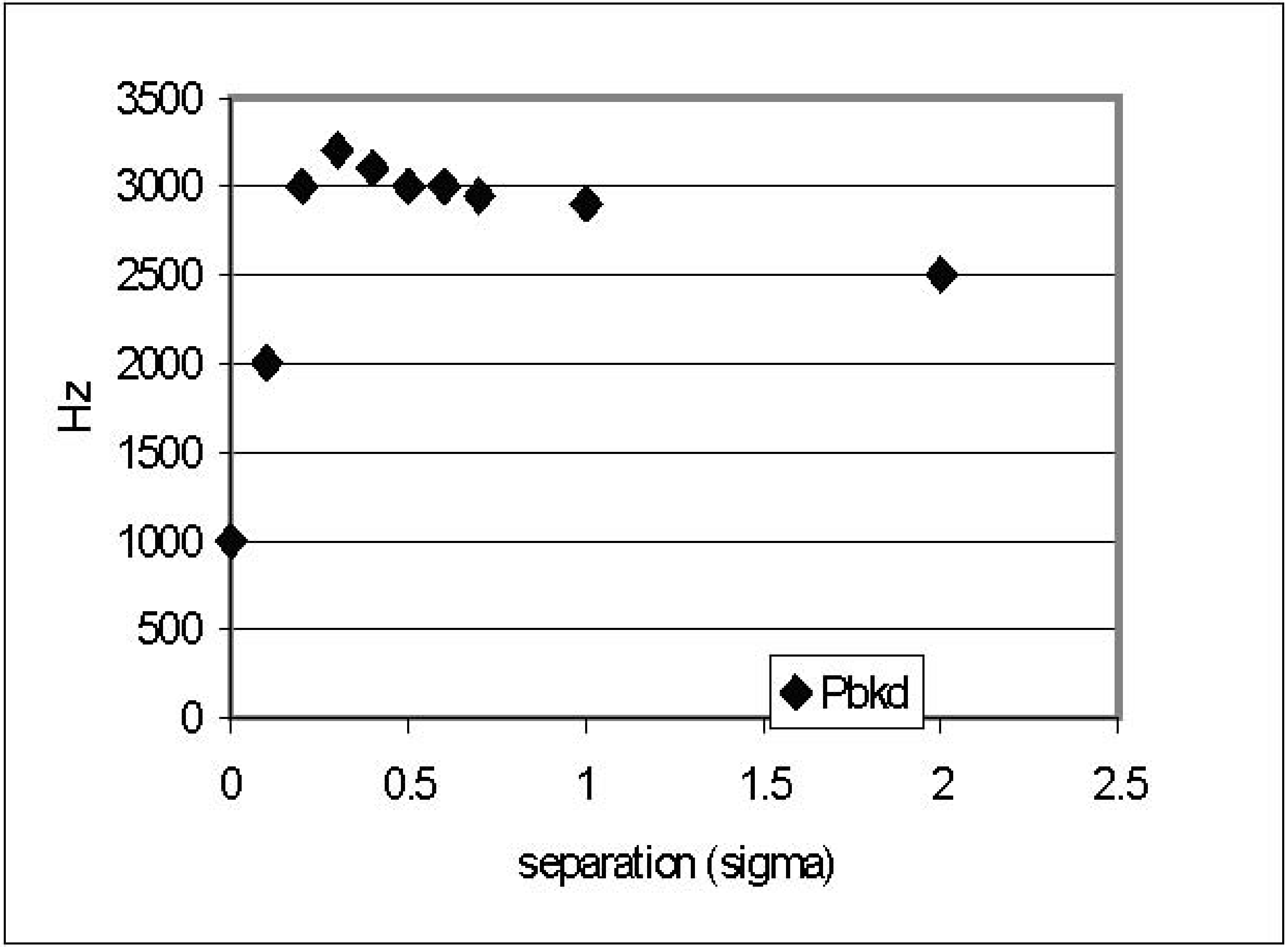
quantity	unit	value
proton energy	GeV	100.0
bunches per beam	...	12
bunch intensity	10^{11}	1.7
long-range location	m from IP	10.6
emittances $\epsilon_{x,y}$ (95%)	mm mrad	10-15
$\beta_{x,y}$, long-range location	m	105
tunes (Q_x, Q_y)	...	B(0.69,0.70)
		Y(0.71,0.69)
vertical separation	mm/σ	1–11/0.7–6.3

- LR at s=10.6m
- Octupoles on in Yellow
- Blue beam moved

measurement of losses vs. separation (Wolfram Fischer)



proton background in **SPS collider** with 1 head-on and one off-center collision as a function of beam-beam separation (K. Cornelis, LHC99)



long-range beam-beam observations in HERA

- lifetime of proton beam drops from 50 h to 1-5 h for a single off-center collision with beam-beam separation between 0.3 and 2 σ

  (F. Willeke & R. Brinkmann, PAC 93' T. Limberg, LHC'99)

Feasibility of 50 ns Bunch Spacing

Of course feasible from the accelerator point of view, and such beam was already stored in the SPS (giving a ~2x higher e-cloud threshold)

The only reason why it is not considered for nominal LHC operation is that for 50-ns spacing there are no collisions at LHCB.

With the same bunch parameters as the 75-ns upgrade case, it would give 50% higher luminosity. For 18% less bunch current it will give the same luminosity at 22% higher total beam current, but with improved luminosity lifetime. *Actually this is an attractive option, if electron cloud still ok.*

parameter	symbol	nominal	ultimate	baseline	alternative	*backup II*
transverse emittance	ε [μm]	3.75	3.75	3.75	7.5	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	3.4	4.9
bunch spacing	Δt [ns]	25	25	12.5	25	50
beam current	I [A]	0.58	0.86	1.72	1.72	1.22
longitudinal profile		Gauss	Gauss	Gauss	Gauss	Flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	3.78	14.4
beta* at IP1&5	$\beta*$ [m]	0.55	0.5	0.25	0.25	0.25
full crossing angle	θ_c [murad]	285	315	445	630	430
Piwinski parameter	$\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0.75	0.75	2.8
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	9.2	9.2	8.9
events per crossing		19	44	88	176	340
Initial lumi lifetime	τ_L [h]	22	14	7.2	7.2	5.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.7	2.7	2.3
	$T_{run,opt}$ [h]	21.2	17.0	12.0	12.0	10.4
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6	3.6	3.1
	$T_{run,opt}$ [h]	15.0	12.0	8.5	8.5	7.3
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	13.34 (7.85)	2.56 (2.1)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.5	0.5	0.36
image current heat	P_{IC} [W/m]	0.15	0.33	1.87	3.74	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	0.113 (1.13)	0.11 (1.13)	0.09 (0.9)

?! ↑