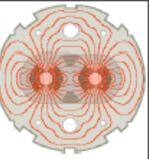


LHC Machine : Luminosity Monitoring and Measurement

- **Introduction, main needs for machine**
- **Parameters, observables, bringing beams into collisions**
- **Luminosity Monitoring in LHC commissioning**
 - **450 GeV run**
 - **7 TeV**
- **Luminosity from Machine Parameters**



Introduction : Luminosity in machine operation

Many parameters will have to be controlled in operation :
orbit, separation, tune, chromaticity, feedback ...

Most important will be :

- **Keep beams (safety) : good lifetime & tolerable backgrounds**
- **Optimise the integrated luminosity, - with **relative****

Luminosity as the main performance parameter in optimisation

We need fast, robust and simple luminosity information whenever beams are requested to collide

- **independent, fast, relative Luminosity monitoring on the machine side is provided using the BRAN detectors**

We will also have a rough knowledge of the absolute Luminosity from beam parameters (beam intensities and sizes in collision)

- **the experiments are expected to determine the absolute luminosities themselves**

Parameter Range

and single bunch luminosities

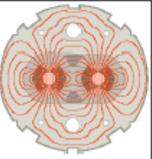
as relevant for lumi / separation scan statistics

Event rates for $\sigma = 10$ mb, which is about the cross section with high energy neutrons in the BRAN

ϵ_N μm	ϵ nm	p GeV/c	β^* m	σ^* μm	N_p	L $\text{cm}^{-2}\text{s}^{-1}$	$\dot{N} = L\sigma$ Hz	$\frac{\dot{N}}{f_{\text{rev}}}$	ξ
3.75	7.82	450	11	293.3	5×10^9	2.60×10^{25}	0.26	0.000023	0.000 16
3.75	7.82	450	11	293.3	4×10^{10}	1.66×10^{27}	16.64	0.0015	0.001 30
2.5	5.21	450	11	239.4	4×10^{10}	2.49×10^{27}	24.94	0.0022	0.001 95
3.75	7.82	450	11	293.3	1.15×10^{11}	1.37×10^{28}	138	0.0122	0.003 74
3.75	0.503	7000	11	95.14	5×10^9	4.00×10^{26}	4.00	0.00036	0.000 16
3.75	0.503	7000	11	95.14	9×10^{10}	1.30×10^{29}	1296	0.115	0.002 93
3.75	0.503	7000	2	31.71	1.15×10^{11}	1.11×10^{30}	11087	0.986	0.003 74
3.75	0.503	7000	0.55	16.63	1.15×10^{11}	3.54×10^{30}	35400	3.15	0.003 74

Commissioning is planned with 43, 156 bunches. No crossing angle

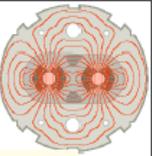
Try to get smaller emittances : 2.5 μm may be achievable for the few bunches in commissioning
 Would help in many respects: luminosity, aperture, magnet imperfections (multi-pole errors)
 On the other hand : noise, vibration and beam-beam will induce slow emittance growth



We will use 43 or 156 bunches, and later over 2000 bunches, which may significantly differ in intensity and emittance.

For optimising collisions and total integrated luminosity it is sufficient to take the sum from individual bunches.

For a full analysis and optimisation of lifetime, background and stability, measurements should be able to distinguish between bunches, for quantities like current, beam size (emittance), tune and luminosity



head-on b.b. tune shift

$$\xi_x = \frac{r_c N \beta_x^*}{2\pi \gamma \sigma_x (\sigma_x + \sigma_y)} \quad \xi_y = \frac{r_c N \beta_y^*}{2\pi \gamma \sigma_y (\sigma_x + \sigma_y)}$$

calculated, using the classical particle radius, here for the proton $r_c = r_p = 1.5347 \times 10^{-18}$ m

In the LHC we have by design round beams with $\sigma = \sigma_x = \sigma_y, \beta^* = \beta_x^* = \beta_y^*$

so that

$$\xi = \frac{r_c N \beta^*}{4\pi \gamma \sigma^2}$$

in terms of the normalised emittance $\sigma = \sqrt{\beta \epsilon_N / \gamma}$ we get simply

$$\xi = \frac{r_c N}{4\pi \epsilon_N}$$

numerically

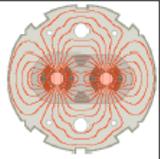
N	ξ
5×10^9	0.000163
4×10^{10}	0.00130
1.15×10^{11}	0.00374

independent of beam energy and β^*
just a function of bunch intensity
which does not vary too much.

This is of the same order as the natural tune spread, $\delta Q/Q \approx 10^{-3}$ from $\delta p/p = 4.7 \times 10^{-4}$, $Q' = 2$ and should be observable. Was used successfully to optimise Luminosity in other machines :

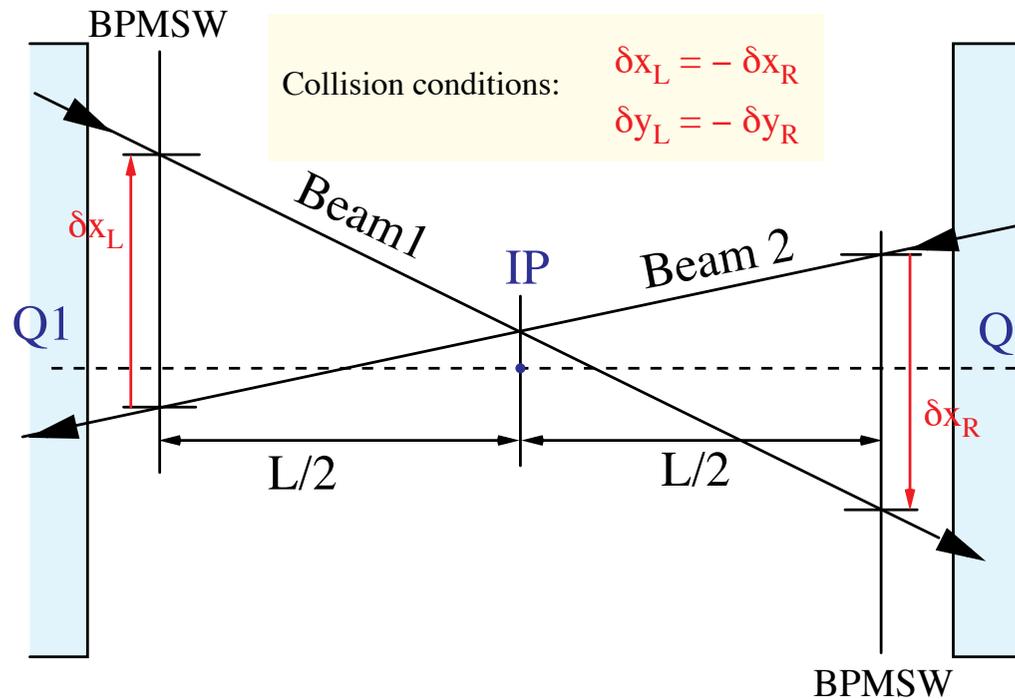
Beam-beam transfer function, ISR, Hemery, Hofmann, JP Koutchouk et al. at PAC 1981

“Tune coupling” with excitation was used in HERA to steer collisions, S. Herb, Lauterberg 1992



Get beams colliding, tolerances, based on S. Fartoukh LCC 3/2001

Adjust orbits such, that the beam 1 and 2 difference left/right of the IP is the same. measured with special (beam) directional stripline couplers BPMSW at about 21 m L/R from IP in front of Q1. There are 2 each in IR1 (Atlas), IR2 (Alice), IR5 (CMS) and IR8 (LHCb) Beams must then collide. This is **independent of offsets and crossing angles.**

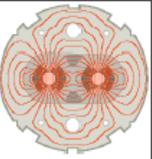


Expected resolution (mainly limited by electronics which is separate for b1, b2)

when both planes (x, y) are considered together

$$\delta_{IP} = \sqrt{\left(\frac{\delta x_L + \delta x_R}{2}\right)^2 + \left(\frac{\delta y_L + \delta y_R}{2}\right)^2} = \sqrt{2} \sigma_{BPM}$$

initial separation $\sqrt{2} \times (50 - 200) \mu\text{m}$, say conservatively $\delta_{IP} = 300 \mu\text{m}$ or about **1 σ**



BRAN : not designed for 450 GeV, performance marginal :

low rate, pulse height / noise comparable and angular coverage insufficient.

Discussed in LHCCWG (4 Oct. 06): too much effort and too late to change this

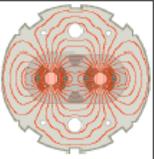
Emphasis is on having a short engineering run with some collisions

Bring beams into collisions using the BPM information

Fine tuning somewhat optional.

Effects of collisions should be visible in various places, consider to use :

- **signals from the BRAN**
- **luminosity signals from experiments**
- **beam-beam effect**
- **lifetime, loss rate (BLM)**



Machine

BRAN : expected to be fully operational in all IPs

providing fast relative luminosity signals used for optimisation like separation scans, monitor bunch by bunch variations

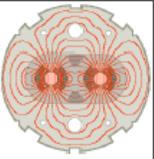
Experiments

Provide absolute luminosities, differential and integrated over the fill, whenever beams are colliding

What we are interested in for statistics, status page, online display of specific luminosity during the fill

and comparison is the “delivered luminosity”, that is :

background subtracted and corrected for any dead-time and inefficiency



Continuous signal exchange is foreseen - see next talk.

Here just some comments :

Good communication between experiments is important. In LEP we had

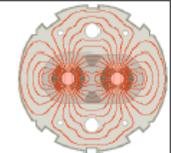
- **frequent direct contacts and (some times too many) by phone and experimentalists coming to the control room**
- **bi-weekly schedule meetings chaired by the Physics coordinator**
- **electronic news, typically posted by the machine-coordinator**
- **TV-screen status page** AB/CO teletext services <http://hpslweb.cern.ch/teletext.html> 

also planned for the LHC

**depending on machine mode : Adjust, Stable Beams, Unstable Beams, Injection, Filling, Ramp & Squeeze
with implementation by Markus Albert AB / OP**



proposed LHC status page in mode with collisions

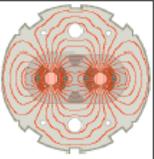


111 CERN AB 31-11-07 12:20:26
 LHC Run 1234 data of 31-11-07 12:20:16

— ** STABLE BEAMS ** —

E = 0.450 TeV	Beam	In Coast	0.5 h	
Beams	Beam 1	Beam 2		
#bun	43	43		
Nprot(t)	1.71e12	1.73e12		
tau(t) h	121	140		
Luminosities	ATLAS	ALICE	CMS	LHC-B
L(t) 1e28 cm-2s-1	5.23	6.23	7.13	1.21
/L(t) nb-1	0.78	0.68	0.78	0.12
BKG 1	1.20	0.52	0.90	0.33
BKG 2	0.85	0.82	0.50	0.60

Comments 31-11-07 11:40:26
COLLIMATORS in coarse settings
Separation Scan in IR1/Atlas



$$\mathcal{L} = \frac{N^2 f_{\text{rev}} n_b}{4\pi\sigma^{*2}}$$

For head-on collisions of round beams and
N particles / bunch for n_b bunches

Gives **absolute** luminosity

Accuracy : knowledge of effective beam sizes
(overlap integral) at IP

$$\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

Reduction by crossing angle. θ_c is the full crossing
angle, nominally ~ 300 mrad

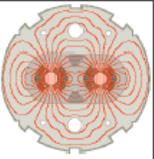
Not an issue for commissioning.

$\sim 1\%$ or still rather negligible for 7 TeV, $\beta^* = 11$ m
only really significant ($\sim 20\%$) at 7 TeV squeezed
 σ_z is the r.m.s bunch length, 7.55 cm at 7 TeV

We expect to be able to predict absolute luminosities for head-on collisions based on beam intensities and dimensions, to maybe 20-30 % and potentially much better if a special effort is made.

Planned : LHC Machine luminosity determination - as subject of PhD thesis.

Luminosity with Separation

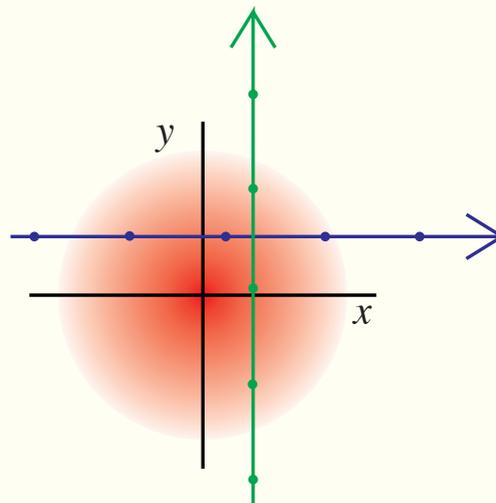


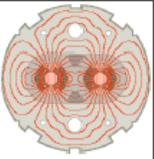
Luminosity with separation

$$\frac{\mathcal{L}}{\mathcal{L}_0} = \exp \left[- \left(\frac{\delta x}{2\sigma_x} \right)^2 - \left(\frac{\delta y}{2\sigma_y} \right)^2 \right]$$

δx	δy	$\frac{\mathcal{L}}{\mathcal{L}_0}$
σ_x	σ_y	
0	0	1
1/2	0	0.9394
1/2	1/2	0.8825
1	0	0.7788
1	1	0.6065
2	0	0.3679
2	2	0.1353

**Commissioning :
simple, orthogonal
x / y scan**

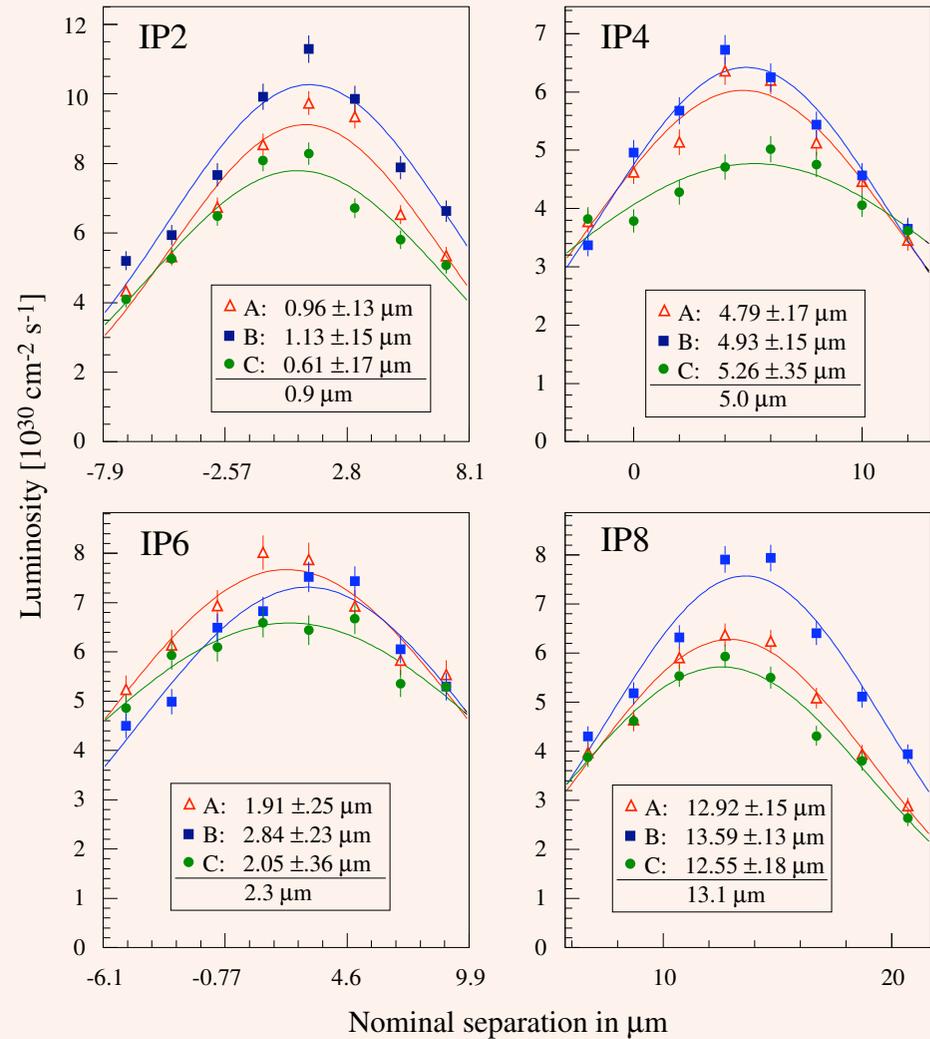




LEP example:
vertical separation scans using LEP luminosity detectors in operation with 4 bunch trains of each 3 bunches

Time: about 5 min / IP

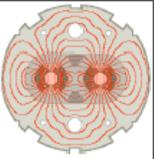
should be faster in the LHC
but needed on two planes x/y



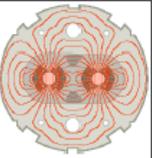
different from LEP, the effect of one beam on the other is really small in LHC
(negligible dynamic β effects)

Separation scans in the LHC should allow for reliable beam size measurements at IP

for further considerations and follow up



- **Came up recently by request from P. Grafstrom, briefly discussed with Rhodri Jones : improved $\sim 10 \mu\text{m}$ BPM precision to minimise beam separation should be possible without crossing angle using extra button pickups. (non-directional, limited to 156 bunches)**
- **Measurements and machine studies - of importance for Luminosity : measurements β -function around the ring and locally at the IPs, waist scan**
- **Use and combine all available relevant information on interaction rates and beam sizes and position from machine + experiments important to cross calibrate, detect any errors and essential to determine uncertainties**



Optimisation of Luminosity (total integrated in 1y, with good running conditions) **is of top priority right from the start-up.**

- **BPM resolution and beam sizes are comparable.**

Steering beams into collisions should not be difficult.

- **Separation scans mainly rely on the LHC luminosity detectors BRAN,**

BRAN performance marginal at 450 GeV, but also fine tuning of Lumi not really an issue for an engineering run

- **We expect also to be able to see the effect of collisions on the tune signal**
- **Experiments are expected to determine themselves the absolute luminosities**
- **The absolute luminosity for head-on collisions can in principle be predicted from currents and beam sizes**

Good machine / experiments communication important

- **automatic, detailed signal exchange**
- **simple summary - displayed on TVscreen**
- **regular (schedule) meetings**