Specification of the Measurement of the Luminosity (and Backgrounds?)

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Functional Specification

MEASUREMENT OF THE LUMINOSITY AND BACKGROUNDS AT THE LHC

Abstract

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Table of Content

Scope:

1) Overall view of the luminosity/background issue
2) **Specification of the machine instruments** (Luminometer, background monitors?)

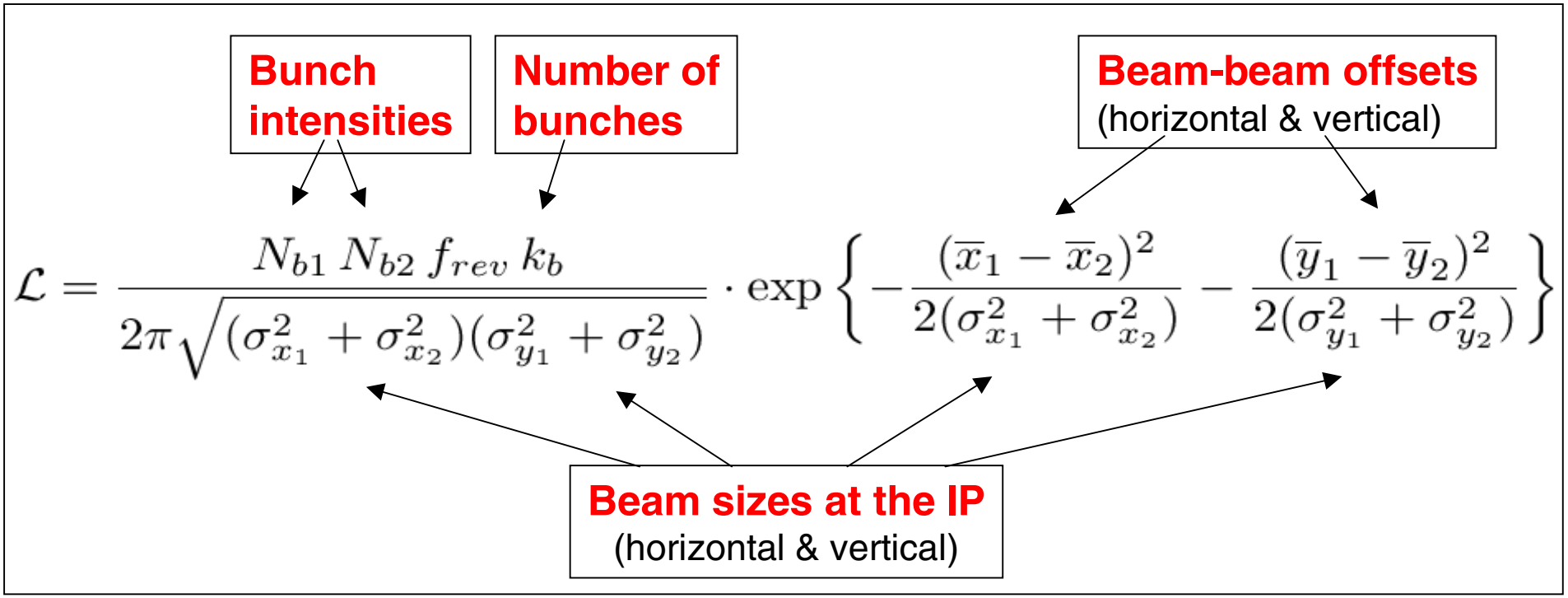
Observables:

1) Counting rates of collision products
2) Beam-beam electro-magnetic coupling (beam-beam scan: L, orbit, … vs b-b offset)

Derived info: (parameters)

1) Absolute and relative luminosity
2) Transverse residual separation of the colliding bunches
3) Position of the vertex in 3D space
4) Crossing angle
5) IP spot sizes of bunches
6) `Standard' background rates (?)

Peak luminosity: *Two independent LHC beams…*



Optimize peak luminosity:

Increase	bunch intensities number of bunches
Decrease	beam-beam offsets beam sizes at IP's

Strategy & Responsibilities

• It is the **responsibility of the experiments to measure their own luminosity**.

• **Standardized, simple, fast and robust machine luminometers** are necessary to set-up the machine for physics, optimize, compare from run to run… Most used: Relative measurement (maximize). The absolute luminosity may be calibrated for cross-checks (equalize luminosity performance).

• **Background** to the experiments:

- It is an issue for LHC
- Experience (ISR) shows that standard background monitors have been very helpful. What about LHC?
- Could be provided by the physics community

Beam & Machine Conditions

1. **Running scenarios**

2. **Range of beam parameters**
   - Initial peak luminosity
   - Luminosity decay
   - Expected background rates
   - Ions

3. **Range of machine conditions**

Example scenarios to define range in luminosities

Low resolution signal desirable

Commissioning scenario

First collisions at 7 TeV, 1 on 1, pilot intensity, injection optics (large IP spot size). Set up IP's.

7 TeV collisions, 1 on 1, pilot intensity, squeezed optics (smaller IP spots size). Set up IP's.

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7 TeV collisions, 1 on 1 or few on few, nominal intensity. Set up luminosity.

Initial running

Nominal running

Ultimate running

Required to measure with good resolution (L and time)

Bunch population	Number of bunches	Bunch spacing	Mode	Experiment (not exclusive)	IP beta	Luminosity [cm^{-2} s^{-1}]
(a) Collisions studies with single pilot bunch						
5×10^{9}	1	n/a	p-p	ATLAS/CMS	18 m	2.0×10^{26}
5×10^{9}	1	n/a	p-p	ATLAS/CMS	0.5 m	7.2×10^{27}
5×10^{9}	1	n/a	p-p	ALICE	10 m	3.6×10^{26}
5×10^{9}	1	n/a	p-p	LHC-b	35 m	1.0×10^{26}
(b) Collision studies with single high intensity bunch						
2.75×10^{10}	1	n/a	p-p	ATLAS/CMS	0.5 m	8.7×10^{29}
1.1×10^{11}	1	n/a	p-p	ATLAS/CMS	18 m	9.9×10^{28}
1.1×10^{11}	1	n/a	p-p	ATLAS/CMS	0.5 m	3.6×10^{30}
1.1×10^{11}	1	n/a	p-p	ALICE	10 m	1.8×10^{29}
1.1×10^{11}	1	n/a	p-p	LHC-b	35 m	5.1×10^{28}
(c) Early p-p luminosity run (different scenarios)						
2.75×10^{10}	1260	50 ns	p-p	ATLAS/CMS	0.5 m	1.1×10^{33}
2.75×10^{10}	2520	25 ns	p-p	ATLAS/CMS	0.75 m	1.5×10^{33}
1.1×10^{11}	936	75 ns	p-p	ATLAS/CMS	0.75 m	2.2×10^{33}
(d) Nominal p-p luminosity run						
1.1×10^{11}	2808	25 ns	p-p	ATLAS/CMS	0.5 m	1.0×10^{34}
				LHC-B	35 m	1.0×10^{32}
				ALICE[1]	10 m	1.0×10^{30}
(e) Ultimate p-p luminosity run						
1.7×10^{11}	2808	25 ns	p-p	ATLAS/CMS	0.5 m	3.0×10^{34}
(f) TOTEM runs						
1.1×10^{11}	36	2.5 μs	p-p	TOTEM (7 TeV)	1100 m	1.0×10^{28}
				TOTEM (.9 TeV)	150 m	1.0×10^{28}
(g) Ion runs						
7×10^{7}	1		Pb-Pb	ALICE/ATLAS/CMS	0.5 m	1.7×10^{24}
7×10^{7}	592		Pb-Pb	ALICE/ATLAS/CMS	0.5 m	1.0×10^{27}

Luminosity decay:

Assume:

Intra-beam scattering	Beam blow-up with τ = 100 h (nom)
Beam-restgas scattering	Intensity decay with τ = 85 h (nom)
Beam-beam interaction	Intensity decay with τ = 16 h (nom) (1/2 value, 2 high luminosity IP's)

Neglect: Radiation damping, ripple blowup, dynamical β^* squeeze
Losses due to non-linearities, collective instabilities

Exponential beam lifetime: τ_{lumi} **= 14.8 h** (approximation)

Turn-around time T_{turn}
Lumi lifetime τ_{lumi}

Optimal length of physics run T_{run}

τ_{lumi} \ T_{turn}	1	6	10	20	[hours]
6.5	3	6	9.5	11.5	
10	4	9	11.5	15	T_{run}
15	5	12	15	20	
19	5.5	13	16.5	22	

O. Bruning

20 h run length → 25% of peak lumi → Assume decrease by factor 5!

Ions:

Initial peak luminosity is low: 1.7×10^{24} cm^{-2} s^{-1}

Large cross-section Pb-Pb will produce high event rates for luminometers.

Range of machine conditions:

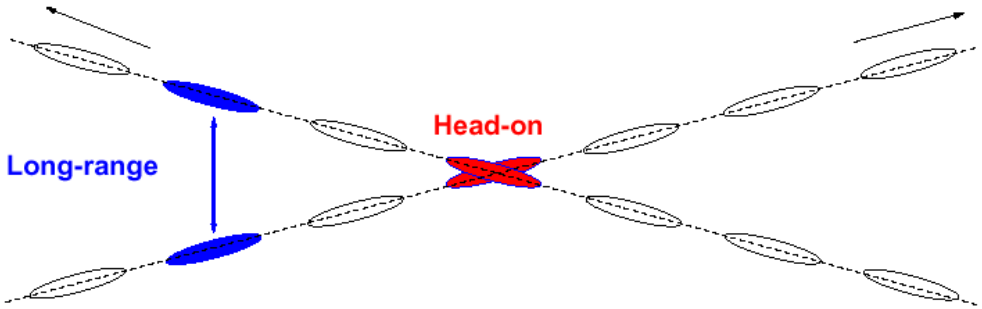
(a) Ranges in crossing angles

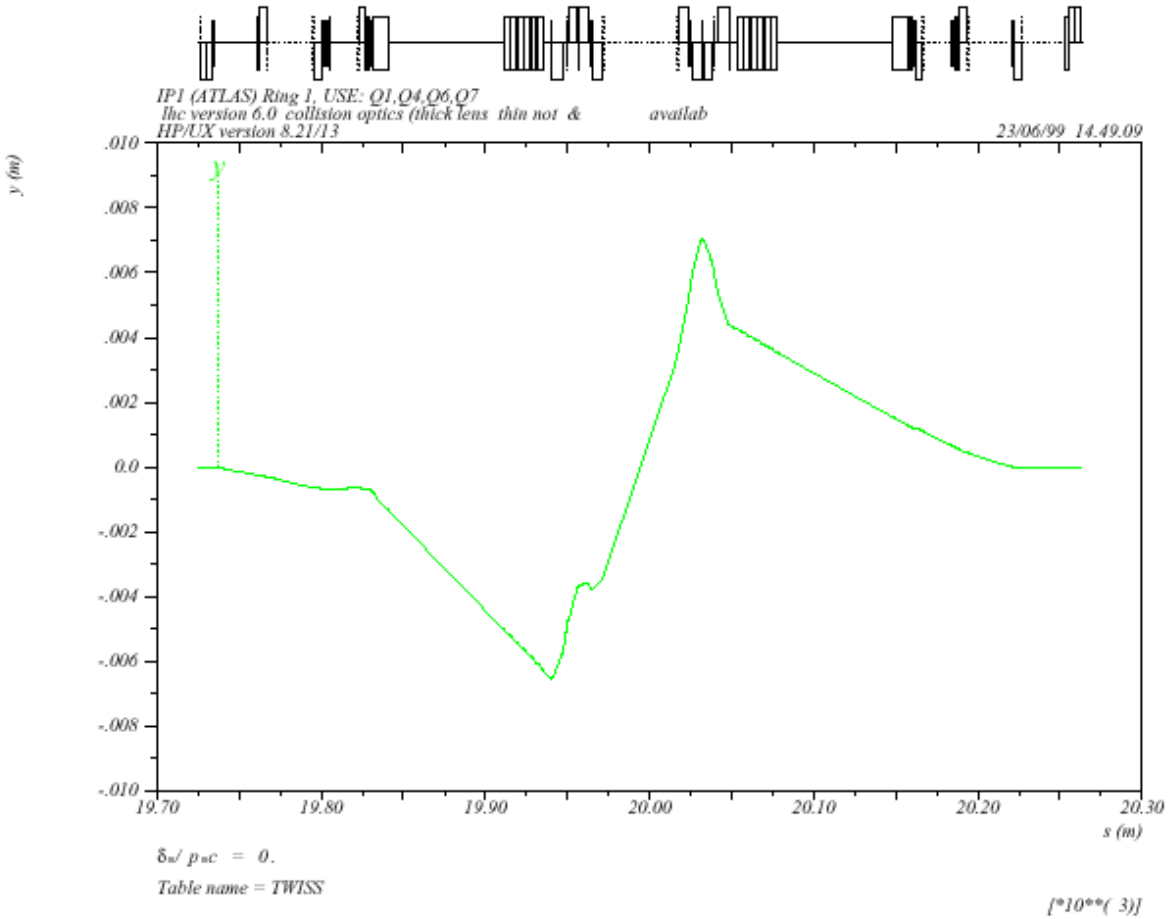
IR	Experiment	IP beta	Crossing angle plane	Half total crossing angle	Range for nominal cases
1	ATLAS	0.5 m	Vertical	±150 μrad	
2	ALICE	10 m	Vertical	±150 (80) μrad	±(35-150) μrad
5	CMS	0.5 m	Horizontal	±150 μrad	
5	TOTEM	1100 m	Horizontal	0 μrad	
8	LHC-B	35 m	Horizontal	±285 (150) μrad	±(200-285) μrad

Table 2: Magnitude and plane of the total crossing angle for nominal LHC. In brackets the contribution from the external orbit bump is listed for IR2 and IR8.

Luminometer must cope with crossing angle range from 0 to maximum (sign of slope at IP must be assumed to be free).

Beam-beam crossing: *W. Herr et al*





(b) Transverse position of the vertex

Tolerance from the experiments:	± 1 mm	run-to-run
	± 3 mm	long term

(tolerance with respect to experimental geometry)

Assume for luminometers: **Transverse position to vary by ± 3 mm**

(c) Longitudinal position of the vertex

Tolerance from the experiments: ± 10 cm

Assume for luminometers: **Longitudinal position to vary by ± 10 cm**

Anticipated uses:

(a) Initial beam finding and overlap optimization

BPM's at IP: **Δy (IP) ~sqrt(2) * δ_{res}**

BPM resolution	Δy(IP)	in sigma	β^*	
200 μm	283 μm	18 σ	0.5 m	Low
200 μm	283 μm	3 σ	18.0 m	Int
50 μm	70 μm	4.4 σ	0.5 m	High
50 μm	70 μm	0.7 σ	18 m	Int

Required luminosity measurement to go further:

L resolution	**~ 1 × 10^{28} cm^{-2} s^{-1}**
Time response	**Minutes**
Accuracy	**10 %**

(b) Luminosity optimization (and re-optimization at start of physics)

L resolution	**1% for full beam**
L reproducibility	**1 %**
Time response	**1 s**

(c) Luminosity feedback

L resolution	**1% for full beam**
Time response	**1 s**

(d) Luminosity equalization between experiments

Absolute L accuracy	**given by experiments**
L reproducibility	**1 %**
L resolution	**1 % for full beam**
Time response	uncritical

(e) Minimization of beam-beam excitation

Allowed beam-beam offsets	**0.2 σ**
L resolution	**1 % per bunch**
Time response	**minutes**

$$L \approx L_0 \cdot e^{-\left[\Delta y_{IP}^2 / \left(2\sigma_y^*\right)^2\right]}$$

(f) Monitoring of crossing angle

Luminometers might provide estimate of crossing angle. This is desirable, if device remains robust!

Desired angle accuracy	**7 μrad**

(g) Monitoring of vertex position

Experiments

(h) Bunch-by-bunch measurements

Desirable for various multi-bunch studies (see also e)

L resolution	**few % to 10 % per bunch**
Time response	**minutes**

(i) Monitoring of background

Bunch-by-bunch?

Signal every second?

Resolution 1-10%?

Machine-Experiment Information exchange:

Entity	Detail
Spectrometer Magnets	Currents and polarity
Position of Moveable Detectors Components	LHCb Vertex Detector (VELO) TOTEM Roman Pots
Background Measurements	Spatial and temporal distributions
Beam Characteristics	Vertex position (x,y,z) Luminous region
Absolute and Instantaneous Luminosity	Various sources for instantaneous (calorimeter currents, dedicated counters) TOTEM for absolute

The **vertex position** is measured in the reference frame of the experiment.

A **conversion** to the machine reference frame shall be done before transmission.

It will be based either on survey data measured during shut-downs or on continuous monitoring wherever available.

The **relative luminosity** can be measured from trigger rates and both the **integral/average and bunch-by-bunch values** will be provided.

Transmission of the summary information from the experiments to the machine can be performed at least **every minute**.

The **bunch-by-bunch luminosity** can be reported at a rate of **1 Hz**.

The expected **accuracy is of the order of a few per cent**.

The same detectors are planned to measure the **backgrounds** and would deliver the data **at the same rate**.

Machine to experiments:

Relative luminosity, as useful.

General information on machine status (Page 1).

Logging database of all machine measurments.

Conclusions

We are at the end of the collection of the requirements.

The issue of whether the background monitors are included is to be settled.

The next step is the to go from requirements to functional specifications.

This should be well advanced or ready by Xmas.