Experience at CERN with luminosity monitoring and calibration, ISR, SPS proton antiproton collider, LEP, and comments for LHC…

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LHC Lumi Days
Friday 14 January 2011

Luminosity calibration at CERN

There is a long history of luminosity calibration at CERN….

- ISR 1968–1983
  - Van der Meer scan performed by beam displacement with magnets
  - Beam were crossing at a large angle, scan in only one plane (vertical) the beam height overlap was therefore measured
- SPS proton antiproton collider 1984-1991
  - Van der Meer scan performed by beam displacement with electrostatic separators
  - Van der Meer scans had to be performed in both planes
- LEP 1989-2001
  - Scans were performed by beam displacement with electrostatic separators – to optimise luminosity
  - Scans had to be performed in both planes
- LHC
  - ongoing, this workshop

Parameters and luminosity calibration: ISR

- beam energy 31GeV
- proton-proton collider and proton-antiproton collider
- two separate beam pipes – different orbits for the two beams
- coasting beams (no bunches)
- collision at large angle in horizontal plane
- beam current of up to 40A (Van der Meer scans performed with a current of a few Amperes)
- very large beams (size in the order of cm)
- beam separation with magnets
- calibration done for proton-proton and proton-antiproton collisions
- at the IP a wire scanner was installed to measure the beam profile

ISR luminosity calibration

ISR-PO/68-31
June 18th, 1968

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CALIBRATION OF THE EFFECTIVE BEAM HEIGHT IN THE ISR

by

S. van der Meer

- Proposal for calibration the beam height in ISR by S. van der Meer
- One challenge is the calibration of the beam displacement during the scan

The counting rate for zero displacement can be determined at leisure during the performance of the experiment for which the calibration is needed.

Of course, this method suffers from all the disadvantages connected with beam displacements outlined in ref.[1]. On the other hand, it might be suitable for somewhat less precise measurements in cases where the experiment requires that the intersection region remains without the obstructions inherent to the wire method.

REFERENCES

1) P. Darriulat, C. Rubbia, CERN internal document 68/340/5 SIS/si.

2) W. Schnell, CERN internal document PS/6513.

ISR luminosity calibration

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CERN-ISR-ES-BOM/82-15

CALIBRATION OF THE BEAM DISPLACEMENTS USED IN ISR LUMINOSITY MEASUREMENTS

P. Bryant and K. Potter

Measurements of the ISR luminosity by the Van der Meer method require accurate vertical displacements of the beams of an intersection point. An absolute calibration of these displacements in intersection 2 has been carried out using beam scrapers. The displacements given by a new control program are found to be linear and reproducible but to be too large by 1.8 ± 0.4 % at beam energies from 15 to 31 GeV. A summary of previous studies of these beam displacements, including beam intensity effects which would not be seen in the calibration reported here, is given in appendix 1.

- Calibration done using beam scrapers at the IP to measure the beam displacement during Van der Meer Scans
- Large effort to understand systematic errors

ISR pp and ppbar collider luminosity calibration

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CERN-EP/84-163
29 November 1984

PRECISE MEASUREMENTS OF PROTON-

TOTAL CROSS-SECTIONS AT THE CERI

G. Carboni[1], D. Lloyd

CERN, Geneva,

M. Ambrosio, G. Barbarino, G. P

Dipartimento di Fisica dell'Unive

V. Cavasinni, T. Del Prete, M. Morgant

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State University of New Yo

ABSTRACT

A detailed account is given of high-precision measurements of the total hadronic cross-sections of proton-antiproton and proton-proton interactions at centre-of-mass energies of 30.6, 52.8, and 62.7 GeV. The experiment was performed at the CERN Intersecting Storage Rings (ISR) using the total-interaction-rate method, in which additive correction terms for trigger losses were held to less than 6% of the final result. An experimental determination of the vertical beam-displacement scale permitted luminosity-monitor calibrations to be made with high intrinsic accuracy. The over-all precision (systematic and statistical errors combined) achieved in the total cross-section was ±1.1% for proton-antiproton reactions and the 0.7% for proton-proton reactions. In the proton-proton case the measurement was the most precise such measurement made at the ISR.

- Results reported, error of 1.1%
- not so clear to me how such small error

Parameters and luminosity calibration: SPS

- beam energy 315 GeV
- proton-antiproton collider
- one beam pipe, same orbit for both beams
- bunched beams
- head-on collisions
- beam current of less than 0.1A
- beam separation with electrostatic separators
- luminosity calibration with high beta optics (beta = 2500m in the horizontal plane, 270 GeV per beam, beam size of several mm)
  - Using optical theorem and direct coulomb scattering
  - Measurement of the proton-antiproton total cross section at the SppS collider by a luminosity dependent method / UA4/2 Collaboration, Phys. Lett. B 344 (1995)
  - A precise measurement of the real part of the elastic scattering amplitude at the SppS / UA4/2 Collaboration, Phys. Lett. B 316 (1993)

Luminosity: simplified equations for bunched beams

Number of protons per bunch in beam 1: n_{p1}

Number of protons per bunch in beam 2: n_{p2}

Revolution frequency: f_{rev}

Beam sizes in horizontal and vertical plane for beam 1 and beam 2: σ_{x1} σ_{x2} σ_{y1} σ_{y2}

Luminosity =

$$\frac{n_{p1} \cdot n_{p2} N_c \cdot f_{rev}}{2 \cdot \pi \cdot \sqrt{\left(\sigma_{x1}^2 + \sigma_{x2}^2\right) \cdot \left(\sigma_{y1}^2 + \sigma_{y2}^2\right)}}$$

Counting rate when beams are separated by d: $N_{count} = const \cdot e^{\left[\frac{d^2}{2 \cdot \left(\sigma_{x1}^2 + \sigma_{x2}^2\right)}\right]}$

Parameters to be measured

- revolution frequency
- number of collisions: should be trivial, but is not for LHC due to the non-symmetry of the 4 experiments and the operation with bunch trains. This can make an important correction
- current in the bunches
- beam sizes OR overlap integral by a Van der Meer Scan
- in case of the Van der Meer Scan: the displacement of the beams at the IP need to be measured

SPS ppbar collider luminosity calibration: Van der Meer Scans

CERN $p\bar{p}$ Note 38
November 14, 1977
C. Rubbia

1

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Measurement of the Luminosity of $p\bar{p}$ Collider with a (generalized)

Van der Meer Method

C. Rubbia, CERN

- Generalised Van der Meer scan for luminosity calibration was proposed for SPS in 1977
- Taking into account the difference between ISR (coasting beams, scan in only one plane, and SPS (bunched beams, scans in both planes)
- Not the only method to calibrate the luminosity

SPS ppbar collider luminosity calibration: Other methods

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CERN - SPS DIVISION

SPS/EA/Note 79-6

SOME REMARKS ON LUMINOSITY MEASUREMENT

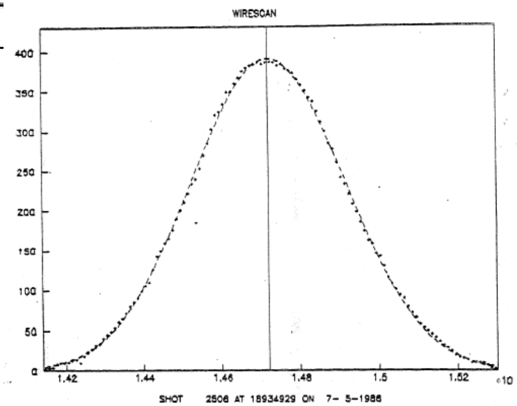
AT THE SPS COLLIDER

C. Bovet and G. von Holtey

- Luminosity determination from beam profile measurements
- Measure horizontal and vertical profiles of both beams (with a scraper or a wire scanner)
- With the knowledge of the beta function, calculate the beam size at the intersection points
- Estimated to be possible with an accuracy of 5–10%
- An assumption of Gaussian beams is fairly accurate (Hereward 1969) – the rms beam size is an excellent assumption

Micron wire scanner at the SPS

	standard deviation σ in micron	beam center ⟨x⟩ in channels (1 channel = 4 micron)
Wire going IN		
protons	119.9 ± 0.3	2264.0 ± 0.1
antiprotons	113.1 ± 0.5	2252.9 ± 0.2
difference $\langle x \rangle_{p} - \langle x \rangle_{pbar}$		11.1 channels = 44.1 micron
Wire going OUT		
protons	120.1 ± 0.3	2261.4 ± 0.1
antiprotons	112.7 ± 0.5	2670.4 ± 0.2
difference $\langle x \rangle_{p} - \langle x \rangle_{pbar}$		9.0 channels = 36.0 micron



CERN SPS/86-26 (MS)

THE MICRON WIRE SCANNER AT THE SPS

J.Bosser, J.Camas, L.Evans, F.Ferioli, J.Mann, O.Olsen, R.Schmidt

- Measurement of the beam profile with an error better than 0.5%
- Same type of (linear) wire scanner is used in LHC
- Should be possible to be used for luminosity calibration at LHC

SPS: a poor mans Van der Meer scan

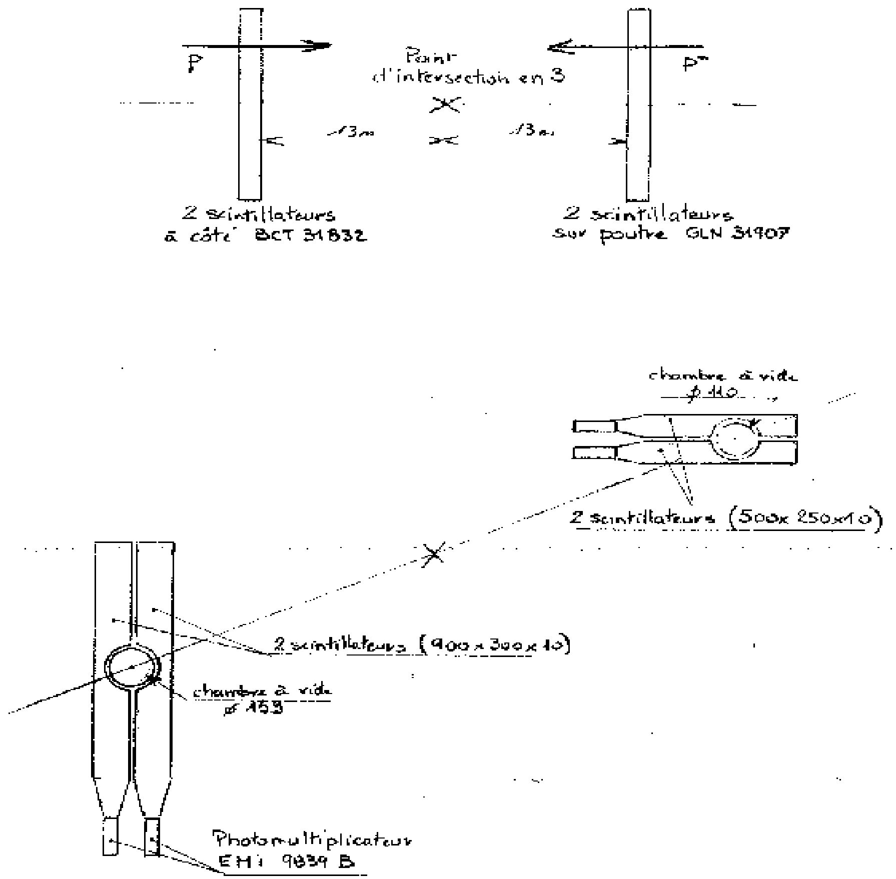
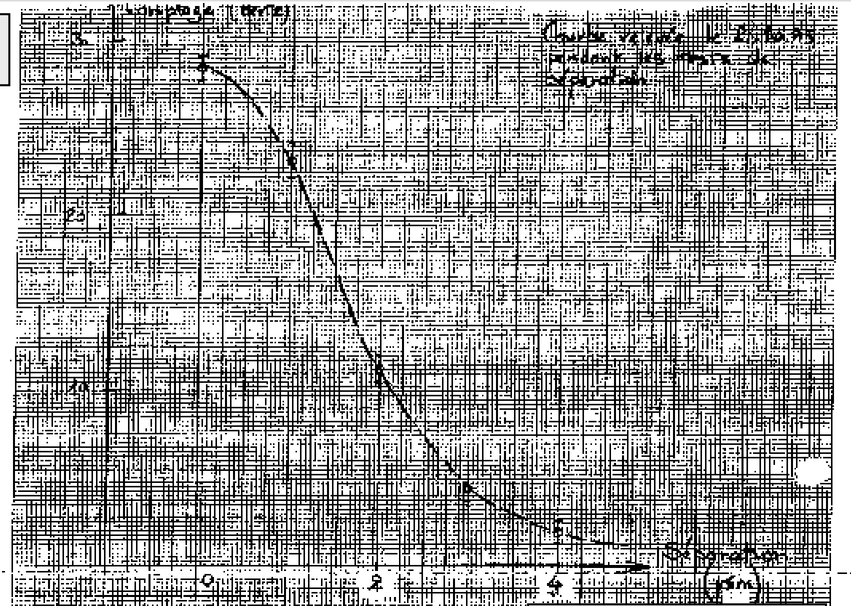


Figure 1

the detector

counting rate



separation

figure 4

- Van der Meer scan was done with a "poor mans" detector
- Has the advantage that an instrument such as a wire scanner can be installed at the IP

LEP

- To calibrate the luminosity other methods are better, essentially Bhabha scattering
- Still, scans have been done frequently to optimise the luminosity
- Van der Meer scan for e+e- luminosity calibration does not work
  - strong beam-beam effects (much stronger than for hadron colliders)
  - beta function and orbit changes during the scan
  - beam size and emittance changes during the scan (beam blow up)
  - beam size dominated by the balance between damping and quantum excitation due to synchrotron light emission PLUS excitation of resonances driven by the beam-beam effect – very different from beam dynamics at hadron colliders
- Small cross section, low event rate
- From LEP we learned effects during scans that need to be considered for LHC
- Precision measurement at LEP was the calibration of the energy

LHC some ideas

There are several options for luminosity calibration:

- With Van der Meer Scans
- Measuring the beam sizes at the interaction point
  - direct measurement by LHC experiments using proton-proton collisions (overlap) and collisions with gas molecules (single beam profiles)
  - indirect measurement, using precise wire scan data and calculating the beam size at the IP with the knowledge of the beta function (the SPS micro wire scanner was invented for precisely measuring the beam size)
  - beta function measurement: exciting beam oscillations with AC dipole and measuring the response
  - beta function measurement now with an error of about 5%, might be possible with an error of 1% for dedicated studies, needs to be demonstrated (R.Tomas). This results in a beam size error of 0.5%
- It is always required to precisely measure the bunch current
  - bunch current measurement is not obvious, calibration needed

LHC some ideas

Van der Meer scans

- To measure the displacement of the beams by the magnets during a scan: the experiments are used (needs to be calibrated once), but the displacement can also be derived from the knowledge from the machine optics and magnetic fields
- Orbit effects when beams are separated need to be considered
  - depends on beam-beam parameter, number of bunches and number of long range interactions
  - very important are simulations – programs exist and should be used
- The entire measurement process should be simulated with MAD and other programs (to understand errors of the measurements and to understand detail of the LHC machine)
- Calibrate the luminosity with different methods is recommended since it is an absolute value to be measured

LHC brainstorming….

- For the SPS, a measurement of the beta function by longitudinal displacement of the IP (waist scan) was considered
  - measure luminosity as a function of the displacement
  - measure the ratio of the beta function in adjacent quadrupoles by measuring the tune shift
- To be seen if this can be done at LHC (optics of the two beams is different)

For the most accurate scans…..

As simple as possible…

- Avoid too many bunches
- Avoid parasitic crossing
- No crossing angle

- Precision experiment – the more precise the more difficult
- If required, long term effort with new ideas, in particular for monitoring the beam parameters
- Will take machine time…… effects on integrated luminosity
- For smallest errors: similar to LEP energy calibration, large effort during many years required close collaboration between machine and experiments
- Is the physics motivation strong enough?

Comments

- Measurement of total cross section by TOTEM and ALFA discussed elsewhere
- The precise measurement of the luminosity is challenging, in particular if the error should be much less than 5%
- Substantial effort is required
- It is proposed to use different calibration principles, in order to get confidence in the results and to avoid systematic error (of possibly unknown nature)
- One method is certainly with the “Van der Meer scan”, likely to give the most accurate measurement
- Another method is using profile measurements with the wire scanner (possibly also synchrotron light) and to calculate the beam size at the IP
- A third method could be by scraping the beam to determine the profiles
- In all cases, the beam current must be measured precisely – the measurement error enters into all methods