

On possibility of luminosity measurement in ATLAS using the process $pp \rightarrow pp + e^+e^-$.

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Abstract

It is suggested to use the QED process of two photon, e^+e^- pair production, for luminosity calibration at LHC. A few days operation at $L \sim 3 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ provides an accuracy of about 1–2 %.

1 Introduction

Usually luminosity of colliders is determined by measuring a rate of events with well known cross section. In the case e^+e^- colliders there are many processes used for this purpose. For proton colliders almost all processes have a large theoretical uncertainty, therefore other approaches are used (see for example [1],[2],[3]):

- 1) measurement of the beam profile and number of particles;
- 2) measurement of dN/dt for elastic scattering at zero angle, rate of inelastic events and the optical theorem.

The first method usually gives the accuracy about 10–15%. The second method is very difficult and there are many questions to it. One example, the process $pp \rightarrow pp + e^+e^-$ has the cross section about $6 \mu\text{b}$, that is about 10% of the inelastic cross section. It also should be taken into account, but detection efficiency for it is much smaller than for other processes that leads to systematic errors. This fact was never taken into account.

In this Note the process

$$pp \rightarrow pp + e^+e^- \tag{1}$$

is suggested for luminosity measurement at LHC. This method was proposed as a method of luminosity measurement at proton colliders already more than 20 years ago [4], but was never used. In this process e^+e^- pairs are produced in collisions of virtual photons surrounding the proton. If one requires a small transverse momenta of the produced e^+e^- pairs (that is characteristic for this process), then each of the virtual photons also has small P_t , that means that it is produced at large distances from the proton and, therefore, this cross section is almost insensitive to a photon structure. Theoretical accuracy for

differential cross section in this region is better than 1%. This process was investigated at e^+e^- storage rings and all its characteristics are well known.

Total cross sections of this process is very large, about 10 mb, and $\sigma_{obs} \sim 1/W_{min}^2$. Main signature of this process is small transverse momenta of produced e^+e^- pairs, that can be used for separation from background processes.

2 Selection criteria

Experimental conditions and structure of ATLAS detector determine set-up of the luminosity calibration experiment and selection criteria. This measurement can be done at luminosities less than $10^{33} \text{cm}^{-2} \text{s}^{-1}$, when we require two low energy particles ($P_t < 1$ GeV) in inner part of detector and anticoincidence from other parts of detector. For other condition (lower and higher luminosities) the luminosity can be extrapolated by measuring a counting rate of a dedicated telescope.

For ATLAS the following set of criteria can be used for selection of the process (1):

1) two opposite charged particles in the central detector at rapidity $|\eta| < 0.85$ with $P_t = 0.4-1$ GeV/c (particles cross inner detector and are absorbed in the coil and calorimeter).

2) nothing in the calorimeter (no blocks above electronic threshold ~ 1 GeV) and in forward inner detector at $|\eta| > 1$ (anticoincidence).

3) $|P_{t,1}| - |P_{t,2}| < 20$ MeV/c.

4) acoplanarity angle $|\Delta\varphi| < 1.5^\circ$

5) e/π efficiency ratio ~ 10 .

With these cuts the cross section is 0.15 nb. It is not large but sufficient for luminosity calibration with 1-2 % accuracy for a few days run (see below).

Some comments to these selection criteria (numbering is in the same order).

1) For particles with $P_t > 0.4$ GeV/c 1-level trigger based on TRD straw tubes can be used. These particles do not spiral in the detector.

2) This anticoincidence (AC) cut suppress most of the hadronic reactions and leaves mainly events of double pomeron exchange $pp \rightarrow ppX$, for example

$$pp \rightarrow pp + \pi^+ \pi^- . \quad (2)$$

It is very important that we should not worry about sources of AC. Besides normal signals, this may be uncontrolled electronic noise of calorimeter, for example. One must measure only the rate of anticoincidence f_{ac} . The measured cross section can be corrected for anticoincidence in a simple way:

$$\sigma = \sigma_{measured} \frac{f_{col.}}{f_{col.} - f_{ac}} , \quad (3)$$

where $f_{col.}$ is a rate of beam collisions. This is so because the investigated process (1) doesn't cause AC. In a multibunch mode this equation is not exact because each pair of colliding bunches have different rate of AC. Estimations show that at 10% spread in

number of particles in bunches and optimum luminosity(see below) this leads to systematic shift $\sim 0.5\%$, which can be corrected, if r.m.s. spread is known.

3)-4) These requirements identify two photon processes using a specific feature of two photon processes - small transverse momenta of e^+e^- pair. The main background process (2) has P_t of $\pi^+\pi^-$ pairs about 0.3 GeV/c and it is strongly suppressed by these cuts(see below).

The cut (4) should be used after all other cuts(including 5)). The final distribution in acoplanarity angle will consist of a wide plateau with a narrow peak due to e^+e^- pairs.

The value of 20 MeV/c for transverse momentum cut is determined by momentum resolution of the detector($\sigma_P/P \sim 1.5\%$ due to multiple scattering is assumed). On first sight this resolution is not correct for electrons, which have large probability of bremsstrahlung radiation in the inner detector of $0.25 X_0$ thickness. But the momentum of electron can be determined using only first two layers of the vertex detector and known beam position. In this case X/X_0 is 1% only and expected momentum resolution is almost the same as on 1 m base without radiation.

5) This requirement is necessary for some additional suppression of the background processes (2) (see below).

3 Cross sections

With the cuts (1-5) the cross section of the process (1) is 0.15 nb. The main background process (2) without cuts (3-4) have the cross section about $5 \mu\text{b}$ [6], i.e. by a factor 30000 larger. The cut (3) gives a factor $\sim 300/10 = 30$ and the cut (4) gives suppression by a factor $\sim 180/1.5 = 100$, together 3000. If particle identification is not used then beside e^+e^- pairs we can use $\mu^+\mu^-$ pairs which are produced via the same two photon diagram with almost the same cross section at $W \gg m_\mu$. In this case e^+e^- , $\mu^+\mu^-$ signal will be seen in acoplanarity angle distribution as $\sim 20\%$ narrow enhancement on flat continuum. Particle identification can improve this ratio, that can decrease time of measurement up to factor 3 (in this case only electrons remain). Some soft identification(which doesn't introduces sytematic errors) is desirable in 2- or 3-level trigger to reduce number of event recording to a "tape"(see below), also it will be necessary, if real background is larger than expected. In the TRD detector two particles cross together about 40 tubes. Electrons and pions at $P = 0.4 - 1$ GeV can be separated by ionization losses, transition radiation only helps. Note, in this experiment the TRD will work in background free condition, only with two charged particles in the inner detector.

4 Number of events.

Due to anticoincidence requirement this calibration run can be done only at luminosities when there is notable probability to have collisions without hadronic events in the

detector($\sigma_{inel} \sim 75$ mb). The effective luminosity

$$L_{ef} = L \frac{f_{col} - f_{ac}}{f_{col}} = L \cdot \exp\left(-\frac{L\sigma_{in}}{f_{col}}\right) \sim L \cdot \exp\left(-\frac{L}{10^{33}}\right) \quad (4)$$

The maximum $L_{ef} \sim 3.5 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ is reached at $L = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. But to make smaller systematic shift due variation of number of particles in bunches it is preferable to work at lower luminosity about $4 \cdot 10^{32}$, when $L_{ef} = 2.7 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ is only by 25% lower than $L_{ef,max}$, but the measurement is by factor 6 less sensitive to variation of bunch population.

Number of events per one day of operation at this luminosity

$$N = \sigma L_{ef} t = 0.15 \cdot 10^{-33} \cdot 2.7 \cdot 10^{32} \cdot 86400 = 3400 \text{ event/day}.$$

If hadronic background is suppressed to the level of effect then one day of work gives accuracy about 2.5%. Without electron identification the same result will be obtain for 3 days(see the previous section). This is also OK.

5 Trigger

The detection of this process require a special trigger which is not foreseen now in ATLAS.

5.1 1-level trigger

In ATLAS 1-level trigger exist only for high energy particles. In our case particles have $P \sim 0.4-1 \text{ GeV}/c$ and cross only inner detector. For normal high luminosity runs 1-level trigger base on inner detector is very difficult, therefore it is not foreseen. For this luminosity calibration experiment such trigger it is absolutely necessary and on first sight it will rather simple(in ATLAS units).

As was already mentioned the rate of the main background process (2) at $P_t > 0.4 \text{ GeV}/c$, $|\eta| < 1$ is about $5 \mu\text{b}$ [6]. Let us take $10 \mu\text{b}$ as reference cross section for background. At $L_{ef} = 2.7 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ the rate of background is about 3 kHz. In ATLAS 1-level has to work up to 100 kHz, so there is no problems here even for 30 times larger background.

For 1-level trigger we can use TRD tubes, joined in about 30 groups in r and φ to provide 100% efficiency for particles and good time resolution, sufficient for connection of event to certain bunch collision. In the 1-level trigger 2 or 3 group should be required(the third is for safety) with two of them separated by more than 90° . The trigger signal from TRD should be swiched in coincidence with AC signal from the forward calorimeter($|\eta| > 1$) for the same bunch crossing. This is delicate task, but it should be solved in ATLAS in any case for main trigger.

5.2 2-level trigger

Secondary trigger should select two particles with

- 1) $|\Delta\varphi| \leq 10^\circ$;
- 2) $|P_{t,1}| \sim |P_{t,2}|$ with $\sim 10\%$ accuracy

With these requirements 2-level trigger rate

$$N_{2-level} \sim N_{1-level} \cdot \left(\frac{10}{180}\right) \cdot 0.1 \sim N_{1-level}/150 \sim 20 Hz$$

This is OK. Technically this task can be done using track-finder based on 2-3 layers of vertex detector.

For "safety" some selection criteria for electrons based on TRD may be foreseen in 2-level trigger.

5.3 3-level trigger

In 3-level trigger complete analysis can be done. Events with relaxed cuts ($N \sim 30 N_{effect}$) or with a rate about 1 Hz, should be recoded to the "tape".

6 Conclusion

1) The process of two-photon e^+e^- pair production with well known cross section can be used for calibration of luminosity in ATLAS detector at LHC.

2) The accuracy about 2% can be achieved for 1 day operation at luminosity about $5 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1}$.

3) For realization of this possibility it is necessary to arrange rather simple 1-level trigger in inner detector, based on TRD detector, and to build track-finder based on the barrel vertex detector. Other variants are also possible.

Consultations with experts have not revealed any "show-stoppers"

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