Luminosity measurements experience at DAFNE

G. Mazzitelli
on behalf of various people that during 13 years have worked on an high background/luminosity accelerator...

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way a machine lumi monitor?
The Physics at DAFNE

Single Bremsstrahlung:
\[ e^+ + e^- \rightarrow e^+ + e^- + \gamma \]

Double Bremsstrahlung:
\[ e^+ + e^- \rightarrow e^+ + e^- + 2\gamma \]

Gas Bremsstrahlung:
\[ e^{\pm} + Z \rightarrow e^{\pm} + Z + \gamma \]

Annihilations
\[ e^+ + e^- \rightarrow 2\gamma \]

Bhabha
\[ e^+ + e^- \rightarrow e^+ + e^- \]

\~ 30Hz@10^{32} on KLOE barrel

and more for higher energy machine...
Coincidence with $\gamma$ @ small angle

$N$ (accidental) = $2 \frac{f_1*f_2}{Dt}$

$Dt = 2.0 \times 10^{-8}$ s

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Fig. 11. Single and double Bremsstrahlung cross sections vs. energy threshold. Analytical result.

--> no possible to make coincidence with gamma physic at small angle
Single Bremsstrahlung luminosity measurements at DAFNE

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Abstract

Luminosity measurements are performed by detecting the photons from single Bremsstrahlung at the two interaction points. Set up and measurement method are presented with special emphasis on background subtraction scheme, error evaluation and machine-related issues.

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1. Introduction

DAFNE, the Frascati phi factory [1], is a 500–2000 MeV electron–positron collider, tuned on the F meson resonance and mainly devoted to the study of CP violation in kaon decay. In order to optimize the luminosity performance, the related machine parameters must be accurately set by relying on a tuning process [1,3] based on the readout of a luminosity monitor. In designing such a monitor the following major requirements were pursued: (i) capability of performing very fast measurements to allow tuning machine parameters in real time, (ii) measurement stability with respect to variations of the beam position and angle at the interaction point (IP), (iii) no interference with the experiments to ensure independent luminosity measurements during the data taking and during the initial phase of the machine commissioning with no experiment installed in the two interaction regions (IPs).

A direct way to measure luminosity consists in measuring the counting rate of a known electromagnetic process while the beams are colliding. Good candidates are radiative Bhabha scattering (BB), single Bremsstrahlung (SB) and double Bremsstrahlung (DB). Cross sections for BB, DB and SB are reported in Refs. [4–7]. An interesting comparison among measurements with the three different processes can be found in Ref. [8]. At DAFNE SB was chosen because it better fulfills requirements (i) and (iii) (iv) and ensures measurements at a few percent level when an efficient background subtraction method is used.

Fig. 2. Single Bremsstrahlung luminosity monitor layout at splitter magnet area.
DAFNE $\gamma$ monitor (con't)

Single Bremsstrahlung:
$$e^+ + e^- \rightarrow e^+ + e^- + \gamma$$

$$L = \frac{\dot{N}_{SB}}{E_{\text{max}}} \int dE \int d\Omega \frac{\partial^2 \sigma_{SB}}{\partial E \partial \Omega}$$

Calibration by Gas Bremsstrahlung

November 1998
Requirements for an accelerator lumi monitor

- fast (< 1 s) at very low luminosity (2/3 order of dynamic range)
- absolute
  - day one
  - MD
  - Detector maintenance
- accurate (~ 10 %)
- wide range beam acceptance
  - Ip displacement
  - vertical and horizontal angle

expected percentage of rate lost in the lumi monitor due to collimator beam acceptance and bem transverse displacement and vertical crossing angle
When running at low current the effect of the incoming beam trajectory on the background is negligible as well as beam beam effect, etc. As as been shown by KLOE 1 run experience, the luminosity monitor is able to perform absolute and correct measurement only in low current condition where background and instrumental effect where negligible.

A luminosity monitor based on the measurement of the photons from the single bremsstrahlung (SB) reaction is used. The SB high counting rate allows fast monitoring, which is very useful during machine tune-up. The contribution of the gas bremsstrahlung reaction is subtracted by measuring the counting rate with two non interacting bunches. The estimated error on the measurements is of the order of 20%.
Luminosity Position Scans

Vertical Position Scan

- $\Sigma_y$
- $y_{max}$
- $L_{max}$

Horizontal Position Scan

- $\Sigma_x$

Calibrated vertical bump

\[ L = f_R \frac{N_+ N_-}{2\pi \sum_x \sum_y} \]

\[ \Sigma_w = \sqrt{\sigma_{w+}^2 + \sigma_{w-}^2} \quad w = x, y \]
Diagnostics (dispersion, electron cloud)

PEP-II photo electron cloud blowup effect on the bunch by bunch luminosity measurements

Vertical Dispersion Difference @ IP

\[ \Delta y_{\text{max}} = (4.8 \pm 0.4) \ \mu m \quad \rightarrow \quad \Delta \eta_{y}^{\text{IP}} = (2.3 \pm 0.4) \ \text{mm} \]

\[ f_{\text{RF}} = 368.243 \ \text{MHz} \]

\[ f_{\text{RF}} = 368.263 \ \text{MHz} \]
but... (KLOE run1)

- High current --> high background:
  - PM saturation;
  - Discriminator over rate;

--> 
  - upgrade of readout system;
  - limitate rates with the same acceptance (maintain angular and beam position acceptance) filling of needle the collimator hole;
  - use independent lumi estimator to validate data: slm lumi based, cross calibration with KLOE

Fig. 2. Luminosity integrated by KLOE from 2001 to 2005.
Geometric Luminosity estimator

\[ L_{geo} = \frac{I^+ I^- 120}{4\pi N_b e^2 f_{rf} \sigma_x^2 \sqrt{\sigma_{ey@SLM}^2 + \sigma_{py@SLM}^2}} \left( \frac{\beta_y^{IP}}{2\beta_y^{SLM}} \right) \]

- Beam overlap
- \( \sigma_x = 2 \text{ mm} \quad \sigma_y = \text{ wid}/2 \)
- \( \beta_y/\beta_y@SLM = 0.03/7.60 \ @ \text{ KLOE} \),
- \( \beta_y/\beta_y@SLM = 0.04/7.53 \ @ \text{ DEAR} \)
- SLM monitor resolution

SLM beam characteristics (vertical and horizontal dimension)
SIDDHARTA run (the crab waist test)

- The crab waist, moreover the background, have introduced very important difficulties in the measures:
  - A) shorter beta minimum respect to beam dimension
  - B) vertical and horizontal rate maximization could not be equivalents to luminosity optimization

- These required:
  - a fast and absolute luminosity measurement not affected by background issue and new beam condition
  - maintaining all the $\gamma$ monitor measurement characteristic, optimization futures, and integration in DAFNE control system
Luminosity and background measurements at the e⁺e⁻ DAΦNE collider upgraded with the crab waist scheme


ABSTRACT

The crab waist collimation scheme has been successfully tried out at the e⁺e⁻ DAΦNE collider during the 2009-2010 run. The gain in luminosity is consistent with the predictions while the background remains satisfactory. Among the various steps used by the DAΦNE accelerator to meet this new machine and improve its performances some online information, absolute luminosity and background level measurements, have been provided by the LUMI detectors: a Bhabha calibrator and two gamma transmutation proportional counters. This paper focuses on the results achieved with this experimental setup, described in details in another article.

1. Introduction

The DAΦNE [5], steadily improving performances in terms of luminosity, beam lifetimes and background. The best peak luminosity was observed in 2009-2010 run, with typical daily integrated luminosities of 4·10³³ cm⁻² s⁻¹ during the KLOE run.

In 2007, the DAΦNE interaction point (IP) has been modified to test the crab waist scheme compensation scheme [6]. The crab waist compensation scheme is based on the蟹 waist compensation schemes with a crab angle of 0°, and has been used in previous experiments with similar configurations. To test this new scheme, the crab waist scheme was implemented in the crab waist compensation scheme which could be achieved with beam collimation similar to those used in previous experiments. To test this new scheme, the crab waist compensation scheme was implemented in the crab waist compensation scheme which could be achieved with beam collimation similar to those used in previous experiments.

The DAΦNE accelerator, located in the National Laboratory of Topical Research (FNAL) in the United States, is optimised for the production of Ð mesons (1.15-1.20 GeV) at a high rate. Since 2004, it has been delivering Ð mesons to three experiments KLOE [5], FONAR [6] and SINDRUM [8].

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Layout and Luminosity Monitors

- **SIDDHARTA**
- **K monitor**
- **Bhabha calorimeter**
- **γ monitor**
- **GEM Bhabha Monitor**
Gamma monitor

- 2 calorimeters PbWO$_4$ crystals, 13 $X_0$ total depth
- Readout by Hamamatsu R7600
- High-statistics, very fast counter, main tool for luminosity optimization…
- …but affected by background [not absolute luminosity measurement]

PbWO$_4$ crystals

collimator

detector segmentation
Kaon Monitor (SIDDHARTA)

PM: Hamamatsu R4998
Scintillators: BC420
Dimensions: 200 x 50 x 2.0 mm

Triple-GEM tracker

Triple-GEM tracker
Triple-GEM trackers

**pads**

**induction gap**

GEM 3

GEM 2

GEM 1

Cathode

**Final luminometers with Carioca FEE**
Bhabha calorimeter design

- Longitudinal segmentation has been optimized keeping in mind that the total available depth is only the length of the quadrupole $\approx 20$ cm

- 11 absorber plates + 12 samplings:
  - $8 \times 0.5 \text{ cm} + 3 \times 1 \text{ cm}$ lead $\approx 12.5 X_0$ should ensure sufficient shower containment
  - $12 \times 1 \text{ cm}$ scintillator
  - 2:1 active:passive ratio should ensure $\approx 15\%/\sqrt{E(\text{GeV})}$ resolution

- Lateral segmentation dictated by the need of keeping a reasonable number of channels and to have some degree of freedom in defining the acceptance

We decided to equip only 10 out of 12 sectors, keeping out the $\phi=0^\circ$-$180^\circ$ plane, since we expect larger backgrounds from there
CaloLumi construction

December ‘07 – January ‘08
CaloLumi installation

7 February 2008
DAQ and Trigger

- Offline and Online measurements (i.e. trigger rate)

- Re-use KLOE’s DAQ
  - KLOE’s SDS boards to split, discriminate and sum the signal to assert a trigger;
  - DAQ software also KLOE-based running on Motorola CPU MVM-E6100
Performance

- Clear Bhabha Peaks!

- Energy resolution
  - Bhabha events in data
  - Nb of counts in one module (?)
  - $\sigma E/E = 17.5\% \ @ 510 \text{ MeV}$
  - $12.4\%/\sqrt{E} \ (\text{GeV})$
  - Consistent with test beams.

- Time resolution good enough to subtract backgrounds from Trigger Rate

# of counts

# of counts in m0

trg_t_m0 - trg_t_m2 (ns)

All trig’d events

Background

Bhabha Peak

trigger due to m0+m2

Entries 10448

$\chi^2/\text{ndf} = 570.3 / 131$

Constant = 310.2

Mean = 3620.

Sigma = 635.1

Entries 1658

# of counts
Background

We can have energy deposits over threshold in another module, in addition to the couple of triggering modules: this gives us the “triples”

We expect a similar level of events with no Bhabha, but with two “spurious” deposits, giving a fake coincidence
Background topology

Cross check looking at runs with only 1 beam

run 1392, e- 350 mA, 100 bunch

run 1394, e+ 290 mA, 100 bunch
Background subtraction (timing rejection procedure)

Fig. 11. ADC distributions in the four calorimeter modules for the representative high-statistics run used to produce most of the plots in this section. All histograms show three components with similar patterns. Events for which that particular module did not trigger belong to the white area on the left: little energy is deposited in these sectors, as expected from background fluctuations. Hence, these events are not real Bhabha decays for which one of the two particles is not detected. The hatched regions contain the events for which the module triggered. Events for which the energy deposit is not coincident in time with the one measured in the opposite module (pure background case) are in the darker area. Their deposited energy is lower than for the in-coincidence events (high purity Bhabha sample) which are in the light-hatched area. These plots justify the timing criterion used to separate signal from background.
Online timing filter effect

- **good e+ injection**
- **bad, dirty, e+ injections**
Soyuz

$\theta > 18^\circ$

Soyuz
Soyuz simulation results effect

- 16°
- 15°
- 12°

The first column shows the results without an effect, while the second column shows the results with an effect of ~200 MeV.
Sputnik

Since May 29th, 2008

$\theta > 22^\circ$

Sputnik
A full simulation has been essential tool for understanding not only the real acceptance and normalization but also how to optimize detector performance.
Today (very bad condition)

- no space available
- final focusing quadrupoles are covering the gamma exit line, and the quantity of material intercepted is depending by orbit path
- very high background condition
- trajectory effect, and overlap complicated by experiment magnetic field
- It's not possible calibrate the lumi monitor

auto-calibration procedure based on running average online luminosity KLOE data
Conclusion

• Have a fast, absolute, background free luminosity monitor on DAFNE has been always a not easy task.
• The crab waist scheme introduced many issue due to:
  - physic (significance) measurements;
  - background.
• In the very simple layout, like SIDDHARTA one, a tracker system (GEM) was not usable alone or a gamma monitor at zero angle, and a large angle calorimeter needed an accurate data analysis.
• To be completely background free we have to use also timing information and strongly increase the shielding detector protection.

The combination of energy, position and timing information looks to be fundamental to avoid background of an accelerators running with the crab waist scheme, as well as accurate selection of the lumi detector acceptance (shielding)
In the same time, the introduction of crab waist, and the consequent complication in the understanding the beam interaction behavior make fundamental have a machine accelerator luminosity detector with the above characteristics.
Conclusion (cont)

- The luminosity monitor is a fundamental instrument for accelerator measurement parameters and operation optimization.

- The physics, in terms of signal, background, and beam-beam behavior in the detector(s) must be very well known and understood (full simulation).

- The detector characteristic and design must be based on the accelerator quantity to be measured and background condition of operation.